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The Michigan Entomological Society traces its origins to the old Detroit Entomological Society and was organized on 4 November 1954 to “...promote the science of entomology in all its branches and by all feasible means, and to advance cooperation and good fellowship among persons interested in entomology.” The Society attempts to facilitate the exchange of ideas and information in both amateur and professional circles, and encourages the study of insects by youth. Membership in the Society, which serves the North Central States and adjacent Canada, is open to all persons interested in entomology. There are four paying classes of membership for 2008:

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All manuscripts are refereed by two reviewers, except for short notes, which are reviewed at the discretion of the Editor.

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Manuscripts must be typed with line numbers, double-spaced, with 1” margins on 8 1/2 x 11” or equivalent size paper, and submitted in triplicate or emailed to the Editor as an attached file. Please use italics rather than underline. Use subheadings sparingly and set them in paragraphs in boldface. Footnotes (except for authors’ addresses, which must be on the title page, and treated as a footnote), legends, and captions of illustrations should be typed on separate sheets of paper. Titles should be concise, identifying the order and family discussed. The author of insect species must be given fully at least once in the abstract and text, but not in the title. If a common name is used for a species or group, it should be in accordance with the common names published by the Entomological Society of America. The format for references must follow that described in the style guidelines used by the Entomological Society of America.

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ODONATOLOGICAL HISTORY IN MICHIGAN – 1875-1996

Mark O’Brien

ABSTRACT

The history of the study of Odonata in Michigan is documented from 1875 to 1996. The early biological surveys from 1900 to 1920 were privately financed, and enabled biologists to collect and catalog the fauna of the most remote parts of Michigan’s Upper Peninsula. The University of Michigan Biological Station at Douglas Lake started in 1908 and became an early base for Odonata studies and continues to do so today with undergraduate and graduate studies at the Station. A series of collectors are profiled from the past century, as well as the roles played in the study of Michigan’s Odonata fauna by prominent odonatologists such as E. B. Williamson, E. M. Walker, C. H. Kennedy, and L. K. Gloyd. The 1958 E. J. Kormondy catalog of Michigan Odonata established a baseline for future workers and by 1996 the Michigan Odonata Survey began cataloging and documenting the state’s Odonata fauna, which is where this historical account finishes.

In 2004, the Michigan Entomological Society celebrated its 50th anniversary. In commemoration of this event, members and attendees at the annual meeting were encouraged to write manuscripts summarizing Michigan histories on their areas of expertise. For me, the choice was fairly obvious, as I work at the institution that holds one of the largest collections of Odonata and related documents in the Western Hemisphere. The historical efforts of collecting, describing, and cataloging the Odonata fauna of Michigan started not long after our state celebrated its 50th birthday. We should not forget the pioneering efforts that began over 100 years ago, and appreciate the obstacles that were in the way of all aspects of such entomological endeavors.

Michigan’s location within the Great Lakes and its diverse habitats has made it an interesting collection destination since the late 1800s. The abundance of wetlands, streams, lakes, and rivers throughout the state certainly promises great habitats for Odonata and other aquatic insects. We tend to forget today that much of Michigan’s Lower Peninsula was logged by 1900, and as a result many of the early surveys were conducted in areas of Michigan’s Upper Peninsula such as Isle Royale, the Porcupine Mountains, and Gogebic County, where the landscape had been less ravaged by loggers. Although a century of reforestation has now taken place, the landscape we see today bears only a vague resemblance to pre-logging conditions (Dickmann and Leefers 2003). Nonetheless, early surveys were launched to explore the more remote areas of the state. At that time, such surveys required sponsors and lasted many months, with transportation provided by railroad, steamship, and horses. After the arrival of the automobile, collecting trips were somewhat less of an ordeal, and biologists began surveying various parts of the state on an ad-hoc basis. The introduction of major highways further aided field work. After the Mackinac Bridge was completed in 1957, the Upper Peninsula became more easily accessible to collectors from the south. Still, it would be another 50 years before a reliably accurate view of Michigan’s Upper Peninsula Odonata fauna would emerge.

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Before 1900. The earliest records from Michigan appear to be in Hagen’s *Synopsis of the Odonata of America* (Hagen 1875). Eighteen species were listed; 16 for “Detroit, Michigan” and two for “Lansing, Michigan.” Hagen did not indicate who collected the specimens he examined, nor when they were obtained. The earliest collections for which there were specimens associated with locality data are from those made by David S. Kellicott (1842-1898), a naturalist from Ohio who published many early papers on Ohio dragonflies as well as papers on other insects, rotifers, and protozoa. Kellicott visited Corunna, Michigan, in July-August 1893, and published a short paper in *The Canadian Entomologist* (Kellicott 1894). His list of 44 species from Shiawassee County has not yet been improved upon by the 29 species that are currently cataloged in the Michigan Odonata Survey (MOS) database. Kellicott was also a friend of Edward Bruce Williamson (1877-1933) and Clarence H. Kennedy (1879-1952), who would figure prominently later as Odonata specialists in Michigan. It is unknown where the specimens that Kellicott collected were deposited, or even if they still exist.

The United States Fish Commission collected along the Great Lakes in 1897-99, and there are four larval Odonata specimens in the University of Michigan Museum of Zoology (UMMZ) preserved in ethanol, taken in Presque Isle County in August 1899. These are the oldest Odonata specimens I have personally seen from Michigan, which is all the more surprising, considering they are preserved in ethanol.

1900 to 1920. An obscure note in *Entomological News* in 1904 reported that Morgan Hebard from Philadelphia (whose family owned extensive tracts of forest in the Upper Peninsula) had collected a specimen of *Aeshna sitchensis* Hagen in Pequaming, near L’Anse in Baraga County, which represented the first record of that species for the United States (Skinner 1904). Hebard was a noted Orthopterist, and had been collecting Orthoptera in Baraga County. In Hebard’s 1910 paper, he wrote “During the summer of 1903, while doing general entomological work at Pequaming, Baraga Co., Michigan, I made an effort to collect a representative series of the Odonata of that region.” All of his 19 species were identified by Philip P. Calvert, among the most highly respected of early North American entomologists.

Finally, some in-state people started making contributions to the study of Michigan Odonata. Geological and biological surveys of the western US and the Great Lakes region became popular as scientific endeavors to catalog the flora and fauna as well as determine the potential value of mineral/ore deposits, forests and fisheries. The Michigan Geological and Biological Survey, influenced by the prominent Charles C. Adams (1873-1955), published a number of works on surveys of Isle Royale, the Porcupine Mountains, and other biologically and geologically interesting regions of Michigan. However, it should be pointed out that many of these surveys were not financed by the State of Michigan, but by prominent amateur naturalists who were bankers, physicians and lawyers (Van de Water 1977). The first of these trips was to Isle Royale and the Porcupine Mountains in the summer of 1904. Alexander G. Ruthven (1888-1971), a herpetologist, collected 13 species of Odonata from the Porcupine Mountains, with all identifications made by E.B. Williamson (Ruthven 1906). Detroit businessman and malacologist Bryant Walker (1856-1936), and two prominent Marquette businessmen, Peter White (1830-1908) and H. M. Kaufman sponsored the trips to these two areas, with a second visit in 1905 sponsored by Walker and White.

Adams acknowledged many people for the 1905 Isle Royale trip, including lighthouse keepers on Isle Royale, various railways, steamship lines, the U.S. Weather Bureau, and others that assisted the naturalists on their journey (Adams 1909). One probable route to Isle Royale from lower Michigan would have involved travel by train from Ann Arbor to Mackinac City, across the Straits of Mackinac by ferry, then by train to the Keweenaw, followed by a boat to Isle Royale. It’s also possible that the party traveled by rail to Duluth, MN
and took a ship to Isle Royale, or returned that way, as Adams (1909) thanked
the caretaker of the Washington Club (Duluth, MN) for use of their grounds.
Such expeditions obviously required careful planning. The letter of transmit-
tal from Alfred C. Lane, State Geologist, to the Honorable Board of Geological
Survey of the State of Michigan (Adams 1909) states that the contributions
come from the University of Michigan Museum and that explorations were
made without expense to the State Survey by means of contributions from
friends of the Museum. This serves as further evidence of the involvement of
private contributors and the UMMZ (referred to as the “University Museum”
in the letter of transmittal).

Adams (1909) indicated that H. A. Gleason (of later botanical fame) col-
lected most of the specimens that accounted for 17 species of Odonata from Isle
Royale, with some taken by Adams and “other members of the party.” Most of
them were identified by E. B. Williamson. However, a letter from E. M. Walker
to Adams (21 September 1912) indicates that there were some errors in the
text, and Walker wrote that he could have identified the *Aeshna* specimens that
Adams had left as “*Aeshna* species?” in the text.

In the Shiras Expedition to Whitefish Point, Chippewa County, 29 July
- 31 August 1913, only 10 Odonata species were listed (Hankinson 1915).
Some of the useful contributions of Hankinson’s paper are the documentary
photographs of the various habitats around Whitefish Point, made nearly a
century ago. That expedition was sponsored by George Shiras III (1859-1942)
of Marquette, Michigan, and of photographic fame. Insects, and especially Odo-
nata, were often secondary in importance to vertebrate and plant collections
on early expeditions, if only because there were fewer entomological experts at
the time. Nonetheless, these early collections remain valuable contributions
to the MOS data files, and the specimens are the earliest physical records from
Michigan’s Upper and Lower Peninsulas. The Shiras expedition differed from
previous ones in the number of entomologists on the team. W. S. McAlpine, a
lepidopterist, was a member of the Shiras Expedition, and his paper (McAlpine
1918) describes the activities of the residents of the area as well as the types
of habitats where he collected Lepidoptera. Another expedition member, A.
W. Andrews published a paper about the Diptera (Andrews 1918), in which he
described: “The Whitefish Point region may be called a fly country preeminent.
The Diptera seem to preponderate in sheer numbers over all other insects, and
in all too many cases are omnipresent. So obnoxious and persistent are some of
the pests that the cattle are forced to feed largely at night, and are kept shut
up in dark sheds during the day when the flies are active.”

These early biological surveys in Michigan, supported by wealthy patrons,
provide some of the earliest data that is verifiable, because by the time the
surveys were underway, public institutions were available for the deposition
of specimens, rather than the specimens remaining in private collections. The
UMMZ acquired many vouchers from these early expeditions, and those collec-
tions were important results from a fledgling State Biological and Geological
Survey. Alexander G. Ruthven later became the director of the UMMZ and
eventually, President of the University of Michigan (UM). It is a long way from
a mosquito-infested campsite on Isle Royale to the President’s Office at the
University of Michigan, but there were likely days when Ruthven would gladly
have traded the UM President’s office for a backwoods tent. The biography of
Ruthven has many details on his ascent from a student to President of UM
(Van de Water 1977).

It was not until the University of Michigan Biological Station (UMBS)
opened in 1908 at Douglas Lake in Cheboygan County when new works ap-
peared on Michigan Odonata. Abigail O’Brien published a short list of Odonata
from the Biological Station in 1910, and a few years later, Arthur T. Evans
published a more comprehensive paper on the Biological Station Odonata,
listing 43 species, including the only known northern Michigan locality for *Hetaerina americana* (Fabr.) on the Maple River (Evans 1915). The photographs that accompany Evans’ paper leave no doubt that *H. americana* was collected there. The UMBS property would become a familiar place to a series of students interested in Odonata, such as C. Francis Byers (Byers 1925), J. W. Leonard, and E. J. Kormondy.

Although E. B. Williamson was one of the “giants” of American Odonatology, he collected very little in Michigan, even though he was located in neighboring Indiana. His first Michigan collections were apparently made while vacationing in Oden (Emmet County), a popular vacation spot for many people living in central Indiana. Vacationing Indiana residents could take an overnight coach to Traverse City, where they changed trains to Oden, north of Petoskey (Browne 1967). Williamson collected in Oden during the late summers of 1906 and 1907. The 1906 collecting was done while returning to Indiana from a collecting trip to the Algoma region of Ontario, Canada (Williamson 1907) which explains why he had only a few specimens from that part of the state. Williamson (1907) states “On my return trip home [from Sault Ste. Marie] I stopped at Oden, Crooked Lake, Michigan, with my uncle, G. T. Williamson, and August 11th and 12th were spent collecting there. Later my cousin, Jesse H. Williamson, caught a few specimens about Oden. These records are mentioned in the lists that follow.” None of his records were really notable, and Williamson merely listed the *Aeshna* species as “W, X, Y, and Z” in the 1907 publication. Walker subsequently identified them and used them in his *Aeshna* revision (Walker 1912). In 1914, Williamson traveled to Buchanan in Berrien County, and in 1919 to St. Joseph County. He had a short collecting trip to Branch County in 1925. However, in 1927, he visited several interesting sites in Jackson, Mackinac, and Luce Counties. The trips in 1927 were made with other staff and curators from the UMMZ. In all, his forays in Michigan resulted in only 250 specimens. Unfortunately, Williamson died at the age of 55 from a stroke. His close association with the UMMZ and interactions with his peers has been summarized by O’Brien (2000). One can only speculate how much more he would have accomplished had he lived to his 70s, and it is likely that Michigan would have played a larger role in his research.

At the request of T. L. Hankinson and C. C. Adams of the Michigan Geological and Biological Survey, aquatic entomologist James G. Needham visited Walnut Lake in Oakland County for a total of 10 days in 1908. Walnut Lake was probably viewed as a good lake for commercial fisheries. Although Needham’s research was primarily aimed at Chironomidae, he listed 34 species of Odonata. He apparently provided lists of what he collected there to R. A. Muttkowski in Wisconsin. Muttkowski listed J. G. Needham of Cornell and R. H. Pettit of the Agricultural College of Michigan (now Michigan State University, MSU) as providing lists of species from Michigan in his *Catalogue of Odonata of North America* (Muttkowski 1910). No localities or collectors were specifically mentioned.

A. F. Combs collected Odonata as a member of the 1915 Bryant Walker expedition to Schoolcraft County (Combs 1917). Most of his observations and collections were made near the Manistique River, and he listed 49 species. Many of those specimens (and those of others from the expedition) bear the locality “Michigan: Schoolcraft Co., Floodwood.” Floodwood is not on current maps, but thankfully, J. S. Rogers wrote: “All the field work was done about a locality known Floodwood, situated on the Manistique River some twenty-six miles northeast of the city of Manistique. The surrounding country was largely the typical cut and burned-over pine land of Michigan, undulating sandy plains bearing a scattered growth of jack pine, birch and aspen...” (Rogers 1918).

An interesting note from Combs’ paper was the addition of an unfamiliar named species. Combs wrote “*Somatochlora walkeri* Kennedy. – This species,
described by Kennedy from the material collected...” He gave a name that was not yet published (nor would it be). What happened is detailed somewhat in Walker’s 1918 paper that described two new *Somatochlora* species. Combs’ specimens were described by Walker as *Somatochlora kennedyi*, and Walker wrote: “I take pleasure in naming this species after Mr. Clarence Hamilton Kennedy in recognition of his valuable contributions to North American odonatology. Mr. Kennedy recognized this species as distinct independently of the writer and at about the same time, so it is particularly fitting that it should bear his name.”

In the introduction to his paper, Walker indicated that he had originally wanted to include the two species in a forthcoming monograph, but “at the request of another writer” he decided to publish them in advance. The “writer” was almost certainly Kennedy. Unfortunately, Kennedy’s correspondence with Walker and with Combs prior to 1919 are missing, but otherwise would have been interesting to read. Combs also collected several times at Whitefish Point in Chippewa County in 1914, 1916, and 1930. He also made collections in Oakland County in 1916 and 1917. In all, there are 448 records attributed to him.

**1921-1950.** The first attempt at a catalog of Michigan’s Odonata species was that of C. Francis Byers in 1927. Byers’ list contained 42 genera and 130 species, and to his credit he personally examined 4300 adult and larval specimens (Byers 1927). The bulk of his specimen data came from the UMMZ collection, with most of the larvae coming from collections made by the UMMZ Fish Division’s stream and lake surveys. Surprisingly, Byers had only collected in the area around Douglas Lake and UMBS, with about 130 specimens deposited in the UMMZ. However, Kormondy (1958) stated that “…examination of Byers’ notes showed that, in most instances, these [identifications] rested upon larvae which are in Byers’ personal collection.” So, it seems that not all of the specimens he collected stayed in Ann Arbor, but may have left with him when Byers went to the University of Florida.

During the 1920s, many larval collections were made in Michigan by UMMZ and Michigan Department of Natural Resources (MDNR) ichthyologists. Fish seining often resulted in the collection of the larger instars of larval Odonata, and those specimens eventually ended up in the UMMZ Insect Division collections. John N. Lowe collected extensively across the Upper Peninsula, and his collections of Odonata larvae were somewhat puzzling at first, as they only had numbers that accompanied them in vials. Fortunately, W. R. Taylor catalogued the collections made by Lowe and cross-referenced his field notes, which was needed to provide proper locality data for the specimens (Taylor 1954). Another collector, Jan Metzelaar, was a highly-regarded fisheries biologist with the UMMZ and the MDNR. His unfortunate demise came from falling from his boat on Grand Lake near Alpena in 1929. He drowned after his chest waders filled with water when he became tangled up in a seine (Hubbs 1929). T. H. Langlois, another familiar name on specimen labels, often collected with Metzelaar, as well as with Carl Hubbs and T. L. Hankinson.

Leonora (Dolly) K. Gloyd (1902-1993) was an assistant to E. B. Williamson, and her association with the UMMZ lasted nearly 70 years. Her husband, Howard Gloyd, was a herpetologist at the University of Michigan, and left in 1936 to become director of the Chicago Academy of Sciences. Dolly Gloyd worked for the Illinois Natural History Survey, all the while raising her children and maintaining a connection to the UMMZ to pursue her work with Odonata. Starting in the 1970s, she spent the majority of her time at the UMMZ. In her earlier years in Ann Arbor, Dolly Gloyd traveled in several expeditions to the U. S. Southwest, as well as some in Michigan, and collected around the Ann Arbor area. In 1932-1936, she collected frequently at Third Sister Lake in Saginaw Forest off Liberty Road in Ann Arbor. Those extensive collections provide good baseline data prior to the suburbanization of the surrounding area and eutrophication of Third Sister Lake. Dolly Gloyd eventually described the damselfly *Enallagma vernale* after examining some unusual *Enallagma* from
Third Sister Lake collected by R. F. Hussey in 1919. The repeated collecting at Third Sister Lake during the 1930s provided only a few additional specimens. It wasn’t until she had a large series from Seney National Wildlife Refuge in Schoolcraft County (the type locality) collected by Pierce Brodkorb in 1938, and some additional material from Douglas Lake (UMBS) collected by I. J. Cantrell and F. E. Lyman in 1939 that she finally published her description (Gloyd 1943). There is still debate on whether or not E. vernale is a valid species or a subspecies of Enallagma cyathigerum (Charpentier) (Donnelly 1989, McPeek 1998, Tennessen 2005).

The noted odonatologist Philip P. Calvert accompanied Dolly Gloyd to collect at Mill Creek in Dexter in July 1935. Ada Olson, a staff member at the UMMZ, accompanied Gloyd on several field trips to the northern Lower Peninsula in 1935. There are photographs in the UMMZ archives from a trip they took to Silver Lake in Oceana County. Insect nets, hanging wet clothes, a tent, and a Model A are not so different from what we see on field trips today. Aside from her collecting, Dolly Gloyd provided an immense amount of help to other students in the group. From the 1930s until the late 1980s, she identified many specimens sent to her by others, and many researchers have acknowledged her assistance in their publications (Garrison 1994). She contributed about 1700 Michigan specimens to the UMMZ collection. Dolly Gloyd had amassed a large collection of Amphiagrion specimens, convinced that she had found a new species which she called “mesonum” that was different from the Eastern Red Damselfly, A. saucium (Burm.) and the Western Red Damselfly, A. abbreviatum (Selys). Given Michigan’s location, these may be intergrades between the two species, however, definitive determination has yet to be done. The UMMZ has a large collection of Amphiagrion which would allow for such an analysis.

Justin W. (“Doc”) Leonard (1909-1975), an aquatic entomologist, wrote primarily on mayflies in Michigan. He was an aquatic/fisheries biologist for the MDNR for the majority of his career. A tireless collector and photographer of mayflies, he sampled throughout Michigan’s trout streams. His specimens of Odonata and other aquatic insects reside at the UMMZ. His doctoral thesis work on Acanthagrion, a genus of Neotropical damselflies, was published posthumously, some 40 years after he was a student at UM (Leonard 1977). He wrote two papers on Michigan Odonata -- a description of the larva of Celithemis fasciata Kirby (Leonard 1934) and his note on Stylogomphus albistylus (Hagen) as a new record for Michigan (Leonard 1940).

1951–1996. In the 1950s, a resurgence in the natural sciences took place in post-war Michigan. Robert Dreisbach (1888-1964), a chemist at Dow Chemical in Midland, was one of the serious avocational entomologists who traversed the state collecting almost any kind of insect. He envisioned a state-wide survey of insects, and he was an avid collector from the early 1930s until the early 1960s. He collected a number of Odonata, most identified by Gloyd. Those specimens reside at the UMMZ and MSU collections. A group of entomologists had been meeting in Detroit and Ann Arbor, and the eventual result was the formation of the Michigan Entomological Society (MES) in 1954. This included a newsletter and a journal that 50 years later, still serve the Great Lakes region. The Newsletter of the MES and the Michigan Entomologist (later renamed The Great Lakes Entomologist) provided an outlet for many students and collectors to publish their new state records, and I cataloged those publications in two earlier papers (O’Brien 1983, 1988).

The previous 50 years of expeditions, collecting trips, summer projects, and accumulation of specimens in museums came to fruition with Edward J. Kormondy’s 1958 Catalog of the Odonata of Michigan. Kormondy, a doctoral student at the UMMZ, worked on Tetragoneuria (Epitheca) for his dissertation (Kormondy 1959), and he no doubt saw the opportunity to update the Michigan catalog while at the UMMZ. Kormondy went on several trips across the state
while collecting for his thesis work, and picked up a number of other Odonata along the way. Kormondy’s compilation of records provided an authoritative list of species and distribution data that was essential for anyone interested in odonates in Michigan. Like any catalog, it was based on the data available, and provided an impetus for additional collecting. The only weakness with Kormondy’s work is the inclusion of unverified literature records as the basis for distributional data. One should examine the specimens to verify identifications that are given in the literature (O’Brien 1998). Nonetheless, Kormondy’s 1958 Catalog is now 50 years old, and the MOS benefited from having it as a starting point. Kormondy’s deposition of 1672 Michigan specimens places him as one of the most prolific collectors during this time period. Whenever a species inventory is published, it seems that new records are discovered soon after. So it was with Kormondy’s catalog, and he published a short paper just a few years later (Kormondy 1962) in *Entomological News* with 245 new county records! In summary, Kormondy remains one of the most prolific and thorough researchers of Michigan Odonata.

Kormondy’s catalog remained as the authoritative reference for the next 50 years. Subsequent work on Michigan Odonata by others in the following years was sporadic, resulting in relatively few publications on the fauna, except for the occasional new record. However, a number of people collected specimens throughout the 1960s to the 1980s, resulting in hundreds of records that were later recorded by the MOS. A significant number of specimens were accumulated by students and staff at MSU from the late 1950s into the 1970s, accounting for about 1900 specimens, from all over the state.

One MSU student, Peter J. Martinat, collected Odonata extensively in Michigan during 1968-1969, and those specimens were identified by Gloyd, who kept a record of them in the UMMZ. The specimens were in Martinat’s personal collection until he left them in the collection at the State University of New York College of Environmental Science and Forestry (SUNY-ESF) at Syracuse, in the late 1970s. Upon hearing of the extensive holdings of Odonata at the UMMZ, Frank Kurczewski of SUNY-ESF transferred the Michigan specimens collected by Martinat to the UMMZ collection in the early 1990s.

During the second half of the 20th century, several biologists in Michigan used Odonata as subjects for testing behavioral and evolutionary hypotheses. Jon Waage, a student at UM, studied *Calopteryx* species in southeast Michigan (especially at Fleming Creek at Matthaei Botanical Gardens). His early papers on adult longevity (Waage 1972) and territoriality (Waage 1973) of *Calopteryx* are classic papers that should be read by anyone working on insect and especially, Odonata behavior. Later, in the early 1980s, Joel Weichsel (also at UM) worked on *Hetaerina* in southeast Michigan, and found the first record of *Hetaerina titia* on a small tributary to the Huron River (Weischel 1987, 1998). Ola Fincke has studied *Enallagma* behavior at UMBS since 1980 (Fincke 1982).

Odonata are widespread, often very showy, and a real challenge to collect with nets, so most of the specimens collected in the latter half of the 20th century were adults collected on the wing. Norman Sloan collected 11 species of dragonflies from mist nets in Baraga County in 1966 while studying the birds that were trapped by the nets (Sloan 1967), and Dolly Gloyd identified the new county records for Sloan. R. H. Winkler published a short paper on dragonflies from Macomb County (Winkler 1966). Robert Glotzhober detailed a short trip to Isle Royale and found an atypical *Sympetrum semicinctum* (Say) that was reported as *S. occidentale* Bartenev (Glotzhober 1985). However, after careful analysis, *S. occidentale* was recently designated a junior synonym of *S. semicinctum* (Pilgrim and von Dohlen 2007). There were no broader concerted efforts at Odonata collecting in Michigan until the 1990s. Van Buskirk listed 50 species of Odonata from Isle Royale (Van Buskirk 1992), still the most remote of Michigan places; and Kielb’s papers on Libellulidae in southeast Michigan
and adjacent Essex County, Ontario (Kielb 1996a), and the distribution of Great lakes dragonflies (Kielb 1996b) were the first attempts at compiling distribution records in many years.

As Odonata became popular elsewhere as subjects for biodiversity studies, and more attention was focused on riparian habitat conservation, dragonflies were an obvious choice for natural heritage programs. Hence, the Michigan Natural Features Inventory (MNFI) started sampling for species considered to be at risk. From 1995-1997, David Cuthrell and others at MNFI sampled various sites in both Michigan peninsulas – collecting adults and also larvae and exuviae. The extensive larval/exuviae collections were identified by William A. Smith in Wisconsin, and were later incorporated into the MOS data and UMMZ collection.

I started working on the insect fauna of the Huron Mountain region in Marquette County in 1985. As a guest researcher of the Huron Mountain Wildlife Foundation, I had access to one of the most interesting and least developed areas of the Upper Peninsula. My early research was focused on Hymenoptera, and after a short hiatus from working in the Huron Mountains, I agreed in late 1995 to start surveying that region for Odonata. In 1996, I started a 6-year project to assess Odonata fauna of the Huron Mountains with the aid of Ethan Bright and Michael Kielb (O’Brien, et al. 2003).

That summer (1996), the three of us realized that the time was ripe for a state-wide survey and we formulated the Michigan Odonata Survey. The preliminary MOS handbook was the starting point for the survey (O’Brien 1997). We thought that the survey could be completed in approximately 7 years. The time frame was off, but as of January 2008, the MOS effort has been a success, and has been used as a template by other states to improve their Odonata survey efforts. The MOS history will be written as a section in the forthcoming Catalog of Michigan Odonata.

Throughout the many decades of collecting and research of Michigan species, collectors and research methodology as well as interests have come and gone. However, the one thing that has kept all of their efforts useful, and still relevant, has been the collections of the UMMZ. Appointed as the “University Museum” early on, the resulting UMMZ has maintained collections for posterity. Hopefully, that treasure trove of biological information will remain for future researchers to use and add to.

ACKNOWLEDGMENTS

Writing a manuscript of this sort would have been impossible without the resources of the University of Michigan Museum of Zoology at hand. The collections, field notes, correspondence archives, and library resources were extremely valuable. I have the added benefit of having worked as the Insect Division Collection Manager for 28 years, and have absorbed the many tales of those that preceded me. I thank my good friend Joan Doman for the serendipitous find of the book at her cabin on Burt Lake that connected E.B. Williamson’s summer visits to Oden with the vacationers from Indiana. I thank Julie Craves, Nick Donnelly, and Bob Glotzhober for their comments and suggestions that greatly improved the manuscript. The anonymous reviews were especially helpful in improving the final version.

LITERATURE CITED


RELATIONSHIP OF WINTER STARCH LEVELS IN YOUNG ASH TREES AND ATTACK BY THE EMERALD ASH BORER (COLEOPTERA: BUPRESTIDAE)

Ryan E. Morgan1*, Peter de Groot1,2 and Sandy M. Smith1

ABSTRACT

The emerald ash borer, *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), is native to northeastern Asia. Since its discovery in North America in 2002, the beetle has killed more than 40 million ash trees (*Fraxinus* spp.) and caused serious environmental and economic damage. Understanding factors that may lead to increased tree susceptibility to *A. planipennis* would help to focus detection surveys on higher risk areas and assist in mitigation measures. Winter starch levels in the roots of deciduous tree species have been shown to be a good predictor of a tree’s susceptibility to native *Agrilus*, and thus we hypothesized that trees with low starch levels would be associated with larger numbers of *A. planipennis* than those with high reserve levels. We compared winter 2003-04 starch levels with summer 2004 capture rates of *A. planipennis* on 200 ash trees in four plantations [two green ash (*F. pennsylvanica*) and two white ash (*F. americana*)]. Tree stress, as measured by root starch levels, was not significantly correlated with densities of *A. planipennis* adults caught on sticky traps on either previously colonized or uncolonized trees. However, significantly more *A. planipennis* adults were collected on previously colonized trees versus trees that had not yet been attacked.

The emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is native to northeastern Asia, and was first discovered in Canada and the United States in 2002 (Haack et al. 2002, Cappaert et al. 2005). Since its discovery, the beetle has become a very significant pest killing more than 40 million ash (*Fraxinus* spp.) in southwestern Michigan alone, and tens of millions more in Ohio, Illinois, Indiana, Pennsylvania, West Virginia, Missouri, Wisconsin, Virginia, and Ontario and Quebec, Canada (Canadian Food Inspection Agency 2007, Poland 2007, United States Department of Agriculture - Animal and Plant Health Inspection Service 2007, EAB Info 2008). In addition to tree mortality, there will be serious environmental and economic impacts (Cappaert et al. 2005) as ash disappears from the landscape. At least 16 endemic species of ash are threatened in North America with the potential loss of tens of billions of dollars to urban forests alone in the United States (Federal Register, United States 2003). Current estimates indicate that the beetle has been in North America for at least 10 years before its discovery in 2002 (Cappaert et al. 2005, Poland and McCullough 2006). This insect is difficult to detect (Poland and McCullough 2006, de Groot et al. 2006) and understanding the factors that may lead to increased susceptibility of trees to *A. planipennis* would help focus detection surveys to higher risk areas and assist mitigation measures.

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*Corresponding author.
Tree vitality (sensu Shigo 2002) is a significant factor in the determination of a tree’s susceptibility to insects and can be an important predictor of a tree’s tolerance to stress. Studies on a native North American buprestid, the twolined chestnut borer, *Agrilus bilineatus* (Weber), have demonstrated that this beetle preferentially attacks and kills stressed oak trees (Haack and Benjamin 1982; Dunn et al. 1986, 1987, 1990a, b; Dunn and Potter 1990). In addition, outbreaks of the twolined chestnut borer are most often found in forested areas with histories of drought, defoliation, and natural or human-assisted disturbances (Haack and Benjamin 1982). Another native buprestid, the bronze birch borer, *Agrilus anxius* Gory, also shows a preference for stressed or low vitality birch trees (Loerch and Cameron 1984), and exotic hosts, such as European white birch, *Betula pendula* Roth (Miller et al. 1991) which adds support to the notion that the beetle prefers stressed host trees. It is possible that *A. planipennis* also prefers stressed trees as studies have shown that tree stress induced by the removal of the phloem and a portion of the outer xylem of ash trees increases attraction of the beetle (Poland et al. 2005, McCullough et al. 2006).

The level of starch stored during the winter in the roots of deciduous trees reflects the net photosynthetic capacity of the tree in previous growing seasons, and is a useful measure of tree vitality (Wargo 1975, 1978). Wargo (1975) developed a simple staining technique for estimating the level of stored starch in the roots of deciduous trees. This technique has been used to evaluate the role of sugar maple vitality on the fecundity of pear thrips (Carey et al. 1992) and to examine the effect of tree vitality on the susceptibility of oak trees to attack by *A. bilineatus* (Haack and Benjamin 1982, Dunn et al. 1987). Higher numbers of *A. bilineatus* captures and attacks were found on oak trees low in root starch levels compared to trees with higher levels of stored starch (Dunn et al. 1987).

In this study, we examined the relationship between winter starch levels of ash trees and attack rates the following year by *A. planipennis*. We hypothesized that ash trees with low starch levels would have a higher number of *A. planipennis* attracted to them.

**MATERIALS AND METHODS**

The study was conducted in four ash plantations within 5-18 km of each other in Essex County, Ontario, Canada. Two plantations contained white ash, *Fraxinus americana* L. (Oleaceae) and two had green ash, *F. pennsylvanica* Marsh. Young plantations were used to ensure the accuracy of detecting attacks and colonization by *A. planipennis* because mature trees often have attacks high up in the crown that remain undetected until the tree shows signs of decline or until the tree has been cut down (Poland and McCullough 2006). In addition, young trees were ideal because the bark is smoother than that of mature trees, which made it easier to detect exit holes. The plantations were situated on poorly drained and predominately clay soils, which is common in the area of the infestation in Essex County. An examination of the annual rings of the callus tissue around *A. planipennis* exit holes suggested that the beetle had been present in the plantations for 1-2 years before 2003 (personal observations, PdG). All plantations were less than 20 years old, and trees ranged from 6.1 - 9.5 m tall with a 3.5-13.3 cm diameter at breast height (DBH). Additional characteristics of the plantations are summarized in Table 1.

During September and October 2003, 50 ash trees were selected throughout each plantation. Within each plantation, a randomly located starting point was selected at a minimum distance of 10 m from any edge and from this starting point, a 150 m U-shaped transect (50 m long on each side) was positioned. The nearest ash tree with no sign of borer colonization (e.g., exit holes) was selected at 3-m intervals along each transect. Ash trees that had been attacked and colonized by *A. planipennis* were identified by the presence of cracks in the bark,
Table 1. Summary statistics of site and tree characteristics, starch levels, and captures of *Agrilus planipennis* in four ash plantations surveyed for root starch levels in Essex County, Ontario, Canada.

<table>
<thead>
<tr>
<th>Plantation</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species of ash</td>
<td>Green</td>
<td>White</td>
<td>Green</td>
<td>White</td>
</tr>
<tr>
<td>Year trees were planted</td>
<td>1991</td>
<td>1985</td>
<td>1993</td>
<td>1988</td>
</tr>
<tr>
<td>No. of ash trees planted</td>
<td>70,000</td>
<td>7,000</td>
<td>8,000</td>
<td>8,200</td>
</tr>
<tr>
<td>Area (ha)</td>
<td>30.0</td>
<td>2.8</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Mean diameter at breast height (cm) ± stdev.</td>
<td>5.70 ± 1.01</td>
<td>7.34 ± 1.65</td>
<td>9.00 ± 1.87</td>
<td>6.82 ± 1.79</td>
</tr>
<tr>
<td>Mean height of ash (m) ± stdev.</td>
<td>6.15 ± 0.91</td>
<td>7.72 ± 1.13</td>
<td>9.47 ± 1.51</td>
<td>7.49 ± 1.48</td>
</tr>
<tr>
<td>Mean crown length (m) ± stdev.</td>
<td>3.69 ± 0.76</td>
<td>4.32 ± 0.97</td>
<td>4.29 ± 0.84</td>
<td>4.16 ± 0.77</td>
</tr>
<tr>
<td>Mean crown width (m) ± stdev.</td>
<td>2.13 ± 0.43</td>
<td>1.96 ± 0.42</td>
<td>2.66 ± 0.48</td>
<td>2.60 ± 0.6</td>
</tr>
<tr>
<td>Starch Levels (n=50)³</td>
<td>No. of trees rated as High (15-30%)</td>
<td>12</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Mean no. of <em>A. planipennis</em> trapped /m² (high)⁴</td>
<td>110.6 ± 16.7</td>
<td>107.3 ± 16.9</td>
<td>68.1 ± 14.5</td>
<td>10.5 ± 3.4</td>
</tr>
<tr>
<td>No. of trees rated as Medium (7-12%)</td>
<td>29</td>
<td>29</td>
<td>27</td>
<td>30</td>
</tr>
<tr>
<td>Mean no. of <em>A. planipennis</em> trapped /m² (med.)</td>
<td>172.6 ± 31.8</td>
<td>81.8 ± 10.8</td>
<td>44.8 ± 10.5</td>
<td>12.1 ± 2.89</td>
</tr>
<tr>
<td>No. of trees rated as Low (3-6%)</td>
<td>9</td>
<td>6</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Mean no. of <em>A. planipennis</em> trapped /m² (low)</td>
<td>122.5 ± 27.0</td>
<td>38.4 ± 12.4</td>
<td>50.4 ± 20.4</td>
<td>5.75 ± 5.75</td>
</tr>
<tr>
<td>Total no. of <em>A. planipennis</em> trapped</td>
<td>603</td>
<td>443</td>
<td>354</td>
<td>54</td>
</tr>
<tr>
<td>Mean no. of <em>A. planipennis</em> trapped /m²</td>
<td>149 a ± 19.7</td>
<td>84 b ± 8.6</td>
<td>52 bc ± 7.85</td>
<td>11 c ± 2.09</td>
</tr>
<tr>
<td>Trees previously colonized by <em>A. planipennis</em> out of the 50 study trees per plantation</td>
<td>40</td>
<td>6</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Main <em>A. planipennis</em> activity period in 2004</td>
<td>June 9-15</td>
<td>June 23-29</td>
<td>June 30-July 6</td>
<td>June 23-29</td>
</tr>
</tbody>
</table>

¹ Means were calculated using 50 trees per plantation, with the exception of means calculated for starch levels.
² stdev. = Standard Deviation.
³ Root tissues used for rating starch levels were extracted from Dec. 2003 - Jan. 2004
⁴ Means for the number of *A. planipennis* trapped /m² are presented with standard errors (± SE) for each starch rating. *Agrilus planipennis* were trapped from May 24 - Aug. 20, 2004
⁵ Means ±SE within a row followed by the same letter are not significantly different at α = 0.05 (Tukey's test).
exposed portions of larval galleries or ‘D-shaped’ holes made by exiting adults (de Groot et al. 2006). During the following spring and summer (May-September 2004), trees were re-examined (second sample) and attack by A. planipennis in the previous year was recorded again.

During December 2003 and January 2004, we exposed one primary root of each of these 200 trees by excavating distally from the root-collar to approximately 1 m from the stem. Samples of root wood (4 × 3 × 2 cm deep) were collected using a hammer and chisel and kept frozen until returned to the laboratory. We used the histochemical techniques of Wargo (1975) to categorize the starch content in the roots as high (15-30%), medium (7-12%), low (3-6%), or depleted (0-1%). Although chemical extraction of starch from root tissue has the advantage of being quantitative, Wargo (1975) and Dunn et al. (1987) found a close agreement in root starch ratings between the colorimetric and histochemical methods. Few trees were found to have depleted levels of starch in our study; therefore, trees with depleted levels of starch were categorized as having low levels for the analysis. Dunn et al. (1987) found that variability in starch content among roots of the same tree existed in 23% of the trees sampled using the Wargo (1975) staining technique. Therefore, we sampled two primary roots from 30% of all trees to determine if differences among roots were present. Within-tree comparisons of starch levels were based on the visual assessment of the root samples.

Beetles attracted to the sample trees were trapped on 45-cm wide polyethylene bands coated with Tangletrap® (Great Lakes IPM Inc., Vestaburg, Michigan, USA). The trap bands were placed around the trunk of each tree just before beetle emergence (unpublished data, PdG), with the mid-point of the trap at 1.3 m above ground (diameter breast height or DBH). Collections were made weekly from 24 May - 20 August 2004 by removing adults from the traps. The number of A. planipennis adult beetles caught on the traps were totalled per tree and standardized (= no. per m² of trapping surface) to account for differences in the trap surface area on trees of varying diameters.

A one-way ANOVA (PROC GLM, SAS Institute 1985) was used to compare differences in the mean number of A. planipennis caught per m² on ash trees with varying levels of winter starch levels. The same analysis was used to compare the differences in beetle captures between plantations. The possibility that starch levels were affected by colonizing A. planipennis did exist; therefore, we further separated the analysis to explore the relationship between starch levels and beetle captures on trees previously colonized by A. planipennis and trees not previously colonized, separately. A significant difference in total beetle captures was detected between plantations (Table 1). Therefore, we further analyzed the relationship between starch levels and beetle captures separately for each plantation. When the ANOVA results were significant (p ≤ 0.05), a Tukey’s multiple comparisons test was used to determine which treatments differed significantly. Homogeneity of variance was tested with Levene’s test and the requirements of the ANOVA were met.

It was not our initial intent to compare the number of beetles captured on trees previously colonized by A. planipennis with those captured on uncolonized trees; however, because many of our study trees were subsequently found to be attacked by A. planipennis during our second period of sampling (May-September 2004), a two sample t-test on the mean number of beetles captured/m² per tree was used to explore this relationship.

Main A. planipennis activity periods for each plantation were determined by selecting the weeks in which the highest percentages of total beetles were captured.
RESULTS AND DISCUSSION

The number of beetles captured per m$^2$ of trapping surface (hereafter referred to as captured) did not differ between ash trees with different levels of stored starch when all plantations were pooled together ($F = 0.22$; df = 2, 197; $p = 0.81$, n = 200) and when each plantation was analyzed separately (Plantation 1: $F = 1.04$, df = 2, 47; $p = 0.36$, n = 50; Plantation 2: $F = 3.04$, df = 2, 47; $p = 0.06$, n = 50; Plantation 3: $F = 0.82$, df = 2, 47; $p = 0.45$, n = 50; Plantation 4: $F = 0.27$, df = 2, 47; $p = 0.77$, n = 50). Plantations were analyzed separately because the number of beetles captured differed significantly between them ($F = 25.52$; df = 3, 196; $p < 0.0001$; $R^2 = 0.28$ (Table 1). Based on visual assessments of the root samples, it was determined that the starch ratings of all 60 trees sampled twice (two primary roots from the same tree) were consistent with each other (both roots contained the same level of stored starch). The number of beetles captured was not related to the amount of winter starch levels within trees previously colonized by *A. planipennis* ($F = 0.91$; df = 2, 66; $p = 0.410$; n = 69), nor within uncolonized trees ($F = 1.08$; df = 2, 128; $p = 0.34$; n = 131). The 2004 main *A. planipennis* activity periods for each plantation studied were: 9-15 June, 23-29 June, 30 June - 6 July, and 23-29 June (Table 1).

Our results suggest winter starch levels in roots are not a predictor of attack by *A. planipennis* in young green and white ash grown in plantations. MacFarlane and Meyer (2005) reviewed the ecology of ash trees and the biology of *A. planipennis* to assess the relative risk to the beetle and noted that a relationship between tree vitality and colonization by *A. planipennis* had not been established. A preliminary analysis by Witter and Storer (2005) of over 400 site and visual assessments conducted in infested Michigan stands during 2003 indicated that mean ash vitality was generally high, with only 5% of sites having poor vitality. Early results from a study by Herms et al. (2005) suggest that *A. planipennis* prefers trees fertilized with nitrogen, however this finding has not yet been correlated to starch levels in the roots.

Trees previously colonized by *A. planipennis* had a significantly higher number of beetles per m$^2$ of trap surface [133 ± 1.53 (mean ± SE); n = 69] than trees that had not yet been colonized (43 ± 0.437; n = 131). These previously attacked ash trees captured over 300% as many beetles as uncolonized trees. Timms et al. (2006) in their study of the spatial distribution and attack dynamics of *A. planipennis* on young ash trees noted that previously attacked trees had a higher incidence of beetles the year after attack than trees that were uninfested. Similarly, Haack and Benjamin (1982) and Haack et al. (1983) also found higher incidence of *A. bilineatus* beetles in oak trees attacked previously than in uncolonized trees. It is likely that some of the newly emerging beetles were captured on the previously attacked trees.

Our results may indicate that *A. planipennis* attacks all ash trees regardless of low or high stress levels, albeit as currently measured by starch levels. Studies cited in Poland (2007) indicate that *A. planipennis* shows a preference for girdled trees in an area, but “stress” has never been specifically measured and compared between girdled and ungirdled trees. The apparent preference by *A. planipennis* for girdled trees may also be a result of qualitative and quantitative differences in host volatiles that it may use in host location and selection. Although our work suggests that winter starch levels are not a good predictor of attack by *A. planipennis*, other measurements of tree vitality, such as electrical resistance may be useful, as it has been for *A. anxius* (Ball and Simmons 1984). Further work is needed to discover appropriate measures of tree vitality that might best predict locations and trees more likely to be attacked by *A. planipennis* when it first arrives in an area, and in so doing, improve early detection and pest mitigation measures to deal with this highly destructive invasive forest insect.
ACKNOWLEDGEMENTS

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LITERATURE CITED


RELATIONSHIPS BETWEEN ASYNCHRONOUS FLOWERING BY BAPTISIA ALBA (FABACEAE) AND THE SEED PREDATOR, APION ROSTRUM (COLEOPTERA: APIONIDAE)

Chris E. Petersen1, Jessica L. Gibbs1, and George Hidalgo1

ABSTRACT

Pre-dispersal seed predation can be so intense as to be a selective force on flowering phenology. This study examined asynchronous flowering by the legume, Baptisia alba (Fabaceae), which is host to the pre-dispersal seed predator, Apion rostrum (Say) (Apionidae). The majority of B. alba flower and initiate pods during peak oviposition activity by the weevil. However a few plants, which always appeared to be smaller and possibly young, tend to flower and initiate pods much later. In this study, we examined if A. rostrum could be an influencing factor, along with plant size, on the initiation and duration of flowering. The study was conducted in the Russell Kirt Tallgrass Prairie, a 7.1 ha re-created prairie located in northeastern Illinois. The activity of ovipositing weevils was monitored by visual observation of adults and examination of inflating pods for eggs. This activity was used in conjunction with a study of 63 B. alba which began when the plants flowered and ended with the ripening of pods. The activity of ovipositing A. rostrum was greatest during June as pods of two-thirds of the B. alba were inflating. These B. alba composed a synchronous group of early flowering plants (EF group). The EF plants had more racemes, produced more flowers and inflated more pods than later flowering plants (LF group). The EF plants also were host to more weevils. Forward stepwise regression analyses showed that the count of A. rostrum/plant was significantly informative in predicting flower initiation date while both the count of A. rostrum/plant and plant size, as indicated by the count of racemes/plant, were likewise informative in predicting the duration of flowering. The smaller LF plants may better escape detection by the weevil by reproducing later while the larger EF plants may be more constrained by other environmental factors. The prolific reproductive nature of larger B. alba may effectively prevent escape from a seed predator which has closely synchronized its development to that of its host.

Pre-dispersal seed predation can be so intense in decreasing the reproductive output of plants as to be a selective force on the timing of flowering (Klips et al. 2005). Seed loss may especially affect individuals of a population that have a narrow window to flower over the course of a season. For such a population, the intensity of seed predation is not only measured by seed loss, but also in nutritional expenditures and inability to compensate by additional reproduction. As a coevolutionary response, synchrony of flowering period may offer to satiate the seed predator (Kelly and Sork 2002, Honek and Martinkova 2005, Klips et al. 2005, Sun et al. 2007). However, pre-dispersal seed predation is often greatest during peak flowering (Molau 1989, Kelly and Sork 2002, Klips et al. 2005, Elzinga et al. 2007). Asynchronous flowering or extended flowering episodes by a plant population may be a strategy to minimize losses to predation.

Silene uniflora Roth (Caryophyllaceae), for example, has an extended flowering period where larger and presumably older plants flower earlier in the season and suffer greater seed losses, but yield more seeds per plant than

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smaller individuals (Pettersson 1994). *Acacia tortilis* (Forsske.) Hayne (Fabaceae) has two flowering seasons (Mduma et al. 2007). Flowering during the dry season ends with early abortion of fruits while flowering during the wet season results in successful fruiting. The authors suggest the first flowering is linked to predator cleansing, where larvae developing in fruits die when the fruits are aborted. The effects of pre-dispersal seed predation on the timing of flowering can also be obscured when a plant is targeted by multiple predators over the course of flowering. The variation shown by *Baptisia australis* (L.) R. Br. (Fabaceae) in flowering time has been explained by multiple pressures of insect seed predators as well as weather (Evans et al. 1989).

This study focused on asynchronous flowering by *Baptisia alba* (L.) Vent, a leguminous native to mesic prairie of the Midwest (Swink and Wilhelm 1994), in relation to pre-dispersal seed predation. This perennial generally flowers from late May into June. However, a few plants develop more slowly and bloom much later, as late as August. Initial observation indicated these late-flowering plants to be smaller and have fewer racemes than the majority of those that bloomed earlier. Renewed growth by *B. alba* begins as the shoot emerges from the ground once the soil thaws during spring. Resembling asparagus, the shoot eventually branches out, forming a large central raceme that can be surrounded by 5 or more, smaller, lateral racemes. Racemes are indeterminate (Haddock and Chaplin 1982). Flowers of the central raceme open first, followed by an evolving inflorescence among satellite racemes. Pod inflation occurs soon after flower pollination. Seeds within developing pods serve as food for developing larvae of *Apion rostrum* (Say) (Coleoptera: Apionidae), the only seed predator of the legume in our study site, the Russell Kirt Tallgrass Prairie located in Glen Ellyn, DuPage County, in northeastern Illinois. Larvae fully consume seeds or hollow out seeds leaving behind the exocarp and little else.

Overwintering weevils appear during the second half of May. The adults can be seen climbing and copulating on stems and leaves. The females insert eggs, one per point of insertion, into the developing pods. Egg number per pod can range above 10 but usually averages below 3 (Petersen and Wang 2007). The adult stage is reached by August and the weevils disperse soon after the ripened pods dehisce. It is unknown where the adults disperse and overwinter. Seed predation can be quite intense with most if not all seeds consumed in pods. In addition, seed loss to predation has also been linked to the abortion of pods having few seeds (Petersen and Sleboda 1994).

In this study, we tested whether *A. rostrum* was a significant factor, along with plant size, in predicting the timing of flower initiation and duration of flowering as to provide evidence of causal relationships. Plant size was also considered to be an influencing factor based on findings of other studies that showed larger plants flowering earlier and for a longer duration than smaller plants (Pettersson 1994, Ollerton and Lack 1998).

**MATERIALS AND METHODS**

The 7.1 ha Russell Kirt Tallgrass Prairie is located on the main campus of College of DuPage which is located in residential Glen Ellyn, IL. Re-creation of this prairie began in 1984 with plantings characterizing the historic local prairie. The most common tall grasses are big bluestem (*Andropogon gerardii* Vitman), prairie dropseed (*Sporobolus heterolepis* Gray), and Indian grass (*Sorghastrum nutans* (L.) Nash). *B. alba* contributes to the 150 forbs found within the prairie (Kirt 1996) which is burned annually during early spring, including the spring of 2007, two months prior to the beginning of this study.

Methodology involved monitoring the activity of adult *A. rostrum* that had overwintered and the development of the new generation of weevils, as well as the flowering period, reproductive yield, and weevil infestations of *B. alba*. 
Monitoring of weevil activity and development offered information of when oviposition was greatest. Visual counts of adult *A. rostrum* were taken from *B. alba* three times a week beginning in May and ending in August 2007 after a 2-week period of not observing adult weevils. These observations, each from 50 randomly selected *B. alba*, were taken either during the morning, afternoon, or evening to take into account varying activity over the course of a day. In addition to these visual counts, a pod was sampled from each of 20 randomly selected plants for observation of weevil infestation and stage of development.

We randomly selected and monitored 63 *B. alba* from initial seed production to, where possible, the ripening of pods. These plants were not included among plants used to monitor weevil development. Each individual plant was monitored for timing of first and last flowering, counts of flowers, counts of inflated pods, counts of ripened pods, counts of racemes, undamaged seed counts within ripened pods, and weevil counts per ripened pod. Counts of flowers and inflated pods were recorded every other day as to keep up with the growth of indeterminate racemes and any pod loss. Counts of seeds and weevils were taken from five ripened pods sampled from each raceme of a plant. The most basal and most distal pods were sampled along with three pods located between. If a raceme had fewer than five pods, all pods were sampled. We estimated the number of mature seeds per plant as the product of inflated pod count and grand mean weevil count in ripened pods among racemes.

As weevils oviposit into inflating pods, estimates of weevil infestation per plant were computed as the product of inflated pod count and grand mean weevil count in ripened pods among racemes. Grand means of seeds matured or weevils offered to treat differences among racemes while the procedure to estimate counts of weevils/plant was believed to most closely predict levels of plant infestation prior to losses of immature pods.

The 63 plants were partitioned according to the timing of the first flowering to examine how parameters of reproductive yield and weevil infestation varied between the early and late flowering plants. Flower initiation was enumerated by assigning a value of 1 to the plant that first flowered, and sequentially thereafter as each of the remaining plants began to flower. The majority of plants (synchronized flowering individuals) began to flower during the first 10 days. These plants, henceforth identified as the “early flowering” (EF) group based on flower initiation, were compared to plants that began to flower after this period of time and are henceforth identified as the late flowering (LF) group based on flower initiation.

All statistical summarization was done using Statistica (Statsoft 2001). Mann-Whitney U tests were used to determine statistical differences between parameters of reproductive yield and weevil infestation of EF and LF groups. Forward stepwise regression was run to test the dependence of the day of first flowering and also flowering duration on counts of *A. rostrum* plant and plant size as equated by raceme number. Only plants that produced ripened pods were considered in analyses. Variables were added to regression models only where \( F > 1.0 \), so that significant regression models potentially included 1 or both independent factors. Counts of *A. rostrum* plant were \( \log_{10}(x + 1) \) transformed and dates of first flowering were \( \log_{10}(x) \) transformed prior to regression analyses to meet normality. Significance was determined at \( P < 0.05 \).

RESULTS

Overwintered adults of *A. rostrum* were spotted on plants from late May through much of June 2007 (Fig. 1). This activity period roughly coincided with the appearance of eggs in pods of *B. alba* (Table 1). Of the 63 *B. alba* plants monitored for flowering characteristics, the earliest individual opened flowers on 20 May, two-thirds began to flower within the first 10-day period and the remaining one-third initiated flowering 11 to 44 days later. Nineteen of the 45
EF plants (42%) and 5 of the 18 LF plants (28%) lost all pods prior to ripening. Among B. alba that produced ripened pods, EF plants flowered for a longer duration, had more racemes/plant, produced more flowers, inflated more pods, and had higher counts of A. rostrum/plant on average than LF plants (Table 2). This trend was also seen between the EF and LF plants that did not ripen pods (Table 3). Differences in mean rank among parameters of plant size and reproductive output between plants within a flowering group, either EF or LF, were not significantly different ($P > 0.05$), except for the median rank of raceme count/plant in the LF group ($U = 12.5; Z = 1.972; P < 0.049$).

Stepwise regression based on a model of factors affecting the first flowering date of B. alba was significant ($R^2 = 0.22; F = 10.4; df = 1, 37; P < 0.003$), with only counts of A. rostrum/plant being significant (Table 4). Both counts of A. rostrum/plant and racemes/plant were included with the model describing factors affecting flowering duration ($R^2 = 0.44; F = 14.1; df = 2, 36; P < 0.001$).

**DISCUSSION**

The activity of adult A. rostrum was greatest during the middle and later part of June when the majority of B. alba pods were inflating, which is evidence of A. rostrum’s close developmental synchrony with the legume. A. rostrum also exploits B. bracteata Muhl. ex Elliot, which is found in the local area (Petersen and Wang 2007). This congener blooms and inflates pods about two to three weeks earlier, produces less pods and seeds, and is less heavily infested by the weevil compared with B. alba. However, the presence of B. bracteata added to the pool of B. alba may be sufficient to affect the timing of A. rostrum oviposition. The weevils were sufficiently rare as to escape detection when the last B. alba were inflating their pods. These late-blooming B. alba may be too few to maintain higher levels of oviposition activity.
Table 1. Mean (± SEM) counts of ovules/pod, seeds/pod, and the various developmental stages of *Apion rostrum* / pod of *Baptisia alba* by sampling date in 2007 at the Russell Kirt Tallgrass Prairie in Illinois. All N = 20.

<table>
<thead>
<tr>
<th>Date</th>
<th>Parameter</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 June 2007</td>
<td>Ovules/pod</td>
<td>34.0 ± 1.0</td>
</tr>
<tr>
<td></td>
<td>Seeds/pod</td>
<td>26.5 ± 1.9</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> eggs/pod</td>
<td>2.6 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>2.6 ± 0.5</td>
</tr>
<tr>
<td>14 June 2007</td>
<td>Seeds/pod</td>
<td>27.2 ± 1.7</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> eggs/pod</td>
<td>2.7 ± 0.7</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> larvae/pod</td>
<td>0.7 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>3.3 ± 0.8</td>
</tr>
<tr>
<td>20 June 2007</td>
<td>Seeds/pod</td>
<td>15.9 ± 1.6</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> egg/pod</td>
<td>0.7 ± 0.4</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> larvae/pod</td>
<td>2.4 ± 0.6</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>3.1 ± 0.6</td>
</tr>
<tr>
<td>27 June 2007</td>
<td>Seeds/pod</td>
<td>7.0 ± 1.1</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> larvae/pod</td>
<td>1.7 ± 0.4</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> pupae/pod</td>
<td>2.2 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>3.9 ± 0.4</td>
</tr>
<tr>
<td>5 July 2007</td>
<td>Seeds/pod</td>
<td>9.0 ± 1.6</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> larvae/pod</td>
<td>2.1 ± 0.4</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> pupae/pod</td>
<td>1.8 ± 0.3</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> adults/pod</td>
<td>0.4 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>4.2 ± 0.5</td>
</tr>
<tr>
<td>12 July 2007</td>
<td>Seeds/pod</td>
<td>5.6 ± 1.1</td>
</tr>
<tr>
<td></td>
<td><em>A. rostrum</em> pupae/pod</td>
<td>1.8 ± 0.5</td>
</tr>
<tr>
<td></td>
<td>Adult <em>A. rostrum</em> / pod</td>
<td>1.8 ± 0.4</td>
</tr>
<tr>
<td></td>
<td>All <em>A. rostrum</em> / pod</td>
<td>3.6 ± 0.5</td>
</tr>
</tbody>
</table>
Table 2. Summary data (mean ± SEM) for *Baptisia alba* size, reproductive output, and plant infestation by *Apion rostrum* according to timing of first flowering. The first flowering date of plants was computed sequentially from the day that the initial plant flowered. Mann-Whitney results of mean rank comparisons between first flowering categories are also provided.

<table>
<thead>
<tr>
<th>Variable</th>
<th>≤ Day 10 (n = 26 plants)</th>
<th>&gt; Day 10 (n = 13 plants)</th>
<th>U</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing of first flowering (day)</td>
<td>6.6 ± 0.7</td>
<td>25.8 ± 3.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flowering duration (day)</td>
<td>19.9 ± 1.1</td>
<td>15.4 ± 1.3</td>
<td>88.5</td>
<td>2.398</td>
<td>0.017</td>
</tr>
<tr>
<td>Racemes/plant</td>
<td>5.4 ± 0.6</td>
<td>2.5 ± 0.5</td>
<td>71</td>
<td>2.920</td>
<td>0.004</td>
</tr>
<tr>
<td>Flowers/plant</td>
<td>100.6 ± 14.9</td>
<td>40.8 ± 6.1</td>
<td>53.5</td>
<td>3.441</td>
<td>0.001</td>
</tr>
<tr>
<td>Inflated pods/plant</td>
<td>67.1 ± 13.5</td>
<td>24.0 ± 4.7</td>
<td>61.5</td>
<td>3.203</td>
<td>0.001</td>
</tr>
<tr>
<td>Ripened pods/plant</td>
<td>18.5 ± 7.8</td>
<td>8.2 ± 3.4</td>
<td>148.5</td>
<td>0.611</td>
<td>0.541</td>
</tr>
<tr>
<td>Seeds matured per plant</td>
<td>65.7 ± 31.6</td>
<td>17.7 ± 8.5</td>
<td>165.5</td>
<td>0.105</td>
<td>0.917</td>
</tr>
<tr>
<td><em>Apion rostrum</em> count/plant</td>
<td>212.2 ± 49.0</td>
<td>53.5 ± 14.7</td>
<td>56.5</td>
<td>3.352</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 3. Summary data (mean ± SEM) for size and reproductive output of *Baptisia alba* that did not produce ripened pods. The first flowering date of plants was computed sequentially from the day that the initial plant flowered. Mann-Whitney results of mean rank comparisons between first flowering categories are also provided.

<table>
<thead>
<tr>
<th>Variable</th>
<th>≤ Day 10 (n = 19 plants)</th>
<th>&gt; Day 10 (n = 5 plants)</th>
<th>U</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Timing of first flowering (day)</td>
<td>6.1 ± 0.7</td>
<td>21.6 ± 3.1</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flowering duration (day)</td>
<td>18.2 ± 1.3</td>
<td>11.0 ± 2.4</td>
<td>14</td>
<td>2.381</td>
<td>0.017</td>
</tr>
<tr>
<td>Racemes/plant</td>
<td>3.9 ± 0.4</td>
<td>1.0 ± 0.0</td>
<td>7.5</td>
<td>2.843</td>
<td>0.005</td>
</tr>
<tr>
<td>Flowers/plant</td>
<td>65.7 ± 9.0</td>
<td>18.2 ± 3.9</td>
<td>9</td>
<td>2.737</td>
<td>0.006</td>
</tr>
<tr>
<td>Inflated pods/plant</td>
<td>36.6 ± 5.9</td>
<td>9.8 ± 2.1</td>
<td>14</td>
<td>2.381</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Table 4. Results of forward stepwise regression according to flowering parameter in the order factors were added to the model. The only factors listed are those included in the model as limited to \( F > 1 \). Counts of *Apion rostrum*/plant were log(\( x + 1 \)) transformed and first flowering dates were log(\( x \)) transformed. N = 39 for each variable.

<table>
<thead>
<tr>
<th>Flowering parameter</th>
<th>Factor</th>
<th>Regression coefficient</th>
<th>t</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>First flowering date</td>
<td><em>Apion rostrum</em>/plant</td>
<td>-0.468</td>
<td>3.221</td>
<td>0.003</td>
</tr>
<tr>
<td>Flowering duration</td>
<td>Racemes/plant</td>
<td>0.393</td>
<td>2.416</td>
<td>0.021</td>
</tr>
<tr>
<td></td>
<td><em>Apion rostrum</em>/plant</td>
<td>0.337</td>
<td>2.072</td>
<td>0.046</td>
</tr>
</tbody>
</table>
The relationships of counts of *A. rostrum*/plant to flower initiation date and flowering duration are in keeping with a coevolutionary interaction. A regression coefficient of -0.468 for initial flowering date indicates other factors are involved, such as a need to attract pollinators in the emerging springtime landscape, should also be considered for their selective significance to early season blooms. The historic tallgrass prairie shows a succession of forbs flowering throughout the growing season (Ladd 1995) and the size of floral display has been shown to be a significant factor relating to seeds matured/individual *B. alba* (Petersen et al. 2006). Pollinators may be attracted only when a threshold density of individuals are in bloom (Elzinga et al. 2007), offering explanation to the synchronous flowering of the majority of *B. alba*.

Smaller, and possibly younger, *B. alba* may delay flower initiation to gather reserves for reproduction, but also to protect their more meager reproductive output by escaping the peak activity of ovipositing weevils. The subsequent lower seed predation among LF plants may reinforce the plastic flowering pattern by *B. alba*.

The larger and majority of *B. alba* that bloom earlier may have the reserves to flower over a longer period of time aiding in the attraction of pollinators as well as extending pod inflation beyond the weevil’s peak oviposition activity. A question arises of why some these *B. alba* do not delay flowering beyond the peak weevil oviposition period? *A. rostrum* is known to infest several other congeners of *Baptisia* in the eastern United States (Evans et al. 1989, Horn and Hanula 2004), indicating that the weevil is able to adapt to its host in local environments. This observation, coupled with the appearance of eggs in pods of LF plants, indicates that a shift in flowering time could be met by a change in oviposition period by the weevil which would not be advantageous to larger plants nor the LF smaller plants. Further constraints may come in the form of weather and the need to secure pollinators. Finally, indeterminate growth, to include the development of satellite racemes, may be a strategy that *B. alba* employs to extend a portion of its reproductive effort as to maximize its reproductive potential over a precarious growing season.

Reproductive yields of plants and populations of seed predators are known to be highly variable over multiple years (Evans et al. 1989, Haddock and Chaplin 1982, Kon et al. 2005, Mduma et al. 2005). A longer-term study of *B. alba*-*A. rostrum* interaction is recommended to gain greater insight into the coevolutionary dynamics between the symbionts. Factors that should be considered in future studies include the need by *B. alba* to secure pollinators, the ecology of overwintering weevils, and in view of the importance of fire to the ecosystem, the frequency and seasonal timing of prairie burns.

**ACKNOWLEDGMENTS**

We thank B. A. Petersen for her valuable comments in preparation of this manuscript.

**REFERENCES CITED**


EVALUATION OF GYPCHEK AND ITS CARRIER ON VARIOUS LEPIDOPTERA SPECIES UNDER LABORATORY CONDITIONS

Melissa L. Yanek\(^1\) and Kenneth F. Raffa\(^1\)

ABSTRACT

An invasive species, *Lymantria dispar* (L.), gypsy moth, poses both a direct threat to oak savannas through the habitat-altering effects of defoliation, and indirectly through potential nontarget effects of control tactics employed against this eruptive generalist. The western leading edge of *L. dispar*, central Wisconsin, overlaps substantial areas of remnant oak savannas and prairies. A major tool employed in ecologically sensitive areas is Gypchek, a gypsy moth-specific nucleopolyhedrosis virus applied in conjunction with Carrier 038-A, a surfactant and sunscreen. We tested Carrier 038-A alone and with Gypchek on an endangered species, the Karner blue butterfly (*Lycaeides melissa samuelis* Nabokov), tobacco hornworm (*Manduca sexta* L.) as a surrogate of sphingid pollinators of the Eastern prairie fringed orchid, *L. dispar*, and seven other Lepidoptera species selected for comparison. We first tested all 10 species using a relatively high volume compared to field application. Where there was potential evidence of nontarget effects we proceeded to a spray-deposition method to approximate field application. Eight species showed no effect of either Gypchek or its carrier, the gypsy moth was sensitive to Gypchek as expected but not to its carrier, and *L. m. samuelis* showed putative effects in this preliminary assay to warrant further testing. With spray-deposition, there was no consistent statistically significant impact of carrier 038-A or Gypcheck with carrier on *L. m. samuelis* larvae. Extrapolation to field conditions is not possible, but it seems likely that the partial canopy cover of oak savannas and partially asynchronous phenology with *L. dispar* would reduce exposure to *L. m. samuelis*. Implications to the management of *L. dispar* in sensitive habitats are discussed.

Invasive invertebrates exert a range of adverse economic, environmental, and sociopolitical consequences. They cost the agricultural and forest products industries in the United States over $20 billion annually (Pimentel 2002). They also alter community structure by a variety of mechanisms (Webb et al. 1995) and can negatively impact threatened, endangered, or sensitive species (McNeely et al. 2001). Less is known about such environmental, relative to economic, effects.

The gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae), was introduced in Massachusetts in the late 1860s. It is now the most damaging defoliator in North American deciduous forests due to its wide host range and eruptive population dynamics in the absence of native natural enemies (Johnson et al. 2006). *L. dispar*’s preferred host plants include but are not limited to *Quercus*, *Carpinus*, *Ulmus*, *Populus*, and *Salix* species (Leonard 1974). Repeated outbreaks can change stand composition, alter nutrient cycling, and reduce stand basal area (Campbell and Sloan 1977, Webb et al. 1995).

The USDA has implemented a three-part strategy to manage *L. dispar*: suppressing established outbreaks, eradicating recent introductions, and slowing

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the spread across North America (Sharov et al. 2002b, Johnson et al. 2006). Control methods include mating disruption and application of the microbial insecticides Bacillus thuringiensis kurstaki (Btk) and Gypchek, a formulated nucleopolyhedrosis virus (LdNPV) (Podgwaite 1999, Sharov et al. 2002a). Microbial insecticides have significant environmental benefits over earlier synthetic pesticides, including reduced toxic residues and lessened effects on nontarget and beneficial species (Liebhold and McManus 1999, Podgwaite 1999). Btk, a naturally occurring soil bacterium that has been cultivated for pest control, affects only larval lepidoptera and has been widely used in federal and state control programs. Many nontarget Lepidoptera are, however, both physiologically and phenologically vulnerable to Btk (James et al. 1993, Herms et al. 1997, Rastall et al. 2003, Boulton and Otvos 2004).

In areas containing sensitive plant or animal species or where concerns over nontarget effects on ecosystems are particularly high, Gypchek is employed (Podgwaite 1999). While Gypchek’s effects on nontarget Lepidoptera seem to be minimal (Barber et al. 1993), further study is needed due to the sensitivity of the habitats for which it is intended and because possible effects of its formulation are largely unknown (Podgwaite 1999). Gypchek is typically applied with a carrier to improve efficacy and stability. Previous formulations included water, a lignan sulfate that acted as an ultraviolet sunscreen, molasses to stimulate feeding, and a sticking agent. Currently, Carrier 038-A (Omnova Solutions) is a ready-to-use carrier made of water and proprietary materials (USDA 2001). It is a dark colored viscous solution, and 95% carrier is typically mixed with 5% Gypchek and water slurry for application (Reardon et al. 1996).

A north-south twenty-four county (as of 2006) barrier in central Wisconsin is currently within the inter-agency program called “Slow the Spread” (Johnson et al. 2006). These counties are just west of the established zone of L. dispar and harbor isolated populations. Most spray blocks are treated with pheromone flakes (providing populations are very low) or Btk. Gypchek is applied to ecologically sensitive areas, such as oak savannas and remnant prairies (WI-DATCP 2006), which comprise a significant portion of central Wisconsin (Curtis 1971).

Oak savannas are semi-open landscapes with 50-80% canopy cover, and are transitional between oak forest and prairie (Leach and Givnish 1999, Meisel et al. 2002). Their soils are well drained to mesic and support a variety of oak species, understory grasses and forbs, and jack pine (Pinus banksiana). These systems are disturbance-dependent and often occur along dunes, lakebeds, and steep hills, mostly in uplands (Curtis 1971). Oak savannas have been reduced to 0.02% and wet-mesic prairies have been reduced to 0.1% of their presettlement areas, due to fire suppression, grazing, habitat alteration, and competition with woody and invasive species (Curtis 1971, Risser 1988, Samson and Knopf 1994). Both oak savannas and prairies support several endangered species that are relatively unique to these habitats. Among these is the Karner blue butterfly, Lycaeides melissa samuelis Nabokov (Lepidoptera: Lycaenidae), and the Eastern prairie fringed orchid, Platanthera leucophaea (Nutt.) Lindl (Orchidales: Orchidaceae).

Lycaeides melissa samuelis is one of six subspecies of L. melissa, which differ in range, color, and morphology (Lane and Weller 1994). The larvae are monophagous, feeding only on wild lupine, Lupinus perennis L. (Haack 1993). Prior to European settlement, its range reflected the northern distribution of lupine, extending from Minnesota to Maine and south to mid-Illinois. It is believed to be extirpated from Iowa, Illinois, Pennsylvania, Massachusetts, Maine, and Ontario (Dirig 1994; Baker 1994). L. m. samuelis is listed as federally endangered, and locally endangered in most states within its range. Wisconsin has the largest population of L. m. samuelis and as of April 2002 there were 211 occurrences across 20 counties (USFWS 2003).
Lycaeides melissa samuelis has two generations per year (Swengel and Swengel 2005; Peterson et al. 2006. The first brood overwinters as eggs, with larvae emerging in mid April. Larvae undergo four instars before entering a prepupal wandering phase. Pupation lasts from seven to eleven days and adults are present from mid-May to mid-June. Adults live an average of four to five days and a maximum of three weeks. Second brood larvae appear in late June to early July and adults fly from mid-July to early August (Peterson et al. 2006, Swengel and Swengel 2005). The second-flight population is typically three to four times more abundant than the first (USFWS 2003). The larvae are often tended by ants (Formicinae, Myrmicinae, and Dolichoderinae) that protect them from parasitism and predation. The ants respond to myrmecophilous organs, including the dorsal nectary, perforated cupola, and tentacular organs (Savignano 1994). These organs exude volatiles that attract and recruit ants and reward them with a rich “nectar” of amino acids and carbohydrates (Pierce 1985, Cushman et al. 1994).

The Eastern prairie fringed orchid is a federally endangered species with only 55 populations in seven midwestern states, a decline of more than 70% from original county records (Bowles 1993). This orchid thrives in disturbed areas in prairies and sphagnum bogs and may depend on fires and other periodic disturbances (USFWS 1999). It presents a conservation challenge because of irregular flowering and dormancy periods (Bowles et al. 1992). It appears to be pollinated largely by night flying hawk moths (Lepidoptera: Sphingidae). In other sphingid-pollinated plants, reproductive success has been decreased by a variety of factors, including fluctuating pollinator populations (Moody-Weis and Heywood 2001). Plant-pollinator mutualisms are an emerging area of conservation interest due to increasing threats to these ecological interactions and their importance for biodiversity and human health (Buchmann and Nabhan 1996). Habitat alteration, the introduction of alien pollinators, and pesticide poisoning are major threats to pollinators (Bond 1994). Because of L. dispar’s wide host range, its habitat overlaps those of numerous lepidopterans, including L. m. samuelis and pollinators of the Eastern prairie fringed orchid. The objective of this study was to evaluate effects of Gypchek and Carrier 038-A on a variety of Lepidoptera species, including the target species L. dispar, L. m. samuelis, and a surrogate (due to unavailability) of sphingid pollinators of the Eastern Prairie Fringed Orchid, under laboratory conditions.

MATERIALS AND METHODS

Insects and Plants

Lycaeides melissa samuelis. In June 2005 and June 2006, adult females were collected from several sites in central Wisconsin in accordance with USFWS Permit TE 100141-0. This permit limited the number of females collected to 30 per year, and mandated that each butterfly be returned to its place of collection within four days. Adults were collected from 13 sites at Fort McCoy Army Base, Wazee Lake Recreation Area, and Black River Falls State Forest (Table 1). They were transported in a chilled cooler to a greenhouse at UW-Madison held at 16:8 (L:D) photoperiod, 26°C. Adults were provided with a 10% clover honey solution with a paper towel wick as a nectar source. Enclosures were moistened using a hand water sprayer 2-3 times daily, and lupine was collected and replaced every other day. In 2005, adults were maintained in 30.5 cm³ mesh cages. Each cage contained a lupine plant either collected from the female’s collection site or grown in the greenhouse. In 2006, enclosures were 4 liter plastic pots filled with Metro-Mix topped by a cylinder (16 cm diameter × 22 cm height) of polyester mesh fabric containing field-collected lupine sprigs in water for oviposition.
In 2005, early instar second generation larvae were collected from lupine plants in the greenhouse, placed in rectangular plastic containers (33.5 cm × 21 cm × 11 cm), and maintained in a growth chamber at 16:8 (L:D) photoperiod, 24-26°C, 50-70% R.H. Lupine sprigs were replaced as needed until insects were used in bioassays.

In May 2006, third and fourth instar larvae from the first generation were collected from eleven sites in Fort McCoy Army Base (Table 1). Larvae were transported to the laboratory in chilled coolers, provided with lupine leaves overnight, and used in experiments the next day. In the second generation of 2006, eggs were removed from the greenhouse and placed in 21.5 cm × 6 cm × 6 cm rectangular clear plastic containers lined with Kimwipes. Containers were maintained in a growth chamber at 16:8 (L:D) photoperiod, 24-26°C, 50-70% R.H. Second instar larvae were transferred into clear plastic circular dishes (8.5 cm diameter × 2 cm depth) containing a lupine leaf in a 1.5 ml microcentrifuge tube filled with water and covered with parafilm. Up to five larvae were placed in each dish and fresh foliage was provided every 2-3 days until they were used for bioassays.

**Lymantria dispar.** *L. dispar* egg masses (New Jersey Standard Strain) were obtained from USDA-APHIS, Otis ANG Base (Cape Cod, MA) and stored at 4°C. Egg masses were surface sterilized in a solution of 395 ml 10% formalin with 5 ml 5% Alconox in distilled water for 1 hour. Egg masses were drained, rinsed in distilled water for an hour, drained, and allowed to dry before being placed in circular plastic dishes (8.5 cm diameter × 2 cm depth) containing a lupine leaf in a 1.5 ml microcentrifuge tube filled with water and covered with parafilm. Up to five larvae were placed in each dish and fresh foliage was provided every 2-3 days until they were used for bioassays.

**Sphingidae.** In June, July, and August of 2005 and 2006, attempts were made to collect sphingid moths from prairie habitats using black lights and direct collecting methods, however, insufficient numbers were obtained. Thus a related commercially available species, tobacco hornworm, *Manduca sexta* (L.) was used as a surrogate sphingid species for pollinators of the Eastern prairie fringed orchid. Tobacco hornworm eggs were obtained from the North Carolina State University Insectary (Raleigh, N.C.) and placed in clear circular dishes (8.5 cm diameter × 2.5 cm depth) lined with moistened filter paper. Larvae were

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**Table 1. Location of *Lycaeides melissa samuelis* collection sites in south central Wisconsin.**

<table>
<thead>
<tr>
<th>Site</th>
<th>County</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black River Falls State Forest</td>
<td>Jackson</td>
<td>N44.30943 W090.56215</td>
</tr>
<tr>
<td>Wazee Lake Recreation Area</td>
<td>Jackson</td>
<td>N44.28516 W090.71308</td>
</tr>
<tr>
<td>Fort McCoy</td>
<td>Monroe</td>
<td>N44.68498 W090.488784</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N44.68659 W090.487821</td>
</tr>
<tr>
<td></td>
<td></td>
<td>N44.68340 W090.487141</td>
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<tr>
<td></td>
<td></td>
<td>N44.68954 W090.486962</td>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>N44.69161 W090.48688</td>
</tr>
</tbody>
</table>

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provided with a 1 cm² piece of diet, which was replaced every 2-3 days, and kept in a growth chamber at 16:8 (L:D) photoperiod, at 24-26°C, 50-70% R.H.

**Other Lepidoptera.** Seven additional lepidopteran species were tested to examine potential effects of Gypchek and its carrier. These were selected based on broadening the taxonomic representation and on availability. *Hyphantria cunea* Drury (Arctiidae) larvae were collected from UW-Madison Lakeshore Nature Preserve, Dane Co., WI, and reared on artificial diet (USDA, Hamden) in circular plastic containers (15 cm diameter × 4 cm depth). Noctuid larvae *Heliothis virescens* Fabricius, *Helicoverpa zea* Boddie, *Agrotis ipsilon* Hufnagel, *Spodoptera exigua* Hübner, *Spodoptera frugiperda* J. E. Smith, and *Trichoplusia ni* Hübner were obtained from laboratory colonies at Benzon Research (Carlisle, PA) and reared on a soyflour diet (Southland Products, Lake Village, AR) in circular plastic dishes (8.5 cm diameter × 2 cm depth). All insects were maintained in growth chambers at 16:8 (L:D) photoperiod, 24-26°C, 50-70% R.H.

**Lupine.** Lupine seeds and mycorrhizal inoculum were obtained from Prairie Moon Nursery (Winona, MN). They were soaked overnight, drained, and mixed with inoculum before planting. Two seeds were planted in each 5 cm × 5 cm × 8 cm plastic container with 3 parts sand, 1 part Metro Mix, and 2 parts peat (Tolson 2001). Plants were transferred into 4 liter pots filled with the same soil mixture when they were above 3 cm. Plants were kept in a greenhouse at 26°C, and fertilized weekly with a 2% fish oil emulsion solution, and watered as needed. Field lupine was collected weekly from Fort McCoy, Wazee Lake, and Black River Falls State Park. Lupine stems were placed in water, covered with plastic, and chilled at 4°C. Field collected lupine was discarded after seven days.

**Bioassays**

**Direct Application Assay (2005-2006).** All 10 species of Lepidoptera were subjected to an initial assay (2005), in which treatments were administered directly to the substrate as a one microliter droplet. Treatments via direct application consisted of control (distilled water), Carrier 038-A, or Gypchek with Carrier 038-A. For all applications containing Carrier 038-A, the carrier was heated to 52°C to reduce viscosity to allow for accurate dilutions. After application, these materials were allowed to cool before test insects were exposed to them. The highest concentration of Gypchek consisted of 95% Carrier 038-A and 5% Gypchek and distilled water slurry. Lower concentrations were a dilution of this solution. Any nontarget species that showed a potential sensitivity to either Gypchek or its carrier would then be tested under less stringent but more realistic conditions, in which substrate was applied using a hand pump sprayer (2006). For the direct application method, one microliter of treatment was applied to a standard diet diskette (4 mm diameter × 0.5 mm height) or (approx. 5 mm × 5 mm) piece of foliage. Insects were starved six hours, given two equal doses 24 hours apart, and provided with uncontaminated diet 24 hours after the second dose. Fresh food was provided as necessary and larvae were monitored for 14 days. Third instar insects were used for all bioassays, except for *L. dispar*, which was tested at the second instar, as this is the life stage where Gypchek is applied in the field. For each insect, the feeding substrate, number of larvae per replication, numbers of replicates, and treatments applied are shown in Table 2.

Due to differences in availability, physiology, size, and adaptability to rearing conditions of the various species tested, some modifications from uniform methodology were required. Freshly molted second instar *L. dispar* larvae (diet assay) were placed individually in clear plastic cylindrical wells (1.6 cm × 2 cm). Freshly molted third instar *M. sexta* larvae were placed in 30 ml clear plastic lidded containers and then transferred after 10 days to circular plastic dishes (8.5 cm diameter × 2.5 depth cm). *H. virescens, H. zea, A. ipsilon, S. exigua, S. frugiperda, T. ni* and *L. dispar* (foliage assay) were kept in white plastic wells
Table 2. Mean percent mortality of Lepidopteran larvae treated with a high (1 microliter) dose of control (distilled water), Carrier 038-A, and varying levels of Gypchek with Carrier 038-A. Significant differences at $P < 0.05$ among treatments are indicated for *Lymantria dispar* by different letters by least square means.

<table>
<thead>
<tr>
<th>Insect</th>
<th>Substrate</th>
<th>Treatment</th>
<th>No. Replicates</th>
<th>N per Replicate</th>
<th>% Mortality ± SE</th>
<th>df</th>
<th>$F$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
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<td><em>Lycaeides melissa samuelis</em></td>
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<td>Control</td>
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<td>11</td>
<td>18.2</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carrier</td>
<td>1</td>
<td>13</td>
<td>61.5</td>
<td></td>
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<td>N/A</td>
</tr>
<tr>
<td></td>
<td></td>
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<td>13</td>
<td>100.0</td>
<td></td>
<td>N/A</td>
<td>N/A</td>
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<td>Control</td>
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<td>12.5 ± 4.17 a</td>
<td>4, 8</td>
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<td></td>
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<td>4</td>
<td>12</td>
<td>16.7 ± 3.40 ab</td>
<td></td>
<td>4×10³</td>
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<td></td>
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<td>4</td>
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<td>10.4 ± 2.08 ab</td>
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<td>4×10⁶</td>
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<td></td>
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<td>25.8 ± 6.28 b</td>
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<td>12</td>
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<td>0.284</td>
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<td><em>Manduca sexta</em></td>
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<td>Control</td>
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<td>12.5 ± 4.79</td>
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<tr>
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<td>8.3</td>
<td>0.650</td>
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<td></td>
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<td>Substrate</td>
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<td>No. Replicates</td>
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<td>% Mortality ± SE</td>
<td>df</td>
<td>F</td>
<td>P</td>
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<td>5.0 ± 5.0</td>
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<td>10.0 ± 0.0</td>
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<td>10</td>
<td>10.0 ± 7.07</td>
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<td><em>Heliothis virescens</em></td>
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<td>12.5 ± 4.2</td>
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<td><em>Helicoverpa zea</em></td>
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<td>9.1 ± 9.1</td>
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<td>12</td>
<td>41.7 ± 41.7</td>
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</table>
(1.5 diameter cm × 1 cm height) covered in clear plastic and H. cunea were kept in (5 cm × 5 cm × 2 cm) clear plastic wells covered with mylar. H. cunea larvae were starved 24 hours. Third instar L. m. samuelis were starved twenty-four hours in 2005 and kept in 30 ml clear plastic lidded containers.

**Spray Droplet Assay (2006).** The only insect that required testing under the less stringent, more realistic condition was L. m. samuelis (see Results). All foliage was rinsed with 10% bleach, then distilled water. Treatments were applied with 1.18 liter RL Flomaster hand sprayer (Lowell, MI). Deposition was estimated by spraying eleven 21.6 cm × 14 cm pieces of white paper with Carrier 038-A from a distance of 0.5 m. The number of droplets was measured in three randomly selected one cm squares per paper. Spray deposition averaged 16.94 ± 1.26 drops per cm², which falls within the recommended spray deposition of 5-20 drops per cm² (Mierzejewski et al. 2000).

Lycaeides melissa samuelis larvae were starved six hours and placed individually in clear circular dishes (8.5 cm diameter × 2 cm depth) with a treated lupine leaf in microcentrifuge tubes filled with water and covered with parafilm. The treatments, distilled water (control), Carrier 038-A alone (carrier), Carrier 038-A with \(4 \times 10^3\) PIB/gallon Gypchek (low virus), Carrier 038-A with \(4 \times 10^6\) PIB/gallon Gypchek (medium virus), and Carrier 038-A with \(4 \times 10^{11}\) PIB/gallon Gypchek (high virus), were applied via spray application. Low and medium virus treatments were given only in the first generation of L. m. samuelis larvae feeding on sprayed foliage for three days and were provided with untreated foliage every third day until pupation. Three replicates of four to eight third and fourth instar larvae per treatment were tested in the first generation. Five replicates of 10 freshly molted third instar larvae per treatment were tested in the second generation.

**Statistical Analysis**

A mixed linear analysis (PROC MIXED; SAS Institute 2000) was performed on treatment, replication, and on the presence of carrier and Gypchek. Separate analyses were performed on each insect species and separate analyses were performed on each generation of L. m. samuelis (see Results). Residuals were examined to assure normality for all species. Mortality was log transformed for the analysis of L. dispar (PROC UNIVARIATE; SAS Institute 2000). A least squared means test was performed on treatment, carrier, and virus when applicable. Also, a power analysis was performed on L. m. samuelis data to determine sample size needed to find power at 0.9 when alpha is equal to 0.05 (Dupont and Plummer 1997).

A separate chi squared analysis was also performed on L. m. samuelis in both generations in 2006. For each generation, the Cochran-Mantel-Haenszel test was performed to determine statistical significance (PROC FREQ; SAS Institute 2000). The probability was examined using both the non-zero correlation, an ordinal analysis, and the general association model, a nominal analysis. These analyses are less conservative than the mixed linear procedure, as they do not include blocking factors such as replications.

**RESULTS**

In the preliminary, high-dosage direct application assay, eight of the nontarget species showed no sensitivity to either the Carrier 038-A or Gypchek (Table 2). Mortality of L. m. samuelis was 3.4 times as high with carrier than on controls. All L. m. samuelis larvae feeding on foliage to which Gypchek plus carrier had been applied died within three days post-treatment. As expected, gypsy moth larvae showed significant mortality to Gypchek in dose-dependant fashion but were not affected by Carrier 038-A.
Based on these preliminary results, both generations of *L. m. samuelis* were treated using the spray droplet method in 2006 (Table 3). Analysis using the mixed procedure indicated there was a significant generational effect on mortality on common treatments ($F = 68.94; \text{df} = 1, 20; P < 0.0001$), so the two generations were analyzed separately. Mortality of the first generation showed no overall treatment effect ($F = 2.80; \text{df} = 2, 4; P = 0.1739$). There was no significant effect of either carrier ($F = 0.00; \text{df} = 1, 4; P = 0.9694$) or virus ($F = 4.11; \text{df} = 1, 4; P = 0.1127$). Mortality of second generation *L. m. samuelis* larvae (Table 3) likewise did not show a significant treatment effect ($F = 1.95; \text{df} = 4, 16; P = 0.1518$). Mortality was 17.7% higher among larvae whose treatments included Carrier 038-A (carrier, low, medium, and high Gypchek) than among the control larvae, but this was not significant ($F = 2.86; \text{df} = 1, 16; P = 0.1099$). Variability was quite high, and a power test estimated the sample size needed for a power of 0.9 when alpha = 0.05 to be 221 for the first generation and 306 for the second generation, more larvae than were available by permit. Therefore these treatments were also analyzed by a chi-squared test. Because a chi-squared test cannot conservatively block multiple factors such as generation and replication, the two generations were analyzed separately. We employed two models. For the nonzero correlation model, treatments were significant for both the first ($\chi^2 = 5.094; \text{df} = 1; P = 0.02400$) and the second ($\chi^2 = 7.087; \text{df} = 1; P = 0.0078$) generations. In the general association model, where treatments were not evaluated as ordinal, treatments were not significant for the first generation ($\chi^2 = 5.2648; \text{df} = 2; P = 0.0719$), but were significant for the second ($\chi^2 = 11.6551; \text{df} = 4; P = 0.0201$) generation.

**DISCUSSION**

Gypchek Carrier 038-A had no effect on nine of ten Lepidoptera species tested. It may have a potential but relatively weak effect on *L. m. samuelis*, at least under laboratory conditions. Evidence of an effect of Carrier 038-A includes higher mortality than the control with both carrier and carrier plus Gypchek in the direct application assay, and possibly increased mortality in the spray droplet assays. This is unlikely due to bioassays with *L. m. samuelis* necessarily being conducted with foliage rather than diet, as *L. dispar* and *S. exigua* were also treated on both diet and foliage, without differences (Table 2). Also, it is unknown whether heating the carrier to reduce viscosity, which is not necessary for field application, might have had an effect on its chemistry and toxicity, although this seems unlikely as no other species were affected. Additional testing with larger sample sizes is needed to resolve the conflicting results arising from different analyses, unexpectedly high control mortality, and high variance.

Regardless of which statistical model is employed, extrapolations from laboratory to field conditions are not possible. The canopy cover of oak savannas is highly heterogeneous (Grundel et al. 1998), so actual deposition likely varies. Further, only a portion of *L. m. samuelis*’s first generation, i.e., late instars, and none of its second generation occurs during actual spraying of Gypchek (Herms et al. 1997, Peterson et al. 2006, WI DATCP 2006). Therefore, to determine true susceptibility of *L. m. samuelis* populations to Carrier 038-A or Gypchek, studies on spray deposition, persistence, and bioactivity under field conditions are required. This would necessitate amendments to current permitting allowances. Prior to any confirmation of serious effects under field conditions, Gypchek should continue to be viewed as a valuable resource, and preferable to *Btk*, in ecologically sensitive areas (Barber et al. 1993, Podgwaite 1999).

Overall, susceptibility of Lepidoptera to Carrier 038-A appears low, as none of the other nine species showed significant mortality, and these species represent a relatively broad host ranges, life histories, and ecologies. Of particular importance is that the sphingid surrogate of the Eastern prairie fringed orchid’s pollinators showed no susceptibility to Gypchek, even at doses causing over 95% mortality to this invasive target species, *L. dispar*.
Table 3. Percent mortality of third instar second generation *Lycaedis melissa samuelis* larvae in 2006 after treatment with distilled water (Control), Carrier 038-A (Carrier) or Carrier 038-A in conjunction with $4 \times 10^3$ PIB/gallon (Low), $4 \times 10^6$ PIB/gallon (Medium), or $4 \times 10^{11}$ PIB/gallon (High) Gypchek applied with a hand sprayer on lupine sprigs. Effect was calculated based on average mortality until adult emergence.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Treatment</th>
<th>No. Replicates</th>
<th>Average N per Replicate</th>
<th>% Mortality ± SE</th>
<th>Df</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>One</td>
<td>Control</td>
<td>3</td>
<td>7</td>
<td>20.0 ± 6.70</td>
<td>2, 4</td>
<td>2.80</td>
<td>0.1739</td>
</tr>
<tr>
<td></td>
<td>Carrier</td>
<td>3</td>
<td>6.3</td>
<td>20.7 ± 4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1 \times 10^{11}$ Gypchek</td>
<td>3</td>
<td>6</td>
<td>52.1 ± 14.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two</td>
<td>Control</td>
<td>5</td>
<td>9.4</td>
<td>64.0 ± 7.05</td>
<td>4, 16</td>
<td>1.95</td>
<td>0.1518</td>
</tr>
<tr>
<td></td>
<td>Carrier</td>
<td>5</td>
<td>9.6</td>
<td>81.1 ± 4.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1 \times 10^3$ Gypchek</td>
<td>5</td>
<td>9.6</td>
<td>79.8 ± 8.30</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$1 \times 10^6$ Gypchek</td>
<td>5</td>
<td>9.8</td>
<td>75.6 ± 6.73</td>
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<td>$1 \times 10^{11}$ Gypchek</td>
<td>5</td>
<td>9.8</td>
<td>91.6 ± 5.18</td>
<td></td>
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</tbody>
</table>
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REFERENCES CITED


EVALUATING THE USE OF PLASTIC BAGS TO PREVENT ESCAPE OF THE EMERALD ASH BORER, *AGRILUS PLANIPENNIS* (COLEOPTERA: BUPRESTIDAE) FROM FIREWOOD

Therese M. Poland¹, Tina M. Ciaramitaro², Deepa S. Pureswaran³ and Andrea Diss-Torrance⁴

ABSTRACT

The emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae), is a highly destructive exotic pest of ash (*Fraxinus*) in North America. Human movement of infested logs, primarily pieces of firewood, is a major pathway for long distance spread of the beetle. Firewood may be confiscated at campgrounds, rest-areas, and key transportation gateways. Treatment guidelines for handling and storage of confiscated firewood are urgently needed to prevent new establishments of *A. planipennis*. In three laboratory experiments, we evaluated the efficacy of using 4-mil-thick plastic bags to contain and prevent escape of beetles from infested firewood-sized logs. For all experiments, control logs were unbagged and kept in horizontal rearing tubes in the laboratory. Treatment logs were loosely double-bagged or tightly single-bagged, and held on open laboratory benches or in rearing tubes or cans. Beetles emerged from both control and treatment logs during the course of the experiments. With a single exception, all beetles emerging from treatment logs died within the bags with no escapees. The one exception was a beetle from a tightly single-bagged log that chewed through the plastic. In contrast, all beetles emerging from control logs were collected live in the rearing containers. Double bagging firewood to contain *A. planipennis* during transport or storage could be an inexpensive and effective way of preventing escape of beetles from ash firewood.

Since the discovery of the emerald ash borer, *Agrilus planipennis* Fairmaire (Coleoptera: Buprestidae) in Detroit, Michigan in 2002, it has caused extensive mortality of ash, *Fraxinus* spp., while spreading across southeast Michigan, Ohio, and Ontario (Haack et al. 2002, Poland and McCullough 2006, Poland 2007). In addition to this core infested area, numerous outlier populations have been found throughout Michigan’s Lower Peninsula, Ohio, Indiana, and Ontario, as well as isolated infestations in Maryland, Illinois, Pennsylvania, West Virginia, Wisconsin, Missouri, Michigan’s Upper Peninsula, and Quebec (EAB Info 2008). It is estimated that the beetle has killed more than 40 million ash trees in Michigan and tens of millions in surrounding states (EAB Info 2008). Spread of *A. planipennis* is a result of natural dispersal and human-assisted movement of infested materials including ash nursery stock, logs and firewood (BenDor et al. 2006).

*Agrilus planipennis* develops in the cambial region of ash trees. Adult beetles

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chew their way out of the tree in early summer leaving D-shaped emergence holes. Each female can lay 50 to 90 eggs in bark crevices during her lifetime (Bauer et al. 2004, Lyons et al. 2004). Eggs hatch within two weeks and the larvae feed in the cambial region from mid-June until mid-October. The larvae create serpentine-shaped galleries or feeding tunnels that are packed with frass. Larvae overwinter as pre-pupae in cells they construct about 1.3 cm deep in the sapwood or outer bark. Pupation begins in spring, followed by adult emergence roughly 3 weeks later (Bauer et al. 2004, Lyons et al. 2004). Some *A. planipennis*, however, overwinter as young larvae rather than as prepupae, and then require a second year of development before emerging as adults (Cappaert et al. 2005).

Federal, state and provincial regulatory and natural resource agencies implemented long term programs to contain and reduce populations of *A. planipennis*. These programs have resulted in the removal of hundreds of thousands of ash trees infested with *A. planipennis*. Some merchantable logs are being processed into products such as lumber and tool handles. Currently, the accepted method for disposal of ash logs to ensure mortality of *A. planipennis* life stages, is to grind wood into 2.54-cm or smaller pieces (USDA APHIS 2003). However, because of the overwhelming volumes of infested ash, not all wood can be processed or disposed of in an approved manner. A common use for much of the infested wood is for firewood.

*Agrilus planipennis* can survive and emerge from logs cut from infested trees (Petrice and Haack 2006); therefore, movement of ash logs from infested to uninfested counties is regulated by a federal quarantine (USDA APHIS 2003). In the case of firewood, all hardwood species are regulated because inspectors cannot easily identify the species of tree that was cut. Nevertheless, *A. planipennis* has continued to spread and new outlier infestations, many of which resulted from human-assisted movement of infested ash material prior to enactment of the quarantine, have been detected each year. Furthermore, movement of firewood is extremely difficult to regulate and enforce. Unlike nursery trees and wood products that are produced and moved by licensed businesses, firewood is often moved by the general public. Despite extensive outreach efforts many individuals are unaware of regulations prohibiting movement of firewood from infested areas.

Petrice and Haack (2006) evaluated the effects of tree cutting date, storage conditions, and splitting on survival of *A. planipennis* in firewood logs. Adults successfully completed development and emerged from logs representing each cutting date (July through December), logs stored in both full sun and shade, both split and whole logs, and logs that were untarped or held under a tarp. Emergence, survival, and size of *A. planipennis* adults was significantly reduced for logs that were cut early during larval development (July or August), and for logs that were split and stored untarped in full sun or shade. However, no firewood handling conditions completely eliminated *A. planipennis* emergence.

In order to prevent the spread of *A. planipennis* through movement of firewood, state regulatory and natural resource agencies are enforcing quarantine regulations by conducting inspections for firewood at campgrounds, rest areas and key transportation gateways. Treatment guidelines for storage and handling of confiscated firewood are urgently needed to prevent new establishments of *A. planipennis*. Personnel responsible for confiscated firewood may not have access to expensive treatment facilities or equipment. Plastic bags are inexpensive and readily available; however, they have not been evaluated for their ability to confine *A. planipennis* adults emerging from firewood. Our objective was to evaluate the use of plastic bags to contain logs and prevent escape of *A. planipennis*. Specifically, we conducted three experiments that compared emergence of *A. planipennis* from control logs placed in rearing tubes and 1) logs that were sealed inside two plastic bags and placed inside vertical or horizontal rearing containers, 2) logs that were sealed inside two plastic bags
and held in the open on a laboratory bench, and 3) pairs of logs that were sealed inside a single plastic bag that was pressed tightly against the logs and held in vertical rearing containers.

**MATERIALS AND METHODS**

Ash trees that were infested with *A. planipennis* were cut between 15 December 2006 and 11 January 2007 at field sites near Brighton, MI (Livingston County) and Lansing, MI (Ingham County). Trees were felled and bucked into logs approximately 60 cm log and 11-12 cm in diameter then held in a cold room for 4 to 10 months at 5 ± 2 °C until used for experiments.

Experiment 1 examined the effect of double bagging on logs held in rearing containers. It was conducted from 1 March 2007 to 10 April 2007. Thirty infested logs were removed from cold storage and randomly assigned to three treatments with 10 logs per treatment: 1) unbagged control logs placed in horizontal rearing tubes; 2) logs that were sealed inside two plastic bags and then placed in horizontal rearing tubes; and 3) logs that were sealed inside two plastic bags and then placed in vertical rearing cans. Rearing tubes consisted of cardboard tubes with plastic end caps (30 cm outside diameter, 1.26 cm thick wall, 75 cm long; Saginaw Paper Tube, Saginaw, MI). One plastic end cap was modified by cutting a 20 cm diameter hole that was sealed with mesh screen. A 6 cm diameter hole was similarly cut in the center of the mesh screen into which a plastic specimen cup was inserted as a collection jar. Infested logs were placed inside the rearing tubes and as beetles emerged from the logs they tended to move into the collection jars in response to light. Rearing tubes were laid horizontally in rows on wooden shelving. Rearing cans consisted of 114 liter (30 gallon) plastic garbage pails. Each garbage pail was modified by cutting a 15 cm diameter hole in the side that was sealed with mesh screen. A plastic specimen cup was inserted into the center of the screen as described above. Plastic bags were “contractor grade” clear, 60 × 120 cm, 4 mil thick (= 4/1000 inch or 0.1 mm) poly bags (BrownCor, Milwaukee, WI). Logs were inserted individually into a bag and the end of the bag was twisted shut and secured with a cable tie. The bagged log was then inserted into a second bag and secured in a similar manner. The double-bagged logs were then placed inside the assigned rearing containers. Logs were held in rearing containers to capture any adults that might escape through the bags. The rearing containers were held in the laboratory at 25 ± 3 °C with overhead fluorescent lighting that was left on constantly.

Experiment 2 evaluated whether the effectiveness of bagging was reduced if bagged logs were fully exposed to ambient light. It was conducted from 11 April 2007 to 26 May 2007. Sixteen infested logs were removed from cold storage and randomly assigned to one of two treatments: 1) unbagged control logs in horizontal rearing tubes; and 2) logs that were sealed inside two plastic bags and held in the open on a bench top in the laboratory. The rearing tubes were in the same laboratory as Experiment 1. The double-bagged logs were in an adjacent laboratory on a bench top beside a window with natural light. The temperature in the adjacent laboratory was similar to that in the rearing container room; however, there was natural light and overhead fluorescent lights were on only during the work day (approximately 08:00 to 17:00) and were not left on overnight or on weekends.

Experiment 3 was conducted during 12–27 November 2007 to determine whether beetles can chew their way out of plastic bags if the bags were tightly wrapped around the logs. Twenty logs were randomly assigned to one of two treatments with 5 pairs of logs per treatment: 1) unbagged pairs of control logs in horizontal rearing tubes; and 2) pairs of logs introduced in a plastic bag that was tightly secured around them and kept in vertical rearing cans.

For all experiments, log dimensions (diameter and length) were measured
and recorded at the beginning of the experiment. In addition, any exit holes from previously emerged *A. planipennis* adults were tallied and marked. After placing the logs inside the bags and rearing containers, they were checked every other day for emerging adults. Each time the collection jars were checked, the lids or end caps of the containers were also removed to retrieve any beetles that remained inside the rearing container. In addition, the bagged logs were examined by carefully inspecting the bag for holes and looking through the transparent bag to note any beetles inside. Once beetles stopped emerging (i.e., no new beetles were collected for 6 days) the experiments were ended. Logs were removed from their rearing containers or bags. All dead *A. planipennis* adults found inside the rearing containers and bags were tallied. The number of new emergence holes on each log was also tallied. For experiment 1, a subsample of four logs from each treatment was dissected to determine the average number of dead adults and larvae that remained inside the logs. For experiment 2, two logs from each treatment were dissected to determine the average number of dead adults and larvae inside. For experiment 3, five logs from each treatment (one log per pair) were similarly dissected and assessed.

For experiment 1, the data were analyzed by one-way ANOVA by treatment (PROC GLM, SAS Institute 2002). The Ryan-Einot-Gabriel-Welsch multiple comparison test was used to compare differences among treatments when ANOVA was significant. Log measurement data were not transformed. The number of existing and new exit holes, number of live and dead adults collected in bags or rearing containers, and number of dead adults and dead larvae inside the logs were standardized by surface area (2000 cm$^2$) similar to the area of a log. Density data per 2000 cm$^2$ were transformed by log (x + 1) to satisfy assumptions of normality and homoscedasticity prior to analysis. For Experiments 2 and 3, log measurement data and transformed (log (x + 1)) density data were compared between the two treatments by a *T*-test (PROC TTEST, SAS Institute 2002). The α-level was set at 0.05 for all statistical tests.

**RESULTS AND DISCUSSION**

For all experiments, several new emergence holes were found on all logs with many live *A. planipennis* adults emerging from the control logs; however, none of the adults that emerged from the double-bagged logs in Experiments 1 and 2 (Tables 1 and 2) chewed through the bags whereas one beetle chewed through the bag of the single-bagged logs in Experiment 3 (Table 3). In Experiment 1, logs assigned to the different treatments were similar in overall dimensions and *A. planipennis* attack density. There were no significant differences among treatments in log length (56.8 ± 0.9 cm, mean ± SE; $F = 0.27$; df = 2, 27; $P = 0.7$), log diameter (11.8 ± 0.8; $F = 3.32$; df = 2, 27; $P = 0.06$), density of exit holes at the start of the study, density of new exit holes at the end of the study, and density of dead adults and larvae found inside the logs at the end of the experiment (Table 1). All 184 *A. planipennis* adults that emerged from the unbagged control logs were collected live in the rearing tubes or collection jars; whereas, all 186 of the *A. planipennis* that emerged from the double-bagged logs held in rearing tubes or in rearing cans were found dead in the bags at the end of the experiment (Table 1).

After finding that no *A. planipennis* escaped from the bags in Experiment 1, we conducted another experiment in which we held the bagged logs under more natural lighting conditions similar to what might be experienced in an outdoor regulatory setting where firewood might be confiscated and held. Since *A. planipennis* respond positively toward light, we believed that beetles might move more readily towards the edges of the bag and try to escape if all sides of the bags were exposed to light rather than when the bagged logs were held in dark rearing containers with only a small opening at the collection jar which provided a point source of light. However, in Experiment 2, we again found
Table 1. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm$^2$ log surface area) from logs that were double-bagged in 4-mil-thick plastic bags and held in containers (rearing tubes or rearing cans) and for unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 10 logs per treatment. A subsample of 4 logs per treatment were dissected to determine the density of dead *A. planipennis* inside the logs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Unbagged logs in rearing tubes</th>
<th>Bagged logs in rearing tubes</th>
<th>Bagged logs in rearing cans</th>
<th>F; df; P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exit holes at start</td>
<td>10</td>
<td>0.1 ± 0.1 a</td>
<td>0.2 ± 0.2 a</td>
<td>0.4 ± 0.1 a</td>
<td>0.85; 2, 27; 0.4</td>
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<tr>
<td>Live adults in container</td>
<td>10</td>
<td>13. ± 4.7 a</td>
<td>0 ± 0 b</td>
<td>0 ± 0 b</td>
<td>37.4; 2, 27; 0.0001</td>
</tr>
<tr>
<td>Dead adults in bag or container</td>
<td>10</td>
<td>0 ± 0 b</td>
<td>6.9 ± 1.9 a</td>
<td>11.6 ± 3.5 a</td>
<td>11.8; 2, 27; 0.0002</td>
</tr>
<tr>
<td>New exit holes</td>
<td>10</td>
<td>14.0 ± 4.7 a</td>
<td>6.9 ± 1.9 a</td>
<td>11.2 ± 3.5 a</td>
<td>0.58; 2, 27; 0.56</td>
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<td>Dead adults in log</td>
<td>4</td>
<td>1.3 ± 1.2 a</td>
<td>1.1 ± 0.8 a</td>
<td>3.1 ± 1.4 a</td>
<td>1.0; 2, 27; 0.38</td>
</tr>
<tr>
<td>Dead larvae in log</td>
<td>4</td>
<td>1.2 ± 0.8 a</td>
<td>0.7 ± 0.4 a</td>
<td>3.4 ± 1.4 a</td>
<td>1.34; 2, 27; 0.37</td>
</tr>
</tbody>
</table>

Means within a row followed by different letters are significantly different from each other, Ryan-Einot-Gabriel-Welsch multiple comparison test, *P* < 0.05. Data were transformed log (x + 1).
Table 2. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm² log surface area) from logs that were double-bagged in 4-mil-thick plastic bags and held on an open laboratory bench and from unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 8 logs per treatment. A subsample of 2 logs per treatment were dissected to determine density of dead *A. planipennis* inside the logs.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>T-Test</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>Unbagged logs</td>
<td>Bagged logs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>in rearing tubes</td>
<td>on lab bench</td>
<td></td>
</tr>
<tr>
<td>Exit holes at start</td>
<td>8</td>
<td>0.7 ± 0.5 a</td>
<td>0.3 ± 0.2 a</td>
</tr>
<tr>
<td>Live adults in container</td>
<td>8</td>
<td>22.7 ± 5.2 a</td>
<td>0.3 ± 0.2 a</td>
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<tr>
<td>Dead adults in bag or container</td>
<td>8</td>
<td>0 ± 0 b</td>
<td>7.8 ± 2.0 a</td>
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<tr>
<td>New exit holes</td>
<td>8</td>
<td>22.7 ± 5.2 a</td>
<td>7.8 ± 2.0 a</td>
</tr>
</tbody>
</table>

Means followed by different letters are significantly different, T-test, *P* < 0.05. Data were transformed by log (x + 1).

Table 3. *Agrilus planipennis* emergence data (mean ± SE, standardized per 2000 cm² log surface area) from pairs of logs that were tightly single-bagged and held in containers (rearing cans), and from pairs of unbagged control logs held in containers (rearing tubes) in the laboratory at 25 ± 3 °C. N = 5 pairs of logs per treatment. One log from each pair was dissected to determine the density of dead *A. planipennis* inside the logs (N = 5 logs).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Treatment</th>
<th>T-Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unbagged logs</td>
<td>Bagged logs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>in rearing tubes</td>
<td>in cans</td>
<td></td>
</tr>
<tr>
<td>Exit holes at start</td>
<td>5</td>
<td>0.7 ± 0.6 a</td>
<td>1.1 ± 0.6 a</td>
</tr>
<tr>
<td>Live adults in container</td>
<td>5</td>
<td>12.9 ± 1.9 a</td>
<td>0.1 ± 0.1 b</td>
</tr>
<tr>
<td>Dead adults in bag or container</td>
<td>5</td>
<td>0 ± 0 b</td>
<td>11.2 ± 3.8 a</td>
</tr>
<tr>
<td>New exit holes</td>
<td>5</td>
<td>13.0 ± 1.9 a</td>
<td>11.3 ± 3.7 a</td>
</tr>
<tr>
<td>Dead adults in log</td>
<td>5</td>
<td>0.3 ± 0.1 b</td>
<td>2.2 ± 0.5 a</td>
</tr>
<tr>
<td>Dead larvae in log</td>
<td>5</td>
<td>3.1 ± 1.4 a</td>
<td>6.7 ± 1.8 a</td>
</tr>
</tbody>
</table>

Means followed by different letters are significantly different, T-test, *P* < 0.05. Data were transformed by log (x + 1).
that no beetles escaped from the bagged logs (Table 2). Logs assigned to the two treatments were similar in overall dimensions. There was no significant difference between treatments in log length (58.5 ± 0.9 cm; $T = 0.5; P = 0.6$) or log diameter (11.8 ± 0.8; $T = 1.59; P = 0.3$), or density of exit holes at the start of the experiment (Table 2). However, there was a significantly higher density of new exit holes on the unbagged control logs compared to the logs that were double-bagged and held on the laboratory bench. This suggests that the control logs may have had a higher attack density than the bagged logs. It is possible that mortality may have been higher within the bagged logs. Only 2 logs were dissected per treatment to determine mortality of adults and larvae within the logs thus replication was too low to determine significant differences. Nevertheless, several adult *A. planipennis* emerged from logs that were double-bagged and held on the laboratory bench and all 59 of the adults died inside the bags by the end of the experiment. Conversely all 217 of the adults that emerged from the control logs were found live in the rearing tubes or collection jars (Table 2).

In the first two experiments, individual logs were placed in bags that were sealed loosely around the logs. When firewood is confiscated, several pieces of wood may be placed in a bag until it is full and the plastic is pressed snugly against the logs. We believed that beetles would be more likely to chew through the plastic bag when it is pressed tightly against the bark that they are chewing through. Therefore, in Experiment 3, pairs of treatment logs were tightly single-bagged, so that the bag was pressed snugly against the bark surface of the logs. Results were similar to those obtained in Experiments 1 and 2. All 132 beetles emerging from unbagged control logs emerged alive into the rearing tubes and collection jars (Table 3). On the other hand, all of the 122 beetles that emerged from the tightly single-bagged logs were found dead pressed against the logs inside the bags, except for one beetle that managed to chew a hole in the plastic bag and was found in the rearing can (Table 3). As with the previous two experiments there was no difference between treatments in log length (57.3 ± 0.5 cm; $T = 0.93; P = 0.37$) or log diameter (11.4 ± 0.4 cm; $T = 1.34; P = 0.19$). There were also no differences in density of new exit holes or dead larvae between the treatment and control logs. However, there was a significantly higher density of dead adults in the bagged-logs compared to the control logs suggesting that the bags were effective in causing some beetle mortality prior to emergence. These results indicate that there is minimal risk of beetles escaping from firewood held in single bags closed tightly around the logs.

This study demonstrates that double-bagging using plastic bags is an inexpensive, accessible, and effective way to prevent escape of *A. planipennis* from ash firewood. A survey by the Michigan Department of Agriculture indicates that about 78% of sites whose origins of infestation could be determined or estimated resulted from firewood movement (M. Philips, pers. comm.). Mandatory double-bagging of firewood that is transported or confiscated would decrease potential escape from infested material.

Bagging firewood is already being implemented by Minnesota and Wisconsin state parks (WiDNR 2008, MnDNR 2008) as well as the Ohio (ODA 2008) and South Dakota Departments of Agriculture (SDDA 2008). Adults that emerge will be contained by the plastic and eventually die. Plastic coverings have been used in other applications to contain, kill, or prevent infestation by other wood-boring insects and bark beetles. Covering logs with polyethylene sheeting, known as “tarping”, has been commonly used to store elm wood infected with Dutch elm disease (Krawczyk et al. 1982, Svihra 1987) to prevent escape and colonization of *Scolytus multistriatus* (Marsham) (Coleoptera: Curculionidae: Scolytinae). Tarping and sealing firewood piles to prevent infestation is used effectively in integrated pest management and control of bark beetles (Buffam and Light 1968, Sanborn 1996, Donaldson and Seybold 1998).

While tightly single-bagging logs presents minimal risk of *A. planipennis*
escaping from infested ash firewood, our results suggest that double-bagging logs loosely in contractor grade 4 mil plastic bags would be a simple, cost-effective means to prevent escape of A. planipennis and establishment of new infestations. Plastic bags may be practical for small quantities of firewood; larger containers might be designed to accomplish the same effect where wood quantities are large. For instance, at the Mackinac Bridge in Michigan, large metal containers are used to hold confiscated firewood.

ACKNOWLEDGMENTS

We thank Robert Haack, Steven Katovich, and Melody Keena for comments on an earlier draft of this manuscript.

LITERATURE CITED


A COMPARISON OF PREFERENCE AND PERFORMANCE OF *ERYNNIS BAPTISIAE* (LEPIDOPTERA: HESPERIIDAE) ON A NATIVE AND AN INTRODUCED HOST PLANT

Susan D. McMahon¹ and Catherine E. Bach¹*

**ABSTRACT**

The increasing number of introduced and invasive plant species present phytophagous insects with many novel host plants. The butterfly *Erynnis baptisiae* (Forbes) (Lepidoptera: Hesperiidae) shifted from a native host plant, *Baptisia tinctoria* (L.), to an introduced host, *Securigera varia* (L.). Critical information about the biology of *E. baptisiae*, a species of special concern in Michigan, and the impact of its host shift is lacking. The purpose of this study was to compare preference and performance of two distinct populations of *E. baptisiae* on its native host and on an introduced plant. Preference was assessed based on female oviposition and larval feeding. Oviposition choice experiments demonstrated no significant preference by females for laying eggs on the native versus the introduced plant. Despite this, larvae from both populations strongly preferred to feed on the native plant, as measured by the number of leaves damaged in feeding choice experiments. Performance was assessed based on pupal weight, pupation success and development time. In rearing experiments, pupal weight was significantly higher when larvae fed on the native plant, regardless of the original host plant. There were no significant differences in the percentage of larvae successfully pupating and emerging as adults. Total development time was significantly shorter for caterpillars feeding on the native plant. Although the introduced plant *S. varia* is an adequate host plant, *E. baptisiae* preferred to feed on the native plant *B. tinctoria*, and also performed better on it. This implies that an increase in the number of *B. tinctoria* plants may increase the fitness of *E. baptisiae*, which may lead to a population increase and stabilization of the state population of *E. baptisiae*.

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closely related host plant species may require adaptations for an insect to successfully switch hosts. For example, Byers et al. (1986) found reduced pupal weight and significantly higher larval mortality rates when fruitworms were fed compounds extracted from the introduced plant crown vetch (*Securigera varia* (L.); Fabales: Fabaceae).

*Erynnis baptisiae* (Forbes) (Lepidoptera: Hesperiidae), commonly called the Wild Indigo Duskywing, is a species of special concern in Michigan due to its decreasing population, and has populations in only four counties (MNFI 2007, NatureServe 2007). Michigan populations of *E. baptisiae* butterflies have not been observed utilizing host plants other than *S. varia* and members of the genus *Baptisia* (Nielsen 1999). Populations of *Baptisia tinctoria* (L.) (yellow wild indigo; Fabales: Fabaceae) are rare and are present in not more than 10 Michigan counties (Voss 2001, USDA NRCS 2007, NatureServe 2007). *B. tinctoria* was the primary host plant of local populations of *E. baptisiae* butterflies, until some populations switched to the introduced plant *S. varia* (Shapiro 1979, Nielsen 1999). *S. varia* is also a member of the pea family, and was introduced to North America from Europe after 1890 as an erosion control agent, a ground cover, or a livestock forage plant (Voss 2001, USDA NRCS 2007). Most primitive members of the skipper subfamily Pyrginae, including *E. baptisiae*, are restricted to host plants within the pea family (Scott 1986). Very little research on this species exists and the impacts of utilizing the introduced plant *S. varia* as a host plant remain unknown.

This study compared the preference and performance of two distinct butterfly populations, one using the native plant *B. tinctoria* and one using the introduced plant *S. varia*. To examine preference, the following questions were addressed: (1) Does oviposition preference differ between females from the two populations when offered a choice of *B. tinctoria* and *S. varia*? (2) Does feeding preference differ between larvae from the two populations when offered a choice of *B. tinctoria* and *S. varia*? and (3) Does the plant species on which a female lays an egg influence subsequent larval feeding preference? To examine performance the following questions were addressed: (1) Do pupal weight and pupation success differ for larvae from the two populations when reared on *B. tinctoria* versus *S. varia*? (2) Does development time vary between the two distinct populations?

**MATERIALS AND METHODS**

**Study Sites.** Two distinct populations of *E. baptisiae* butterflies were located. One population occurs at Petersburg State Game Area, Monroe County, Michigan where adult females lay eggs on the native plant *B. tinctoria* (no *S. varia* is present). The second population occurs at Olson Park, Ann Arbor City Park, Washtenaw County, Michigan where females lay eggs on the introduced plant *S. varia* (no *B. tinctoria* is present).

**Preference experiments.** An experiment examining oviposition preference was carried out on the grounds of the University of Michigan Matthaei Botanical Gardens in Ann Arbor, MI in 2006. This location excludes the range of both butterfly populations studied. Two wooden framed cages approximately 1.5 m³ were constructed and covered with white lightweight polyester netting. The cages were anchored to the ground with stakes, and both the interior and exterior perimeters of the bottom of the cage were lined with sand to prevent butterfly escape.

Four potted plants, two native *B. tinctoria* and two introduced *S. varia*, were placed in the corners of the cages. Native and introduced plants were staggered within the cage, so the same species were not adjacent to one another. Plants were primarily grown from bare root stocks, along with some plants remaining from experiments conducted in 2005. All plants were grown
Gravid females were obtained from each of the two distinct butterfly populations; a total of 10 females were captured from Petersburg, and 22 females were captured from Olson. Due to the rarity of this species, obtaining gravid females was difficult, particularly at Petersburg where the population was noticeably smaller. Single gravid females were placed in the center of the cage with fresh plants (with no eggs) available for each new trial. Each oviposition trial was conducted separately to ensure that female oviposition did not influence other females. Plants were rotated with each experiment to eliminate the potential of female bias for one side of the cage. Natural and artificial nectar sources were available for females. Females were housed in the cages for a period of 24-48 hours and then released at their natal field site. The plants selected by the female, and the number of eggs laid on each plant were recorded.

Larval feeding preference was assessed in an experiment at the same location, using the eggs laid in the oviposition experiment by females from each of the two distinct populations on either *B. tinctoria* or *S. varia*. Eggs were left on the plant on which they were laid and a branch of the opposite plant (native or introduced) was attached, and placed in a lightweight mesh bag. Plants remained in plastic pots and the branches of each plant were attached with a twist tie. The vine-like branches of *S. varia* made it possible to ensure that both plants were located very close to eggs. Thus, each caterpillar had a choice of feeding on both the native and introduced plant. Despite the close proximity of each plant species to eggs, the relatively low mobility of first instar larvae may have introduced a bias toward plant upon which the egg was laid. The amount of herbivory on each damaged leaf in the mesh bag was determined weekly using a standard damage estimate scale (see Bach and Kelly, 2004), where 1 = <5%, 2 = 6-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-99%, and 6 = 100% leaf area removed.

Performance experiments. Assessment of pupal weight was determined by a $2 \times 2$ factorial experiment conducted in the greenhouse at the Terrestrial and Aquatic Research Facility of Eastern Michigan University in 2005. *B. tinctoria* plants were grown either from seed or bare root plants, whereas the introduced plant *S. varia* was obtained from local wild sources. All plants were grown in topsoil in 20-cm plastic pots in the greenhouse.

*Erynnis baptisiae* butterfly larvae of various sizes (almost all were first instars) were collected between 7 July and 11 August 2005 from two field sites: (1) Petersburg State Game Area, and (2) Olson Park, Ann Arbor City Park. A total of 16 caterpillars were collected from Petersburg, and a total of 28 caterpillars were collected from Olson. The caterpillars from each of these two distinct populations were offered no choice of host plant and were reared on either *B. tinctoria* or *S. varia*. Once placed on a plant, larvae were enclosed in lightweight, white mesh bags to ensure they remained on the no-choice host plant. The third generation of *E. baptisiae* overwinters in the larval state, and consequently all research was conducted on the first or second generation of butterflies.

Given the lack of critical information about the biology of *E. baptisiae*, the success rate of larvae from the pupal weight experiment was of interest. The number of larvae that successfully pupated and the number of pupae that successfully emerged as adult butterflies were counted.

Observations revealed differences in the timing of the various life stages (egg, larva, pupa, adult) between the two distinct butterfly populations. Since the host plant may affect development time, it was of interest to track differences. Development times for the two populations were determined based on observations of life cycle transitions resulting from the oviposition and larval feeding preference experiments in 2006. Dates when eggs were laid from each population as well as the dates of emergence of adult butterflies were recorded.
It was not feasible to track development time for individuals, and as a result, development times represent combined transition dates for several eggs laid by females from each population, and the life stage transition represents the earliest date of occurrence of life stage transitions for all eggs laid by a female on a single plant. Specifically, four egg clusters originated from the Petersburg population, and five egg clusters originated from the Olson population.

**Statistical analyses.** Oviposition preference could be analyzed only for the Olson population, because only one female from the Petersburg population laid any eggs (out of 10 gravid females collected). The only sufficient sample size from oviposition preference experiments originated from the Olson population (a total of seven gravid females). To determine whether females from Olson exhibited a significant oviposition preference for *B. tinctoria* or *S. varia*, a *t*-test was conducted.

Larval feeding preference was assessed based on (1) number of damaged leaves, and (2) mean amounts of damage on damaged leaves. Mean amounts of leaf damage were calculated by utilizing the midpoint for the amount of leaf damage within each damage category for each damaged leaf. The number of leaves damaged and the mean amount of leaf damage were assessed on a weekly basis as soon as it was feasible to assess the amount of leaf damage from herbivory (approximately one week after eggs were laid); thus, damage estimates were cumulative. Specifically, leaf damage was assessed on days 1, 11, 18, 26, 32, and 39. Two-way ANOVAs tested for effects of population origin, plant fed upon, and an interaction between population origin and plant fed upon. Since only one female from Petersburg laid eggs in the oviposition experiment, additional eggs (n = 8) from the Petersburg population were obtained from the field location to conduct the larval feeding preference experiments. Because butterflies from Petersburg emerged earlier than those from Olson, days 18 and 26 after the start of the larval feeding preference experiment had the largest sample sizes and the maximum larval feeding overlap of the two populations, and subsequently these data were used to statistically analyze feeding preference. Because there were no significant effects of population origin, plant fed on, or an interaction on the mean amount of damage on damaged leaves, results are not presented for those analyses.

In order to test whether the plant upon which an egg was laid affected larval feeding preference, the only sufficient sample size originated from the Olson population (total number of eggs laid on *B. tinctoria* n = 60, *C. varia* n = 61). Two-way ANOVAs were used to test for effects of the plant upon which the egg was laid, the plant larvae fed upon, and an interactive effect. Again, results on mean amounts of damage are not presented, because there were no significant differences.

Two-way ANCOVAs were conducted on pupal weight, testing for effects of population origin, plant upon which larvae were reared, and an interaction between plant reared upon and population origin, with a covariate of original larval length (mm).

A *t*-test was conducted to determine whether development time differed for the two distinct populations. All analyses of variance and *t*-tests were conducted using SYSTAT 5.0 (Wilkinson, 1990).

**RESULTS**

**Preference.** Females from Olson did not exhibit a significant preference for laying eggs on the native (8.57 ± 2.72) versus the introduced plant (8.71 ± 2.60; *t* = -0.039, df = 6, *P* = 0.97). In fact, four females laid more eggs on *S. varia* than on *B. tinctoria*, and three females laid more eggs on *B. tinctoria* than on *S. varia*. A single female from Petersburg showed a preference for *B. tinctoria* (10 eggs on *B. tinctoria*; 4 eggs on *S. varia*).
When larval feeding preference was measured by the number of damaged leaves, there was a significant preference for feeding upon the native plant, *B. tinctoria* on day 18 ($P = 0.014$; Table 1; Fig. 1). The lack of a significant interaction indicates that larvae from both populations preferred *B. tinctoria*, although there appeared to be a stronger preference exhibited by the *B. tinctoria* population (Fig. 1). There were no significant effects on the number of leaves eaten on day 26 (Table 1; Fig. 1).

For the Olson population, larval feeding preference measured as the number of leaves damaged was significantly affected only by an interaction between the plant the egg was laid upon and the plant the caterpillar fed upon, both for Day 18 ($P = 0.027$; Table 2) and Day 26 ($P = 0.013$; Table 2). These interactive effects clearly show that larvae preferred to feed on the plant upon which they were laid as eggs (Fig. 2).

Table 1. Results from two-way ANOVA of the number of leaves damaged on days 18 and 26, testing for effects of population origin, the plant fed upon, and an interactive effect between population origin and plant fed upon.

<table>
<thead>
<tr>
<th>Factor</th>
<th>$F$</th>
<th>df</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population Origin</td>
<td>2.507</td>
<td>1, 30</td>
<td>0.124</td>
</tr>
<tr>
<td>Plant Fed Upon</td>
<td>6.780</td>
<td>1, 30</td>
<td>0.014</td>
</tr>
<tr>
<td>Interaction</td>
<td>3.089</td>
<td>1, 30</td>
<td>0.089</td>
</tr>
<tr>
<td>Day 26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Population Origin</td>
<td>0.168</td>
<td>1, 30</td>
<td>0.685</td>
</tr>
<tr>
<td>Plant Fed Upon</td>
<td>0.415</td>
<td>1, 30</td>
<td>0.524</td>
</tr>
<tr>
<td>Interaction</td>
<td>1.217</td>
<td>1, 30</td>
<td>0.279</td>
</tr>
</tbody>
</table>

Figure 1. The number of leaves damaged by caterpillars on days 18 and 26 after the start of the feeding choice experiment from the Petersburg population given a choice of *B. tinctoria* (black bars) and *S. varia* (gray bars); and by caterpillars from the Olson population given a choice of *B. tinctoria* (diamond bars) and *S. varia* (diagonal bars). Means and SE are presented (*B. tinctoria* → *B. tinctoria* $N = 5$. *B. tinctoria* → *S. varia* $N = 5$. *S. varia* → *B. tinctoria* $N = 12$. *S. varia* → *S. varia* $N = 12$).
Table 2. Results from two-way ANOVA of the number of leaves damaged on days 18 and 26, testing for effects of plant egg laid upon, plant fed upon and an interactive effect between plant egg laid upon and plant fed upon. Data are from the Olson population.

<table>
<thead>
<tr>
<th>Factor</th>
<th>$F$</th>
<th>$df$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Day 18</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Egg Laid On</td>
<td>1.478</td>
<td>1, 20</td>
<td>0.238</td>
</tr>
<tr>
<td>Plant Fed Upon</td>
<td>0.22</td>
<td>1, 20</td>
<td>0.639</td>
</tr>
<tr>
<td>Interaction</td>
<td>5.698</td>
<td>1, 20</td>
<td>0.027</td>
</tr>
<tr>
<td><strong>Day 26</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant Egg Laid On</td>
<td>2.347</td>
<td>1, 20</td>
<td>0.141</td>
</tr>
<tr>
<td>Plant Fed Upon</td>
<td>0.781</td>
<td>1, 20</td>
<td>0.387</td>
</tr>
<tr>
<td>Interaction</td>
<td>7.353</td>
<td>1, 20</td>
<td>0.013</td>
</tr>
</tbody>
</table>

**Figure 2.** The number of leaves damaged by caterpillars on days 18 and 26 after the start of the feeding choice experiment from eggs laid on *B. tinctoria* and larvae given a choice of *B. tinctoria* (solid black bars) and *S. varia* (solid grey bars); and from eggs laid on *S. varia* and larvae given a choice of *B. tinctoria* (diamond bars) and *S. varia* (diagonal bars). Data are from the Olson population. Means and SE are presented (*B. tinctoria* → *B. tinctoria* $N = 7$. *B. tinctoria* → *S. varia* $N = 5$. *S. varia* → *B. tinctoria* $N = 5$. *S. varia* → *S. varia* $N = 5$).

**Performance.** Results demonstrated significantly greater pupal weight when the native plant *B. tinctoria* was the host plant regardless of the original host plant ($F = 5.7$, df = 1.16, $P = 0.030$; Fig. 3). Neither the population origin ($F = 0.035$, df = 1, 16, $P = 0.86$), nor interactive effects were significant ($F = 0.74$, df = 1, 16, $P = 0.40$). The covariate of original larval length also did not significantly affect pupal weight ($F = 0.38$, df = 1, 16, $P = 0.54$).

The total number of larvae that pupated was 21 of 45, approximately 47% (Table 3). The greatest percentages of pupation success occurred with larvae originally from one plant that were reared on the opposite plant (50% if reared on *B. tinctoria*; 66% if reared on *S. varia*); however, there was no
significant difference between pupation success for larvae reared on the same or the opposite plant ($\chi^2 = 1.84$, df = 1, $P > 0.05$). Although sample sizes are too small to permit statistical analyses, it was interesting that greater percentages of pupae from the Olson population successfully emerged as adults than from the Petersburg population (Table 3).

Development times strongly differed for caterpillars from the Petersburg population, and caterpillars from the Olson population. Caterpillars from both populations consumed both the native plant *B. tinctoria* and the introduced plant *S. varia* (Fig. 4). There were significantly shorter development times for the Petersburg population for the pupal stage ($t = -4.473$, df = 7, $P = 0.003$), and for the total development time from egg to emergence as an adult butterfly ($t = -3.894$, df = 7, $P = 0.006$; Fig. 4). There was insufficient data to test for differences in the egg stage, and there was no significant difference in development time between the two populations for the larval stage ($t = 2.030$, df = 7, $P = 0.082$; Fig. 4).

![Figure 3. Pupal weights (g) of larvae from each of the two host populations reared on the two host plants, *B. tinctoria* or *S. varia*. Means and SE are presented (*B. tinctoria* $\rightarrow$ *B. tinctoria* N = 3. *B. tinctoria* $\rightarrow$ *S. varia* N = 6. *S. varia* $\rightarrow$ *B. tinctoria* N = 6. *S. varia* $\rightarrow$ *S. varia* N = 6).](image)

Table 3. Percentage of larvae that pupated and the percentage of pupae that successfully emerged as adult butterflies from the greenhouse experiment conducted in 2005. Larvae from both original populations were reared upon either *B. tinctoria* or *S. varia*.

<table>
<thead>
<tr>
<th>Original plant</th>
<th>Plant reared upon</th>
<th>% of larvae that became pupae</th>
<th>% of pupae successfully emerged as adults</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>B. tinctoria</em></td>
<td><em>B. tinctoria</em></td>
<td>8 37.5</td>
<td>3 12.5</td>
</tr>
<tr>
<td><em>B. tinctoria</em></td>
<td><em>S. varia</em></td>
<td>9 66.6</td>
<td>6 22.2</td>
</tr>
<tr>
<td><em>S. varia</em></td>
<td><em>B. tinctoria</em></td>
<td>12 50.0</td>
<td>6 33.3</td>
</tr>
<tr>
<td><em>S. varia</em></td>
<td><em>S. varia</em></td>
<td>16 37.5</td>
<td>6 31.3</td>
</tr>
</tbody>
</table>
DISCUSSION

Caterpillars from the native plant population (*B. tinctoria*) strongly preferred feeding on *B. tinctoria* as measured by the number of leaves damaged. Interestingly, caterpillars from the introduced plant population (*S. varia*) also preferred feeding on the native plant *B. tinctoria*. Although *S. varia* is an adequate host plant for larval development, early instar larval feeding preference is consistent with better larval performance on the native plant *B. tinctoria*, as demonstrated by greater pupal weights and shorter development times.

The plant upon which an egg was laid influenced subsequent larval feeding preference. Caterpillars from eggs laid on the native plant *B. tinctoria* preferentially fed on the native plant, while caterpillars from eggs laid on the introduced plant *S. varia* preferred feeding on the introduced plant. However, the overall preference exhibited for feeding on the native plant *B. tinctoria* did not result from a greater number of eggs laid on the native plant, because females from Olson laid approximately equal numbers of eggs on the introduced plant *S. varia* (*n* = 61) and on the native plant *B. tinctoria* (*n* = 60).

Female butterflies select suitable host plants based on visual cues, olfactory responses, and contact chemical cues upon landing on a plant (Murphy and Feeny 2006). Additionally, a female should select the most beneficial plant for larval growth and development when laying eggs (Stanton 1982). The oviposition preference study revealed that female butterflies from Olson showed no consistent preference for either the native *B. tinctoria* or the introduced *S. varia*, yet individual females showed preference (3 preferred *B. tinctoria*; 4 preferred *S. varia*). Gratton and Welter (1998) found that a specialist leafminer showed oviposition preference for established host plants over novel hosts. Barker and Maczka (1996) demonstrated that oviposition preference strongly correlated with larval performance for sawflies.
Because the Olson butterfly population has not had access to the native plant *B. tinctoria* for approximately 30 generations or 10 years (NAPD 2007), the possibility that these distinct populations developed host plant specialization exists. Evidence of host plant specialization would be greater performance on the native plant by the Petersburg population and greater performance on the introduced plant by the Olson population. However, this study revealed no evidence for host plant specialization by these populations. Pupal weight of *E. baptisiae* was significantly greater when *B. tinctoria* was the host plant regardless of the original host plant. In general, greater pupal weight correlates with greater adult fecundity and fitness (Tammaru et al. 2002, Murphy 2004, Moreau et al. 2006), suggesting that *E. baptisiae* fitness will be enhanced by increasing the population of the native plant *B. tinctoria*. These results are interesting because they strongly suggest that neither population performs as well on the introduced host, *S. varia*.

There was a disparity in the timing of life stages (i.e., egg, larva, pupa, adult) between the Petersburg and Olson populations. Development time for the Olson population was significantly longer which may increase exposure to natural enemies and reduce adult fitness (Nylin and Gotthard 1998). Again, this suggests that large *B. tinctoria* populations will result in a stronger *E. baptisiae* population, which may lead to butterfly population stability. An alternative is that *S. varia* may act as a host plant largely free of natural enemies (as has been suggested for other novel plants, Murphy 2004), which may provide a benefit, counteracting longer development time (Murphy 2004). This may be of greater importance if natural enemies (i.e., parasitoids) of larvae present the greatest threat to growth and development.

The host shift of *E. baptisiae* from the native plant *B. tinctoria* to the introduced plant *S. varia* most likely occurred because *B. tinctoria* became largely unavailable. Most skippers in the subfamily Pyrginae solely use host plants within the pea family (Scott 1986). In addition, *S. varia* is a highly palatable forage plant and fixes nitrogen in the soil (USDA NCRS 2007). The host shift to *S. varia* may provide many benefits to *E. baptisiae*, including providing a corridor between *B. tinctoria* populations, particularly considering that *S. varia* was frequently planted along roadways. Furthermore, *S. varia* may act as a buffer and provide a suitable host plant in the event of further decreases in the *B. tinctoria* population. It is also possible that *S. varia* may allow the *E. baptisiae* population to expand its geographic range.

Although *E. baptisiae* can obviously subsist on *S. varia*, it prefers and performs better on the native plant *B. tinctoria*. This implies that an increase in the number of *B. tinctoria* plants may increase the fitness of *E. baptisiae*, which, in turn, may lead to an increase in the population of the butterfly. If the butterfly population increases and becomes stable, the species may attain a secure population status in Michigan.

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LITERATURE CITED


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SURVEY FOR PREVIOUSLY COMMON NATIVE COCCINELLIDAE (COLEOPTERA) IN THE NORTHERN GREAT PLAINS

Louis S. Hesler¹ and Jessica D. Petersen²

ABSTRACT

A survey for coccinellids was conducted among agricultural and non-agricultural habitats in 22 counties of South Dakota, North Dakota, Minnesota, and Iowa from 2005 through 2007. A total of 1226 coccinellids were sampled by sweepnet, timed searches, Malaise traps, and observation. Four native species—Coleomegilla maculata (De Geer), Hippodamia parenthesis (Say), Hippodamia convergens Guérin-Méneville, and Hippodamia tredecimpunctata tibialis (Say)—collectively comprised 55.8% of all coccinellids sampled, and two non-natives—Coccinella septempunctata L. and Harmonia axyridis (Pallas)—comprised 34.8% of coccinellids sampled. H. parenthesis, H. convergens, C. septempunctata, and H. axyridis were also seen commonly while sampling for bean leaf beetle and soybean aphid. The survey had ≥ 95% probability of detecting species that comprised a minimum proportion of 0.0025, 0.0032, and 0.011 of all coccinellids, respectively, across habitats, among only agricultural habitats, and among only non-agricultural habitats. A. bipunctata (L.), Coccinella transversoguttata richardsoni Brown, and Coccinella novemnotata Herbst were not detected in the survey. The results provide further evidence that these three previously common native species have become difficult to detect within the northern Great Plains, and suggest that conservation programs for them are urgently needed. H. axyridis and C. septempunctata were often found in non-agricultural habitats, providing further evidence of their pervasiveness in the landscape. Adult C. septempunctata were feeding upon a native aphid, Uroleucon atriceps (Gillette and Palmer) (Hemiptera: Aphididae), on goldenrod at a prairie in Richland County, North Dakota. This result provides further documentation of non-target predation by non-native coccinellids, and suggests that further studies are needed to determine fully the impact of non-native coccinellids on the native aphid fauna.

The lady beetle (Coleoptera: Coccinellidae) fauna in North America has changed considerably over the last few decades (Gordon 1985, Turnock et al. 2003, Alyokhin and Sewell 2004, Harmon et al. 2007), and this change has been particularly evident within agricultural habitats of the northern Great Plains (Elliott et al. 1996, Turnock et al. 2003). Hippodamia convergens Guérin-Ménerville, Hippodamia tredecimpunctata tibialis (Say), Hippodamia parenthesis (Say), Coleomegilla maculata lengi Timberlake, Coccinella novemnotata Herbst, Coccinella transversoguttata richardsoni Brown, and Cycloneda munda (Say) are aphidophagous species that have been associated commonly with field-crop habitats in eastern South Dakota (Kirk and Balsbaugh, Jr. 1975, Kieckhefer et al. 1992), and Adalia bipunctata (L.) is an aphidophage frequently found in corn fields (Kieckhefer et al. 1992). However, within the last 20 years, the abundance of A. bipunctata, C. novemnotata, and C. transversoguttata richardsoni has declined drastically in eastern South Dakota, while two non-native lady

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beetles, *Coccinella septempunctata* L. and *Harmonia axyridis* (Pallas), have become abundant (Elliott et al. 1996, Hesler 2003, Hesler et al. 2004). Both *C. septempunctata* and *H. axyridis* had been released in the United States for control of agricultural pests, although it is unclear whether North American populations of these non-native coccinellids resulted from those releases, additional introduction(s), or both (Day et al. 1994, Wheeler, Jr. and Hoebeke 1995).

At least three hypotheses have been advanced to suggest that populations of *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* may persist. The first hypothesis proposes that populations of native coccinellids may recover within agricultural habitats (“recovery hypothesis”), as declines of some native species caused by invasive species are often followed by recovery within 10 to 20 years (Strayer et al. 2006). Recovery, in the case of coccinellids, could be facilitated by an increased abundance of prey within crop fields. For instance, recent establishment of the soybean aphid (*Aphis glycines* Matsamura, Hemiptera: Aphididae) in South Dakota and other northern soybean-growing regions (Venette and Ragsdale 2004) has dramatically changed the availability of suitable coccinellid prey in soybean agroecosystems (Gardiner and Parsons 2005). However, recent surveys failed to detect *A. bipunctata*, *C. novemnotata* and *C. transversoguttata richardsoni* in soybean (Hesler et al. 2004, Hesler and Kieckhefer 2008), and surveys of other field crops found only four *C. transversoguttata richardsoni* in alfalfa in the early 1990s (Hesler et al. 2000, 2005). Thus, there is no evidence that populations of previously common coccinellids have recovered in agricultural habitats in eastern South Dakota.

The second, “alternative habitat” hypothesis suggests that populations of *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* may persist in alternative habitats such as grasslands and woods (Obrycki et al. 2000, Hesler et al. 2005, Acorn 2007). However, recent surveys of alternative habitats in eastern and central South Dakota failed to recover *A. bipunctata*, *C. transversoguttata richardsoni*, or *C. novemnotata* (Hesler et al. 2004, 2005; Hesler and Kieckhefer 2008). Therefore, these results provide no evidence to support the alternative habitat hypothesis.

Finally, researchers have hypothesized that population declines of some coccinellid species may be localized (“local rarity” hypothesis). For instance, Obrycki et al. (2000) suggested that the rarity of *A. bipunctata* may be localized to eastern South Dakota because preferred arboreal habitat for *A. bipunctata* is relatively scarce. Indeed, several *A. bipunctata* were collected recently in western South Dakota, although *C. transversoguttata richardsoni* and *C. novemnotata* were not found (Hesler and Kieckhefer 2008). However, the hypothesis of local rarity is largely untested, and areas surrounding eastern South Dakota have not been adequately surveyed for *A. bipunctata*, *C. transversoguttata richardsoni*, and *C. novemnotata*.

Several authors have called for monitoring North American populations of lady beetles to assess the status of indigenous species and the invasiveness of exotics (Wheeler, Jr. and Hoebeke, 1995; Wheeler, Jr. and Stoops, 1996; Ellis et al., 1999; Obrycki et al. 2000; Hesler et al., 2001). Surveys to monitor coccinellids have been conducted in eastern South Dakota during recent years (Hesler et al. 2000, 2004, 2005; Hesler and Kieckhefer 2008). The survey area was expanded in 2005 through 2007 to include additional areas surrounding eastern South Dakota. Surveying eastern South Dakota and the surrounding region may provide evidence to evaluate the hypothesis regarding local rarity versus more widespread declines in native coccinellids. This paper reports on the results of expanded survey efforts from 2005 through 2007.
STUDY SITES AND METHODS

Surveys for coccinellids were conducted in agricultural and non-agricultural habitats of 22 counties in South Dakota, North Dakota, Minnesota, and Iowa from 2005 through 2007 (Fig. 1; Appendix). All sampling sites were within roughly 500 km of Brookings, South Dakota, where previous surveys had first detected declines in the abundance of native coccinellids (Elliott et al. 1996). The surveys consisted of sweepnetting, timed searches, use of Malaise traps (Southwood 1978), and observation. Actual and potential prey were noted when sampling.

Searches and sweeps were conducted on 74 occasions when coccinellids were most likely to be active on plants, i.e., between 1000 and 1600 hrs on sunny to partially sunny days with temperatures 20 °C or greater and wind speed less than 30 km/hr (Elliott et al. 1991, Kieckhefer et al. 1992). Searches were conducted in July and August 2006 and 2007. Sweeps were conducted in May 2005, May to September 2006, and May to August 2007. A few sites were sampled more than once within a year or during the 3-year period. Searches and sweeps were conducted primarily in agricultural (865 minutes, 9200 sweeps) versus non-agricultural habitats (60 minutes, 1600 sweeps).

Figure 1. Map of counties in South Dakota, North Dakota, and Minnesota that were surveyed for lady beetles in 2005, 2006 and 2007. Counties 1 through 9, South Dakota; 10 through 12, North Dakota; 13 through 19, Minnesota; 20 though 22, Iowa. Legend: 1 = Union, 2 = Clay, 3 = McCook, 4 = Hanson, 5 = Davison, 6 = Brookings, 7 = Beadle, 8 = Hyde, 9 = Brown, 10 = Ransom, 11 = Richland, 12 = Cass, 13 = Grant, 14 = Stevens, 15 = Swift, 16 = Carver, 17 = Renville, 18 = Redwood, 19 = Martin, 20 = Clayton, 21 = Linn, 22 = Mahaska.
Timed visual searches lasted 20 minutes in individual corn and soybean fields, patches of goldenrod in a prairie, and a large patch of ruderal vegetation (i.e., thistles, lambsquarters, reed grass) at a county park. Goldenrod was searched once in 2007 in North Dakota, and ruderal vegetation was sampled once each in 2006 and 2007 in Minnesota. Direct observations were made of coccinellids preying upon aphids in these habitats. A few large fields (> 40 ha; e.g., corn in Union County, South Dakota; corn and soybean in Martin County, Minnesota) were subdivided into two or three sections in 2007, and each section was searched for 20 minutes. Each search area was approached to avoid casting shadows that might disturb coccinellids and cause them to flee the sample area. Corn and soybean were sampled just before or during their reproductive stages, when they were often infested by aphids (Hesler and Kieckhefer 2008). Corn and soybean fields were generally abandoned if less than 4 coccinellids were sighted within the first 5 minutes of searching. This was done to maximize the number of coccinellids sampled per unit time at a given location and to focus sampling on areas that yielded relatively greater numbers of coccinellids. Although this approach might have been biased against coccinellid species that occupied low-density habitats, it seemed justified because our previous experience had indicated that few native or non-native coccinellids would be found if additional time were allotted for searching habitats with low initial densities of coccinellids. Counts of adult coccinellids were tallied by species during searches. Larvae and pupae of coccinellids were placed in bottles containing 70 percent alcohol, identified in the laboratory, and added to counts of adult coccinellids.

Sweepnets were used to sample coccinellids in alfalfa, wheat, sweet clover, and prairie tracts. Samples consisted of 200 sweeps in 2005 and 2006, and 300 sweeps in 2007 to conform to procedures of a related long-term survey for coccinellids. Sweep samples consisted of pendular sweeps with a 38-cm-diameter net along mildly serpentine transects. Movement of a sweepnet through an 180°-arc counted as one sweep. After sweeping a habitat, contents of the sweepnet were carefully emptied into a large plastic bag that was then tied shut, taken to the laboratory, placed in a freezer, and processed later.

Malaise traps were employed in 2007 at nature preserves located in three counties in eastern and central Iowa as part of a broader insect diversity survey. The utility of Malaise traps for sampling coccinellids is low (Tedders and Schaeffer 1994, Hesler et al. 2004), but the long periods in which the traps were employed would have compensated for their relatively low capture rate. The traps were placed within 5 m of streams that ran through mixed deciduous woods (three sites), or adjacent to the edge of a wetland (one site) that was situated among grass and sparse trees (e.g., river birch). Insects were extracted from the collection container of each trap about every 2 wks, and specimens were held in 70 percent ethanol until identification and counting.

Additional records of coccinellids were made while sweeping soybean fields for bean leaf beetles, Cerotoma trifurcata (Forster) (Coleoptera: Chrysomelidae), in McCook County (1200 sweeps; 13 August 2006), Brookings County (1800 sweeps; 17 August 2006), and Clay County, South Dakota (~2000 sweeps; 26 May 2007). Beetles swept from fields were promptly placed in bags, transported back to the lab in chilled containers, and then transferred into cages. Coccinellids were sorted from bean leaf beetles and other insects, with each sample estimated to contain a few hundred coccinellids. As the primary goal was to process bean leaf beetles, coccinellids were not counted, but species were recorded as they were discovered during sorting and their relative abundances were noted afterward. Finally, coccinellids were additionally sampled by a roughly 20-minute observation in 2006 within the patch of ruderal park vegetation in Carver County, Minnesota.
Identification of adult coccinellids was based on Gordon (1985) and Gordon and Vandenberg (1991). Larval coccinellids were identified using keys in Rees et al. (1994), Rhoades (1996), and Gordon and Vandenberg (1995). Voucher specimens of some coccinellids and aphid prey sampled are deposited at the North Central Agricultural Research Laboratory, Brookings, South Dakota. Counts of coccinellids are reported separately for agricultural and alternative, non-agricultural habitats. A one-tailed binomial distribution test was used to calculate the 95% confidence limit of the minimum individual proportions of *A. bipunctata*, *Coc. novemnotata*, and *Coc. transversoguttata richardsoni* in agricultural habitat, non-agricultural habitat, and the total survey area based on the total number of coccinellids sampled in each (Clopper and Pearson 1934).

**RESULTS**

Overall 1226 coccinellids consisting of 11 native and two non-native species were counted in the survey (Table 1). The vast majority (1189 individuals, or 97%) consisted of aphidophagous species in the subfamily Coccinellinae (Iperti 1999, Vandenberg 2002). Four native species—*C. maculata*, *H. parenthesis*, *H. convergens*, and *H. tredecimpunctata tibialis*—comprised 55.8% of all coccinellids counted, whereas the non-natives *C. septempunctata* and *H. axyridis* comprised 34.8% (19.4% and 15.4%, respectively) of all coccinellids counted. Other taxa accounted for 6% of coccinellids counted. *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* were not detected in the survey.

More coccinellids were counted in agricultural (954) than non-agricultural habitats (272) (Table 1). The survey had 95% or greater probability of detecting individual species that comprised a minimum proportion of 0.0025, 0.0032, and 0.011 of coccinellids, respectively, across all habitats, among only agricultural habitats, and among only non-agricultural habitats. The absence of *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* indicates that these species each occurred in proportions below the 95% detection levels within respective habitats during the survey.

There was considerable overlap, but some noteworthy exceptions, in coccinellid species composition between agricultural and non-agricultural habitats (Table 1). The order of abundance in agricultural habitats was *C. maculata*, *C. septempunctata*, *H. axyridis*, *H. convergens*, *H. tredecimpunctata tibialis*, and *H. parenthesis*. In contrast, *H. parenthesis* accounted for nearly half of all coccinellids sampled in non-agricultural habitats, due largely to 95 adults, 1 pupa, and 35 larvae found in a patch of alfalfa and sweet clover in Fargo, North Dakota, on 9 July 2006. *C. septempunctata*, *C. munda*, *H. axyridis*, and *C. maculata* each comprised from 7% to 16% of coccinellids sampled in non-agricultural habitats, but *H. tredecimpunctata tibialis* was not sampled in non-agricultural habitats. Among non-agricultural habitats, adult *C. septempunctata* were observed feeding upon a native aphid, *Uroleucon atripes* (Gillette and Palmer) (Hemiptera: Aphididae), on goldenrod at a prairie in Richland County, North Dakota. In addition, *C. septempunctata* and *H. axyridis* were found on ruderal vegetation at a park in Carver County, Minnesota in 2006 and 2007, where their immature stages were associated with mealy plum aphids, *Hyalopterus pruni* (Geoffroy) (Hemiptera: Aphididae), on common reed.

A few hundred additional coccinellids were sampled each time during collections of bean leaf beetles, with samples containing primarily *H. parenthesis*, *H. convergens*, *C. septempunctata*, and *H. axyridis*, and relatively few *C. maculata*, *H. tredecimpunctata tibialis*, and *C. munda*. The same relative abundance of these seven coccinellid species was seen during coincidental sampling of soybean aphid in soybean fields in Brookings County in 2005 through 2007. No *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* were observed in soybean fields during sampling for bean leaf beetles and soybean aphid.
Table 1. Abundance of coccinellids sampled from 2005 through 2007 in South Dakota, North Dakota, Iowa and Minnesota.

<table>
<thead>
<tr>
<th>Species</th>
<th>Total, all habitats</th>
<th>Agricultural habitats(^1)</th>
<th>Non-agricultural habitats(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Adults</td>
<td>Pupae</td>
</tr>
<tr>
<td><em>Scymnus</em> sp.</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><em>Hyperaspis undulata</em></td>
<td>7</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><em>Brachiacantha ursina</em></td>
<td>28</td>
<td>26</td>
<td>26</td>
</tr>
<tr>
<td><em>Brachiacantha</em> q. quadripunctata</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Anisosticta bitriangularis</em></td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Coleomegilla maculata</em></td>
<td>258</td>
<td>239</td>
<td>174</td>
</tr>
<tr>
<td><em>Hippodamia tredecimpunctata</em> tibialis</td>
<td>100</td>
<td>100</td>
<td>64</td>
</tr>
<tr>
<td><em>Hippodamia parenthesis</em></td>
<td>201</td>
<td>67</td>
<td>6</td>
</tr>
<tr>
<td><em>Hippodamia convergens</em></td>
<td>125</td>
<td>123</td>
<td>98</td>
</tr>
<tr>
<td><em>Hippodamia</em> sp.</td>
<td>9</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><em>Coccinella septempunctata</em></td>
<td>238</td>
<td>194</td>
<td>102</td>
</tr>
<tr>
<td><em>Coccinella</em> sp.</td>
<td>32</td>
<td>32</td>
<td>0</td>
</tr>
<tr>
<td><em>Cycloneda munda</em></td>
<td>31</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td><em>Harmonia axyridis</em></td>
<td>189</td>
<td>163</td>
<td>81</td>
</tr>
<tr>
<td><em>Psyllobora vigintimaculata</em></td>
<td>5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1226</td>
<td>954</td>
<td>560</td>
</tr>
</tbody>
</table>

\(^1\)Individual habitats of maize, soybean, alfalfa, winter wheat, or spring wheat.

\(^2\)Individual habitats of prairie; native grass plots; predominantly sweet clover; sweet clover and thistle; grassy clearing among woods; ruderal vegetation (thistle, lambsquarters, and reed grass); deciduous forest; or wetland edge. Counts do not include observation of several adults and larvae of *Harmonia axyridis* and *Coccinella septempunctata*, 1 adult *Coleomegilla maculata*, and 1 adult *Cycloneda munda* in ruderal vegetation, Lake Susan Park, Carver County, Minnesota, 28 July 2007.
DISCUSSION

The results of our survey are consistent with other recent studies of coccinellids in the northern Great Plains. For instance, the six most abundant species of coccinellids in our study are typically the most abundant coccinellids in both agricultural (Kieckhefer et al. 1992, Hesler et al. 2000, Wright and DeVries 2000, Hesler and Kieckhefer 2008) and non-agricultural habitats (Hesler et al. 2005, Rand and Louda 2006) of the northern Great Plains. In addition, the absence of *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* in our survey is also consistent with results from other recent studies in the region in which these species were near or below detectable levels (Wright and DeVries 2000, Hesler 2003, Hesler et al. 2004, Kriz et al. 2006, Harmon et al. 2007, Hesler and Kieckhefer 2008). Several hypotheses had been advanced to suggest that species such as *A. bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* may eventually recover within agricultural habitats (Strayer et al. 2006), may persist in various alternative habitats (Obrycki et al. 2000, Acorn 2007), or may be locally rare within a region (Obrycki et al. 2000). Nonetheless, the collective results of this survey and several previous studies suggest that these species have not recovered in agricultural habitats, and that their decline is not simply local but extends to both agricultural and alternative, non-agricultural habitats over much of the northern Great Plains. However, several *A. bipunctata* were collected recently in western South Dakota, although *C. transversoguttata richardsoni* and *C. novemnotata* were not found (Hesler and Kieckhefer 2008). Future studies are needed to determine reasons for the abundance of *A. bipunctata* in western South Dakota and to determine how conditions there may differ from those in other regions of the northern Great Plains where this species has become extremely rare.

*Adalia bipunctata*, *C. novemnotata*, and *C. transversoguttata richardsoni* were once common and widespread throughout much of North America (Gordon 1985). Devising plans for the conservation of these three species will depend on studies to adequately identify any extant populations (Acorn 2007, Hesler and Kieckhefer 2008) and determine factors that influence their viability. Many researchers have called for long-term monitoring of coccinellid populations, especially in light of continued establishment and expanding geographic range of other non-native species such as *Hippodamia variegata* Goeze (Wheeler, Jr. and Stoops 1996, Ellis et al. 1999, Gardiner and Parsons 2005). Such studies will require sustained, widespread survey efforts dependent largely on collective human resources (Losey et al. 2007). Marshaling groups of people to conduct the surveys may be accomplished by networks of researchers via government agencies such as the USDA’s Cooperative Agricultural Pest Survey program (Ellis et al. 1999), through citizen science programs (Losey et al. 2007), or some combination of these and possibly other groups.

Finally, our study documented additional instances in which *C. septempunctata* and *H. axyridis* were preying upon aphids in non-agricultural habitats. These two non-native, generalist predators were released for control of agricultural pest aphids (Schaefer et al. 1987, Tedders and Schaefer 1994, Koch 2003), but both have been documented to prey on non-target aphids and to pose a risk to native insects (Koch 2003, Koch et al. 2005, Schellhorn et al. 2005, Hesler and Kieckhefer 2008). Thus, further studies are urgently needed to determine the impact on non-target insects by *C. septempunctata* and *H. axyridis*.

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### Appendix. Sampling locations and methods.

<table>
<thead>
<tr>
<th>State</th>
<th>County (number)</th>
<th>Sample site</th>
<th>Habitat</th>
<th>Date</th>
<th>Sample method</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Dakota</td>
<td>Union (1)</td>
<td>7 mi S, 1¼ mi W Alcestor</td>
<td>Soybean</td>
<td>17 July 2006</td>
<td>20-minute search</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Maize</td>
<td>17 July 2006</td>
<td>20-minute search</td>
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## Appendix. Continued.

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1 Counties numbered as in Figure 1.
EIGHT NEW OHIO STATE RECORDS OF TRUE BUGS FROM PITFALL TRAPS

Stephen W. Chordas III¹, L. Brian Patrick², and Matthew B. Lauffer³

ABSTRACT

Thirty one species of true bugs (Hemiptera: Heteroptera) were collected from pitfall traps set in old-field grasslands in Summit and Portage Counties, Ohio, between 2002 and 2005. Of these, eight were new state records including: Corimelaena pulicaria (German), Cryphula trimaculata (Distant), Emesaya brevipennis brevipennis (Say), Hebrus burmeisteri Lethierry and Sverin, Oncerotachelus acuminatus (Say), Pagasa fusca fusca (Stein), Pycnoderes obscura-tus Knight, and Stygnocoris rusticus (Fallen). Current distribution maps (north of Mexico) and bionomical information are provided for each species.

Documentation of the true bugs (Hemiptera: Heteroptera) of the United States and Canada is an ongoing effort. The most recent comprehensive sources of information on distribution are the catalog of North American Heteroptera (Henry and Froeschner 1988) and the checklist of Canadian species (Maw et al. 2000). Records are lacking for many common species that would be expected to occur in Ohio (Henry and Froeschner 1988).

Between 2002 and 2005, pitfall traps were used to capture insects and investigate the influence of management practices (e.g., mowing, fertilizer use) on grasslands in the Bath Nature Preserve, Summit County Ohio (Patrick et al. 2008a, b). Although only a small fraction of the total insect community, 31 bug species were collected during the study, eight of which are new state records.

The purpose of this paper is to document the eight species as new state records for Ohio. Additionally, we provide current distribution maps (north of Mexico) for all eight species because new records have been published since the catalog by Henry and Froeschner (1988).

METHODS

Bugs were captured in pitfall traps and preserved in 80% ethanol. Wheeler, Jr.(1983), Henry and Froeschner (1988), McPherson (1992), Wheeler, Jr. (1992), Maw et al. (2000), Williams (2000), Chordas et al. (2005), Chordas and Kovarik (in press) were used as distributional references. Blatchley (1926), Knight (1941), McPherson (1982), and Hilsenhoff (1986) were used as taxonomic references. Voucher specimens were deposited in the entomological collections at Kent State University (Kent, Ohio). Duplicate specimens of state record taxa were deposited in the first author’s personal collection (SWAC collection Columbus, Ohio). Additionally, voucher specimens of Pycnoderes obscuratus Knight, 1926 (Miridae) were deposited in the United States National Museum (USNM, Washington, D.C).

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³Department of Biological Sciences, Kent State University, Kent, Ohio 44242.
Collection sites: All species, except for the *Hebrus* species, were collected from the following location: Ohio, Summit County, Bath Township, Bath Nature Preserve [41°10'36.2" N; 81°38'58.7" W], pitfall traps in old-field grassland, coll. L.B. Patrick. Dates (or date ranges) of collection are listed individually for each species. Patrick et al. (2008a) provided detailed habitat characterization, as well as specific and vegetative parameters of the location where these hemipterans were collected, and Patrick et al. (2008b) provided details on the pitfall trap sampling procedure. The *Hebrus* species was collected from a pitfall trap placed in the riparian zone of a constructed wetland pool on the Arthur and Margaret Herrick Aquatic Ecology Research Facility at Kent State University, Portage County, Ohio [41° 8'16.77"N : 81°20'22.32"W] (Lauffer 2004).

**RESULTS AND DISCUSSION**

**Hebridae**

*Hebrus burmeisteri* Lethierry & Severin, 1896. Although considered a semiaquatic bug, this species was captured in a pitfall trap that was close to the water’s edge of a man-made wetland. Previously recorded for Michigan, Kentucky, and Pennsylvania (Fig. 1). *H. burmeisteri* was expected to occur in Ohio. A single specimen was collected on 30 July 2003.

**Miridae**

*Pycnoderes obscuratus* Knight, 1926. No species of this genus had been reported previously from Ohio. This is not surprising as the mirids are not well known for Ohio, and the species of this genus apparently are rarely encountered throughout their known ranges. There are few records of any of the *Pycnoderes* species for the eastern United States (Thomas Henry, USNM, personal communication). Four specimens were collected: 11-25 August 2004 (1 specimen), 1-15 July 2005 (2 specimens), and 29 July - 12 August 2005 (1 specimen). These Ohio records represent a western range extension and only the 3rd state (in addition to Pennsylvania and Virginia [Thomas Henry, personal communication]) with records of this species (Fig. 2).

This species was difficult to identify as there are few mirid keys that include Great Lakes fauna and none that is specific to Ohio; Watson’s (1928) Miridae of Ohio lacks a key. *P. obscuratus* was not included in Knight’s (1941) monograph of the Miridae of Illinois or in Blatchley’s (1926) key, although Blatchley did mention it in the text summary of *P. balli* Knight. *P. obscuratus* originally was described as a variety of *P. balli*, from which this species is clearly different. Because our specimens did not fit any *Pycnoderes* species in

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**Figure 1.** *Hebrus burmeisteri* distribution north of Mexico.

**Canada:** Nova Scotia, Ontario, Quebec, Saskatchewan.

**United States:** Florida, Georgia, Illinois, Iowa, Kansas, Kentucky, Maryland, Massachusetts, Michigan, Missouri, New Hampshire, New Jersey, Ohio, Pennsylvania, South Carolina, Virginia, Wisconsin.
Blatchley’s (1926) key or any of his limited descriptions, we sent our specimens to Thomas Henry (USNM) for identification. A further confounding item was that all four of our Ohio specimens were partly brachypterous, a character not mentioned by Blatchley (1926).

Other bugs captured along with *P. obscuratus* in the same pitfall traps were three species of Rhyparochromidae: *Myodocha serripes* Olivier, 1811, *Ptochiomera nodosa* Say, 1832, and *Stygnocoris rusticus* (Fallen, 1807). Other bugs captured in different pitfall traps during the same collection period and in the same sample plot were *Corimelaena pulicaria* (Germar, 1829) (Thyrocoridae) and *Cryphula trimaculata* (Distant, 1882) (Rhyparochromidae). *P. obscuratus* was captured only in unfertilized plots; three of the four specimens were captured in plots with the plant litter removed (see Patrick et al. 2008a, b for treatment details).

**Nabidae**

*Pagasa fusca fusca* (Stein, 1857). This damsel bug is widespread in North America (Fig. 3) and was expected for Ohio. One specimen was collected 30 June - 14 July 2005. No other bugs were captured with *P. fusca fusca* in the same pitfall trap, although *C. trimaculata* was captured in other pitfall traps during the same collection period and in the same sample plot.

**Reduviidae**

*Emesaya brevipennis brevipennis* (Say, 1928). This slender assassin bug occurs throughout the Great Lakes area, across the eastern half of the United States and into Canada, with one disjunct record from California (Fig. 4). Ohio was within the known range of this species, and its occurrence was expected. Two specimens were collected 24 July - 7 August 2003 and 18 July - 1 August 2004. The only bug captured with *E. brevipennis brevipennis* in the same pitfall trap was *S. rusticus*. No other bugs were captured in other pitfall traps during the same collection period and in the same sample plot.

*Oncerotrachelus acuminatus* (Say, 1832). Although there are no records of this species from Canada, it now is reported from all of the states bordering the Great Lakes except Wisconsin (Fig. 5). Previously recorded from Michigan, Indiana, and Pennsylvania, this species was expected to occur in Ohio. Three specimens were collected 1-15 June 2005 (2 specimens) and 30 June - 14 July 2005 (1 specimen). No other bugs were captured with *O. acuminatus* in the same pitfall traps, although *M. serripes* and *S. rusticus* were captured in different pitfall traps during the same collection period and in the same sampling plot.
Figure 3. *Pagasa fusca fusca* distribution north of Mexico.

**Canada:** Alberta, British Columbia, Labrador, Manitoba, Newfoundland, Northwest Territories, Nova Scotia, Ontario, Quebec, Saskatchewan, Yukon,

**United States:** Arizona, California, Colorado, Idaho, Illinois, Indiana, Kansas, Louisiana, Maine, Minnesota, Mississippi, Missouri, Nebraska, Ohio, Pennsylvania, New York, South Dakota, Texas, Utah, Wisconsin.

Figure 4. *Emesaya brevipennis brevipennis* distribution north of Mexico.

**Canada:** Ontario,

**United States:** Arkansas, California, Connecticut, Florida, Georgia, Illinois, Indiana, Iowa, Kansas, Maryland, Massachusetts, Michigan, Missouri, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, Rhode Island, Texas.

Figure 5. *Oncerotrachelus acuminatus* distribution north of Mexico.

**United States:** Alabama, Delaware, Florida, Illinois, Indiana, Kansas, Maryland, Massachusetts, Michigan, Minnesota, Missouri, New Jersey, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Texas.
**Rhyparochromidae**

*Cryphula trimaculata* (Distant, 1882). This species has been reported through the mid-central United States, the Great Lakes region, and scattered locations along the eastern United States (Fig. 6) with an Arkansas record reported recently (Chordas and Kovarik, in press). Numerous specimens (102) were captured during this study and during every month from May through August. Although this bug was common in the pitfall traps in this study, the first author has not encountered it in sweep-net or beating collections from various locations throughout Ohio over the past decade.

Bugs captured with *C. trimaculata*: were *Isthmocoris piceus* (Say, 1832) (Geocoridae) and *Pseudopachybrachius basalis* (Dallas, 1852) (Rhyparochromidae). Other bugs captured in different pitfall traps during the same collection period and in the same sampling plot were: *Amonestus spinifrons* (Say, 1825) (Cydnidae), *Blissus leucopterus* (Say, 1832) (Blissidae), *C. pulicaria*, *Mormidea lugens* (Fabricius, 1775) (Pentatomidae), *M. serripes*, *P. fusca fusca*, *Phlegyas abbreviatus* (Uhler, 1876) (Pachygronthidae), *P. obscuratus*, and *S. rusticus*. Nearly half (48) of the 102 specimens were captured in unfertilized plots with plant litter removed; the remaining specimens were evenly distributed among other treatments.

*Stygnocoris rusticus* (Fallen, 1807). A non-indigenous, Palearctic species recorded from the United States in the early 1900s (Wheeler, Jr. 1983), it now is known from several northern states and across Canada (Fig. 7). It feeds on fallen seeds from composites (Asteraceae) and other plants (Sweet.
1964, Wheeler 1992), an activity that increased the likelihood of capturing them in pitfall traps. Numerous specimens (51) were captured, and S. rusticus was encountered in pitfall traps each year from June through August.

Other bugs captured with S. rusticus during the same collection period and in the same pitfall traps were: C. pulicaria, E. brevipennis brevipennis, I. piceus, M. serripes, Neopamera bilobata (Say, 1832) (Rhyparochromidae), P. basalis, and P. obscuratus. Other bugs captured with S. rusticus in other pitfall traps during the same collection period and same sampling plot were: C. trimaculata, a Nabis nymph, and O. acuminatus. Of the 51 specimens of S. rusticus, 42 were captured in sampling plots from which plant litter had been removed (23 and 19 specimens in unfertilized and fertilized plots, respectively). Given that S. rusticus feeds on fallen seeds of composites (Wheeler, Jr. 1992), and virtually all forbs (including composites) had been eliminated from all fertilized plots (Patrick et al. 2008a), it is interesting that nearly as many S. rusticus were encountered in fertilized plots (22 specimens) as unfertilized plots (29 specimens). Apparently, these bugs are utilizing various food sources.

**Thyreocoridae**

**Corimelaena pulicaria** (Germar, 1839). Although only recorded for Michigan and Pennsylvania bordering Ohio (Fig. 8), this species is common and widespread and was expected for Ohio. Our two specimens were captured during 1 - 15 July 2005. The only other bug captured with C. pulicaria in the same pitfall trap during the same collection period was S. rusticus. Other bugs captured with C. pulicaria in different pitfall traps during the same collection period and in the same sampling plot were: P. obscuratus, C. trimaculata and M. serripes.

![Figure 8. Corimelaena pulicaria distribution north of Mexico](image)

**Canada:** Alberta, British Columbia, Manitoba, Nova Scotia, Ontario, Quebec, Saskatchewan.

**United States:** Arkansas, California, Colorado, Connecticut, Florida, Georgia, Illinois, Iowa, Kansas, Louisiana, Maine, Maryland, Massachusetts, Michigan, Minnesota, Mississippi, Missouri, Nebraska, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, South Dakota, Texas, Vermont, Virginia, Wisconsin.

**ACKNOWLEDGMENTS**

We thank Tom Henry (USNM, Washington D.C.) for identifying our Pycnoderes obscuratus specimens and providing additional notes on this species, and Mark W. Kershner (Kent State University) for facilitating the mailing of specimens between the authors. We also thank the Editor, Therese Poland, and two anonymous reviewers for their helpful comments on a previous draft of this manuscript.
LITERATURE CITED


ADDITIONAL RECORDS OF SPIDERS, HARVESTMEN, MILLIPEDES, AND ISOPODS OF TOFT POINT NATURAL AREA, DOOR COUNTY, WISCONSIN

Bruce A. Snyder1,2, Michael L. Draney2

ABSTRACT

The large, non-insect arthropod fauna, spiders (Araneae), harvestmen (Opiliones), millipedes (Diplopoda), and isopods (Isopoda), of Toft Point Natural Area, Door County, Wisconsin, was intensively surveyed in a previous study, using a combination of systematic sampling and less formal collections. During 2005-2006, additional limited formal and informal collections of these taxa were completed. Systematic sampling focused on the shrub carr habitat type, which was not sampled intensively in the previous study. Herein, we report the results of these collections, which together add 16 species to the Toft Point fauna, including 13 Door County records, three of which are also new state records. Two spider families, Theridiosomatidae and Anyphaenidae, are reported from Toft Point for the first time. Although the number of spider species reported from Toft Point has exceeded our estimate of 100 (Snyder et al. 2004), the high proportion of new records from this minimal sampling effort suggests that additional sampling at this diverse location will yield many more species.

Methods & Materials

All specimens reported here have been deposited in the collections of the authors. The junior author identified all Araneae and Opiliones, and the senior author identified all Diplopoda and Isopoda.

Systematic sampling: We spent part of one day (27 July 2006) collecting systematically in two habitats at Toft Point: 1) shrub carr, a habitat known to harbor a diverse arthropod assemblage (Draney, unpublished data), yet was not intensively sampled in Snyder et al. (2004), and 2) open sedge mat, a habitat that yielded many interesting taxa in the preliminary survey and which we...
wanted to sample more intensively. At each habitat, we collected four 4-liter canvas geology bags of leaf litter/sphagnum moss, attempting to access all visible microhabitats, vegetation patches, and terrain positions. This litter was extracted in Berlese funnels for three days in the lab following the protocol of Snyder et al. (2004).

**Additional sampling:** On 27 July 2006, we also conducted sweepnet sampling at the open sedge mat habitat for 0.5 person-hours, and a few additional specimens were collected when encountered at other habitats on this date. Additionally, we took advantage of a limited amount of invertebrate collecting done for various purposes since the publication of Snyder et al. (2004). These were:

On 8 June 2005, UW-Green Bay student Jenna King took a photo at Toft Point, which the junior author identified as the fishing spider *Dolomedes triton* Walckenaer (Araneae: Pisauridae). Photos are often insufficient for determining these invertebrates to the species level, but this species is distinctive enough to constitute an exception.

The junior author did a small amount of collecting while leading a field trip to the site on 16 July 2005.

On 28 August 2005, UW-Green Bay student Nick G. Walton collected a number of invertebrates at Toft Point (with the permission of UW-Green Bay) in order to complete a class project.

On 9 September 2006, the junior author lead a “spider foray” at the site as a program for the Friends of Toft Point, and any specimens deemed potentially interesting by the junior author were collected for later identification. In addition to sampling natural areas such as the cobble beach, old fields, and several forest types, significant time was spent searching for spiders around the exteriors of several abandoned buildings on the site, which have remained unoccupied for several decades.

**RESULTS**

**Isopoda:** Systematic sampling yielded only four isopod specimens. These represented a new habitat for *Trachelipus rathkei* (Brandt) (Trachelipidae), a species already known from Toft Point (Table 1).

**Diplopoda:** In the preliminary survey (Snyder et al. 2004), one millipede species was determined to genus but could not be assigned to a particular species because no adult male individuals were collected. Millipede male copulatory organs (gonopods) are only fully developed in the adult form, and have been regarded for the past century as one of millipedes’ most valuable identifying characters (Sierwald and Bond 2007). Because of this, collections can rarely be determined to the species level without the presence of adult males.

During additional collecting, one adult male millipede was collected in the open sedge mat habitat, and was determined to be *Pseudopolydesmus serratus* (Say) (Polydesmidae). This is the only species of this genus known in this region; *P. serratus* occupies a range bounded by Minnesota, the Gaspé Peninsula of Quebec, North Carolina, and Mississippi (Hoffman 1999). *P. serratus* should therefore be considered a new county record, rather than a new state record as was listed in the preliminary survey (Snyder et al. 2004).

Systematic sampling added three species to the fauna of the shrub carr habitat type (Table 1). One of these species is reported for the first time from Door County: *Scytonotus granulatus* (Say) (Polydesmidae) was collected by systematic sampling in both shrub carr and open sedge mat habitats. This species has been previously reported from Wisconsin (Shelley 1993, Snyder et al. 2006). The addition of *S. granulatus* represents a 25% increase in the known Toft Point millipede fauna, a sizeable increase relative to the effort expended.
Opiliones: The additional collecting yielded three species of harvestmen belonging to two families (Table 1). One species, *Leiobunum verrucosum* (Wood) (Sclerosomatidae), represents a new county and Toft Point record. The other two species were collected previously, but were each found in Toft Point habitats from which they had not been previously collected.

Araneae: The additional collecting yielded 30 species of spiders from 11 families (Table 1). Fourteen of the species (46%) had not previously been collected at Toft Point, and we collected 11 of the 16 repeat species in a habitat they were not previously reported from in Toft Point. Only 5 species (17%) were collected solely from previously reported habitats, and thus do not represent new biogeographic information. Eleven species (36%) had not previously been reported from Door County, and of these, three species (10% of the new collection) were new state records:

The linyphiid *Ceraticelus bulbosus* (Emerton) is a holarctic species known from northern Europe through Siberia and Alaska to Newfoundland, and has been recorded from the northern states of Washington, Michigan, Connecticut, Maine, and New York. One male was collected from open sedge mat litter extraction.

The linyphiid *Scironis tarsalis* (Emerton) is known from Alaska to Newfoundland as well as the northern states of Washington, Michigan, Maine, New Hampshire, New York, and Vermont. One female was collected from shrub carr litter extraction. It has recently also been collected from Cedarburg Bog in Ozaukee County, Wisconsin (Draney unpublished data).

The corinnid *Scotinella pugnata* (Emerton) has been collected from Alberta, Ontario, Colorado, Montana, and New Hampshire (Shorthouse 2008). Three males and one female were collected from shrub carr litter extraction.

Note that all three new state records were collected by Berlese extraction of leaf litter/sphagnum moss. Finally, a single female of an additional linyphiid species that we are currently unable to identify was collected by this method in shrub carr. This individual is not included in Table 1 or the species counts.

DISCUSSION

As was apparent in Snyder et al. (2004), the litter collection/Berlese extraction method samples a set of species almost completely distinct from that accessible to the various hand-collecting methods. In the present study, only the harvestmen *Odiellus pictus* (Wood) (Phalangiidae) and the millipede *P. serratus* were collected in the litter samples and by another method. Among the spiders, 13 species were collected in the two litter samples, and 17 species were collected by other methods. Seven of the 13 new county records were from litter sample extractions, including all three new state records.

Few studies in this region have considered the millipede fauna and although the Toft Point fauna is depauperate relative to similarly-sized locations in other regions of North America (e.g., the southern Appalachian Mountains), we expect additional millipede species to be recorded here. Specifically, *Narceus annularis* (Rafinesque) (Spirobolidae) has been reported in unpublished studies (see Snyder et al. 2004), but has not been collected at Toft Point a second time. *Pleuroloma flavipes* Rafinesque (Xystodesmidae) is known from most of Wisconsin, except the northeast portion (Shelley 1979), and the mild climate at Toft Point should be favorable to this species. Wisconsin falls in the middle of the range for *Oriulus venustus* Chamberlin (Parajulidae); it has been reported in Wisconsin north (Vilas County) and south (Ozaukee County) of Toft Point, and near the Lake Michigan shore in the state of Michigan (Shelley 2002).

Two spider families are newly recorded here from Toft Point (Theridiosomatidae, Table 1, and Anyphaenidae) bringing the total number of spider
Table 1. Additional arthropod records for Toft Point Natural Area.

<table>
<thead>
<tr>
<th>Class/Order/Family</th>
<th>Species</th>
<th>Habitats</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Isopoda</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trachelipidae</td>
<td><em>Trachelipus rathkei</em> (Brandt)</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td><strong>Diplopoda</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polydesmidae</td>
<td><em>Pseudopolydesmus serratus</em> (Say)</td>
<td>OS, SC†</td>
<td>A1, L‡</td>
</tr>
<tr>
<td></td>
<td><em>Scytonotus granulatus</em> (Say)*</td>
<td>OS, SC</td>
<td>L</td>
</tr>
<tr>
<td>Cleidogonidae</td>
<td><em>Cleidogona celerita</em> Williams and Hefner</td>
<td>OS, SC</td>
<td>L</td>
</tr>
<tr>
<td><strong>Julidae</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>Ophyiulus pilosus</em> (Newport)</td>
<td>OS</td>
<td>L</td>
</tr>
<tr>
<td><strong>Opiliones</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phalangiidae</td>
<td><em>Odiellus pictus</em> (Wood)</td>
<td>SC, UC</td>
<td>A2, L</td>
</tr>
<tr>
<td></td>
<td><em>Phalangium opilio</em> L.</td>
<td>UC (and UC trail)</td>
<td>A3, A1</td>
</tr>
<tr>
<td>Sclerosomatidae</td>
<td><em>Leiobunum verrucosum</em> (Wood)*</td>
<td>UC</td>
<td>A1</td>
</tr>
<tr>
<td><strong>Araneae</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Araneidae</td>
<td><em>Acanthepeira stellata</em> (Wackenaer)</td>
<td>OF</td>
<td>A2 (sweepnet)</td>
</tr>
<tr>
<td></td>
<td><em>Araneus nordmanni</em> (Thorell)*</td>
<td>UC</td>
<td>A1</td>
</tr>
<tr>
<td></td>
<td><em>Cyclosa conica</em> (Pallas)</td>
<td>UC (trail)</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td><em>Larinioidea cornutus</em> (Clerck)</td>
<td>SM</td>
<td>A3 (sweepnet)</td>
</tr>
<tr>
<td></td>
<td><em>Mangora gibberosa</em> (Hentz)</td>
<td>OS</td>
<td>A1 (sweepnet)</td>
</tr>
<tr>
<td>Corinnidae</td>
<td><em>Castianeira descripta</em> (Hentz)</td>
<td>CB</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td><em>Scotinella pugnata</em> (Emerton)**</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td>Gnaphosidae</td>
<td><em>Zelotes fratris</em> Chamberlin</td>
<td>UC (trail)</td>
<td>A3</td>
</tr>
<tr>
<td>Hahniidae</td>
<td><em>Antistea brunnea</em> (Emerton)</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td>Linyphiidae</td>
<td><em>Ceraticelus bulbosus</em> (Emerton)**</td>
<td>OS</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Cheniseo fabulosa</em> Bishop &amp; Crosby</td>
<td>OS, SC</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Erigone atra</em> Blackwall</td>
<td>CB</td>
<td>A3</td>
</tr>
<tr>
<td></td>
<td><em>Glyphesis idahoanus</em> (Chamberlin)</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Grammonota gigas</em> (Banks)</td>
<td>OS</td>
<td>L</td>
</tr>
</tbody>
</table>
### Table 1. Continued.

<table>
<thead>
<tr>
<th>Class/Order/Family</th>
<th>Species</th>
<th>Habitats</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philodromidae</td>
<td><em>Maso sundevalli</em> (Westring)</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Pocadicnemis americana</em> Millidge</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Scironis tarsalis</em> (Emerton)**</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td>Pisauridae</td>
<td><em>Thanatus formicinus</em> (Clerck)*</td>
<td>SC</td>
<td>A4 (under rock)</td>
</tr>
<tr>
<td>Salticidae</td>
<td><em>Dolomedes triton</em> Walckenaer*</td>
<td>?</td>
<td>A5</td>
</tr>
<tr>
<td></td>
<td><em>Eris militaris</em> (Hentz)</td>
<td>CB, OF</td>
<td>A1 (sweepnet)</td>
</tr>
<tr>
<td></td>
<td><em>Phidippus clarus</em> Keyserling</td>
<td>OS</td>
<td>A1 (sweepnet)</td>
</tr>
<tr>
<td></td>
<td><em>Sitticus striatus</em> Emerton*</td>
<td>OS</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Synageles occidentalis</em> Cutler*</td>
<td>OS</td>
<td>A1 (sweepnet)</td>
</tr>
<tr>
<td>Tetragnathidae</td>
<td><em>Leucauge venusta</em> (Walckenaer)</td>
<td>UC (trail)</td>
<td>A4</td>
</tr>
<tr>
<td></td>
<td><em>Tetragnatha extensa</em> (L.)</td>
<td>“scrub”</td>
<td>A4 (sweepnet)</td>
</tr>
<tr>
<td></td>
<td><em>Tetragnatha pallescens</em> O. P. -C.</td>
<td>SC</td>
<td>A4 (sweepnet)</td>
</tr>
<tr>
<td>Theridiidae</td>
<td><em>Robertus longipalpus</em> (Kaston)*</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td>Theridiosomatidae</td>
<td><em>Theridiosoma gemmosum</em> (L. Koch)*</td>
<td>SC</td>
<td>L</td>
</tr>
<tr>
<td>Thomisidae</td>
<td><em>Ozyptila distans</em> Dondale &amp; Redner</td>
<td>OS</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td><em>Xysticus emertonii</em> Keyserling*</td>
<td>SM</td>
<td>A3 (sweepnet)</td>
</tr>
</tbody>
</table>

*= New Door County Record (Araneae according to J. Jass, Milwaukee Public Museum, unpublished data compilation; Diplopoda according to Shelley 1993); **= New Wisconsin State Record (According to Sierwald et al. 2005); ‡= no adult males present to confirm specific determination.

Species in **bold** are new Toft Point records; **Underlined** habitats represent new habitat records of species reported from Toft Point by Snyder et al. (2004).

Habitats (for further information, refer to Snyder et al. 2004): CB-Cobble Beach; OS-Open Sedge Mat; OF-Old Field; SC-Shrub Carr; SM-Sedge Meadow; UC-Upland Conifer Woods.

families from Toft Point to 19. Anyphaenidae was represented by an *Anyphaena* sp. immature from 9 Sept. 2006, old field sweep behind Toft House (not in Table 1). The species list has increased from 113 to 127. Spiders new to Wisconsin made up 12.4% of the original list (14 of 113 species), and 10% of the new list (3 of 30 species). This shows that the rate of new species accumulation has not slowed, and many more species (including, presumably, species not presently known from Wisconsin) will be found to occur at Toft Point.

Of some interest in lists such as these is the species that are not found. One example is the bridge spider, *Larinioides sclopetarius* (Clerck) (Araneidae). Introduced from Eurasia, it is presently the most common orb-weaver on buildings throughout Wisconsin (Draney, personal observation). Although we thoroughly searched for spiders in and around the abandoned buildings at Toft Point, we collected only its congener, *L. cornutus* (Clerck), a species normally found away from buildings. It is possible that the Toft buildings are too far away from other habitations to be readily colonized without human transportation, and were abandoned before *L. sclopetarius* was introduced or became common in Wisconsin.

**ACKNOWLEDGMENTS**

We thank J. King, N. G. Walton, and the participants of the Friends of Toft Point spider foray for providing additional specimens for us. We thank J. Jass, Milwaukee Public Museum, for providing her unpublished compilation of Wisconsin county records for Araneae and K. Hyland, G. Albers, and P. Hendrix for their support. We would also like to thank the Friends of Toft Point for their continuing excellent efforts towards managing this biologically significant site. Finally, we thank two anonymous reviewers for their constructive comments.

**REFERENCES**


BIOLOGICAL NOTES ON THREE NEWLY REPORTED LEAF MINERS OF CACALIA ATRIPICIFOLIA IN MICHIGAN

Ronald J. Priest

ABSTRACT

A stand of Cacalia atriplicifolia was surveyed for seven years in Clare County, Michigan, to determine leaf mining species present, mine characteristics, parasitoids, and seasonal occurrence. Three species were recovered: Trypeta flaveola Coquillett (Diptera: Tephritidae), Phyllocnistis insignis (Frey & Boll) (Lepidoptera: Gracillariidae), and Dichrorampha incanana (Clemens) (Lepidoptera: Tortricidae). One parasitoid, Utetes sp. (Hymenoptera: Braconidae) was recovered from T. flaveola. This plant is a newly reported larval host for each of these species and the first reported larval host of D. incanana. Leaf mine characteristics and life histories of these three species are discussed.

Leaf mining insects present an excellent opportunity to study larval habits, parasitoids, and seasonal occurrence all within the confines of a single leaf. Needham et al. (1928) reviewed much of the known information for the four orders with leaf miners: Coleoptera, Diptera, Hymenoptera, and Lepidoptera. Robinson et al. (2002) listed host plants for caterpillars of America North of Mexico. More recently De Prins and De Prins (2005) provided host records, parasitoids, and distributions of Gracillariidae worldwide. Han and Norrbom (2005) provided host records in their revision of New World species of the genus Trypeta. These works, however, do not record the larval host for the species reported here.

I discovered a stand of Cacalia atriplicifolia, in Clare County, Michigan, T18N-R03W, Section 13 nw/nw one county northeast of its previously known Michigan range (Voss 1996). This plant ranges throughout eastern United States, west, and south to Oklahoma (Anderson 2006). In Michigan this magnificent herbaceous plant reaches its northern limit in the southern half of the Lower Peninsula. This plant has an erect 2.5 m flowering stem. Leaves are thick, very succulent, and up to 15 cm wide. When a prairie associate, C. atriplicifolia it occurs with fewer than 6 plants, at least at other Michigan sites I have visited. At this 20-acre sandy site, however, it is co-dominant with Centaurea maculosa, Comptonia peregrina, and Solidago junceo.

I report here, life history notes and leaf mine characteristics of the three leaf mining species found: Trypeta flaveola Coquillett (Diptera: Tephritidae), Phyllocnistis insignis (Frey & Boll) (Lepidoptera: Gracillariidae), Dichrorampha incanana (Clemens) (Lepidoptera: Tortricidae), and one parasitoid, Utetes sp. (Hymenoptera: Braconidae), reared from T. flaveola. This plant is a newly reported larval host for each of these miners and the first reported larval host for D. incanana.

MATERIALS AND METHODS

Seventeen field surveys were made between 31 August 2001 and 16 July 2007. Active miners were obtained on 11 of these surveys. Three visits preceded
and one succeeded host plant presence to determine limits of mining activity. The first survey consisted of a walk through the entire stand to determine if, and then where, areas of leaf miners occurred. Subsequent surveys focused observations there. On each visit representative specimens were recovered when located. Leaves of each putative species were placed into separate quart-sized Ziploc® freezer bags. This brand and style of plastic bag is both clear and thicker than other brands I've tried. They allow easy visibility of larvae within and inhibit water vapor escape thus extending host leaf palatability and larval life longer than other bags.

After each visit, each leaf was placed in a separate freezer bag and held at ambient temperature, indoors, for larvae to complete feeding. Representative larvae were killed in hot water, about 88°C and preserved in 80% ethanol. Some larvae were photographed (Priest 2007) while mining. Vacated mined leaves were pressed then placed separately in 3x5 inch glassine envelopes with a data card. As T. flaveola larvae exited their mines and pupated, they were placed in separate vented glass vials of approximately 20 ml capacity containing a layer of clean moist sand. P. insignis were maintained in individual freezer bags for adult issue. When D. incanana exited their mines they were placed singly in vented 20 ml vials with a piece of folded paper toweling to serve as a pupation site. Vials were then placed in 1-gallon plastic boxes with slightly moistened paper toweling and sealed with a tight fitting lid.

Mines not producing adults by November were wintered by placing vials in their boxes in an unheated garage. They were checked weekly for adequate moisture. In mid-February boxes were brought indoors to induce adult emergence. Vials were examined daily. When emergence was observed, adults were retained alive 24 hours prior to preserving. Pupal skins were mounted with their associated adults. Adult parasitoids were mounted according to Noyes (1982).

Most larvae, adults, parasitoids, and preserved mines are deposited in the A. J. Cook Arthropod Research Collection, Michigan State University. A few specimens of T. flaveola were retained by B. Foote and some deposited in the U. S. National Museum. The male D. incanana is in the collection of M. Sabourin. Botanical nomenclature follows Voss (1985, 1996).

RESULTS AND DISCUSSION

Mines were found only on shaded leaves. Pinus strobus and Rhus typhina provided overstory shade. Three leaf mining species were encountered on C. atriplicifolia: T. flaveola, P. insignis, and D. incanana. In addition, several specimens of, Utetes sp. (Hymenoptera: Braconidae), were recovered from T. flaveola. Adults of none of these species were observed in the field.

Trypeta flaveola Coquillett

Larvae of this species were recovered on nine of 17 surveys with adults issuing from eight of the nine rearings. One to several mines per leaf were frequently seen. T. flaveola was the most common miner at this site both in individuals observed and leaf area mined. Mines were observed on most leaves fully shaded with some leaves nearly completely mined especially during late summer. Mine. Early season mines, more clearly differentiated than later ones, have only one miner. The completed mine is a wide branched track made in an irregular undulating pattern from one leaf surface to the other and back again. The mine perimeters are pale yellow-green with the interior dirty green. Frass is deposited as irregular black particles in a discontinuous trail along its midline (Fig. 1). Larvae make a herringbone pattern similar to Frick’s (1971) description of T. angustigena Foote (now a junior synonym of T. flaveola, Han and Norrbom 2005). Larva. Last instar larvae are entirely light yellow except for black mouth hooks. Larvae can exit one mine and initiate another. This
was evident after opening some mines of near fully developed larvae and finding the mined areas too small for the larvae to have developed from egg to maturity there. This larval ability was also mentioned by Frick (1971). Last instar larvae exit their mines to pupate, presumably in the soil. **Pupa.** Pupae are pale yellow, circular in cross section, approximately 4.3 × 2.0 mm. **Seasonal Occurrence.** (Fig. 2) Larvae recovered early to late June emerged as adults from early to late July. Those recovered in late August emerged from early to mid-September. Larvae recovered in September, however, wintered as pupae emerging the following spring.

The only discussion of multiple generations for this species is Frick (1971). There appears to be five generations per year in California. From this study, it appears *T. flaveola* has two generations (Fig. 2). *C. atripilicifolia* is a newly documented larval host for this fly though other reported hosts include six other genera of Asteraceae (Frick and Hawkes 1970, Frick 1971). **Parasitoid.** *Utetes* sp. was recovered from puparia of four rearings. Only one parasitoid emerged per puparium. Their emergence occurred over the same time period as *T. flaveola* with the last parasitoids appearing no more than three days after the last fly issued. *Utetes* sp. is closely synchronous with *T. flaveola* and has two generations per year at this site (Fig. 2). According to Kula (personal communication) this is the first known species of *Utetes* parasitizing a non-fruit boring tephritid. No parasitoids were recovered from wintered puparia.

**Phyllocnistis insignis** (Frey & Boll)

Larvae were recovered on five of 17 surveys with adults issuing from each recovery. One to five mines per leaf were seen though larvae are solitary miners.

**Mine.** (Fig. 3) The mine is an upper surface linear track that may wander over much of the leaf. The width just accommodates the larva and is widened as the larva grows. No frass is visible in the smallest portions of the mines. By
second or early third instar (there are only three feeding instars in *Phyllocnistis* spp., the fourth is non-feeding, Davis 1987) black frass is visible as very thin intermittent lines against one or both mine perimeters. By late third instar, frass lines are more apparent on both sides of mines with occasional frass segments deposited interiorly. **Larva.** Feeding larvae are pale yellow. The third instar widens the mine terminus usually located at an interior portion of the leaf. **Pupation.** The mine sides are drawn together forming a pouch-like cocoon area with one to two upper surface wrinkles. Larvae face either basally or apically to pupate. The cocoon is approximately 4.0 - 4.3 × 1.5 mm, initially white and later turning brown. Upon emergence pupal skins are partially extended through the cocoon and upper leaf surface. Frass deposition, pupation location, and position of this larva contrast markedly from another Michigan *Phyllocnistis* species, *P. populiella* Chambers, mining *Populus tremuloides* Michaux. That species deposits its frass in a thin central more-or-less continuous line throughout its mine and usually constructs its cocoon at the leaf margin with, “the head facing away from the mine”, (Condrashoff 1964). **Seasonal occurrence.** Though few adults were recovered in this study, it appears there may be three generations per year (Fig. 4). All adults issued by fall. Since the above ground host plant dies by November and egg are deposited on leaves (Davis 1987), this species winters as adults. **Parasitoid.** None reared.

***Dichrorampha incanana*** (Clemens)

I collected caterpillars twice, both times in late August 2001 and 2002. Each time 5 larvae were obtained. This is the first published larval host for this tortricid (John Brown, personal communication). **Mine.** The mine begins as a lower surface linear track along a vein. Later it is widened into a full-depth
irregular blotch mine (Fig 5). The initial linear track is used as a retreat when disturbed. Frass produced is black, deposited in clusters at the mine perimeter, and scattered as expansion of the blotch occurs. **Larva.** Last instar larvae are pale yellow with tan heads and lighter prothoracic shields. Feeding is in the usual dorsal side up position. Larvae exit mines from late August to late September to pupate, presumably, in the soil. **Adult.** Two adults were recovered, a female that emerged on 2 October 2002 and a male in 2003 after wintering. **Seasonal occurrence.** Though voltinism can not be determined from this study, some inference may be made by combining these data with Miller’s (1987) adult recovery records. He lists Michigan and Wisconsin recovery dates as 17-19 July indicating one generation per year. Adult emergence reported in this study of early October and spring, suggests a second generation in the north-central states. **Parasitoid.** None reared.

From my observations, leaf miners generally seem unable to tolerate full sun exposure particularly in the summer and require shading for their full development. That *C. atriplicifolia* usually grows in full sun may explain in part why miners reported here have not been previously reported from this host. Larvae were recovered partially grown. To show a full life cycle, the bars in Figs. 2 and 4 would be extended by about one or two thirds of a month earlier than shown. The number of generations suggested from this data are tempered by the dearth of specimens recovered and lack of more evenly spaced surveys. I visited seven sites in five southwest Lower Peninsula counties where *C. atriplicifolia* had been documented. At only one, in Cass County, were mines observed. *P. insignis* miners had died prior to fully developing. It is significant though that all data reported here was obtained from a single site and host, not disparate sites and multiple hosts, reflecting one deme per species.

Fig. 3. Fully grown *Phyllocnistis insignis* miner. Thin frass lines against the mine perimeters and expansion of the mine terminus in preparation for cocoon building are visible.
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Fig. 4. *Phyllocnistis insignis* rearings. Left ends of bars are the third of the month larvae were recovered while the right ends are adult emergence times. The numbers within each bar are adults recovered. Zeros outside the bars are visits without live larvae seen.


Fig. 5. Two feeding *Dichrorampha incanana* larvae. The black frass contrasts against the full-depth mines.


REMARKS ON THE RARELY COLLECTED HEMIPTERAN CERATOCOMBUS VAGANS McATEE AND MALLOCH (HEMIPTERA: CERATOCOMBIDAE)

Stephen W. Taber¹

ABSTRACT

The rarely collected hemipteran Ceratocombus vagans McAtee and Malloch was found in west-central Michigan. Though no alternative identification is possible among currently recognized species of its family, the males do not satisfy the family and genus requirements of most standard keys used to identify hemipterans, nor do they satisfy the diagnoses for the species itself. If the material is correctly determined, keys and diagnoses should be altered accordingly. Illustrations are supplied toward this end, as no suitable photographs of C. vagans were found in the peer-reviewed literature.

The true bugs of the small hemipteran infraorder Dipsocoromorpha are among the smallest and most rarely collected members of their order in North America. Current classification allows for the northeastern United States a single member of the dipsocoromorphan family Ceratocombidae, the tiny Ceratocombus vagans McAtee and Malloch (1-1.7 mm) and only three additional species in the family for all of the continental United States and Canada (Henry 1988). These bugs are believed to be highly generalized, presumably primitive, and of a predatory type that branched off early in hemipteran evolution, perhaps closely following the origin of the gnat bug infraorder Enicocephalomorpha that is the sister group to the rest of Hemiptera (Schuh and Slater 1995, Lattin 2000). Though considered rare and even quite rare (Borror and White 1970, Triplehorn and Johnson 2005), dipsocoromorphan species such as Ceratocombus vagans perhaps are at least locally abundant and simply not apparent to the collector due to their small sizes of approximately 1-2 mm length (Blatchley 1926) and their secluded way of life.

The Michigan material treated here was retrieved on 13 July 2008, in Newaygo County, Michigan, in an area known on maps as “Oxford Swamp,” from leaf litter and duff, mostly the previous season’s dry leaves of oak and red maple (Acer rubrum L.), collected at the base of a large black oak that probably was Quercus velutina Lamarck though the living leaves were too high above ground to make a positive identification. The habitat was lowland deciduous forest consisting mostly of the two trees listed above but also paper birch (Betula papyrifera Marshall) and wild black cherry (Prunus serotina Ehrhart). Both marsh and swamp lay within 50 m of the shaded, forested collection site, making the habitat of the moist and mesic type favored by these insects (Blatchley 1926, Schuh and Slater 1995, Lattin 2000).

The organic material was packed into plastic bags in the field, returned to the laboratory, and distributed among several Berlese funnels with hardware cloth placed between the litter and the collecting vial attached to the tip of the funnel below. The preservative in the vials was FAAG prepared according to a formula recommended for the preservation of soft-bodied forms such as insect

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larvae and found superior to 80% ethanol for this work (Ward’s 1978). Two adult males of the type described in the literature as “micropterous” (Lattin 2000) or perhaps better as “brachypterous”, one adult female of the same wing condition, and one fifth-instar were recovered in the berlesate, which was taken from the funnels and processed four months after the funnels were loaded (Figs. 1-3). These voucher specimens have been deposited in the entomology collection at Saginaw Valley State University, University Center, Michigan.

The arthropod community in which the bugs lived included carabid beetles; ponerine, myrmicine, and dolichoderine ants; midges; spiders; several specimens of the diminutive lygaeid Antillocoris pilosulus (Stål); various beetle larvae including numerous individuals that were each encased in a dark, frass-like, and probably frass-containing covering, suggesting that they were chrysomelids; and numerous mites and collombolans. Collembolans are among the foods of Ceratocombus vagans, which subdues its quarry much as a rattlesnake does, by piercing its prey with a quick jab, releasing, and waiting for the toxin’s effect before returning to take its meal (Lattin 2000).

The primary motivation for this contribution is the morphological character visible in a dorsal view of one of the two adult males (Fig. 1). By casual inspection, the anterior width of the scutellum is clearly not greater than one half the width of the anteriorly adjacent posterior margin of the pronotum. In fact, by precise measurement the width of the scutellum was found to be equal to 0.45 the width of the pronotal margin. Yet according to a genus-level key (Blatchley 1926, p. 647) and a family-level key (Slater and Baranowski 1978, p. 23), this number should be greater than 0.5. The extent of the expected condition is illustrated by the latter reference for the species Leptonannus latipennis (Uhler) (p. 207, Fig. 419), for which the anterior scutellum width is remarkably greater than one half of the adjacent pronotum width, and for a species which the authors believed might be synonymous with C. vagans. The adult Michigan female shown here also exemplifies the expected condition (Fig. 2). Again, it appears to be the condition shown in a small color photograph in a recent guide to eastern North American insects (Marshall 2006, p. 132, Fig. 6). A line drawing of a female Ceratocombus mareki Stys from Madagascar does feature a scutellum width greater than one half the width of the pronotum (Stys 1977, p. 304; 1995, p. 76) but that author was unsure of the usefulness of the scutellum character (Pavel Štys, pers. comm. 2008). Anyone who attempts to identify the material found in west-central Michigan using available keys will be faced with contradiction if these bugs truly are C. vagans.

A second problematic feature is found on the costa of the forewing, a “fracture” required for Ceratocombidae regardless of the wing condition in a family-level key (Triplehorn and Johnson 2005, p. 276), and in several illustrations for the condition of C. vagans itself (Blatchley 1926, p. 648; Slater and Baranowski 1978, p. 206 for C. vagans and p. 207 for L. latipennis; Lattin 2000, p. 137). In all illustrations, the condition is obvious and does appear to indicate a fracture cutting entirely through the costa at approximately the midpoint of its length, but when Michigan males are viewed at 90× with a Bausch & Lomb zoom stereomicroscope, no fracture or indication thereof was visible on the costa of intact specimens. This feature was quickly noticed on the female, which also bears the wide scutellum expected for C. vagans, so that one sex possesses the two key characters, whereas the other does not possess one of these and seems not to possess the other. Only by removing a male wing was something even suggesting a fracture visible. When I examined the wing photographed in Euparal mounting medium on a microscope slide with a cover slip and at a magnification of 125×, a faded region of the costa became visible when the lighting was manipulated (Figs. 4-5). Even then the condition does not look as strong as published illustrations suggest and seems more like a
Figure 1. *Ceratocombus vagans*. Brachypterous male.

Figure 2. *Ceratocombus vagans*. Brachypterous female.
Figure 3. *Ceratocombus vagans*. Fifth instar.

Fig. 4. Right wing of brachypterous male *Ceratocombus vagans*. Photographed with false phase contrast illumination at 125×. The region expected to show the costa fracture is circled.
lightened area than a fracture. Freshly collected specimens have numerous long setae on the forewings that were lost in the preparation process of the example shown here because the male was originally pointed dry on a pin.

Even when not dried before manipulation, these extremely delicate, tiny hemipterans must be handled with great care. Both adult specimens shown here were eventually damaged during attempts to provide the best photographs possible despite their continuous preservation in FAAG without being dried at any point. The long and threadlike antennae are particularly susceptible to breakage and the pronotum of one specimen was pierced accidentally by the tip of the fine-tipped forceps that are necessary when handling such diminutive insects.

Additional specimens will be collected in 2009. It already appears, however, that keys to North American hemipteran families and genera should be revised to accommodate the contradiction of the scutellar character emphasized here, whether or not the material represents a new species or a case of previously unrecognized sexual dimorphism in *C. vagans*.

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LITERATURE CITED


The adventive European cantharid beetle, *Rhagonycha fulva* is recorded from the continental United States for the first time. A single adult was collected from a beating sheet while sampling an *Aesculus* sp. tree in southeastern Wisconsin on 6 August 2004. Additional specimens were collected from flowers of *Achillea millefolium* on 16 and 28 July 2005. The tachinid, *Strongygaster triangulifera* is reported as a parasitoid of *R. fulva*.

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*Rhagonycha* Eschscholtz (Coleoptera: Cantharidae) is largely Holarctic in distribution; 46 species are known from America North of Mexico (Ramsdale 2002). Adults are readily hand collected or taken while beating or sweeping flowers and foliage where they are typically found aggregating in large numbers. *Rhagonycha fulva* (Scopoli), commonly known as the “hogweed bonking beetle” is native to the western Palearctic. Jackson and Crowson (1969) surmised this species (as *Rhagonycha ustata* Gemminger) is both phytophagous and predaceous, consuming the fluids and softer tissues of their prey as well as floral nectar.

On 6 August 2004, a single adult of *R. fulva* (Fig. 1) was beaten from an *Aesculus* sp. tree in Doctors Park, Fox Point, Milwaukee, Wisconsin. Additional specimens were collected at the Schlitz Audubon Nature Center, 618 meters northeast of Doctors Park, on 16 July 2005 (seven specimens) and on 28 July 2005 (three specimens). Specimens collected in 2005 were observed copulating and feeding on inflorescences of a clone of *Achillea millefolium* Linnaeus. Both Doctors Park and Schlitz Audubon Nature Center are located along Lake Michigan’s southwestern shoreline.

The three specimens collected on 28 July were brought back to the laboratory alive where they were housed, individually. Two puparia of the tachinid parasitoid, *Strongygaster triangulifera* (Loew), were extracted from a single specimen; a second specimen yielded a single puparium between 30 July and 1 August. The third specimen did not yield any parasitoids. A single adult tachinid emerged 11 August 2005 from one of the three puparia. The other two puparia were held over the winter, but no additional tachinids emerged the following year. *Strongygaster triangulifera* is a known parasitoid of adult Coleoptera [Tenebrionidae, Coccinellidae, Chrysomelidae, Curculionidae] (Sabrosky and Arnaud, Jr. 1965; Arnaud, Jr. 1978; as *Hyalomyodes triangulifera*). The single specimen of *R. fulva* collected on 6 August 2004 is deposited in the personal collection of Alistair S. Ramsdale. Ten specimens of *R. fulva* as well as puparia and a single adult specimen of *S. triangulifera* are vouchered in the Insect Research Collection (IRCW) of the Department of Entomology, University of Wisconsin-Madison.
Green (1940) reported specimens of *R. fulva* (as *Cantharis fulvus* Scopoli) from “Tex,” although he considered the record doubtful, cautioning that until others were collected its occurrence should remain uncertain. Brown (1950) and Hicks (1955) reported *R. fulva* as abundant in British Columbia. Brown (1950) also discussed the possibility that materials used historically in ship ballast were a source of introduction for many European insects into the Maritime Provinces. Similar logic could perhaps also explain the Wisconsin (Great Lakes) and British Columbia (Pacific Ocean) disjuncts in the known range of *R. fulva*.

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