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Observations on the Biological Control Agents of the American Plum Borer (Lepidoptera: Pyralidae) In Michigan Cherry and Plum Orchards

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Abstract

The American plum borer, *Euzophera semifuneralis* (Walker) (Lepidoptera: Pyralidae), is an important pest in orchards, yet little is known regarding its biological control. We performed a comprehensive survey of the natural enemy complex contributing to American plum borer control in Michigan plum and cherry orchards, while also exploring the relationship between pest infestation and tree wounding from mechanical harvesting. We scouted 30 orchards with varying degrees of tree wounding to document extent of infestations of American plum borer and another pest, the lesser peach borer, *Synanthedon pictipes* (Grote and Robinson) (Lepidoptera: Sessiidae). We simultaneously recorded biological control agents, including the presence of a *Hirsutella* fungal pathogen. Live American plum borer larvae and pupae were collected for rearing and identifying hymenopteran parasitoids. American plum borer infestations were highest in orchards with high levels of tree wounding, or in orchards that used minimum pesticides or were abandoned. Numerous organisms were documented as biological control agents including various species of birds, spiders, beetles, and ants. Ichneumon wasps were the dominant parasitoids, of which *Venturia nigricoxalis* (Cushman) (Hymenoptera: Ichneumonidae) was the most common. *Liotryphon variatipes* (Provancher) (Hymenoptera: Ichneumonidae) was commonly reared from a closely associated sessiid pest, but not from American plum borer. *Hirsutella* was commonly found and had a density-dependent relationship with American plum borer infestations. Our information gathered on the natural enemy complex of *E. semifuneralis* includes many new host associations and can serve as a starting point for developing biological control programs for fruit orchards in the Great Lakes region.

The American plum borer, *Euzophera semifuneralis* (Walker) (Lepidoptera: Pyralidae), has been considered the most important indirect insect pest of Michigan plum and cherry orchards since the mid 1970s (Brunner and Howitt 1981, Biddinger 1989). It is also an important pest of tart cherries in Pennsylvania (Biddinger and Hull 1994), New York (Kain and Agnello 1999), and Wisconsin (Weiner and Norris 1983), and a minor pest of almonds (Van Steenwyk et al. 1986), pecans (Pierce and Nickels 1941), olives (Essig 1917), and in the burr knots of clonal apple rootstocks (Kain et al. 2004). Although found throughout most of the U.S. and parts of Canada and Mexico and possessing a wide host range that includes 15 plant families (Biddinger and Howitt 1992), very little is known about the biological control of this pest. Considered to be double-brooded

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in Michigan, New York and Pennsylvania, it is thought to have only a single generation in parts of Canada and possibly three generations in the southern part of its range (Biddinger and Hull 1994, Kain et al. 2004). This study focused on the biological control agents of American plum borer in Michigan on cherry and plum, for which it is currently the most economically important pest.

On these Michigan crops, American plum borer larvae are cambium feeders. The hatching larvae access the cambium through wounds or cracks in the overlying bark. In the early 1970s, such wounds became much more abundant in eastern tart cherry orchards because manual harvesting was then largely replaced with hydraulic trunk and limb shakers that mechanically harvest fruit. The hydraulic clamps of these mechanical harvesters frequently cause the cracking and tearing away of bark and often crush the underlying cambium around the trunks and lower scaffold limbs during harvest. Once established through these wounds, American plum borer larvae feed on the cambium and very quickly enlarge the initial damaged area. Trunks and scaffold limbs may be girdled in 5 years or less (Biddinger 1989).

Control of American plum borer is often accomplished with the application of long residual insecticides, such as chlorpyrifos (and until recently, endosulfan), to the trunks and scaffold limbs early in the season (Biddinger and Howitt 1992, Kain and Agnello 1999). The use of such insecticides is becoming increasingly restricted, making biological control a more relevant option, even at low levels, than ever before. A two-year study of the life history and control of this previously obscure insect in Michigan cherry and plum orchards (Biddinger 1989) found several biological control agents that can contribute to the regulation of this pest and are presented for further investigation.

Materials and Methods

American plum borer life history observations were made throughout the cherry growing areas of western Michigan during 1985-1987. To determine the degree of infestation by this moth and the relationship to tree wounding, 30 orchards with varying levels of tree wounding (from mechanical shakers), tree age, and general maintenance were sampled throughout the state. Ten wounded trees per orchard were randomly selected and evaluated for the presence of live American plum borer larvae and pupae, old exuvia, and the presence of another lepidopteran pest often found in close association, the lesser peachtree borer, *Synanthedon pictipes* (Grote and Robinson) (Lepidoptera: Sessiidae). Orchards were categorized based on percent trees wounded by mechanical shakers (0-20%, 20-50% and 50-100%). Differences in mean density of American plum borer larvae among these categories were examined through one-way ANOVA and Tukey means test in JMP 5.0.1a (SAS Institute 2002).

Natural enemies were scouted and recorded for all orchards. Large quantities of live American plum borer larvae and pupae (approximately 1,500 individuals) were collected from the field to rear out and document the parasitoid complex. American plum borer larvae and pupae were also being reared in the laboratory to develop a commercial pheromone lure for monitoring the biology of this pest and for the timing of insecticide applications (Biddinger et al. 1994). For the development of a sex pheromone for use as a monitoring tool, these samples were heavily biased toward collecting late instars, pre-pupae, and pupae sampled the late fall and early spring of the overwintering generation, and during the mid-summer pupal period for the summer generation. Undoubtedly, this affected the sampling of the parasitoid complex associated with this pest and excluded parasitoids of the eggs and early instars. Counts of *Hirsutella* mummies were recorded when scouting for American plum borer infestations. A relationship between larval density and *Hirsutella* mummies was examined using bivariate regression in JMP. Both larval density and *Hirsutella* values were log(x+1) transformed to account for a small number of large values skewing the distribution of residuals. Field scouting was also conducted to document vertebrate predators and arthropod predators observed feeding on American plum borer.

Results and Discussion

American Plum Borer and Tree Wounding. American plum borer larvae (Fig. 1), pupae, and/or pupal exuvia were found in 26 out of the 30 orchards surveyed (Table 1). Lesser peachtree borer was found in 22 of the 30 orchards (Table 1). American plum borer density differed among orchards with different levels of tree wounding ($F = 22.38$; df = 2, 27; $P < 0.0001$). Orchards with little wounding (0-20%) had significantly fewer larvae and pupae than orchards with greater than 20% wounding (Fig. 2).

Biological Control of American Plum Borer

Insectivorous birds and mammals. Several species of insectivorous birds were observed contributing to the control of American plum borer. The most prominent of these were the downy woodpecker (*Dendrocopos pubescens*) and the yellow-shafted flicker (*Colaptes auratus*), which could commonly be found probing the trunks of plums and cherries, mainly in the spring and summer. In the fall, nuthatches (Sittidae) and related insect-feeding species were seen to probe the wounds and splits in the barks seeking quiescent larvae in their overwintering hibernaculae. Blackslee (1915) also noted woodpeckers as being important predators of American plum borer on apple in Virginia. Infrequently, shrews (probably *Blarina brevicauda*) were also found under the loose bark around infested shaker wounds and were observed in the late fall feeding on overwintering hibernacula and on the pupae early in the spring.

Parasitoid wasps. The most commonly noted parasitoids of American plum borer were the ichneumon wasps (Hymenoptera: Ichneumonidae) (Table 2). Blackslee (1915) lists some of the members of this family in his study and indicates one of these as *Idecthis* sp. as being very common and accounting for over 13% of 104 larvae reared from the field. These were later identified as *Idechthis nigricoxalis* by Cushman (1915), but are now placed in the genus *Venturia*. This species, *Venturia nigricoxalis* (Cushman) (Fig. 3; Table 2), was by far the most commonly reared ichneumon parasitoid in Michigan as well. *V. nigricoxalis* was found to have two generations each season, with adult emergence delayed slightly after the peak flight of American plum borer adults in

Figure 1. Larva of the American plum borer, *Euzophera semifuneralis*. Photo: DJB

Table 1. Results of American plum borer, lesser peach tree borer (LPTB) and *Hirsutella* survey in 30 Michigan cherry and plum orchards (10 trees / orchard) with different levels of tree wounding, tree age and maintenance.

Orchard #	**Location**	**Pupal exuvia**	**Live larvae or pupae**	***Hirsutella* mummies**	**% wounded trees**	**Orchard condition: Age, General Care, LPTB presence**
4	Leelenau Co., Bingham Twp.	0	0	0	0-20	3-5 yr., very good, no LPTB
7	Leelenau Co., Peshawbestown	16	12	0	0-20	8-10 yr., good, no LPTB
8	Leelenau Co., Northport	4	1	2	0-20	6-8 yr., very good, few LPTB
10	Benzie Co., M-22 near Grace Rd.	7	1	0	0-20	5-10 yr., good, few LPTB
11	Benzie Co., 665 at M-31	16	3	0	0-20	6-10 yr., good, many LPTB
12	Benzie Co., Joyfield at M-31	14	2	0	0-20	6-8 yr., good, LPTB present
14	Charlevoix Co., Norwood Rd.	1	1	0	0-20	6-8 yr., good, few LPTB
15	Charlevoix Co., M-66 at Rainey Rd.	4	2	0	0-20	8-10 yr., fair, no LPTB
16	Charlevoix Co., Bernard Rd. #1	0	0	0	0-20	6 yr., good, no LPTB, 1st year shaken
23	Oceana Co., Garfield Rd.	1	2	0	0-20	8-10 yr., good, no LPTB
25	Allegan Co., T. Nichols Exp. Sta.	14	10	2	0-20	15 yr., good, many LPTB[a]
29	Van Buren Co., 64th at 46th	0	0	0	0-20	5 yr., very good, no LPTB
30	Van Buren Co., Lawrence near Red Arrow	0	0	0	0-20	8-10 yr., good, few LPTB
2	Grand Traverse Co., Amon's M-31	24	3	4	20-50	10 yr., poor, LPTB present
3	Grand Traverse Co., Three Mile Rd.	36	11	11	20-50	8-10 yr., very good, LPTB present
6	Leelenau Co., M-22 near Revolt Rd.	37	11	0	20-50	6-8 yr., good, no LPTB
9	Leelenau Co., Empire	31	3	4	20-50	8-10 yr., fair, LPTB present

Table 1. Continued.

Orchard #	Location	Pupal exuvia	Live larvae or pupae	*Hirsutella* mummies	% wounded trees	Orchard condition: Age, General Care, LPTB presence
19	Mason Co., M-31 near Chauvex	7	12	1	20-50	6-8 yr., good, LPTB present
21	Oceana Co., Old M-31 at Hart	22	31	2	20-50	8-10 yr., good, LPTB present
24	Allegan Co., 62nd St.	9	50	2	20-50	10-15 yr., fair, LPTB present
27	Berrien Co., Carmody Rd.	25	13	1	20-50	15-20 yr., good, LPTB present
1	Grand Traverse Co., Yuba Rd.	72	13	5	50-100	10+ yr., poor, LPTB present
5	Leelenau Co., Horn Rd.	310	100	0	50-100	25+ yr., no LPTB
13	Antrim Co., Quarterline at O'Dell	64	16	2	50-100	8-10 yr., fair, LPTB present
17	Charlevoix Co., Bernard Rd. #2	17	16	2	50-100	30+ yr., fair, few LPTB (Sweet Cherry)
18	Manistee Co., Ninemile at M-31	29	10	1	50-100	6-10 yr., fair, primarily LPTB
20	Oceana Co., Van Buren at M-31	32	29	0	50-100	10 yr., very poor, many LPTB
22	Oceana Co., west of Mears	91	37	6	50-100	25+ yr., poor, many LPTB
26	Allegan Co., 109th St.	479	255	106	50-100	20-25 yr., poor, LPTB present[b]
28	Cass Co., M-62	25	29	0	50-100	8-10 yr., fair, LPTB present

[a] never mechanically harvested

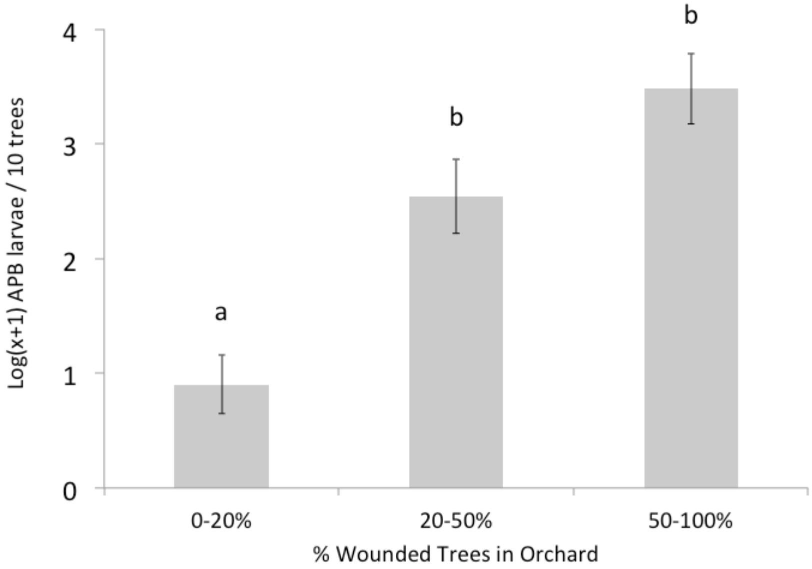

Figure 2. American plum borer (APB) larval density (mean ± SE) in orchards with varying degrees of tree wounding.

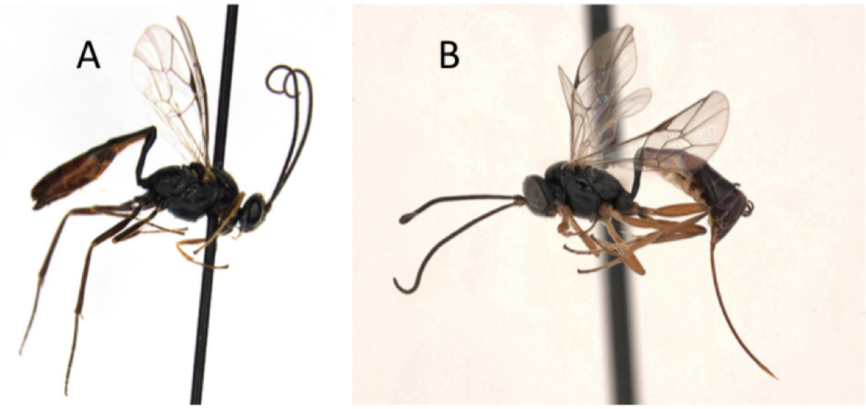

Figure 3. *Venturia nigricoxalis*, a parasitoid (Hymenoptera: Ichneumonidae) of American plum borer. (A) male; (B) female. Photos: DJB

Table 2. Summary of characteristics of hymenopteran parasitoid species recovered from American plum borer (APB), *E. semifuneralis*, and Sesiidae larvae in Michigan cherry and plum orchards, 1985-1988.

Ichneumonidae parasitoids	**Species**	**APB generation**	**% APB parasitism**	**Parasitoid guild**	**Alternative Lepidopteran hosts**	**Range**
Subfamily						
Campopleginae	*Ventura nigricoxalis* (Cushman)	Both	<15%	Larval – koinobiont endoparasitoid of larvae	*Euzophera ostricolorella* Hulst. *Synanthedon exitiosa* *Synanthedon pictipes* (<1% parasitism)	NY, MI, & IN – south to southern GA & AK
	Campoletis pyralidis (Walley)	Summer[a]	1 specimen	Larval	*Acrobasis* ssp.	Quebec south to eastern SC, west to Saskatoon & nw AK
	Diadegma sp.	Summer[a]	<1%	Larval		
Phygadeuontinae (= Cryptinae) (= Gelinae)	*Mesostenus thoracicus* (Cresson)	Not reared[a]		Cocoon – idiobiont ectoparasitoid of pupae or pre-pupae	*Acrobasis* ssp.	Quebec west to British Columbia, south to FL, TX & southern CA, Bermuda & Mexico
	Mesostenus gracilus (Cresson)	Not reared		Cocoon		Nova Scotia south to FL, west to MN, TX

Table 2. Continued.

Ichneumonidae parasitoids	Species	APB generation	% APB parasitism	Parasitoid guild	Alternative Lepidopteran hosts	Range
Pimplinae	*Coccygomimus aequalis* (Provancher)	Not reared[a]		Cocoon – idiobiont ectoparasitoid of pupae or pre-pupae	*Grapholita molesta* *Cydia pomonella* *Acrobasis* ssp.	
	Lyotryphon variatipes (Provancher)		<1%	Cocoon	*Synanthedon pictipesa* (<10% parasitism) *Cydia pomonella* *Grapholita molesta*	Quebec, NH, south to MD, WV, west to MN

[a] New host records according to Krombein et al. (1979).

mid-May and again throughout July. Krombein et al. (1979) lists *Euzophera ostricolorella* Hulst (Lepidoptera: Pyralidae), a sibling species of American plum borer as an alternate host for *V. nigricoxalis*. This species is a common economic forest pest of poplars and tulip trees in the eastern U.S., but appears to be uncommon and limited to the southern counties of Michigan according to Neunzig (1990). Krombein et al. (1979) also lists two common sesiid stone fruit orchard pests (Lepidoptera: Sesiidae) as alternate hosts: the peachtree borer, *Synanthedon exitiosa* (Say); and the lesser peachtree borer, *Synanthedon pictipes* (Grote and Robinson). Also listed as an alternate host is the oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), which is a major pest of pome and stone fruits.

Attempts to rear the adults of *V. nigricoxalis* during this study in the laboratory were unsuccessful and the adults died in 3-5 days, despite attempts to prolong activity with honey-water solutions. It is assumed that the adults of this parasite are also short-lived in the field and attack early instars of American plum borer soon after hatching, but before they are fully concealed while feeding in the cambium, as the ovipositors of the female wasps are relatively short. Parasitized larvae generally died as full-grown larvae or pre-pupae, and in the case of the overwintering generation, this occurred soon after diapause was broken in April. Only one parasite adult completed development per host. *V. nigricoxalis* was most commonly found in older orchards which generally had received many successive years of mechanical harvester injury and thus had higher populations of plum borer larvae. This parasite was also more abundant where chemical control programs had been neglected, but could be found in some numbers in all but the most intensively sprayed orchards. Parasitism rates reached as high as 25% in older, semi-abandoned orchards, but averaged about 10-15% in most established commercials orchards more than 5 years of age.

Blackslee (1915) also noted *Itoplectis marginatus* (Provancher) (Hymenoptera: Ichneumonidae) as a parasitoid of American plum borer in Georgia. Cushman (1921) later placed this name and *Scambus marginatus* as being pseudonyms of *Ephialtes aequalis* (Provancher). Also listed by Blackslee (1915) as parasitoids were several species that he misidentified as belonging to *Pimpla* (Hymenoptera: Ichneumonidae). Cushman (1915) later identified these specimens as all being *E. aequalis*, which is now a pseudonym of *Coccygomimus aequalis* (Provancher). *C. aequalis* is very common in Michigan (R. Fisher, personal communication), but was not reared during this study. Also noted by Blackslee (1915), as far less common ichneumon parasitoids of American plum borer, were *Mesostenus thoracicus* (Cresson) and *Mesostenus gracilus* Cresson, which both occur in Michigan, but were also not reared in this study.

Another ichneumon parasitoid of American plum borer reared from our study was *Campoletis pyralidis* Walley. First described as an undetermined species of *Campoletis* from larvae reared on forest species of *Acrobasis* larvae (Lepidoptera: Pyralidae) by Finlayson (1967), it was later described as a species from these adults (Walley 1970). *C. pyralidis* is listed as an eastern US species that ranges up into Canada and westward to Ohio, but has not been previously recorded in Michigan (R. Fisher, pers. comm.), and *E. semifuneralis* is a new host record (Krombein et al. 1979). Only a single specimen was reared from an overwintering generation larva of American plum borer, so it does not appear to be very common.

During our study, we commonly found the lesser peachtree borer, *S. pictipes*, in close association with *E. semifuneralis* in plum and cherry and often in the same wound (Biddinger and Howitt 1992). In the course of this study, *Liotryphon variatipes* (Provancher) (Hymenoptera: Ichneumonidae) was found to be a very common parasitoid of the lesser peachtree borer, reaching levels of 10-20% parasitism, but surprisingly was never reared from American plum borer. According to Krombein et al. (1979), *S. pictipes* is a new host record for

L. variatipes, but he does list two other very common orchard tortricid pests (Lepidoptera: Tortricidae) as hosts: codling moth, *Cydia pomonella* (L.); and oriental fruit moth, *Grapholita molesta* (Bsk.). Both of these pests overwinter as larvae on the trunks of mainly apple, but also cherry and plum, and would be in the same general search area for a parasitoid as the larvae of American plum borer and the lesser peachtree borer.

Predatory arthropods. Two species of spiders were found as predators of American plum borer (Table 3). Both were from the crab spider family (Thomisidae), and although many species of spiders were found in the galleries under the cherry bark, only those individuals that were actually found feeding on larvae were saved for identification. The most common of these was a *Coriarachne* sp., of which only immatures were collected feeding on overwintering larvae in mid-October, and hence could not be identified to species. Another species of spider found feeding on American plum borer larvae was *Xysticus triguttatus* Keyserling, which ranges throughout most of Canada and throughout all but the western US (Turnbull et al. 1965). Adults were found feeding on larvae in mid-April as American plum borer broke diapause and probably overwintered in this stage. Neither spider species was found under the bark of cherry during the summer months and were presumed to move into the orchard after overwintering. Neither spider species was found to specialize on borer larvae, and were only rarely found feeding on the smaller instars or sick individuals that were moribund and 'greasy' to the touch and appearance.

Tenebriodes corticalis (Melsheimer) (Coleoptera: Trogossitidae) larvae were the only beetles found feeding on American plum borer larvae during our study (Table 3). Blackslee (1915) also noted it as a predator of American plum borer on apple and it is reported to range throughout the US and Canada, Mexico and Guatelmala (Barron 1971). The larvae were mostly found in older trees that had loose bark with extensive galleries, such as those found in neglected or abandoned orchards, and fed on all larval instars of American plum borer throughout the season. In our study, they were found overwintering as full-grown larvae under the tree bark in close association with the borer larvae and pupated in the spring like American plum borer. Although adults of *T. corticalis* are also known to be predaceous (Barron 1971), they were never found feeding on American plum borer larvae. *T. corticalis* is an important predator of various forest insects, especially the Scolytidae, and may serve as a predator of the scolytid pests of fruit orchards known as shot-hole borers.

We noted ants to be significant predators of American plum borer (Table 3), as did Blackslee (1915). Ant colonies were common under the bark of older, extensively damaged cherry and plum trees in Michigan, but lepidopteran borer larvae were rarely found on trees with ant colonies. Because lepidopteran borers were observed on nearby healthier trees without ant colonies, it seems that predation by ants may be significant in some cases. Unfortunately, trees of this age and level of bark damage were often not producing a commercial crop, so the benefits of ant predation to cherry growers may be minimal. Blackslee (1915) noted a large nematode, tentatively identified as a *Mermis* sp. (Hymenoptera: Formicidae), as a parasite reared from American plum borer larvae that we did not find.

Fungal pathogens. Finally, a *Hirsutella* sp. of pathogenic fungi was found to be very common in American plum borer larvae in commercial orchards throughout Michigan (Table 1). It was identified to genus by Richard Humbar (USDA-ARS, Ithaca, NY) and Katherine Hodge (Cornell University), but several attempts to rear the pathogen on agar were unsuccessful and precluded species identification. Speare (1920) recognized *Hirsutella* as belonging to the Stilbaceae of the Fungi Imperfecti. Petch (1932) found the sexual stages of one species of *Hirsutella* that is now classified as *Cordyceps* and since that study, several species of *Hirsutella* have been found to be the condial or imperfect stages of

Table 3. Summary of predators and pathogens observed feeding on American plum borer (APB), *E. semifuneralis*, and Sesiidae larvae in Michigan cherry and plum orchards, 1985-1988.

Predators and pathogens	Species	APB generation	Alternative lepidopteran hosts
Spiders	*Coriarachne* sp.	Overwintering	
	Xysticus triguttatus Keyserling	Overwintering	
Coleoptera			
Tenebrionidae	*Tenebriodes corticalis* (Melsheimer)	Overwintering	
Entomophagous nematode	*Mermis* sp.	Summer	
Fungal pathogen (Fungi imperfecti)	*Hirsutella* sp.	Both generations[a]	*Cydia pomonella*
			Synanthedon exitiosaa
			Synanthedon scitulaa

[a] New host records according to available literature

species of *Cordyceps* (Charles 1941, Mains 1951). The most similar *Hirsutella* species found to what we reared from *E. semifuneralis* is that of *H. subulata* Petch, which was reared from codling moth in Virginia apple orchards and illustrated in Mains (1951).

Most *Hirsutella*-infected larvae of American plum borer were found with long external hyphal 'horns' growing outward from the larva and sometimes attaining more than twice the length of the larva (Fig. 4). The cadavers of the larvae first became somewhat 'greasy' in appearance, then extremely hard and rigid soon after death, as the internal organs were quickly converted to hyphae. Later the hyphal horns emerged through the oral and anal openings, appendages, genital openings and sometimes laterally through the body wall. Many of the mummified larvae found in the field never developed these horns. Fresh mummies brought indoors required moisture before developing these horns, and those collected fresh in the fall required a cold period, as reported by Charles (1941) for *H. subulata* on codling moth larvae. Fresh mummies of American plum borer with and without horns could be found in both the spring and summer generations, indicating this pathogen may be capable of at least two generations each year. In both generations, the larvae were generally killed by the pathogen before pupation, although several younger instar larvae and a few pupae with the characteristic fungal horns were also found. In the field, development of the fungal horns and presumably spore release coincided with American plum borer adult emergence and egg-laying.

Mummified borer larvae from the overwintering generation developed horns during May, and the spores were probably ingested by the hatching larvae in late May and early June. These infected larvae died prior to pupation in mid-June to July, and developed horns to release spores that infected the young larvae of the next generation during late July and August. The infected larvae of this second generation died in October, prior to constructing overwintering hibernacula, and did not develop horns until after adult emergence the following spring. Mummies of the overwintering larvae required a cold period of about

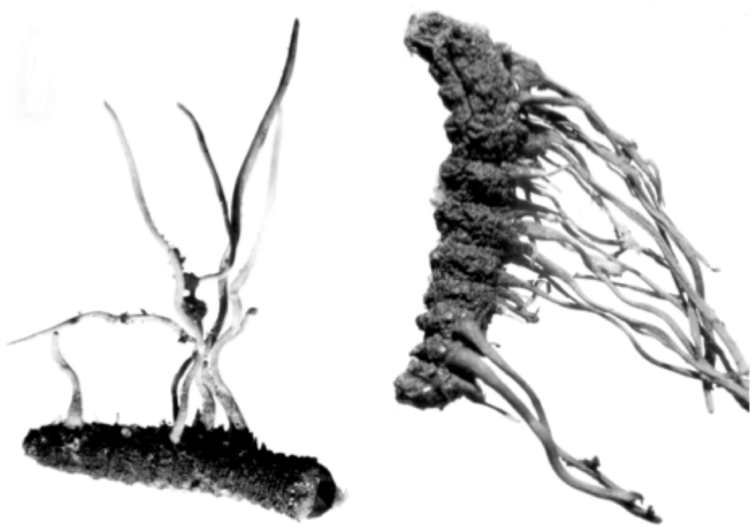

Figure 4. *Hirsutella*-infected American plum borer larvae. Photos: DJB

two weeks before development, as reported by Charles (1941), but the summer generation did not. Almost all the larvae killed by this pathogen in the summer were in their last instar, but those larvae of the overwintering generation were killed in whichever instar they happened to be in when diapause began, and were often of earlier instars.

Trees with heavy infestations of borers with the fungal pathogen could often be distinguished by the white fungal horns protruding through the cracks in the bark to disseminate the spores. In a plum orchard in Allegan County, 114 out of 278 larvae on a single tree, or 41%, were killed by this pathogen before pupation within a single season (Biddinger 1989). In this orchard, almost 16% of the lesser peachtree borers were killed by what appeared superficially to be this same pathogen. This or a similar species of *Hirsutella* was also found in a few specimens of dogwood borer, *Synanthedon scitula* (Harris), (Lepidoptera: Sesiidae) larvae in Michigan apple orchards, and more commonly on lesser peachtree and peachtree borer larvae in peach orchards. All specimens are now kept by Dr. Kathie Hodge at the Cornell Plant Pathology Herbarium. In a survey of the tart cherry and plum orchards throughout the fruit growing counties of western Michigan (Biddinger 1989), 15 out of 26 orchards that had American plum borer (about 58%) were found to have this fungal pathogen present. This survey also indicates that this pathogen seems to be density-dependent, since it is most prevalent in those orchards with the highest populations of American plum borer (Fig. 5; $F = 11.21$, df = 1, 28; $P = 0.0023$, $R^2 = 0.29$). However, the significant, yet relatively weak, correlation suggests that the variance is only partially explained by American plum borer density, and other environmental factors are likely contributing to *Hirsutella* incidence.

Conclusion. Numerous biological control agents for American plum borer exist and can cause significant mortality (>25%) to this pest. The many new host associations of parasitoids, pathogens and predators is surprising for a major pest of cherries in the Great Lakes region, and for which a wide host and

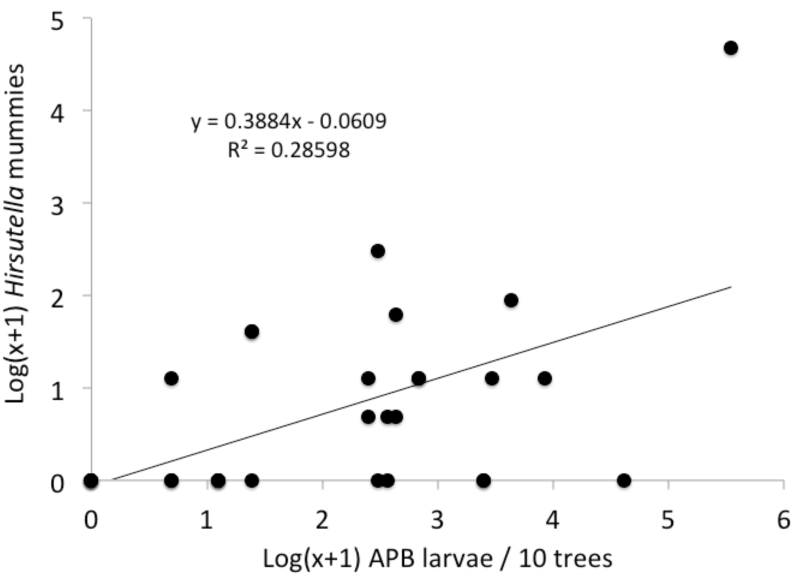

Figure 5. Relationship between American plum borer (APB) density and *Hirsutella* infections.

geographical range spanning many important crops exists (Essig 1917, Weiner and Norris 1983, Van Steenwyk et al. 1986, Biddinger and Howitt 1992, Kain et al. 2004). *E. semifuneralis* has the potential to serve as an alternate host for parasitoids of other major pests such as the oriental fruit moth, codling moth, peach tree borer, lesser peach tree borer and dogwood borer, which are commonly found in close association on the trunks of many of these crops. Similarly, a new parasitoid host association of *L. variatipes* for the lesser peach tree borer, could mean that this sessiid pest could serve as a closely associated alternate host for codling moth and oriental fruit moth parasites. Further investigation of the density-dependent *Hirsutella* fungal pathogen reared from American plum borer appears to be warranted as it may be the same species identified attacking codling moth in the past (Charles 1941). It, or a similar species, also appears to attack three major sesiid pests of pome and stone fruit in Michigan. Additionally, reducing tree wounding during the mechanical harvest of cherries would demote American plum borer back to minor-pest status; this could be a suitable area of research for agricultural engineers.

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