

Seasonal Activity, Within-Tree Distribution, and Ovipositional and Feeding Preference of the Elm Leafminer, *Fenusa ulmi* (Hymenoptera: Tenthredinidae)¹

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Abstract

Seventy-six different elm taxa were visually rated for elm leafminer (*Fenusa ulmi* Sundeval) defoliation. European elm taxa were more found to be more susceptible to feeding damage by the elm leafminer compared to Asian and North American elm taxa. European elms *U. glabra*, *U. elliptica*, *U. sukaczewii*, and elms with *U. glabra-wallichiana* parentage were highly susceptible to elm leafminer leaf feeding damage. Of the 37 Asian elm taxa evaluated, only *U. laciniata* was highly susceptible to feeding damage. The North American species *U. rubra* was the only North American elm susceptible to elm leafminer feeding. Adult emergence, initial leafmining, and cessation of leafmining were highly correlated with indicator plant full bloom phenology providing an accurate degree-day (DD) model for practitioners in predicting and monitoring for elm leafminer life stage development and related plant damage. Elm leafing out phenology of susceptible European elms was highly correlated with elm leafminer adult emergence and oviposition. Less susceptible European elm taxa, such as *U. procera*, and *U. carpinifolia* and cultivars, consistently leaf out later after peak adult leafminer emergence. Interestingly, the majority of Asian elm taxa such as *U. davidiana*, *U. japonica*, *U. lamellosa*, and *U. pumila* leaf out at the same time as susceptible elm taxa, but experience no or negligible feeding damage. Two Asian species, *U. wilsoniana* and *U. parvifolia*, leaf out later after peak adult emergence and oviposition has passed. No consistent pattern was observed for within tree ovipositional wounds and subsequent leafminer feeding damage for tree height or cardinal direction for both small and large elm tree species. Results from this study indicate there is a large number of Asian and North American elm taxa that provide a rich genetic pool for future elm breeding programs.

Index words: *Fenusa ulmi*, elm leafminer, *Ulmus*, susceptibility.

Species used in this Study: *Fenusa ulmi* Sundeval, *Ulmus procera* Salisb., *Ulmus glabra* Huds., *Ulmus laciniata* Trautv., *Ulmus elliptica* K.Koch, *Ulmus sukaczewii*.

Significance to the Nursery Industry

Results from this study confirmed a high correlation between elm leafminer life stage development and indicator plant full bloom phenology. In addition, a high correlation was determined between leafing out phenology of susceptible European elm taxa and elm leafminer adult emergence and oviposition. There was no consistent pattern for within tree canopy for egg laying and subsequent feeding larval feeding damage for either small or large trees for tree height or canopy quadrant. These findings suggest a practitioner can sample from any part of the tree crown and/or cardinal direction and be reasonably assured of getting an accurate assessment of potential leafminer feeding damage. The close relationship between elm leafminer life stage development, indicator plant phenology, and elm host phenology provides a helpful degree-day (DD) model for monitoring for susceptible elms trees and for timely, efficient, and effective pest management decision making as part of a plant health care (PHC) program.

Additionally, results reported here and by others have determined Asian and North American elm taxa are less susceptible to feeding by the elm leafminer compared to

European elm taxa. In addition, some of the same Asian and North American elm taxa evaluated in this study have been found to be less preferred and susceptible to other common defoliators such as the elm leaf beetle (*Pyrrhalta luteola*), Japanese beetle (*Popillia japonica*), spring cankerworm (*Paleacrita vernata*), fall cankerworm (*Alsophila pometaria*), and gypsy moth (*Lymantria dispar*), and vascular wilt diseases including Dutch elm disease (DED) (*Ceratostyis ulmi*), and elm yellows ('*Candidatus Phytoplasma ulmi*'). Results from this study will provide direction for future elm breeding programs.

Introduction

The elm leafminer, *Fenusa ulmi* Sundeval (Hymenoptera: Tenthredinidae), is a common pest of elms (*Ulmus* spp.) in late spring and early summer. The legless, flattened larva was first reported by Felt (8) feeding on *U. glabra* 'Camper-down' elms near Albany, New York. Felt (8) also described elm leafminer on English elm (*Ulmus procera*), Scotch elm (*U. glabra*), and American elm (*U. americana*). Its range has expanded to include the northeastern United States, southeastern Canada, and the Great Lakes states (4, 21). Adult elm leafminers are 3 mm (0.12 in) long, black sawflies that emerge in early to mid May and shortly thereafter lay eggs in the upper leaf epidermis. Mature larvae drop out of the leaf and, according to Felt (8), burrow down into the soil to a depth of about 25 mm (1 in) where they overwinter. Adult leafminer emergence is difficult to anticipate and easily missed in the field. Once the larvae are inside the leaf tissue, chemical contact control is ineffective. This problem has been somewhat mitigated with the development and utilization of systemic insecticides.

¹Received for publication September 19, 2013; In revised form April 1, 2014. The authors would like to acknowledge the partial funding and support provided by the J. Frank Schmidt Charitable Trust, and the support and assistance of the ground maintenance staff at the Morton Arboretum, as well as Dr. Dan Hermes of Ohio State University.

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Degree day (DD) models are helpful tools in predicting insect emergence and lifestage activity (37). In conjunction with DDs is the use of key indicator plant phenology that corresponds with leafminer biological activity. Hermes (17) determined adult elm leafminer emergence occurs at an average of 228 DD₅₀ (May 9) and Adams (1) indicates elm leafminer feeding damage occurs between 363 to 530 DD₅₀ (mean = 447 DD₅₀). Use of DDs and plant phenology information can be extremely helpful to the plant health care (PHC) practitioner, thus reducing the possibility of severe leafminer defoliation and the subsequent loss in elm tree vitality and aesthetic value.

Extensive breeding and selection programs have focused on insect-resistant trees for forest and landscape uses (2, 5, 6, 20, 35, 40, 41). The United States Department of Agriculture genetic improvement programs that are currently being carried out on elms with efforts concentrated on disease resistance (38, 41, 42) have more recently included resistance to the elm leaf beetle (*Pyrrhalta luteola*; 12, 13, 14, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31).

Asian elms appear to have high levels of resistance to Dutch elm disease, elm leafminer and elm yellows (18, 23). A previous study on 30 elm accessions in Wisconsin showed that the most severe elm leafminer feeding injury occurred on the European elms *U. glabra*, *U. procera*; Asian elm *U. laciniata*; and the North American species *U. rubra* (11, 38). In this same study, they found that *U. japonica* and *U. carpinifolia* were somewhat less preferred by the elm leafminer and that *U. americana*, *U. thomasi*, *U. parvifolia*, and *U. pumila* were the least preferred. Hybrids containing Asian and European elm parentage varied in susceptibility to feeding damage (11).

With the exception of the study by Felt (8) and the more recent studies by Gurries and Smalley (11) and Condra et al. (3), there is still much to be learned about the susceptibility of *Ulmus* and their hybrids, particularly Asian elms, to feeding damage by the elm leafminer. Even less well known is the within tree distribution of the leafminer.

In 1994, as part of a comprehensive elm breeding research program, we initiated a study with the following objectives: to evaluate Asian, European, and North American elm taxa for susceptibility to feeding by the elm leafminer; to determine differences in within tree distribution of adult ovipositional sites and larval feeding damage; and to develop degree models for key insect life stages and corresponding key indicator plants for predicting adult emergence, initiation of larval feeding and termination of larval feeding.

Materials and Methods

Feeding susceptibility survey. A leafminer defoliation survey was conducted in 1994–2000 on 77 different elm taxa growing in The Morton Arboretum, Lisle, IL. After the cessation of larval feeding (usually early July in a given year), the entire tree canopy of 31 European, 37 Asian, and 9 North American elm taxa were visually examined and rated by two individual estimates for percent defoliation (nearest 5%). At least three trees per genotype were examined. Trees ranged in size from 3 to 15 m (9 to 45 ft) in height and a DHB of 5 to 61 cm (2 to 24 in). Refer to Table 1 for a listing of elm taxa surveyed.

Adult emergence and density. Adult emergence was monitored by placing four ground traps 0.6 by 0.6 m (2 by 2 ft)

square at the four cardinal directions within the dripline of the susceptible host trees. The traps were constructed from 2.5 by 10 cm (1 in by 4 in) untreated pine lumber. The top of the square trap was covered with fine screen mesh and anchored down with 4.7 cm (12 in) long stakes driven into the ground to prevent movement and prevent escape by emerging adult leafminers. The traps were checked daily, and the total number of adult leafminers were counted and collected. No killing agent was used. In addition, four 7.5 by 12.5 cm (3 by 5 in) yellow sticky cards were hung in each quadrant (N, S, E, W) of the tree. Cards were changed every seven days. Ground traps and yellow sticky cards were checked daily and the total number of adult leafminers was recorded until all adult emergence had ceased.

Within tree egg wound distribution and percent leaf area consumed. In order to ascertain if tree height was a factor in leafminer oviposition and subsequent defoliation, foliage samples were collected in late May 1995 and 1996 approximately 7 to 10 days after oviposition had ceased from six different elm taxa in The Morton Arboretum elm collection with a history of elm leafminer defoliation. Three trees were sampled for each of six different elm taxa for a total of 18 trees. The trees were divided into two tree height groups. Shorter trees [<6 m (18 ft) tall] included *U. glabra*, *U. elliptica*, and *U. sukaczewii*. Taller trees [>6 m (18 ft)] were *U. × hollandica*, *U. laciniata*, and *U. procera*. The shorter trees were divided into two canopy sampling zones designated upper and lower. The canopy of the larger trees was divided into three canopy sampling zones identified as lower, middle, and upper. Each of the larger tree canopy sampling zones (i.e. lower, middle, upper) was further divided into exterior and interior zones. Within each canopy sampling zones of both the smaller and larger trees, a single branch from each of the four cardinal directions (N, S, E, W) was selected and the terminal 31 cm (12 in) of each branch was removed using a pole pruner. Five mature elm leaves from each branch were randomly selected and visually examined for the total number of ovipositional wounds and recorded. After examination, the same five sample leaves were dried in a plant press and later placed under a Delta-T area meter (Delta T Devices, Model # RS-232-C, Burwell-Cambridge, England) and the total amount of leaf area consumed by larvae was determined and recorded. Each shorter tree had a total of 40 leaves (two zones by four branches per zone by five leaves per branch) sampled and evaluated. Each large tree had a total of 24 branch samples (six zones by four branches per zone by five leaves per branch) taken for a total of 120 leaves sampled and evaluated per tree. A total of 360 leaves (three trees per species by three species by 40 leaves per tree) were sampled and evaluated for the nine shorter trees, and 1,080 leaves were sampled and evaluated for the nine taller trees (three trees per species by three species by 120 leaves per tree).

Cumulative degree days, indicator plant phenology, elm tree phenology, and adult leafminer emergence and oviposition. Cumulative degree days (DDs) were calculated using a base temperature of 50 F (DD₅₀) using daily maximum and minimum air temperatures recorded at The Morton Arboretum, Lisle, IL. Daily field observations were made using calendar dates for initial adult emergence, peak adult emergence, ovipositional activity, initial larval feeding, and

Table 1. Susceptibility measured as mean percent defoliation \pm SEM of Asian, North American, and European elms (*Ulmus* spp.) for the elm leaf miner (*Fenusa ulmi*) 1994 to 2000).

Species/hybrid	Mean % defoliation	Susceptibility ^z	Reference ^y
European			
<i>U. canescens</i>	0 \pm 0.00	Very low	2
<i>U. carpiniifolia</i>	7/8 \pm 0.813	Very low	1,2
<i>U. carpiniifolia</i> (Europe)	8	Very low	1
<i>U. carpiniifolia</i> (Spain)	18	Very low	1
<i>U. carpiniifolia</i> 'Gracilis'	0 \pm 0.00	Very low	2
<i>U. carpiniifolia</i> 'Koppmannii'	0 \pm 0.00	Very low	2
<i>U. carpiniifolia</i> 'Pendula'	16 \pm 0.234	Moderate	2
<i>U. carpiniifolia</i> 'Sarniensis'	16 \pm 3.231	Moderate	2
<i>U. carpiniifolia</i> 'Umbraculifera'	5 \pm 0.621	Very low	2
<i>U. carpiniifolia</i> 'Variegata'	10 \pm 0.565	Low	2
<i>U. carpiniifolia</i> 'Wredei'	0 \pm 0.00	Very low	2
<i>U. carpiniifolia</i> var. <i>suberosa</i>	5 \pm 0.00	Very low	2
<i>U. carpiniifolia</i> \times <i>U. glabra</i> 'Regal'	65	Moderate	1
<i>U. crassifolia</i>	7 \pm 6.667	Very low	2
<i>U. elliptica</i>	50 \pm 3.56	High	2
<i>U. foliaceae</i>	0 \pm 0.00	Very low	2
<i>U. glabra</i>	65 \pm 9.94	Very high	2
<i>U. glabra</i> (Europe)	43	Moderate	1
<i>U. glabra</i> (Norway)	63	Moderate	1
<i>U. glabra</i> (Spain)	7	Very low	1
<i>U. glabra</i> \times <i>U. carpiniifolia</i> 'Pioneer'	17	Low	1
<i>U. glabra-wallichiana</i> \times <i>U. carpiniifolia</i> 'Plantyn'	29	Moderate	1
<i>U. glabra-wallichiana</i> \times <i>U. glabra</i> 'Lobel'	35/59 \pm 2.14	Moderate to Very high	1,2
<i>U. glabra-wallichiana</i> \times open pollinated 'Dodoens'	53/51 \pm 1.62	Very high	1,2
<i>U. glabra</i> \times <i>U. glabra</i> 'Belgica'	11/40 \pm 2.326	Low to High	1,2
<i>U. glabra</i> \times <i>U. glabra</i> 'Commelin'	8/40 \pm 0.00	Low to High	1,2
<i>U. glabra</i> \times <i>U. glabra</i> 'Groeneveld'	45 \pm 2.32	High	1,2
<i>U. glabra</i> \times <i>U. glabra</i> 'Klemmer'	7 \pm 5.62	Low	2
<i>U. glabra</i> \times <i>U. glabra</i> 'Major'	50 \pm 0.00	High	2
<i>U. glabra</i> \times <i>U. glabra</i> 'Superba'	50 \pm 0.00	Very high	2
<i>U. glabra</i> \times <i>U. glabra</i> 'Vegeta'	61/49 \pm 2.22	High to Very high	1,2
<i>U. laevis</i>	5 \pm 0.00	Very low	2
<i>U. procera</i>	44/12 \pm 3.73	Low to High	1,2
<i>U. procera</i> 'Christine Buisman'	5 \pm 0.00	Very low	2
<i>U. procera</i> 'Purpurea'	40 \pm 0.00	High	2
<i>U. sukaczewii</i>	48 \pm 5.000	High	2
<i>U. 'Urban'</i>	40 \pm 0.00	Moderate	2
Asian			
<i>U. bergmanniana</i>	0 \pm 0.00	Very low	2
<i>U. bergmanniana</i> var. <i>lasiophylla</i>	0 \pm 0.00	Very low	2
<i>U. bergmanniana</i> \times <i>U. japonica-wilsoniana</i>	1 \pm 0.15	Very low	2
<i>U. bergmanniana</i> \times <i>U. parvifolia</i>	0 \pm 0.00	Very low	2
<i>U. bergmanniana</i> \times <i>U. pumila</i>	3 \pm 1.09	Very low	2
<i>U. castaneifolia</i>	0 \pm 0.00	Very low	2
<i>U. chenmoui</i>	0 \pm 0.00	Very low	2
<i>U. davidiana</i> var. <i>mandshurica</i>	0 \pm 0.17	Very low	2
<i>U. davidiana</i> \times <i>U. japonica</i>	0 \pm 0.00	Very low	2
<i>U. elongata</i>	0 \pm 0.00	Very low	2
<i>U. gaussenii</i>	0 \pm 0.00	Very low	2
<i>U. glaucescens</i>	10 \pm 5.000	Low	2
<i>U. glaucescens</i> var. <i>lasiocarpa</i>	0 \pm 0.00	Very low	2
<i>U. japonica</i>	13/4 \pm 2.31	Very low	1,2
<i>U. japonica-bergmanniana</i> \times <i>U. pumila</i>	19 \pm 1.111	Low	2
<i>U. japonica</i> \times <i>U. pumila</i>	3 \pm 2.55	Very low	2
<i>U. laciniata</i>	33/35 \pm 3.24	Moderate	1,2
<i>U. laciniata</i> var. <i>nikkoensis</i>	15 \pm 0.00	Low	2
<i>U. laciniata</i> \times <i>U. macrocarpa</i>	20 \pm 1.12	Moderate	2
<i>U. laciniata</i> \times <i>U. pumila</i> '701'	20	Low	1
<i>U. lamellosa</i>	0 \pm 0.00	Very low	2
<i>U. macrocarpa</i>	0 \pm 0.00	Very low	2
<i>U. 'Morton'</i> -Accolade™	10 \pm 3.26	Low	2
<i>U. 'Morton Stalwart'</i> -Commendation™	30 \pm 8.35	Moderate	2
<i>U. 'Morton Glossy'</i> -Triumph™	12 \pm 4.95	Low	2
<i>U. 'Morton Red Tip'</i> -Danada Charm™	14 \pm 3.69	Low	2
<i>U. 'Morton Plainsman'</i> -Vanguard™	0 \pm 0.00	Very low	2
<i>U. parvifolia</i>	0 \pm 0.00	Very low	1,2
<i>U. parvifolia</i> \times <i>U. americana</i> #2225	3	Very low	1
<i>U. parvifolia</i> \times <i>U. glabra</i> #2227	3	Very low	1

Continued...

Table 1. Continued ...

Species/hybrid	Mean % defoliation	Susceptibility ^z	Reference ^y
<i>U. parvifolia</i> × <i>U. pumila</i> #2224	0 ± 0.00	Very low	1
<i>U. parvifolia</i> × <i>U. pumila-rubra</i>	0 ± 0.00	Very low	2
<i>U. propinqua</i>	0 ± 0.125	Very low	2
<i>U. propinqua</i> var. <i>suberosa</i>	0 ± 0.131	Very low	2
<i>U. pumila</i>	12 ± 7.67	Low	1,2
<i>U. pumila</i> 'Dropmore'	3 ± 0.361	Very low	2
<i>U. pumila</i> × <i>U. carpinifolia</i>	5 ± 4.67	Low	2
<i>U. pumila</i> × <i>U. japonica</i> 'Cathedral'	5/8 ± 3.33	Very low to Low	1,2
<i>U. pumila</i> × <i>U. japonica</i> 'Sapporo Autumn Gold'	8	Low	1
<i>U. pumila</i> × <i>U. parvifolia</i>	2 ± 1.36	Moderate	2
<i>U. szechuanica</i>	0 ± 0.00	Very low	2
<i>U. wilsoniana</i>	0 ± 0.00	Very low	2
North American			
<i>U. alata</i>	0 ± 0.00	Very low	2
<i>U. americana</i>	0/2 ± 0.49	Very low	1,2
<i>U. americana</i> 'Augustine'	0 ± 0.00	Very low	2
<i>U. americana</i> 'Columnaris'	0 ± 0.00	Very low	2
<i>U. americana</i> 'Littleford'	0 ± 0.00	Very low	2
<i>U. americana</i> 'Moline'	0 ± 0.00	Very low	2
<i>U. crassifolia</i>	0 ± 0.00	Very low	2
<i>U. rubra</i>	27/12 ± 0.169	Low	1,2
<i>U. serotina</i>	0 ± 0.00	Very low	2
<i>U. thomasii</i>	4/3 ± 0.518	Very low	1,2

^zNP = 0% defoliation; VL = 1–5% defoliation; L = 6–15% defoliation; M = 16–35% defoliation; H = 36–50% defoliation; and VH = >50% defoliation.

^yReferences: 1 = Guries and Smalley (1994); 2 = based on field defoliation surveys by Miller and Ware conducted at the Morton Arboretum (1994 to 1998).

cessation of larval feeding on elm trees growing in the elm collection at The Morton Arboretum with a history of elm leafminer defoliation. Indicator plant phenology data were collected by selecting 17 commonly found and easily identified woody landscape plants growing in close proximity to the elm collection in The Morton Arboretum. First and full bloom were designated as the primary plant phenological indicator for all indicator plants in order to ensure and capture consistent phenological field observations. In order to better define the relationship between indicator plant phenology and adult emergence, peak adult emergence, ovipositional activity, initial larval feeding, and cessation of larval feeding, a correlation analysis was performed using Julian dates (JDs) for first and full bloom indicator plant phenology, and JDs for initial adult emergence, peak adult emergence, ovipositional activity, initial larval feeding, and cessation of larval feeding for 1995–2000.

In spring, daily observations were made in late to mid morning for elm host plant phenological development including bud swell, partial leafing out, and full leaf expansion for all elms growing in The Morton Arboretum elm collection. Full leaf expansion was designated as the main plant phenological event for all elms observed in order to insure consistent phenological field observations. A correlation analysis was performed using initial adult leafminer emergence Julian dates (JDs) and JDs for full elm leaf expansion for 1995–2000 to determine the relationship between adult elm leafminer emergence and elm host susceptibility to leafminer defoliation.

Measurement head capsule widths. Larval head capsules were collected from leaves at the completion of larval feeding. Each mine was opened and the head capsules were exhumed and preserved in 70% isopropyl alcohol. Head

capsules were measured at the widest point using a microscope equipped with an eyepiece micrometer.

Statistical analysis. Measures of plant susceptibility based on within plant ovipositional leaf wounds and percent leaf area consumed were subjected to analysis of variance (ANOVA) using taxon as the main effect. Proportion of leaf tissue consumed was arcsine transformed before analysis to correct for non-normality. Means of significant effect were compared with a Student-Newman-Keuls (SNK) multiple comparison test. All data are presented as means ± standard error (SEM). All data were analyzed using SigmaStat for Windows (Jandel Scientific 1992).

Results and Discussion

Measures of plant susceptibility based on percent defoliation (1994–2000). A complete summary of elm taxa susceptibility expressed as mean percent defoliation is presented in Table 1. Within European elms, *Ulmus elliptica*, *U. glabra*, *U. sukaczewii*, *U. glabra-wallichiana* × *U. × hollandica* 'Lobel', *U. glabra-wallichiana* × open pollinated 'Dodoens', *U. × hollandica* 'Belgica', *U. × hollandica* 'Commelin', *U. × hollandica* 'Major', *U. × hollandica* 'Superba', *U. × hollandica* 'Vegeta', *U. procera* and *U. procera* 'Purpurea', and *U. 'Urban'* were highly susceptible with 40 to 65% defoliation. Among Asian elms and hybrids, only *U. laciniata* and *U. 'Morton Stalwart'* Commendation™ were moderately susceptible with 35 and 30% defoliation, respectively. With the exception of *U. rubra*, no or negligible leafminer feeding damage was observed on North American elm taxa.

Cumulative degree-days (DD₅₀) for initial adult emergence, oviposition, initial larval mining, and cessation of larval mining (1995–2000). Ground traps and yellow sticky

Table 2. Calendar dates and cumulative degree days (DD₄₀ and DD₅₀) for adult emergence, adult female oviposition, first larval feeding, and larval maturity of the elm leafminer based on ground trap and yellow sticky card counts, 1995 to 1998^a.

Life stage	1995	1996	1997	1998	1999	2000
Initial adult emergence (calendar dates)	May 12–14	May 15–17	May 16–20	April 27–28	April 30–May 1	April 25–27
Initial adult emergence (DD ₃₀) ¹	170–198 (Mean = 184 ± 8.08)	132–249 (Mean = 191 ± 8.89)	164–200 (Mean = 182 ± 8.15)	203–203 (Mean = 203 ± 0.00)	153–159 (Mean = 156 ± 2.91)	196–203 (Mean = 200 ± 3.15)
Peak adult emergence (calendar dates)	May 13	May 18	May 19	April 30–May 1	May 3–6	April 28–30
Peak adult emergence (DD ₅₀)	184 (Mean = 184 ± 0.00)	192 (Mean = 192 ± 0.00)	197 (Mean = 197 ± 0.00)	217–228 (Mean = 223 ± 5.50)	184–213 (Mean = 199 ± 4.91)	215–221 (Mean = 225 ± 5.51)
Oviposition (calendar dates)	May 12–17	May 19–24	May 30–June 5	May 10–15	May 10–14	May 3–8
Oviposition (DD ₃₀)	170–236 (Mean = 203 ± 9.85)	224–353 (Mean = 269 ± 12.01)	284–340 (Mean = 317 ± 9.37)	335–401 (Mean = 368 ± 13.61)	235–332 (Mean = 284 ± 8.62)	214–288 (Mean = 251 ± 3.15)
First larval mines (calendar dates)	May 19	May 22	May 30	May 13	12 May	8 May
First larval mines (DD ₃₀)	248 (Mean = 248 ± 0.00)	281 (Mean = 281 ± 0.00)	284 (Mean = 284 ± 0.00)	318 (Mean = 318 ± 0.00)	330 (Mean = 330 ± 0.00)	300 (Mean = 300 ± 0.00)
Larval maturity	June 2–9	June 10–17	June 12–19	May 20–27	May 26–June 6	May 22–June 1
Larval maturity (DD ₃₀)	439–566 (Mean = 506 ± 16.97)	466–592 (Mean = 524 ± 33.08)	393–521 (Mean = 457 ± 20.64)	333–575 (Mean = 454 ± 8.68)	445–581 (Mean = 513 ± 7.36)	446–623 (Mean = 535 ± 11.23)

^aCumulative DD₃₀ values are based on daily maximum and minimum temperatures taken at the official National Weather Service recording station at The Morton Arboretum, Lisle, IL.

trap monitoring during 1995–2000 field seasons detected initial adult elm leafminer emergence occurred at a mean of 180 DD₅₀ (range = 156–203 DD₅₀) and peak adult emergence occurred at a mean of 204 DD₅₀ (range = 184–223 DD₅₀) (Table 2). Field observations revealed that oviposition occurred at a mean of 286 DD₅₀ (range = 203–368 DD₅₀). First larval mines appeared at a mean of 289 DD₅₀ (range = 248–330 DD₅₀) and larval maturity occurred at a mean of 560 DD₅₀ (range = 506–614 DD₅₀) (Table 3).

Initial adult leafminer emergence and initial larval leafmining were highly correlated with indicator plant phenology ($r = 0.99$; $F = 675$; $P = 0.024$) and ($r = 0.91$; $F = 18.03$; $P = 0.013$), respectively (Table 4). A weak correlation occurred between cessation of larval leafmining and indicator plant phenology ($r = 0.91$; $F = 9.55$; $P = 0.091$). This weak correlation between cessation of larval leafmining and indicator plant phenology could be due to the degree of susceptibility between different elm hosts and larval development. Personal experience has shown that it can be quite difficult to determine precisely when larval mining has ceased due to different larval instars present at the time of evaluation. From a practical perspective, this event is not all that important as chemical treatments would have been required long before larval leafmining damage began. In addition, the elm leafminer has only one generation per year so pinpointing precisely when elm leafminer feeding has ceased would not have any practical effect on chemical treatments required to mitigate subsequent defoliation later in the season as seen with other leafminer species that have more than one generation per year.

Indicator plant phenological data (1994–2000). A summary of key indicator plants and associated first and full bloom plant phenology coinciding with elm leafminer larval and adult life stages and related plant damage are summarized in Table 4. Adult emergence commenced when *Cercus canadensis*, *Craetagus phaenopyrum*, *Malus* ‘Mary Potter’, *Ribes odoratum*, and *Viburnum lantana* were in first to full bloom. End of adult emergence coincided with *Kolkwitzia amabilis* and *Spiraea* × *vanhouttei* in first bloom. Larval leafmining began when *Spiraea* × *vanhouttei*, *Kerria japonica*, *Aesculus hippocastanum*, *Kokwitzia amabilis*, *Prunus serotina*, *Robinia pseudoacacia*, *Syringa vulgaris* ‘Miss Ellen’, *Physocarpus opulifolius* and *Wisteria macrostachya* were in first to full bloom. Larval feeding was complete and larvae were exiting the leaf to enter the soil when *Kerria japonica*, *Kokwitzia amabilis*, *Syringa patula* ‘Miss Kim’, *Physocarpus opulifolius*, *Spiraea nipponica* ‘Snowmound’, and *Wisteria macrostachya* were in first to full bloom.

Host elm plant phenology, and adult leafminer emergence (1995–2000). A strong correlation was observed between initial adult emergence and leafing out of elms ($r = 0.91$; $F = 23.62$; $P = 0.005$). Field observations revealed that *Ulmus. elliptica*, *U. glabra*, *U. laciniata*, and *U. sukaczewii*, *U. glabra-wallichiana* × *U. × hollandica* ‘Lobel’, and *U. glabra-wallichiana* × open pollinated ‘Dodoens’ consistently leafed out at the same time of initial adult elm leafminer emergence. All of these species are susceptible to moderate to high leafminer feeding damage. Certain *U. × hollandica* cultivars, ‘Commelin’, ‘Groeneveld’, ‘Superba’, and ‘Vegeta’, leaf out near peak or slightly beyond peak adult emergence and are equally susceptible to high levels of leafminer feed-

Table 3. Mean number of ovipositional wounds per square centimeter of leaf surface area by genotype, tree zone, and tree quadrant, 1996 ± SEM.

Elm genotypes	N ²	Mean number of ovipositional wounds (per cm ² of leaf surface)
<i>U. sukazweskii</i>	2	1.9 ± 0.12c
<i>U. glabra</i>	3	1.3 ± 0.13c
<i>U. procera</i>	3	0.7 ± 0.04b
<i>U. × hollandica</i>	3	0.7 ± 0.04b
<i>U. laciniata</i>	2	0.5 ± 0.04a
Zones		
Lower		1.9 ± 0.2a
Middle		2.0 ± 0.1a
Upper		2.0 ± 0.2a
Interior		1.9 ± 0.1a
Quadrants		
North		1.9 ± 0.1a
South		2.3 ± 0.1b
East		1.7 ± 0.1a
West		1.8 ± 0.1a

ing damage. This is in contrast to certain *U. × hollandica* cultivars such as ‘Belgica’ and ‘Klemmer’, *U. carpinifolia* and cultivars, and the North American species, *U. thomasii*, which are typically breaking bud or just flowering and do not leaf out until peak adult emergence has passed, resulting in less feeding damage.

Interestingly, many of the resistant Asian elms such as *U. davidiana*, *U. japonica*, *U. lamellosa*, *U. pumila*, and others also tend to begin leafing out at approximately the same time as initial adult emergence but suffer no or negligible

feeding damage. Other Asian elms, such as *U. parvifolia* and *U. wilsoniana*, generally do not leaf out until peak adult emergence has passed.

Species preference based on ovipositional wounds (1996). Overall, significantly more ovipositional wounds per cm² were found on *U. glabra* and *U. sukazweskii* compared to *U. procera*, *U. × hollandica*, and *U. laciniata* ($F = 102.2$; $df = 4,2500$; $P < 0.0001$). Mean number of ovipositional wounds ranged from 0.5·cm⁻² on *U. laciniata* to 1.9·cm⁻² on *U. sukaczewii* (Table 3).

Within tree ovipositional wound distribution (1996). Overall, the mean number of ovipositional wounds by canopy zones of the aforementioned sample trees (i.e. lower, middle, upper, interior) was not significant ($F = 1.9$; $df = 3,2390$; $P = 0.60$). The mean number of ovipositional wounds by quadrant was significant for these same sample trees with more eggs being laid in the southern quadrant compared to the eastern, western and northern quadrants ($F = 21.7$; $df = 3,2390$; $P < 0.0001$) (Table 3).

Percent leaf area consumed by larvae (1995–1998). There was a significant difference in mean percent leaf area removed among elm taxa ($F = 292$; $df = 2,238$; $P < 0.0001$) by elm leafminer larvae (Table 5). Significantly more leaf tissue was removed consistently on the smaller trees of *U. glabra* and *U. sukaczewii* in comparison to *U. elliptica* ($F = 83.1$; $df = 2,206$; $P < 0.0001$). This pattern continued from 1996–1998 with the percent leaf area consumed <12% (data not shown).

A less consistent pattern was observed on large trees where initially *U. procera* experienced significantly more leaf area removed (27%) compared to *U. × hollandica* and *U. laciniata* in 1995 ($F = 499.6$; $df = 2,270$; $P < 0.0001$) (Table 5).

Table 4. Key plant indicators and plant phenology associated with the elm leafminer life cycle, 1998 to 2000².

Life Stage	Key plant indicator	Plant phenology
Beginning of adult emergence	<i>Cercis canadensis</i>	Full bloom
	<i>Crataegus phaenopyrum</i>	First bloom
	<i>Malus</i> ‘Mary Potter’	First to full bloom
	<i>Ribes odoratum</i>	Full bloom
	<i>Viburnum lantana</i>	First to full bloom
End of adult emergence	<i>Kolkwitzia amabilis</i>	First bloom
	<i>Spiraea × vanhouttei</i>	First bloom
Beginning of larval leafmining	<i>Spiraea × vanhouttei</i>	First bloom
	<i>Kerria japonica</i>	Full bloom
	<i>Aesculus hippocastanum</i>	Full bloom
	<i>Kolkwitzia amabilis</i>	Full bloom
	<i>Prunus serotina</i>	Full bloom
	<i>Robinia pseudoacacia</i>	Full bloom
	<i>Syringa vulgaris</i> ‘Miss Ellen’	Full bloom
	<i>Physocarpus opulifolius</i>	Full bloom
	<i>Wisteria macrostachya</i>	First bloom
	End of larval leafmining (larvae exiting leaves and entering soil)	<i>Kerria japonica</i>
<i>Kolkwitzia amabilis</i>		Full bloom
<i>Syringa patula</i> ‘Miss Kim’		Full bloom
<i>Spiraea nipponica</i> ‘Snowmound’		First bloom
<i>Physocarpus opulifolius</i>		Full bloom
<i>Wisteria macrostachya</i>		Full bloom

²Key plant indicators and plant phenology information is based on field observations taken at The Morton Arboretum, May–June, 1998–2000.

Table 5. Percent leaf area consumed for small and large elms species, 1995 ± SEM.

Species/hybrid	Percent leaf area consumer (nearest 1%) ^a
Small trees	
<i>U. elliptica</i>	4 ± 0.1a
<i>U. glabra</i>	14 ± 0.1b
<i>U. sukczewii</i>	16 ± 0.1b
Mean	11
Large trees	
<i>U. × hollandica</i>	10 ± 0.1a
<i>U. laciniata</i>	8 ± 0.1a
<i>U. procera</i>	27 ± 0.1b
Mean	15
Zone	
Small trees	
Lower exterior	15 ± 0.0b
Upper exterior	9 ± 0.1a
Mean	12
Large trees	
Lower interior	18 ± 0.1a
Lower exterior	20 ± 0.1a
Middle interior	21 ± 0.1a
Middle exterior	17 ± 0.1a
Upper interior	20 ± 0.1a
Upper exterior	19 ± 0.1a
Mean	18
Quadrant	
Small trees	
North	10 ± 0.0a
South	13 ± 0.0a
East	14 ± 0.0a
West	12 ± 0.0a
Mean	12
Large trees	
North	21 ± 0.1b
South	16 ± 0.1a
East	20 ± 0.1b
West	21 ± 0.1b
Mean	20

^aValues within columns followed by the same letter are not significantly different ($P < 0.05$; Student-Newman-Keuls multiple comparison test).

However, in subsequent years (1996–1998) *U. × hollandica* had consistently more leaf area removed but at levels <11% compared to *U. procera* and *U. laciniata* (data not shown).

In small trees, no consistent pattern of percent leaf area removed was observed. In only one year (1995) of the four year sampling period was significantly more leaf tissue removed in the lower exterior (LE) zone (15%) compared to the upper exterior (UE) zone (9%) of small trees ($t = 8290.0$; $df = 1,206$; $P = 0.04$) (Table 5). For years 1996–1998, percent leaf area removed was <12% for all zones (data not shown).

As with small trees, no consistent pattern was apparent in percent leaf removed for large trees during the four year sampling period. There was significantly more leaf tissue

removed from the lower interior (LI) and lower exterior (LE) zones in 1996 ($F = 9.5$; $df = 3,152$; $P = 0.02$). In 1998, significantly more leaf area was removed from the middle exterior (ME), upper interior (UI), and upper exterior (UE) zones ($F = 17.0$; $df = 3,820$; $P = 0.005$) and percent leaf area removed for all zones never exceeded 8% during the 1996–1998 growing seasons (data not shown).

Only in 1996 was there significantly less leaf tissue removed from the south quadrant of small trees compared to the north, east, and west quadrants ($F = 15.7$; $df = 3,340$; $P = 0.001$) (data not shown) and percent leaf tissue removed for all quadrants never exceeded 15% during the study. For large trees, significantly more leaf tissue was removed from leaves in the north, east, and west quadrants only in 1995 and percent leaf tissue removed for all quadrants never exceeded 7% for years 1996–1998. ($F = 17.6$; $df = 3,1629$; $P = 0.0005$) (data not shown).

Head capsule widths and number of larval instars. Head capsule measurements suggest the elm leafminer appears to have five instars in northern Illinois (Table 6). These results are consistent with other *Fenusa* leafmining species. Needham et al. (36) states that members of *Fenusinae*, including *F. ulmi*, *F. dohrnii*, *Profenusa collaris*, *F. varipes*, and *F. curta* all have five to six instars. Friend (9, 10) reported the birch leaf-mining sawfly (*F. pumila*) has five instars and Digweed et al. (7) found that *F. pumila* proceeds through four larval instars in Canada. Digweed et al. (7) reports that other exotic birch leafmining species such as the amber marked leafminer [*Profenusa*=*Fenusa thomonsi* (Konow)] and the early birch leaf edgeminer [*Fenusella nana* (Klug)] typically have four to five larval instars. Head capsule widths reported by Friend (9, 10) are comparable to head capsule widths observed in this study.

Preference by geographic origin. Based on defoliation survey results for *Ulmus* taxa, 16 of the 30 European elm taxa evaluated are highly susceptible to elm leafminer feeding damage compared to only two susceptible Asian taxa and no North American taxa. Among European elm taxa, *U. elliptica*, *U. glabra*, *U. sukczewskii* and hybrids ‘Lobel’ and ‘Dodoens’ containing *U. × hollandica*, *U. glabra* and *wallichiana* parentage, *U. × hollandica* ‘Belgica’, *U. × hollandica* ‘Commelin’, *U. × hollandica* ‘Major’, *U. × hollandica* ‘Superba’, *U. × hollandica* ‘Vegeta’, *U. procera* and *U. procera* ‘Purpurea’, and *U. ‘Urban’* are highly susceptible to elm leafminer with greater than 40% defoliation. Guries and Smalley (11) found the most severe elm leafminer feeding injury on *U. glabra*, and hybrids containing at least 40% *U. glabra* or *U. wallichiana* parentage (i.e. ‘Dodoens’, ‘Lobel’), *U. × hollandica* ‘Vegeta’, *U. procera*, and *U. laciniata*. The

Table 6. Head capsule width measurements ± SEM for elm leafminer larval instars feeding on European elms, 1999 to 2000 (330 to 445 DD₅₀).

Date	Mean head capsule width (mm)
1 st Instar (JD = 130 or 10 May)	0.58 ± 0.022
2 nd Instar (JD = 134 or 14 May)	0.65 ± 0.001
3 rd Instar (JD = 141 or 21 May)	0.74 ± 0.012
4 th Instar (JD = 144 or 24 May)	0.81 ± 0.008
5 th Instar (JD = 147 or 27 May)	0.85 ± 0.006

high correlation between leafing out of the aforementioned European elms and adult elm leafminer emergence suggests a lack of resistance for elm leafminer feeding damage. In contrast, results from this study suggest Asian elms have some level of resistance to elm leafminer larval feeding. Asian elms such as *U. davidiana*, *U. japonica*, *U. lamellosa*, and *U. pumila* leaf out at the same time as adult elm leafminer emergence but experience very low to low defoliation. Consistent with our findings, Guries and Smalley (11) report that *U. japonica*, *U. pumila*, *U. parvifolia* and hybrids, *U. americana*, and *U. thomasi* had no or negligible elm leafminer feeding damage. Other Asian elm taxa, *U. wilsoniana* and *U. parvifolia* avoid leafminer feeding damage by leafing out well passed the adult emergence time period. Additionally, we found *U. carpinifolia* and cultivars, and *U. × hollandica* ‘Belgica’ and ‘Klemmer’ to have very low to moderate susceptibility to elm leafminer consistent with findings by Guries and Smalley (11).

Asian and North American elm taxa appear to be less susceptible to egg laying by the adult female elm leafminer and subsequent larval feeding damage and provide a rich gene pool for future elm breeding programs. Like Guries and Smalley (11), this study found virtually all of the Asian taxa less susceptible elm leafminer feeding. Many of these same Asian species (i.e., *U. davidiana*, *U. japonica*, *U. lamellosa*, *U. propinqua*, *U. glaucescens*, *U. macrocarpa*, and others) have also been shown to be less suitable for other leaf-feeding insects such as the elm leaf beetle, Japanese beetle, spring and fall cankerworms, and gypsy moth (15, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 43).

Oviposition and plant phenology. Adult elm leafminers emerge over a very narrow window of a few days to a week. Field observations indicate that during warm periods, adults may only be present for 3 to 5 days and then disappear. This makes field detection and application of chemical control by the PHC practitioner extremely challenging. In addition, adult emergence and egg-laying can vary greatly from year to year based on weather conditions. The use of degree day (DD) models in conjunction with indicator plant phenology can greatly aid practitioners in more accurate monitoring and detection of adult emergence and oviposition facilitating more timely and efficient chemical treatments resulting in more effective control minimizing plant damage.

Based on field observations, trap catches, and weather data associated with this study, adults are present for just a few days and with a difference of only 69 DD₅₀ between initial and peak adult emergence. For example, with daily high temperatures in the range of 70 to 80F and lows in the 50sF, and using a threshold of 50F, 60 to 70 degree days could be accumulated within a week. In addition, both the birch and alder leafminers overwinter in the top 1 to 2 inches of the soil, at the same depth as the elm leafminer (7, 9, 36). They emerge within the same range of accumulated DDs and correspond to key indicator plants common to elm leafminer adult emergence (7, 9, 36, 37, 39). The degree day accumulations for elm leafminer feeding (range of 289 to 560 DD₅₀) are well within the range of DDs for two other members of the *Fenusa* genus, the alder leafminer (*Fenusa dohrnii*) and the birch leafminer (*F. pusilla*), which have larval leafmining occurring between 275 to 500 DD₅₀ (7, 10, 16, 37, 39).

Orton (37) lists four common indicator plants, *Robinia pseudoacacia*, *Aesculus hippocastanum*, *Spiraea × vanhout-*

tei in full bloom and *Syringa vulgaris* with late to finish bloom during larval leafmining by *F. dohrnii* and *F. pusilla*. These are consistent with plant phenology records noted in this study for elm leafminer larval feeding.

Synchronization between host plant phenology and insects may also be a factor in what may initially appear to be host plant resistance versus true host plant resistance. Field observations made in the elm collection at The Morton Arboretum from 1995 to 2000 clearly showed that the more susceptible elm taxa of *U. elliptica*, *U. glabra*, *U. laciniata*, and *U. sukczewii* consistently leafed out earlier than other elm species and were closely synchronized with adult leafminer emergence. Elm leaf taxa that are in flower at the time of adult leafminer emergence such as *U. × hollandica* cultivars, *U. procera*, and *U. carpinifolia* and cultivars suffered feeding damage, but at a lower amount than the aforementioned preferred hosts. In addition, the Asian elm species of *U. davidiana*, *U. japonica*, *U. lamellosa*, and *U. pumila* leaf out in synchrony with adult emergence but suffer virtually no significant feeding damage and therefore are less susceptible due to their physiology. Many of the other Asian taxa such as *U. parvifolia* and *U. wilsoniana* and certain North American taxa do not leaf out until after peak leafminer emergence has passed and consequently avoid feeding damage, appearing resistant. These phenological traits should be more fully explored in plant breeding programs.

Within tree distribution. For highly preferred elm taxa, the adult female elm leafminer appears to show no preference for oviposition with regard to height or location (i.e. interior versus exterior) within the tree canopy. While there is a statistically significant difference with regard to quadrant preference, it has no biological significance (i.e., 1.7 ovipositional wounds for east versus 2.3 wounds for south) for practitioners. Tree height appears to play a minor role for small trees with the upper zone having less leaf area consumed, but this pattern does not hold for large trees. Like zones, there are no major patterns for tree quadrant for small trees as it relates to mean number of ovipositional wounds and mean percent leaf area consumed. Leaf area consumed is the same for all quadrants of small trees, but in large trees the south quadrant experiences the least area consumed. While statistically significant, these differences are negligible from a biological and management perspective with no more than a 6% range in leaf area consumed, barely detectable with the naked eye. This is in contrast to other leaf eating insects, especially the Japanese beetle. It is commonly known that adult Japanese beetles begin feeding in the top of the canopy and progress downward. If sampling is confined to the lower portions of the tree canopy, feeding damage can be overlooked or underestimated. In contrast, results from this study indicate practitioners should be able to examine susceptible elm trees for elm leafminer damage from any canopy zone (low, middle, upper) and canopy quadrants (N, S, E, W) with confidence they are obtaining an accurate leafminer damage assessment. This is can minimize time needed in sampling trees for pest management decision making.

Based on the results of this study, a plant health care technician and practitioner could sample from any zone and/or quadrant of either a small or large preferred host tree and obtain a very accurate picture as to pest density and potential for leaf damage. This information can greatly benefit the field practitioner in making plant health care

(PHC) treatment decisions and assuring more efficient use of time and materials.

Implications for future elm breeding programs. The large number of Asian and North American elm taxa demonstrating less susceptibility to the elm leafminer feeding damage provide a rich genetic pool for future elm breeding programs. Many of the taxa are demonstrating resistance or are minimally less preferred by other leaf-feeding insect pests such as the elm leaf beetle, Japanese beetle, spring and fall cankerworms, and gypsy moth. Five new elm hybrids, 'Accolade', 'Commendation', 'Danada', 'Triumph', and 'Vanguard', containing Asian elm parentage mentioned in this study have been recently released into the landscape trade and are gaining in popularity for use in landscapes and urban forests. With the aforementioned rich gene pool, more are bound to follow, reducing the need for chemical sprays and reducing the impact on applicators and the environment.

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