Seasonal Density and Impact of Mining of *Lyonetia prunifoliella* (Lepidoptera: Lyonetiidae) on Semidwarf Apple Trees in Connecticut[1]

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J. Entomol. Sci. 31(4): 440-452 (October 1996)

ABSTRACT Number of adults on unbaited yellow sticky traps and of new mines and pupae on semidwarf 'McIntosh' or 'Mutsu' apple, *Malus domestica* Borkhausen, trees was recorded weekly at Southington, CT, to determine the seasonal density of *Lyonetia prunifoliella* (Hübner) in 1989 and 1990. Densities were highest between August and October when leaves of the second flush were developing. On sprayed 'Mutsu' trees, *L. prunifoliella* had at least six generations between May and November 1989, and four during these months in 1990. An application of permethrin in April probably eliminated the first generation in 1990. On 'Mutsu' apple trees, the loss of leaves of the second flush in 1990 was significantly greater on terminal shoots with mining than on those without it. Foliar mining also significantly reduced the length and basal diameter of terminal shoots. By reducing woody growth on young trees, the premature loss of leaves may delay the first harvest. Pruning in summer and fewer applications of fertilizer might slow the population growth of *L. prunifoliella*.

KEY WORDS Abscission, apple, damage, density, *Lyonetia prunifoliella*, Lyonetiidae, mining

Lyonetiid larvae in the genus *Lyonetia* Hübner mine leaves of successional woody plants in north temperate areas (Needham et al. 1928, Kuroko 1964, Emmet 1985, Maier 1995). *Lyonetia prunifoliella* (Hübner), formerly known as *L. speculella* Clemens (Schmitt et al. 1996), is a Holarctic pest of apple, *Malus domestica* Borkhausen (Frost 1924, Chang 1965, Sekita 1991), and *L. clerkella* (L.) is a Palaearctic pest of apple and peach, *Prunus persica* (L.) Batsch (Berg 1960, Berlinger 1971, Esmaili 1971, Naruse 1978). In the mid-1980s, populations of *L. prunifoliella* reached outbreak levels in apple-growing areas of northeastern North America (Maier 1988, Brown 1989). Brown (1990) has reported that density is similar in unmanaged and managed orchards, which suggests that *L. prunifoliella* may already have developed some resistance to insecticides. When populations of *Lyonetia* spp. become large, injury from

[1] Received 25 January 1996; Accepted for publication 24 August 1996.

larval mining causes leaves to abscise prematurely (Naruse 1978, Maier 1988). In apple orchards, vigorous cultivars planted on dwarfing rootstocks are especially susceptible to damage (Maier 1988, Sekita 1991) because from August to October they continually produce new leaves which females select for oviposition.

First instars of *L. prunifoliella* form individual linear mines below upper surfaces of the youngest leaves (Frost 1924, Maier 1988), especially on vegetative shoots of apple trees (Brown and Welker 1992). Third (last) instars eat all of the tissue between the upper and lower epidermis, sometimes making one or more new mines on leaves below where the first instars mined. Larvae pupate in silken cocoons suspended from undersides of leaves. Adults have a light aestival morph and a darker autumnal morph (Maier 1988, Schmitt et al. 1996); the latter overwinters (Sekita and Yamada 1979a,b). In eastern Asia, spring and summer generations can be completed in 2 to 5 wk, the developmental time decreasing with increasing temperature (Chang 1965, Sekita 1991). In West Virginia, Schmitt et al. (1996) have estimated that a generation completed during August and September requires about 5 wk.

The objectives of this study were to document the widespread occurrence of *L. prunifoliella* in Connecticut orchards, to determine the weekly density of adults on sticky traps and of new mines and pupae on trees, and to measure the effect of mining on the abscission of leaves and on woody growth of semidwarf apple trees.

Materials and Methods

Infestations in Orchards. Orchards throughout Connecticut were sampled in early October 1987 and 1988 to determine the percentage of trees infested by *L. prunifoliella*. In each orchard block of 1 to 2 ha, 50 or 100 semidwarf trees were inspected for mining. Trees selected for sampling were uniformly distributed throughout the block, and the same trees were observed in both years. The commercial orchards received 9 to 12 insecticidal applications (mainly azinphosmethyl) annually.

Seasonal Density. Life stages of *L. prunifoliella* were sampled mainly on semidwarf 'Mutsu' apple trees (M7 rootstock) randomly selected in a 1-ha planting of mixed varieties at Southington, Hartford Co., CT (41°37' N latitude). Adults also were sampled in a nearby 'McIntosh' orchard, which is described by Maier (1993). The 'Mutsu' orchard was bordered by a plum orchard to the north, by a peach orchard to the south, and by apple orchards to the east and west. The 'Mutsu' trees, which were planted in 1986, were about 2 m high in 1989. These trees were pruned annually. They were separated by 4.3 m within rows and by 6.7 m between rows. Herbicides were used to maintain a 1-m wide weed-free strip in the center of each row.

Apple trees of both cultivars were sprayed with insecticides and fungicides. In 1989, 'McIntosh' trees were sprayed with 70-s oil (Superior 70 oil, FMC Corp., Middleport, NY) at 66 liters AI/ha on 15 April; azinphosmethyl (Guthion 50W, Mobay Chemical Corp., Kansas City, MO) at 0.7 kg AI/ha on 20 May, at 0.8 kg AI/ha on 25 May, and at 0.9 kg AI/ha on 31 May, 10 and 26 June, 3 and 22 July, and 2 and 31 August; and methomyl (Lannate 1.8L,

E. I. DuPont de Nemours and Co., Inc., Wilmington, DE) at 1.5 kg AI/ha on 31 May. In 1990, these trees were treated with 70-s oil at 21.4 liters AI/ha on 13 April; permethrin (Pounce 3.2 EC, FMC Corp., Middleport, NY) at 0.5 kg AI/ha on 27 April; azinphosmethyl at 0.8 kg AI/ha on 11, 15, and 25 May, 9 and 20 June, 15 and 29 July, and 12 and 26 August; and carbaryl (Sevin 50W, Rhone-Poulenc Ag Co., Research Triangle Park, NC) at 0.6 kg AI/ha on 25 May and at 1.8 kg AI/ha on 30 June. The total of non-oil sprays was 10 in 1989, and 12 in 1990.

In 1989, 'Mutsu' trees were treated with azinphosmethyl at 1.4 kg AI/ha on 18 and 26 June and on 3 July and with endosulfan (Thiodan 50W, FMC Corp., Middleport, NY) at 2.8 kg AI/ha on 2 August. In 1990, these trees were sprayed with 70-s oil at 55.4 liters AI/ha on 14 April; permethrin at 0.5 kg AI/ha on 29 April; and azinphosmethyl at 0.8 kg AI/ha on 11, 15, and 25 May, 2, 9, 20, and 30 June, 15 and 29 July, and 12 and 26 August. The total of non-oil insecticidal applications was 4 in 1989 and 12 in 1990. The first harvest was in 1990.

Adult abundance was monitored weekly from May to November 1989 and 1990 on unbaited yellow sticky traps (Trécé, Salinas, CA) placed singly on five 'McIntosh' trees randomly selected in the northwesternmost row of an orchard. In 1990, abundance also was recorded on traps placed on five 'Mutsu' trees randomly chosen in a second orchard located 0.1 km to the north. Although the two-sided traps (14 × 23 cm) were designed to catch adults of the apple maggot, *Rhagoletis pomonella* (Walsh), they also effectively capture the crepuscular and nocturnal adults of gracillariid species with leaf-mining larvae (Maier 1992). On 'McIntosh' trees, each trap was hung vertically at 2 m in the center of the canopy, which was 3 m in diam. On 'Mutsu' trees, each trap was suspended at 1.5 m in the center of the canopy, which was about 1 m in diam. Traps were replaced every 2 wk. Trees with traps were not sampled for immatures.

All of the leaves on 'Mutsu' trees were inspected weekly to count the number of new linear mines and pupae. The number of trees sampled was 22 in 1989 and 7 in 1990. In 1989, the sampled trees were distributed randomly throughout the planting. In 1990, trees were located at the eastern edge of the orchard. In addition, 10 unsprayed wild trees of unknown cultivar were examined for mines every 2 wk in spring 1990. Mines and pupae were counted only when they first appeared, and none was removed from trees. Because females oviposit only in the youngest leaves, new mines recorded weekly were confined to the upper 1 to 3 leaves of each stem. The silken hammocks of new pupae were marked with waterproof ink to prevent them from being recounted later.

Temperature was recorded at a permanent weather station at Hamden, New Haven Co., which was 25 km to the south of Southington. Daily mean temperature was calculated by averaging the daily high and low temperature.

Voucher specimens of adults of *L. prunifoliella* are deposited in the insect collection in the Department of Entomology, Connecticut Agricultural Experiment Station, New Haven, CT.

Impact of Mining. Abscission caused by mining of leaves of the second flush was measured on 'Mutsu' apple trees at the Southington orchard in 1990. Leaves of the first flush did not abscise from larval mining. In early August at the start of the second flush, terminal shoots were randomly selected to be part of the experimental (mining allowed) or the control group (mining prevented).

The second flush produced about 50% of total leaves on terminals. Leaf drop was monitored weekly until the number of abscised leaves on control terminals exceeded 5% of the total leaves on them. Mining on terminal shoots of control trees was prevented by spraying the new foliage (usually 1-3 leaves/terminal/application) every week until October with a dilute solution of oxamyl (Vydate 2L, E. I. DuPont de Nemours and Co., Inc., Wilmington, DE) at 0.6 g AI/liter, which reduces populations of *L. prunifoliella* (Brown 1989). At the end of November, the length and the width of terminal shoots that developed in 1990 were measured.

Means for percentage of abscised leaves and for length and width of stems with and without mined leaves were compared with two-tailed *t* tests (Wilkinson 1988). Before analyzing data on abscission, an arcsin transformation was performed on the data.

Results and Discussion

Infestations in Orchards. Larvae of *L. prunifoliella* mined leaves in all apple orchards inspected in 1987 and 1988 (Table 1). The range and mean of percentages of infestation were similar in 1987 and 1988. The infestation level was lowest in the three orchards sampled in the eastern half of Connecticut. Although Brown (1990) used different sampling methods, he similarly concluded that the annual abundance of *L. prunifoliella* did not vary greatly. Over 5 yr, he found that the greatest annual change in relative abundance in orchards of West Virginia was about three-fold.

Seasonal Density. In the 'McIntosh' orchard, adults had eight flights in 1989, and five or six in 1990 (Fig. 1). Two or three large flights occurred between September and early November when insecticides were not being applied and when new leaves were being produced. Catches on traps were more variable on most dates in late 1990 than in late 1989. Based on their dark coloration, the two adults on traps on 4 May 1989 and one on 26 April 1990 had overwintered; the autumnal morph was not seen again during the spring and summer. The second and third small flights between late-May and June 1989 were absent in 1990. Permethrin applied on 27 April 1990 probably killed most of the autumnal adults before they could oviposit to start the first generation in May. The limited number of new leaves unfurling between mid-June and late-July, the insecticidal applications between May and July, or both, probably suppressed population growth. On the 'Mutsu' trees, moths were first captured in July (Fig. 2). They had three well-separated flights, with possibly an additional one at the beginning (mid-August) and the end (late-September) of the large flight that peaked in mid-September. Permethrin applied on 29 April 1990 apparently killed autumnal adults that had overwintered and would have started a generation in May.

In Japan, Yoshii and Abe (1990) observed that *L. prunifoliella* annually had at least one large flight and six to seven smaller ones. Because moths live 10 to 20 d (Yoshii and Abe 1990), each of the flights (except the last of the year and the first of the next year by autumnal adults) recorded in Japan and Connecticut probably contained adults of a different generation.

Table 1. Percentage of semidwarf apple trees infested by *Lyonetia prunifoliella* in Connecticut orchards in October 1987 and 1988.

Orchard Location*	Cultivar	No. trees examined	% Trees with mines: 1987	1988
	Orchards sprayed with insecticides			
Ledyard	Many	50	6	6
East Lyme	Idared	50	12	14
Plainfield	Many	100	19	22
Middlefield	Many	100	25	37
Wallingford	Empire	100	63	73
Bethlehem	Many	50	68	82
Southington A	Cortland and Rome	50	96	80
Sharon	Many	100	81	98
Southington B	Empire and McIntosh	100	99	100
	Orchards not sprayed with insecticides			
Hamden	Many	50	78	76
Salisbury	Many	50	96	98
Mean			58.5	62.4

* Orchards A and B at Southington were separated by 1 km. The orchard at Hamden received 11 captan sprays in 1987, and 13 in 1988.

The density of new mines on 'Mutsu' trees was highest in the same week in early September 1989 and 1990 (Fig. 3). There were five or six periods of mining in 1989, with the first and last being the smallest, and three or four in 1990. The springtime application of permethrin apparently caused sufficient adult mortality to suppress the first generation in 1989 and 1990. On unsprayed wild apple trees at Southington, I observed four new mines in mid-May 1990, which corresponded to the first generation that developed on the foliage of the first flush of 1989. The density of mines between August and September had two large peaks, which overlapped. In Connecticut, the mean temperature was 22.6° C in August and 18.4°C in September 1989, and it was 22.7 and 17.6°C in these respective months in 1990. In Japan, the life cycle (egg to adult) can be completed in 3 to 4 wk at 17°C, in 2.5 to 4 wk at 20°C, and in 2 to 3 wk at 23°C

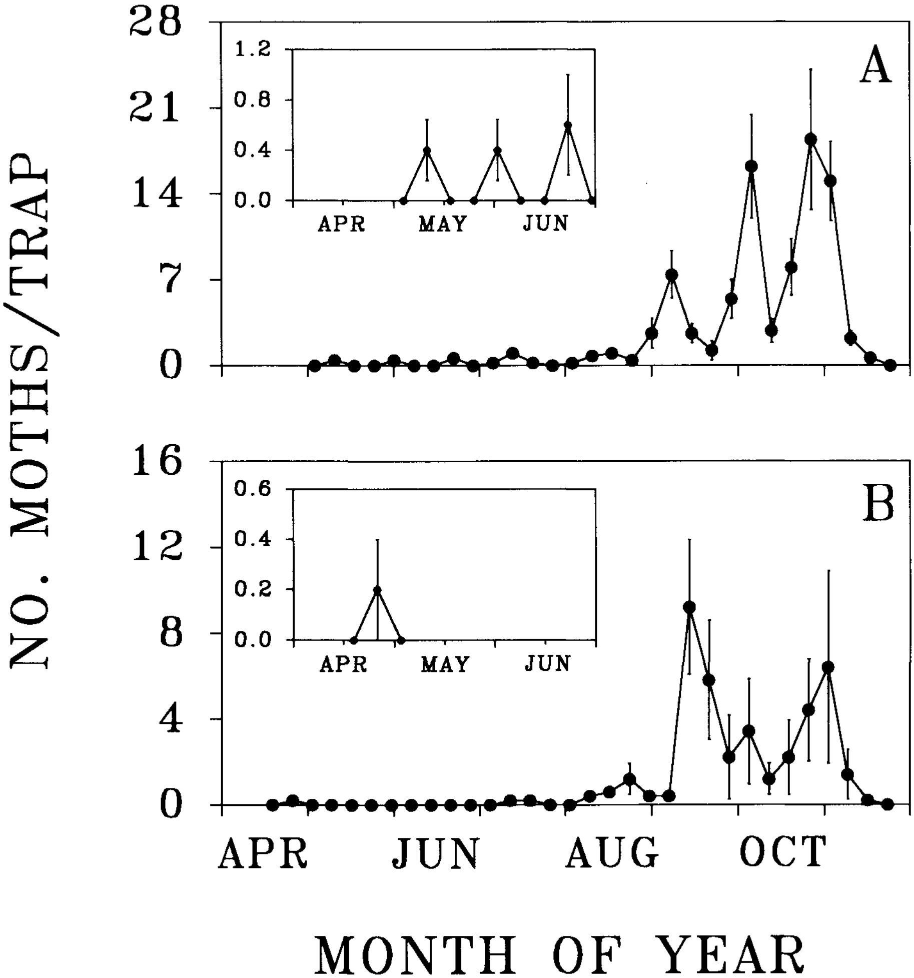

Fig. 1. Weekly density of moths of *Lyonetia prunifoliella* captured on unbaited yellow sticky traps on semidwarf 'McIntosh' apple trees at Southington, CT, during (A) 1989 and (B) 1990. Insets are enlarged graphs of data taken between April and June. Vertical lines represent ± standard error of the mean.

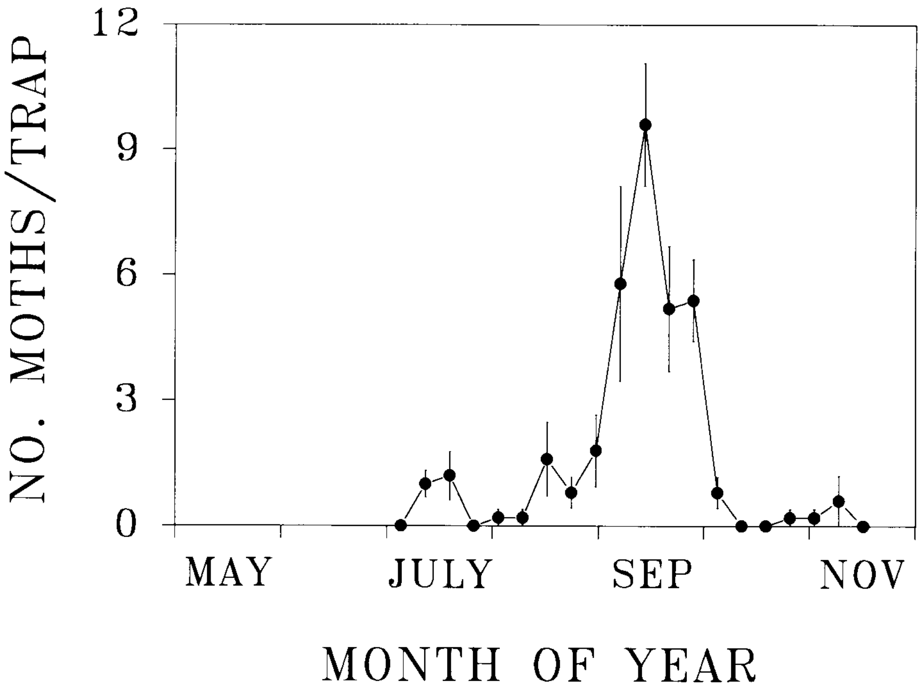

Fig. 2. Weekly density of moths of *Lyonetia prunifoliella* captured on unbaited yellow sticky traps on semidwarf 'Mutsu' apple trees at Southington, CT, during 1990. Vertical lines represent ± standard error of the mean.

(Sekita 1991). Thus, if populations in the two areas have similar temperature-dependent development and short-lived adults, the overlapping peaks recorded in Connecticut may represent at least two generations. Long-lived adults that have two or more bouts of oviposition could also cause the overlapping peaks in larval abundance late in the growing season.

Pupal density also had two overlapping peaks between August and September of each year, with another four smaller ones in 1989 and two in 1990 (Fig. 4). In 1990, the absence of the first two periods of pupation seen in 1989 was probably due to the application of permethrin in April and to the smaller sample size in 1990 (7 trees) than 1989 (22 trees).

Based on the seasonal density of adults on traps (Fig. 1-2), new mines (Fig. 3), and pupae (Fig. 4), *L. prunifoliella* can have at least six generations per year when moths that overwinter are not killed by springtime applications of insecticides. Another generation may be possible because eight distinct flights (the last flight of a year and the first of the next spring are made by the same moths) were recorded on 'McIntosh' trees in 1989 (Fig. 1). In West Virginia,

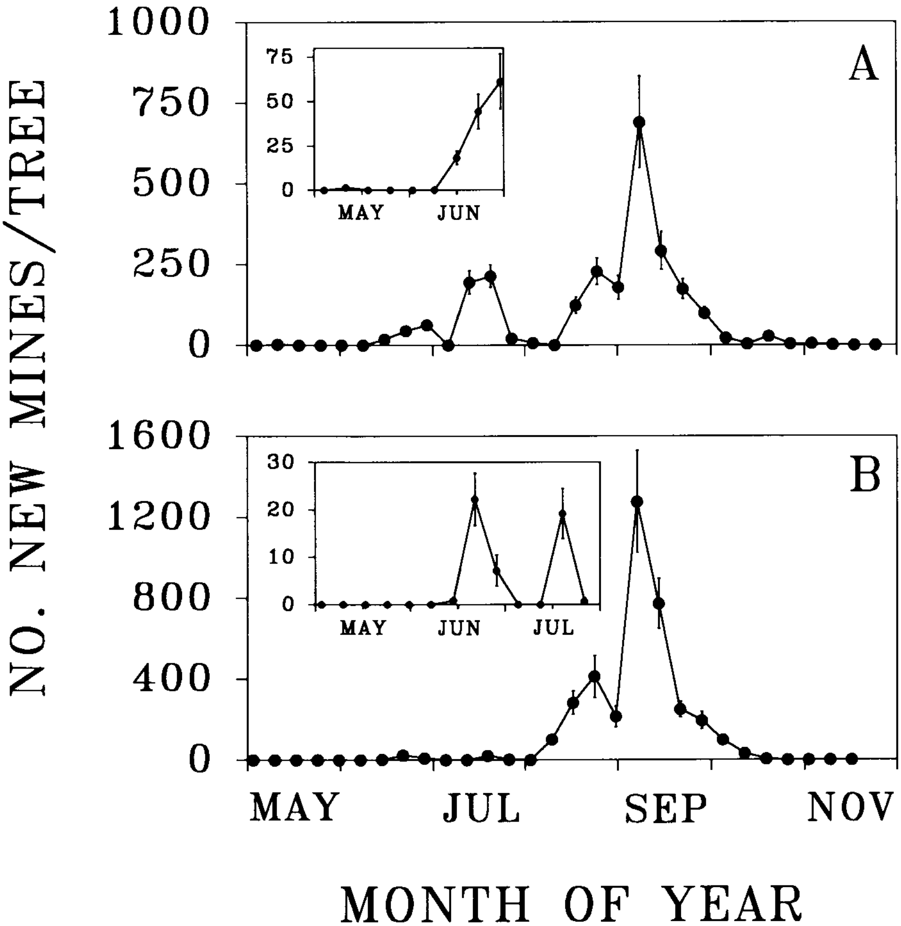

Fig. 3. Weekly density of new mines of *Lyonetia prunifoliella* observed on semidwarf 'Mutsu' apple trees at Southington, CT, during (A) 1989 and (B) 1990. Insets are enlarged graphs of data taken between May and July. Vertical lines represent ± standard error of the mean.

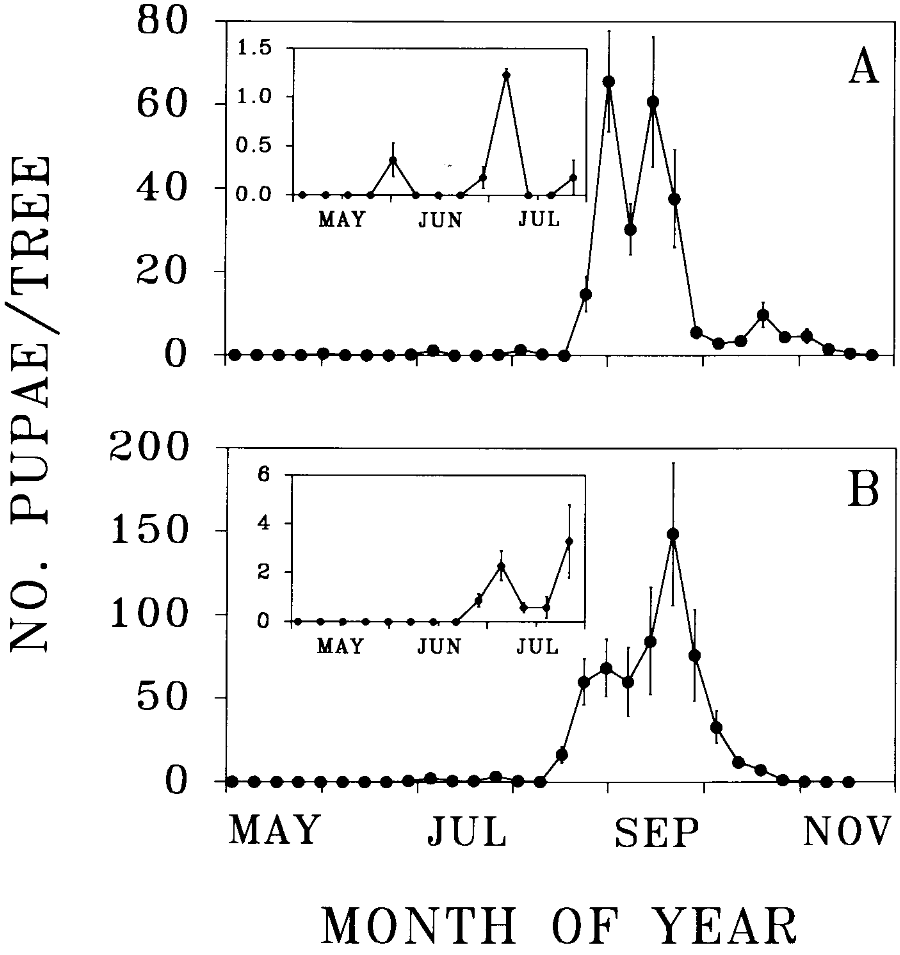

Fig. 4. Weekly density of pupae of *Lyonetia prunifoliella* observed on semidwarf 'Mutsu' apple trees at Southington, CT, during (A) 1989 and (B) 1990. Insets are enlarged graphs of data taken between May and July. Vertical lines represent ± standard error and mean.

Schmitt et al. (1996) have estimated that *L. prunifoliella* has six to eight generations annually. Chang (1965) has observed five generations in Yantai, China (37°30′ N latitude). In Japan, Sekita and Yamada (1979b) and Sekita (1991) have reported five or six in Aomori (41°50′ N), whereas Yoshii and Abe (1990) have noted six in Fukushima (37°44′ N). Emmet (1985) has reported only one generation in Great Britain, but he provided no quantitative data to support his contention. Leafminers may be overlooked in spring and early summer when their populations are small (Fig. 1-4).

The density of *L. prunifoliella* peaks between August and October (Fig. 1-4) when semidwarf apple trees are continually producing leaves of the second flush. Females lay eggs in these new leaves, and larvae survive best in this succulent foliage (Sekita 1991). Even though Brown (1989) and Maier (1995) sampled much less frequently than I did in this study, they also found that density is highest in August or September. Furthermore, Sekita and Yamada (1979b) reported that in Japan *L. prunifoliella* attains its highest abundance in one of these two months. In a multiyear study, Sekita (1991) determined that Japanese populations of *L. prunifoliella* tend to increase from spring to fall. In some years, however, the last generation may not have time to develop fully (Sekita and Yamada 1979b).

Impact of Mining. Larval mining by *L. prunifoliella* caused premature leaf drop of 'Mutsu' leaves of the second flush (Fig. 5). Between 13 September and 22 November, the mean percentage of dropped leaves was significantly greater on shoots with mined leaves than on those without mined leaves (t = 3.3 - 12.8; df = 50; P < 0.002). On 1 November, by which time all apples would be picked, shoots with mining (n = 31) had lost 35.9 ± 3.7% (SE) of their leaves, whereas those without damage (n = 21) had dropped only 1.5 ± 0.6%. On shoots with mining, leaves dropped up to 1 November were entirely brown from being mined. Brown leaves that died from mining sometimes remained on the stem for several weeks before dropping; thus, the date of leaf abscission by itself may underestimate the potential impact of mining.

Mining also significantly reduced the length (t = 2.5; df = 50; P = 0.016) and basal diameter (t = 4.4; df = 50; P < 0.001) of terminal shoots that grew in 1990. The total length of shoots with and without mining was 73.9 ± 3.0 cm (n = 31) and 84.4 ± 3.2 cm (n = 21), respectively, whereas the diameter was 0.47 ± 0.01 cm with mining and 0.54 ± 0.01 cm without it.

Based on the seasonal density of mines (Fig. 3), larval mining by *L. prunifoliella* should have its greatest impact on the second flush of semidwarf trees. Naruse (1978) has shown that the rate of defoliation of peach trees is linearly related with larval density of *L. clerkella*. If the negative effect of mining on woody growth of young apple trees was repeated for several years, the initial year of cropping might be delayed. A severe infestation on trees with dwarfing rootstock may have a greater negative impact on the growth and the fruiting of cultivars, such as 'Mutsu,' that are harvested late in the growing season than on those harvested earlier. The negative effect of mining may decrease with tree age and with size.

Chemical control of *L. prunifoliella* in July or August would be difficult because applications of pyrethroids or carbamates, which currently are not recommended for use late in the growing season, would disrupt biocontrol of

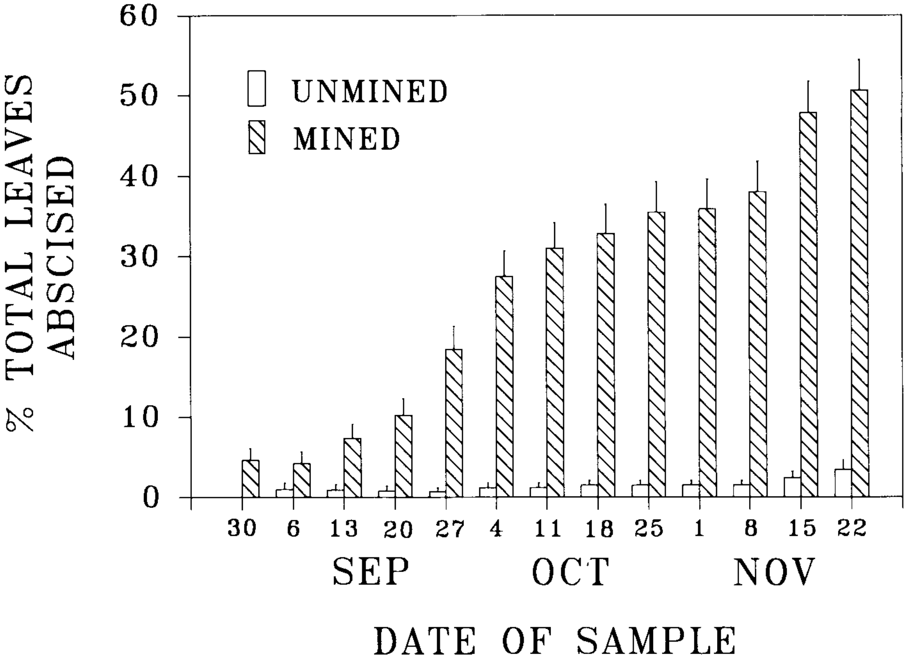

Fig. 5. Comparison of the weekly abscission of leaves (percentage of total leaves of the second flush dropped) with or without larval mines of *Lyonetia prunifoliella* on terminal shoots of 'Mutsu' apple trees at Southington, CT, in 1990. Vertical lines at the top of bars represent standard error of the mean.

other pests in apple orchards. Summer pruning of vegetative shoots, such as root sprouts and water sprouts, may slow population growth because the amount of larval food would be reduced. Also, if applications of fertilizer that encourage vegetative growth were avoided, the rate of population growth might be decreased.

Acknowledgment

C. Alling and D. Best provided excellent technical assistance throughout this study. I appreciate the cooperation of D. Todd and M. S. Ramsay (Lewis Farms, Southington) who allowed me to study leafminers in their orchard. Many other apple growers assisted by permitting me to survey their orchards in 1987 and 1988. I thank L. Mustermann (School of Epidemiology and Public Health, Yale University, New Haven) for translating parts of Japanese articles. R. Weseloh (Connecticut Agricultural Experiment Station) and anonymous reviewers made helpful comments on earlier drafts of this manuscript.

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