Leucanthiza Dircella (Lepidoptera: Gracillariidae): A Leafminer of Leatherwood, *Dirca Palustris*

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LEUCANTHIZA DIRCELLA (LEPIDOPTERA: GRACILLARIIDAE): A LEAFMINER OF LEATHERWOOD, *DIRCA PALUSTRIS*

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ABSTRACT

Leatherwood, *Dirca palustris* (Thymelaeaceae), is an understory shrub ranging throughout most of the eastern and central United States and adjacent Canada. During 1997–1999, we conducted studies to identify and assess the impact of a leafminer that was causing significant damage to leatherwood plants in eastern Gogebic County, Michigan. *Leucanthiza dircella* was identified as the only insect responsible for the leaf mining activity on leatherwood. In northern Michigan, *L. dircella* completed one generation per year. Adult moths were captured on yellow sticky panels suspended from leatherwood branches. In 1997 and 1998, most adults were captured during the first sampling period of each year: 6–12 June 1997 and 3–19 May 1998. In 1999, no moths were collected during 5–29 April but adults were collected between 30 April and 22 June 1999. In 1999, initiation of adult flight coincided with *D. palustris* leaf flush. In 1997, leaf mines were very noticeable by 30 June. The mean number of live *L. dircella* larvae per mine was 3.5 on 17 July 1997 and then decreased as the season progressed, with most larvae having exited the mines by late August to pupate in the soil. In late August 1997, the mean surface area of a single leaf was 17.8 cm^2 and the mean surface area of a single mine was 5.9 cm^2. At the end of the 1997 growing season, 31% of the leatherwood leaves contained *L. dircella* mines, and 11% of the total leaf surface area had been mined. In 1999, only 8% of the leaves in the study area contained *L. dircella* mines. No leatherwood mortality was evident as a result of *L. dircella* leaf mining. Seven species of hymenopteran parasitoids were reared from *L. dircella* larvae, including one braconid in the genus *Pholetesor* and six eulophids in the genera *Chrysocharis*, *Closterocerus*, *Pnigalio*, and *Sympiesis*. Three coleopterans that were commonly observed on leatherwood plants during all years included: *Glyptina brunnea* (Chrysomelidae), *Phyllobius oblongus* (Curculionidae) and *Polydrusus sericeus* (Curculionidae).

Leatherwood, *Dirca palustris* L. (Thymelaeaceae), is an understory shrub that grows to a height of 1–3 m and ranges throughout most of the eastern and central United States and adjacent Canada (Fernald 1950, Vogelmann 1953). Leatherwood is most often found growing in nutrient rich, mesic hardwood stands (Britton and Brown 1970, Cleland et al. 1993, Kotar et al. 1988,

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Radford et al. 1979). The common name leatherwood is earned from the plant's tough fibrous bark, which Native Americans utilized as a source of fiber for making items such as mats, bags, cords, and rope (Whitford 1943).

Leatherwood contains toxins that cause irritation and blistering when contacted by skin, and gastrointestinal discomfort when swallowed (Fuller and McClintock 1986, Muenscher 1964). Because of these properties, there has been some preliminary research exploring the potential of leatherwood extracts as deterrents for vertebrate herbivores (Ramsewak et al. 1999, Zasada et al. 1999). Interestingly, there are some references of leatherwood being used by early settlers for medicinal purposes (Fielder 1975). An ointment was made with leatherwood bark and sarsaparilla (*Aralia* sp.) for treating severe skin diseases, and a tea made from the leatherwood roots was used for treating kidney problems. Moreover, a study was conducted during the early 1900's, testing the efficacy of leatherwood extracts as a purgative (Lecours 1924).

Leatherwood has been planted as an ornamental shrub because its early spring bloom, tree-like appearance, and tolerance to full sun make it very suitable for shrub beds and rock gardens (Esson 1949, Tredici 1983). Tredici (1983) also noted that leatherwood is easily germinated from seeds that have been subjected to a cold period.

Although uncommon throughout most of its range, when leatherwood does occur in the forest understory, it frequently grows in dense patches (Nevling 1962). This is often the case in mature hardwood forests in northern Wisconsin and the western Upper Peninsula of Michigan, where leatherwood may be an important understory component (Curtis 1959, Kotar et al. 1988, John C. Zasada, USDA Forest Service, Rhinelander, WI, pers. obs.). During 1997–1999, we conducted a study to identify and determine the impact of any insects that were causing significant leaf mining damage to leatherwood plants in eastern Gogebic County, Michigan.

MATERIALS AND METHODS

Studies were conducted during 1997–1999 on the Ottawa National Forest, Watersmeet Ranger District, near Taylor Lake in eastern Gogebic County, Michigan (Fig. 1). The area selected was classified as mature hardwood forest and was composed primarily of sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and American basswood (*Tilia americana*). Leatherwood was abundant in the understory and had undergone heavy leaf mining damage during the early 1990's (John C. Zasada, pers. comm.). In 1997, from 6 June through 25 August, we attached one double-sided yellow sticky panel (15 cm by 30 cm) on each of six leatherwood plants, 1 to 2-m tall, to capture adult leafminers. Sticky panels were collected at two-week intervals, with the exception of the first two sample periods which were collected at six-day and four-day intervals, respectively. Each sticky panel was placed in a plastic bag, and frozen for later inspection. During each site visit, we visually examined leatherwood foliage for ovipositing insects and leaf mining activity. We collected specimens of suspect insects that belonged to leaf mining families. We also collected leaf samples from ten leatherwood plants at two-week intervals beginning 17 July 1997. Each sample consisted of one branch tip per plant, ca. 20-cm in length. Each branch tip typically had 6 to 12 leaves and included 2 to 3 year's growth. We selected a branch tip that appeared to represent the leaf mining activity currently found on each individual plant being sampled. Leaf samples were placed in-

Figure 1. County outline map of Michigan, with dots representing the approximate location of (1) the leatherwood study site in Gogebic County, ca. 46° 15′ N Lat, 89° 3′ W Long; (2) the nearest weather station in Watersmeet, Gogebic County, ca. 46° 17′ N Lat, 89° 10′ W Long; and (3) the weather station in Stambaugh, Iron County, ca. 46° 3′ N Lat, 88° 37′ W Long. Darkened area on insert map indicates the location of Michigan within the United States.

dividually in plastic bags, and stored on ice for later processing in the laboratory.

On 25 August 1997, after leaf mining had ceased and most larvae had exited the mines, we collected leaf samples in a 200-m by 100-m area surrounding the central study site. We sampled 110 leatherwood plants, taking one branch sample from each plant that was 1 m in height or taller. Each branch sample was chosen to be representative of the leaf mining damage level for the particular plant being sampled.

In the laboratory, the 1997-collected leaves that contained mines were held over a strong light, allowing the number of larvae inside of each mine to be counted. We also recorded if mines contained holes through which larvae could have exited to pupate in the soil. In addition, we noted if leaves pos-

sessed fungal rust spots and if the section of branch sampled had evidence of other insects such as scale insects. After the leaves were examined, they were photocopied so the total leaf surface area and total mined area could be determined. Photocopying allowed for a simple means of leaf "preservation" and it accurately depicted mined and non-mined areas of each leaf. Using scissors, we cut out each photocopied leaf and passed it through a leaf area meter to determine total surface area. Each paper "leaf" was measured twice and the average surface area recorded. We then removed and measured the mined area of each photocopied leaf. The same procedure was followed for the leaf samples collected from the 110 plants on 25 August 1997.

The number of larvae per mine and percent of mines with exit holes were analyzed for differences among sample dates using a one-way-ANOVA (PROC GLM, SAS Institute 1990). For certain statistical analyses, leaves were first placed in 10-cm^2 leaf size classes. A one-way-ANOVA (Proc GLM) was used to test for differences in percent of leaves mined and percent of leaves with rust spots among leaf size classes. Arcsin square-root transformations were performed on all percentage data prior to analyses. Tukey's Studentized Range Test was used to separate means when ANOVA was significant. A significance level of $P \leq 0.05$ was set for all analyses.

Leaves containing larvae were placed on moistened paper towels inside of plastic bags in 1997. We used a pin to make small holes in the upper surface of the bags to reduce molding. The bags were examined at least twice weekly for insects emerging from the leaf mines. Leafminer pupae were removed and placed in petri dishes on moistened paper towels. Hymenopteran parasitoids emerging from the leaf mines were placed in vials containing 70% ethyl alcohol and were later sent to specialists for identification. Leafminer pupae were overwintered at 4°C for 120 days. Adult leafminers emerging from overwintered pupae were pinned and used as reference specimens for identifying insects captured on the sticky panels. The number of adult leafminers captured on each sticky panel was recorded. Voucher specimens of leafminer adults and hymenopteran parasitoids are currently stored in the USDA Forest Service insect collection, Michigan State University, East Lansing, Michigan.

In 1998, we placed one sticky panel (15 cm by 30 cm) on each of 20 leatherwood plants from 3 May through 3 November. Sticky panels were collected on 19 May, 1 June and 7 July. We replaced sticky panels on 7 July to monitor any mid- to late-season adult leafminer activity; these traps were collected 3 November 1998.

In 1999, we placed one sticky panel (15 cm by 30 cm) on each of 12 leatherwood plants from 5 April through 4 August and samples were collected on 12 April, 22 April, 29 April, 10 May, 17 May, 27 May, 4 June, 15 June, 22 June and 4 August. The last sample period was longer than earlier periods in 1999, and was meant to monitor any mid- to late-season adult leafminer activity. On 25 August 1999, we sampled one branch from each of 22 leatherwood plants in the study area. For each branch, we recorded the number of mined and unmined leaves. Samples were collected from the same area sampled in 1997 and branches were selected following the same protocol as used in 1997.

Also in 1999, leatherwood shoot and leaf development were monitored on three leatherwood plants. On each plant, we selected a branch tip in each of the four cardinal directions and marked the terminal bud of each with a plastic tie. Beginning 29 April, we examined each marked bud and recorded current-year's shoot length and length of the largest leaf on that shoot during each sticky panel collection through 22 June (see above). Also, beginning 10 May through 15 June, we recorded the number of leaves present on each of

the marked current-year's shoots. Shoot length, leaf length, and the number of leaves present were analyzed for differences among sample dates using a mixed model ANOVA (PROC MIXED, SAS Institute 1990), with shoots within leatherwood plants assigned as a random effect of the model. Least squared means significant at the $P \leq 0.05$ level were separated using Tukey's Studentized Range Test.

We obtained official weather records from the National Oceanic and Atmospheric Administration (NOAA, Asheville, North Carolina), for Watersmeet, Gogebic County, Michigan, which is approximately 10 km west of the study site (Fig. 1). Occasionally, weather records were not reported by the Watersmeet weather station. When that occurred, we used data from the next closest recording station, which was Stambaugh, Iron County, Michigan, located approximately 40 km east of the study site (Fig. 1). Daily heat sums were calculated for 1997, 1998 and 1999 using the averaging method, i.e. average of daily high and low temperature subtracted from base temp, and the Baskerville-Emin method (Baskerville and Emin 1969). Heat sums for each method were calculated using base 5°C and base 10°C.

Biology. All adult leafminers emerging from the overwintered pupae were identified as *Leucanthiza dircella* Braun (Lepidoptera: Gracillariidae) (Fig. 2) by Ronald Priest (Michigan State University, adjunct curator). This moth has been reported from Clermont County, Ohio (Braun 1914, Forbes 1920), and from Michigan (Nielsen 1998).

Most *L. dircella* moths were captured in May and early-June during all three sample years, although the number of moths captured varied greatly between years. In 1999, adults were first captured between 30 April and 10
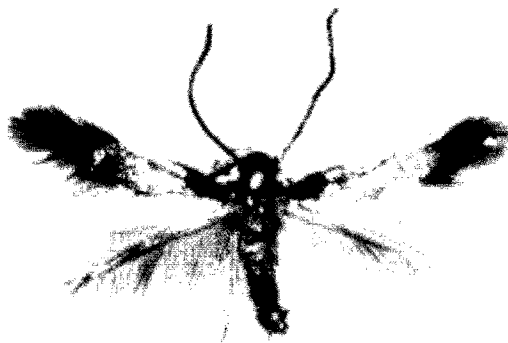

Figure 2. *Leucanthiza dircella* adult that emerged in the lab 15 July 1999 from a larva collected 21 May 1999 in Ingham County, Michigan (total wingspan approximately 6.2 mm). Specimen provided by Ronald Priest.

Table 1. Mean number of *Leucanthiza dircella* adults collected per yellow sticky trap (2-sided; each side 15 cm by 30 cm) per sampling day and heat sums for 1997, 1998, and 1999. Heat sums (start date = March 1) were calculated using the averaging method (Averaging) and Baskerville-Emin method (B–E) for the bases 10°C and 5°C.

Sampling period	Julian days	Adults/ trap/day	Heat sums base 10°C*		Heat sums base 5°C**	
			Averaging	B–E	Averaging	B–E
1997 (41 moths collected on 6 traps)						
6 June–12 June	157–163	0.97	66–104	104–144	199–266	221–285
13 June–17 June	164–168	0.07	112–125	152–170	279–313	298–330
18 June–30 June	169–181	0.03	131–246	175–291	323–498	340–509
1 July–17 July	182–198	0.01	257–377	301–428	514–713	524–715
18 July–29 July	199–210	0.00	387–475	439–529	728–871	730–866
1998 (631 moths collected on 20 traps)						
3 May–19 May	123–139	2.03	12–60	38–106	66–178	100–219
20 May–1 June	140–152	0.16	65–83	112–145	188–245	228–290
2 June–7 July	153–188	0.01	83–234	147–306	249–545	295–582
1999 (21 moths collected on 12 traps)						
5 April–12 April	95–102	0.00	0	7–8	8–9	24–31
13 April–22 April	103–112	0.00	0	8–12	9–14	32–44
23 April–29 April	113–119	0.00	0–1	12–23	14–30	44–67
30 April–10 May	120–130	0.02	1–32	25–64	33–104	72–142
11 May–17 May	131–137	0.02	32–48	66–87	110–149	147–188
18 May–24 May	138–144	0.04	50–57	90–102	157–184	194–223
25 May–3 June	145–154	0.03	57–94	102–145	184–253	223–292
4 June–15 June	155–166	0.05	99–197	150–249	263–411	301–444
16 June–22 June	167–173	0.01	197–226	250–282	416–473	449–503
23 June–4 August	174–216	0.00^2	237–604	293–665	489–1066	519–1073

*Heat sums as of end of each day.
**Two *L. dircella* adults were captured during this sample period but the number captured per trap per day was < 0.01.

May when Baskerville-Emin heat sums (base = 10°C; start date = 1 March) were between 25 and 64, respectively. The greatest number of *L. dircella* adults was captured on sticky panels between 6 to 12 June 1997 and between 3 to 19 May 1998. Trap catches were consistently low in 1999 (Table 1). Given that we captured adults during the first sampling periods in 1997 and 1998, it is likely that adult flight initiated before sticky panels were deployed during those two years. Pooling the 1997 and 1998 data, *L. dircella* capture rates were highest when Baskerville-Emin heat sums were between 38 and 144 (base = 10°C; start date = 1 March; Table 1). For comparison, heat sums calculated with the Baskerville-Emin method using base 5°C and heat sums calculated with the averaging method using bases 5 °C and 10°C are also included in Table 1.

As expected, the mixed model ANOVA for *Dirca palustris* shoot length and leaf length varied significantly among sampling dates ($P < 0.0001$). The first evidence of flushing occurred 29 April 1999 when bundles of small leaves were found protruding from the buds. Shoot elongation was completed by 17 May and leaves were fully expanded between 24 May and 3 June 1999 (Fig. 3). The number of leaves per shoot averaged 5.8 on 10 May 1999, and
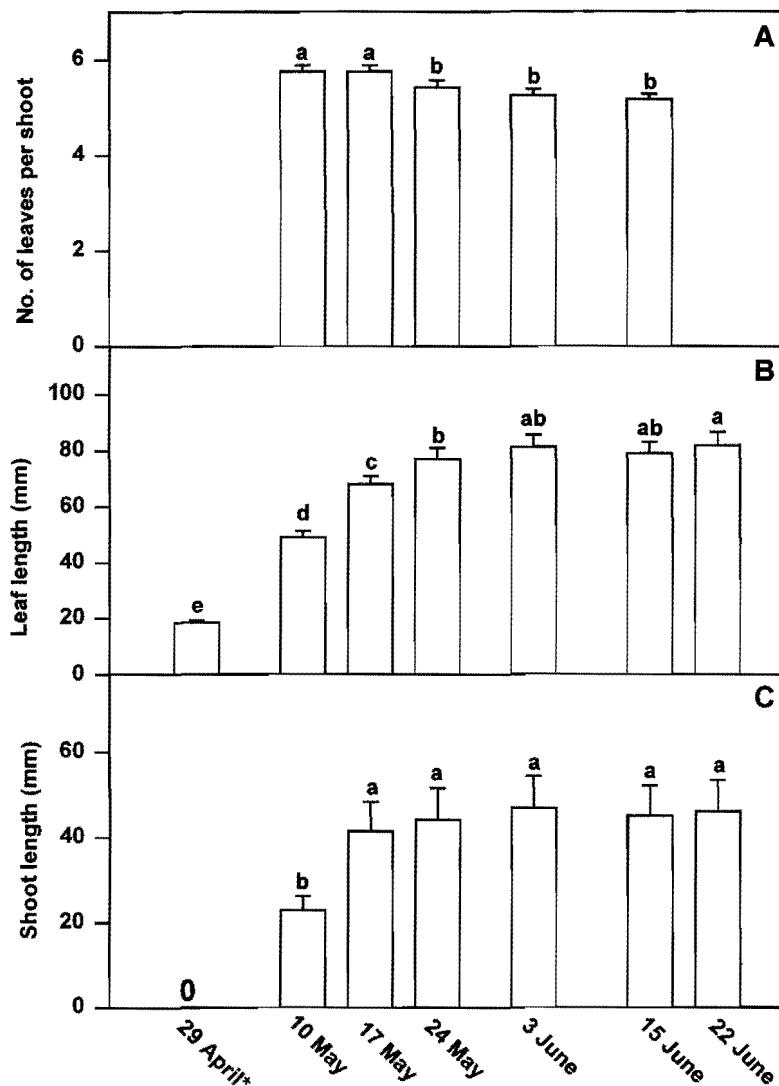
Figure 3. Mean (+ 1 SE) (A) number of *Dirca palustris* leaves per current-year's shoot during the period of 10 May through 15 June 1999, (B) length of the longest leaf on a current-year's shoots during the period of 29 April through 22 June 1999, and (C) current-year's shoot length during the period 10 May through 22 June 1999 based on 12 shoots on 3 plants (4 shoots per plant). Means with the same letter are not significantly different at $P \leq 0.05$ (Tukey's Studentized Range Test). *Only a tight bundle of leaves protruded from buds on 29 April; leaf length measured from tip of longest leaf to base of leaf bundle; new shoots were not visible.

Table 2. Mean (±SE) number of live *Leucanthiza dircella* larvae found per leaf mine and the percent of leaf mines with holes (through which *L. dircella* larvae could exit) that were collected from leatherwood plants in Gogebic County, Michigan, during the period 17 July to 25 August 1997.

Sampling date	No. of mines	Live larvae per mine	Percent mines with holes
17 July	37	3.5 ± 0.4 a*	11 ± 5 c*
29 July	56	1.9 ± 0.2 b	21 ± 6 c
13 August	47	0.5 ± 0.1 c	68 ± 7 b
25 August	44	0.1 ± 0.1 c	100 ± 0 a

*Means followed with the same letter (within columns) are not significantly different at the $P \leq 0.05$ level (Tukey's Studentized Range Test).

then decreased slightly as the season progressed (Fig. 3). This decrease in leaf number was primarily due to the abscission of leaf-like stipules, which were first counted as leaves during the early sampling dates.

Comparing the heat sums during moth activity, i.e., number of moths collected on sticky panels (Table 1), with *D. palustris* phenology (Fig. 3), it appears that most moths were captured during the period of active *D. palustris* leaf and shoot elongation. This relationship is not surprising since *L. dircella* is host specific to *D. palustris*. Emerging early during *D. palustris* leaf flush would allow *L. dircella* adults to oviposit when leaf tissues are likely soft and most nutritious (Mattson and Scriber 1987). Early season oviposition would also allow the resulting larvae to develop during the entire growing season. This synchronization is probably most important in the northernmost range of *L. dircella* where development time may be limiting.

Leaf mines were first obvious in 1997 when we visited the study site on 30 June. Each mine contained 1 to 10 legless larvae that formed upper surface blotch mines. The mean (± SE) number of live larvae per mine was 3.5 (± 0.4, N = 37 mines) on 17 July 1997 and then decreased through the remainder of the season (Table 2). Larvae began exiting mines in July, but most exited during August (Table 2). In general, larvae fed through mid-August 1997, at which time they developed thoracic legs and exited the mines to pupate. In the laboratory, after larvae exited the mines, they moved to the corners of the plastic bags where they formed a translucent, silk chamber and then pupated. In nature, larvae probably pupate in the soil or leaf litter.

Leucanthiza dircella likely overwinters in the pupal stage, given that a cold period (4°C for 120 days) was required before adults would emerge in the laboratory. Adults emerged 7–10 days after pupae were removed from cold storage and held at room temperature (ca. 20–24°C).

Leucanthiza dircella had only one generation per year in the study area in northern Michigan. Interestingly, *L. dircella* was reported as having two generations per year in Ohio (Braun 1914, Forbes 1920). A minimum of two generations per year likely occurs in southern Michigan, given that new *L. dircella* larval feeding mines were observed during both May and September on leatherwood plants in Ingham County, Michigan in 1999 (T. R. Petrice, pers. obs.). Furthermore, adults emerged in the laboratory on 14 June 1999 from larvae that were collected in Ingham County 21 May 1999 and were not subjected to a cold period.

Parasitoids. In the laboratory, seven species of hymenopteran parasitoids emerged from *L. dircella* larvae in 1997. They consisted of the bra-

conid *Pholetesor* sp. (8 specimens); and the eulophids (*Chrysocharis polita* Howard (5), *Closterocerus trifasciatus* Westwood (6), *Pnigalio maculipes* Crawford (4), *P. minio* (Walker) (2), *Pnigalio* sp. (3), and *Sympiesis* sp. (1). Only one of these species, *P. maculipes*, was previously reported as attacking *L. dircella* (Krombein et al. 1979). The genera *Pnigalio* and *Sympiesis* are ectoparasitic, which is a common method of parasitism on leafminers since the leaf mine itself serves to protect the parasitoid larvae as well as the host insect. A common behavior often associated with leafminer parasitoids is for the adult female wasps to feed on their insect hosts through the leaf tissues (Askew and Shaw 1979). This provides the adult wasp with protein, which aids in egg production. Young leafminer larvae are often the targets of this behavior, and their flattened cadavers are often found in leaf mines. Indeed, we noticed several dead larvae in mines that were in this condition in 1997.

Leaf mining damage. A total of 879 leaves was collected in late August 1997 from 110 leatherwood plants and of these, 31% contained *L. dircella* leaf mines. Of the 275 leaves containing mines, 259 leaves contained only 1 mine (94%), 14 leaves (5%) contained 2 mines, and 2 leaves (1%) contained 3 mines. The mean leaf size was 17.8 cm^2 (range = 0.9 to 66.6 cm^2, N = 879 leaves) and the mean mined surface area was 5.9 cm^2 (range = 0.2 to 24.0 cm^2, N = 293 mines). Although 31% of the leaves contained mines, only 11% of the total leaf surface area for all 879 leaves was mined by *L. dircella* in 1997.

Another interesting trend was the size of the leaves attacked by *L. dircella*. After dividing the leaves into six size classes, leaves that were 21 cm^2 in surface area or greater had the highest levels of leaf mining (F = 70.31; df = 5, 873; $P < 0.0001$) (Fig. 4). Leaves that were 10 cm^2 in size and smaller were seldom attacked (Fig. 4). The smallest mined leaf measured 7.5 cm^2. When considering only leaves 11 cm^2 and larger, more than 54% of the leaves contained mines. One explanation for this difference is that smaller leaves may not have flushed at the time when adult *L. dircella* were ovipositing in early summer. However this is unlikely since leatherwood has determinate growth and the number of leaves did not increase after initial leaf expansion in early spring of 1999 (Fig. 3). A more likely explanation is that female moths preferentially oviposited in larger leaves.

The *L. dircella* population declined in the study area in 1999. Only 8% of the leatherwood leaves contained mines in 1999 compared with 31% in 1997. The number of adult moths captured on sticky panels was also much lower in 1999 than in 1997 or 1998 (Table 1). Parasitism could have contributed to this decline, given the rich parasitoid fauna reared from *L. dircella* larvae in 1997. Braun (1914) noted high parasitism rates of *L. dircella* larvae.

Freezing temperatures during 1998–1999 winter may have also contributed to the decline of *L. dircella* in 1999. According to NOAA weather records, in the first half of December 1998, minimum temperatures dipped well below 0°C for several days, yet there was no snow cover on the ground. When the study site was visited on 15 December 1999, snow was absent from the ground and the first several cm of soil were frozen (W. J. Mattson, pers. obs.). *Leucanthiza dircella* pupal mortality may have occurred as a result of freezing and cold temperatures, especially since it occurred in early winter when pupae may have not yet acclimated to their full cold hardiness. In both 1996 and 1997, NOAA weather records indicated that snow covered the ground throughout December, thus insulating the soil and leaf litter.

Other damage and insects. In addition to leaf mining damage, 8% of the 879 leaves collected on 25 August 1997 possessed rust spots of an unidentified fungus. Rust spots on leatherwood leaves were not apparent until 30 June 1997, at the same time leaf mines were first noted. A significantly
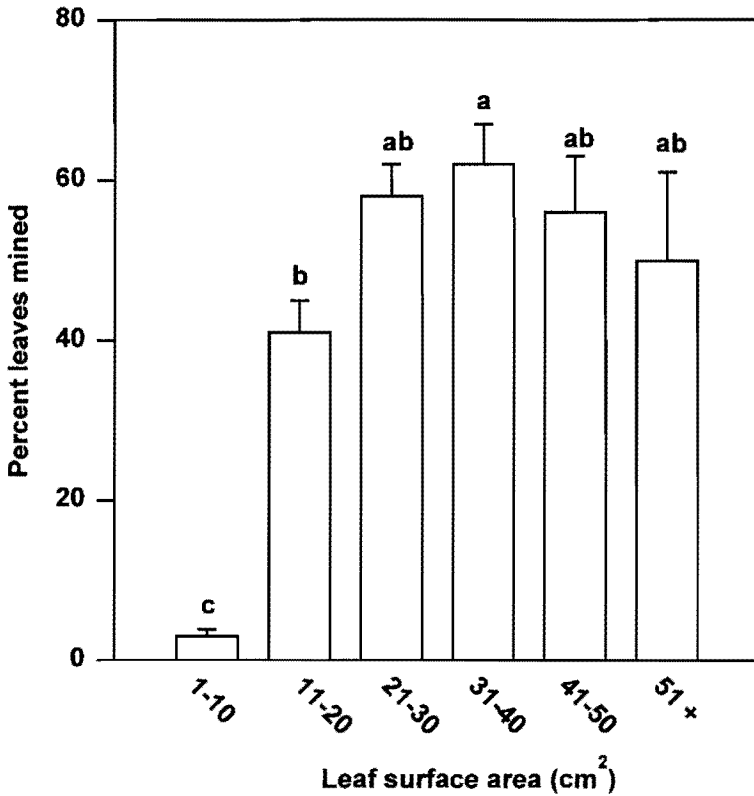
Figure 4. Mean percent (+1 SE) of leaves in six size classes that were collected on 25 August 1997 from 110 leatherwood plants and had evidence of leaf mining by *Leucanthiza dircella*. Means with the same letter are not significantly different at $P \leq 0.05$ (Tukey's Studentized Range Test).

higher percentage of leaves in the 51 cm² and larger leaf size class possessed rust spots (27%), than did leaves in the smaller leaf size classes (F = 6.10; df = 5, 873, $P < 0.0001$).

The trunk and limbs of several leatherwood plants in the study area were infested with unidentified scale insects (Homoptera). Of the branch samples collected from the 110 plants on 25 August 1997, 3% had evidence of scale insects.

Several other insects were observed on leatherwood foliage in addition to *Leucanthiza dircella* adults, although actual feeding was not witnessed. These included one native beetle (Coleoptera), *Glyptina brunnea* Horn (Chrysomelidae); and two exotic beetles, *Phyllobius oblongus* (L.) (Curculionidae) and *Polydrusus sericeus* Schaller (Curculionidae). *Phyllobius oblongus* and *P. sericeus* were also captured frequently on sticky panels during 1997–1999. These two weevils are generalist herbivores that are native to

Europe (Mattson et al. 1994). All three of these beetles inhabit the soil as lar-
vae, feeding on plant roots.

At the end of the 1999 growing season, no leatherwood mortality was evi-
dent as a result of *L. dircella*. However, we did not measure possible growth
loss due to several consecutive years of heavy leaf mining damage. Stem
analysis of leatherwood plants in the study area revealed that annual stem
elongation varied from 40–180 mm (Cynthia V. Jones, Southern Illinois Uni-
versity at Edwardsville, per. obs.). Some of this variation in annual stem
elongation may be attributable to leaf mining damage by *L. dircella*. If
leatherwood becomes a popular ornamental shrub, then control of *L. dircella*
may need to be considered when damage becomes significant.

ACKNOWLEDGMENTS

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