Seasonal Abundance of *Phyllocnistis citrella* (Lepidoptera: Gracillariidae) and its Parasitoids in South Florida Citrus

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ABSTRACT Seasonal abundance and parasitism of the leafminer *Phyllocnistis citrella* Stainton were investigated from summer 1993 through spring 1995 on 'Tahiti' limes in Dade County, Florida. *P. citrella* population density increased from spring through fall and declined during winter 1994 and 1995. Eight species of parasitoids attacked *P. citrella* immatures in commercial and experimental lime orchards. The Eulophid *Pnigalio minio* (Walker), a primary ectoparasitoid, comprised ≈80% of the parasitoids that emerged from parasitized *P. citrella*. Species and abundance of adult parasitoids varied considerably between leafminer generations. Overall percentage of parasitism was higher on unsprayed than sprayed trees.

KEY WORDS *Phyllocnistis citrella, Pnigalio minio, Cirrospilus, Closterocerus, Zagrammosoma multilineatum, Horismenus*

THE LEAFMINER, *Phyllocnistis citrella* Stainton occurs on citrus throughout southeast Asia, Australia, East and West Africa (Claussen 1931, Badawy 1969, Beattie 1993, Heppner 1993a). This pest was unknown in the western hemisphere until its invasion in south Florida in May 1993 (Heppner 1993a). The pest spread rapidly and by August 1993 occurred throughout the commercial citrus growing areas of Florida. Currently, the leafminer has become a major pest of citrus, especially on young trees. Subsequently, *P. citrella* has spread to many other areas in Central, South, North America, and islands of the Caribbean Region (Knapp et al. 1995).

Phyllocnistis citrella is a microlepidopteran which, during its larval stages, mines the adaxial and abaxial surfaces of newly formed leaves. Injured young leaves curl, become chlorotic then become necrotic. Consequently, heavily infested leaves (>4 mines per leaf) are frequently distorted and may abscise (Peña and Duncan 1993).

Worldwide evidence suggests that *P. citrella* populations are amenable to biological control by hymenopterous parasitoids (Ishii 1953, Batra and Sandhu 1981). Thirty-nine species of Hymenoptera have been recorded from its area of origin in Southeast Asia (Heppner 1993b). Most parasitoids of *P. citrella* are eulophids; however, the complexes are usually complemented by encyrtids, elasmids, eurytomids, and pteromalids. The success of any biological control project depends on appropriate biological, ecological, and population studies of the species involved (Miller 1983). Here we report on the temporal distribution of *P. citrella* on lime and present an assessment of south Florida native parasitoids as biological control agents of *P. citrella*.

Materials and Methods

The seasonal occurrence of parasitoids of *P. citrella* was studied from 1993 through 1995, at 4 lime orchards in Dade County, Florida. One of the 4 orchards, remained insecticide-free during this study; this orchard consisted of 80 lime, *Citrus aurantifolia* Christm. (Swingle) trees (spaced 6 m between rows and 6 m within a row), maintained at the University of Florida Tropical Research and Education Center in Homestead, FL. The remain-

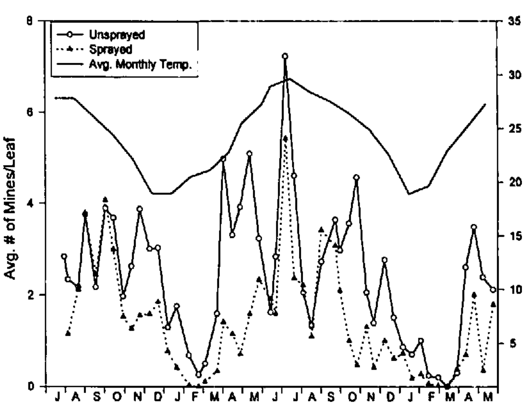

Fig. 1. Average number of leaves mined by *P. citrella* in Homestead, 1993–1995.

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Table 1. Mean number ± SEM of leafminer larvae, pupae, and active mines per leaf in each orchard, Homestead, Florida, collected twice a month, June 1993–December 1994

Orchard	Larvae/leaf	Pupae/leaf	Mines/leaf
Unsprayed	1.43 ± 0.04a	0.21 ± 0.01a	2.69 ± 0.04a
Sprayed 1	0.90 ± 0.03b	0.15 ± 0.01b	1.48 ± 0.04b
Sprayed 2	0.82 ± 0.03b	0.16 ± 0.01b	1.31 ± 0.03c
Sprayed 3	1.40 ± 0.04a	0.25 ± 0.01a	2.18 ± 0.01a

Means in columns followed by the same letter do not differ significantly at the 1% level of significance based on a priori least significant difference test (Sokal and Rohlf 1981). Sprayed 1, abamectin + 435 FC oil (3×), copper sulfate (1×); methidathion (2×); imidachloprid (2×). Sprayed 2, abamectin + FC435 oil (3×), copper sulfate (1×); carbaryl (2×) ethion (1×); chlorpyrifos (1×). Sprayed 3, abamectin + 435 FC oil (2×) supracide (3×); copper sulfate (2×); ethion (2×); chlorpyrifos (1×).

ing 3 orchards, each consisting of ≈224 trees, received applications of abamectin + FC 435 oil, copper sulfate, methidathion, chlorpiryfos, carbaryl or ethion. The number of insecticide applications in these 3 orchards varied from 4–8/yr.

The density of *P. citrella* at each orchard was determined by randomly picking 1 terminal (11.49 ± 5.87 leaves per terminal) from the middle or upper regions of 5 trees (57.56 ± 23.50 leaves per orchard) twice a month. Each terminal was placed in a plastic bag, transported to a laboratory and examined under a microscope to determine the presence of leafminers. Leaves with *P. citrella* larvae and pupae were held separately for parasitoid or *P. citrella* adult emergence in 1-liter paper cartons. These cartons were then held in the laboratory at 21 ± 3°C, and 75–80% RH for 2 mo. *P. citrella* and parasitoids that emerged were removed from containers, identified by M. Schauff and G. Evans or by the authors, and counted. Semimonthly means of *P. citrella* larval and pupal densities per leaf were calculated. Seasonal trends of the dynamics of *P. citrella* parasitoids were assessed using numbers of adult moths and larval and pupal parasitoids emerging over time.

Results and Discussion

Dynamics. In total, 10,028 leaves were inspected between June 1993 and May 1995 to determine the presence of *P. citrella* immature stages. *P. citrella* density (mines per leaf) increased in successive generations during summer and early fall 1993, declined during winter, and showed 5- and 3-fold increase in density during the spring of 1994 and 1995, respectively (Fig. 1). The most likely reason was that the large spring increase in density was related to development of the lime canopy and an increase in favorable temperatures for miner development. Oschlund and Davenport (1987) reported that vegetative flush in lime trees occurs primarily during December–January, March to July, and October. Even though vegetative shoots were abundant during the winter, *P. citrella* population density was reduced from December through February, especially during 1994–1995. Oviposition may have been reduced when night time temperatures were reduced during the winter. The spring increase in miner level seemed to be more related to increases in temperature during the spring months than to shoot proliferation. Because the number of leaves susceptible to miner oviposition varies over time, density measurements reflect both variable numbers of leafminers and leaves. High population peaks were also observed in summer (June–July) and in fall (September–October). According to Knapp et al. (1995), total generation time can fluctuate between 13 and 52 d depending on temperature. In general, the *P. citrella* population trend from 1993 through mid-1995 showed a 6-mo period of population density build-up followed by a period that can be associated with survival and host exploitation and a 3rd period that may lead to population stability. The dynamics of the population shown in Fig. 1, suggests that we are approaching a 3rd stage on the population growth of *P. citrella*.

The average level of *P. citrella* usually decreased in successive generations in the sprayed orchards compared with the unsprayed orchard. Densities of *P. citrella* differed among the orchards (ANOVA, $P < 0.0001$) and, with the exception of the unsprayed site and 1 of the treated orchards, use of different insecticides prevented progressive increases through the season (Table 1; Fig. 1).

Parasitism. *P. citrella* parasitoids collected in Homestead, FL, were identified by M. Schauff and G. Evans as *Pnigalio minio* (Walker), *Cirrospilus* sp., *Closterocerus* sp., *Sympiesis* sp., *Horismenus* sp., *Zagrammosoma multilineatum* (Ashmead), *Oncophanes* sp., and *Elasmus tischeriae* (Howard) (Table 2). More than 312 parasitoids emerged and 87.4% were eulophids. *P. minio* and *Cirrospilus* sp.

Table 2. Frequency of parasitoids of the citrus leafminer

Species	Frequency	Female:Male	%
Pnigalio minio	251	0.87:1	80
Cirrospilus sp.	23	0.78:1	7
Closterocerus sp.	12	2.00:1	4
Zagrammosoma multilineatum	6	5.00:1	2
Horismenus sp.	16	2.00:1	5
Other species	6	Not recorded	2

Chi-square$_{[15,\ 0.005]}$ = 32.80; proportions of the *Pnigalio* were significantly different when compared with other parasitoid species.

Table 3. Percentage of parasitoids per species emerging during each season, 1993–1995

Parasite species	Seasonal species composition, %							
	1993		1994				1995	
	S (n = 25)	F (n = 58)	W (n = 16)	Sp (n = 35)	S (n = 48)	F (n = 78)	W (n = 17)	Sp (n = 35)
P. minio	84	78	69	71	88	82	88	66
Cirrospilus sp.	0	3	6	23	2	6	6	17
Closterocerus sp.	8	5	0	0	0	6	0	3
Z. multilineatum	0	2	6	6	0	2	0	3
Horismenus sp.	8	12	13	0	6	0	0	11
Other species	0	0	6	0	4	3	6	0

Parasitoid species composition during winter (W) (December, January, February), spring (Sp) (March, April, May), summer (S) (June, July, August), and fall (F) (September, October, November). Values in parentheses represent total number of parasitoids emerging during each season.

had a lower female to male ratio compared with *Z. multilineatum*, *Closterocerus*, and *Horismenus* sp. (Table 2). The most abundant parasitoid during all seasons was *P. minio* ($\chi_{[15;}\, P = 0.0005] = 32.80$) (Table 3). *Cirrospilus* sp., was present from fall 1993 through spring 1995. *Closterocerus* sp. was not observed during winter. *Z. multilineatum* was collected during fall 1993–1994 and early winter 1994 and spring 1994 and 1995. *Horismenus* sp., was 2nd in abundance after *Pnigalio* during the fall of 1993 and winter of 1994, but the same trend was not observed during fall of 1994 or winter of 1995 (Table 3). *P. minio* was usually the only parasitoid observed during early population increases of *P. citrella* in March and April 1994 and 1995.

Parasitism in the unsprayed orchard generally followed a trend similar to that of *P. citrella* density in 1993 and 1994. However, different trends were observed between 1993 and 1994 with regards to levels during November and December. More larval parasitoid adults emerged during the winter in 1994 than in 1993 (Fig. 2). In general, a positive relationship was evident between *P. citrella* larval density and abundance of parasitoids ($r^2 = 0.46$, $P = 0.0001$, $n = 36$) (Fig. 2). However, pupal density did not correlate well with parasitoid densities ($r^2 = 0.12$, $P = 0.04$, $n = 36$) (Fig. 3). *P. minio* and *Z. multilineatum* and *Closterocerus sp.* emerged from both larvae and pupae. *Horismenus* sp., emerged only from pupae and *Cirrospilus* sp., emerged only from larvae. The 4 orchards varied considerably in the relative number of parasitoids emerging per sample. The number of parasitoids was higher (97–101 parasitoids) for the unsprayed field and sprayed orchard 3 compared with sprayed orchards 1 and 2 with a range between 51 and 61 parasitoids. Frequency of parasitoids appeared dependent on the site sampled and the control tactics employed (Table 4). The highest frequency of *Pnigalio* in one of the sprayed orchards may be related to its polyphagous nature and to an ability to survive exposure to insecticides applied for insect control in lime orchards.

In south Florida, levels of parasitism in commercial orchards might indicate that, through parasitoid conservation, biological control of *P. citrella* by its native parasitoids could play an important role in leafminer management. However, despite the relatively high levels of parasitism that sometimes appeared to keep *P. citrella* infestations below an average of 1 mine per leaf, parasitism alone may not be enough to maintain *P. citrella* density below 2 mines per leaf during the summer months. Parasitoids of *P. citrella* are not host specific and

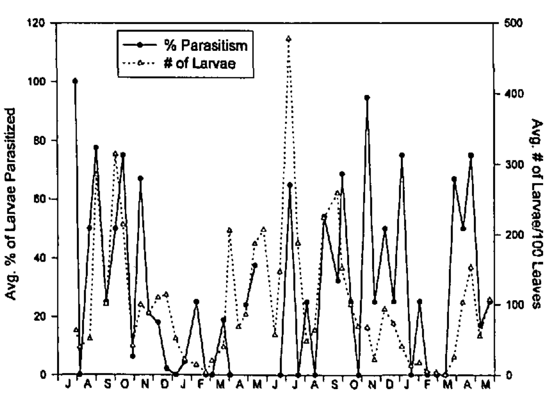

Fig. 2. Seasonal trends of larval parasites and average number of *P. citrella* larvae collected in Homestead, 1993–1995.

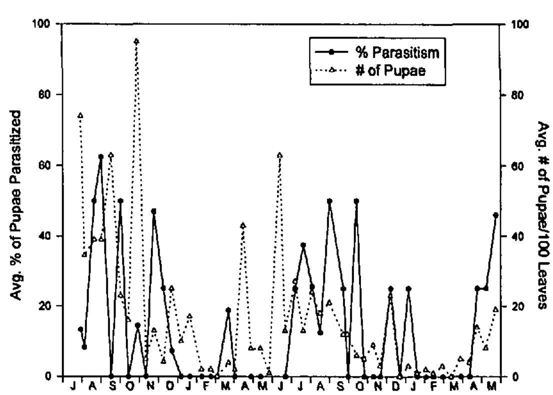

Fig. 3. Seasonal trends of pupal parasites and average number of *P. citrella* pupae collected in Homestead, 1993–1995.

Table 4. Frequencies of each citrus leafminer parasitoid species in sprayed and unsprayed lime orchards, Homestead, FL, 1993–1995

Parasitoid	Orchard				G Value
	Unsprayed	Sprayed			
		1	2	3	
Pnigalio minio	52	38	57	96	45.62**
Cirrospilus sp.	21	3	0	0	46.68**
Closterocerus sp.	2	2	4	4	4.78NS
Z. multilineatum	4	2	0	0	28.88**
Horismenus spp.	13	4	0	1	81.82**
Other (Elasmidae, Braconidae)	5	1	0	0	68.96**

$\chi^2_{0.005\ [3]} = 12.388$; **, *G* values significant at $P < 0.005$.

attack immatures of other lepidopteran miners (Browning and Peña 1995). They parasitize alternate hosts on *Vitis rotundifolia* and *Persea americana* foliage, including miners such as *Phyllocnistis* spp. According to Cornell and Hawkins (1993) those parasitoids that successfully colonize hosts as invaders are regularly generalists, which can switch hosts more easily and initially be more succesful than specialists. Although *Pnigalio* has been reported to parasitize other species of leafminers, this species may be showing a high response to the presence of an invading insect. This phenomenon could explain why *P. minio* was still dominant during the winter months when *P. citrella* densities were lowest.

The number of indigenous parasitoid species attacking *P. citrella* in south Florida was high (8) when compared with 3 indigenous species in Australia (Beattie 1993) and 3 indigenous species in India (Heppner 1993b). The numbers of indigenous parasitoids in Florida are slightly lower when compared with the native region of Thailand (n = 13) and the invaded region of Japan (n = 11) (Heppner 1993b). The differences between Florida and Australia may indicate that the richness in native leafminer parasitoids differs between newly invaded subtropical areas. The differences between Florida, Thailand and Japan may also indicate that in the newly colonized Florida areas, the indigenous parasitoids are still accumulating and responding to the invader. Thus, a larger number of *P. citrella* parasitoids is expected to appear in Florida in the following years.

This study showed variable low to moderate levels of *P. citrella* parasitism occurred over time through the seasons in lime orchards. Such fluctuations may in part be the result of regularly applied cover sprays directed toward *P. citrella,* broad mite, *Polygophagotarsonemus latus* (Banks), citrus snow scale, *Unaspis citri* (Comstock) and citrus rust mite, *Phyllocoptruta oleivora* (Ashmead). The differences in abundance of parasitoids in the unsprayed orchard and insecticide treated orchards may reflect the susceptibility of the parasitoids to the different chemicals applied. Consequently, to maximize the effectiveness of parasitoids in the management of *P. citrella* in commercial orchards, growers may need to minimize the use of insecticides. To achieve this, the following 4 *P. citrella* management considerations are suggested: (1) time spray applications, if possible, during periods of low adult parasitoid activity; (2) select an insecticide that is the less harmful to the parasitoids but still highly toxic to leafminers; (3) treat alternate tree rows or leave areas untreatred as a reservoir for parasitoids; (4) incorporate citrus leafminer economic thresholds into an integrated pest management program to reduce the need for unnecessary insecticidal sprays.

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