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Source: Florida Entomologist, 97(1) : 291-294

Published By: Florida Entomological Society

URL: https://doi.org/10.1653/024.097.0143

MOVEMENT OF *PHYLLOCNISTIS CITRELLA* (LEPIDOPTERA: GRACILLARIIDAE) FROM A GROVE TO TRAPS AND SENTINEL PLANTS IN ADJACENT LAND

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The leafminer, *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae), is a global pest of citrus (Rutaceae) (Heppner & Fasulo 2010). Larvae burrow into young leaves and create serpentine mines that damage leaves and create wounds susceptible to infection (Achor et al. 1997; Schaffer et al. 1997). Male *P. citrella* are attracted to lures containing a 3:1 blend of (*Z*,*Z*,*E*)-7,11,13-hexadecatrienal (triene) and (*Z*,*Z*)-7,11-hexadecadienal (diene), the major components of the female sex pheromone (Lapointe et al. 2006). While the 3:1 blend has been shown to be necessary and sufficient to attract large numbers of *P. citrella* males (Lapointe et al. 2006), the triene was identified as the most effective compound for mating disruption applications (Lapointe et al. 2009; Stelinski et al. 2010). The effectiveness of mating disruption for controlling the population may be limited by immigration of mated females into pheromone-treated areas from neighboring untreated areas. Very little is known about the active or passive movement of *P. citrella.* Therefore, we constructed sampling transects to estimate the extent to which males and females move up to 1,200 m away from an infested grove and the importance of wind for that movement.

Our study site (N 27° 26' W 80° 41', BAE Groves Inc., Fort Pierce, Florida) included citrus groves (4.4 km^2), an adjacent pastureland, and a reservoir (2.6 km^2, Fig. 1A). In 2013, we placed 20 Pherocon® green bucket traps (Trécé, Adair, Oklahoma) in pastureland 75, 150, 300, 600, and 1,200 m west of the groves along 4 linear transects spaced 20 m apart on 8 Apr. We also placed 4 traps 268 m within the adjacent grove, aligned with rows 23 m apart on 26 Apr, at which time fresh lures were also placed in pasture traps. We monitored traps until 26 Jul 2013. Each trap was provisioned with a *P. citrella* pheromone lure (ISCAlure-Citrella, ISCA Technologies, Riverside, California), a kill strip (Hercon, Emigsville, Pennsylvania), and a resealable plastic bag (30 x 30 cm, U.S. Plastics, Lima, Ohio). Traps were attached to posts or stakes 1 m above the ground. Trap liners were replaced every 1-2 weeks (12 Apr, 19 Apr, 26 Apr, 10 May, 17 May, 31 May, 14 Jun, 28 Jun, 12 Jul, 26 Jul), kill strips once (12 Jul), and lures twice (26 Apr, 28 Jun). We identified *P. citrella* by wing coloration (Keathley et al. 2013). To avoid error during counts, we used a dissecting microscope to examine specimens and excluded moths that did not fit the pattern for *P. citrella.* Mean (± SEM) trap catch (males per trap per week) was 301 ± 31 within the grove and 1.9 ± 0.6, 1.7 ± 0.8, 0.7 ± 0.2, 0.4 ± 0.1, and 0.5 ± 0.2 at 75, 150, 300, 600, and 1,200 m, respectively. The number of males captured per trap per week in pasture declined with increasing distance from the groves (linear regression of Log_{10} transformed variables, $F_{1, 18} = 15.8$, $P < 0.001$, $R^2 = 0.47$, $y = 1.28 - 0.574x$, Analytical Software 2008). This declining capture with increased distance from the groves supports the hypothesis that moths arrived from the groves, although other more distant sources cannot be ruled out because male *P. citrella* has been trapped as far as 6.4 km from a known host plant source (Kawahara et al. 2013). Weather data were obtained from a RainWise (Bar Harbor, Maine) MK-III-LR weather station (Weather Underground 2013) at Wynne Ranch (N 27° 27' 16" W 80° 40' 27") 2.2 km from the study site. Data were collected nightly at 5 min intervals from 8 PM to 12 AM when male *P. citrella* respond to pheromone lures (Stelinski & Rogers 2008). At each interval, wind was "calm" or blowing from one of 16 directions that were cardinal, primary intercardinal, or secondary intercardinal (e.g., N, NNE, NE, ENE). Resolution of wind speed was 1 mph (0.45 m/s). The mean (± SEM) number of wind direction observations per trapping period was 506 ± 39 (n = 7 periods). For each trapping period, we converted the number of moths captured in the pasture to a percentage of the number captured within the grove then correlated these values with wind direction using Pearson correlations.

Incidence of wind from the northeast (N, NNE, NE, ENE) was positively correlated with capture of moths at 75 m (r = 0.86, P = 0.01), 300 m, (r = 0.93, P = 0.003), 600 m (r = 0.87, P = 0.01), and 1,200 m (r = 0.70, P = 0.08). Combined capture of moths across all distances was similarly correlated (r = 0.88, P = 0.009). This capture of moths downwind from the nearest known population suggests that male *P. citrella* moths were transported passively on wind currents from the groves before orienting to pheromone traps. Southeast winds (ESE, SE, SSE, S) were not correlated

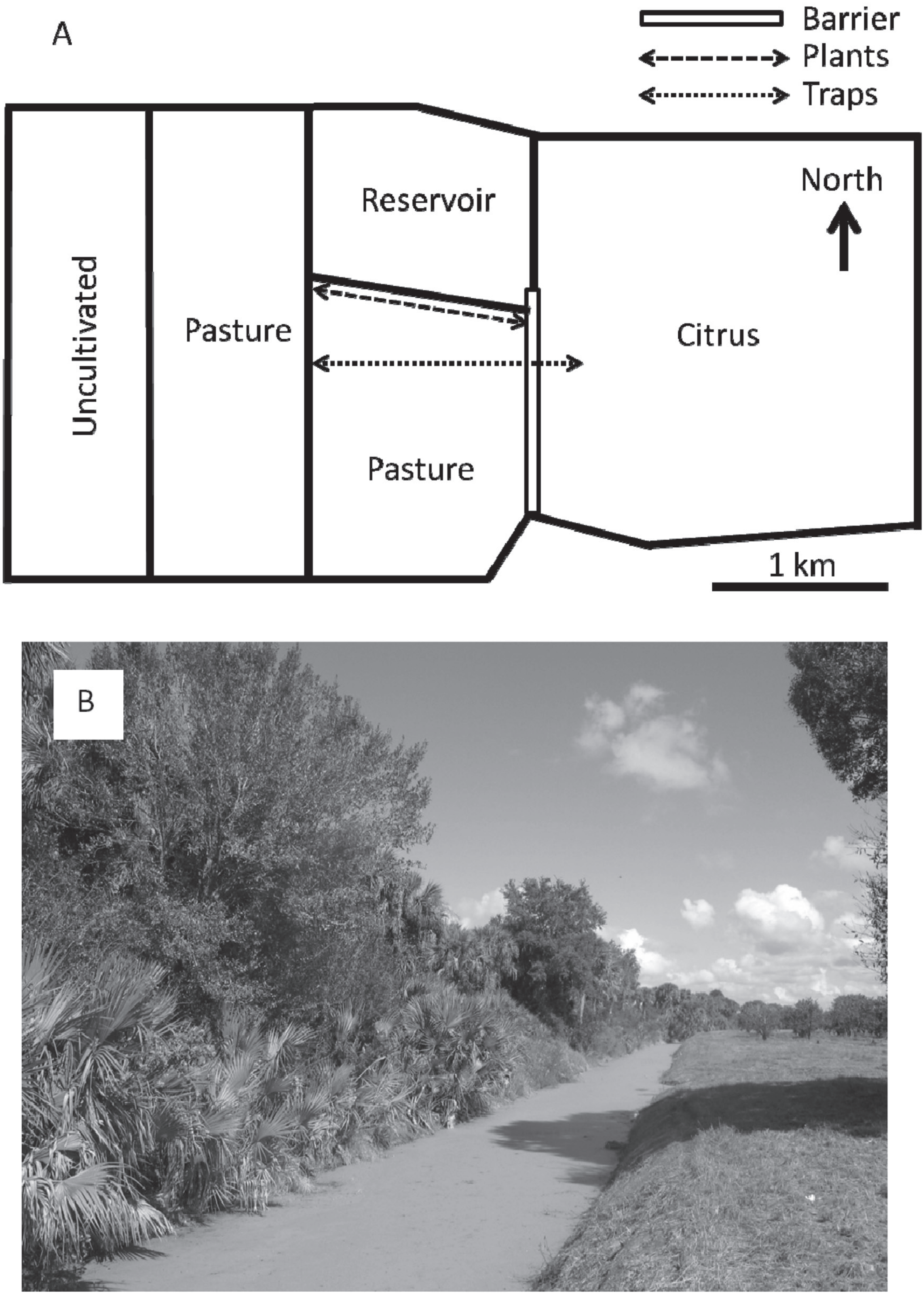

Fig. 1. (A) Map of study site showing transects of traps and sentinel plants, and (B) barrier of trees and shrubs separating pasture and groves (right).

with capture. Passive movement of moths from the southeast may have been hindered by a thick barrier of trees and shrubs between the pasture and groves (Fig. 1B); however, this barrier ended 360 m north of the traps.

To study female movement, we placed sentinel 'Valencia' orange trees from a protected greenhouse along the south edge of a reservoir 75, 150, 300, 600, and 1,200 m west of the groves along 4 linear transects spaced 5 m apart on 15 Apr, two each on upper and lower roads (Fig. 1A). Trees were planted in 35 cm diam plastic pots (Cerio Corp, Mobile, Alabama). We evaluated infestation of *P. citrella* by searching plants and removing all infested shoots at 6-7 weeks after deployment (24 and 31 May). We examined shoots under a microscope, and counted the cumulative number of immature leaf miners per plant. Severity of infestation declined with increasing distance up to 600 m but was highest 1,200 m west of the groves (Fig. 1A) where 75% of trees were infested by 6 weeks. That infestation may have arrived partly from other citrus groves 3.2 km northwest or 2.9 km northeast. On 14 Jun we searched plants and removed all new flush and damaged leaves. On 12 Jul we evaluated infestation again by sampling 10 new shoots per plant and examining these as before (Fig. 2B). Infestation declined up to 600 m, but there was no infestation at 1,200 m on the second evaluation. This is the first reported movement of *P. citrella* females to sentinel plants ≥ 1.2 km from a known source. Movement of females across distances ≥1.2 km from a known source suggests that groves treated to disrupt mating of *P. citrella* will be vulnerable to mining damage caused by mated females arriving from neighboring groves within 1.2 km. Females may move passively on wind currents, in which case direction of wind will be important in relation to sources of infestation.

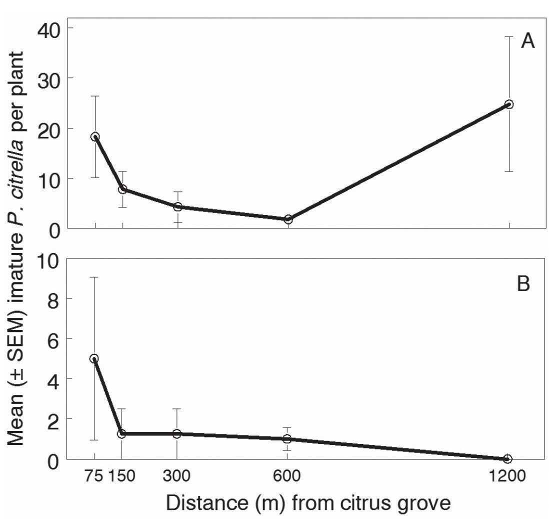

Fig. 2. Mean (± SEM) number of immature *P. citrella* on sentinel orange trees placed 75, 150, 300, 600, and 1,200 m (n = 4) west of a citrus grove and evaluated (A) 6-7 weeks after initial placement and (B) 4 weeks after trees were pruned to remove all flush and damaged leaves.

Summary

Male *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) were captured in pheromone-baited traps in pastureland 1.2 km west of an infested citrus grove. Capture of males was correlated with northeast wind blowing from the groves, which suggests males were transported passively on wind currents from groves before orienting to pheromone traps. Female *P. citrella* located and oviposited on 75% of sentinel citrus plants placed 1.2 km west of the groves by 6 weeks. Movement of this species as far as 1.2 km suggests that groves treated with pheromone components for mating disruption will be vulnerable to damage caused by mated females arriving from neighboring groves within 1.2 km. Treated groves may be particularly susceptible to influx of moths carried on wind.

Key Words: citrus leaf miner, lure, infestation, sex pheromone, upwind flight, 'Valencia' orange

RESUMEN

Machos del minador de hojas *Phyllocnistis citrella* Stainton (Lepidoptera: Gracillariidae) fueron capturados en trampas de feromonas en pastizales hasta 1.2 kilometros al oeste de un huerto de cítricos. El número de los machos capturados en el pastizal disminuyó con el aumento de distancia de los huertos. La captura de machos fue correlacionada con un viento del noreste que sopló desde los huertos. Esto sugiere que los machos fueron transportados pasivamente por las corrientes de viento de los huertos antes de navegar en contra el viento hacia las trampas de feromonas. Las plantas de cítricos centinales colocadas 1.2 kilometros al oeste de los huertos se infestó en 6 semanas. Estos datos sugieren que la eficacia de perturbación sexual en P. citrella puede ser dependiente de la escala, con mejores resultados donde se trata en áreas más grandes.

Palabras Clave: minador de las hojas de cítricos, señuelo, infestación, feromona sexual, vuelo contra el viento, naranja 'Valencia'

Acknowledgments

We thank Larry Markle, Josh MacNaught, Rylan Mermer, and Rafael Forero (USDA, ARS, Ft. Pierce, FL) for technical assistance, Ronnie Rohm and Brant Schirard for use of the study site, and Wynne Ranch for weather data. This research was funded in part by the Citrus Research and Development Foundation. Mention of a trade-

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