Movement of Mexican Rice Borer (Lepidoptera: Crambidae) Through the Texas Rice Belt

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ABSTRACT Pheromone-baited traps were used to monitor the movement of the Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), through the Texas rice belt from 2000 to 2005. Based on location of discovery in each county and year, the average rate of spread from 1980 to 2005 was 23 km/yr. From 2000 to 2005, the leading edge of the infestation has moved 16.5 km/yr toward Louisiana. The 1.8-fold increase (99% confidence interval) of the area occupied from 2000 to 2005 in the Texas rice belt indicates an expansion of the distribution of *E. loftini*. If movement continues to occur at similar rates, *E. loftini* will reach Louisiana by 2008.

KEY WORDS Mexican rice borer, *Eoreuma loftini*, pheromone trap, movement

The Mexican rice borer, *Eoreuma loftini* (Dyar) (Lepidoptera: Crambidae), is an invasive species from Mexico discovered in Texas in 1980 (Johnson and van Leerdam 1981). Described from different host plants in Arizona (Dyar 1917), *E. loftini* was found on sugarcane, *Saccharum officinarum* L., in Mexico in the states of Baja California, Sonora, Sinaloa, Nayarit, Jalisco, Colima, Michoacán, and Huastecas (Morill 1925, Van Zwaluwenburg 1926, Riess 1981, Johnson 1984). The range later expanded to eastern Mexico, with recoveries made in Nuevo Leon, Tamaulipas, San Luis Potosi, and Veracruz (Rodriguez-del-Bosque et al. 1989), and to southeastern Mexico in Oaxaca (Rodriguez-del-Bosque and Smith 1991) and Yucatan (Klots 1970). After Dyar's initial recovery of the insect in Arizona, more specimens were found in southern Arizona (Van Zwaluwenburg 1926) and in the Imperial Valley in California, close to the Mexican border (Osborn and Phillips 1946).

The first interception of *E. loftini* in the Lower Rio Grande Valley of Texas from Mexico occurred in 1959 in Brownsville, when a single larva was found on sugarcane plants being transported from Mexico (Johnson 1984). From 1966 to 1982, 94% of the interceptions were made from sugarcane, with additional interceptions from corn, *Zea mays* L.; lemongrass, *Cymbopogon citratus/flexuosus* L.; and tomatoes, *Lycopersicum* spp. (Johnson 1984). *E. loftini* became established on sugarcane in the Lower Rio Grande Valley of Texas in 1980 (Johnson and van Leerdam 1981), surpassing the sugarcane borer, *Diatraea saccharalis* (F.), in economic importance the same year (Johnson 1981). *E. loftini* now comprises >95% of the sugarcane stalk borer population in the Lower Rio Grande Valley (Legaspi et al. 1999). In Texas, the range of *E. loftini* has continued to expand well into the rice, *Oryza sativa* L., production area along the Gulf coast (Browning et al. 1989) where it can cause substantial yield loss (Reay-Jones et al. 2005a). The Mexican rice borer represents an increasing threat to the Louisiana sugarcane and rice industries as its range expands through Texas (Reagan et al. 2005).

Brown et al. (1988) demonstrated the existence of the *E. loftini* female sex pheromone by studying the response of adult males to ovipositor extracts. The synthetic pheromone was subsequently synthesized (Shaver et al. 1988), and field experiments demonstrated that the pheromone, combined with the universal pheromone trap, was an effective means of capturing male moths (Shaver et al. 1991). Using the female sex pheromone to monitor the movement of *E. loftini* allows researchers and farmers to anticipate the establishment of this devastating pest in new regions of the Gulf Coast. The objective of this research was to quantify the movement of *E. loftini* through the Texas rice belt.

Materials and Methods

This study was initiated with monitoring in 1999 in Waller and Wharton counties (Texas) from 15 May to 15 October. The purpose of this initial monitoring was to determine the leading edge of the population. Extensive monitoring was conducted in the Texas rice belt from 2000 to 2005 (Table 1). Two standard universal pheromone traps (white bottom/yellow mid-

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Table 1. Daily numbers of *E. loftini* moths collected per trap in Texas rice belt counties 2000–2005

Yr	Austin					Brazoria					Calhoun				
	Start[a]	End[b]	n[c]	Daily trap count	SD	Start[a]	End[b]	n[c]	Daily trap count	SD	Start[a]	End[b]	n[c]	Daily trap count	SD
2000						5/19	11/15	13	0.39	0.39	7/19	11/7	17	6.56	4.26
2001	5/31	8/11	8	3.64	2.08						6/12	8/24	11	6.94	5.85
2002	6/25	12/10	11	1.78	1.48	5/25	11/30	23	10.9	11.9	5/28	12/3	26	11.8	10.2
2003	6/27	12/29	5	3.48	3.39	5/10	11/22	29	11.5	9.37					
2004						5/1	11/30	30	11.1	13.9					
2005						5/21	11/26	25	21.6	26.7					
	Chambers					Colorado					Fort Bend				
2000	5/20	11/10	25	0	0	5/22	11/14	26	5.86	4.40	5/22	9/7	13	2.59	1.96
2001	5/18	10/30	26	0	0	5/11	11/30	29	2.04	1.66	6/25	8/22	7	4.14	4.77
2002	5/2	11/10	25	0	0	5/2	11/26	30	7.99	9.53	6/10	8/22	8	3.83	4.52
2003	4/11	11/28	34	0	0	5/23	12/2	27	11.6	26.3					
2004	4/4	11/5	30	0.0071	0.029	5/9	11/29	30	8.30	9.31					
2005	8/1	11/25	14	18.3	16.6	5/9	12/5	30	6.31	7.81					
	Galveston					Harris					Jackson				
2000											5/15	11/13	43	4.21	2.91
2001						5/26	11/30	26	4.38	2.25	5/23	11/13	25	1.65	1.50
2002	5/9	10/24	24	5.69	4.44	5/22	11/26	26	14.3	13.5	4/23	10/4	23	5.17	4.47
2003	5/27	12/17	28	9.09	6.06						5/23	11/13	22	5.32	4.97
2004	5/3	12/6	31	3.08	2.54						6/13	8/31	7	3.75	3.75
2005	6/13	11/29	25	9.63	8.03						5/16	8/21	12	2.20	1.80
	Jefferson					Liberty					Matagorda				
2000	5/24	11/8	25	0	0	6/10	11/10	23	0	0	5/16	10/6	32	22.6	22.9
2001	5/18	11/30	29	0	0	6/2	8/5	13	0	0	6/15	10/26	20	8.77	8.71
2002	5/3	11/8	25	0	0	6/10	11/10	23	0	0	5/24	11/9	26	2.13	3.61
2003	4/11	11/28	34	0	0	6/10	11/10	23	0	0					
2004	4/9	11/5	30	0	0	7/12	11/15	18	1.50	1.37	5/15	10/11	13	1.66	1.14
2005	5/6	11/25	27	0.0095	0.031	6/10	12/2	25	4.61	4.35	5/16	10/19	17	13.2	16.0
	Orange					Waller[d]					Wharton				
2000	8/2	11/15	16	0	0	5/24	11/8	23	0.45	0.53	5/30	11/13	24	5.92	2.59
2001	8/2	11/15	16	0	0						5/29	11/26	18	6.03	3.37
2002	8/2	11/15	16	0	0						5/29	12/5	33	5.51	5.75
2003	6/6	11/27	24	0	0	6/9	12/29	30	12.4	23.3	5/16	11/14	27	2.99	2.56
2004	6/1	10/5	18	0	0	5/10	12/06	30	4.55	4.61	5/3	11/9	28	1.48	1.82
2005	8/2	11/15	16	0	0	6/28	12/19	39	12.3	14.7					

[a] Date of initial trap deployment.
[b] Date of end of trapping.
[c] Number of trap counts.
[d] Monitoring also occurred from 15 May to 15 October 1999.

dle/green top; Unitrap, Great IPM, Vestaburg, MI), separated ≈100 m, were set up in each county adjacent to the same field and baited with a synthetic female *E. loftini* sex pheromone lure (Luresept, Hercon Environmental, Emigsville, PA), which was replaced every 3 wk. An insecticidal strip (Vaportape II, Hercon Environmental) was placed in each bucket to kill trapped insects and prevent them from damaging each other. Insecticidal strips were replaced every 6 wk. The traps were attached to a metal pole 1 m above the soil surface. Trap collections were placed in plastic bags and frozen for later identification and enumeration. Samples were sporadically dissected to verify insect identification by examining genitalia. Frequency of trap monitoring, reported in Table 1, varied with county and year. Monitoring also occurred in southwestern Louisiana parishes and around processing facilities in south central Louisiana receiving sugarcane from Texas. Pheromone traps in adjacent counties in Texas were separated by an average of 58.3 km.

For each trap collection date, year, and county, average number of moths across both traps was determined. A daily rate of capture was calculated using equation 1.

$$f_{ijk} = \frac{n_{ijk}}{d_{ijk} - d_{i-1jk}} \qquad [1]$$

where

f_{ijk} is the interpolated number of moths caught per trap on collection date i, year j, and county k

n_{ijk} is the average number of moths caught per trap

d_{ijk} is the collection date expressed in Julian days.

For each year of trapping, daily estimates began when the first day of moth trapping occurred in at least one of the counties and ended when the last day of moth trapping occurred. On dates where daily rates of capture were not available, estimates were derived using a chi-square approximation method (equation 2).

$$\hat{f}_{i'jk} = \frac{f_{..k} f_{i'j.}}{f_{...}} \quad [2]$$

where

$\hat{f}_{i'jk}$ is the estimated number of moths caught per Julian day i' for each year and each county

$f_{..k}$ is the number of moths caught per day averaged across all trap dates and years for county k

$f_{i'j.}$ is the number of moths caught per Julian day i' for each year, averaged across all counties

$f_{...}$ is the number of moths caught per day averaged across all trap dates, all years and all counties

For each trapping date, the centroid of the distribution was determined by weighting the latitude and longitude of the traps in each county with the estimated number of moths caught per day (equations 3 and 4).

$$x_{i'j.} = \frac{\sum_{k=1}^{15} x_k f_{i'jk}}{\sum_{k=1}^{15} f_{i'jk}} \quad [3]$$

$$y_{i'j.} = \frac{\sum_{k=1}^{15} y_k f_{i'jk}}{\sum_{k=1}^{15} f_{i'jk}} \quad [4]$$

where

$x_{i'j.}$ is the longitude of the centroid for trap date i' and year j across all counties

x_k is the longitude of the trap in county k.

$y_{i'j.}$ is the latitude of the centroid for trap date i' and year j across all counties

y_k is the latitude of the trap in county k.

Variances and covariances were determined for each date during the sampling period (equations 5–7).

$$S_x{}^2 i'j. = \frac{\sum_{k=1}^{15} f_{i'j.} x_k{}^2 - \frac{\left(\sum_{k=1}^{15} f_{i'j.} x_{k.}\right)^2}{\sum_{k=1}^{15} f_{ijk}}}{\left(\sum_{k=1}^{15} f_{ijk}\right) - 1} \quad [5]$$

$$S_y{}^2 i'j. = \frac{\sum_{k=1}^{15} f_{i'j.} y_k{}^2 - \frac{\left(\sum_{k=1}^{15} f_{i'j.} y_k\right)^2}{\sum_{k=1}^{15} f_{ijk}}}{\left(\sum_{k=1}^{15} f_{ijk}\right) - 1} \quad [6]$$

$$S_{xyi'j.} = \frac{\sum_{k=1}^{15} (f_{i'j.} x_k)(f_{i'j.} y_k) - \frac{\left(\sum_{k=1}^{15} f_{i'j.} x_k\right)\left(\sum_{k=1}^{15} f_{i'j.} y_k\right)}{\sum_{k=1}^{15} f_{ijk}}}{\left(\sum_{k=1}^{15} f_{ijk}\right) - 1} \quad [7]$$

where:

$S_x{}^2 i'j.$ is the variance of longitude for trap date i' and year j averaged across counties

$S_y{}^2 i'j.$ is the variance of latitude for trap date i' and year j

$S_{xy}{}^2 i'j.$ is the covariance of latitude for trap date i' and year j

Principle axes and 99% confidence ellipse of the bivariate scattergram of mean annual centroids were calculated using the method of Johnson and Wichern (2002), providing an estimate for the area occupied by the species in the Texas rice belt.

The direction and length of the major and minor axes of the ellipse indicate for each year the spatial distribution of *E. loftini.* To verify that our data were normally distributed, a 99% percentile of the cumulative distribution function of annual *E. loftini* trap counts was plotted using distances from the initial infestation in 1980 near Weslaco, TX.

Results

In total, 108,946 *E. loftini* moths was caught in pheromone traps in this study, with an average ± SEM of 5.8 ± 0.28 moths per trap per day across counties. Ten to 14 of the 15 counties in the Texas rice belt were monitored for *E. loftini* populations during every year of the study (Table 1). *E. loftini* moths were found in counties previously not monitored in 2000 (Brazoria, Colorado, Fort Bend, and Wharton), 2001 (Austin and Harris), and 2002 (Galveston) (Fig. 1). For our analysis, we assumed that *E. loftini* moths were present in these counties before initial discovery with daily capture rate before the start of trapping estimated using equation 2. However, newly infested counties were discovered in 2000 (Waller), 2004 (Chambers and Liberty) and 2005 (Jefferson) (Fig. 1). The traps in Waller, Liberty, Chambers and Jefferson counties

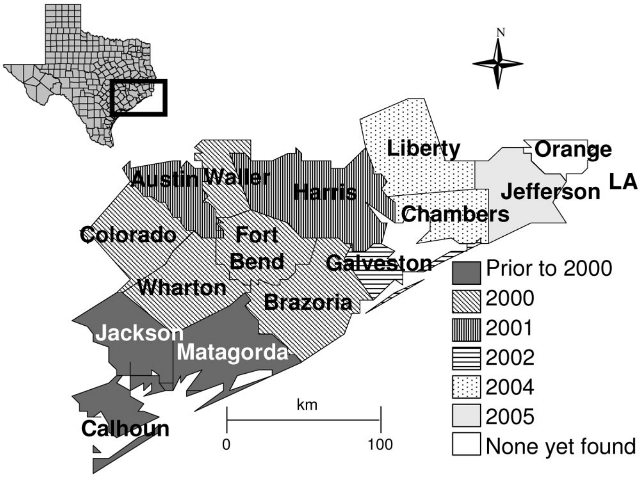

Fig. 1. Movement of *E. loftini* through the Texas rice belt from 2000 to 2005.

were located 473.9, 538.9, 556.5 and 575.5 km respectively, from the initial point of discovery in 1980 in Weslaco, TX (Hidalgo County). The average rate of *E. loftini* spread was 23.0 km/yr from 1980 to 2005 (Jefferson County trap) based on distance between trap locations and date of discovery (Fig. 1 and 2). Moths were not detected in Louisiana during our study.

Although the mean annual locations using the cumulative distribution function method were identical to those calculated using equations 3 and 4, the location of the 99% percentiles were not as distant from the centroids as estimated using the variance (equations 5 and 6) and covariance (equation 7). This indicates that the variance and covariance were not normally distributed. To correct for this, the size of each 99%

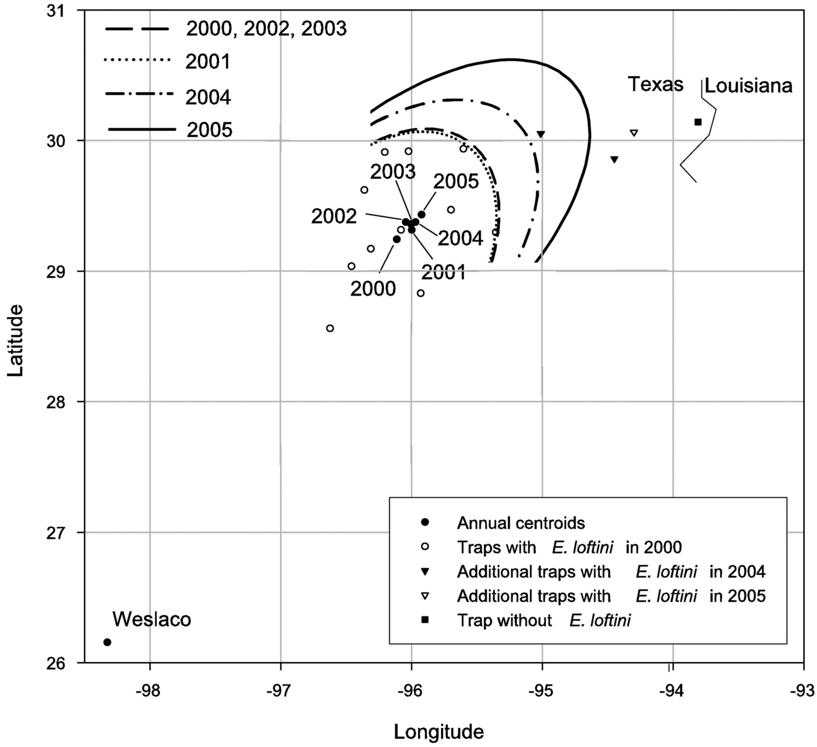

Fig. 2. Spatial pattern expressed as centroids and 99% confidence regions for *E. loftini* moths captured in pheromone traps from 2000 to 2005.

Table 2. Characteristics of 99% confidence interval of annual centroids estimating the area in the Texas rice belt occupied by *E. loftini*

Yr	Principal axis		Minor axis		Area (km^2)
	Slope	Length (km)	Slope	Length (km)	
2000	1.801	275.0	0.5552	134.4	29,034
2001	1.426	272.5	0.7011	161.2	34,506
2002	1.290	283.9	0.7750	141.2	31,490
2003	1.451	269.9	0.6893	161.0	34,120
2004	0.9838	301.5	1.016	180.7	42,789
2005	0.9085	351.2	1.101	186.2	51,343

confidence interval (CI) ellipse was reduced to the 99% percentile of the respective cumulative distribution. The area in the Texas rice belt occupied by *E. loftini* increased 1.8-fold from 2000 to 2005 (Table 2). The slopes of the centroid's principal and minor axes decreased from 2000 to 2005, indicating a spatial shift in a northeastern direction (Table 2). From 2000 to 2005, the annual mean centroids moved 27.7 km, averaging 5.5 km/yr. The northeastern location on the ellipse defined by the intersection between the principal axis and the ellipse moved on average 16.5 km/yr from 2000 to 2005 (Fig. 2). The insect will reach Louisiana by 2008, assuming a constant rate of spread.

Discussion

The movement of the annual centroids reflects shifts in the spatial pattern of *E. loftini* populations; however, the major finding of our analysis is a 1.8-fold increase in the area of the Texas rice belt occupied by *E. loftini* from 2000 to 2005, indicating an expansion of this species distribution. The rate of spread during our six year study (16.5 km/yr) was slower than the rate of spread based on boundary movement estimated from 1980 to 2005 (23 km/yr). Laboratory studies by Browning and Smith (1988) showed that *E. loftini* is able to withstand relatively prolonged periods of cold temperatures, with 89 and 64% larval survival at −5°C after 24 h and 72 h, respectively. Although cooler weather may have slowed the spread, the insect has likely not yet reached its northern limit, as indicated by high trap catches in our study in the northern locations such as Liberty County.

E. loftini populations are present in counties south of the Texas rice belt (Browning et al. 1989) and the insect was reported north of the Texas rice belt in October 2005, ≈30 km northwest of College Station in Robertson County, TX (J. A. Jackman, personal communication). These areas were not monitored in our study; therefore, our analysis included only a portion of *E. loftini* infestations in Texas. However, our interest focused on the northeastern front, as the insect approaches Louisiana. The 99% confidence ellipses were determined using data from 15 counties in the Texas rice belt. The expansion in ellipse size results from movement of *E. loftini* populations toward Louisiana.

Pheromone traps can be invaluable in monitoring the movement of invasive insect species (Robacker and Landholt 2002). However the ability to detect movement of insects relies on appropriate deployment of traps. Before setting traps up in the field, a monitoring program must establish the scale of insect movement that needs to be detected, which will depend on the objectives of the study. If detection of *E. loftini* moths is to be determined during the year of invasion, the distance between traps should not exceed the expected annual rate of spread. Assuming rates of spread is a constant, the distance between traps must therefore not exceed 16.5 km for annual movement to be detected. Because annual rates of spread may vary, traps should be placed substantially closer than 16.5 km. The accuracy of rates of spread estimate decreases as distance between traps increases (Sharov et al. 1997). The average distance between *E. loftini* pheromone traps in our study was 58.3 km. Reducing distances between traps would likely assist in developing a more accurate and consistent monitoring program.

Rates of spread of invasive insects vary with species and can be strongly influenced by human activities. Analysis of historical records of the gypsy moth, *Lymantria dispar* (L.), in North America showed varying rates of spread from 9.5 to 20.8 km/yr, with variability linked to human-caused movement (Leibhold et al. 1992). Spread of the leafminer *Cameraria ohridella* Deschka & Dimič was monitored in eastern France by using pheromone traps from 2001 to 2003, with annual rates of spread varying from 17.0 to 37.9 km/yr (Augustin et al. 2004). Establishing estimates of variability for rates of spread of insects can assist in improving monitoring programs.

Invasive pests of agricultural crops represent a growing threat because of the increased volume, speed of travel, and types of commodities that are transported throughout the world (Schwalbe and Hallman 2002). An estimated 500 species of insect and mite crop pests have been introduced into the United States, causing approximately $13.5 billion per year in crop losses (Pimentel et al. 2002). Estimates of the effects of *E. loftini* damage on sugarcane revenue have varied from $575/ha, when considering only the producer's loss (Meagher et al. 1994), to $1,181/ha, when considering the effects on producer and miller (Legaspi et al. 1999). In rice, yield losses attributed to *E. loftini* and to *D. saccharalis*, have exceeded 50% in untreated controls in replicated experiments conducted in the Texas rice belt (Reay-Jones et al. 2005a). The threat represented by *E. loftini* for Louisiana sugarcane growers is emphasized by the extreme susceptibility of current commercial sugarcane cultivars (Reay-Jones et al. 2003). This invasive species has the potential to cause major yield losses in the Louisiana sugarcane and rice industries.

In September 2004, *E. loftini* was detected for the first time in the sugarcane-producing region of South East Texas within ≈50 km of the Louisiana border, prompting a previously agreed to quarantine by the Louisiana Department of Agriculture and Forestry and the Texas Department of Agriculture (Reagan et al. 2005). A 1.6-km radius quarantine was initiated around locations in fields where *E. loftini* moths were captured, prohibiting the transport of sugarcane from quarantined fields into Louisiana for processing. In 2005, the quarantine was expanded to all sugarcane growing in southeastern Texas.

As a consequence of our pheromone trapping results, the quarantine was rapidly initiated in 2004 and expanded in 2005. The use of pheromone traps is a necessity to detect this devastating pest especially during the initial years of presence in a newly infested area. When the insect becomes established in Louisiana sugarcane, the use of adequate management strategies such as resistant cultivars, irrigation to minimize plant stress and insecticides will likely be implemented (Reay-Jones et al. 2005b). The swift deployment of such tactics will rely on the monitoring of population movement by using pheromone traps. Our study has indicated that *E. loftini* will reach Louisiana by 2008, assuming the spread continues at the same rate.

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