

Changes in the spatial and temporal population density of the Mediterranean fruit fly (Diptera: Tephritidae) in a citrus orchard

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Abstract

This paper compares the results obtained when analysing the population density of the Mediterranean fruit fly (*Ceratitis capitata* [Wiedemann]) by standard methods and kriging interpolation. The data used were collected during a pest control experiment involving mass trapping of the females of this species in a citrus orchard. These captures provided a series of diagrams showing the heterogeneous spatial distribution of the flies. Since trapping began at the end of June, the insects were first caught preferentially in trees at the western and southern borders of the orchard. As the number of flies grew the rest of the crop was invaded. Kriging provided information that would allow more efficient pest management by focusing control efforts on areas where target populations are at their largest.

Additional key words: *Ceratitis capitata*, kriging, mass trapping, pest management, spatial distribution.

Resumen

Distribución espacio-temporal de las capturas de la mosca mediterránea de la fruta (Diptera: Tephritidae) en una parcela de cítricos en Mallorca

En este trabajo se comparan los resultados obtenidos al evaluar la densidad poblacional de una plaga mediante el método de muestreo convencional y el procesado de los mismos mediante *kriging*. Para ello se utilizaron los datos obtenidos durante un experimento de control de la mosca mediterránea de la fruta *Ceratitis capitata* (Wiedemann) a base del trapeo masivo de hembras en una plantación de cítricos, obteniéndose una serie de diagramas que muestran la distribución espacial heterogénea de las capturas en la parcela. Se observa como al iniciarse éstas a final de junio, se localizan preferentemente en los árboles situados en los bordes occidental y sur de la plantación, para luego ir invadiendo todo el cultivo a medida que aumenta el nivel del insecto. El uso del *kriging* se muestra en este estudio como una eficaz herramienta para el manejo de plagas, aportando información que permite aplicar de forma más precisa los métodos adecuados para su control, concentrándolos en las zonas en las que hay mayor densidad poblacional.

Palabras clave adicionales: *Ceratitis capitata*, control de plagas, distribución espacial, kriging.

Introduction

The Mediterranean fruit fly, or medfly, *Ceratitis capitata* (Wiedemann) [Diptera: Tephritidae, Ceratinini] damages a very large number of fruits and vegetables (Liquido, 1989); indeed, it is one of the most important pests of tropical, subtropical and temperate regions (FAO/IAEA, 1993; White and Elson-Harris, 1994).

The economic importance of this species is due not only to the direct crop losses it occasions but also to the high cost of its control, including the outlay for trap systems (used in intensive monitoring) and insecticide. The use of the latter is associated with environmental problems, and for some time attention has been focused on developing alternatives. Recently, a highly selective and effective combination of synthetic food attractants (Biolure: ammonium acetate, trimethylamine and putrescine) has been developed for capturing medfly females (Heath *et al.*, 1997; Epsky *et al.*, 1999; Miranda *et al.*, 2001; Alemany *et al.*, 2004a, among

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others). In Spain, Biolure attractants have been very useful in their mass trapping on peaches (Sastre *et al.*, 1999), custard apples (Ros *et al.*, 2002) and citrus fruits (Alemany *et al.*, 2004b).

Employing data gathered in earlier work (Alemany *et al.*, 2004b), the aim of the present study was to compare the results obtained by standard and kriging analysis of changes in medfly population density. The conventional method estimates population density by transforming data into average captures per trap per sampling period (Hedström, 1993; Katsoyannos *et al.*, 1999). However, this only shows temporal changes in the target organism's population; it provides no information on spatial distribution. With the kriging interpolation method (Davis, 1986; Isaks and Srivastava, 1989), spatial heterogeneity is revealed. The data examined were collected during the season-long mass trapping of females for the control of the medfly in an isolated citrus orchard (*Citrus aurantium* L.) in Mallorca (Spain). The capture results represent a full annual flight curve, i.e., from the emergence of the first adults in early summer until the population tapered out when the cold weather arrived in November. This is the first time such results have been reported for *Ceratitis*.

Material and Methods

Study site. The mass trapping experiment took place in an isolated 0.7 ha citrus orchard in the Sóller Valley in the northwestern mountain range of Mallorca (Balearic Islands, Spain). The plot was located 265 m above sea level. In Mallorca, oranges are normally harvested in June and July, but in the present orchard this is not performed until mid August (it is probably the last to be harvested on the island); it is therefore at great risk of *Ceratitis* infestation. The orchard had 225 trees - mostly Late Valencia orange trees and a few lemon trees separated 5 × 5 m from one other. These citrus trees were far from other *C. capitata* hosts except for a number of large fig (*Ficus carica* L.) trees, two in the northwest corner of the plot, and four more outside its confines but near its western border (Fig. 1). The surrounding area was home to a large olive (*Olea ceratonia* L.) plantation and a wild pine forest (*Pinus halepensis* L.). The mean annual temperature of the area is 17°C and the mean precipitation 850 mm, most of which falls between September and April. During the experiment, temperatures were recorded weekly in the orchard.

Precipitation data were registered at a weather station belonging to the National Meteorological Institute of Mallorca, some 10 km away.

Trapping systems and data analysis. For conventional monitoring, eight Tephri traps (Sorygar Ltd.) were baited with Biolure® female-biased attractant. Another four were baited with Trimedlure (TML, AgriSense-BCS Ltd.) as a standard male monitoring system. These were put in place on May 14th to detect the beginning of medfly activity. A dichlorvos plug (DDVP, Kenogard Ltd.) provided insecticide inside the traps. Weekly captures of males and females were recorded. The female attractant was renewed every 6 weeks, and the Trimedlure and DDVP every 8 weeks. Trap catches were converted into flies per trap per day (FTD).

For the mass trapping experiment, which started on July 8th, 117 additional Tephri traps baited with the Biolure attractants were placed on at least every third tree (Fig. 1). Four traps were also placed in the canopies of the two large fig trees (two in each tree) in the northwestern corner of the plot. A DDVP plug was again used in each trap. All oranges were fully ripe by June and were harvested in the middle of August. Mass trapping was terminated at the end of November when the adult population decreased with the onset of the first cold weather. Male and female flies were recorded separately every other week. All trap captures were converted to FTD values.

For the spatial analysis (i.e., kriging analysis), the location of each tree was defined on a topographic map of the orchard using a GPS system. The *C. capitata*

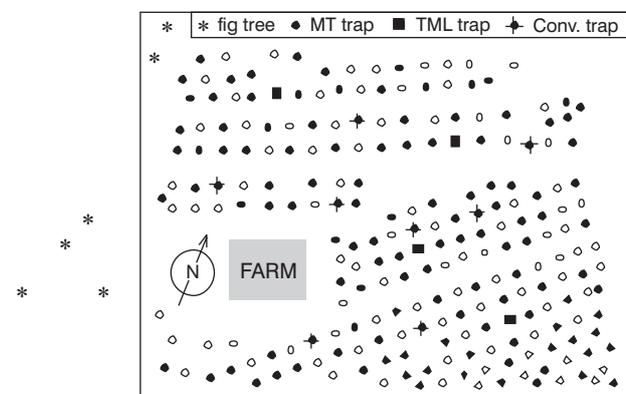


Figure 1. Topographic map of the citrus orchard; location of trees, traps and surrounding vegetation. MT: mass trapping, TML: Trimedlure, Conv: conventional trapping.

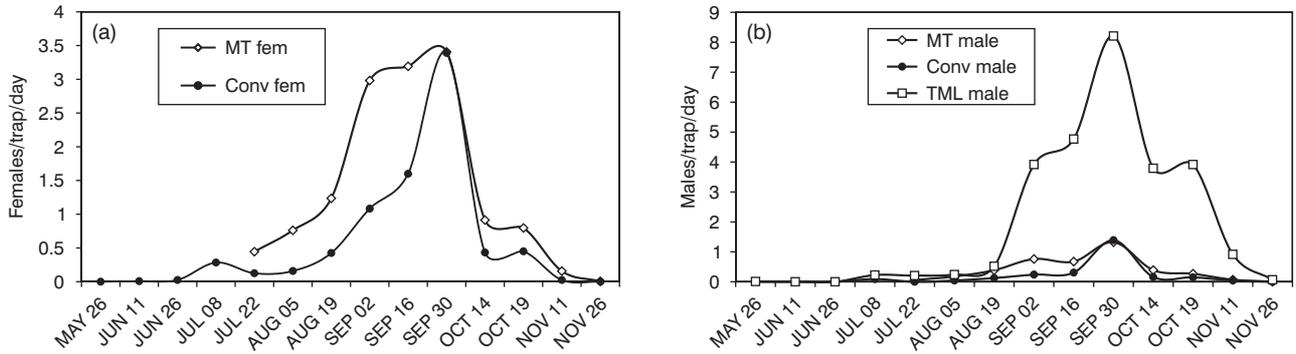


Figure 2. a) *C. capitata* captures (transformed into females/trap/day) obtained with the 125 Biolure-baited traps in the mass trapping (MT) experiment and with the 8 Biolure-baited traps used in conventional monitoring. b) Captures (transformed into males/trap/day) obtained with the 125 Biolure-baited traps in the MT experiment, and with the 8 Biolure and 4 TML traps in conventional standard monitoring.

captures obtained with the 125 Biolure-baited traps were mapped using Surfer v 8.03 software (Surface Mapping System, Golden Software Inc., Golden, Colorado, US). Interpolated differential shading was used to indicate large/small captures.

Results

Conventional monitoring: temporal population density changes. The first captures were made on June 24th (0.42 females and 0.14 males/trap/day). Two weeks later (July 8th) the mass trapping experiment began, and initial capture values of 0.85 females and 1.42 males/trap/day were obtained. Figure 2 shows the

female and male captures made with the conventional monitoring system and in the mass trapping experiment. In Fig. 2a it should be noted how, after July 8th when the other 117 traps were added, the captures made with the initial Biolure traps diminished. From the second week of August, both male and female fruit fly captures began to show an exponential growth pattern, suggesting that the mass trapping strategy was unable to control the population. In the middle of October, captures began to decrease, probably coinciding with a fall in minimum temperatures to around 13°C. After maintaining a constant level over the last two weeks of that month, captures finally tapered off to zero by the end of November, when minimum temperatures dropped to near 5°C. Figure 3

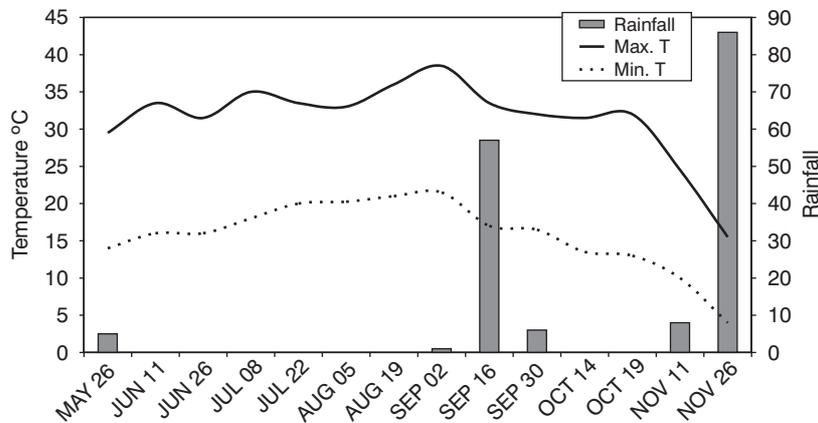


Figure 3. Maximum and minimum temperatures and rainfall ($\text{mm m}^{-2} \text{day}^{-1}$) during the experimental period.

shows the maximum and minimum temperatures and precipitation recorded during the experiment.

Changes in spatial and temporal population density. The kriging interpolation results for the female captures recorded every two weeks in the 125 Biolure traps were used as an indicator of the heterogeneity of the pest's distribution in the orchard. The spatial and temporal female captures patterns are represented in nine diagrams in Figure 4.

In the diagram for the 22nd July, the largest captures were made in trees located at the borders of the orchard (Fig. 4a), especially the southern and western sides. In the middle of August, progressively larger captures were obtained, coinciding with the time of fig ripening. The highest pest densities were recorded in the northwest corner of the orchard and along the western border, near the large fig trees (Fig. 4b-c). From this time on, the medfly population showed a very high growth rate and

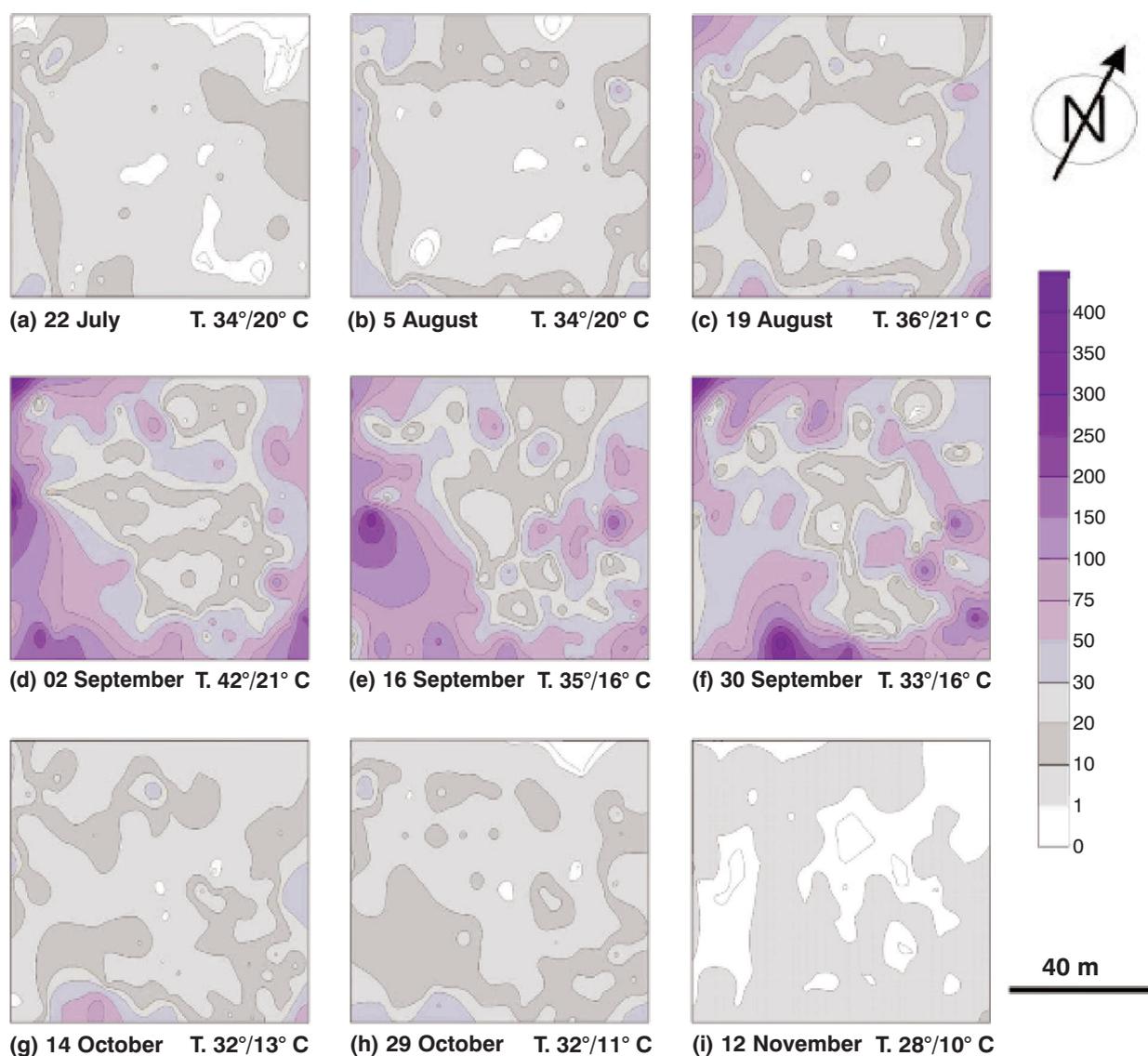


Figure 4. Spatial distribution of the total *C. capitata* female captures obtained during the mass trapping experiment. Shading indicates high/low total number of captures. Dates and maximum and minimum temperatures are provided.

individuals spread progressively inwards until the entire plot had been invaded (Fig. 4d-f). Fortunately, fruit harvest took place at this time. From August to September when the ripe figs were still on the trees or fresh on the ground, the medfly population reached its maximum (see peak in Fig. 2), but as the figs dried, captures in the fig trees decreased sharply.

The population density started to decrease in October (Fig. 4g-h) probably in relation to a reduction in the minimum temperature. At this time the main captures were again made at the orchard borders. Finally, in the middle of November, the minimum temperature fell to 10°C (Fig. 4i), leading to noticeably smaller captures. By this time, the number of females caught on the fig trees was lower than on the orange trees. At the end of November, when the temperatures dropped to 5°C, no females were caught.

Table 1 shows a comparison of the captures (transformed into FTD values) obtained on the two fig trees and on the orange trees on the western border of the plot. The total captures obtained in these two fig trees, and on the west-side citrus trees, were much higher than those for the rest of the orchard.

Discussion

The main purpose of this work was not to analyse the mass trapping results and their effectiveness, but to show the advantages of kriging analysis. Figure 2 shows that the results obtained with FTD assessment (i.e., the conventional method for following pest development) only reflect changes in relative population density over time, while the spatial analysis (kriging interpolation) of the same data provides, apart from the relative population density, a within-field heterogeneity distribution of the captures. The latter analysis provides very valuable additional information for pest management. For example, in this scenario,

when captures started in early summer, control measures would have been best focused on the western border and in the northwestern corner of the orchard where the medfly population densities were highest - something only kriging analysis could show (Fig. 4a). Additionally, kriging analysis showed the impact of unmanaged auxiliary host crops (fig trees) on pest development; the largest captures were obtained near the fig trees in the northwest of the orchard and along the western border. They were also coincident with the ripening of the figs (Fig. 4d and e). It is a well known that *C. capitata* prefers figs to oranges since the former contain more sugar and nutrients (Hendrichs and Hendrichs, 1990). These fruits can therefore act as powerful pest multipliers. Fortunately, the oranges were harvested just as the figs ripened and the mass trapping experiment was successfully completed before fly numbers became overwhelming (Alemayn *et al.*, 2004b).

Kriging has recently been used by several authors in pest management studies. For example, Crist (1998) assessed a geostatistical method to determine the spatial distribution of termites in a shortgrass steppeland, Ribes-Dasi *et al.* (2001) determined the spatial distribution of *Cydia pomonella* and *Pandemis heparana* in a wide study area, and Régnière and Sharov (1999) developed a potential temperature-dependent distribution map for the male gypsy moth. The results of the present work, which spatially represent the captures of *C. capitata* over a full flight curve, were similar to those reported by Thomas (2000) for wild beetles, showing population waves emanating from the boundaries of the study area.

In conclusion, kriging analysis seems to be an extremely useful complement to the FTD index. This spatial approach may have much to offer in pest management, especially with respect to wide area control methods (e.g., the sterile insect technique) (Hendrichs *et al.*, 2002; Avilla and Ribes-Dasi, 2004).

Table 1. Number of female flies/trap/day captured on the fig trees and the orange trees at the western border, and the mean number of flies/trap/day for the entire orchard

	Jul 22	Aug 5	Aug 19	Sept 2	Sept 16	Oct 10	Oct 29	Nov 12	Nov 26
Fig trees	2.3	7.7	21.2	9.9	22.0	1.9	0.1	0.2	0.0
Western border orange trees	2.6	3.4	9.4	6.2	2.9	1.1	1.5	0.3	0.0
Mean total captured	1.7	2.7	6.4	6.8	7.4	1.9	1.6	0.3	0.0

The understanding of the heterogeneous spatial distribution of target insects enables control measures to be taken at the most appropriate time and in the most appropriate place, thus reducing the economic and environmental costs involved (Enkerlin, 2003).

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