Forecasting the flight activity of *Lobesia botrana* (Denis & Schiffermüller) (Lepidoptera, Tortricidae) in Southwestern Spain

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Abstract

This study aimed at elaborating a forecasting tool of the phenology of the serious pest *Lobesia botrana* in Southwestern Spanish vineyards, by analysing data on male catches in sex pheromone traps recorded over a 12-year period. Our data confirmed the minor importance of the first generation which appears during flowering time, both in terms of male trap catches and damage of *L. botrana* to the inflorescences. Therefore, data related to the first flight were not further processed, although they were considered for the computation of degree-days of the following generations. The outcome of the elaboration of temperature accumulations and data on male captures for the second and third flights was a statistically acceptable linear behaviour obtained by properly transforming the variables. The models established proved to be efficient and may represent a useful tool to improve the efficacy of integrated pest management strategies targeting *L. botrana* in the studied region.

Introduction

The European grapevine moth, *Lobesia botrana* (Denis & Schiffermüller) (Lepidoptera, Tortricidae), represents the main pest of vineyards in the Mediterranean basin and Asia Minor, inhabiting regions situated between 29° and 47° latitude (Roditakis and Karandinos 2001). The highest population levels and the most severe economic damage are consistently recorded in areas with an annual average temperature around 20°C and a relative humidity around 70%, respectively, regarded the optimal eco-climatic conditions for this insect (Stellwaag 1928).

In the majority of the Spanish vineyards, this lepidopteran pest usually develops three generations (Coscollá 1992). The first generation appears during the flowering time and is usually not controlled by chemical treatments unless the number of moth catches in pheromone traps and presence of nests on vine inflorescences is abnormally large. The following generations attack the berries provoking direct as well as indirect damage, such as the fungal rottenness caused by *Botrytis cinerea* (Persoon: Fries) which is favoured by the larval activity inside the berry during maturation. In many occasions, a fourth generation usually develops, unless the temperatures fall. This last, partial generation does not deserve treatment because its flight coincides with the grape harvest and, as a consequence, the risk of losses disappears.

In Spain, *L. botrana* was first detected in the middle sixties in Ribera del Guadiana Denomination of Origin (Central Southwestern Spain) and currently it represents the main target of grapevine IPM. Sometimes, seven or more treatments per year with traditional and/or I.G.R products or *Bacillus thuringiensis*, are necessary to keep this harmful pest under the economic injury level. Other IPM techniques, such as mating disruption or plastic pheromone dispensers are not currently implemented.

Monitoring of grapevine pests, their natural enemies, and diseases during the phenological development of the plants is locally being carried out by IPM teams, named Atrias, which co-operate with the grape farmers and the agricultural administrations to determine the best moments to perform phytosanitary treatments. Therefore, in order to optimise grapevine management, it would be extremely useful to have a predicting model for the flight activity and the different generation times of *L. botrana*, in a similar way as described by Ahmad and Ali (1995) and Ahmad et al. (1995) for other lepidopteran species, such as *Ephestia* spp. and *Cydia pomonella*.

Linear models were the first which were developed to describe insect phenology (Howe 1967). However, the lack of linearity in insect developmental rate at low and high temperatures suggested that these models were inadequate, leading to, since the early 1980s, development of non-linear phenological models for integrated pest management programmes (Wagner et al. 1984). For the grapevine moth several models have been proposed (Touzeau 1981; Cravedi and Mazzoni 1994; Milonas et al. 2001), including one which takes in account the relative influence of specific climatic factors on the dynamics of these insects (Schmidt et al. 2003). However, since the distribution of the emergence times varies according to sites, climate and years, their validity is restricted to the local conditions. Recently, a stochastic model based on Bayesian approach and hierarchical modelling has been suggested to overcome the usual limits of models based on field data (Moravie et al. 2006).

The purpose of the present paper was to elaborate a forecasting tool of the emergence and population size of *L. botrana* adults in Southwestern Spanish vineyards, based on data collected during 12 years and considering the relationship between male catches in sex pheromone traps and the accumulation of day-degrees. In spite of the limitations of these traps, a direct relationship between the number of catches of male moths and their rate of emergence has been assumed (Potter and Timmons 1983), the latter being directly influenced by the heat the insects received during pre-adult phases.

Moreover, by comparing these results with those obtained in a shorter study in Andalusia (Del et al. 2001), this work aimed at detecting the variation of the outcome using the same method to compare areas in SW Spain that are about 300 km distant from each other.

Material and Methods

This study was set up in southern parts of the wine producing region Ribera del Guadiana (Extremadura) (UTM: 29S 716870, 4276904), between 1990 and 2002. This area is characterized by a typical mix of Mediterranean and continental climate, with short and mild winters (average temperature 10°C) and dry, hot summers (average temperature 27°C). Rainfall ranging from 350–400 mm/year in flat areas and 450–600 mm/year on higher grounds. The vineyards cover over 80 000 ha and produce 3 300 000 hl per year. The main cultivars are Alarije, Pardina, Tempranillo (Cencibel), Garnacha; recently, international varieties such as Cabernet Sauvignon and Merlot have been introduced.

Data on male flight monitoring were obtained using twelve delta traps (Trapline d, Syngenta Agro) baited a synthetic pheromone of *L. botrana*. These traps were established in the central part of the six most important vineyard districts (about 5 ha size) with two traps in each district. The traps were placed 1 m above the ground, from the beginning of March until the end of October, and were checked once a week. Sticky bottoms were replaced as needed and pheromone lures were changed once a month. Temperature data were obtained from several meteorological stations situated close to the districts where the pheromone traps had been placed.

The flying periods of the second generations were calculated as the duration in day-degrees between the beginning of the second and the start of the third one.

To achieve a reliable prediction model, data from temperature accumulations (degree-days) were plotted against data from male captures, which had been conveniently transformed (as described afterwards). Data from the year 1996 were excluded from the analyses because of the low presence of *L. botrana* during that year.

Computation of degree-days corresponding to the emergence of the second generation started on 1 March of each year. To calculate daily day-degrees, the lowest threshold temperature used was 7°C, whereas the highest threshold temperature considered was 30°C, similarly to the studies carried out by Gabel and Mocko (1986) and Del (1996).

Computation for the third generation started from the day, when 50% of captures of the previous emergence was recorded, in accordance with the methodologies followed by Bovey (1966) and Touzeau (1981). In fact, we observed in the field that the time period necessary for the first 50%

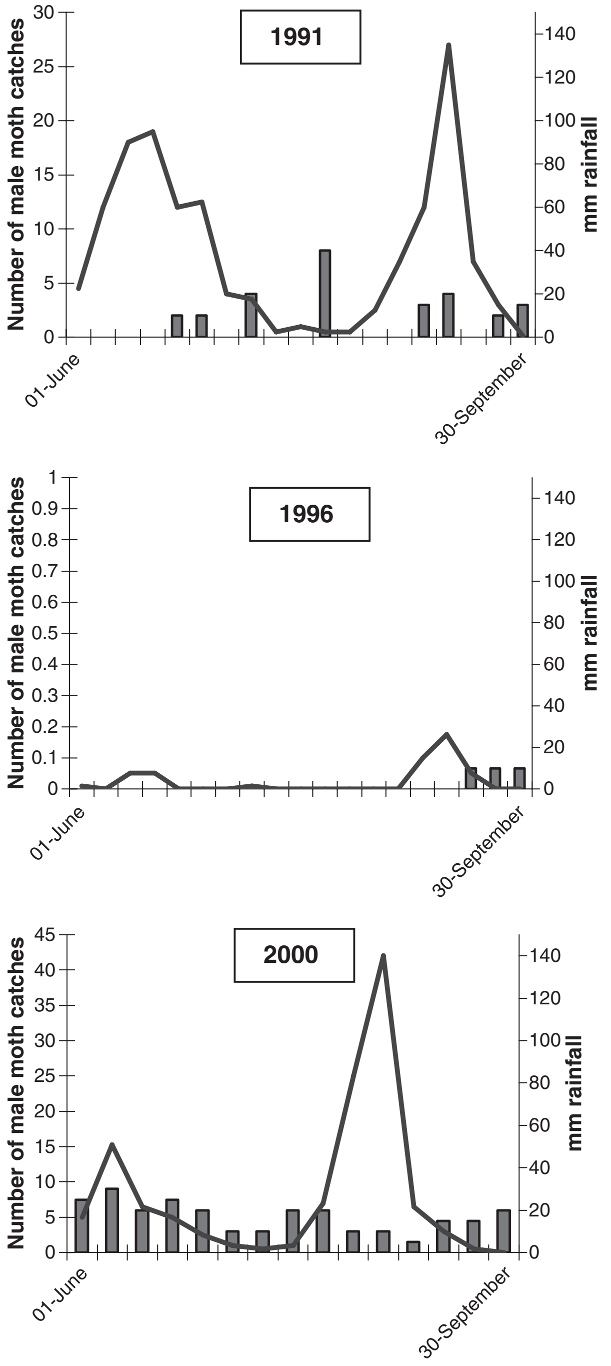

Fig. 1 Representation of second and third flight curves of *Lobesia botrana*, based on pheromone trap catches, and pluviometric data from the sampled area in SW Spain during selected years (1991, 1996, 2000) (on Y axis, left, number of male moth catches; on Y axis, right, mm rainfall; on X axis the time period).

L. botrana individuals to complete their development and emerge as adults was considerably similar to the time period that usually elapses between appearance of the imagines and the egg laying by the following generation (Touzeau 1981).

When the maximum and minimum temperature records were available, the cumulative daily day-degrees were calculated, following the method of González-Andújar and Hernández Vinuesa (1990) based on modified sine waves. For this purpose a computer program, developed by the CSIC (Advanced Scientifical Investigation Center) (Córdoba, Spain), was used to manage the collected data set and to determine the corresponding fits.

Flight activity of *L. botrana* was calculated from the weekly number of captured males. The period considered ranged from 1990 to 2002. Collected data were transformed into population-day data by applying the formula:

$$Population - day \ = \ \sum_{\mathrm{i}} \frac{N_{\mathrm{i}} + N_{\mathrm{i}-1}}{2} D_{\mathrm{i}}$$

where: N_{i} = number of captured adults/trap number at i-th sample, D_{i} = number of days elapsed between the (i−1)-th and i-th samples.

For each year and each generation, linear equations were obtained. The *x*-variables used in the models (as shown in the figures), corresponds to the decimal logarithm of the thermal integrals, whereas the *y*-variables indicate the transformation of population-day data in terms of values of the Probit function.

Finally, several statistical analyses were applied at the 5% confidence level to evaluate results. To present a preliminary quantification in days of the expected errors, Table 3 compares the mean degree-day accumulations values corresponding to 10%, 50% and 95% of captures, to the predicted ones.

Results

Flight activity of the first generation was always very low, as deduced by the numbers of male catches, which were below 3 individuals/trap/week. At the same time, the presence of symptoms on clusters was identified on less than 2% of sampled vines. Therefore, data related to the first flight were not further processed, due to the low population levels of adults, although they were considered for the computation of degree-days corresponding to the emergence of the following generations.

Among all curves related to the second and third flights of *L. botrana* males obtained during the 12-years sampling period, fig. 1 only shows those associated to years with abnormally low (1996) or high (1991, 2000) rainfall levels. The M/T/D index

(Number of males catches/Number of traps/days) during 1996 was lower than 0.5. This was very likely due to the serious drought in this area in 1995–1996, when rainfall was zero. Therefore, we connected the index of presence of this lepidopteran species directly to humidity levels (Torres-Vila et al. 1996).

With regard to the data for the second and third flights, we used log-probit linear equations to express the temperature accumulations vs. male catches (Table 1). The correlation coefficients found were considerably high; especially for data related to the second generation, where the value 0.95 was exceeded in 90% of the cases.

To increase the reliability of the data, all available data were re-processed and the average linear regressions were obtained for each flight considered. The results are given in Table 2, and straight lines fitting best are drawn in figs 2–3.

The correlation coefficients were similar for both flights, their values being 0.836 and 0.873 respectively. Moreover, $P < 0.05$ and the values of the F distribution to test the hypothesis at the 95% confidence level exceeded the boundaries of the confidence intervals, suggesting a linear relationship between the variables. Therefore, both equations (Table 2) represent reliable expressions useful for the prediction of emergences of *L. botrana*. Moreover, these equations help to design models for the integrated control of *L. botrana* in the Ribera del Guadiana county in the future.

Based on the previously described equations, a preliminary quantification of the expected errors in terms of days was performed. Table 3 compares the mean degree-day accumulations values corresponding to 10%, 50% and 95% of captures, to the predicted ones. As expected, the highest errors correspond to the second flight, and the lowest to the third flight.

Discussion

Studies on the flight pattern of insect pests aims at establishing warning systems and represent a useful tool for undertaking phytosanitary actions, thus facilitating prognosis and prevention (Savopoulou-Soultani et al. 1996). The predictive power of flight curves has been of particular interest with regard to timing of chemical control measures (Butcher and Haynes 1960). Nevertheless, a day-degree model might as well provide an adequate forecast, given the practical limitations on the ability to monitor *L. botrana* activity in the field (Knight and Croft 1991).

An intensive discussion has centred upon the use of linear as compared to non-linear models for insect

Table 1 Log-probit linear equations showing temperature accumulations vs. male catches with pheromone traps

Flight	Year	Regression lines	d.f.	r	SE
Second	1990	$y = 3.8924x - 8.2311$	15	0.9623	0.0628
	1991	$y = 7.6107x - 18.9397$	18	0.9724	0.1558
	1992	$y = 4.3006x -0.4721$	22	0.9294	0.1101
	1993	$y = 14.3345x - 40.5638$	19	0.9525	0.5632
	1994	$y = 4.3081x - 10.5585$	25	0.9591	0.080
	1995	$y = 5.2194x - 13.1213$	20	0.9189	0.1798
	1997	$y = 6.6479x - 16.7350$	21	0.9658	0.1166
	1998	$y = 9.4373x - 24.9567$	19	0.9116	0.5889
	1999	$y = 2.3287x - 2.7258$	25	0.9456	0.048
	2000	$y = 6.9564x - 16.9299$	29	0.9782	0.1165
	2001	$y = 8.5457x - 15.4552$	35	0.9525	0.2512
	2002	$y = 4.8554x - 27.2445$	21	0.9856	0.3545
Third	1990	$y = 4.9612x - 11.2659$	19	0.8056	0.5326
	1991	$y = 5.6921x - 12.7222$	19	0.9738	0.2808
	1992	$y = 6.9859x - 16.8736$	25	0.9098	0.3949
	1993	$y = 5.3233x - 11.9370$	21	0.9676	0.2605
	1994	$y = 6.1457x - 13.7788$	30	0.9790	0.2529
	1995	$y = 5.2294x - 12.0171$	35	0.9126	0.4218
	1998	$y = 4.7750x - 10.6127$	33	0.9150	0.3850
	1999	$y = 6.0936x - 13.3489$	28	0.9963	0.1064
	2000	$y = 5.3910x - 12.1561$	25	0.8754	0.4664
	2001	$y = 8.7561x - 20.4698$	26	0.9675	0.3445
	2002	$y = 7.6666x - 18.5636$	19	0.9933	0.2540

d.f., degrees of freedom; r, correlation coefficient; SE, standard error.

Table 2 Regression equations (temperature accumulations-male catches) obtained by processing all available data

	Second flight	Third flight
Regression equation	$y = 9.2581x - 24.3779$	$y = 5.7725x - 13.0323$
d.f.	269	280
F	196.59	315.23
r	0.8359	0.8729
P	0.005	0.001
SE	0.6665	0.6299

d.f., degrees of freedom; F, F-value; r, correlation coefficient; SE, standard error.

Table 3 Comparison between predicted and observed values of degree-day accumulations corresponding to 10%, 50% and 95% of captures

Flight		10%	50%	95%
Second	Predicted values	815.34	902.35	1225.32
	Observed values	881.58	946.58	1233.27
	Error (mean)	66.24	44.23	7.95
Third	Predicted values	655.22	896.24	1420.41
	Observed values	601.54	887.23	1424.42
	Error (mean)	53.68	9.01	4.01

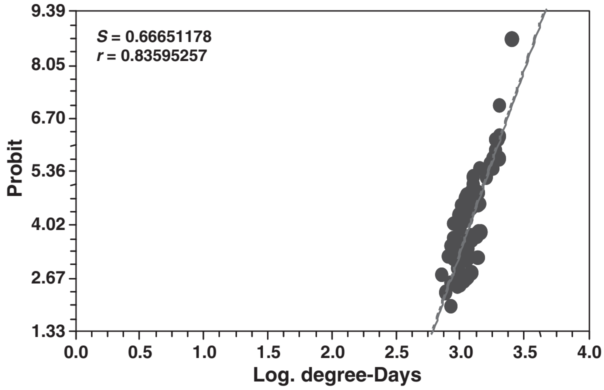

Fig. 2 Second flight linear regression of trap captured *Lobesia botrana* (expressed by a Probit function) vs. degree-days accumulation (transformed in Log. degree-days).

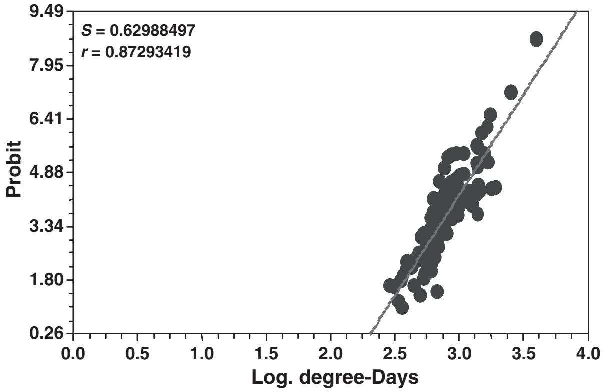

Fig. 3 Third flight linear regression of trap captured *Lobesia botrana* (expressed by a Probit function) vs. degree-days accumulation (transformed in Log. degree-days).

Table 4 Linear correlations obtained for Sherry vineyards, in 'Marco del Jerez' county (Del et al. 2001)

	Second flight	Third flight
Lineal regression	$y = 16.4437x - 40.8194$	$y = 15.8238x - 39.7001$
d.f.	115	128
F	316.2	1746.16
r	0.8563	0.9652
SE	0.8612	0.4296

d.f., degrees of freedom; F, F-value; r, correlation coefficient; SE, standard error.

development. Linear models of degree-day have been extensively used on a practical level, due to the simple calculation of its parameters and because they often provide the desired precision (Fan et al. 1992). However, their application is limited to the linear part of the relationship existing between the developmental rate and temperature, as there are non-linear models which provide better predictions for the set of this relationship (Wagner et al. 1984; Briere and Pracros 1998). In fact, non-linear models provide an advantage theoretically, but they also add considerable complexity. On the opposite, linear day-degree models require much less data for their implementation and are more functional and easier to use in the field as extension-type phenology models (Welch et al. 1978; Dent 1997; Young and Young 1998).

One of the main problems associated to the degree-day model remains in the absence of a prediction of the upper threshold level for development, as well as an overestimation of the lower threshold level. However, for the majority of the species this linear approximation is usually acceptable, as long as the temperatures to which insects are subjected under natural conditions are not extreme ones (Higley et al. 1986). In the area of our samplings, Tierra de Barros, the average daily temperature never exceeded levels above 30°C.

In the present study, based on data collected during 12 years, the linear relation between temperature accumulations and pheromone trap catches of L. *botrana*, conveniently transformed, turned out to be statistically significant. As a result, the equations obtained may be used to predict the flight patterns of the species and may help to identify the most useful time periods to perform control measures.

It has been proved that damages of the inflorescences caused by the first *L. botrana* generation do not negatively affect the grape yield (Roehrich 1978; Roehrich and Schmid 1979; Gabel 1989). Moreover, vine is believed to be tolerant to diseases that affect the inflorescences (Coscollá 1992). For these reasons, no control measures are usually undertaken for the first generation of *L. botrana*. Therefore, this period has not been further considered for the present study. Comparing the linear correlations obtained for this geographical area as compared to those obtained for another Spanish county (Marco del Jerez) located 200 km south of Tierra de Barros (Del et al. 2001) (Table 4), and using the same confidence levels, considerable differences were observed when comparing the slopes related to the second generation, whereas the coefficients fitted for the third generation were more similar. These findings indicate that linear regression models are efficient for the description of insect development within a given geographical area; however, the results cannot be easily translated into other areas, where particular conditions with regard to temperature regimes may impact specific genetic features of *L. botrana*.

Therefore, considering the increasing interest for biorational insecticides, for which precise timing of treatments is specifically important, the equations obtained by both methods may be used to forecast the emergences of the males of this insect in the area of Ribera del Guadiana, taking into account that the speed of development is predominantly directed by temperature and precipitation, and that accurate information on insect phenology is needed in order to improve the efficiency of these biorational pest control measures (Pitcairn et al. 1992; Judd et al. 1996).

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