Vitis **52** (2), 91–96 (2013)

Predictive model for the emergence of *Xylotrechus arvicola* (Coleoptera: Cerambycidae) in La Rioja vineyards (Spain)

F. J. Soria[1], M. A. López[1], M. A. Pérez[1], L. Maistrello[2], I. Armendáriz[3] and R. Ocete[1]

[1] Laboratorio de Entomología Aplicada, Facultad de Biología, Universidad de Sevilla, Sevilla, Spain
[2] Dipartimento di Scienze della Vita, Università di Modena and Reggio Emilia, Reggio Emilia, Italy
[3] Centro de Agricultura Ecológica y de Montaña (CAEM). Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA), Ministerio de Economía y Competitividad, Plasencia, Cáceres, Spain

Summary

***Xylotrechus arvicola* (Coleoptera, Cerambycidae) (Olivier) is a polyphagous borer which attacks different woody species in natural habitats in Spain. This coleopteran is also becoming a real impacting pest in several Spanish wine producing territories. Infested vines show adult exit holes, rachitic shoots, a higher incidence of wood fungal diseases and fragility. At the beginning of the 1990s, a heavy increase of infestation was observed in La Rioja vineyards, the only Qualified Guarantee of Origin Region (A.O.C.) in Spain. Due to the endophytic development of the larvae of *X. arvicola*, adults are the designated target for the integrated management. Therefore, the aim of the present paper was to study the flight period of the pest and to calculate the value of degree-days for the emergence of both sexes from data collected in the field during 2003-2008 in a Tempranillo cultivar in Tirgo (La Rioja). Adult emergences occurred from the end of May to mid-August and a certain degree of protandry was detected. The predictive models obtained for each year fit a sinusoidal curve in all cases, except for males in 2004, when the adjustment was polynomial. The obtained correlation coefficients were considerably high, as the value 0.99 was exceeded in 72 % of the cases. These results obtained in La Rioja vineyards suggest that control strategies aimed at the reduction of the adult population of *X. arvicola* in the view of the integrated management, should be performed between mid-June and the end of July.**

K e y w o r d s : pest control, damages, degree-days, Tempranillo cultivar, threshold temperatures.

Introduction

Xylophagous cerambycids constitute the severest economical pest on wood exploitations all over the world, especially when, due to wood trading, these wood-boring beetles are introduced in countries different from their areas of origin (Cocquempot 2006, Cavey 1998, Grebennikov *et al.* 2010).

Focusing on vineyards, among the 26 genera of coleopterans reported to attack grapevines in Europe (Galet 1982), the mostly cited cerambycid was *Vesperus xatarti* Dufour considered it as a real pest from the middle of the XIX century (Jacquelin Du Val 1850) and was subsequently also recorded in Spain (Mendizábal 1937, Ruiz Castro 1947). *Clytus arietis* (L.) was reported as a pest in Spanish vineyards (Ruiz Castro 1943, Domínguez García-Tejero 2004) as well as in France (Baggiolini and Epard1968). Considering other continents, *Acalolepta vastator* (Newman) causes important damages in Australian vineyards (Goodwin 2005), whereas *Xylotrechus pyrrhoderus* Bates was a pest in several areas planted with French cultivars, like 'Cabernet Sauvignon' and 'Chardonnay', from the beginning of 1980 in P.R. China (Armendáriz *et al.* 2008a, Sakai *et al.* 1984).

Xylotrechus arvicola (Olivier) is a polyphagous borer, a native species in Spain where it attacks different woody species in natural habitats, from the Cantabrian sea to the Sierra Nevada mountain range (Bahillo 1995, Vives 2000, 2001). It is a very common beetle affecting *Populus, Salix* and *Ulmus* species along river bank forests situated in the Northern-Central regions of the country (Ocete *et al.* 2010). Damages in vineyards were discovered since the second half of the decade of the 1970s, when larvae excavating galleries inside the wood of the vines were detected at pruning time in some plots situated in the vicinity of rivers in La Rioja region, a wine producing area which, nowadays, is the only Qualified Guarantee of Origin region (A.O.C.) in Spain.

At the beginning of the 1990s a heavy increase of *X. arvicola* infestation was observed in La Rioja, also in vineyards located far from gallery forests (Ocete and Del Tío 1996) as well as on several species of fruit and ornamental trees (Ocete *et al.* 2009). The reason of this outbreak is presently unknown, but most specialists hypothesize it might be the consequence of the use of specific pesticides that might have adversely affected the natural enemies of this beetle. The absence of winter treatments with the biocide sodium arsenite, whose use was forbidden in the last seven years might also play a role. A few surveys showed that the level of infestation of this pest is influenced by grapevine cultivar, pruning type and age of the vines (Peláez 2001, Álvarez and Villarías 2003, Collazos 2004).

X. arvicola infested vines are extremely fragile (Armendáriz *et al.* 2009), show adult exit holes of about 4 mm

Correspondence to: Dr. I. Armendáriz, Centro de Agricultura Ecológica y de Montaña (CAEM). Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA). Ministerio de Economía y Competitividad. Avda. de España, 43, 10600 Plasencia, Cáceres, Spain, E-mail: i.armendariz2009@gmail.com

diameter, rachitic shoots, a lower production of harvest (OCETE *et al.* 2004), some changes in the composition of the must (OCETE *et al*. 2009) and a higher incidence of wood fungal diseases (MORENO *et al.* 2003). Whether these cerambycid borers, attracted by dead wood, just follow the partial dieback of grapes caused by the pathogenic fungi or, by their activities, they might play a role in facilitating the transmission of the grapevine trunk diseases, it is still an open question. This coleopteran is also becoming a real impacting pest in several other Spanish wine producing areas, like Castilla y León (PELÁEZ 2001, ÁLVAREZ and VILLARÍAS 2003, MORENO 2005, ARMENDÁRIZ *et al.* 2008b, 2009), Castilla-La Mancha (OCETE *et al*. 2002), Navarra and Aragón (EVENA 2005, OCETE *et al.* 2009). So, at present time, about 695,000 ha could be potentially infested in the cited vineyards. The evolution of the spatio-temporal distribution of the pest was monitored in La Rioja, where the percentage of infested vines grew to 94 % in just nine years and the number of dead vines varied from 2 to 17 % in seven years in the same plot used for this survey (OCETE *et al.* 2010).

As *X. arvicola* is able to complete its life cycle in the grapevines (MORENO 2005), in order to prevent serious damages, it is important to focus the control of this pest inside the vineyards. The larvae of this cerambycid have an endophytic development of about two years, therefore chemical larvicide treatments are unfeasible. An agronomic mechanical practice, bark removing, seems to reduce the oviposition levels (ARMENDÁRIZ *et al.* 2008b), but it is too expensive to be included in vineyard management practices. For these reasons, adults are the designated target for the integrated management of *X. arvicola.* In this view, the aim of the present paper was to study the flight period of this pest and to obtain the value of degree-days for the emergence of both sexes to be used in equations of prediction, according to Integrated Pest Management (IPM) postulates.

Material and Methods

Previous trials to monitor the flight of adults using water and food traps gave very poor results. Thus, for this survey, after pruning time (January 15th), 5 kg of infested vines of *V. vinifera* L. 'Tempranillo', were introduced into 10 prismatic plastic containers (100x70x25 cm) covered by plastic nets and left on the field in the village of Tirgo (42º32’ 26.1’’ N, -2º 57’ 20.8’’ W). From March 1st to August 30th the emergence of adults was observed weekly to get a flight curve. Meteorological data were obtained from the official station at Cuzcurrita de Río Tirón (Servicio Nacional de Meteorología), located about 1 km from the vineyard plot where containers were left in the open air. The survey was carried out during 6 years, from 2003 to 2008.

In order to achieve a reliable prediction model, data from temperature accumulations (degree-days) were plotted against data from male, female and total emergences (as described below). Computation of degree-days corresponding to the adult emergence started on 1 April of each year. To calculate daily degree days, the lowest threshold temperature used was set at 10 °C, whereas the highest threshold temperature considered was 35 °C, according to limit temperatures found by ARMENDÁRIZ *et al.* (2008b) and GARCÍA (2012). Laboratory studies show that at constant temperatures lower than 12 °C and exceeding 35 °C, egg mortality is 100 % (GARCÍA *et al.* 2011). To manage the collected data set and to determine the corresponding fits, the cumulative daily day-degrees were calculated, according to the method of GONZÁLEZ-ANDÚJAR and HERNÁNDEZ (1990).

Emergence period of *X. arvicola* was calculated from the weekly number of captures. They were transformed into population-day data applying the formula:

$$Population - day = \sum_i \frac{N_i + N_{i-1}}{D} D_i$$

where: N_i = number of captured adults / containers 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 sex, regression models were obtained. The x-variables used in the models correspond to the degree-days accumulation, whereas the y-variables indicate the population-day percentage. Finally, U-Mann Whitney statistical analyses were applied at the 5 % confidence level to evaluate results. Data were analyzed using the CurveExpert 1.37 Programme (Daniel Hyams Copyright©, 1995-2001), applied to a large number of both linear and nonlinear regression models. The model that showed the highest precision was selected.

Results

X. arvicola adult emergences in the selected La Rioja vineyards site occurred from the end of May to mid-August (Fig. 1 a-f). The number of adults per kilogram of stored grapevine wood varied between 0.94 in 2004 and 1.82 in 2008. The average value throughout the considered period was 1.35 adults·kg^{-1}.

A certain degree of protandry was detected in each considered year, with males emerging one to four weeks in advance compared to the females, and the first female emerged in mid-June. In June the emergence of males outnumbered females and the difference was statistically significant (U.Mann-Whitney: Z = -2.909, p = 0.004). In July the percentage of emergence of both sexes was practically similar. In August, the emergence of females became slightly higher. In most cases the global emergence curve presents a single peak that occurs between late June and mid-July. The percentage of males emerged when the first female was detected varied between 15 and 38 %, with an average value of 25.7 %. In every case, the number of males was higher than that of females, with a sex-ratio of 1.4:1. However, these differences were not statistically significant in any of the considered years, after applying U-Mann Whitney test. The predictive model of each year (total emergences, females and males, respectively) fits a

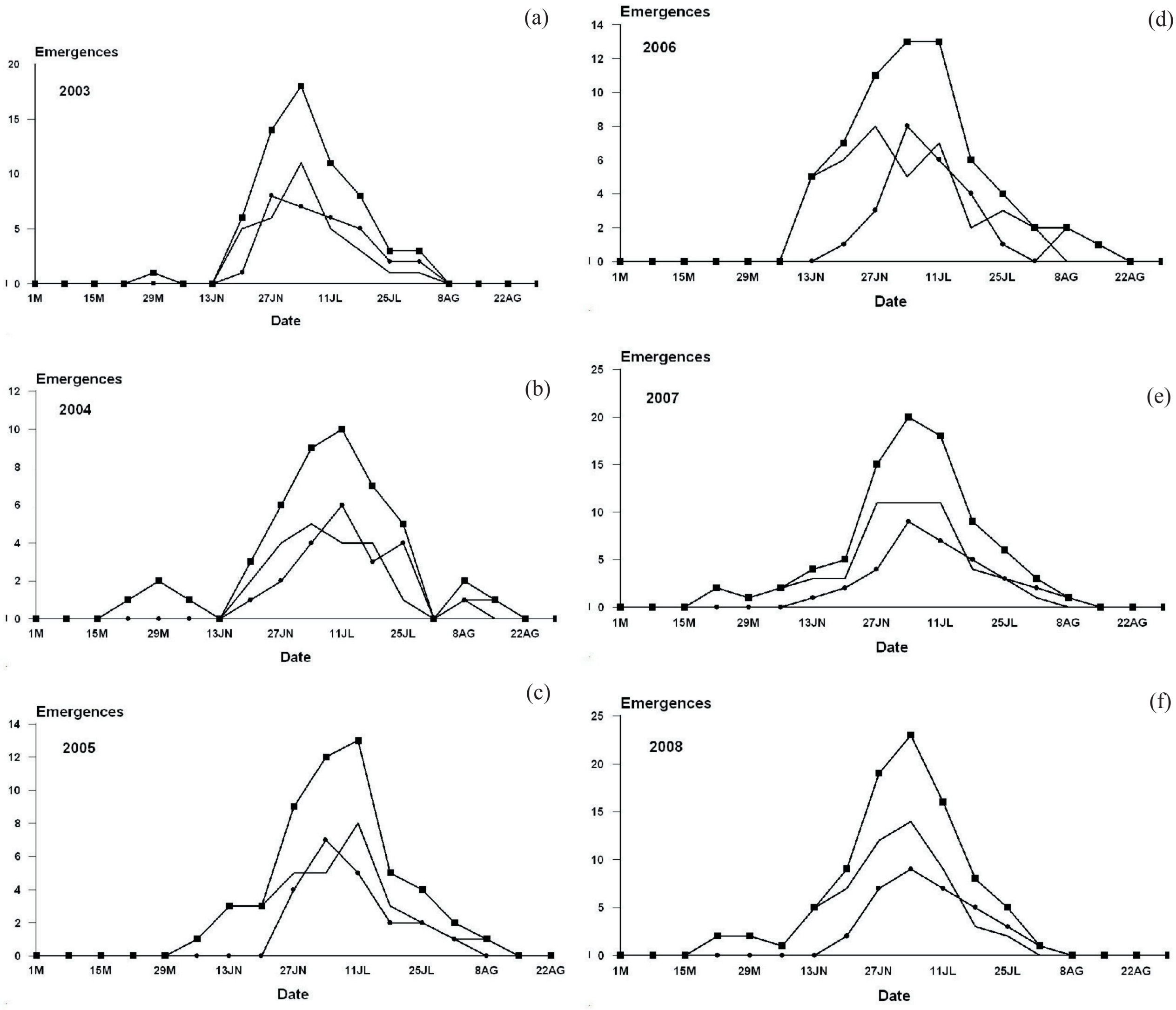

Fig. 1 (**a-f**): Diagrams representing the weekly emergence of *X. arvicola* during the recorded years (2003-2008). (— males, ● females, ■ males + females)

Table 1

Predictive model of each year (total emergences: males and females)

Sex	Year	Regression equation	d.f.	r	S.E.
Females + Males	2003	y=46.5135+55.7044*cos*(0.00365x+2.3949)	10	0.9887	7.4651
	2004	y=52.2523+49.1086*cos*(0.00360x+2.8038)	13	0.9904	5.9970
	2005	y=46.9220+55.9358*cos*(0.00367x+2.4756)	10	0.9926	5.9086
	2006	y=45.0829+55.1922*cos*(0.00341x+2.5657)	10	0.9944	4.7939
	2007	y=50.3438+52.0171*cos*(0.00405x+2.6543)	12	0.9911	5.9998
	2008	y=50.2990+51.9288*cos*(0.00477x+2.6957)	11	0.9942	4.9434
Females	2003	y=32.7186+67.7436*cos*(0.00372x+2.4465)	7	0.9977	3.3618
	2004	y=43.8972+57.0451*cos*(0.00397x+2.4655)	9	0.9909	6.3829
	2005	y=27.9539+71.9804*cos*(0.00469x+1.9730)	6	0.9937	5.8927
	2006	y=40.3008+57.1907*cos*(0.00347x+2.3788)	9	0.9895	6.7781
	2007	y=41.7085+59.4847*cos*(0.00442x+2.3471)	9	0.9959	4.3760
	2008	y=39.3773+62.5086*cos*(0.00544x+2.2476)	7	0.9974	3.7196
Males	2003	y=46.8941+55.5658*cos*(0.00377x+2.4189)	10	0.9886	7.5721
	2004	$y=4.7449+0.000087x+0.00034x^2-2.461*10^{-7}x^3$	12	0.9890	6.0406
	2005	y=46.6555+54.1072*cos*(0.00356x+2.5814)	10	0.9661	4.0967
	2006	y=43.5357+54.5086*cos*(0.00385x+2.5059)	8	0.9969	3.6510
	2007	y=51.6543+50.7863*cos*(0.00404x+2.7968)	11	0.9902	6.0331
	2008	y=51.2648+51.0438*cos*(0.00476x+2.8523)	10	0.9955	4.1921

d.f.: degrees of freedom; *r*: correlation coefficient; S.E.: standard error.

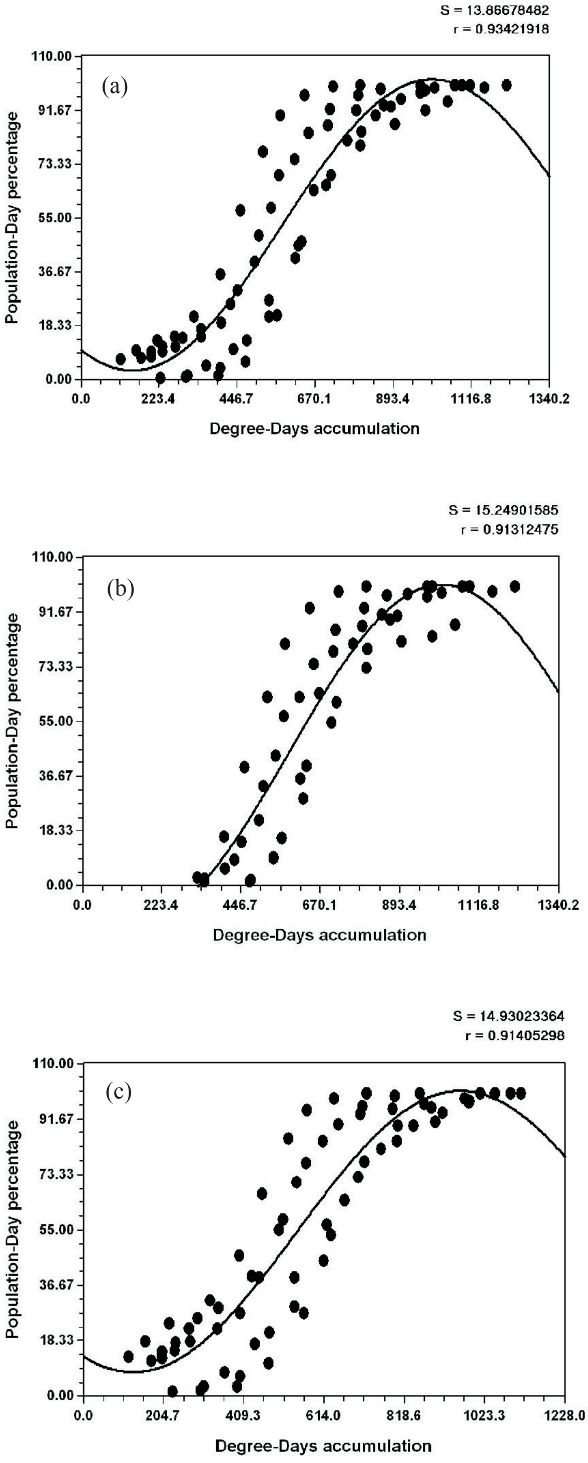

Fig. 2: (**a-c**) Diagrams representing the sinusoidal model obtained for the emergences of *X. arvicola* (total (**a**), females (**b**) and males (**c**)).

sinusoidal curve in all cases except for males in 2004, when the adjustment was polynomial (Tab. 1, Fig. 2 a-c). The obtained correlation coefficients were considerably high, as the value 0.99 was exceeded in 72 % of the cases.

To increase the reliability of results, all available data were re-processed and the predicted model fitted for total emergences to a sinusoidal model (Tab. 2). The correlation coefficient was higher than 0.93 for both sexes together, which indicates a good adjustment of the models found. The correlation coefficients were higher than 0.91 in the case of separated sexes, without any statistically significant difference.

Based on the previously described equations, a preliminary quantification of the expected errors was performed for males, females and for total emergence. Tab. 3 shows the comparison between observed and expected values of degree-day accumulation, according to 10, 50 and 90 % level of the three groups of emergences. Errors tend to become smaller while the values of accumulation of emergence increase.

Discussion

The developmental rates of insects are strictly dependent on temperature, as a certain amount of accumulated energy is necessary to pass from one instar to the next one (Wagner *et al.* 1987, Fierre and Stephen 2007). The present study aimed at detecting the flight period and at calculating the value of degree-days for the emergence of both sexes of *X. arvicola,* a xylophagous cerambycid that is a pest of increasing importance in Spanish vineyards.

Results from this survey performed in La Rioja territory show that this wood borer is a typical monovoltine species with a single flight peak that occurred between late June and mid-July, although the period of emergence covered also mid August. Similar experiences carried out in the Valladolid province (Castilla y León), about 200 km towards the SW of our plot, indicate that the emergence of adults usually starts in March and finishes at the end of July (Moreno 2005). Tests carried out in the same place by Armendáriz *et al.* (2008b) indicate that the emergence started in May, that the number of adults censused before the beginning of June was really very low and that there were two peaks, in the end of June and in the first week of July. In Southern Navarra, on *Prunus spinosa* L. plantations used to produce a distilled drink named *Patxaran*, the period of emergence spans between May 14 and August 26 (Biurrun *et al.* 2007). Occurrence of protandry shown in

Table 2

Sinusoidal model of total emergences, males and females of *X. arvicola*

Sex	Sinusoidal model	d.f.	r	S.E.
Females + Males	y=52.5846+49.4006cos(0.00366x+2.6055)	71	0.9342	13.8667
Females	y=44.5903+56.0174cos(0.00365x+2.5890)	52	0.9131	15.2490
Males	y=54.3222+46.4611cos(0.00376x+2.6651)	66	0.9140	14.9302

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

Table 3

Comparison between predicted and observed values of degree-day accumulations corresponding to 10, 50 and 90 % of captures

Flight		10 %	50 %	90 %
	Predicted values	291.59	561.15	810.15
Males + Females	Observed values	329.73	580.27	799.32
	Error (mean)	38.14	19.12	10.83
	Predicted values	399.03	607.68	839.94
Females	Observed values	486.36	595.44	847.92
	Error (mean)	87.33	12.24	7.98
	Predicted values	207.48	519.08	776.41
Males	Observed values	287.24	545.94	765.70
	Error (mean)	79.76	26.86	10.71

our survey was observed for *X. arvicola* in other Spanish vineyards (Moreno 2005, Armendáriz *et al*. 2008a, b) and is often detected in other cerambycid species (Goodwin and Pettit 1994). The sex ratio of 1.4 is higher than data obtained by Garcia *et al.* (2012) in laboratory and field observation, as it happens in other *Xylotrechus* species, like in the coffee stem borer, *X. quadripes* Chevrolat (Bhaskara and Krishnamoorthy 1987). Sometimes, the main problem in calculating the degree-day model is the absence of the upper threshold of the pest species and the overestimation of the lower one. In this case it was not an obstacle due to previous calculation made by García (2012). Results from this study show that the correlation coefficients were higher than 0.91, indicating a good adjustment of the models found, like in the case of another vineyard pest, *Lobesia botrana* (Denis and Schiffermüller) (Lepidoptera, Tortricidae), according to Gallardo *et al.* (2009). Therefore, the equation found for adults of both sexes together represents a reliable prediction of the emergence of this coleopteran species. Thus, according to these data obtained in La Rioja, control strategies aimed at the reduction of the adult population of this pest (*e.g.* using chemical treatments in coincidence with other vine pest like the European grape moth, *L. botrana*, provided the efficacy of the chemicals on the adult borers is guaranteed) should be performed between mid-June and the end of July. Infested wood should be eliminated together at pruning time, as suggested by Moreno *et al.* (2004), taking into account the endophytic development of larval and pupal stages.

However, in the view of a truly wide integrated management procedure of *X. arvicola*, more environmental-friendly control strategies compatible with ecological agriculture and integrated productions should be detected, and many important aspects might be taken in account. First of all, it would be of primary interest to investigate the genetics and population dynamics of this cerambycid to understand if there are continuous migrations from the riparian vegetation into the vineyards or if the grapevine pests represent a specifically adapted population. Research on the natural enemies of these borers should be performed in order to detect the most effective ones in the vineyard ecosystem. A very important point is understanding the factors that allowed this cerambycid to become a pest of vineyards only in Spain and not in nearby areas with similar vine cultures such as France, Italy, Portugal and Northern Africa. The continuous use of non-selective chemical control and the consequent changes in entomofauna could explain the origin and increase of this pest in Spanish vines. On the other hand sodium arsenite was forbidden when the cerambycid was established as a pest and, beside the fact that legislation is similar in the nearby European countries, no problems with this insect have been recorded elsewhere.

Another important, still unsolved, aspect is the relationship between *X. arvicola* and grapevine trunk fungal diseases. Presently the coexistence between the insect and the pathogenic fungi has been observed (Ocete and Del Tío 1996) and a recent investigation showed that most of the *X. arvicola* infested vine branches had spores of different fungi species. Most of them were related to dieback of grapes (Benavides pers. comm.) and a possible role of the insect as a vehicle for the fungal spores has been hypothesized but not yet investigated. Moreno (2005) suggests a female oviposition preference for fungus infected vines stocks, however in la Rioja we witnessed *X. arvicola* attacks also in three year old vines not affected by the wood fungi. Therefore the question of who arrived first remains and further studies are needed to elucidate this relationship.

The methodology used for this survey allowed for the first time to obtain a predictive model to detect the emergence period of this pest. However, we believe that a thorough investigation aimed at obtaining sex pheromone capsules would allow an easier and more reliable monitoring of this serious pest and would be useful to establish better comparisons of vineyards from different geographical areas. Finally, it is important to remark that the increasing importance of *X arvicola* as a vineyard pest and the fungal wood diseases somehow associated with it that are causing grapevine decline represent a serious handicap for La Rioja viticulture.

Acknowledgements

The authors would like to thank the help of D. García and G. del Río, viticulturists of Tirgo (La Rioja) and the critical review of the manuscript by A. Minnery and A. Villán Busto.

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Received July 12, 2012