Research Article

Received: 27 February 2022 Revised: 5 April 2022 Accepted article published: 14 April 2022 Published online in Wiley Online Library: 5 May 2022

(wileyonlinelibrary.com) DOI 10.1002/ps.6928

Xylotrechus arvicola (Coleoptera: Cerambycidae) capture in vineyards in relation to climatic factors

Álvaro Rodríguez-González,[a*] Rosa Ana Malvar,[b] Marcos Guerra,[c] Esteban Sanchez-Maillo,[d] Horacio José Peláez,[e] Guzmán Carro-Huerga[a] and Pedro Antonio Casquero[a]

Abstract

BACKGROUND: Captures and seasonal abundance of *Xylotrechus arvicola* (Coleoptera: Cerambycidae) in relation to climatic factors were studied in vineyards between the years 2013 and 2020. Insects captures from vine wood in two *Vitis vinifera* varieties were evaluated every year by counting the number of insects captured with CROSSTRAP®. The captured insects were grouped (by sex and total) into ranges of 10 days and compared to climatic data (daily average, temperature and rainfall) for each cultivar and year.

RESULTS: The capture periods spanned from 1 June and 31 July, with the period from 1 to 30 June having the greatest number of insect captures, as long as weather conditions were favourable, i.e. temperature above 20.00 °C and accumulated rainfall in 10 days lower than 0.40 mm, verified through the analysis of parameter estimates, in which, only the temperature parameter was significantly.

CONCLUSIONS: The study provided useful information for the integrated pest management of *X. arvicola* through mass trapping in vineyards when temperature exceeds 20.00 °C and the accumulated rainfall is less than 0.40 mm in 10 days to obtain peak captures. This is the first quantitative study of *X. arvicola* control associated with temperature and rainfall in *Vitis vinifera*.

Keywords: *Vitis vinifera*; cerambycid pest; Tempranillo variety; Prieto Picudo variety; temperature; rainfall; captures

1 INTRODUCTION

Ectothermic insects are highly sensitive to environmental temperature, which plays a key role in their metabolic regulation[1] and thus, influences many of their physiological processes, such as growth[2] and development.[3] This phenomenon has profound ecological implications for the insect, its interaction with the environment, and its life cycle.[4] Regarding insect pests, these effects produced by the temperature can weigh significantly on its expansion and severity. Many studies show that ectothermic species adapted to warm conditions display their maximal fitness level at high environmental temperatures, consequently reaching their developmental optimum.[1,5] Therefore, global warming and the expected increase in mean global temperature can represent a major factor in the present and future impact of ectothermic insect pests.[6] When referring to vineyards, global warming benefits insect pests in areas where thermal conditions are typically colder than their optimum by bringing the environmental temperature closer to that optimal point.[7]

The vineyard is the main monoculture crop worldwide with high levels of habitat disturbance due to, among other things, considerable use of agrochemicals[8] or insecticides to control diseases and pest. The use of monoculture cropping practices has been identified as an underlying contributor to pest and disease outbreaks in agriculture due to the concentration of plant host resources for pests, and the absence of a non-crop habitat necessary to support natural enemy populations.[9–11] In regards to pests that affect vascular tissue of the vine (its wood), the vine wood borers *Sinoxylon sexdentatum* (Coleoptera: Bostrychidae), *Xylotrechus arvicola* (Coleoptera: Cerambycidae)[12] and *Schistocerus bimaculatus* (Coleoptera: Bostrychidae).[13] There are also pests that affect the root system of the vine, such as the *Vesperus xatarti* (Coleoptera: Cerambycidae) known as ´Castañeta´

---

[*] Correspondence to: Á Rodríguez-González, Grupo Universitario de Investigación en Ingeniería y Agricultura Sostenible (GUIIAS), Instituto de Medio Ambiente Recursos Naturales y Biodiversidad, Escuela de Ingeniería Agraria y Forestal, Universidad de León, Avenida de Portugal 41, 24009 León, Spain. E-mail: alrog@unileon.es

[a] Grupo Universitario de Investigación en Ingeniería y Agricultura Sostenible (GUIIAS), Instituto de Medio Ambiente Recursos Naturales y Biodiversidad, Escuela de Ingeniería Agraria y Forestal, Universidad de León, Avenida de Portugal 41, 24071, León, Spain

[b] Misión Biológica de Galicia, CSIC, Apartado 28, 36080, Pontevedra, Spain

[c] Grupo Universitario de Investigación en Ingeniería y Agricultura Sostenible (GUIIAS), Escuela de Ingeniería Agraria y Forestal (Campus de Ponferrada), Universidad de León, Avenida de Astorga 15, 24401, Ponferrada, Spain

[d] Freelance, Zamora, Spain

[e] Freelance, Valladolid, Spain

and, until now, the most destructive pest that European vineyards have suffered since its appearance in the late 19th century, *Phylloxera vastatrix* (Hemiptera: Phylloxeridae).[13]

In relation to the cerambycids that attack wood in vineyards, the most cited one is *Vesperus xatarti* Dufour, considered as an insect pest since the mid 19th century[14] and being subsequently recorded in Spainish vineyards.[15,16] *Clytus arietis* (L.) has also been reported as a pest in Spanish[17,18] and French vineyards.[19] Worldwide, *Acalolepta vastator* (Newman) causes important damages in Australian vineyards,[20] whereas *Xylotrechus pyrrhoderus* Bates is a pest in several vineyards of the 'Cabernet Sauvignon' and 'Chardonnay' varieties in China since the beginning of 1980.[21,22]

Xylotrechus arvicola is a cerambycid pest of vineyards (*Vitis vinifera*) in all the main wine producing areas of Spain, such as La Rioja Alta and Alavesa,[23,24] Navarra[25] and Castilla y León.[26] This insect pest has the ability to spread throughout vineyards with different training systems.[27] The action of the larvae within the wood favours the appearance of wood diseases, among which one can highlight *Diplodia seriata* De Not (*Botryosphaeriales: Botryosphaeriaceae*), *Eutypa lata* Tul and Tul (*Xylariales: Diatrypaceae*), *Phaeoacremonium minimun* Gams, Crous, Wingf., Mugnai (*Diaporthales: Togniniaceae*) and *Phaeomoniella chlamydospora* Crous and Gams (*Diaporthales: Togniniaceae*).[28]

Xylotrechus arvicola eggs are laid by females under the rhytidome or in cracks of vine wood.[29] Most of the hatching occurs 8 days after oviposition.[30] Fecundity of females and viability of *X. arvicola* eggs in nature are extended over a longer period than those kept in laboratory conditions.[31] *Xylotrechus arvicola* eggs are white or cream, quite homogeneous and elongated (with a length of around 1.8 mm and a width of approximately 0.7 mm, on average).[32] The larvae are legless and white (with an average size of 22 mm in the last instar, reaching up to 32 mm).[33] Once the larva hatches from the egg, it gets inside the wood without any difficulty, boring galleries within the plant.[34] Grapevine wood attacked by *X. arvicola* larvae is more sensitive to mechanical external factors in vineyards, such as strong winds, harvest weight and vibration applied by harvesting machines.[35,36] The most susceptible stages in which this pest can be controlled are adults and eggs, along with their neonate larvae, i.e. within the first 24 h after egg hatching before it gets into the wood.[30] Once the larvae penetrates into the wood, they cannot be reached with foliar-applied chemicals that do not have penetrative potential,[30] and it is also very difficult to penetrate with systemic insecticides. Information about natural enemies of *X. arvicola* is still scarce,[37] but the use of microbial control agents (MCAs), such as fungi or bacteria, is a possibility that has been raised for its control. Previous studies[38] have extracted, isolated and identified numerous antagonistic fungi of pathogens of the genus *Trichoderma* from vineyard substrates and vine wood affected by *X. arvicola*, showing promising results.[39]

For control of *X. arvicola* through cultural measures, the rhytidome can be removed from the vines, but this technique is expensive and time-consuming and, therefore, unsustainable for extensive cultivation.[40] Apart from preventive treatments, there is an important lack of studies on the control of *X. arvicola*.[29] So far, insecticides with different modes of action[41] applied in Petri dishes[30] or over grapevine wood samples[34] have been evaluated against *X. arvicola* stages only under laboratory conditions.

The treatment on *X. arvicola* adults is difficult, due to their staggered emergency pattern.[42] The emergency period ranges from 15 June to 15 July in vineyards from La Rioja (Spain), lasting to 15 August.[43] From March to late July in vineyards from Valladolid (Castilla y León, Spain)[32] and from 14 May to 26 August in plantations of *Prunus spinosa* L. in Navarra (Spain).[44]

The emergence pattern of this insect in vineyards has been poorly studied until now. With that in mind, the objective of this study was to determine the seasonal period during which *X. arvicola* adults emerge from grapevine wood and how it relates to the climatic conditions that surrounds them. That is, to describe the seasonal abundance of *X. arvicola* adults in periods of rising temperatures and rainfall in two *Vitis vinifera* varieties, in order to provide useful information for the control of this insect through Integrated Pest Management (IPM).

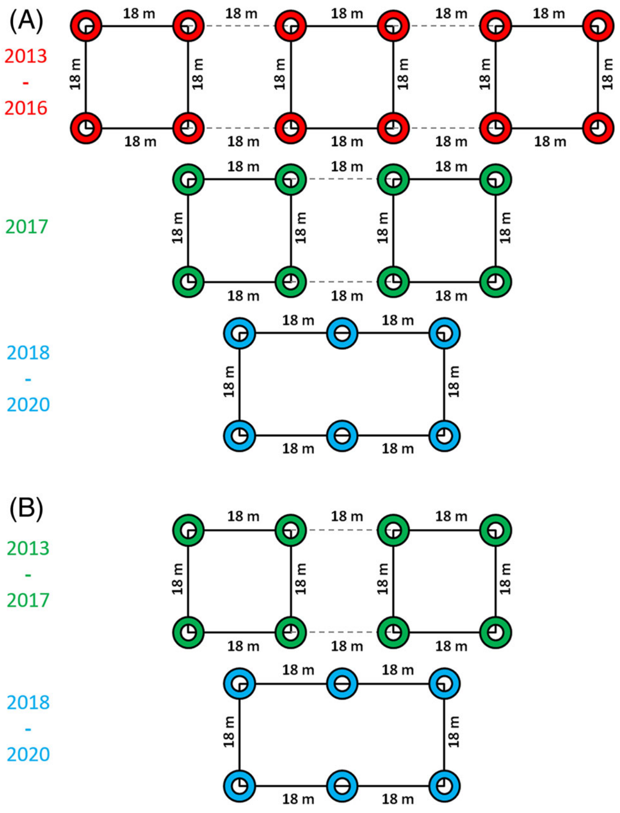

Figure 1. Graphic diagram of the distribution of the traps–lures in the vineyards: (A) ´Tempranillo´ variety: red circles represent traps placed from 2013 to 2016; green circles represent traps placed in 2017; blue circles represent traps placed from 2018 to 2020; (B) 'Prieto Picudo' variety: green circles represent traps placed from 2013 to 2017; blue circles represent traps placed from 2018 to 2020.

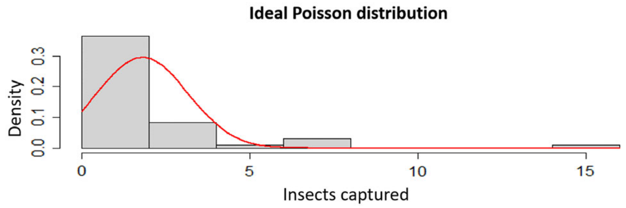

Figure 2. Ideal Poisson distribution. Probability mass function of insects captured. Data represented were obtained calculating λ for RD of CI, the formula ($\lambda = \frac{k}{n}$) was used to obtain the figures and, '*k*' was considered as total number of events and '*n*' was described as number of units. Values for insect emergency was $\lambda = 1.81$. Poisson function distribution according to these values were represented as a red line overlapping data from results of insects as a histogram representation in order to visualize graphically the trend.

Table 1. General linear model (GENMOD procedure) of *Xylotrechus arvicola* insects totals captured in two vineyards varieties from 2013 to 2020

Analysis of maximum likelihood parameter estimators[a]

Parameter	df	Estimate	Standard error	Wald confidence limits (at 95%)		Wald's Chi-square	Pr > Chi-square
Ranges of days	1	−1.1850	0.9222	−2.9925	0.6225	1.65	0.1988
Temperature	1	0.0902	0.0424	0.0070	0.1733	4.52	0.0336
Rain	1	−0.0066	0.0102	−0.0266	0.0134	0.42	0.5174

[a] The negative binomial dispersion parameter was estimated by maximum likelihood.

2 MATERIAL AND METHODS

2.1 Trapping

Insects were captured using traps (CROSSTRAP®, Econex, Murcia, Spain). The trap consists of a polypropylene lid (33 cm in diameter) with a central carabiner attached to a steel spring. Two reinforced polyvinyl chloride (PVC) sheets (80.0 × 30.0 cm^2) are held in place by four steel springs in the upper section of the lid. In the lower section, the reinforced PVC sheets are held in place by a polypropylene funnel (30 cm in diameter) and four steel springs. The collection cup (12.5 cm diameter × 19 cm height) for the captured insects is located in the lower section of the funnel.[45] All panels were coated with Fluon (Dyneon; 3 M, Bracknell, UK) as recommended by Graham *et al.*[46] CROSSTRAP® were first attached to a 1.5 m PVC pipe, and hung from an L-shaped arm, with a distance of 18 m between each trap. All traps were monitored every 2 or 3 days. Lures were attached to the trap at the midway point and insects were trapped in a receiver at the base.

2.2 Lures

The lures used in this experiment were contained inside low-density polyethylene bags (95 mm × 60 mm × 50 μ thick; Transpack, Southampton, UK) with a press seal. Ethanol (Ethanol Absolute; VWR Chemicals Prolabo, Fontenay-sous-Bois, France) (1 mL) was impregnated onto a cotton dental roll (a cylindrical mass of

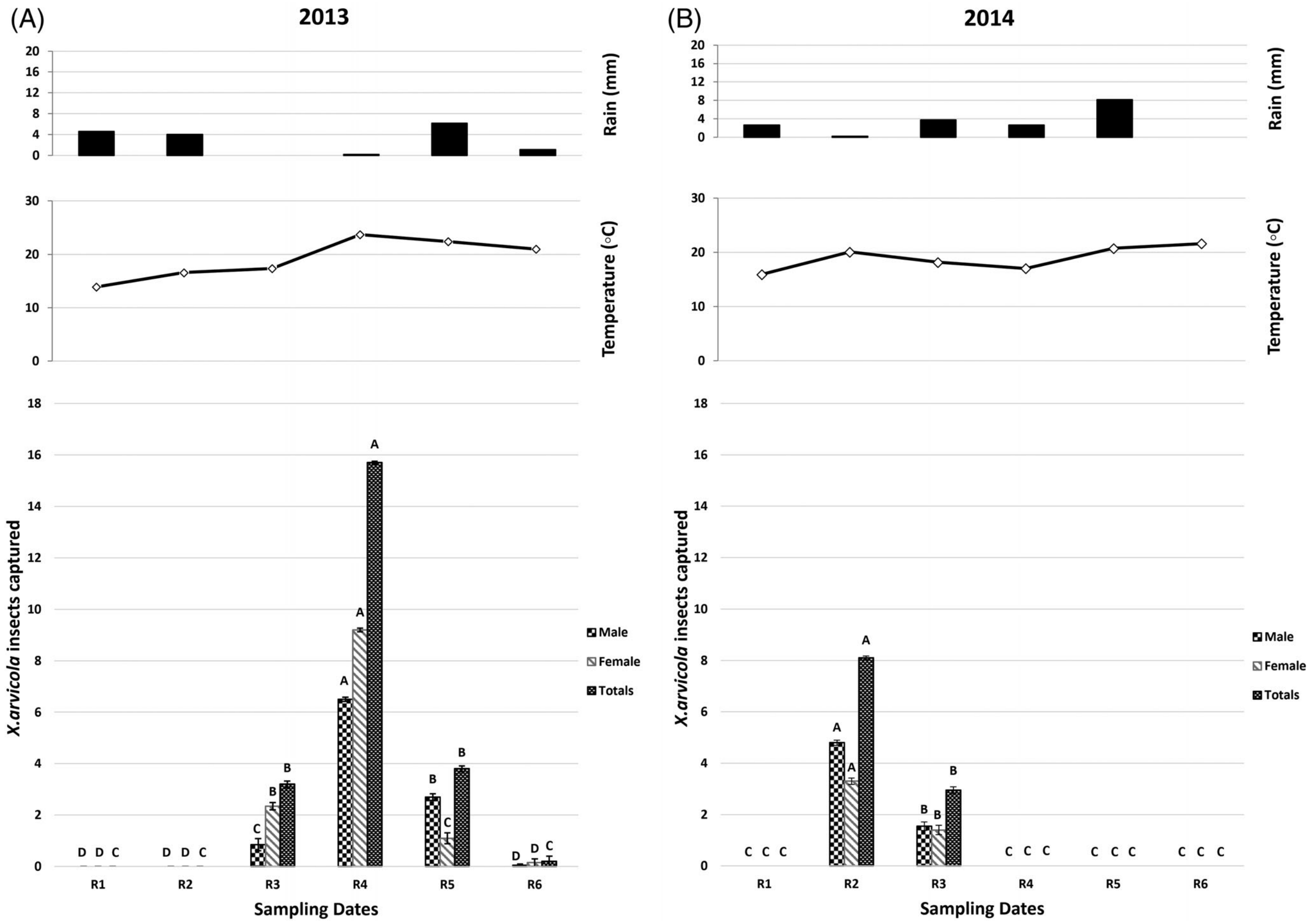

Figure 3. Accumulated capture in 10-day-ranges of *Xylotrechus arvicola* adults captured from vine wood of two *Vitis vinifera* varieties and their relation to the climatic conditions rain (mm) and average temperature (°C): (A) captures in 2013, (B) captures in 2014. In insect capture graphs, different capital letters indicate significant differences in captures among different ranges of days within each sex category. Vertical bars represent the mean and the standard error (SE). Statistical differences are indicated by different letters (Tukey's HSD, $P < 0.05$).

purified and sterilized cotton used as packing or absorbent material in various dental procedures) (35 mm × 8 mm; Kent Express Dental Supplies, Gillingham, UK), which had previously been placed inside each polyethylene bag. Lures were changed every 10 days during the course of the experiment.

2.3 Experimental vineyards

This experiment was carried out during the months of June and July, from 2013 until 2020, in two vineyards uniformly planted with two varieties: 'Tempranillo' and 'Prieto Picudo' varieties, both located in Gordoncillo (42°08′14.9″N, 5° 25′ 41.6″ W) (León, Castilla y León, Spain). The vineyards were chosen on the basis of the presence of external damage and symptoms due to *X. arvicola*, such as larval galleries inside the plants observed in pruning cuts, and exit holes of *X. arvicola* adults on trunks and branches of vines. The rows were spaced 3.0 m and the distance between plants within the rows was 1.5 m. Vineyards were surrounded by vineyards of other varieties. The two vineyards, 'Tempranillo' and 'Prieto Picudo,' had the same characteristics in terms of age, 24 years old; training system of vines, bilateral cordon, spur pruning over two branches per trunk at 0.6 m above the ground; soils, calcareous soils, with low minerals and organic matter content; height above sea level, 747 m; average annual temperature, 11.7 °C; and average annual rainfall, 500 mm.

With regard to the 'Tempranillo' vineyard, from 2013 to 2016, an area of 0.162 ha (18 m length × 90 m width) was divided into three blocks of 0.03 ha, each containing four trap–lure combinations, making a total of 12 traps in this vineyard. During 2017, an area of 0.09 ha (18 m length × 54 m width) was divided into two blocks of 0.03 ha, each containing four trap–lure combinations, making a total of eight traps in this vineyard. From 2018 until 2020, an area of 0.06 ha (18 m length × 36 m width) was used as one block, containing six trap–lure combinations (Fig. 1).

In regard to the ´Prieto Picudo´ vineyard, from 2013 to 2017, an area of 0.09 ha (18 m length × 54 m width) was divided into two blocks of 0.03 ha, each containing four trap–lure combinations making a total of eight traps in the vineyard. From 2018 to 2020, an area of 0.06 ha (18 m length × 36 m width) was used as one block, containing six trap–lure combinations (Fig. 1).

All the traps inside each block were randomized distributed. All traps–lures were monitored every 2 or 3 days. The position of the traps–lures was not rotated during the 8 weeks evaluation.

2.4 Insect captures and seasonal abundance

Adult captures of *X. arvicola* was measured by counting the beetles captured in the traps described earlier. *Xylotrechus arvicola* adults captured were identified and sexed in the laboratory, according to the description of Moreno.[32] For analysis, the capture results were calculated as insects, males, females and totals,

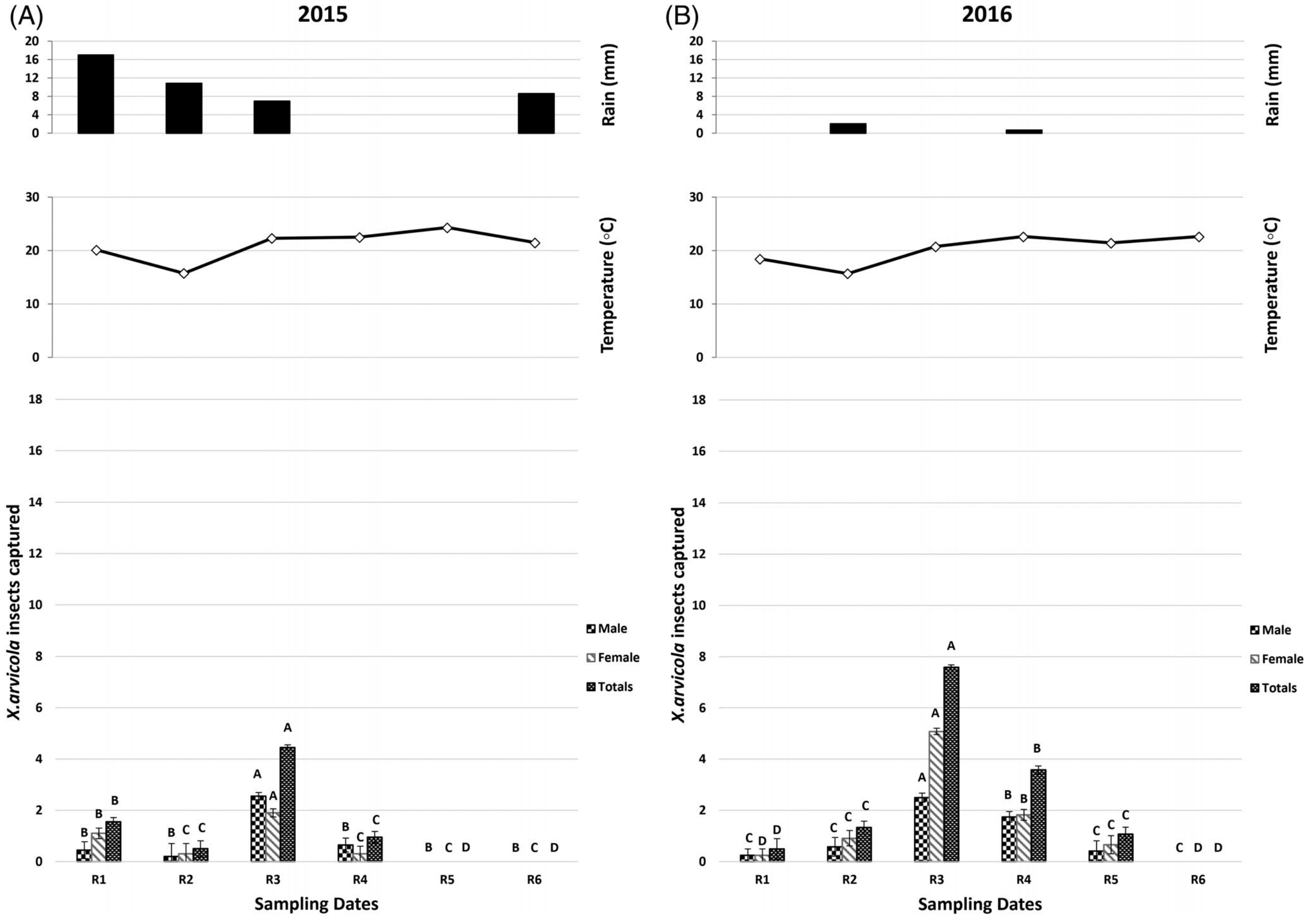

Figure 4. Accumulated capture in 10-day-ranges of *Xylotrechus arvicola* adults captured from vine wood of two *Vitis vinifera* varieties and their relation to the climatic conditions rain (mm) and average temperature (°C): (A) captures in 2015, (B) captures in 2016. In insect capture graphs, different capital letters indicate significant differences in captures among different ranges of days within each sex category. Vertical bars represent the mean and the standard error (SE). Statistical differences are indicated by different letters (Tukey's HSD, $P < 0.05$).

per day. The captured insects were gathered into ranges (R) of 10 days, and have been labelled as follows (R1 = 1–10 June, R2 = 11–20 June, R3 = 21–30 June, R4 = 1–10 July, R5 = 11–20 July and, R6 = 21–31 July). The captures within each range of days were compared to the data of daily average temperature and daily rainfall amount for each variety and year.

2.5 Statistical analysis

Data was retrieved from counts, data comes from counting events in an experimental unit and a Poisson or negative binomial distribution are suitable for this analysis.[47] Thus, GENMOD procedure was performed in order to test the proper analysis of variance model and a chi-squared test was performed to check distribution function. After this test, the suitable distribution was considered as a Poisson distribution and the link function was log. Captures of insects (CI) (males, females and totals) were considered as dependent variable, while ranges of days (RD), temperature (T) and rain (R) were considered as independent variables. The GLIMMIX procedure (Poisson distribution with log as link function) was used for analysis of variance and all factors were considered fixed.[48] Year × RD was significant, so analysis of variance was performed for each year. Means were back transformed using the ILINK option in the LSMEANS statement and compared using Tukey's honestly significant difference (HSD). Data was analysed using the SAS version 9.1.2 software (SAS Institute, Cary, NC, USA). Graphics were represented using R version 4.0.3.

3 RESULTS

3.1 Poisson function distribution

The model information (GENMOD procedure) indicates that the response is distributed via Poisson. Data represented in Fig. 2 were obtained calculating λ for RD of CI, the formula ($\lambda = \frac{k}{n}$) was used for obtaining those figures. 'k' was considered as total number of events and 'n' was described as number of units. Values for insect emergency was $\lambda = 1.81$. Poisson function distribution according to these values were represented as a red line overlapping data from results of insects as a histogram representation in order to visualize graphically the trend. Table 1 shows the analysis of parameter estimates being T the significant predictor.

GLIMMIX procedure, general linear model only indicates significant interaction among year and RD. Effects of years and varieties were not significant. Then the GLIMMIX procedure was performed for each year.

3.2 Insect captures and climatic conditions

During 2013, the greatest number of insects captured were in R4 range. These numbers of insects captured during the period described earlier were significantly higher ($F = 35.66$; df = 5114;

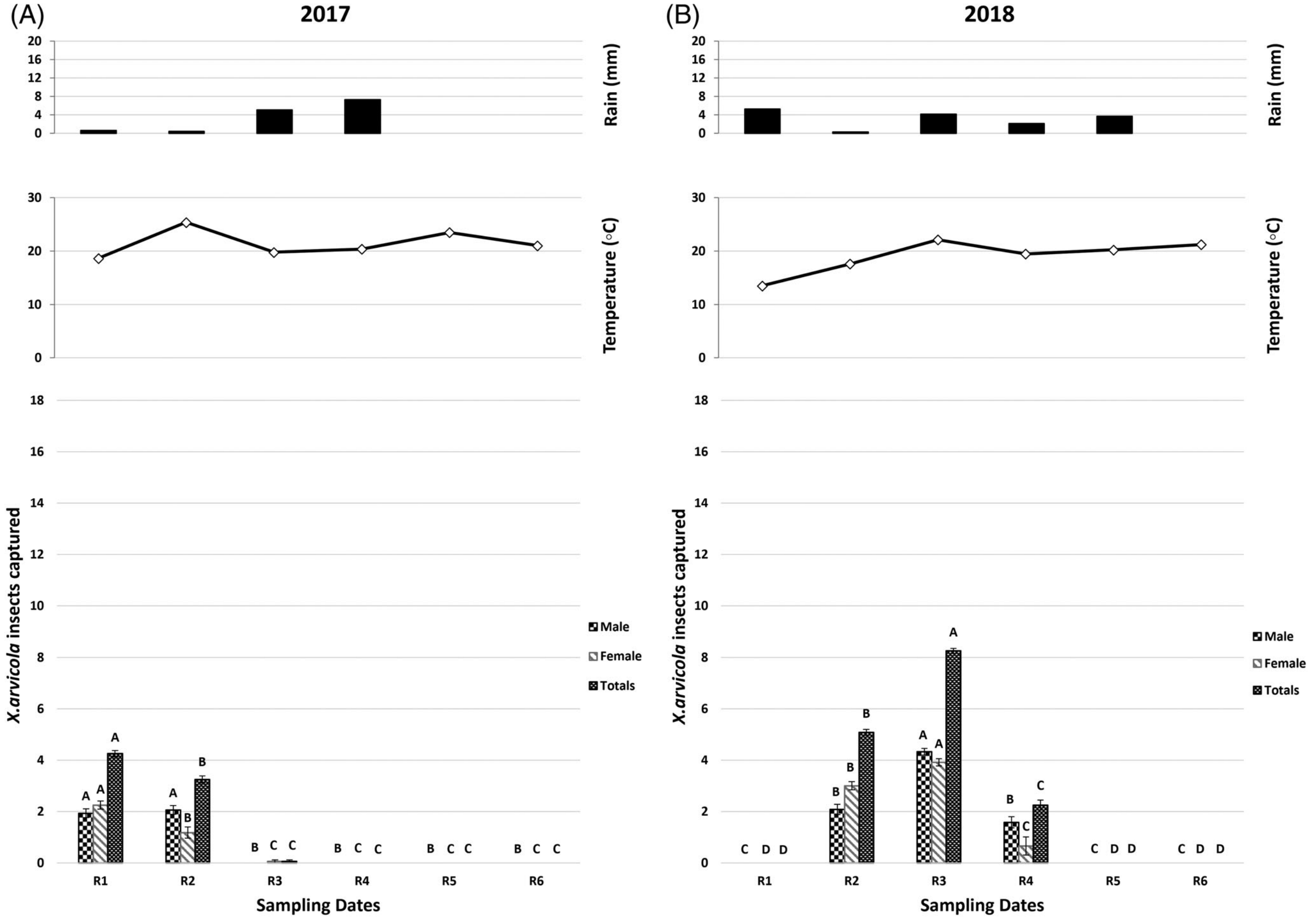

Figure 5. Accumulated capture in 10-day-ranges of *Xylotrechus arvicola* adults captured from vine wood of two *Vitis vinifera* varieties and their relation to the climatic conditions rain (mm) and average temperature (°C): (A) captures in 2017, (B) captures in 2018. In insect capture graphs, different capital letters indicate significant differences in captures among different ranges of days within each sex category. Vertical bars represent the mean and the standard error (SE). Statistical differences are indicated by different letters (Tukey's HSD, $P < 0.05$).

$P \leq 0.001$, females) (F = 19.67; df = 5114; $P \leq 0.001$, males) (F = 55.69; df = 5114; $P \leq 0.001$, totals) than the ones obtained in the other two periods in which insects were also captured, R3 and R5 ranges. The first captures for both varieties took place on 21 June, once the rains had ended, and when the average temperature increased from 17.40 to 23.70 °C. From the 11 July on, captures decreased, due to an increase in heavy rain or storm, 6.16 mm (Fig. 3(A)).

In 2014, the greatest number of insects captured were captured in R2 range. The insects captured during that period were significantly higher (F = 2.89; df = 5114; $P \leq 0.001$, females) (F = 5.99; df = 5114; $P \leq 0.001$, males) (F = 8.82; df = 5114; $P \leq 0.001$, totals) than captures in R3. The first captures took place on 11 June, when the rainfall decreased and the average temperature increased, from 15.90 °C in R1, to 20.10 °C in R2. From 21 June on, captures significantly decreased, due to an increase in the rainfall (3.70 mm in R3 range and 2.60 mm in R4 range), and a decrease in the average temperature to 17.00 °C (Fig. 3(B)).

During 2015, the capture period ranged from 1 June to 10 July in both varieties. R3 range registered a significantly greater number of captures (F = 6.25; df = 5114; $P \leq 0.001$, females) (F = 10.53; df = 5114; $P \leq 0.001$, males) (F = 16.07; df = 5114; $P \leq 0.001$, totals) than the rest of the ranges. The first captures were obtained in R1 range, with a rainfall of 16.90 mm and an average temperature of 20.20 °C. In R2 range, a reduction in rainfall to 10.80 mm, and a decrease in the average temperature in comparison to that of the previous ranges, from 20.20 to 15.80 °C, reduced the number of captures. Subsequently, in R3 range, a new decrease in the rainfall to 6.90 mm, and an increase in the temperature to 22.30 °C, caused that the greatest number of captures was registered in this period (Fig. 4(A)).

In 2016, the capture period ranged from 1 June to 20 July. The R3 range registered a number of insects captured, significantly greater (F = 14.64; df = 5,66; $P \leq 0.001$, females) (F = 6.48; df = 5,66; $P \leq 0.001$, males) (F = 20.99; df = 5,66; $P \leq 0.001$, totals) than those for the rest of the capture periods. The first captures were obtained in R1 range, period without rain and with an average temperature of 18.40 °C. In the next capture period, R2 range, an increase in the rainfall to 2.00 mm and a decrease in the average temperature in comparison to the previous period, from 18.40 to 15.70 °C, resulted in a sharp drawdown of insects captured. During R3 range, an absence of rainfall and an increase in the temperature, from 15.70 °C in R2 to 20.80 °C in this range, contributed to reach the greatest number of captures during this period (Fig. 4(B)).

In 2017, the capture period ranged from 1 June to 30 June. The most abundant captures were in ranges R1 and R2, with significant differences for number of captures (F = 3.24; df = 5,90; P = 0.009, females) (F = 2.11; df = 5,90; P = 0.012, males) (F = 3.76; df = 5,90; P = 0.003, totals). In this year, from 21 June

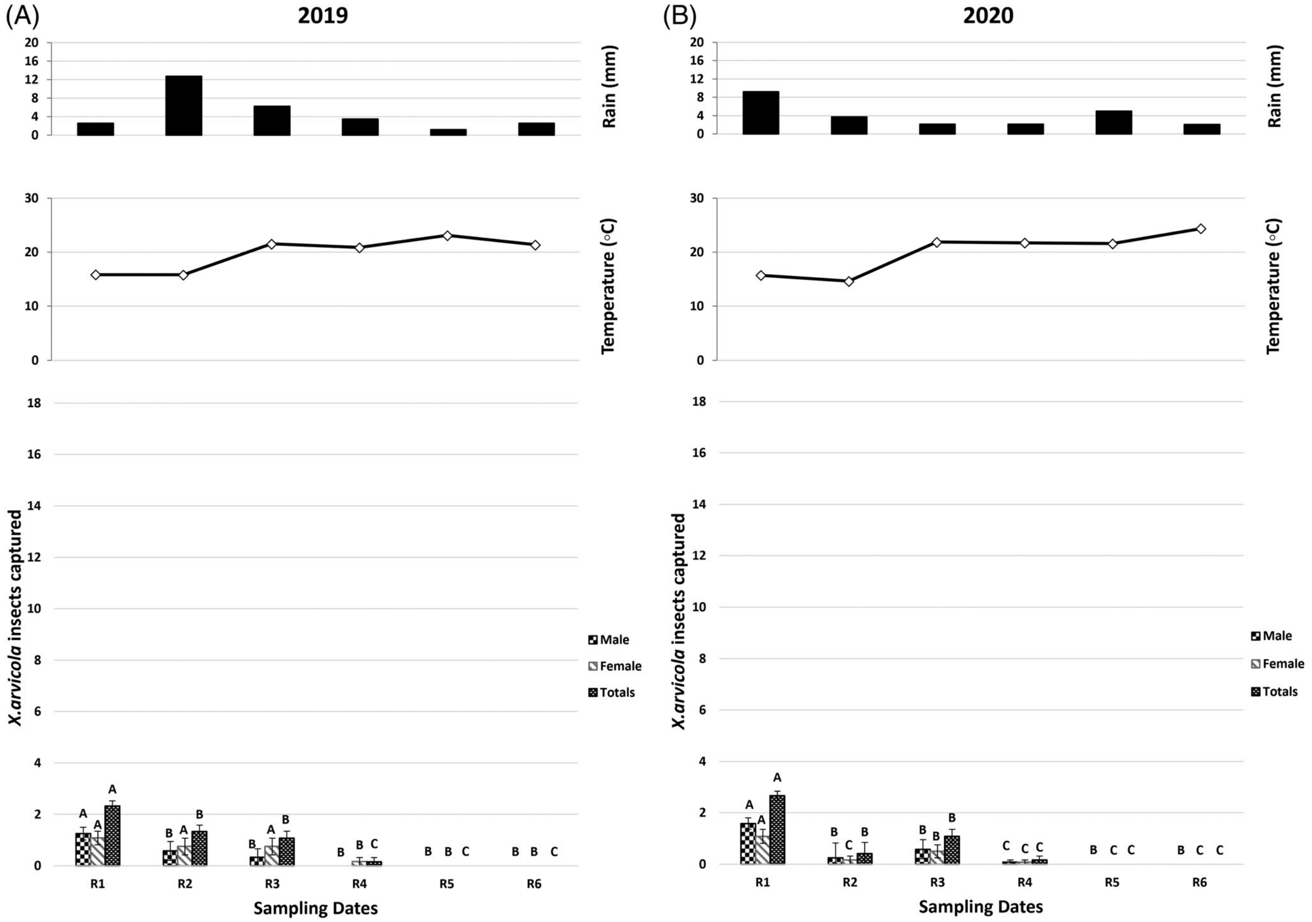

Figure 6. Accumulated capture in 10-day-ranges of *Xylotrechus arvicola* adults captured from vine wood of two *Vitis vinifera* varieties and their relation to the climatic conditions rain (mm) and average temperature (°C): (A) captures in 2019, (B) captures in 2020. In insect capture graphs, different capital letters indicate significant differences in captures among different ranges of days within each sex category. Vertical bars represent the mean and the standard error (SE). Statistical differences are indicated by different letters (Tukey's HSD, $P < 0.05$).

onwards, a decrease in the average temperature with respect to the previous capture periods, from 25.40 °C to 19.80 °C, combined with an increase in the rainfall, 5.00 mm in range R3, and 7.30 mm in range R4, hindered the capture of more insects during this year (Fig. 5(A)).

During 2018, the capture period ranged from 11 June to 10 July. The captures obtained in R3 range were significantly higher ($F = 4.29$; df = 5,66; $P = 0.002$, females) ($F = 3.61$; df = 5,66; $P = 0.006$, males) ($F = 7.51$; df = 5,66; $P \leq 0.001$, totals) than those in the rest of the periods. The first captures were obtained in R2, with a rainfall of 5.20 mm and an average temperature of 17.60 °C. In R3, a reduction in the rainfall to 0.30 mm, and an increase in the temperature, 22.10 °C, with respect to the previous period, increased the number of insects captured. In the next period, R4 range, a rainfall of 2.10 mm, and a drop in temperature to 19.50 °C, decreased the number of insects captured (Fig. 5(B)).

In 2019, the capture period ranged from 1 June to 10 July. The captures in R1 range were higher ($F = 1.24$; df = 5,66; $P = 0.301$, females) ($F = 1.34$; df = 5,66; $P = 0.257$, males) ($F = 3.33$; df = 5,66; $P = 0.009$, totals) than those captured in R4, R5 and R6 ranges. The first captures were obtained in R1, with a rainfall of 2.54 mm and an average temperature of 15.84 °C. In R2 range, an increase in the rainfall to 12.74 mm, and a very similar temperature (15.83 °C), with respect to the previous ranges, kept low the number of insects captured. In the following periods, R3 and R4 ranges, with rainfall of 6.27 and 3.53 mm, and an increase in the temperature to 21.53 and 20.87 °C, respectively, the number of insects captured decreased (Fig. 6(A)).

Finally, in 2020, the capture period ranged from 1 June to 10 July. The catches obtained in R1 range were significantly higher ($F = 2.35$; df = 5,66; $P = 0.05$, females) ($F = 3.58$; df = 5,66; $P = 0.006$, males) ($F = 5.92$; df = 5,66; $P \leq 0.001$, totals) than those obtained in the R2, R3, R4, R5 and R6 ranges. The first captures were obtained in R1 range, with a rainfall of 9.21 mm and an average temperature of 15.75 °C. In R2 range, a reduction in the rainfall (3.74 mm). and in the temperature (14.64 °C), reduced the number of insects captured. In the next period, R3 range, less rainfall (2.15 mm) and an increase in the temperature to 21.28 °C, increased the number of insects captured (Fig. 6(B)).

4 DISCUSSION

The captures of *X. arvicola* in the vineyards was conditioned by climatic factors, so the greatest number of insect catches occurred when the temperature exceeded 20.00 °C and the accumulation of rain was lower than 0.40 mm, what is considered a dry environment. The relationship between the appearance of insects and the climatic conditions of the area has also been described by other authors, as for example, Berkov and Tavakilian[49] who hypothesized that the emergence of cerambycids in forests of French Guiana is affected in rainy seasons, either because excessive moisture affects the host's suitability or because the volatile molecules that attract cerambycids are not able to circulate efficiently in an excessively humid understory. The combination of moderately low temperatures, high humidity, and a lack of wind probably results in excessive host moisture content, which may be particularly detrimental to cerambycid larvae.[50] Hanks *et al.*[51] showed that high bark moisture contents prevented early instar larvae of the cerambycid *Phoracantha semipunctata* (Coleoptera: Cerambycidae) from reaching the optimal feeding zone near the cambium; larvae instead created feeding galleries close to the surface of the bark, where they failed to pupate. It is possible that when moisture content exceeds a critical value (about 60%), pore spaces fill with water and deprive larvae of oxygen.

The results confirmed that the rate of development, emergence and capture of *X. arvicola* in the vineyards is strictly related to the temperature. The increase in the number of insects captured as the temperature raised was verified through the analysis of parameter estimates, in which, only the temperature parameter was significant. It has been proved that the temperature that insects accumulate is the energy needed to move from one stage to the next.[52] Similar behaviour has been described by other authors in other cerambycids through the relationship between optimal temperature and emergence, such as *Monochamus saltuarius* Gebler (Coleoptera: Cerambycidae),[53] or *X. arvicola* itself.[54] Winters and springs with warn temperatures, such as those observed in recent years as a result of climate change, can cause the expansion of this pest to vineyards located at latitudes with cold temperatures that prevent the optimal development of the pest; that is, that global warming benefits insect pests in vineyards by bringing the ambient temperature closer to their optimum development temperature.[7] Therefore, the results here reported open up the possibility of carrying out future studies, such as calculating the thermal integral that *X. arvicola* needs, or obtaining models that relate the rate of development to the temperature of the insect to the environmental temperature for the different larval stages and the pupa stage of this insect. With these models, and the knowledge of when the egg-laying takes place (if there is no diapause), it would be also possible to predict the period of emergence of the insects by measuring the temperature, which would mean an advance in its integrated control.

According to Peláez *et al.*[40] cold springs could delay the appearance of adults in vineyards, leading to a higher concentration of *X. arvicola* adults a few days later. Climatic data obtained[55] from the nearest weather station to the study vineyards (Mayorga de Campos, Valladolid, Spain) recorded an average temperature of 10.62 °C in spring 2013, cooler than those in 2014 (13.40 °C), 2015 (13.60 °C), 2016 (11.70 °C), 2017 (14.70 °C), 2018 (11.70 °C), 2019 (12.32 °C) and 2020 (13.33 °C). These findings may help explain both the delay in the appearance of insects in vineyards during 2013 (there were no captures until 21 June), and the concentration of captures a few days later in the same year, in comparison to the results of the rest of the years.

In relation to ranges of days, significant differences were found in the number of captures among range of days, so the highest number of captures of *X. arvicola* was reached in R1, R2 and R3 ranges (from 1 to 30 June), this fact was verified through the significant CI × RD interaction in all the years, except for the year 2013, when captures were delayed to R4 range in both varieties, due to colder-than-standard spring temperatures, as explained previously. The range of dates obtained for the emergence of *X. arvicola* is in accordance with those described by other authors in other areas and crops, that are from late June to mid-July in vineyards of La Rioja[43]; from March to the end of July in vineyards of Valladolid (Castilla y Leon)[32] or from 14 May to 26 August in *Prunus spinosa* L. orchards in Navarra.[44]

In regard to results by variety, over the 8-year period of this work a greater number of insects (males, females and totals) was captured in the 'Tempranillo' vineyard compared to the 'Prieto Picudo' vineyard. Moreover, captures in 'Tempranillo' vineyard were also higher during the periods of peak captures, and lasted a longer period of time (except for 2019, when the period of captures was 10 days longer in 'Prieto Picudo'). This could indicate that 'Tempranillo' has a greater susceptibility to be attacked by

X. arvicola than 'Prieto Picudo'. Previous studies made by Ocete and del Tío[23] and Moreno *et al*.[56] confirm these results and support that the 'Prieto Picudo' variety is also sensitive to be attacked by *X. arvicola*, but with a low incidence.[39] It has already been demonstrated that a great number of *X. arvicola* is captured in Tempranillo variety, regardless of the trap type (commercial or prototypes).[57] Peláez *et al*.[40] found differences in the incidence of *X. arvicola* attacks (as proportion of affected vines) with regard to the levels of carbohydrates in the wood, so 'Tempranillo', 'Viura' and 'Cabernet Sauvignon' varieties, with low holocellulose and high lignin contents, have higher incidence of *X. arvicola* attacks when compared to the 'Mencía' variety, with low lignin and high holocellulose contents.

Finally, the emergence timing and the length of this period for *X. arvicola* adults in vineyards, varied greatly among years and varieties. The explanation for this, according to Peláez *et al*.,[40] García-Ruiz[42] and Rodríguez-González *et al*.,[57] all with similar results, is that this pest has a staggered and/or prolonged emergence period over time, or a staggering of egg laying.

In conclusion, the results of this experiment showed that low spring temperature delayed the appearance of adults in the vineyards. The capture periods spanned from 1 June and 31 July, with the period from 1 to 30 June having the greatest number of insect captures, as long as weather conditions were favourable, i.e. temperature above 20.00 °C and accumulated rainfall in 10 days lower than 0.40 mm, verified through the analysis of parameter estimates, in which, only the temperature parameter was significant. Therefore, our study provided useful information for the control of this pest through an IPM strategy, which would focus on positioning of the traps in periods when the climatic conditions in the vineyards favour the capture of insects, optimizing their function and providing peak captures.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of Science, Innovation and Universities (Spain) (Resolution of 27 July 2018, BOE No. 184, 31 July), that was awarded with a grant to Álvaro Rodríguez González (PTA2017–14403-I) through the programme Technical Support Staff (Call 2017), and by the project "Global approach to improve wine production againstt the climate changed based on robotics, IR technology and on biotechnological and vineyards handling strategies" (Acronym: GLOBALVITI; Reference: IDI20160746) and "Study of the new factors related to the soil, the plant and the oenological microbiota that influence the acidity balance of wines and their guarantee of quality and stability in hot climates (Acronym: LOWpHWINE 2020; Reference: IDI20210391)". Also, the grant awared to Guzmán CarroHuerga comes from the Ministry of Education, Culture and Sports (Spain), gran number (FPU15/04681). The authors are thankful to the Diputación de León, Servicio de Desarrollo Rural y Medio Ambiente for the project 'Control integrado del taladro de la vid *Xylotrechus arvicola* en la provincia de León', and to 'Gordonzello' and 'Pago de Carraovejas' wine cellars. The authors would like to thank the 'Carolina Rodríguez' foundation of the Universidad de Leon, which has supported this research with the 'Mariano Rodríguez' award for young researchers (Call 2017). Also, the authors are grateful to Dr Vicente S. Marco Mancebón (Universidad de La Rioja, Logroño, Spain) for many helpful comments on the editing of this manuscript and to Juan Casquero García for the proofreading of the English version.

DATA AVAILABILITY STATEMENT

The data that support the findings will be available in [repository name] at [DOI/URL] following an embargo from the date of publication to allow for commercialization of research findings.

REFERENCES

1 Kingsolver JG, ASN presidential address: the well-temperatured biologist. *Am Nat* **174**:755–768 (2009).

2 Angilletta MJ, Steury TD and Sears MW, Temperature, growth rate, and body size in ectotherms: fitting pieces of a life-history puzzle. *Integr Comp Biol* **44**:498–509 (2004).

3 Zuo W, Moses ME, West GB, Hou C and Brown JH, A general mode for effects of temperature on ectotherm ontogenetic growth and development. *Proc R Soc B Biol Sci* **79**:1840–1846 (2012).

4 Ragland GJ and Kingsolver JG, The effect of fluctuating temperatures on ectotherm life-history traits: comparisons among geographic populations of Wyeomyia smithii. *Evol Ecol Res* **10**:29–44 (2008).

5 Knies JL, Kingsolver JG and Burch CL, Hotter is better and broader: thermal sensitivity of fitness in a population of bacteriophages. *Am Nat* **173**:419–430 (2009).

6 *Intergovernmental Panel on Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contributions of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge (2014).

7 Deutsch CA, Tewksbury JJ, Huey RB, Sheldon KS, Ghalambor CK, Haak DC *et al*., Impacts of climate warming on terrestrial ectotherms across latitude. *Proc Natl Acad Sci* **105**:6668–6672 (2008).

8 Provost C and Pedneault K, The organic vineyard as a balanced ecosystem: improved organic grape management and impacts on wine quality. *Sci Hortic* **208**:43–56 (2016).

9 Landis DA, Wratten SD and Gurr GM, Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu Rev Entomol* **45**:175–201 (2000).

10 Andow DA, Vegetational diversity and arthropod population response. *Annu Rev Entomol* **36**:561–586 (1991).

11 Wilson H and Daane KM, Review of ecologically-based Pest Management in California Vineyards. *Insects* **8**:108 (2017).

12 Sáenz-Romo MG, Veas-Bernal A, Martínez-García H, Ibáñez-Pascual S, Martínez-Villar E, Campos-Herrera R *et al*., Effects of ground cover management on insect predators and pests in a Mediterranean vineyard. *Insects* **10**:421 (2019).

13 Ministerio de Agricultura, Alimentación y Medio Ambiente, Guía de Gestión Integrada de Plagas. Uva de Transformación. Madrid, Spain (2014).

14 Jacquelin Du Val C, Note sur le male du Vesperus xatarti Mulsant. *Ann Soc Entomol Fr* **8**:347–349 (1850).

15 Mendizábal M, Notas para un Estudio de las Especies Españolas del Género Vesperus. Publicaciones del Ministerio de Agricultura. Instituto de Investigaciones Agronómicas; sección de Fitopatología, Madrid. Spain (1937).

16 Ruiz Castro A, Fauna entomológica de la vid en España. Estudio sistemático-biológico de las especies de mayor importancia económica. IV (Coleoptera). CSIC, Madrid, Spain (1947).

17 Ruiz Castro A, Fauna entomológica de la vid en España, 23–24. Tomo I. Consejo Superior de Investigaciones Científicas, Madrid, Spain (1943).

18 García-Tejero FD, Plagas y Enfermedades de las Plantas Cultivadas. Mundi-Prensa, Madrid. Spain (2004).

19 Baggiolini M and Epard S, Un nouveau ravageur de la vigne, le Clyte (*Clytus arietis* L). *Agricul Roman VII* **7–8**:91–92 (1968).

20 Goodwin S, A new strategy for the chemical control of fig longicorn, *Acalolepta vastator* (Newman) (Coleoptera: Cerambycidae), infesting grapevine. *Aust J Entomol* **44**:170–174 (2005).

21 Armendáriz I, Juárez JS, Campillo G, Miranda L and Pérez-Sanz A, Daños mecánicos producidos por *Xylotrechus arvicola* (Olivier, 1875) (Coleoptera, Cerambycidae). *Bol San Veg Plagas* **34**:477–483 (2008).

22 Sakai T, Nakagawa J, Takahashi J, Iwabuchi K and Ishii K, Isolation and identification of the male sex pheromone of the grape borer *Xylotrechus pyrrhoderus* bates (Coleoptera: Cerambycidae). *Chem Lett* **263–264**:263–264 (1984).

23 Ocete R and del Tío R, Presencia del perforador *Xylotrechus arvicola* (Olivier) (Coleoptera: Cerambycidae) en viñedos de la Rioja Alta. *Bol San Veg Plagas* **22**:199–202 (1996).

24 Ocete R and López MA, Principales insectos xilófagos de los viñedos de la Rioja Alta y Alavesa. *Vitic Enol Prof* **62**:24–30 (1999).

25 Ocete R, López-Martínez MA, Prendes C, Lorenzo CD and González-Andújar JL, Relación entre la infestación de *Xylotrechus arvicola* (Coleoptera: Cerambycidae) (Olivier) y la presencia de hongos patógenos en un viñedo de la Denominación de Origen "La Mancha". *Bol San Veg Plagas* **28**:97–102 (2002).

26 Pelaez H, Maraña JR, Urbez JR and Barrigon JM, *Xylotrechus arvicola* (Olivier, 1795) (Coleoptera: Cerambycidae). Presencia en los viñedos de Castilla y León. IV Congreso Ibérico de Ciencias Hortícolas; (Extremadura, Spain: Caceres). *Actas Horticulturae* **30**:1326–1332 (2001).

27 Rodríguez-González A, Peláez HJ, Mayo S, González-López O and Casquero PA, Biometric traits of *Xylotrechus arvicola* adults from laboratory and grape field. *Vitis* **55**:73–78 (2016a).

28 García-Benavides P, Martin-Zamorano P, Ocete-Pérez CA, Maistrello L and Ocete R, Biodiversity of pathogenic wood fungi isolated from *Xylotrechus arvicola* (Olivier) galleries in vine shoots. *J Int Sci Vigne Vin* **47**:73–81 (2013).

29 Peláez H, Hernández JM, Martín MC, Moreno CM and Santiago Y, *Determinación de las características del huevo de Xylotrechus arvicola (Coleoptera: Cerambycidae, Olivier, 1795)*, ed. by Libro de Actas del X Congreso Ibérico de Entomología, Castilla y León, Spain: Zamora, p. 52 (2002).

30 Rodríguez-González A, Peláez HJ, Mayo S, González-López O and Casquero PA, Egg development and toxicity of insecticides to eggs, neonate larvae and adults of *Xylotrechus arvicola*, a pest in Iberian grapevines. *Vitis* **55**:83–93 (2016b).

31 Rodríguez-González A, Peláez HJ, González-López O, Mayo S and Casquero PA, Reproductive patterns of *Xylotrechus arvicola* (Coleoptera: Cerambycidae), an emerging pest of grapevines, under laboratory conditions. *J Econ Entomol* **109**:1226–1230 (2016c).

32 Moreno CM, *Xylotrechus arvicola (Olivier 1795) (Coleóptera: Cerambycidae): descripción morfológica, ciclo biológico, incidencia y daños en el cultivo de la vid*. PhD thesis. Publicaciones del Instituto Tecnológico Agrario de Castilla y León (ITACYL), Valladolid, Spain (2005).

33 Moreno CM, Martín CM, Urbez JR, Maraña R, Moro S, García D *et al.*, Descripción de dos coleópteros que afectan al viñedo en Castilla y León. *Phytoma* **147**:34–42 (2003).

34 Rodríguez-González A, Peláez HJ, González-Núñez M and Casquero PA, Control on egg and neonate larvae of *Xylotrechus arvicola* (Coleoptera: Cerambycidae), a new vineyard pest, under laboratory conditions. *Austr J Grape Wine Res* **23**:112–119 (2017a).

35 Rodríguez-González A, Casquero PA, García-González J, Rodríguez-Robles D, Morán-Del Pozo JM and Juan-Valdés A, Analysis of the mechanical properties of wood attacked by *Xylotrechus arvicola* larvae, and its influence on the structural properties of the plant. *Vitis* **58**:105–112 (2019).

36 Rodríguez-González A, Casquero PA, Carro-Huerga G, García-González J, Álvarez-García S and Juan-Valdés A, Failure under stress of grapevine wood: the effects of the cerambycid *Xylotrechus arvicola* on the biomechanics properties of Vitis vinifera. *Maderas: Cienc Tecnol* **20**:167–178 (2020).

37 García-Ruiz E, Marco V and Pérez-Moreno I, *Xylotrechus arvicola*: posibilidades de control biológico. *Terralia* **61**:38–44 (2007).

38 Rodríguez-González A, Mayo S, González-López O, Reinoso B, Gutierrez S and Casquero PA, Inhibitory activity of *Beauveria bassiana* and *Trichoderma* spp. on the insect pests *Xylotrechus arvicola* (Coleoptera: Cerambycidae) and *Acanthoscelides obtectus* (Coleoptera: Chrisomelidae: Bruchinae). *Environ Monit Assess* **189**:12 (2017b).

39 Rodríguez-González A, Carro-Huerga G, Mayo-Prieto S, Lorenzana A, Gutiérrez S, Peláez HJ *et al.*, Investigations of *Trichoderma* spp. and *Beauveria bassiana* as biological control agent for *Xylotrechus arvicola*, a major insect pest in Spanish vineyards. *J Econ Entomol* **111**: 2585–2591 (2018a).

40 Peláez H, Moreno C, Santiago Y, Maraña R, Urbez JR, Lambert SM *et al.*, *Xylotrechus arvicola*: Un cerambícido en el cultivo de la vid. *Terralia* **55**:50–60 (2006).

41 García-Ruiz E, Aragón-Sánchez M, Sáenz-Romo MG, Martínez-García H, Marco-Mancebón VS and Pérez-Moreno I, Efecto ovicida de los juvenoides fenoxicarb y piriproxifen sobre *Xylotrechus arvicola* (Coleoptera: Cerambycidae). *Entomol Mex* **1**:261–266 (2014).

42 García-Ruiz E, Contribución al Manejo de Plagas en vid: *Xylotrechus arvicola* y *Lobesia botrana* Denis & Schiffermüller (Lepidoptera: Tortricidae). PhD thesis, University of La Rioja, Logroño, Spain (2009).

43 Soria FJ, López MA, Pérez MA, Maistrello L, Armendáriz I and Ocete R, Predictive model for the emergence of *Xylotrechus arvicola* (Coleoptera: Cerambycidae) in La Rioja vineyards (Spain). *Vitis* **52**:91–96 (2013).

44 Biurrun R, Yanguas R, Garnica I and Benito A, Xylotrechus arvicola. El taladro del endrino. *Navarra Agrar* **164**:47–51 (2007).

45 ECONEX, Feromonas y Trampas. https://www.eeconex.eu/insect-traps/ [accessed 28 January 2022].

46 Graham EE, Mitchell RF, Reagel PF, Barbour JD, Millar JG and Hanks LM, Treating panel traps with a fluoropolymer enhances their efficiency in capturing cerambycid beetles. *J Econ Entomol* **103**:641–647 (2010).

47 Davis JW, Introduction to Generalized Linear Mixed Models A Count Data Example University of Georgia, Griffin Campus (2018).

48 Stroup WW, Generalized Linear Mixed Models Modern Concepts, Methods and Applications. ISBN 9781439815120, 555 pages (2012).

49 Berkov A and Tavakilian G, Host utilization of the Brazil nut family (Lecythidaceae) by sympatric wood-boring species of Palame (Coleoptera, Cerambycidae, Lamiinae, Acanthocinini). *Biol J Lin Soc* **67**:181–198 (1999).

50 Lee CJ, Baxt A, Castillo S and Berkov A, Stratification in French Guiana: Cerambycid beetles go up when rains come down. *Biotropica* **46**: 302–311 (2014).

51 Hanks LM, Paine TD, Millar JG, Campbell CD and Schuch UK, Water relations of host trees and resistance to the phloem-boring beetle *Phoracantha semipunctata* F. (Coleoptera: Cerambycidae). *Oecologia* **119**:400–407 (1999).

52 Fierre MK and Stephen FM, Red oak borer (Coleoptera: Cerambicidae) flight trapping in the Ozark National Forest, Arkansas, Florida. *Flo Entomol* **90**:488–494 (2007).

53 Jung CS, Koh SH, Nam Y, Ahn JJ, Lee CY and Choi W, A model for predicting spring emergence of *Monochamus saltuarius* (Coleoptera: Cerambycidae) from Korean white pine. *Pinus Koraiensis J Econ Entomol* **108**:1830–1836 (2015).

54 García-Ruiz E, Marco V and Pérez-Moreno I, Effects of variable and constant temperatures on the embryonic development and survival of a new grape pest, *Xylotrechus arvicola* (Coleoptera: Cerambycidae). *Environ Entomol* **40**:939–947 (2011).

55 Inforiego, Instituto Tecnológico Agrario de Castilla y León (ITACYL). Consejería de Agricultura y Ganadería: Valladolid, Castilla y León, Spain. http://www.inforiego.org/opencms/opencms [accessed 20 September 2021] (2021).

56 Moreno CM, Martín Y, Santiago Y, De Evan E, Hernández JM and Peláez H, Presencia de *Xylotrechus arvicola* (Olivier, 1795) (Coleoptera: Cerambycidae) en viñedos de la zona centro de Castilla y León. *Bol San Veg Plagas* **30**:475–486 (2004).

57 Rodríguez-González A, Sánchez-Maíllo E, Peláez HJ, Mayo S, González-López O, Carro-Huerga G *et al.*, Evaluation of commercial and prototype traps for *Xylotrechus arvicola* (Coleoptera: Cerambycidae), an insect pest in Spanish vineyards. *Austr J Grape Wine Res* **24**:190–196 (2018b).