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Assessment and Monitoring Damage by *Coraebus florentinus* (Coleoptera: Buprestidae) in Mediterranean Oak Forests

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Abstract

Coraebus florentinus (Herbst) is a wood borer beetle that damages the most abundant *Quercus* species making up the Mediterranean forests. Damage is due to the feeding activity of the larvae which cuts the sap flow into the branch where it develops, drying it. In the last decades, the geographical range and the damage records of this species have expanded northwardly as a result of the climate global change since warmer conditions favor higher reproduction and quicker development of this species. On this paper, historical series of data after ten years evaluating damages by *C. florentinus* in Hornachuelos Natural Park (Southern Spain) are analyzed under the perspective of the environmental temperature increase linked to the global climate change. The assessment was done between 2007 and 2017, in two sampling plots of Mediterranean mixed-oak forests where holm and cork oaks are the predominant tree species. Results show that the infestation levels of this species at the beginning of the assessment period were higher than those described previously in the nineties and that they increased progressively during the monitoring time. The results also agree with the expansion of its distribution areas noticed in other areas of Europe. The foreseeable rising of damages of *C. florentinus* is discussed, at greater scale, under the perspective of future scenery of environmental warming and oaks decaying by losing fitness due to higher soil aridity.

Keywords

Buprestidae, Coleoptera, *Coraebus florentinus*, Damage, Mediterranean, Monitoring, Oak Forests

1. Introduction

The environmental degradation of the Mediterranean forests is an increasingly considered question when designing the management measures dealing with biodiversity or climate change [1]. The challenge of guaranteeing natural resources for future implies sustainable management of the forests, protection of relic preserved spaces and restoration of disturbed zones [2]. In agreement with these statements, the Habitat Directive (92/43/EEC, 1992), relative to the conservation of unmanaged habitats and of wild fauna and flora, established the obligation of taking all the compensatory measures necessaries to ensure the overall coherence of Nature 2000 Net (European Ecological Network for Conservation of Biodiversity [3]). Accordingly, the construction of the Breña dam (completed in 2008 in the Guadiato River basin, southern Iberian Peninsula) required the implementation of an actions' package to offset the environmental disturbance caused by flooding part of a nature reserve and by the construction of the infrastructure itself [4]. Being part of these actions, between 2007 and 2017, the research project titled "Study and Monitoring Plan of wood borer beetles damaging *Quercus* species" has been developed, including the assessment and monitoring of damage caused by *Coraebus florentinus* (Herbst, 1801).

C. florentinus is a xylophagous jewel beetle (Coleoptera: Buprestidae), which bores the branches of different species of *Quercus* [5]. Because of its affinity by holm (*Quercus ilex*, Linné 1753) and cork oaks (*Q. suber*, Linné 1753), this insect is mainly distributed in the Mediterranean forests where these tree species predominate [6].

The damage is due to the feeding activity of larvae, which makes longitudinal and annular galleries under the bark of terminal branches, interrupting the sap flow and drying the branches in which the insect completes its development [7]. The reduction in the number of healthy branches results in a progressive decay and loss of vigor of the tree [8]. The symptoms for recognizing damage caused by this species are easily identifiable and widely described in literature [5] [9] [10] [11] [12].

In several countries from the Mediterranean basin (Italy, Spain and Portugal) it has been detected that populations of the buprestid are growing at the same time that the damages they produce are increasing [8]. These processes are linked, in addition to other factors, to the progressive abandonment of pruning in the Mediterranean oak forests [13], in spite of being the most effective control method for some pests like this case [6] [14].

More recently, it has been noted that the geographical range of this species is also extended towards Center-Europe and that its damages have been north-worldly expanded. This may be explained because *C. florentinus*, as a thermophilous species [15] [16], is favored by the environmental warming linked to the global change [17] since increasing temperature rises the reproduction rate and quickens development [5].

Even though it is catalogued as a primary pest of medium importance [14], the combined effect of increasing populations, expanding geographical distribution and intensification of damages, have determined the inclusion of *C. floren-*

tinus among the wood borer species involved in oak declines in Europe [18].

On the other hand, the direct influence of climate on the oaks species making up the mixed Mediterranean forest has been analyzed from different perspectives: chorological [19], eco-physiological [20] [21] and phytosanitary [22]. However, other more indirect and long-term consequences should also be considered, such as forestalling the disturbing effects of climate change on phytophages, xylophages or pathogens [23]. The increase in environmental temperature affects phenology, life cycles and distribution of phytophagous insects [24], as well as synchronization of insect-plant interactions [25] [26]. A rise in temperature may, therefore, favor the development of thermophiles pest, intensifying their effects or widening their distribution as it has been evidenced for *C. florentinus* [17].

Measuring the success of management and restoration requires having a survey plan that allows assessing environmental changes in space and time [2], including the effect of the climate change on the pests.

Under this framework of reference, this research was scheduled, whose main objective was to assess and to monitor the damages caused by *C. florentinus*, during a ten years period and to analyze them under the perspective of the environmental temperature increase linked to the global climate change.

2. Material and Methods

2.1. The Study Area

Field work was carried out in a natural space belonging to the Hornachuelos Natural Park (southern Iberian Peninsula; **Figure 1**) and is included in the area of environmental improvement linked to the construction of the Breña dam [4]. The climate is typically Mediterranean (annual rainfall between 500 - 800 mm; average annual temperature of 17˚C approx.). The altitude ranges from 250 to 725 m (a.s.l.) [27]. Lithologically, palaeozoic metamorphic rocks predominate;

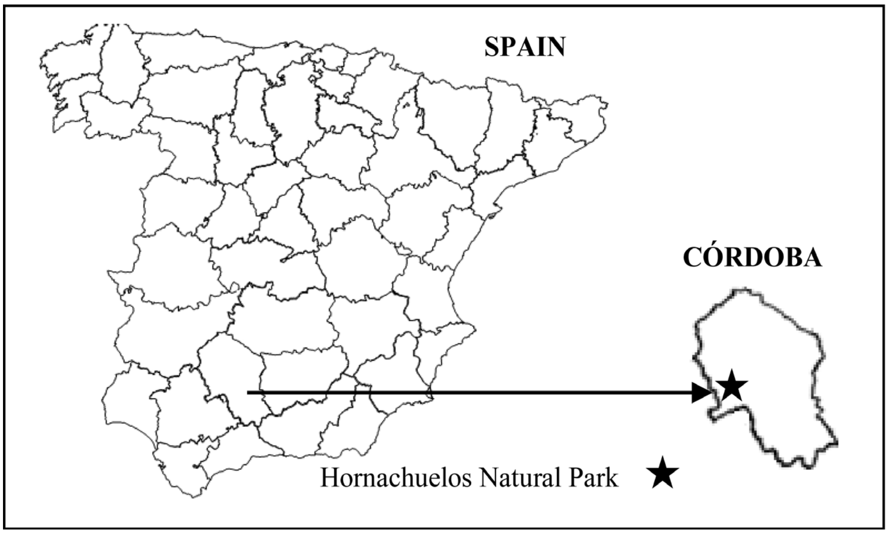

Figure 1. Location of the research area.

particularly, quartzite, slates, or semiacidic intrusive rocks. Sandy or clayey substrates can also be found. Soils are chemically and physically homogeneous and contain high levels of organic material and carbon [28].

Landscape is dominated by Mediterranean mixed sclerophyllous forests that sit on the thermo and meso-Mediterranean belts. Vegetation is composed by evergreen trees, with predominance of holm oaks (*Q. ilex*), cork oaks (*Q. suber*) and phanerophyte communities of shrubs and bushes [29].

2.2. Field Tasks

Data relative to the damages by *C. florentinus* were taken between 2007 and 2017. Field work was carried out in two plots located in the Hornachuelos Natural Park, named "Los Lagares" and "Mezquitillas" (P1 and P2, respectively), where previously different levels of damage caused by *C. florentinus* had been quantified [30] [31]. The main environmental features of each plot (altitude, orientation, orography, surface, vegetal composition and coverage, tree density, and woodland age) are summarized in **Appendix 1** (**Table A1** and **Table A2**). Detailed information about the sampling dates, species of *Quercus* prospected and the respective number of trees examined at each sampling is provided in **Table 1**. At each sampling date and in each plot, 60 trees were randomly selected, geo-referenced, and carefully surveyed prior to assess damages by *C. florentinus* (**Table 1**). A total of 612 holm oaks and 228 cork oaks were inspected for damage caused by *C. florentinus* along the overall period of monitoring.

Considering that age and density of oaks could affect the courses of damages produced by *C. florentinus* [11] [13], these parameters were also recorded when sampling was done. As it is accepted that the age of tree may be inferred from the diameter, the normal perimeter (measured at 1.30 m) of all selected trees was taken [32] [33]. The age of tree was inferred from its diametric value, through the expression proposed by Plieninger *et al.* [34] for *Q. ilex* and by Montero and Cañellas [35] for *Q. suber*. The density of trees was estimated by the Closest Individual Method [36], because it allows appraising in non-delimited spaces.

Table 1. Sampling dates and number of *Quercus ilex* and *Q. suber* sampled in P1 (Los Lagares) and P2 (Mezquitillas) at each sampling year.

Year	Sampling date		Number of trees sampled in P1		Number of trees sampled in P2	
	P1	P2	*Q. ilex*	*Q. suber*	*Q. ilex*	*Q. suber*
2007	7 June	25 June	60	0	30	30
2008	2 May	6 May	52	8	42	18
2009	16 June	12 June	60	0	25	35
2010	6 May	7 May	38	22	27	33
2012	12 June	19 May	43	17	42	18
2013	20 June	28 June	48	12	58	2
2017	9 June	15 June	48	12	39	21

Data of environmental temperatures were obtained from the website of the Agriculture and Fisheries Council, Junta de Andalucía, Spain [37] (**Appendix 2**, **Table A3**).

Diagnosis of damage was made by observing the branches showing clear symptoms of current attack of the insect (yellowish leaves still bearing in the treetop). These branches are well distinguishable from those infected in preceding years because the older ones only conserve few, obscure, and dry leaves still hanging on the branch, or are totally defoliated, acquiring a singular aspect, easily recognizable on the canopy [8] [38] [39].

2.3. Data Analysis

To assess damage by *C. florentinus*, the following parameters were estimated [6] [11] [13]:

1) Infestation Level (IL): Percentage of trees damaged from the total sampled.

2) Population Intensity (PI): Average number of dry branches/damaged tree.

The following statistical tests were performed to evaluate the model bias.

The independent sample T-test was used to check differences between P1 and P2, relative to the tree density, the average diameter (independently for each *Quercus* species), and the IL and PI indices, considering the total sample of trees prospected in each sampling plot, along the complete sampling period. If the normality assumptions were not satisfied, after checking by the Shapiro-Wilk test, the equivalent non-parametric Mann-Whitney U/Wilcoxon Ranked Sum test was performed [40].

To explore relationships between tree age and damage (parameters IL and PI) or between tree density and damage (parameters IL and PI), the r-Pearson correlation coefficient was used for normally distributed variables. If not, the Spearman rank correlation coefficient was instead calculated.

To determine the fitting model for the relationship between the average environmental temperatures and damage (parameters IL and PI), a simple linear regression was performed, where Y was IL or IP as dependent variables and X was Temperature as predictor variable [41].

All statistical tests were conducted with $\alpha = 0.05$.

Calculations were performed using SP Statistical Software (SPSS 20.0, 2011) and Past Software [42].

3. Results

3.1. Analysis of the Starting Situation: Testing Differences between the Sampling Plots

First of all, differences in the diameter of the trees sampled in P1 and P2 plots were checked, considering independently the samples of *Q. suber* and *Q. ilex*, because the difference in average size of them.

The results indicate that there are significant differences in the diameter of the holm oaks and the cork oaks sampled in plots P1 and P2 ($Z = -4.462$, $P = 0$; $Z =$

−3.495, $P = 0$, respectively); corresponding to P1 the oldest trees in both species.

Differences in tree density between P1 and P2 were tested but considering the overall sample. On this case, the statistical test did not found significant differences (T = −0.671, $P = 0.515$).

To complete the analysis, the parameters Infestation Level and Population Intensity were compared: regarding IL, the initial values corresponding to 2007 were higher in P2 (12.5) than in P1 (5.0); while there were non-significant differences in PI values of the two sampling plots (T = −1.798, $P = 0.097$).

3.2. Relationships between Tree Age, Density and Damage by *C. florentinus*

To explore relationships between tree age and damages by *C. florentinus* correlations between the initial values (2007) of Infestation Level and Population Intensity of each sample and its respective average diameter were calculated, considering independently each oak species and sampling plot. Correlation values and their respective significance (**Table 2**) show non-significant correlation between tree diameter and damages by *C. florentinus*.

Correlation between the damage's indicator parameters and the density of the set of trees sampled in each plot (**Table 3**) resulted statistically significant only between Infestation Level and tree density in P1 plot.

3.3. The Course of Damage over Time

The course of the Infestation Level and the Population Intensity in the sampling plots (P1 and P2) in the period 2007-2017 are displayed in **Figure 2(a)** and

Table 2. The Pearson (r-P) or Spearman (r-S) correlation coefficient and probability (*P*) between tree diamater and damages (IL and PI) by *C. florentinus* for each tree species (*Quercus ilex* and *Q. suber*) sampled in P1 (Los Lagares) and P2 (Mezquitillas). IL: Infestation Level; PI: Population Intensity.

Sampling Plot		IL		PI	
		P	r-P/r-S	*P*	r-P/r-S
P1	*Q. ilex*	0.349	0.419	0.221	0.530
	Q. suber	0.873	0.100	0.188	0.700
P2	*Q. ilex*	0.427	−0.361	0.058	−0.739
	Q. suber	0.089	0.686	0.207	0.543

Table 3. The Pearson correlation coefficient (r-P) and probability (*P*) between damages (IL and PI) by *C. florentinus* and tree density in P1 (Los Lagares) and P2 (Mezquitillas). IL: Infestation Level; PI: Population Intensity; * indicates statistical significance.

Sampling Plot	IL		PI	
	P	r-P	*P*	r-P
P1	0.010*	0.877	0.160	0.594
P2	0.630	−0.224	0.208	0.543

Figure 2(b), respectively. The trend lines show an increase in the Infestation Level which is more evident in P1 than in P2 plots, even though the initial infestation was higher in P2 than in P1 (subsection 3.1). The same effect is observed in the Population Intensity, although in this case the difference in the slope is attenuated being that the range of variation is lower.

If relationships between data of Infestation Level or Population Intensity with respect to the average annual temperature are fitted to a Linear Simple Regression Model (Figure 3), the "r" statistic results positive and statistically significant in both sampling plots (Table 4).

4. Discussion

"As climate shifts, so do pests" [43]; to verify this statement in the particular case of *C. florentinus* in the southern of Iberian Peninsula summarizes the starting point of this research. In fact, it has been proved that changes in climate can

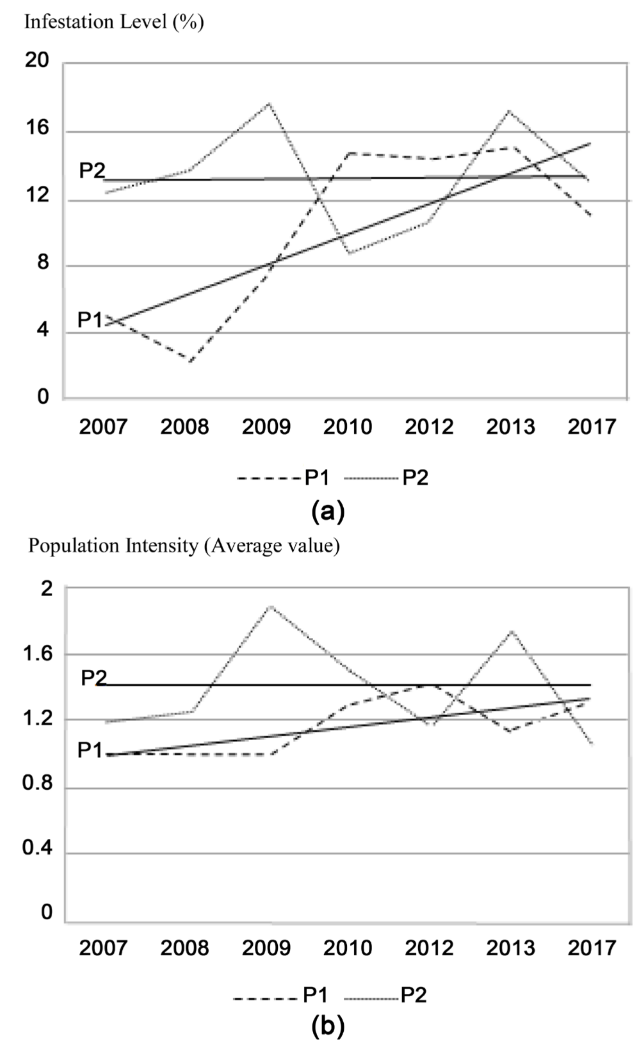

Figure 2. Temporal course of the Infestation Level (a) and the Population Intensity (b) and their respective trend lines during the monitoring period in P1 (Los Lagares) and P2 (Mezquitillas) sampling plots.

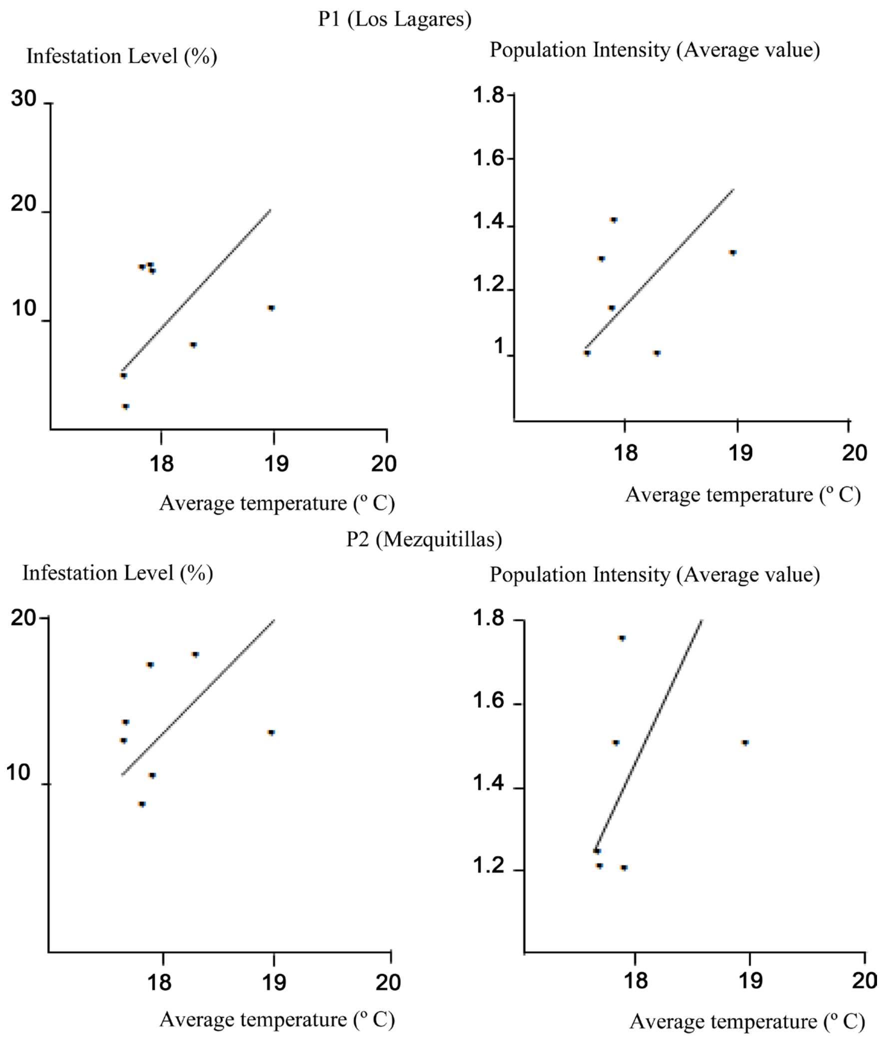

Figure 3. Fitted Linear Simple Regression Models showing relationship between the average environmental temperature and the parameters Infestation Level and Population Intensity in the *P*1 (Los Lagares) and *P*2 (Mezquitillas) sampling plots.

Table 4. Values of the Linear Regression coeficient (r) and probablility (*P*) between damage (Infestation Level: IL; Population Intensity: PI) and Annual Average Temperature (˚C) for each sampling plot (P1: Los Lagares; P2: Mezquitillas); * indicates statistical significance.

Statistics values	Linear Simple Regression			
	P1		P2	
	IL	PI	IL	PI
r =	0.196	0.334	0.198	0.395
P =	0.014*	0.001*	0.021*	0.050*

influence distribution range and populations size of forest insects [44]. Temperature directly could affect rate of development, voltinism, population density, and extent of host plant exploitation and even the geographical distribution of this species [45]. In addition, it has been proven that shifts in temperature may also affects fitness and resistance of the host trees, which likewise impacts the progress of the damage in the forest [17].

Accordingly, prior to setting goals for environmental management it is necessary to assess the current situation of the area to be enhanced [45]. Trying to address this question, we look for the information relative to the effect of the climate change on the southern Iberian Peninsula. The last report from the International Panel on Climate Change [46] highlights the Mediterranean as one of the most vulnerable regions in the planet to be impacted by global warming. Simulations with impact models have shed some light on the risks and sensitivities to climate change, but they pose limitations when are applied at the regional scale and for low levels of warming [47].

Descending to the local scale of the studied area, we have verified significant thermal rising on the last decades. Indeed, the bioclimatic study of the Hornachuelos Natural Park, performed with data from the 60 s and 70 s [48], gave an average annual value of 16.8˚C, while if the period is extended to 1992, the average annual temperature rises to 17.5˚C [37].

Between 2000 and 2005, the average temperature for the area was 17.6˚C; and our data (**Table A3** in **Appendix 2**) show average annual temperature ranging between 17.7˚C in 2007 to 19.0˚C in 2017, which confirms the increasing trend at the local scale of the Hornachuelos Natural Park.

On the other hand, it should be paid attention to the direct influence of climate on the oaks species making up conforming the Mediterranean forests [19] [20] [21] [22] and on their pathogens and phytophagous insects [23] [24] [25] [26].

On the first of these issues, it is known that the oak's response to climate has varied in recent decades in Mediterranean areas as consequence of the increasing temperature and aridity [49]. Species like *Q. ilex* are likely to be most susceptible of suffering the negative effects of climate change [50] because increasing temperature without rising precipitation, intensifying ETP rates and water stress, which may prompt significant changes in the distribution of the species [19].

The second question to be considered is, in our case, the effect of thermic rising on the wood borer insects. Studies on some Buprestidae species (*Agrilus sinuatus* Olivier 1780, and *A. sulcicollis* Lacordaire 1835) [24] reveal that the geographical ranges have changed significantly as consequence of the climate change. Other research [51] found that the emerald ash borer (*A. planipennis* Fairmaire 1888) shows great tolerance to wide ranges of high temperature. Regarding to *C. florentinus*, laboratory essays have highlighted faster development and enhanced survival at higher temperatures [5] [6] [26]. In addition, previous data [11] recorded also in the Hornachuelos Natural Park found infestation levels ranging from 3.02% to 9.80% in the period 1988-1993 and between 3% and 5% for 1991-1994 [12], in the same area. All these values are noticeably lower than those we found more than twenty years later. If the evolution of the insect populations is assessed by the course of the damage that it produces in the forest, the temperature increase found for the study area would be compatible with a significant increase in the parameters that allow quantifying their damages.

In fact, this happens: when the slope of the lines of the infestation levels of the last ten years is analyzed, an upward trend is detected that runs parallel to the thermal variation noticed. This result was verified after performing the linear regression between both parameters. Something similar, although quite less evident, occurs with the intensity of population.

This result may be interpreted as that the temperature favors the development of the populations of *C. florentinus*, but they do no concentrate damages in the same proportion. It tends to expand their occupancy area, infesting more trees. This may also explain that the level of infestation has increased less in the plot where more damage was initially quantified, and it is compatible with the expansion predicted in the models developed [17] to explicate the immigration of *C. florentinus* towards regions of Central Europe.

According to our results, other environmental factors, as the age of the trees, seem to be less significant on the course of the pest on the research area. Nevertheless, results relative to relationships between damage and tree density is significant in the plot P1 "Los Lagares". On this regard, it is known that stand density could attenuate the response to climate by smoothing extreme conditions. But, nevertheless, the effect of competition might reverse this positive influence at individual level. It has been suggested that reduction of density by thinning could increase the individual resistance to drought stress and that this differential response varies with climatic shifts [52] [53]. As the detailed study of these effects on the *Quercus* species studied has not been addressed in the present work, more research is necessary to make a more whole interpretation of the results.

5. Conclusion

In conclusion, based on the current results and those of prior research, it can be stated that there has been a local thermal increase that has affected the populations of *C. florentinus* in the southern Iberian Peninsula, extending their damage but not intensifying them significantly. The foreseeable spreading of the insect on the future climate scenarios makes necessary the implementation of effective control activities, as selective pruning [6], in the management of Mediterranean oak forests, as a preventive measure to avoid the demographic explosion of this pest.

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Appendix 1

Table A1. Environmental features of the plot P1 (Los Lagares): surface, orography, orientation, altitude, vegetal composition, coverage, tree density and woodland age.

P1 (Los Lagares)	
Average surface	1.82 ha
Orography	Hillside with medium slope
Orientation	South
Average altitude	426 m
Shrub composition	*Cistus* sp. L., *Phlomis purpurea* L., *Lavandula stoechas* L., *Rubus ulmifolius* Schott, *Daphne gnidium* L., *Genista hirsuta* Vahl., *Pistacia lentiscus* L., *Rosmarinus officinalis* L.
Canopy cover fraction	25% - 50%
Average woodland composition	*Quercus ilex* L. (≈80%) and *Q. suber* L. (≈20%). Pure forest of holm oaks
Average density woodland	60 trees/ha
Woodland age	Average diameter *Q. ilex* = 35.99 ± 3.56 cm; Average diameter *Q. suber* = 60.59 ± 10.13 cm

Table A2. Environmental features of the plot P2 (Mezquitillas): surface, orography, orientation, altitude, vegetal composition, coverage, tree density and woodland age.

P2 (Mezquitillas)	
Average surface	1.40 ha
Orography	Hillside with low/medium slope
Orientation	South
Average altitude	541 m
Shrub composition	*Cistus* sp., *P. purpurea*, *R. ulmifolius*, *D. gnidium*, *G. hirsuta*, *P. lentiscus*, *Hedera helix* L., *L. stoechas*, *Smilax aspera* L., *R. officinalis* L., *Nerium oleander* L.
Canopy cover fraction	25% - 50%
Average woodland composition	*Q. ilex* (≈90%) and *Q. suber* (≈10%). Pure forest of holm oaks
Average density woodland	80 trees/ha
Woodland age	Average diameter *Q. ilex* = 31.06 ± 6.01 cm; Average diameter *Q. suber* = 52.84± 11.31 cm

Appendix 2

Table A3. Average of maximum, minimum and mean temperatures (˚C) of the research area during the sampling period.

Average temperature	Sampling period										
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Maximum	24.8	24.4	25.3	24.2	25.5	25.1	24.5	25.3	25.8	25.0	26.5
Minimum	11.6	11.7	11.9	12.0	12.6	11.6	11.9	12.6	12.0	12.4	12.3
Mean	17.7	17.7	18.3	17.8	18.5	17.9	17.9	18.5	18.5	18.4	19.0