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ORIGINAL PAPER

Long-term monitoring of saproxylic beetles from Mediterranean oak forests: an approach to the larval biology of the most representative species

Patricia Gallardo[1] · Ana M. Cárdenas[1]

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Abstract Branches of *Quercus* species killed by *Coraebus florentinus* (Coleoptera, Buprestidae) are a chief resource for many saproxylic insects, mainly of the orders Coleoptera and Diptera, in the oak forests of the southern Iberian Peninsula. To investigate the biology of these species, a total of 127 dry oak branches that had been previously colonised by *C. florentinus* were collected and kept in the laboratory, in conditions comparable to the outdoor climate. For 4 years, the emergence of saproxylic insects from the branches was monitored. We obtained 651 individuals, belonging to 19 species of 6 families. Three buprestids (*Anthaxia hungarica, A. millefolii* and *Agrilus angustulus*) and one cerambycid (*Chlorophorus ruficornis*) made up 68% of the total abundance. Results on host tree preferences indicated that *A. hungarica* and *C. ruficornis* show more affinity to holm oaks (*Q. ilex*). Conversely, *A. angustulus* and *A. hastulifer* prefer cork oaks (*Q. suber*). Preimaginal stages have long durations, but vary in relation to the body size of species: smaller species such as *A. angustulus* and *A. millefolii* exhibit shorter larval time, reaching the maximum of emergences after 12 months monitoring, whereas larger species such as *A. hungarica* and *C. ruficornis* display a longer pre-adult period (3 and 4 years, respectively). The insects were found to be active in spring and summer and to have a balanced sex ratio in all of the species studied. Finally, our results also indicate the importance of long-term maintenance of these branches in the natural environment for the conservation of saproxylic biodiversity in the Iberian "dehesa".

Keywords Buprestidae · Cerambycidae · *Coraebus florentinus* · Host preference · Saproxylic beetles

✉ Patricia Gallardo
b42gatop@uco.es

Ana M. Cárdenas
ba1cataa@uco.es

[1] Department of Zoology, University of Córdoba, Campus Rabanales, E-14071, Córdoba, Spain

Introduction

Saproxylic organisms are species that depend, during some part of their life cycle, upon wounded or decaying woody material from living, weakened or dead trees (Stokland et al. 2012). The term "woody material" includes the wood as well as the bark or sap (from inner bark, sapwood, or flowing from wounds) at any stage of decay. Consequently, saproxylic species live in wounds, dead branches or cavities of otherwise healthy trees (Stokland et al. 2012) and they are usually classified into the following five trophic guilds (Speight 1989; Bouget 2005; Quinto et al. 2014): xylophagous, saproxylophagous/saprophagous, xylomycetophagous, predators and commensals.

These insects play a key ecological role in forest ecosystems, contributing to the maintenance of trophic chains (Schlaghamersky 2003); their larvae favour decomposition and the recycling of plant matter, and the adults contribute to plant pollination (Davies et al. 2008). Saproxylic organisms include representatives of all major insect orders, but Coleoptera and Diptera are especially well represented (Quinto et al. 2014).

These insects are considered important for the biodiversity of Mediterranean woodlands (Dajoz 2001; Schlaghamersky 2003; Bouget et al. 2008; Quinto 2013). Their relevance to the functioning of forest ecosystems has been proven in numerous scientific studies and they are considered to be bioindicators of the structure and degree of conservation of vegetation (Pérez-Moreno 2010). In spite of this, there has been a decrease in the abundance of many saproxylic species due to unsuitable management of Mediterranean forests over the last few decades, which has resulted in the disappearance of mature forests and dead wood. For this reason, many of these insects are included in European lists of protected species (Nieto and Alexander 2010; Ramírez-Hernández et al. 2014) and diverse action plans have been implemented for their conservation (Cavalli and Mason 2003).

The southern Iberian Peninsula is dominated by the "dehesa", a particular pasture ecosystem included in the European Habitats Directive and Natura 2000 network (Ramírez-Hernández et al. 2014). This type of ecosystem arose as a result of the reduction in the original forest area due to human activity and has persisted for centuries. The "dehesa" has the appearance of a savannah with isolated trees (Díaz et al. 1997), an herbaceous layer under the canopy and an undeveloped scrub. This ecosystem houses a rich community of saproxylic insects due to the presence of mature trees that harbour numerous microhabitats. Nevertheless, continuous and intensive human intervention negatively impacts the diversity of saproxylic insects (Ramírez-Hernández et al. 2014).

Most studies generally focus on the environmental patterns of these beetles in different microhabitats (Lindhe et al. 2005; Winter and Möller 2008; Vuidot et al. 2011; Widerberg et al. 2012; Horák and Rébl 2013) or on the evolution of beetle assemblages after environmental disturbances (Wermelinger et al. 2002; Bouget and Duelli 2004; Bouget 2005; Grove and Forster 2011). There are also numerous studies that evaluate the effectiveness of capture traps (Martikainen and Kalia 2004; Quinto et al. 2012). However, aspects of the biodiversity, biology and larval development of these insects in the Mediterranean region are poorly studied (Micó et al. 2005), despite the fact that research on the biology of immature stages and breeding sites of saproxylic insects may be used as a tool for establishing woodland management programmes (Rotheray and MacGowan 2000; Sánchez-Martínez et al. 2013).

This work is part of a monitoring plan of wood-boring beetles from *Quercus* species in the "Sierra de Hornachuelos" Natural Park. Among the studies linked to this project, we also evaluate the damage caused by the borer *Coraebus florentinus* (Herbst, 1801), a xylophagous beetle of the Buprestidae family, which feeds mainly on branches of *Quercus* spp. that make up the Mediterranean forests (*Q. suber* Linné, *Q. ilex* Linné, *Q. robur* Linné, *Q. pubescens* Willdenow, *Q. cerris* Linné, *Q. coccifera* Linné, *Q. toza* Linné, *Q. pedunculata* Ehrhart, *Q. canariensis* Willdenow, *Q. faginea* Lamarck and *Q. sessiliflora* Smith; Cárdenas and Gallardo 2012) and *Castanea sativa* W. Miller (Balachowsky 1962). *C. florentinus* is a common jewel beetle in Iberian oak forests, where it cause lesions in branches and shoots of oaks, not severely damaging mature trees, but threatening young oaks (Evans et al. 2004; Buse et al. 2013). This is because the larvae feed by boring longitudinal and annular galleries inside the terminal branches, interrupting sap flow and causing the death of branches (Jurc et al. 2009). These branches then become a main trophic resource to a large number of other species, such as the above-mentioned saproxylic insects (Brechtel and Kostenbader 2002; Recalde and San Martín 2003; Niehuis 2004). Species such as *C. florentinus* therefore play important functional roles in forest ecosystems because they can act as ecosystem engineers. They manipulate their host plants to build a variety of structures which are subsequently occupied by other organisms (Calderón-Cortes et al. 2011), and in turn, contribute to nutrient cycling (Amman 1977; Schowalter 1981), alteration of tree architecture (Feller 2002; Martínez et al. 2009), resource regulation (Duval and Whitford 2008) and alteration of the composition and hydrology of forests (Feller and McKee 1999).

Assessing the incidence of *C. florentinus* gave us the opportunity to have enough dead oak branches to address some as yet unknown aspects of the biology of the most abundant saproxylic beetle species in the study area. The chief objectives of this research were to identify which species are associated with oak branches colonised by *C. florentinus*, to consider their host selection and to provide information on their life cycles. We analysed preferences for species of *Quercus* and the phenology and duration of the pre-adult stages of the life cycle of *Anthaxia hungarica* (Scopoli, 1772), *A. millefolii polychloros* (Abeille, 1894), *Agrilus angustulus* (Illiger, 1803) and *Chlorophorus ruficornis* (Olivier, 1790) (See Table 1). We have focused on these species because, along with the powder post beetle *Lyctus brunneus* (Stephens, 1830), they turned out to be the most abundant species present during the monitoring period. However, we did not consider *L. brunneus* in our study because it is a cosmopolitan and well-known species, and much information on its biology can be found in the literature (i.e. Ito 1983; Dajoz 2001).

Materials and methods

Studied species

The information available in the literature on the biology and distribution of the 4 species of saproxylic beetles studied is displayed in Table 2. Descriptions of feeding habits are based on the classifications of Compte and Caminero (1982), Dajoz (2001) and Pérez-Moreno (2010) and the nomenclature of species is according to Fauna Europaea (2004).

Table 1 Number of specimens of saproxylic beetles collected from branches of *Quercus ilex* and *Q. suber*

Species of saproxylic beetles	Number of specimens	
	Q. ilex	*Q. suber*
Family Buprestidae		
Acmaeoderella adspersula (Illiger, 1803)	15	1
Anthaxia hungarica (Scopoli, 1772)	87	4
Anthaxia millefolii polychloros (Abeille, 1894)	132	28
Anthaxia salicis (Fabricius, 1776)	1	–
Chrysobothris affinis (Fabricius, 1794)	–	1
Nalanda fulgidicollis (Lucas, 1846)	4	–
Agrilus angustulus (Illiger, 1803)	80	25
Agrilus graminis (Kiesenwetter, 1857)	–	1
Agrilus hastulifer (Ratzeburg 1837)	–	15
Agrilus laticornis (Illiger, 1803)	1	–
Family Cerambycidae		
Chlorophorus ruficornis (Olivier, 1790)	84	3
Xylotrechus antilope (Schönherr, 1817)	–	5
Trichoferus fasciculatus (Faldermann, 1837)	10	1
Family Lyctidae		
Lyctus brunneus (Stephens, 1830)	143	3
Family Tenebrionidae		
Alphitobius diaperinus (Panzer, 1797)	1	–
Probaticus granulatus (Allard, 1876)	1	–
Family Cleridae		
Tillus ibericus (Bahillo de la Puebla, López-Colón and García-París 2003)	3	–
Family Carabidae		
Calodromius bifasciatus (Dejean, 1825)	1	–
Dromius agilis (Fabricius, 1787)	1	–

Area

Field work was carried out in a natural space belonging to the Hornachuelos Natural Park (southern Iberian Peninsula), where dry branches due to feeding activity of the jewel beetle *C. florentinus* were known to occur (Gallardo 2011). The vegetation is that of a Mediterranean mixed sclerophyllous forest, characterized by the predominance of holm oaks (*Q. ilex*) and cork oaks (*Q. suber*). There are middle-aged trees, ranging between 65 and 100 years old, with a mean density of 45 trees/ha (Cárdenas and Gallardo 2012).

Field sampling

A total of 127 dry oak branches were monitored: 105 branches from holm oaks and 22 branches from cork oaks. Differences in number of branches of oak species are due to the proportion of each tree species in the area

Table 2 Data on the biology (feeding habit and larval host tree), the world distribution of the 4 saproxylic species studied, and literature source

Species	Feeding habit	Larval host tree	Distribution	References
Anthaxia (Cratomerus) hungarica (Scopoli, 1772)	Xylophagous	*Q. ilex*, *Q. faginea*, *Q. canariensis*, *Q. pubescens*, *Q. pirenaica* and *Q. coccifera*	Southern Europe, Russia, Asia Minor, Iran and North Africa	Cobos (1986); Molino-Olmedo (1997, 1998); Verdugo (2002)
Anthaxia (Haplanthaxia) millefolii polychloros (Abeille de Perrin, 1894)	Xylophagous	Genus *Quercus*, *Amygdalus*, *Sorbus*, *Pistacia*, *Acer*, *Ulmus* and *Nerium*. *Q. pirenaica*	Western Mediterranean, from Portugal to Italy, the western Mediterranean islands, Switzerland, Germany and Slovakia	Verdugo (2005); Ricarte et al. (2009)
Agrilus (Anadus) angustulus (Illiger, 1803)	Xylophagous	Genus *Quercus*, *Fagus*, *Castanea*, *Corylus*, *Vitis*, *Rubus* and *Betula*	Palaearctic, from the Iberian Peninsula to Siberia and North Africa	Verdugo (2002, 2005)
Chlorophorus ruficornis (Olivier, 1790)	Xylophagous	*Q. ilex* and *Q. pyrenaica*. *Fraxinus angustifolia*	Iberian endemism that extends to the southern France	Vives (2000, 2001); De Diego and Martínez-Porres (2005); López-Pérez (2009); Ricarte et al. (2009)

(Gallardo 2011). All branches gave clear indications of being colonized by *C. florentinus* (detailed descriptions of dry branches are available in Romanyk and Cadahia 1992). Branches were collected between March and June 2007 and during the same period in 2008. This time coincides with the drying of branches as a consequence of the feeding activity of *C. florentinus* larvae (Jurc et al. 2009; Cárdenas and Gallardo 2012). For the identification and collection of branches, a visual search of the tops of oaks was done, and dry branches were collected. For each branch, the following data were recorded: age (old or new), date of collection and the plant species from which the branch was sourced.

Related to the age, a branch was considered to be old if it was completely dry and virtually defoliated, or retained few leaves that were coppery brown in colour. Branches were considered new or recent if they were in the drying process, while retaining leaves that displayed a yellowish-orange colour. Data on the number of branches collected at each sampling period, age, and the plant species from which the branch was sourced are summarized in Table 3. Once the branches were defoliated, they were cut to a length of approximately 40 cm. Each branch was labelled and individually stored in perforated polythene bags for transportation.

Monitoring

In the laboratory, branches were kept in breathable bags of fiberglass (1 mm mesh) in conditions comparable to the outdoor climate (data on temperature and humidity for the research period are available on the Córdoba University website: https://www.uco.es/servicios/scai/unidades/generales/estacion/estacion.htm).

Twice a week, from April 2007 to December 2010, branches were carefully examined in order to detect and follow the emergence of saproxylic fauna. According to the order in which they were found, insects were removed from the bag, preserved in 70% ethanol and stored until subsequent sexing and identification.

Table 3 Number of dead branches (killed by *Coraebus florentinus*) collected for the experiment in spring 2007 and 2008, indicating the age (new or old) and plant species from which the branch was sourced (*Q. ilex* or *Q. suber*)

	Quercus ilex		*Quercus suber*		Total
	New branches	Old branches	New branches	Old branches	
2007	42	21	5	3	71
2008	11	31	6	8	56
Total	53	52	11	11	127

Data analysis

Species with fewer than 20 individuals emerging over the complete monitoring period (4 years) were not considered because data were insufficient for analysis.

To determine whether these xylophagous species show host tree preferences, standardized data (percentage of individuals of each species emerging from each plant species) were analysed using the Chi-squared test. Calculations were performed using SPSS 20.0 (SPSS 2011).

To test relationships between body size of saproxylic species and the developmental duration time of their larvae, the Pearson correlation coefficient was calculated. The average size of each studied species was obtained from the literature (Vives 2001 for cerambycids and; Verdugo 2005 for buprestids). The developmental time of larvae was estimated as the mean time (in weeks) spent by each species until emergence as an adult.

Results

Throughout the monitoring period, we obtained a total of 651 individuals belonging to 19 species of saproxylic beetles distributed among 6 families (see Table 1). These species can be assigned to their respective functional trophic group: 14 species of xylophagous belonging to the families Buprestidae (10 sp), Cerambycidae (3 sp) and Lyctidae (1 sp), 2 species of saproxylophagous (Tenebrionidae) and 3 predator species: Carabidae (2 sp) and Cleridae (1 sp).

The families Buprestidae and Cerambycidae comprised nearly 70% of the species and 80% of the total specimens found. Three buprestid beetles species (*Anthaxia hungarica, A. millefolii* and *Agrilus angustulus*) and one member of the Cerambycidae (*Chlorophorus ruficornis*) accounted for 68% of the obtained saproxylic fauna. In the following paragraphs, the relevant aspects of the larval biology of these species, such as host tree preference, the developmental time course and the sex ratio and synchronization of adults, are analysed.

Host tree preference

The number of individuals of each species emerging from *Q. ilex* and *Q. suber* are listed in Table 1. Results were low for most species, preventing the identification of host tree preferences.

Nevertheless, it is noticeable that all the specimens of *A. hastulifer* (Ratzeburg, 1837) (15) and *Xylotrechus antilope* (Schönherr, 1817) (5) came from branches of *Q.*

suber in spite of the proportion of branches of *Q. suber* being considerably lower than for *Q. ilex* (about 5:1).

Focussing on the species under study, the results of statistical comparison of the number of adults of each species emerging from branches of holm and from those of cork oaks are shown in Table 4. There were no significant differences in the case of *A. millefolii*; while for the other species there were significant differences between host trees. The number of emergences of *A. hungarica* and *C. ruficornis* from branches of holm oaks was significantly greater than from cork oaks. Contrarily, most of the specimens of *A. angustulus* come from *Q. suber*.

Developmental biology

The extent and location of the emergence period of imagoes along the total monitoring time of the branches are plotted in Fig. 1. The longest developmental period was observed in *A. hungarica*. Occurrences of this jewel beetle were recorded at two distinct times: 2 years (24 months) and 3 years (35 months) after collection, simultaneously in both new and old branches. The maximum number of emergences was 23 individuals, coming from new branches after 35 monitoring months; the emergences from old branches were scarcer (during the second year of monitoring) or occasional (during the third

Table 4 Chi-squared (χ^2) and probability (P) values of the differences in the number of specimens (standardized data) of each saproxylic species emerging from holm oak (*Q. ilex*) or cork oak (*Q. suber*)

Saproxylic beetles		Number of specimens (standardized data)	Chi-squared statistic	
			χ^2	P
Anthaxia hungarica	Holm oak	126	0.0040	0.95
	Cork oak	127		
Anthaxia millefolii	Holm oak	83	41.83	9.95E-11
	Cork oak	18		
Agrilus angustulus	Holm oak	76	7.6	0.0058
	Cork oak	114		
Chlorophorus ruficornis	Holm oak	80	46.34	9.94E-12
	Cork oak	14		

Degrees of freedom (d.f.) = 1

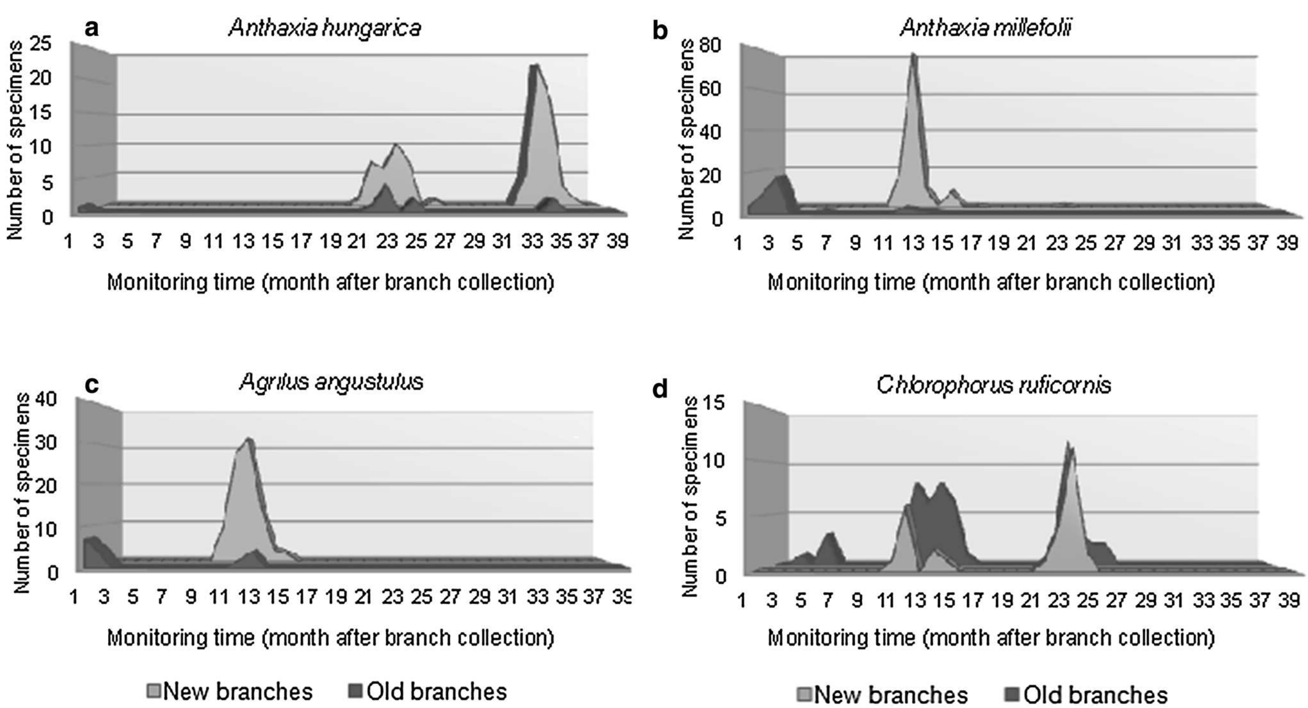

Fig. 1 Extent and location of the emergence period of imagoes along the total monitoring time, distinguishing between old and new branches. **a** *Anthaxia hungarica*; **b** *A. millefolii*; **c** *Agrilus angustulus*; **d** *Chlorophorus ruficornis*

year). These results indicate that this species has a broad larval developmental time, which may extend in some cases to 4 years. However, according to the highest value observed, it can be concluded that the larvae of this species spend between 2 and 3 years completing their preimaginal development.

In reference to *A. millefolii*, in the new branches, the first emergences of adults occurred after 11 months of monitoring, and continued for 16 months more, reaching a maximum at 12 months, with 80 adults recorded. However, in the case of old branches, the first emergences were observed during the first 3 months of monitoring. These results clearly fit to a life-cycle of 1 year of pre-adult development time. A quite similar developmental time was obtained for *A. angustulus*: adults started to emerge from the new branches after 11 months of observation, peaking just after 1 year of monitoring. In the case of old branches, the first 'hatchings' occurred during the first 3 months of observation.

Regarding images of the longhorn beetle *C. ruficornis*, we recorded two peaks of emergences, 12 and 24 months after beginning the experiment, in both new and old branches. Some early emergences were also observed in old branches at the beginning of the monitoring period (between the third and fifth months after collection). All of these results indicate that the pre-adult developmental period for this species ranges from 1 to 3 years, although most of them completed their development after 2 years.

In order to determine if males and females of each species were synchronized in their respective emergence timeline, the number of individuals of each sex obtained along the monitoring time were analysed (the age of the branch was not considered in this case). The results are given in Fig. 2, where it can be seen that, for all studied species, males and females emerge together.

Data indicate (Fig. 3), that they could all be considered to be spring-summer time species, with a broad emergence period, which starts in April and extends to July in the case of *A. hungarica* and *A. angustulus*, but begins a month later for the other species: *A. millefolii* and *C. ruficornis*. In detail, the first to appear were the imagoes of *A. hungarica* and *A. angustulus* (April) which reached a maximum in May (about 50 emergences in both cases), and continued towards mid-July. The adults of *A. millefolii* and *C. ruficornis* were quite synchronized, increasing in number towards the end of spring (June), with 111 and 57 individuals, respectively. Some sporadic emergences were also observed in September and October for *A. millefolii* and *C. ruficornis*. In addition, the curves for males and females run quite parallel and are similar in size (Fig. 3). In fact, the sex ratio is close to 1 in all cases (1.12; 1.03; 1.23 and 0.94 for *A. hungarica, A. millefolii, A. angustulus* and *C. ruficornis*, respectively).

Finally, regarding relationships between body size of each species and their respective developmental time (Table 5), the value of the Pearson's correlation coefficient

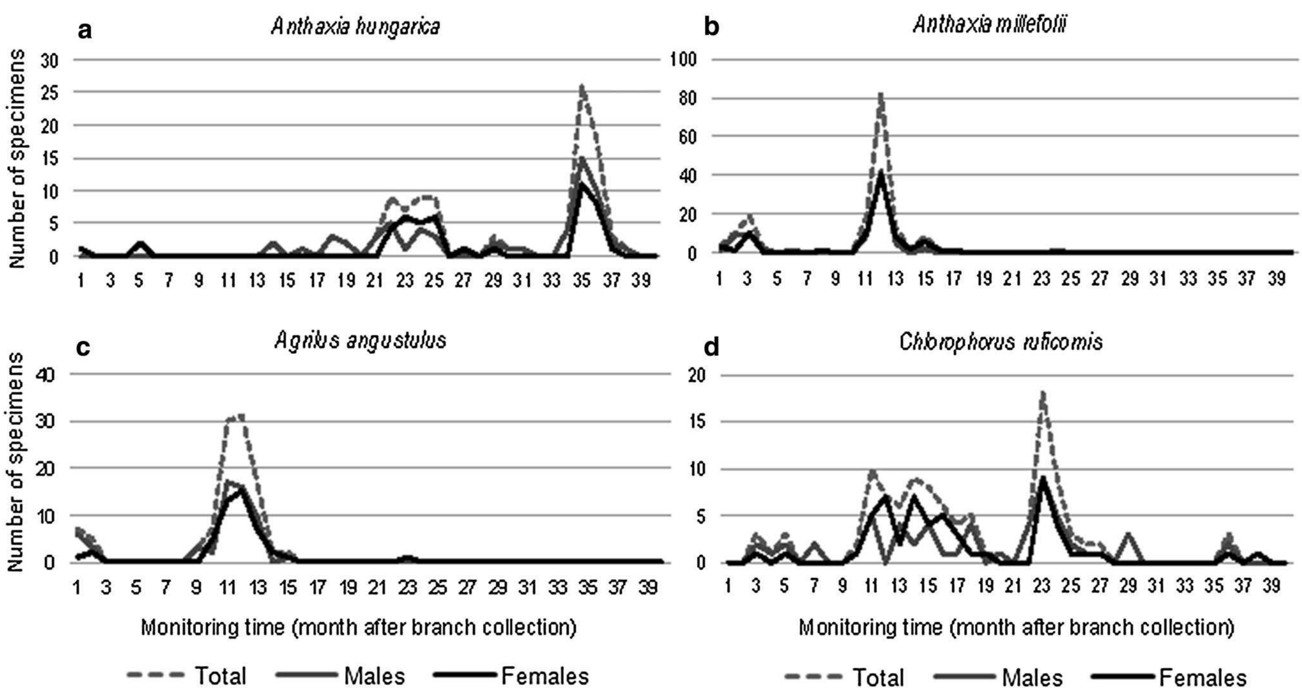

Fig. 2 Number of specimens (total adults, males and females) emerging along the total monitoring time, **a** *Anthaxia hungarica*; **b** *A. millefolii*; **c** *Agrilus angustulus*; **d** *Chlorophorus ruficornis*

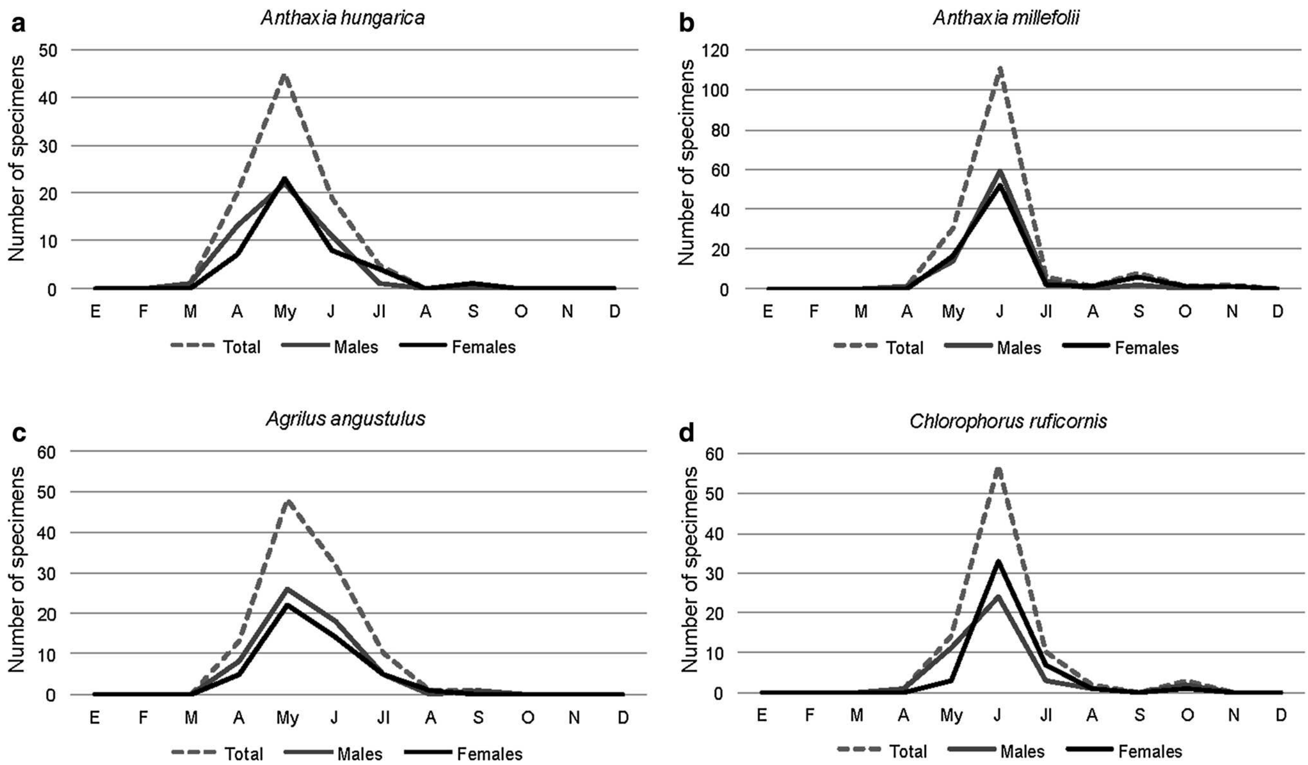

Fig. 3 Number of specimens (total adults, males and females) monthly emerging along the annual cycle. **a** *Anthaxia hungarica*; **b** *A. millefolii*; **c** *Agrilus angustulus*; **d** *Chlorophorus ruficornis*

Table 5 Average body size (mm) of each saproxylic species and their respective average duration of development time (in weeks)

Saproxylic beetles	Average size	Average developmental time
Anthaxia hungarica	7.5	30.75
Anthaxia millefolii	5.5	12.31
Agrilus angustulus	5.1	11.77
Chlorophorus ruficornis	7.5	19.64

was $r = 0.854$, indicating a clear dependence between these variables.

Discussion

The branches of *Quercus* spp. that have died, due to being colonised by *C. florentinus*, and remain in the canopy harbour a large number of saproxylic beetles, which use this deadwood as a habitat and food resource. Our results show a higher diversity of saproxylic beetles on *Quercus* branches in the studied area than in those of other Iberian *Quercus* forests: 19 species of saproxylic compared to 17 species recorded in the northern Iberian Peninsula (Recalde and San Martín 2003). Of the total of 19 species collected, 13 belonged to the families Buprestidae and Cerambycidae and only 4 species of these families accounted for 68% of the abundance; 3 of them belonged to the Buprestidae (*A. hungarica, A. millefolii* and *A. angustulus*) and the fourth species was of the Cerambycidae (*C. ruficornis*). A very similar result was obtained by Recalde and San Martin (2003) when monitoring branches of *Q. faginea* and *Q. rotundifolia*: of a total of 17 species, 11 belonged to these 2 families of beetles, also revealing *A. angustulus* as one member of the most abundant species.

In spite of the proven importance of understanding the basic biological and ecological requirements of saproxylic fauna in order to carry out effective strategies for conservation (Rotheray and MacGowan 2000; Rotheray et al. 2001; Davies et al. 2008), the available information on the life histories of this group is limited (Ricarte et al. 2009).

Concerning host tree preference, as was expected in strictly xylophagous beetles, the species studied did not show host specificity, being able to colonise the different species of *Quercus* growing in the study area. Considering all the fauna collected, it should be noted that only *A. hastulifer* and *X. antilope* seem to prefer *Q. suber* as their host tree. They were recorded on this tree in significant numbers, despite the fact that cork oak constitutes a minor proportion of the available branches in comparison to the holm oaks. However, the literature indicates that these two species may be polyphagous (Verdugo 2002; Calvo-Sánchez et al. 2004) with preponderance on several *Quercus* species (Pil and Stojanocic´ 2005; Luna 2009). Moreover, emergences of *A. hungarica, A. millefolii, A. angustulus* and *C. ruficornis* were observed from branches of holm oaks as well as from those of cork oaks, confirming the polyphagia attributed to xylophagous insects. In general terms, these species do not show host specificity because they are the first to colonise and to profit from the early stages of wood decomposition. It is known that the degree of host specificity in a saproxylic assemblage decreases with increasing wood decay (Jonsell et al. 1998; Grove 2002; Wu et al. 2008).

Notwithstanding the absence of strict specificity, some preference has been shown in our study: females of *A. hungarica* preferentially laid eggs on branches of *Q. ilex*. The literature mentions that their larvae develop on different *Quercus* species, while Verdugo (2002, 2005) and Sakalian (1993) categorised this buprestid as a narrow oligophagous species. Pérez-Moreno and Moreno (2009) assigned a broader trophic range and indicated that the species is not exclusive to *Quercus* spp., also colonising some conifers.

The larvae of *A. millefolii* are also considered polyphagous, as they feed on different *Quercus* species and other plants such as *Amigdalus, Nerium, Pistacia, Acer, Sorbus* and *Ulmus* (Verdugo 2002; Ricarte et al. 2009). In our case, the Chi square test revealed no significant differences in emergences from holm or cork oaks. Recalde and San Martín (2003) recorded emergences of *A. millefolii* from branches of *Q. rotundifolia* and *Q. faginea*. Consequently, this species could be considered as a broader polyphagous species.

In the case of *A. angustulus*, throughout our experiment, the number of emergences from branches of cork oaks was significantly greater than those from holm oaks. Recalde and San Martín (2003) recorded adults of this species emerging from branches of *Q. rotundifolia* and *Q. faginea*, although emergences were more numerous in the latter species. Other studies indicate that the larvae of this species also feed on wood of *C. sativa, Betula alba* (Ehrh.), *Fagus, Corylus, Vitis* and *Rubus* (Verdugo 2002, 2005; Nittérus et al. 2004), therefore, *A. angustulus* seems to be polyphagous in its larval stage.

The longhorn beetle, *C. ruficornis*, seems to be the most stenophagic of all species examined, showing a significant preference for holm oak wood. This is partly consistent with studies by López-Pérez (2009) and Sama (2002), who consider *C. ruficornis* to be monophagous on *Q. ilex*. Nevertheless, De Diego and Martínez-Porres (2005) obtained emergences of this cerambycid from branches of *Q. pyrenaica*. Accordingly, the species must be considered as narrow oligophagous instead of monophagous. This interpretation is more appropriate for xylophagous insects like *C. ruficornis*, as mentioned earlier.

In addition to the food preferences of saproxylic species for some of the oaks, factors such as competition and predator avoidance may explain preferences for a particular plant resource (Grimbacher and Stork 2007). Microclimatic conditions related to the vertical stratification of the canopy (such as solar radiation, temperature and wind speed gradients) could also determine the presence of saproxylic species (Bouget et al. 2011). Although in Mediterranean forests the canopy is relatively open because they are often grazed, some microclimatic differences that may also affect the presence of saproxylic organisms could occur due to differences in the tree size of the predominant species (cork and holm oaks), rather than to a vertical gradient in the canopy structure.

Prior to this study, information on the duration of preadult stages in the species examined here was scarce or absent. Only in the cases of *A. millefolii* and *A. angustulus* has it been mentioned that their larvae take approximately 1 year to complete development (Verdugo 2005). This is in agreement with our results, whereby the maximum frequency of emergences occurred after 12 months of monitoring the branches. The remaining species, *A. hungarica* and *C. ruficornis*, display a longer larval period, lasting 3 years for the longhorn beetle and 4 years in the case of the jewel beetle. No information is available to compare with these results. Nonetheless, in general terms, it is established that the immature life stage of xylophages is long and is highly influenced by environmental conditions (such as humidity) and the nutritional content of the wood (Dajoz 2001). In addition, another factor involved in the duration of the larval period is adult size (Hack and Slansky 1985; Walczyńska et al. 2010). Our results supported this assertion that smaller species, such as *A. angustulus* and *A. millefolii*, have a shorter larval lifetime than larger species, such as *A. hungarica*.

With respect to adult phenology, all of the studied species show a broad hatching period, extending from mid-spring to early summer in *A. hungarica* and *A. angustulus*, and being restricted to May–July in *A. millefolii* and *C. ruficornis*. Similar emergence patterns have been pointed out by other authors (Vives 2000, 2001), but with a slight delay attributable to variation in environmental characteristics, such as temperature and humidity, which can be linked to geographical differences (Verdugo 2005).

The balanced sex ratio obtained in all of the species studied was similar to those observed in other xylophagous jewel beetles (Bonsignore et al. 2008) and longhorn beetles (Venette 2008). The male- or female-biased sex ratios revealed in some studies (Domínguez et al. 2013) are related to differing responses between the sexes in the face of external stimuli (such as pheromones and colour) used for sampling by traps (Curletti 2010; Grant et al. 2010). The synchronisation of emergence in males and females is related to the shortness of their life as adults and raises the question of how such synchrony enhances the reproductive success of both sexes (Vives 2000; Gwynne 2003).

Finally, considering the great species richness linked to dry branches by the feeding activity of *C. florentinus*, our results support the importance of the maintenance and long-term preservation of these branches in the natural environment for the conservation of saproxylic biodiversity in the Iberian “dehesa”.

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