Anales de Biología 43: 123-137, 2021
http://dx.doi.org/10.6018/analesbio.43.13
ISSN/eISSN 1138-3399/1989-2128

ARTICLE

Temporal dynamic and key species of the sarcosaprophagous entomofauna in a Mediterranean natural environment

María Pérez-Marcos[1,2], Mª Dolores García[2,3], Elena López-Gallego[1,2] & Mª Isabel Arnaldos[2,3]

1 Biological Control & Ecosystem Services. Instituto Murciano de Investigación y Desarrollo Agrario y Alimentario (IMIDA). C/ Mayor s/n. E-30150 La Alberca (Murcia), Spain.

2 Department of Zoology, Faculty of Biology, Regional Campus of International Excellence “Mare Nostrum”, University of Murcia, Murcia, Spain.

3 External Service of Forensic Sciences and Techniques, University of Murcia, Murcia, Spain.

Correspondence
M. Pérez-Marcos
E-mail: maria.perez28@carm.es

Received: 21 January 2021
Accepted: 18 May 2021

Resumen

Dinámica temporal y especies clave de la entomofauna sarcosaprófaga en un medio natural mediterráneo

Los insectos pueden detectar la presencia de un cadáver a gran distancia, colonizándolo rápidamente y siendo los primeros en explotar este recurso. La composición y dinámica de la comunidad, junto con su presencia en un lugar específico, son clave para su posterior aplicación forense. Por este motivo, se estudió la fauna entomosarcosaprófaga asociada a un cadáver en una zona montañosa de la provincia de Murcia (SE, España). Las especies *Chrysomya albiceps*, *Calliphora vicina* y *C. vomitoria* fueron las especies más valiosas como indicadores estacionales. Estas especies, junto con *Dermestes frischii*, *Camponotus sylvaticus* y la superfamilia Chalcidoidea, definen un patrón claro de colonización que varía según la estación del año. Finalmente, la especies *Iberoformica subrufa* pueden tener valor potencial como indicador de hábitat del área estudiada.

Palabras clave: Descomposición; Entomología forense; Sucesión entomológica; Insectos indicadores; Especies clave.

Abstract

Insects can detect the presence of a cadaver at a great distance, colonizing it rapidly and being the first to exploit this resource. Its composition and dynamics, together with its presence in a specific location, are key to its subsequent forensic application. For this reason, it was studied the entomosarcosaprophagous fauna associated with a carcass in a wild mountainous area of the province of Murcia (SE, Spain). The species *Chrysomya albiceps*, *Calliphora vicina* and *C. vomitoria* were the most valuables species as seasonal indicators. These species, together with *Dermestes frischii*, *Camponotus sylvaticus* and those of the Chalcidoidea superfamily, define a clear pattern of colonization that varies according to the season of the year. Finally, the species *Iberoformica subrufa* may be of potential use as habitat indicator of the studied area.

Key words: Decomposition; Forensic entomology; Insect succession; Insect indicators; Key species

Introduction

A corpse is an important energy resource and, at the same time, an ecosystem characterized by its short period of existence. Insects have the ability to detect the presence of a corpse at a great distance, colonizing it rapidly, and being the first to exploit this resource (Charabidze & Gosselin 2014). For forensic purposes, the most important fact is that insects are attracted to the carcass in a predictable successional sequence during the process of decomposition (Richards & Goff 1997, Matuszewski *et al.* 2011). The distribution and abundance of insects depend on the geographic location, time of year, environmental characteristics and the habitat in which the corpse is located, and the faunal succession in a cadaver follows a certain order depending on these conditions (Anton *et al.* 2011, Brundage *et al.* 2011, Moretti *et al.* 2011, Bembow *et al.* 2013). Arthropod activity and their community composition commonly shift through the different stages of decomposition either because of alteration of the resource, changes in the environmental conditions or through competitive and/or predatory interactions with other invertebrates or invasive species, which also influences the pattern of succession (Hofer *et al.* 2017, Carmo *et al.* 2018). Consequently, the colonization pattern will also be influenced by the trophic relationships observed in the sarcosaprophagous community with respect to the phases of decomposition of the corpse.

A wide variety of arthropod species that play an active role in the decomposition processes are attracted by a cadaver. The orders Diptera and Coleoptera are the most important since they include the first species capable of detecting and finding a corpse, even from great distances, showing a seasonal presence, together with some species endemic to certain areas (Campobasso *et al.* 2001, Byrd & Castner 2010). In the Iberian Peninsula few studies have considered entomosarcosaprophagous fauna as a whole, the majority contributing with data on certain groups (see table S1 in Appendix). Therefore, the complete study of the wide variety of entomological species related to corpses and their sequence is of great interest and a useful tool in forensic studies. For this reason, a study all along the four seasons of the year in a wild mountainous area of the province of Murcia, south-eastern Spain, was carried out to provide information on the entomosarcosaprophagous fauna composition though the different decomposition stages and its temporal evolution in such environmental conditions.

Materials and methods

Study area and experimental design

The study was conducted in Sierra Espuña Regional Park, a protected area (Site of Community Importance ES0000173) in the centre of the province of Murcia (Murcia Region) (37º49’50”N 1º29’56”W). The area is located at about 400 masl, facing South, and characterized by an understory dominated by *Rosmarinus* sp. and *Thymus* sp., and an arboreal stratum of *Pinus* sp. (Pérez-Marcos *et al.* 2016).

Samplings were conducted between 15th September 2006 and 31st July 2007. Sampling duration for the autumn season was 60 days, (September 15th–November 13rd, 2006), for winter and spring 59 days (January 8th–March 7th, 2007 and April 2dn–May 30th, 2007, respectively), and for summer 47 days (June 15th–July 31st, 2007). In our study, domestic piglets (*Sus scrofa* L.) of about 5 kg were used as baits models (Battán Horenstein *et al.* 2010, 2012, Prado e Castro *et al.* 2012, 2013, Bembow *et al.* 2013, Mañas-Jordá *et al.* 2018). The pigs were provided by the Veterinary Faculty Farm of the University of Murcia where they were sacrificed by premedication, in accordance with the current Spanish legislation on the protection and sacrifice of animals used for experimentation and other scientific purposes (Real Decreto 1201/2005). One piglet per season was used, and in each season, the trap was set in place a week before starting the assay in order for the substrate conditions to stabilize. Samples were collected with a 60x70x70 cm modified Schoenly trap (Schoenly *et al.* 1991, Prado e Castro *et al.* 2009). This method has been confirmed as the effective device for characterizing the sarcosaprophagous succession in several geographical areas (Arnaldos *et al.* 2001, 2004, Ordóñez *et al.* 2008, Battán Horenstein *et al.* 2010, Battan Horenstein & Salvo 2012, Prado e Castro *et al.* 2012, 2013, 2014, Lyu *et al.* 2016, Mañas-Jordá *et al.* 2018). The receptacles in which arthropods were captured contained Morrill liquid as preservative (Morrill 1975, Schoenly 1981). In each season, samples were taken daily for the first 16 days, and then every 2 days. Temperature and relative humidity inside the trap were continuously recorded with a HOBO® U10-Temp /RH Data Logger, and at the bait-soil interface they were registered every sampling day with a portable hygrometer Delta OHM DO 9406 attached to a probe Delta OHM HD 8501SAT/500.

Following the classification of Anderson and VanLaerhoven (1996), five decomposition stages were considered: fresh (between the moment of death and the moment when bloating is first evident); bloated (between gases started to accumulate in the carcasses resulting in a definite bloated appearance and when the body deflates due to insects piercing the carcass); decomposition (marked by the complete deflation of the carcass due to the action of larvae breaking the skin); late decomposition (much of the flesh has been removed and maggots left the remains as prepupal insects); and dry remains (very little of the carcasses remained except bones, cartilage and some skin). This methodology was also used in Pérez-Marcos *et al.* (2016) for a preliminary study regarding the spring entomofauna of the same area. Labelled samples were taken to the laboratory, where the Morrill liquid was changed to ethanol (70%). Specimens were counted and identified to the maximum level under a stereomicroscope following Chinery (1998) for order level. McAlpine (1981) and Carles-Tolrá (2004) were followed to identify Diptera families. Diptera species were also confirmed with the keys provided by Gregor *et al.* (2002) for Muscidae family and González Mora & Peris (1988), González Mora (1989) and Peris & González Mora (1991) for Calliphoridae. Coleoptera families and species were identified following Plata (1971), Outerelo & Gamarra (1986), Zahradník (1990), Yélamos (2002) and Bajerlein *et al.* (2012). Hymenoptera families and species were identified according to Martínez *et al.* (1985) and Gómez & Espadaler (2006).

Analysis of data

The structure of the entomosarcosaprophagous community was analyzed on depending on the different decomposition stages and on the different seasons. Differences in faunal composition, considering all the species that visited the baits though the five decomposition stages and the four seasons, were tested by PERMANOVA, using the function "adonis" by Bray Curtis dissimilarity and a random subset of 999 permutations, with the available function in the "vegan" package (Oksanen *et al.* 2019). Second generation of Diptera emerged on the corpse were avoid in the analysis. A pairwise multilevel comparison was then carried out between the different decomposition stages and between the different seasons, with the function “pairwaise.adonis” using Bray Curtis dissimilarity. In addition, a principal component analysis (PCA) was carried out using the function "prcomp" ("stats" package), to determine how samples from the different decomposition stages and from the different seasons were grouped as a function of the abundance of the different species (R-Development-Core-Team 2017). Species abundance was previously standardised by the log (x+1) to correct deviations from normality. Finally, a Similarity Percentages analysis (SIMPER) run for “permutations=999” was used to find the discriminating species between pairs of decomposition stages and seasons, using the function “simper” of the “vegan” package (R-Development-Core-Team 2017).

Results

Environmental conditions throughout the four seasons studied

Temperature in the trap oscillated between an absolute minimum of 6.47 ºC and an absolute maximum of 35.54 ºC in autumn, 0.45 and 34.16 ºC in winter, 5.24 and 39.62 ºC in spring, and 16.90 and 45.08 ºC in summer, what illustrates the high temperatures and the great climatic variability of the area. The average daily temperatures in the trap for all the study period ranged between 4.67 and 31.63 ºC in winter and summer, respectively (Fig. 1). In the bait-soil interface the temperatures had less oscillations and ranged between 7.00 and 36.30 ºC also in winter and summer. The relative humidity in the trap, measured as daily average, varied between 30.29% in spring and 100% in autumn and winter (Fig. 1), while in the bait-soil interface its minimum reached 26.00% in summer and the maximum was measured in autumn and winter with a value of 100%.

Decomposition stages duration throughout the different seasons

The different stages had quite different duration depending on the season (Fig. 2). In general, and as expected, in autumn and summer they occurred

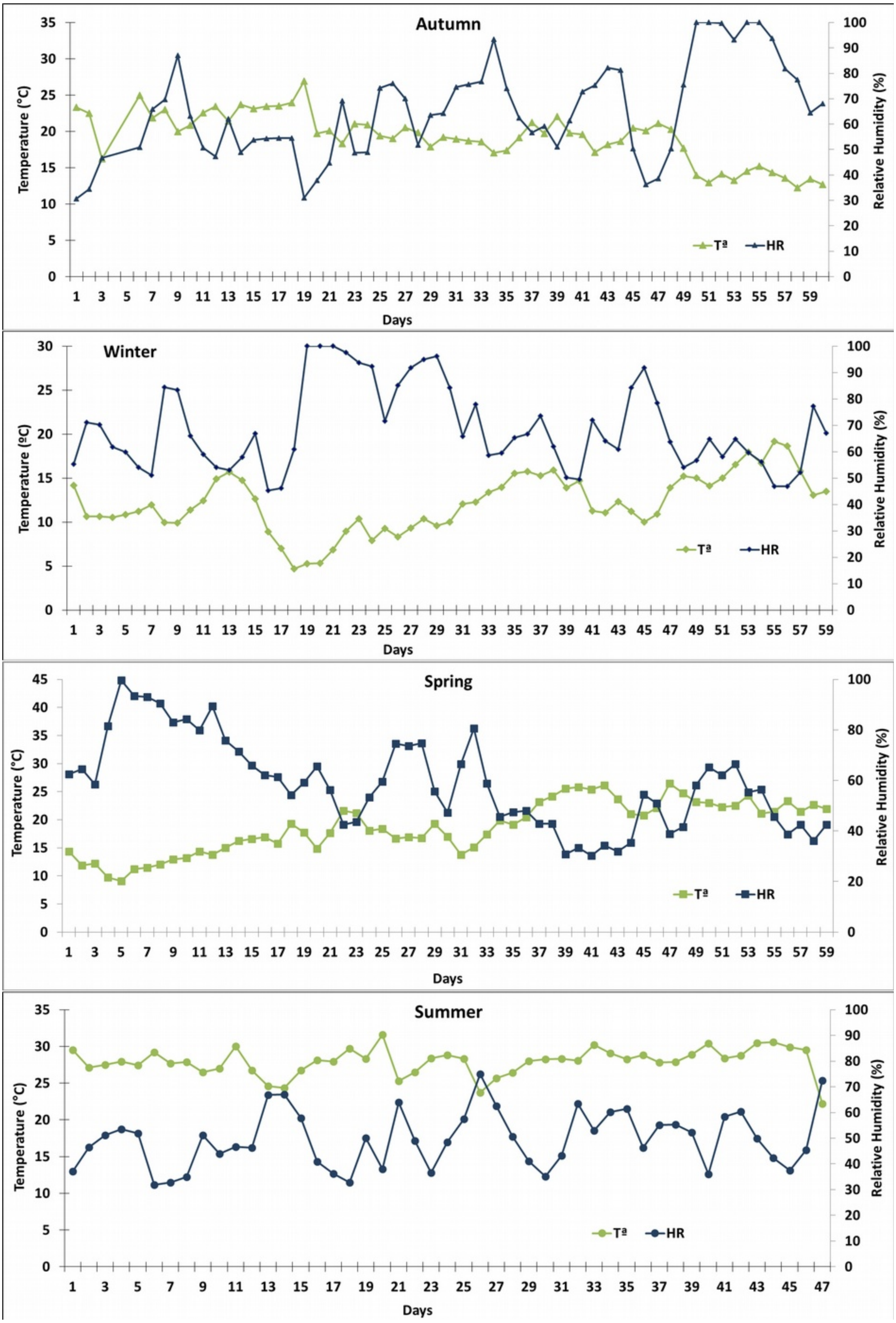

Figura 1. Variables ambientales, temperatura media (Tª) y humedad relativa media (HR) durante las cuatro estaciones de muestreo.

Figure 1. Environmental variables, mean temperature (Tª) and mean relative humidity (HR) during the four sampling seasons.

more rapidly than in the colder seasons, reaching the dry remains stage very early.

The fresh stage started at the time of death and corresponded to the first 2 or 3 days, with the exception of spring when it lasted 8 days. The bloated stage lasted 3 days in autumn, spring and summer and 6 days in winter, being not very apparent in winter and spring. The decay phase was very evident, lasting only 2 days in autumn and summer, 3 days in spring and 24 days in winter. The late decomposition stage lasted 2 days in autumn and summer, 9 in spring and 18 in winter. Finally, during the dry remains stage, only skin and bones remained. In autumn and summer, this occurred very early (from day 11 and 10, respectively) onwards, while in spring and winter it begun on days 24 and 52, respectively (Fig.2).

Composition and dynamic of the entomosarcosaprophagous community

A total of 52,567 individual arthropods, belonging to the orders of greatest forensic relevance, were collected and identified (42,789 in the adult stage and 9,778 in the pre-imaginal stage). Within them, 28 families and 52 species were recognized. The order with the highest number of specimens collected was Diptera, with 90.59% of the total adults and 79.64% of the preimaginals, followed by Coleoptera (3.28% of the adults and 20.36% of the preimaginals) and, finally, by Hymenoptera that constituted a 6.13% of the total adults (Table S2, Appendix). The dynamic of the most representative families of the three orders is described in the end of the Appendix.

Adults of the order Diptera were dominant in abundance in all seasons studied, while their larvae were the most abundant preimaginals in spring, winter and autumn. Among families of this order, Calliphoridae accounted for 65.19% of the total sarcosaprophagous adults recollected. Next, but with a much lower abundance, was Muscidae, representing 16.07%, and the Sphaeroceridae family with 5.88%, meanwhile other minority Diptera families represented less than 2.38% of the total (Table S2, Appendix).

Adults of the Coleoptera constituted the second order in abundance in winter and spring, and their larvae were the most abundant preimaginal in summer. Within this order, the most abundant family was Dermestidae (1.37% of the total adults registered in the study), followed by family Histeridae (1.11%). The remaining families showed less than 0.5% of the total abundance (Table S2, Appendix).

Finally, the order Hymenoptera was recorded more abundantly in autumn and with very low abundances in winter (just 4 individuals). The most abundant taxon within this order was the superfamily Chalcidoidea (3.89%), followed by the family Formicidae (1.88%), and with much lower abundances the families Vespidae and Apidae (less than the 0.27% of the whole adult sarcosaprophagous community) (Table S2, Appendix).

Correspondence of the stages of decomposition and seasons with the entomosarcosaprophagous community studied

On one hand, the PERMANOVA showed a significant effect of decomposition stage on the abundance of the different species (F=12.4, df=4, 125, $P<0.001$). Moreover, the pairwise test showed significant differences between Decomposition and Late Decomposition; Late Decomposition and Dry remains ($P<0.05$); but not between Fresh and Bloated and Bloated and Decomposition stages ($P=0.36$ and $P=0.49$, respectively). On the other hand, when the seasons were considered, the PERMANOVA also showed a significant effect on the abundance of the different species (F=9.71, df=3, 126, $P<0.001$). Moreover, the pairwise test showed significant differences between all the seasons ($P<0.05$) except between Winter-Spring and Autumn-Summer ($P=1.0$).

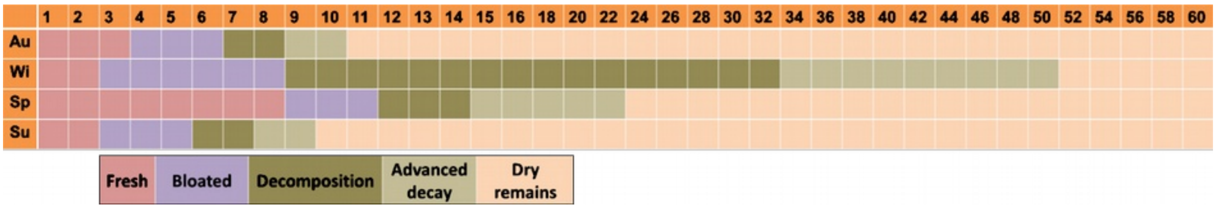

Figura 2. Duración de los diferentes estadios de la descomposición para cada estación muestreada. Au: otoño, Wi: invierno, Sp: primavera, Su: verano.

Figure 2. Duration of the different decomposition stages for each season. Au: autumn, Wi: winter, Sp: spring, Su: summer.

Considering the decomposition stages, although differences between the first stages were no significant, the SIMPER analysis showed which species contributed significantly between them (Table S3, Appendix). For instance, *Chrysomya albiceps* (Wiedemann, 1819), *Calliphora vicina* Robineau-Desvoid, 1830, *Lucilia sericata* (Meigen, 1826) and Phoridae family characterized the bloated stage (Table S2, Appendix). Moreover, *C. albiceps*, *C. vicina*, *Calliphora vomitoria* (Linnaeus, 1758) and *Musca domestica* Linnaeus, 1758 characterized the decomposition stage when compared to the bloated stage. Furthermore, *Calliphora* larvae, *C. albiceps*, Pollenninae, *Saprinus detersus* (Illiger, 1807), Muscidae, *Thanatophilus ruficornis* (Küster, 1851) and Fanniidae were the groups which contributed significantly in the differences between decomposition and late decomposition stages, being all of them more abundant in the late decomposition. Finally, *Calliphora* and *Chrysomya* larvae, Pollenninae, *S. detersus*, *T. ruficornis* and Fanniidae contributed significantly to the differences between late decomposition and dry remains, characterizing the late decomposition.

In agreement with these results, PCA showed how species are distributed according to the stages of decomposition and seasons (Figs. 3, 4). The PC1 axis explained 20.0% of the variance and was mainly correlated to Pheidole and Dermestidae larvae on the positive side and with Phoridae, Muscidae, Fannidae or *L. sericata* on the negative side. The PC2 axis explained 15.6% and was positively correlate mainly with *C. vicina* and *C. vomitoria* and was negatively correlated to Chalcidoidea and *Camponotus sylvaticus* (Olivier, 1792)

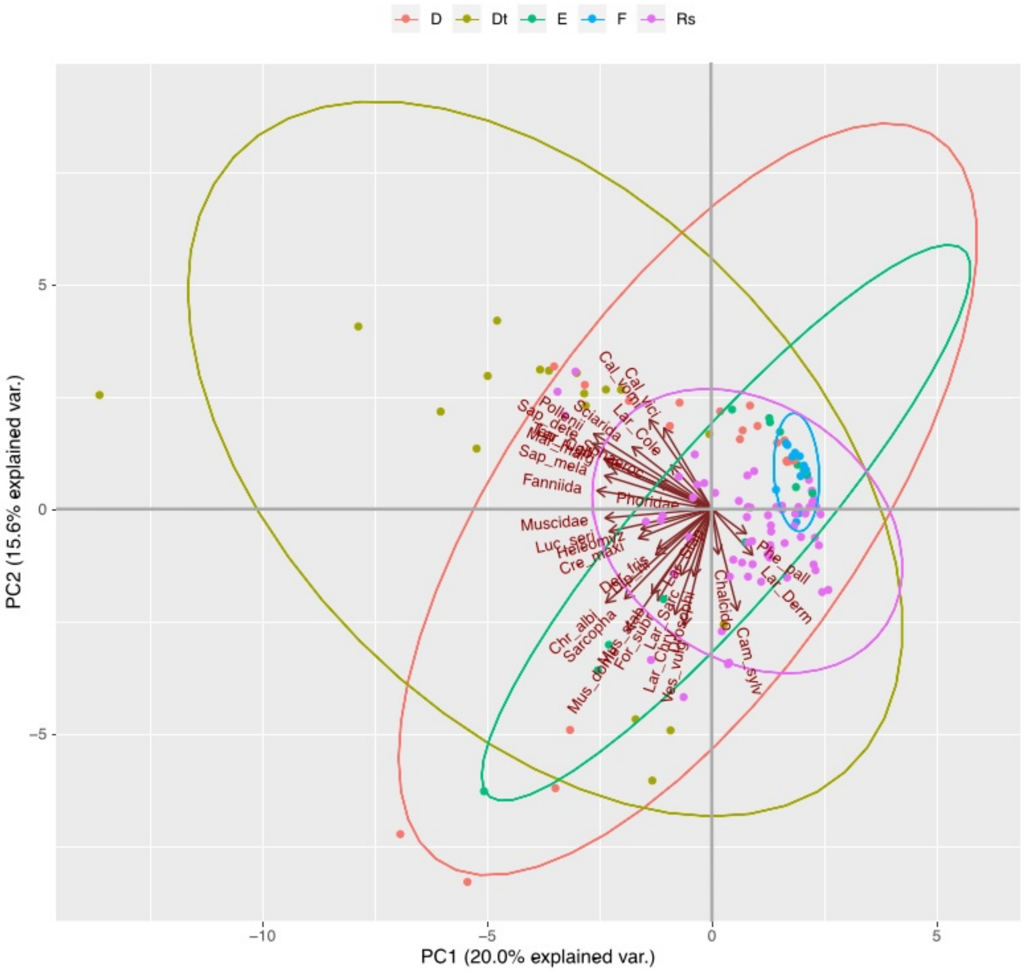

Figura 3. Representación de los dos primeros ejes del PCA realizado sobre la abundancia total de cada especie muestreada en cada cadáver identificando la etapa de descomposición a la que corresponden. (F= fresco, E= enfisematoso, D= descomposición, Dt= descomposición tardía, Rs= restos secos).

Figure 3. Biplot representations of the first two axes of the PCA performed on the total abundance of each specie sampled on each corpse identifying the decomposition stage to which they correspond. (F= fresh, E= bloated, D= decomposition, Dt= late decomposition, Rs= dry remains).

Figura 4. Representación de los dos primeros ejes del PCA realizado sobre la abundancia total de cada especie muestreada en cada cadáver identificando la estación a la que corresponden.

Figure 4. Biplot representations of the first two axes of the PCA performed on the total abundance of each specie sampled on each corpse identifying the season to which they correspond.

(Figs. 3, 4). In the first case, a low segregation between the samples of the first decomposition stages was observed, meanwhile there was a higher segregation of the decomposition in relation to the late decomposition stage and late decomposition and dry remains stages (Fig. 3).

On the other hand, when considering the seasons, there is a low segregation between the samples of winter and spring and autumn and summer, meanwhile there was a higher segregation between the colder and the warmer seasons (Fig. 4). However, although the differences between the cold seasons were not significant, the SIMPER (Table S4, Appendix) showed how there were some species that marked differences between them, but mainly because spring was related with higher abundances than winter. The same occur between autumn and summer, not having significant differences between them but being summer related with higher abundances than autumn. However, the differences between both kind of seasons, warm and cold, could be explained because the presence of some species. For instance, the colder seasons were related with *C. vicina*, *C. vomitoria* or Histeridae and the warmest seasons were related with *C. albiceps*, *M. domestica*, Chalcidoidea and the presence of Formicidae as also confirms the PCA analysis.

Overall characterization of the community and indicator species of the decomposition stages

In a global analysis of the community, the data point to *C. vicina* as being an indicator of the earlier stages in the coldest seasons, winter and spring. Despite of it, this species was not collected during the fresh stage in winter, when the family Phoridae was the most abundant group (Table 1). *C. albiceps* and *M. domestica* characterised the bloated stage in the warmer seasons (autumn and summer). In turn, *C. albiceps* and Muscidae characterised the phase of decomposition for the colder periods (winter and spring) acting as secondary flies (Table 1). The late decomposition stage was fundamentally different mainly because of the migration of Diptera larvae. It should be noted that the larvae of *C. albiceps* pupate under the corpse, while those of *Calliphora* spp. move

	Decomposition stages				
Season	**Fresh**	**Bloated**	**Decomposition**	**Late decomposition**	**Dry remains**
Autumn		*Chrysomya albiceps* *Musca domestica*	*Creophilus maxillosus*	Diptera larvae	*Dermestes frischii* Chalcidoidea Dermestidae larvae
Winter	Phoridae	*Calliphora vicina*	*Chrysomya albiceps* Muscidae	Diptera larvae *Saprinus detersus*	*Dermestes frischii* Coleoptera larvae
Spring	*Calliphora vicina* *Calliphora vomitoria*		*Chrysomya albiceps* Muscidae	Diptera larvae *Saprinus detersus*	*Dermestes frischii* Dermestidae larvae
Summer		*Chrysomya albiceps* *Musca domestica* Sarcophagidae		Diptera larvae	*Dermestes frischii* Chalcidoidea Dermestidae larvae

Tabla 1. Principales taxones indicativos de las diferentes estados de descomposición.
Table 1. Main taxa indicative of the different stages of decomposition

away from it, being reflected in the different number of larvae registered in the trap. This phase was also characterized by the presence of *S. detersus* (Table 1). Finally, the dry remains stage was mainly defined by the presence of *Dermestes frischii* Kugelann, 1792 and coleopteran larvae in all four seasons, and the superfamily Chalcidoidea in autumn and summer (Table 1).

Discussion

Temperature and humidity are one of the main environmental variables determining the duration of the decomposition stages, since they both have an essential influence on the decomposition processes (Ioan *et al.* 2017) and the presence and biology of arthropod species (Campobasso *et al.* 2001). These environmental variables are conditioned by the climate, which in our study area is semiarid, with high temperatures and an important daily variability, and with scarce rainfall. Throughout the decomposition process of the cadaver studied in the different seasons, the fresh stage was very similar in all seasons except spring, which is attributable to the very low temperatures during the first days of this season. The bloated stage was the most difficult to define since during winter and spring the carcass was not clearly swollen, possibly also due to the low temperatures, being the gases produced by the metabolic processes gradually expelled. The other stages were different regarding the moment they started and how long they lasted. In this respect, autumn and summer were the most similar seasons, with similar temperatures, and winter was when decomposition and late decomposition stages started later and lasted longer; in fact, in this season the dry remains stage really started at the end of the sampling period. The general trend in which low temperatures were related with longer decomposition stages coincides with other studies performed in the same geographical region at a periurban location (Arnaldos-Sanabria 2000) or at a higher altitude (Begoña-Gaminde 2015).

Likewise, the colonization pattern and the insect abundance depend on the time of year, geographic location, environmental characteristics and the habitat in which a corpse is located (Anton *et al.* 2011, Brundage *et al.* 2011, Moretti *et al.* 2011, Bembow *et al.* 2013). And, for forensic purposes, the knowledge of the composition and the dynamic of the entomosarcosaprophagous community found in a corpse are one of the most important data since insects play an active role in the decomposition process (Richards & Goff 1997, Byrd & Castner 2010, Amendt *et al.* 2011, Tomberlin *et al.* 2011). Although the community found in the corpse was very extensive, we are only going to focus on those species or families that have an outstanding value.

Regarding our work and as other works suggested, Calliphoridae was the most abundant family (e.g. Anderson & VanLaerhoven 1996, Arnaldos *et al.* 2001). Within the family, *Chrysomya albiceps* was the most abundant and its dynamics coincided with those mentioned by other authors for the Iberian Peninsula (Arnaldos-Sanabria 2000, Martínez-Sanchez *et al.* 2000, Baz *et al.* 2007, Prado e Castro *et al.* 2012, Martin-Vega & Baz 2013), being the most abundant species during the warmest sampling months, confirming a high temperature preference of this species. On the contrary, *Calliphora* species were related to the coldest seasons according to their thermophobic character (Martínez-Sanchez *et al.* 2000, Arnaldos *et al.* 2001, Greco *et al.* 2014, Díaz-Aranda *et al.* 2018). On the one hand, *C. vicina* was the first species in arriving to the cadaver and was predominant in winter and spring. On the other hand, *C. vomitoria* had a seasonal distribution similar to *C. vicina* but always appears delayed than the other species, which coincide with other studies in the Iberian Peninsula (Arnaldos *et al.* 2001, Prado e Castro *et al.* 2012, Martin-Vega & Baz 2013, Begoña-Gaminde 2015, Díaz-Aranda *et al.* 2018). Furthermore, its great abundance registered in our study may be explained because *C. vomitoria* is known to prefer rural environments at the same time as the mentioned low temperatures (Smith 1986). The preimaginal stages of the dipterans are considered to form part of the necrophagous group as they feed directly from the carcass, being one of the main causes of the loss of tissue (Prado e Castro *et al.* 2012) and they are a very important element in the decomposition process. However, it should be considered that second and third stage of *C. albiceps* larvae may, depending on the nutrient substrate, be predators of other larvae, so that they can be at the same time considered a necrophagous and necrophilic component of the sarcosaprophagous community (Smith 1986, Battan Horenstein 2008).

Within Muscidae family, *M. domestica*, which was the most representative species, was present in all seasons except winter and, regarding the decomposition stages, this species acted as secondary fly. These findings agree with the results of previous works (Arnaldos-Sanabria 2000, Arnaldos *et al.* 2001, Battán-Horenstein *et al.* 2010, Prado e Castro *et al.* 2012).

Moreover, it should be emphasized that the family Phoridae was the second in abundance during the winter. It appeared from the fresh stage which coincided with the results of Anton *et al.* (2011) who pointed to the Phoridae as an indicator of this season. From the forensically point of view, this is especially interesting since winter is the season that presents, in general, the lowest abundances and diversity of insects.

Finally, as regards Sarcophagidae presence in the different decomposition stages, our results are consistent with what is known about the family. They do not appear in the fresh stage (Smith 1986), probably as a result of their larviparous vital strategy, which enable them to lay live larvae in cadavers with a certain degree of success when the decomposition process is already underway and other flies are present (Prado e Castro *et al.* 2012).

In what refers to the Coleoptera order, the most abundant family during the whole sampling period was Dermestidae, which agrees with Sánchez-Piñero (1997) and Arnaldos-Sanabria (2000). This family is usually associated with the last decomposition stages (Early & Goff 1986) since their larvae feed on the dried tissue and skin of many animals (Bonacci *et al.* 2017). In our work, it was present in autumn and summer mainly from the decomposition stage onward, and in winter and spring from late decomposition onwards, and in all cases, it was more abundant in the late decomposition and dry remains stages. However, many studies mention adults of this group in the earliest decomposition stages (Arnaldos-Sanabria 2000, Castillo-Miralbes 2001, Arnaldos *et al.* 2004, López Dos Santos 2008, Pérez-Bote *et al.* 2012, Prado e Castro *et al.* 2013, Begoña-Gaminde 2015) throwing doubt on the generalization implied in the initial premise. In this regard, it should be borne in mind that the adults, especially those of genus *Dermestes* are occasional predators and cannibalistic and will eat young larvae and puparia (Byrd & Castner 2010), which would explain their presence in the mentioned earlier decomposition stages. Furthermore, the larvae of Dermestidae are mainly necrophagous, since they feed directly from the corpse, and are associated with the latter stages of decomposition (Arnaldos-Sanabria 2000, Castillo-Miralbes 2001, Martin-Vega & Baz 2013, Begoña-Gaminde 2015). Our results coincide and confirm this previous affirmation. The seasonality of the larvae coincided also with other works done in the same region (Arnaldos-Sanabria 2000, Begoña-Gaminde 2015).

The distribution of Histeridae in all seasons, mainly in the colder ones, coincided with the results obtained by Prado e Castro *et al.* (2013), however, it does not coincide with those obtained in other studies on the southern of Spain (Sanchez-Piñero 1997, Arnaldos-Sanabria 2000, Begoña-Gaminde 2015) where Histeridae were collected more frequently during the summer, with lower or zero abundances in autumn and winter. On the other hand, this family was collected mainly between the decomposition and dry remains stages, coinciding with the Diptera larvae (Arnaldos-Sanabria 2000, Arnaldos *et al.* 2004, Aballay *et al.* 2012, Begoña-Gaminde 2015, Zanetti *et al.* 2015). However, in other areas, they were captured from the earliest stages of the decomposition (Castillo-Miralbes 2002, Prado e Castro *et al.* 2013), which could indicate that this group is not consistent in their seasonal nor decomposition stage appearance. *Saprinus detersus* was the most abundant species as well as occurred in Begoña-Gaminde (2015) and López-Gallego (2016) in different altitudes of the same area, however, in Central Spain, it was the second species in abundance (Martín-Vega *et al.* 2015), in Lisbon, although present, this species was not very abundant (Prado e Castro *et al.* 2013) and in a periurban area in Murcia it was not found (Arnaldos-Sanabria 2000). All the above could point to the possible interest of *S. detersus* as a wild habitat indicator species; so further studies on this species could be very interesting to accurately define this possible indicator role.

Finally, in the case of the Hymenoptera, the superfamily Chalcidoidea, has been considered as a necrophilic component of the community due to its parasitoid nature, being able to attack the larval and pupal stages of Diptera (Smith 1986, Frederickx *et al.* 2013). According to Meskin (1986), *Chrysomya albiceps* is one of the most parasitized species by this group, because *Chrysomya* pupates under the corpse, making it more vulnerable, which could explain the dynamics exhibited by the Chalcidoidea in our study. Nonetheless, it is advisable to consider this group at the species level to properly understand such results.

On the other hand, the importance of the family Formicidae within the entomosarcosaprophagous fauna appears reflected in several works (Early & Goff 1986, Martínez *et al.* 2002, Pérez-Marcos *et al.* 2020). They are considered omnivores and, when they are abundant, they can affect the population of necrophages, reaching to alter the natural process of decomposition. *Camponotus sylvaticus*, which was the most abundant Formicidae species in our work, was also observed in a periurban environment in Murcia (Martínez *et al.* 2002) and at the highest altitude of Sierra Espuña (Begoña-Gaminde 2015), but with very low abundance, whereas it was not collected in other places of the Iberian Peninsula (Castillo-Miralbes 2002, Prado e Castro *et al.* 2014, Neto-Silva *et al.* 2017). In addition, in our case, *Iberoormica subrufa* Roger, 1859 was of great interest since it has been not found in other areas, related or not to the cadaveric ecosystem (Castillo-Miralbes 2002, Martínez *et al.* 2002, Cantarineu-Guillen & Tinaut 2012, Prado e Castro *et al.* 2014, Begoña-Gaminde 2015, Neto-Silva *et al.* 2017, Pérez-Marcos *et al.* 2020). This fact gives it a potential value as a geographical and environmental indicator. The other Formicidae species were collected in very low numbers, which, in certain cases, strongly contrasts with other data from the same area. For instance, considering the work conducted in a periurban site in the same region (Martínez *et al.* 2002, Arnaldos *et al.* 2004), the most abundant species was *Pheidole pallidula* (Nylander, 1849) which was present in all seasons and in all decomposition stages while, in our case, it was present in very low numbers. Moreover, at the highest altitude of Sierra Espuña (Begoña-Gaminde 2015), this species was not collected and the most abundant was *Crematogaster auberti* Emery, 1869, which was not collected in our case. These data, as well as those referring to other areas of the Iberian Peninsula, underline the great variability existing in the composition of the Formicidae community related to carcasses, confirming the forensic importance of its species as potential geographical and seasonal indicator (Pérez-Marcos *et al.* 2020).

All these differences both between the decomposition stages and between the seasons as it was previously shown, were confirmed on the analysis results. For instance, the PCA and the SIMPER analysis showed which taxa differentiated them. In the first case, although no differences between first stages of decomposition were found, SIMPER analysis showed some species which contributed significantly. For instance, *C. albiceps*, *C. vicina*, *L. sericata* and Phoridae family characterized the bloated stage; *C. albiceps*, *C. vicina*, *C. vomitoria* and *M. domestica* characterized the decomposition stage when compared to the bloated stage; *Calliphora* larvae, *C. albiceps*, Pollenninae, *S. detersus*, Muscidae, *T. ruficornis* and Fanniidae were the groups which contributed significantly in the differences between decomposition and late decomposition stages, being all of them more abundant in the late decomposition; and *Calliphora* and *Chrysomya* larvae, Polleninae, *S. detersus*, *T. ruficornis* and Fanniidae contributed significantly to the differences between late decomposition and dry remains, characterizing the late decomposition. However, there were some cases where these differences may not be sufficient to make them significant, because each pair of stages had similar fauna or, in many cases, was composed of species that are not associated with any specific phase (Matuszewski 2017). Moreover, because similar species arrive first to the corpse in low abundances, there were found some similarities between the different seasons in the fresh stage. Therefore, as Martín-Vega & Baz (2013) stated, more studies to confirm the observed patterns are advisable.

When comparing the whole community considering the four seasons, cold and warm seasons were grouped separately. Even so, although the differences between the cold seasons are not significant, the SIMPER shows how there are some species that mark differences between them, but mainly because spring was related with higher abundances than winter. And the same occur between autumn and summer, not having significant differences between them but being summer related with higher abundances than autumn. The differences between warm and cold seasons could be explained due to the presence of some species. For instance, the colder season were related with *C. vicina*, *C. vomitoria* or Histeridae family because of their thermophobic character as other authors suggested (Martínez-Sanchez *et al.* 2000, Arnaldos *et al.* 2001, Greco *et al.* 2014, Díaz-Aranda *et al.* 2018) and the warmest seasons were related with *C. albiceps*, *M. domestica*, Chalcidoidea and the presence of Formicidae because of their high temperature preference (Meskin 1986, Smith 1986, Arnaldos-Sanabria 2000, Martínez-Sanchez *et al.* 2000, Baz *et al.* 2007, Prado e Castro *et al.* 2012, Frederickx *et al.* 2013, Martin-Vega & Baz 2013).

Conclusions

Our study confirms the numerical dominance of different groups or species in the decomposing remains, their diversity and their importance in forensic studies. Knowledge of the specific association of some species with certain habitats is of capital importance in applied forensic entomology because it could indicate the postmortem transportation of a corpse (Amendt *et al.* 2011). In our case, it has been observed that in a natural area in a semi-arid environment with low rainfall and high temperatures, *C. albiceps*, *C. vicina* and *C. vomitoria* are valuable as seasonal indicators. *Calliohora vicina* and *C. vomitoria* appeared predominantly in winter and spring, while *C. albiceps* appeared in autumn and summer. These results point to the value of these taxa as seasonal indicators. Moreover, the community species define a clear pattern of colonization that varies according to the season of the year. In the warmer seasons, the species *M. domestica* and *C. albiceps* mainly characterized the bloated stage. In the colder seasons, spring and winter, the dominant species in the early stages were *C. vicina* and *C. vomitoria*. The advanced stages, in turn, were characterized by *D. frischii* and coleopteran larvae in the four seasons, *C. sylvaticus* in all seasons except winter, and Chalcidoidea in autumn and summer. Finally, the species *Iberoformica subrufa* may be of potential use as habitat indicator of the studied area.

To conclude, the fact that in some cases differences in the species certainly exist, emphasises the need to study the sarcosaprophagous community in as many different conditions as possible to avoid applying unadjusted data in the evaluation of carrion decomposition and the sarcosaprophagous community related to a specific place (Sanchez Piñero 1997, Martin-Vega & Baz 2013, Prado e Castro *et al.* 2014). Furthermore, taxonomical studies, like this one, are necessary to know accurately the specific composition of the populations of several groups not always considered when studying the sarcosaprophagous community. This knowledge would allow explaining the dynamics of certain taxa and the role they play within such community, increasing their forensic importance as geographical, environmental or seasonal indicators.

Acknowledgments

We thank Drs. Concepción Marcos and Angel Pérez-Ruzafa for their valuable comments and help in analysing data. This research was funded by the Ministry of Education and Science of the Government of Spain, grant number CGL2005-04668/BOS project.

References

Aballay F, Dominguez M & Fernandez-Campón F. 2012. Adult Fanniidae associated to pig carcasses during the winter season in a semiarid environment: Initial examination of their potential as complementary PMI indicators. Forensic Science International 219: 284.e1-284.e4. http://dx.doi.org/10.1016/j.forsciint.2011.11.019

Amendt J, Richards CS, Campobasso CP, Zehner R & Hall MJR. 2011. Forensic entomology: applications and limitations 7: 379–392. https://doi.org/10.1007/s12024-010-9209-2

Anderson G & Vanlaerhoven S. 1996. Initial Studies on Insect Succession on Carrion in Southwestern British Columbia. Journal of Forensic Sciences 41: 617–625. https://doi.org/10.1520/JFS13964J

Anton E, Niederegger S & Beutel R. 2011. Beetles and flies collected on pig carrion in an experimental setting in Thuringia and their forensic implications. Medical and Veterinary Entomology 25: 353–364. https://doi.org/10.1111/j.1365-2915.2011.00975.x

Arnaldos-Sanabria MI. 2000. Estudio de la fauna sarcosaprófaga de la Región de Murcia. Su aplicacion a la medicina legal: Universidad de Murcia. Doctoral Thesis. https://digitum.um.es/digitum/handle/10201/29375

Arnaldos M, García M, Romera E, Presa JJ & Luna A. 2005. Estimation of postmortem interval in real cases based on experimentally obtained entomological evidence. Forensic Science International 149: 57–65. https://doi.org/10.1016/j.forsciint.2004.04.087

Arnaldos M, Romera E, Garcia M & Luna, A. 2001. An initial study on the succession of sarcosaprophagous Diptera (Insecta) on carrion in the southeastern Iberian peninsula. International Journal of Legal Medicine 114: 156–162. https://doi.org/10.1007/s004140000146

Arnaldos M, Romera E, Presa JJ, Luna A & Garcia M. 2004. Studies on seasonal arthropod succession on carrion in the southeastern Iberian Peninsula. International Journal of Legal Medicine 118: 197–205. https://doi.org/10.1007/s00414-004-0446-3

Arnaldos M, Ubero-Pascal N, García R, Carles-Tolrá M, Presa JJ & Garcia M. 2014. The first report of Telomerina flavipes (Meigen, 1830) (Diptera, Sphaeroceridae) in a forensic case, with redescription of its pupa. Forensic Science International 242: 22–30. https://doi.org/10.1016/j.forsciint.2014.07.023

Bajerlein D, Konwerski S & Madra A. 2012. European bettles of forensic importance. 9th meeting of the European Association for Forensic Entomology. Torun, Poland.

Battan-Horenstein M. 2008. Estructura y dinámica estacional de la comunidad sarcosaprófaga de una zona hemisinantrópica de Córdoba (Argentina). Universidad Nacional de Córdoba, Argentina. Doctoral Thesis.

Battán-Horenstein M, Rosso B & García MD. 2012. Seasonal structure and dynamics of sarcosaprophagous fauna on pig carrion in a rural area of Cordoba (Argentina): Their importance in forensic science. Forensic Science International 217: 146–156. https://doi.org/10.1016/j.forsciint.2011.10.043

Battan-Horenstein M & Salvo A. 2012. Community dynamics of carrion flies and their parasitoids in experimental carcasses in central argentina. Journal of Insect Science 12. https://doi.org/10.1673/031.012.0801

Battán-Horenstein M, Xavier Linhares A, Rosso de Ferradas B & García D. 2010. Decomposition and dipteran succession in pig carrion in central Argentina: ecological aspects and their importance in forensic science. Medical and Veterinary Entomology 24: 16–25. https://doi.org/10.1111/j.1365-2915.2009.00854.x

Baz A, Botías C, Martín-Vega D, Cifrián B & Díaz-Aranda L. 2015. Preliminary data on carrion insects in urban (indoor and outdoor) and periurban environments in central Spain. Forensic Science International 248: 41–47. https://doi.org/10.1016/j.forsciint.2014.12.012

Baz A, Cifrián B, Díaz-Aranda LM & Martín-Vega D. 2007. The distribution of adult blow-flies (Diptera: Calliphoridae) along an altitudinal gradient in Central Spain. Annales de la Société entomologique de France (N.S.) 43: 289–296. https://doi.org/10.1080/00379271.2007.10697524

Begoña Gaminde I. 2015. Sucesión de la entomofauna cadavérica en un medio montañoso del Sureste de la Península Ibérica: Universidad de Murcia. Doctoral Thesis. https://digitum.um.es/digitum/handle/10201/47091

Bembow M, Lewis A, Tomberlin JK & Pechal JL. 2013. Seasonal necrophagous insect community assembly during vertebrate carrion decomposition. Journal of Medical Entomology 50: 440–450. https://doi.org/10.1603/me12194

Bonacci T, Brandmayr P, Greco S, Tersaruolo C, Vercillo V & Brandmayr TZ. 2010. A preliminary investigation of insect succession on carrion in Calabria (southern Italy). Terrestrial Arthropod Reviews 3: 97–110. http://dx.doi.org/10.1163/187498310X517123

Bonacci T, Zetto Brandmayr T, Brandmayr P, Vercillo V & Porcelli F. 2011. Successional patterns of the insect fauna on a pig carcass in southern Italy and the role of Crematogaster scutellaris (Hymenoptera, Formicidae) as a carrion invader. Entomological Science 14: 125–132. https://doi.org/10.1111/j.1479-8298.2010.00423.x

Bonacci T, Greco S, Cavalcanti B, Brandmayr P & Vercillo V. 2014. The flesh fly Sarcophaga (Liopygia) crassipalpis Macquart, 1839 as an invader of a corpse in Calabria (Southern Italy). Journal of Forensic Science, Criminolgy 1: 404. http://dx.doi.org/10.15744/2348-9804.1.404

Bonacci T, Vercillo V & Benecke M. 2017. Dermestes frischii and D . undulatus (Coleoptera: Dermestidae) on a Human Corpse in Southern Italy: First Report. Romanian Journal of Legal Medicine 25: 180–184. https://doi.org/10.4323/rjlm.2017.180

Bonacci T, Vercillo V, Brandmayr P, Fonti A, Tersaruolo C & Zetto Brandmayr T. 2009. A case of Calliphora vicina Robineau-Desvoidy, 1830 (Diptera, Calliphoridae) breeding in a human corpse in Calabria (Southern Italy). Journal of Legal Medicine 11: 30–32. https://doi.org/10.1016/j.legalmed.2008.06.004

Brundage A, Bros S & Honda J. 2011. Seasonal and habitat abundance and distribution of some forensically important blowflies (Diptera: Calliphoridae) in Central California. Forensic Science International 212: 115–120. https://doi.org/10.1016/j.forsciint.2011.05.023

Byrd J & Castner J. 2010. Insects of forensic importance. In Forensic Entomology: The Utility of Arthropods in Legal Investigations (Byrd JH & Castner JL eds.). Boca Raton, Florida: CRC Press, pp. 39-126.

Campobasso C, Di Vella G & Introna F. 2001. Factors affecting decomposition and Diptera colonization. Forensic Science International 120: 18–27. https://doi.org/10.1016/s0379-0738(01)00411-x

Campobasso CP, Disney RHL & Introna F. 2004. A case of Megaselia scalaris (Loew) (Diptera, Phoridae) breeding in a human corpse. Anil Aggrawal's Internet Journal of Forensic Medicine and Toxicology 5: 3–5.

Cantarineu-Guillen J & Tinaut A. 2012. Introducción al conocimiento de los formícidos de la Región de Murcia (Hymenoptera, Formicidae). Boletín Asociación Española de Entomología 36: 145–162.

Carles-Tolrá M. 2004. Dípteros. In Curso Práctico de Entomología (Barrientos JA ed.). Capítulo 42. Manuales de la Universitat Autònoma de Barcelona 41. Barcelona: Asociación Española de Entomología, CIBIO (Centro Iberoamericano de la Biodiversidad) y Universitat Autònoma de Barcelona (Servei de Publicacions), pp. 657-682.

Carmo R, Vasconcelos S, Brudange A & Tomberlin J. 2018. How do invasive species affect native species? Experimental evidence from a carrion blowfly (Diptera: Calliphoridae) system. Ecological Entomology 43: 483–493. https://doi.org/10.1111/een. 12524

Castillo-Miralbes M. 2002. Estudio de la entomofauna asociada a cadáveres en el alto Aragón (España). Monografias de la Sociedad Entomológica Aragonesa 6.

Castillo-Miralbes M. 2001. Principales especies de coleópteros necrófagos presentes en carroña de cerdos en la comarca de la litera (Huesca). Graellsia 57: 85–90.

Charabidze D & Gosselin M. 2014. Insectes Cadavres & Scenes de crimes. Principes et applications de l'entomologie medico-légale. Louvain-la-Neuve: De Boeck.

Chinery M. 1998. Guida degli insetti d'Europa. Roma: Franco Muzzio Editore.

Díaz-Aranda LM, Martín-Vega D, Gómez-Gómez A, Cifrián B & Baz A. 2018. Annual variation in decomposition and insect succession at a periurban area of central Iberian Peninsula. Journal of Forensic and Legal Medicine 56: 21–31. https://doi.org/10.1016/j.jflm.2018.03.005

Dominguez-Martinez J & Gómez-Fernández L. 1963. Momificación cadaverica particularmente rápida, operada bajo la acción de numerosas larvas de Chrysomya albiceps. Revista Iberica de Parasitología 23: 43–62.

Early M & Goff M. 1986. Arthropod succession patterns in exposed carrion on the island of O'ahu, Hawaiian Islands, USA. Journal of Medical Entomology 23: 520–531. https://doi.org/10.1093/jmedent/23.5.520

Farinha A, Dourado CG, Centeio N, Oliveira AR, Dias D & Rebelo MT. 2014. Small bait traps as accurate predictors of dipteran early colonizers in forensic studies. Journal of Insect Science 14(1): 7 [16] . https://doi.org/10.1093/jis/14.1.77

Frederickx C, Dekeirsschieter J, Verheggen F & Haubruge E. 2013. The community of Hymenoptera parasitizing necrophagous Diptera in an urban biotope. Journal of Insect Science 13: 32 https://doi.org/10.1673/031.013.3201

García-Rojo AM. 2004. Estudio de la sucesión de insectos en cadáveres en Alcalá de Henares (Comunidad Autónoma de Madrid) utilizando cerdos domésticos como modelos animales. Boletín Sociedad de Entomología Aplicada 34: 263–269.

García Rojo AM, Honorato L, González M & Téllez A. 2009. Determinación del intervalo postmortem mediante el estudio de la sucesión de insectos en dos cadáveres hallados en el interior de una finca rústica en Madrid. Cuadernos de Medicina Forense 15: 137–145.

Gómez K & Espadaler X. 2006. Exotic ants (Hymenoptera: Formicidae) in the Balearic Islands. Myrmecologische Nachrichten 8: 225-233.

González Mora D. 1989. Los Calliphoridae de España, II: Calliphorini (Diptera). Eos 65: 39–59.

González Mora D & Peris SV. 1988. Los Calliphoridae de España, I: Rhiniinae y Chrysomyinae (Diptera). Eos 64: 91–139.

Greco S, Brandmayr P & Bonacci T. 2014. Synanthropy and temporal variability of Calliphoridae living in Cosenza (Calabria, Southern Italy). Journal of Insect Science 14: 216. https://doi.org/10.1093/jisesa/ieu078

Gregor F, Rozkosny R, Bartak M & Vanhara J. 2002. The Muscidae (Diptera) of Central Europe. Folia Facultatis Scientiarum Naturalium Universitatis Masarykianae Brunensis, Biologia, 107.

Hofer I, Hart AJ, Martin-Vega D & Hall MJR. 2017. Optimising crime scene temperature collection for forensic entomolgy casework. Forensic Science International 270: 129–138. https://doi.org/10.1016/j.forsciint.2016.11.019

Ioan B, Manea C, Hanganu B, Statescu L, Solovastru L & Manoilescu I. 2017. The Chemistry Decomposition in Human Corpses. Revista de Chimie -Bucharest 68: 1352–1356.

López-Dos Santos N. 2008. Estudio de sucesión faunística en cadáveres expuestos en ambientes silvestres. Universidad de Murcia.

López-Gallego E. 2016. Sucesión de la Entomofauna Sarcosaprófaga en un Hábitat Forestal Mediterráneo: Universidad de Murcia. Doctoral Thesis. https://digitum.um.es/digitum/handle/10201/51550

Lyu Z, Wan L, Yang Y, Tang R & Xu L. 2016. A checklist of beetles (Insecta, Coleoptera) on pig carcasses in the suburban area of southwestern China: A preliminary studiy and its forensic relevance. Journal of Forensic and Legal Medicine 41: 42–48. https://doi.org/10.1016/j.jflm.2016.04.009

Mañas-Jordá S, León-Cortés J, García-García MD, Caballero U & Infante F. 2018. Dipteran diversity and ecological succession on dead pigs in contrasting mountain habitats of Chiapas, México. Journal of Medical Entomology 55 (1): 59–68. https://doi.org/10.1093/jme/tjx190

Martín-Vega D & Baz A. 2013. Sarcosaprophagous Diptera assemblages in natural habitats in central Spain: spatial and seasonal changes in composition. Medical and Veterinary Entomology 27, 64–76. https://doi.org/10.1111/j.1365-2915.2012.01028.x

Martín-Vega D & Baz A. 2010. Datos sobre Dermaptera capturados en trampas cebadas con carroña en el centro de la Península Ibérica. Boletín Sociedad de Entomología Aragonesa 48: 571–573.

Martín-Vega D, Baz A, Cifrián B, Gómez-Gómez A & Díaz-Aranda LM. 2019. Long-term insect successional patterns on pig carcasses in central Spain. International Journal of Legal Medicine 133: 1581–1592. https://doi.org/10.1007/s00414-019-02088-z

Martín-Vega D, Cifrián B, Díaz-Aranda LM & Baz A. 2015. Environmental correlates of species diversity for sarcosaprophagous Diptera across a pronounced elevational gradient in central Spain. Italian Journal of Zoology 81: 415–424. https://doi.org/10.1080/11250003. 2014.940007

Martín Vega D. 2011. Estudio de los agregados de Dípteros sarcosaprófagos y su relación con los ecosistemas naturales de la comunidad de Madrid. Universidad de Alcalá. Doctoral Thesis.

Martínez MD, Acosta FJ & Ruiz E. 1985. Las subfamilias y géneros de las hormigas ibéricas. Claves para la identificación de la fauna española. Madrid: Universidad Complutense.

Martínez-Sanchez A, Rojo S & Marcos-García MA. 2000. Annual and spatial activity of dung flies and carrion in a Mediterranean holm-oak pasture ecosystem. Medical and Veterinary Entomology 14: 56–63. https://doi.org/10.1046/j.1365-2915.2000.00205.x

Martínez-Sánchez AI, Rojo S, Rognes K & Marcos-García MA. 1998. Califóridos con interés faunístico en agroecosistemas de dehesa y catálogo de las especies ibéricas de Polleniinae (Diptera: Calliphoridae). Boletín Asociación Española de Entomología 22: 171–183.

Martínez MD, Arnaldos MI, Romera E & García MD. 2002. Los Formicidae (Hymenoptera) de una comunidad sarcosaprófaga en un ecosistema mediterráneo. Anales de Biología 24: 33–44.

Martinez Sánchez A. 2003. Biología de la comunidad de Dípteros necrófilos en ecosistemas del sureste de la península ibérica. Universidad de Alicante. Doctoral Thesis.

Matuszewski S. 2017. A general approach for postmortem interval based on uniformly distributed and interconnected qualitative indicators. International Journal of Legal Medicine 131: 877–884. https://doi.org/10.1007/s00414-016-1520-3

Matuszewski S, Bajerlein D, Konwerski S & Szpila K. 2011. Insect succession and carrion decomposition in selected forests of Central Europe. Part 3: Succession of carrion fauna. Forensic Science International 207: 150–163. https://doi.org/10.1016/j.forsciint.2010.09.022

Mcalpine JF. 1981. Key to Families-Adults. In Manual of Nearctic Diptera. Vol. 1. (McAlpine JF, Peterson BV, Shewell GE, Teskey HJ, Vockeroth JR & Wood DM coord.). Monograph no. 27. Ottawa, Canada: Research Branch, Agriculture Canada.

Meskin I. 1986. Factors affecting the coexistence of blowflies (Diptera: Calliphoridae) on the Transvaal Highveld, South Africa. South African Journal of Science 82: 244–250.

Moretti T, Bonato V & Godoy W. 2011. Determinig the season of death from the family composition of insect infesting carrion. European Journal of Entomology 108: 211–218. http://dx.doi.org/10.14411/eje. 2011.029

Morrill WL. 1975. Plastic pitfall trap. Environmental Entomology 4: 596.

Muñoz-Lozano C, Martín-Vega D, Martínez-Carrasco C, Sánchez-Zapata JA, Morales-Reyes Z, Gonzálvez M & Moleón M. 2019. Avoidance of carnivore carcasses by vertebrate scavengers enables colonization by a diverse community of carrion insects. PLoS ONE 14: 1–22. https://doi.org/10.1371/journal.Pone.0221890

Neto-Silva A, Dinis-Oliveira RJ & Prado e Castro C. 2017. Diversity of the Formicidae (Hymenoptera) carrion communities in Lisbon (Portugal): preliminary approach as seasonal and geographic indicators. Forensic Sciences Research 1–9. https://doi.org/10.1080/20961790.2017.1372875

Oksanen J, Blanchet FG, Friendly M, Kindt R, Legendre P, McGlinn D, Minchin PR, O'Hara RB, Simpson GL, Solymos P, Stevens MHH, Szoecs E & Wagner H. 2019. Vegan: Community Ecology Package. R package version 2.5-6.

Ordóñez A, García M & Fagua G. 2008. Evaluation of the collection efficiency of the Schoenly trap for collecting adult sarcosaprophagous dipterons. Journal of Medical Entomology 45(3): 522–532. https://doi.org/10.1093/jmedent/45.3.522

Outerelo R & Gamarra P. 1986. Las familias y géneros de los estafilínidos de la Península Ibérica. Madrid: Universidad Complutense de Madrid.

Pérez-Marcos M, Arnaldos-Sanabria MI, García MD & Presa JJ. 2016. Examining the sarcosaprophagous fauna in a natural mountain environment (Sierra Espuña, Murcia, Spain). Annales de la Societe Entomologique de France 52(5): 264-280 https://doi.org/10. 1080/00379271.2016.1259014

Pérez-Marcos M, López-Gallego E, Arnaldos MI, Martínez-Ibáñez D & García MD. 2020. Formicidae (Hymenoptera) community in corpses at different altitudes in a semiarid wild environment in the southeast of the Iberian Peninsula. Entomological Science 23(3): 297-310. https://doi.org/10.1111/ens.12422

Pérez-Bote J, Vicente-Rivera V & Santos-Almeida A. 2012. La comunidad sarcosaprófaga en un entorno periurbano. Boletín de la Asociación española de Entomología 36(3-4): 299–314.

Peris SV & Gónzalez-Mora D. 1991. Los Calliphoridae de España, III: Luciliini (Diptera). Boletín de la Real Sociedad Española de Historia Natutal (Sec. Biol.) 87:187–207.

Plata Negrache P. 1971. Revisión de la familia Dermestidae Latr. en la Península Ibérica e Islas Baleares. Universidad de Granada. Doctoral Thesis.

Prado e Castro C, Chichorro D, Serrano A & Garcia MD. 2009. A modified versión of Schoenly trap for collecting sarcosaprophagous arthropods. Detailed plans and construction. Anales de Biología 31: 1–6.

Prado e Castro C & García M. 2010. Additions to the Piophilidae (Diptera) fauna from Portugal, with new records. Graellsia 66: 101–105. http://dx.doi.org/10.3989/graellsia.2010.v66.013

Prado e Castro C, Garcia MD, Martins da Silva P, Faria e Silva I & Serrano A. 2013. Coleoptera of forensic interest: A study of seasonal community composition and succession in Lisbon, Portugal. Forensic Science International 232: 73–83. https://doi.org/10.1016/j.forsciint.2013.06.014

Prado e Castro C, Garcia M, Palma C & Martínez-Ibáñez M. 2014. First report on sarcosaprophagous Formicidae from Portugal (Insecta: Hymenoptera). Annales de la Société entomologique de France 50(1): 51–58. http://dx.doi.org/10.1080/00379271.2014.934037

Prado e Castro C & García MD. 2009. First record of Chrysomya megacephala (Fabricius, 1794) (Diptera, Calliphoridae) from Portugal. Graellsia 65: 75–77. https://doi.org/10.3989/graellsia.2009.v65.i1

Prado e Castro C, García MD, Arnaldos MI & González-Mora D. 2010. Sarcophagidae (Diptera) atraídos a cadáveres de cochinillo, con nuevas citas para la fauna portuguesa. Graellsia 66(2): 285–294. https://doi.org/10.3989/graellsia.2010.v66.023

Prado e Castro C, Serrano A, Martins da Silva P & Garcia MD. 2012. Carrion flies of forensic interest: a study of seasonal community composition and succession in Lisbon, Portugal. Medical and Veterinary Entomology 26: 417–431. http://dx.doi.org/10.1111/j.1365-2915.2012.01031.x

Prado e Castro C, Sousa JP, Arnaldos M, Gaspar J & Garcia MD. 2011a. Blowflies (Diptera: Calliphoridae) activity in sun exposed and shaded carrion in Portugal. Annales de la Société entomologique de France 47(1-2): 128–139. http://dx.doi.org/10.1080/00379271.2011.10697704

Prado e Castro C, Arnaldos MI, Sousa JP & García MD. 2011b. Preliminary study on a community of sarcosaprophagous Diptera in central Portugal. Entomologia Generalis 33 (3): 183-198. http://dx.doi.org/10.1127/ entom.gen/33/2011/183

R-Development-Core-Team. 2017. A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Real Decreto-ley 1201/2005, de 10 de octubre, sobre protección de los animales utilizados para experimentación y otros fines científicos. Boletín Oficial del Estado, 21 de octubre de 2005, núm. 252,

Richards E & Goff M. 1997. Arthropods succession on exposed carrion in three contrasting habitats on Hawaiian Islands, Hawaii. Journal of Medical Entomology Entomol 34: 328–339. https://doi.org/10.1093/jmedent/34.3.328

Saloña-Bordas MI, Moneo J & Díaz-Martín B. 2009. Estudio sobre la distribución de Califóridos (Diptera, Calliphoridae) en la Comunidad Autónoma del País Vasco. Boletín de la Sociedad Española de Entomología 33: 63–89.

Sanchez-Piñero F. 1997. Analysis of spatial and seasonal variability of carrion beetle (Coleoptera) assemblages in two arid zones of Spain. Community and Ecosystem Ecology 26: 805–814. https://doi.org/10.1093/ee/26.4.805

Schoenly K. 1981. Demographic bait trap. Environmental Entomology 10(5): 615–617. https://doi.org/10.1093/ ee/10.5.615

Schoenly K, Griest K & Rhine S 1991. An experimental field protocol for investigating the post-mortem interval using multi-disciplinary indicator. Journal of Forensic Sciences 36: 1395–1415.

Smith KGV. 1986. A manual of Forensic Entomology. London: The Trustees of the British Museum (Natural History).

Tantawi TI, El-Kady EM, Greenberg B & El-Chaffar HA. 1996. Arthopod succesion on exposed rabbit carrion in Alexandria, Egypt. Journal of Medical Entomology 33(4): 566–580. https://doi.org/10.1093/jmedent/33.4.566

Tomberlin J, Bembow M & Tarone A. 2011. Basic research in evolution and ecology enhances forensics. Trends in Ecology and Evolution Evolution 26(2): 53–55. https://doi.org/10.1016/j.tree.2010.12.001

Velásquez Y, Martínez-Sánchez A & Rojo S. 2011. A Preliminary Analysis of Early Colonization of Pig Carcasses by Blowflies (Diptera: Calliphoridae) in the Iberian Peninsula. Pest Tecnology 5: 23–25. https://doi.org/10.1016/j.tree.2010.12.001

Yélamos T. 2002. Fauna Ibérica (Vol. 17): Coleoptera Histeridae. Madrid: Consejo Superior de Investigaciones Científicas.

Zahradník J. 1990. Guía de los Coleópteros de España y Europa. Barcelona: Omega.

Zanetti N, Visciarelli E & Centeno N. 2015. Trophic roles of scavenger beetles in relation to decomposition stages and seasons. Revista Brasileira de Entomologia 59(2): 132-137. https://doi.org/10.1016/j.rbe.2015.03.009