Facultat de Ciències

Memòria del Treball Final de Grau

# Assessing the response of beetle community to the management of a Mediterranean burned forest

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# Index

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# Abstract

In the last years, the practice of removing all the deadwood after wildfire and use it with energetic purposes has increased. With the objective to evaluate and decrease the impacts of these practices upon biodiversity, from the University of Girona the project *Anifog* has been created, conducted by the *Pecat* research team, where a Handbook of Good Management Practices in burned forests has been done to guide managers and forest workers. In my Final Grade Work has been evaluated how two different management practices following the handbook recommendations affect the diversity of saproxylic beetles. The first management consists on logging dead trees or those damaged by the wildfire leaving part of the wood on-site (Sustainable logging), and the second one consists on leaving the forest unaltered after the fire (Non-intervention). Saproxylic beetles have an important ecological role in the recycling of nutrients found in deadwood and, therefore, are important for the recovering of the ecosystem after a wildfire. Furthermore, they are used in our study as bioindicators of the deadwood and its associated biodiversity. The study was done in seven experimental plots in a forest of the Catalan Coastal Range during the summer of 2017, one year after the fire and two-three months after logging. With the obtained results it has been proved that there are differences among treatments according to species richness, being a greater number in sustainable logging. If we look at the individuals' abundance, we can see at first sight that there are more specimens in sustainable logging than in non-intervention treatment even though these differences are not statistically significant. In the PCA it is shown that, of the whole set, there are six species which are the most abundant from which four are representative of the traps belonging to the sustainable logging treatment. Furthermore, concerning food regimes form each species, the most abundant are also found in the sustainable logging treatment, being the xylophagous and mycophagous, specifically those saproxylic. So, even if the differences among treatments are not vast we can see a small difference in response to the type of management done in each one, being the one of sustainable logging that with better results regarding to the biodiversity recovery.

# Resumen

En los últimos años se ha incrementado la tala de madera muerta después de un incendio por el creciente uso de biomasa con finalidades energéticas. Con el objetivo de avaluar y disminuir los impactos de estas prácticas sobre la biodiversidad, desde la Universitat de Girona se ha creado el proyecto *Anifog*, dirigido por el grupo de investigación *Pecat*, donde se ha redactado un manual de Buenas Prácticas de gestión de los bosques después de un incendio para guiar a gestores y trabajadores forestales. En mi Trabajo de Fin de Grado se han evaluado dos tipos de gestiones siguiendo las recomendaciones del manual y cómo estas afectan la diversidad de escarabajos saproxílicos. La primera gestión consiste en talar los árboles muertos o dañados por el incendio dejando parte de la madera muerta *in-situ* (Buenas Prácticas), y la segunda trata de no intervenir en el área (Control). Los escarabajos saproxílicos tienen un importante papel ecológico en el reciclaje de nutrientes que se encuentran en la madera muerta y, por tanto, son importantes para la recuperación del ecosistema después del incendio. Por ello, en nuestro estudio se han utilizado como bio-indicadores del estado de la madera muerta y la biodiversidad asociada. El estudio se realizó en siete parcelas en un bosque de la Sierra Litoral Catalana durante el verano de 2017, un año después del incendio y dos o tres meses después de la tala. Con los datos obtenidos se ha comprobado que existen diferencias entre tratamientos por lo que a riqueza de especies se refiere, habiendo un mayor número en el de buenas prácticas. Si miramos la abundancia de individuos, a simple vista se observa que hay más individuos en buenas prácticas que en el control, aunque estas diferencias no son estadísticamente significativas. En el análisis PCA se observa que, de todo el conjunto, hay seis especies que son las más abundantes de las cuales cuatro son representativas de trampas correspondientes al tratamiento de buenas prácticas. Además, en referencia a los modelos alimentarios de cada especie, los más abundantes también se encuentran en el tratamiento de buenas prácticas, siendo xilófagos y micófagos, concretamente aquellos con carácter saproxílico. Así pues, aunque las diferencias entre tratamientos no sean abismales ya puede verse una ligera diferencia en respuesta al tipo de gestión realizada en cada uno, siendo la de buenas prácticas aquella con mejores resultados en cuanto a recuperación de la biodiversidad.

## Resum

En els últims anys s'ha incrementat la pràctica de retirar tota la fusta morta després d'un incendi i aprofitar-la posteriorment amb finalitats energètiques, majoritàriament. Amb l'objectiu d'avaluar i disminuir els impactes d'aquestes pràctiques sobre la biodiversitat, des de la Universitat de Girona s'ha creat el projecte *Anifog*, dirigit pel grup de recerca *Pecat*, on s'ha redactat un manual de Bones Pràctiques de gestió dels boscos després d'un incendi per quiar a gestors i treballadors forestals. Al meu Treball de Final de Grau s'han avaluat dos tipus de gestions seguint les recomanacions del manual i com aquestes afecten la diversitat d'escarabats saprixílics. La primera gestió consisteix a talar els arbres morts o danyats per l'incendi deixant part de la fusta *in-situ* (Bones Pràctiques), i la segona tracta de no intervenir a la zona (Control). Els escarabats saproxílics tenen un important paper ecològic al reciclatge dels nutrients que es troben a la fusta morta i, per tant, son importants per la recuperació de l'ecosistema després d'un incendi. Per això, al nostre estudi s'han fet servir com a bio-indicadors de l'estat de la fusta morta i la seva biodiversitat associada. L'estudi es va realitzar a set parcel·les a un bosc de la Serralada Litoral Catalana durant l'estiu de 2017, un any després de l'incendi i dos o tres mesos després de la tala. Amb les dades obtingudes s'ha comprovat que existeixen diferencies entre tractament pel que fa a la riquesa, havent un major nombre d'espècies al de bones pràctiques. Si mirem l'abundància d'individus, a simple vista s'observa que hi ha més individus a bones pràctiques que al control, tot i que aquestes diferències no són estadísticament significatives. A l'anàlisi PCA s'observa que, de tot el conjunt, hi ha sis espècies que són les més abundants de les quals quatre són representatives de trampes corresponents al tractament de bones pràctiques. A més, referent als models alimentaris de cada espècie, els més abundants també es troben al tractament gestionat, essent xilòfags i micòfags, concretament aquells amb caràcter saproxílic. Així doncs, tot i que les diferències entre tractaments no siguin abismals ja s pot veure una lleugera diferència en resposta al tipus de gestió realitzada a cadascun, essent la de bones pràctiques aquella amb millors resultats en quant a la recuperació de la biodiversitat.

# 1. Introduction

Mediterranean basin is considered one of the largest biodiversity hotspot in the world due to its unique ecological characteristics that contain a wide plant and animal biological diversity (Scarascia-Mugnozza & Oswald, 2000). Its hot dry summers and humid cool winters have influenced the vegetation and wildlife found there, but also did the last Iced Age providing the region with a large number of terrestrial and marine endemic species (Sundseth, 2009). Humans have exploited these resources since remote times with different activities, e.g. forest fires, clearances, livestock grazing and cultivation (Sundseth, 2009), but it has not been always easy to find a balance between exploitation and conservation of natural resources (Scarascia-Mugnozza & Oswald, 2000).

## 1.1. The *Anifog* Project

Although the Mediterranean region is the most affected by wildfires in Europe, representing a 85% of them (San-Miguel-Ayanz et al., 2012), the information related to the post-fire management is scarce for this region (Castro, Marañón-Jiménez, Sánchez-Miranda, & Lorite, 2009; San-Miguel-Ayanz et al., 2012). In Europe the use of biofuels has increased and for that reason wood extraction has risen and trees burned by forest fires are one of the sources of this wood, obtained by recovering logging. Those loggings consist of making the most of the whole trunk, when previously branches and small trees were left in the burned area (Mauri & Pons, 2016).

Moreover, some species can only survive in burned forests and therefore some countries, where fire is uncommon, do controlled burning in small areas to help nature conservation. Leaving part of this burned wood in the same place increase the biodiversity of saproxylic species as it produces new resources and areas with no competition ideal for them (Toivanen & Kotiaho, 2007; Johansson, 2006). In any case, while in Scandinavia a lot of attention has been paid to saproxylic species related to burned wood, in the Iberian Peninsula there are no data on the relationship between fire and the diversity of saproxylics (Méndez Iglesias, 2009).

In consequence, *Pecat* researchers from University of Girona are carrying out the *Anifog* project (http://anifog.wixsite.com/anifog) with the objective of providing answers, recommendations and new questions focused on post-fire ecology and management. For this reason, they have different research areas which include the elaboration of a Handbook of Good Management Practices for sustainable post-fire management. This handbook, authored by Eduard Mauri and Pere Pons (2015), contain recommendations for the managers and related staff involved in forestry activities to mitigate or prevent the negative impacts of recovery logging in Mediterranean burned forests so that it will be possible to conserve biodiversity and ecosystem services. In addition, they are structured in different sections including landscape planning, soil protection, plant regeneration and fauna (vertebrates and invertebrates) conservation.

## 1.2. Saproxylic beetles

Saproxylic invertebrates are defined by Speight (1989) as species "dependent, during some part of their life cycle, upon the dead or dying wood of moribund or dead trees (standing or fallen), or upon wood-inhabiting fungi, or upon the presence of other saproxylic" and they are among the first organisms to colonize a burned forest (Boulanger & Sirois, 2007). However, this definition does not have into account the deadwood found in young or living trees with internal decay as well as some dead branches or dead boughs in the lower canopy which act as microhabitats for saproxylic species (Alexander, 2008). Furthermore, it includes other species dependent on fluxes of sap and its decomposition products and other organisms different from fungi that feed directly on wood (Alexander, 2008). Of the invertebrates, arthropods are the most diverse insects and, within this group are beetles. They belong to the Coleoptera order which is the most diverse and abundant among the insects and the animals as a whole (Grimaldi & Engel, 2005) and from the 166 families of this order, 90 are saproxylic (Maldonado, 2014).

Forest reserves usually contain a great quantity and heterogeneity of deadwood which has been created thanks to small or large-scale disturbances (wildfires, storms) and, in addition, it has not been managed nor subjected to the man pressure (Johansson, 2006; McGeoch, Schroeder, Ekbom, & Larsson, 2007). That is why a greater diversity of the saproxylic insects is found in old growth forests than in those managed for years, becoming one of the most ideal habitat for the saproxylic species (McGeoch et al., 2007). However, in the last years forest management has increased, diminishing the number of mature forests and increasing the fragmentation of those that are still mature. In addition, in southern Europe, when a forest is burned it is usually harvested leaving very little woody biomass on-site. Saproxylic beetles are suffering a decrease regarding to its richness attributed to the low availability of dead wood in forests. Therefore, different actions have been carried out, for example stablishing non-intervention reserves, prolonging harvest cycle or leaving on site harvest remnant in the woods and improve these forests by providing a more natural tree species composition (Vodka, Konvicka, & Cizek, 2009). Furthermore, there has been a tendency of decreasing natural disturbances which negatively affects because those permit the generation of new ecological niches with favourable characteristics for the development of those saproxylic insects, e.g. deadwood, old trees, deciduous trees and swamp forests (Johansson, 2006). For example, the presence of wildfires is decreasing in some parts of the world and many beetles rely on these disturbances to survive.

Lastly, saproxylic beetles have an important role in the decomposition of deadwood, providing the recycling of nutrients resulting from it. Deadwood is an important source of nutrients and its decomposition notably enrich the soil where future plant species will grow and other species associated to them will as well (García López, 2016). As reported by Grove (2002), the diversity of beetles will depend on the deadwood decomposition degree, which in turn changes according to the wood moisture content and the exposure to sun, the amount of deadwood in the area, the disturbances periodicity (such as wildfires) and the fragmentation of the habitat.

### 1.2.1. Species composition of saproxylic beetles

As mentioned in Della Rocca, Stefanelli, Pasquaretta, Campanaro, & Bogliani (2014), saproxylic beetles together with fungi are a clue element in the decomposition of coarse woody debris (CWD) and in nutrient recycling. Some studies confirm that after a wildfire the number of saproxylic species increase thanks to the newly-created habitats and ecological niches with no competition yet (Boulanger & Sirois, 2007; Moretti et al., 2010).

Practices related to timber removal from forests have been carried out for years, decreasing the number of mature trees where most of the deadwood in a forest is found, essential for the set of saproxylic insects (Nieto & Alexander, 2010). These practices have caused a reduction, even a regional extinction, of the saproxylic species. For that reason, the European Commission has created the European Red List of Saproxylic Beetles with in order to take appropriate conservation measures that improve their status (Nieto & Alexander, 2010). In this list there are the threatened species in Europe and, along with the “Libro Rojo de los Invertebrados Amenazados de España” (Verdú, Numa, & Galante, 2011) and Saproxylic Invertebrates and Their Conservation (Speight, 1989), the species found during the sampling were compared, determining their conservation status, if this information was available.

### 1.2.2. Saproxylic beetles as bioindicators

For a species to be considered a bioindicator it is necessary that it complies with a series of conditions. According to Rainio & Niemelä (2003) some of these conditions are that they should have well-known taxonomy and ecology, be distributed over a broad geographic area, have specialisation to certain habitat requirements, provide easy warning of change, be easy and cost-effective to survey and its response should reflect the response of other species. Even though there is not an unanimous definition for bioindicators (Rainio & Niemelä, 2003), McGeogh (1998) define them as "a species or group of species that reflects 1) the abiotic or biotic state of an environment, 2) represents the impact of environmental change on a habitat, community or ecosystem, 3) or indicates de diversity of other species within an area".

Following the definition by Speight (1989), saproxylic beetles are often used as indicators of woodland biodiversity. They are a key component for the decomposition of the organic matter into nutrients and minerals essential to the well-functioning of the soil (Speight, 1989). Moreover, they promote the existence of other species in the same area that are, in some way, related to the saproxylic organisms (A. García-López, Galante, & Micó, 2016).

Then, saproxylic beetles are good indicators because their richness depends on the quality and quantity of deadwood available in the forest which depends on the fragmentations and management (Méndez Iglesias, 2009). Furthermore, they are a high diverse group (Alejandra García-López, Martínez-Falcón, Micó, Estrada, & Grez, 2016) with a high specialization degree which gives an accurate knowledge of the conservation state and biological value of a forestry area, as said by Pérez Moreno & Moreno Grijalba (2009) according to Maldonado (2014).

Nevertheless, in this research we work in a forest recently burned, with plenty of deadwood available for saproxylic beetles. If deadwood is exported from the forest, the habitat for these individuals can be destroyed or degraded. Saproxylic beetles are easy to catch by flying traps and, once we get them, we will be able to relate their diversity to the occurrence of other species related with them or with the deadwood.

## 2. Objectives

Our working hypothesis is that those management practices proposed by the Handbook of Good Management Practices realised by the *Anifog* project help to improve the state of the forests after a wildfire. That is in our study, which one favor the presence of beetles, in particular saproxylic beetles, as they are good indicators of the fauna related to deadwood and their relationship with it, and which practice can also help the recovery of forest's biodiversity.

To do that, we have compared beetle community under two different "treatments"; burned areas managed by good-practices (see Mauri and Pons (2016) named as Sustainable logging, and burned areas unaltered after fire, Non-intervention, to assess which management is better in terms of preserving a high diversity level of saproxylic beetle species after a fire. To accomplish this, species richness (number of species) and abundance (number of individuals) of saproxylic beetles will be tested to see if there are differences between treatments. Furthermore, we will study which species better represents each trap from both sustainable logging and non-intervention treatment with a PCA according to its abundance. To see how the beetle food regimes are distributed among treatments we will perform a FAMD which also answers to the abundance of each species. Thus, we could have an idea of how does the forest management affect beetle food regime.

Finally, with the obtained results we want to determine which type of forest management is better to conserve and favour saproxylic beetles' diversity in the Mediterranean forests once a wildfire has occurred.

# 3. Methods

## 3.1. Study area

The study was carried out in Santa Maria de Deu del Vilar Sanctuary, in the municipal term of Blanes, Girona province (41º42'45.78''N, 2º46'43,65''E). The area has 30.7 hectares and it belongs to the Catalan Coastal Mountain Range in La Selva region. It is principally composed by cork oaks (*Quercus suber*), stone pine (*Pinus pinea*) besides *Eucalyptus* sp. plantations and maritime pine (*Pinus pinaster*) around the study area which can affect the specific composition of coleopteran present in the plots due to its proximity. Referring to plant species, the most common genus are *Cistus* and *Erica* and, as mentioned by Felipe (2017), some herbs like *Brachypodium retusum, Calicotome spinosa* o *Arbutus unedo*, among other, are plentiful. Unlike other neighbouring areas such as Montnegre-Corredor Park or, even closer, the Site of Community Importance (SCI) of Tordera Oak Grove, the study area is not within a protected area. The climate is Mediterranean by its proximity to this sea, with dry and hot summers and mild and wet winters (Scarascia-Mugnozza & Oswald, 2000) with mean annual temperatures ranging from 16 to 19 ºC and annual precipitations of 400-700 mm.

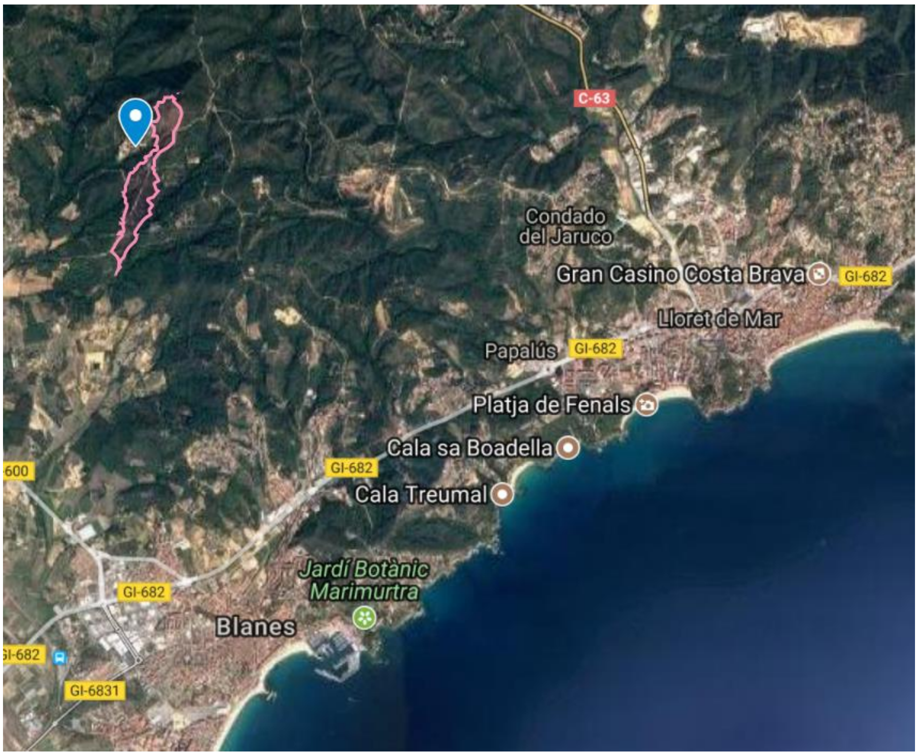


**Figure 1**. Aerial image of the location of the burned perimeter (red) and the El Vilar Sanctuary, indicated by a blue icon. Both are situated in a forestry area in the north-west of Blanes. Source: MyMaps.

The wildfire occurred in Blanes from July 24th to 28th 2016 and 30.61 ha were burned. Most of the area was burned by a severe crown fire. Fortunately, the weather conditions were not favourable for the fire expansion; 48 hours previous to the fire between 5 and 10 mm of rain were accumulated, the humidity was high (80-100%) and in the moment of the fire the temperature was 29ºC, 40% of relative humidity and a SSW wind of 17 km/h.

## 3.2. Study design

The study was designed to analyse the differences of saproxylic beetles' species between two types of post-fire forest management. To do this, seven plots around a hectare were selected corresponding to two treatments:

- Non-intervention (N): distributed into 3 plots where no management was performed.
- Sustainable logging (S): distributed into 4 managed plots. Dead trees were logged in April 2017 (before the sampling) with light machinery, their logs being retired (> 90% of them) and leaving piles of branches and preserving standing living trees on site

In each plot one to three flying-traps were installed (Table 1; Figure 2), obtaining a total of 14 traps. Plots from both treatments were interspersed and traps separated to each other by at least 50 meters because the area available for the study was limited. The vegetation composition was very similar among plots and the flying traps were situated mainly in cork oaks (*Q. suber*), except two that were located in *P. pinea* trees (Vol S3.2. and Vol N3.1.)

**Table 1**. Type of experiment (Non-Sustainable logging and Sustainable logging, abbreviated by "N" and "S") with the respective number of each plot and the number of traps realised in each one.

| **Non-intervention** | **Nº of traps** |
|---|---|
| N.1 | 1 |
| N.2 | 3 |
| N.3 | 3 |
| Total | 7 |
| **Sustainable logging** | |
| S.1 | 1 |
| S.2 | 2 |
| S.3 | 2 |
| S.4 | 2 |
| Total | 7 |

It is necessary to specify that samples are independent from each other as they come from different traps situated in different trees but these samples are pseudo-replicates and the real replicates are plots specific in each treatment (three for Non-intervention and four for Sustainable management).

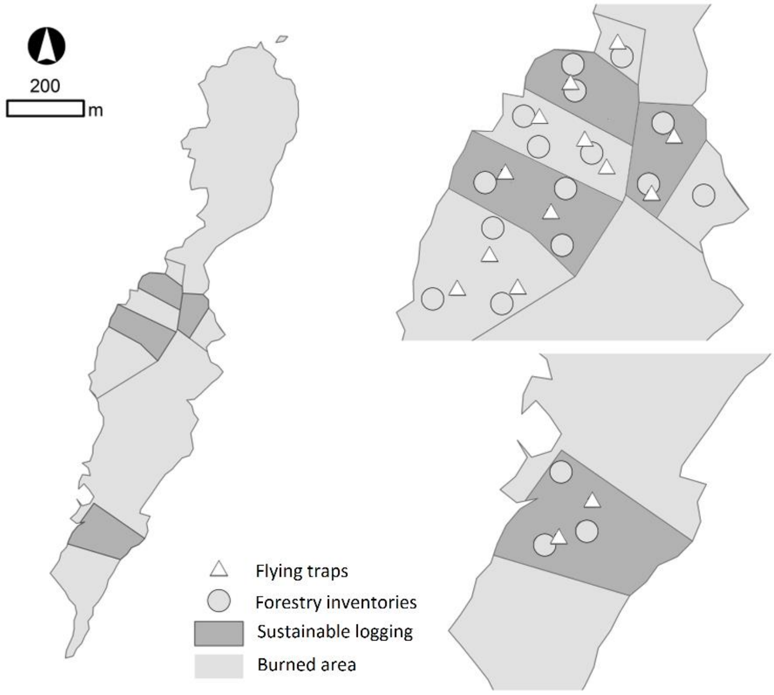


**Figure 2**. Map of the study area where the affected area by the fire in 2016 is coloured by grey. Sustainable logging plots are indicated by dark grey. The distribution of the flying traps is indicated by white triangles and the forestry inventories are indicated by grey circles. Source: *Anifog* project, UdG (drawn by C. Tobella).

## 3.3. Sampling

Traps were installed on 1st June 2017, approximately a year after the wildfire. Every 15 days from the placement of the traps, samples were collected, that is, the first sample was collected the 16th June, the second in the 1st July and the third and last, the 16th July, by Esther Lucha Ruiz with the collaboration of Pere Pons, member of the *Pecat* research group, and external members, all of them between 7:30 and 11:30 in the morning.

Window flying traps are the most frequently used technique for catching flying active saproxylic beetles as they consist of crossed-vanes which are considered invisible to the insect (Bouget, Brustel, Brin, & Noblecourt, 2008). In addition, they have a significant and strong effect on the abundance and species richness of saproxylic beetles (Bouget et al., 2008).

We used CROSSTRAP ® MINI with wet collection container (with slider) from ECONEX brand (Figure 3). It consists of a 33-cm diameter polypropylene lid and two PVC sheets between the lid and a 30-cm polypropylene funnel, placed in the lower section with a collection cup where insects fell when they collided with the PVC sheets. The collection container was surrounded by a green membrane to prevent visitors to be attracted by its white original colour and avoid any damage. The trap was placed in the trees approximately at about 3 or 4 meters from the ground by a rod and separated from the trunk to avoid it to blow or be damaged (Figure 4). Furthermore, insects will be capable of going to the trap and not get mixed up with the main tree. Once they collided with the sheets, they fell into the collection cup helped by the funnel previously filled by 1,2-Propandiol EMPLURA ® (from now on named as propylene glycol) that will cause death of the specimens and its conservation for further studies. Besides the propylene glycol, a few soap drops were added to the container so the superficial tension was broken and it facilitated the insects' immersion.

**Figure 3**. Commercial image of the CROSSTRAP ® MINI traps used. Source: ECONEX ® Feromonas y trampas (https://www.e-econex.com/trampas-para-insectos/).

**Figure 4**. Traps recollection on the first sampling day (16-06-2017). Source: Esther Lucha.

## 3.4. Identification of individuals

Every 15 days, the content of the collector was transferred to a sample jar with the corresponding trap code (Vol N x.y. or Vol S x.y., where "x" is the plot number and "y" is the number of the trap) and the date of the sampling. When the collector is placed again it is essential to refill it with a conservation liquid (propylene glycol and a few soap drops). In the laboratory, the content was analysed and classified in 1) coleoptera, 2) diptera and 3) other arthropoda. First, with a strainer, the propylene glycol was dismissed and deposited in a bigger container to be recycled. The remaining insects were transferred into a Petri's plate, previously cleaned out with alcohol 70%, for its classification into the mentioned groups. With the help of identification keys and the SZH10 Research Stereo binocular microscope (Olympus DF PLANAPO I X) insects were separated into three different polypropylene sample containers specific for sampling, with a variable volume depending on the quantity and size of the classified individuals (Figure 5). They were filled with alcohol 70% to cover and preserve the specimens, with an inside and outside-label where the order, type of experiment (Non-intervention "N" or Sustainable logging "S"), trap code, sampling date and number of individuals were indicated (Table 2); the inside consists of a piece of parchment paper written by pencil, being useful if the outside label is erased.

Once the classification was finalised, beetle jars were sent to Amador Viñolas, an expert of the order Coleoptera at the Natural Sciences Museum in Barcelona, so he could classify them to a specific level and to obtain biological results of the captured species, as well, for its later evaluation and to study its interrelation with the burned area.

**Table 2**. Example of label for the classification of the insects from each sampling pot.

| | |
|---|---|
| **Order** | Coleoptera |
| **Type of experiment and trap number** | VOL S4.2 |
| **Date** | 16/06/2017 |
| **Number of individuals** | 168 |

**Figure 5**. Classified samples of the individuals in different sample containers.

## 3.5. Ecological differences

Just to have some information available that allows us to better interpret the results of the coleopteran sampling, it has been studied the wood biomass and the vegetation among treatments. This information comes from a Master's Thesis realised in the *Pecat* research group (Felipe, 2017). The wood biomass was obtained by forest inventories (FI) conducted in Spring 2017, one or two months before the coleopteran sampling. Depending on the plot dimension, between 1 and 3 inventories were conducted with a 10 meters radius in each plot, getting a total of 10 FI for the treatment Sustainable logging and 8 FI for the Non-intervention. In the S treatment, the logging and retiring of trunks supposed an immediate loss of wood biomass which was quantified just before and after the logging. For the treatment N forest inventories were done only once because the loss of the standing biomass takes place in a long-term with the progressive falling of burned trees (Table 3). On the other hand, the FI also provided the abundances (number of standing trees > 7 cm DBH – diameter at breast height, 1.25 m) of the tree species (Table 4).

**Table 3**. Wood volume in the S and N plots before and after the logging according to the requirements of each treatment. In the case of N (non-sustainable logging) there is any cut down.

| | S | N |
|---|---|---|
| **Wood biomass before the logging (m3/ha)** | 87.2 | 84.2 |
| **Wood biomass after the logging (m3/ha)** | 75.2 | 84.2 |
| *Living standing trees but affected by fire (trunk and branches)* | 9.0 | - |
| *Remaining wood (logged trunks in-site because no-one collected them):* | 8.8 | - |
| *Remaining wood as branches piles* | 13.9 | - |
| *Used wood (trunks for saw and to grind)* | 55.5 | - |

The understory plant species covering percentage is also available based on the 30 meters long vegetation transects and 31 points where data was collected, performed in both treatments (Table 5). In the N treatment 7 transects were distributed into the different available plots. Further, in S treatment 7 transects were conducted in cleared ways trampled by forestry machinery and 7 transects out of the ways, of which the total percentage of understory plants covering was obtained (Table 6). The percentage values belong to the number of points where the species appears in relation to the total amount of points in each treatment. Thus, in treatment S 434 points are obtained (31 points x 14 transects) and 217 points in N (31 points x 7 transects). All of the transects were done in May 2017, after the logging.

Those values will allow, afterwards, interpret the results and draw conclusions to value which type of management (non-intervention or sustainable logging) favour a better biodiversity in a forest recently affected by a wildfire.

**Table 4**. Tree species abundance (number of standing trees > 7 cm DBH) in each treatment, showed as number of trees per hectare. Data from 18 forest inventories.

| | | **S** | **N** |
|---|---|---|---|
| **Arboreal species** | *Pinus pinea* | 321.5 | 210.9 |
| | *Quercus suber* | 455.2 | 409.8 |
| | *Quercus ilex* | 9.5 | 39.8 |
| | *Quercus pubescens* | 6.4 | 0 |

**Table 5**. Herbaceous plants and shrub species covering, showed as percentage. Data come from 21 vegetation transects; 14 in S (sustainable logging) and 7 in N (non-intervention).

| | | **% S** | **% N** |
|---|---|---|---|
| **Understory species** | *Arbutus unedo* | 1.8 | 2.3 |
| | *Brachypodium retusum* | 2.5 | 7.8 |
| | Branca cremada | 12.4 | 0.9 |
| | Branca morta | 0.5 | 0 |
| | *Calicotome spinosa* | 1.4 | 4.1 |
| | *Cistus monspeliensis* | 2.9 | 0.5 |
| | *Cistus salviifolius* | 14.7 | 13.4 |
| | *Clematis vitalba* | 0.7 | 0 |
| | *Conyza bonariensis* | 0.7 | 0 |
| | *Conyza canadensis* | 0 | 0.9 |
| | *Erica arborea* | 2.9 | 5.5 |
| | *Lonicera implexa* | 0.5 | 0 |
| | *Myrtus communis* | 0.9 | 0.9 |
| | *Phillyrea angustifolia* | 0 | 0.5 |
| | *Quercus ilex* (rebrot) | 1.4 | 0.9 |
| | *Quercus pubescens* (rebrot) | 0.5 | 0.9 |
| | *Quercus súber* (rebrot) | 0.2 | 0.9 |
| | *Rubia peregrina* | 2.1 | 2.7 |
| | *Smilax aspera* | 0.2 | 0.5 |
| | *Viburnum tinus* | 0.2 | 1.4 |

## 3.6. Data analysis

The data from the sampling are summarized in Table 6, with which the analyses were performed.

**Table 6**. Species collected during the sampling with its total value of abundance in each treatment (N for Non-intervention and S for Sustainable logging), their food regime (defoliator (DE), detritivore (D), seed feeders (G), fungal feeding (M), predators (P), predator-detritivore (PD), xylophagous (X) or they feed of the trees' exudate (E) or vegetation (V)). and whether they are or not saproxylic species. Also the conservation status is included from the European Red List of Saproxylic Beetles (2010). Categories of the conservation of the species found in this study: Least concern (LC) and not evaluated (NE), meaning this species has not been assesed in the European Red List or it is not saproxylic. *Xantholinus linearis'* food regime is unknown.

| Species | Total N | Total S | Food regime | Saproxility | Conservation status |
|---|---|---|---|---|---|
| *Abdera quadrifasciata* | 1 | 1 | M | SA | NE |
| *Acanthocinus griseus* | 3 | 2 | X | SA | NE |
| *Acmaeodera octodecimguttata* | 4 | 3 | X | SA | NE |
| *Adalia decempunctata* | 88 | 72 | P | NS | NE |
| Aderidae (family) | 1 | 0 | X | SA | NE |
| *Agrilus elegans* | 1 | 0 | V | NS | NE |
| *Agrilus hastulifer* | 2 | 6 | V | NS | NE |
| *Agrilus integerrimus* | 1 | 2 | X | SA | NE |
| *Allandrus undulatus* | 2 | 5 | M | SA | NE |
| *Allonyx quadrimaculatus* | 0 | 1 | P | SA | NE |
| *Ampedus praestus* | 0 | 3 | P | SA | LC |
| *Anaspis lurida* | 5 | 15 | X | SA | NE |
| *Anaspis ruficollis* | 19 | 9 | X | SA | NE |
| *Anobium hederae* | 1 | 0 | X | SA | NE |
| *Anotylus* sp. | 0 | 1 | D | NS | NE |
| *Anthaxia confusa* | 1 | 1 | X | SA | NE |
| *Anthaxia umbellatarum* | 0 | 1 | X | SA | NE |
| *Anthocomus fenestratus* | 2 | 0 | P | NS | NE |
| *Aplocnemus virens* | 1 | 0 | P | SA | NE |
| *Arhopalus ferus* | 18 | 57 | X | SA | NE |
| *Arhopalus rusticus* | 7 | 20 | X | SA | NE |
| *Arhopalus syriacus* | 0 | 1 | X | SA | NE |
| *Arthrolips convexiuscula* | 3 | 11 | D | NS | NE |
| *Arthrolips obscura* | 17 | 32 | D | NS | NE |
| *Atetha* sp. | 17 | 22 | M | NS | NE |
| *Attelabus nitens* | 0 | 1 | DE | NS | NE |
| *Aulonium ruficorne* | 1 | 3 | P | SA | NE |
| *Axinotarsus marginalis* | 0 | 1 | P | NS | NE |
| *Berginus tamarisci* | 496 | 563 | M | SA | NE |
| *Bruchidius seminarius* | 0 | 1 | V | NS | NE |
| *Buprestis novemaculatus* | 1 | 1 | X | SA | NE |
| *Calodromius bifasciatus* | 1 | 2 | P | NS | NE |
| *Carphoborus pini* | 35 | 361 | X | SA | NE |
| *Cartodere satelles* | 5 | 6 | E | SA | NE |
| *Catapion pubescens* | 1 | 0 | V | NS | NE |
| *Cerambyx welensii* | 0 | 2 | X | SA | NE |

| | | | | | |
|---|---|---|---|---|---|
| *Cetonia aurataeformis* | 0 | 2 | V | NS | NE |
| *Chlorophorus glabromaculatus* | 8 | 13 | X | SA | LC |
| *Chrysobothris solieri* | 12 | 15 | X | SA | NE |
| *Cis* sp. | 2 | 1 | M | SA | NE |
| *Cleopomiarus distinctus* | 1 | 0 | V | NS | NE |
| *Colobicus hirtus* | 1 | 0 | P | SA | NE |
| *Coraebus undatus* | 2 | 1 | X | SA | NE |
| *Corticaria* sp. | 0 | 2 | M | SA | NE |
| *Corticeus pini* | 1 | 2 | P | SA | NE |
| *Cryptolestes spartii* | 6 | 8 | PD | SA | NE |
| *Crypturgus mediterraneus* | 270 | 609 | X | SA | NE |
| *Crypturgus numidicus* | 115 | 389 | X | SA | NE |
| *Cybocephalus planiceps* | 2 | 3 | P | NS | NE |
| *Cylister elongatum* | 2 | 1 | P | SA | NE |
| *Cypha apicalis* | 5 | 0 | D | NS | NE |
| *Cypha ovulum* | 7 | 11 | D | NS | NE |
| *Denops albofasciatus* | 1 | 0 | P | SA | NE |
| *Diaperis boleti* | 12 | 2 | M | SA | NE |
| *Dromius agilis* | 1 | 5 | P | SA | NE |
| *Dryocoetes autographus* | 0 | 1 | X | SA | NE |
| *Endophloeus markovichianus* | 0 | 1 | P | SA | NE |
| *Enicmus rugosus* | 26 | 24 | M | SA | NE |
| *Ernobius parens* | 3 | 1 | X | SA | NE |
| *Galerucella lineola* | 0 | 2 | DE | NS | NE |
| *Gastrallus laevigatus* | 0 | 1 | X | SA | NE |
| *Gnathoncus communis* | 0 | 1 | P | NS | NE |
| *Harmonia axyridis* | 11 | 45 | P | NS | NE |
| *Hylastes angustatus* | 1 | 0 | X | SA | NE |
| *Hymenorus doublieri* | 1 | 2 | X | SA | NE |
| *Ips sexdentatus* | 69 | 5 | X | SA | NE |
| *Lacon punctatus* | 0 | 2 | X | SA | LC |
| *Laemophloeus monilis* | 22 | 79 | PD | SA | NE |
| *Lathropus sepicola* | 1 | 0 | PD | SA | NE |
| *Lissodema denticolle* | 2 | 0 | P | SA | NE |
| *Litargus conexus* | 29 | 18 | M | SA | LC |
| *Magdalis memnomia* | 1 | 2 | X | SA | NE |
| *Magdalis rufa* | 2 | 12 | X | SA | NE |
| *Melanophila acuminata* | 0 | 1 | X | SA | NE |
| *Melanophila cuspidata* | 1 | 4 | X | SA | NE |
| *Melanopsacus grenieri* | 0 | 5 | M | SA | NE |
| *Meliboeus fulgidicollis* | 1 | 3 | X | SA | NE |
| *Mycetophagus quadriguttata* | 0 | 2 | M | SA | NE |
| *Mycterus curculionoides* | 1 | 7 | X | SA | NE |
| *Myrrha octodecimguttata* | 0 | 1 | P | NS | NE |
| *Nathrius brevipennis* | 0 | 2 | X | SA | NE |
| *Nemozoma elongatum* | 0 | 1 | P | SA | LC |
| *Nudobius collaris* | 2 | 0 | D | NS | NE |
| *Oedemera femoralis* | 32 | 9 | V | SA | NE |
| *Oedemera flavipes* | 1 | 2 | X | SA | NE |
| *Opilo domesticus* | 0 | 3 | P | SA | NE |

| | | | | | |
|---|---|---|---|---|---|
| *Orchestes pilosus* | 1 | 0 | DE | NS | NE |
| *Orphilus niger* | 1 | 0 | V | NS | NE |
| *Orthotomicus longicollis* | 71 | 73 | X | SA | NE |
| *Oryzaephilus surinamensis* | 0 | 1 | M | NS | NE |
| *Pentaphyllus chrysomeloides* | 2 | 2 | M | SA | NE |
| *Phaenops cyanea* | 2 | 2 | X | SA | NE |
| *Phyllotreta undulata* | 0 | 1 | DE | NS | NE |
| *Placonotus testaceus* | 21 | 48 | PD | SA | NE |
| *Platypus cylindrus* | 1 | 1 | X | SA | NE |
| *Polydrusus cervinus* | 2 | 0 | V | NS | NE |
| *Propylea quatuordecimpunctata* | 1 | 0 | P | NS | NE |
| *Protaetia cuprea* | 1 | 1 | X | SA | NE |
| *Protaetia opaca* | 26 | 33 | X | SA | LC |
| *Pseudorchestes persimilis* | 1 | 3 | DE | NS | NE |
| *Ptinus dubius* | 8 | 15 | X | SA | NE |
| *Rhaphitropis oxyacanthae* | 1 | 2 | M | SA | NE |
| *Rhynchophorus ferrugineus* | 2 | 0 | X | SA | NE |
| *Rhyncolus sculpturatus* | 14 | 31 | X | SA | NE |
| *Scopaeus minimus* | 1 | 0 | P | NS | NE |
| *Scraptia dubia* | 1 | 0 | X | SA | NE |
| *Scymnus subvillosus* | 3 | 9 | P | NS | NE |
| *Sericoderus lateralis* | 1 | 0 | D | NS | NE |
| *Stenorhynchites coeruleocephala* | 13 | 19 | DE | NS | NE |
| *Stylosomus minutissimus* | 0 | 1 | V | NS | NE |
| *Symbiotes gibberosus* | 5 | 4 | M | SA | NE |
| *Synchita fallax* | 16 | 27 | M | SA | NE |
| *Temnochila coerulea* | 13 | 9 | P | SA | LC |
| *Teretrius parasita* | 1 | 0 | P | SA | NE |
| *Thanasimus formicarius* | 2 | 2 | P | SA | NE |
| *Tomicus minor* | 43 | 21 | X | SA | NE |
| *Tribolium castaneum* | 1 | 0 | P | SA | NE |
| *Trogoderma versicolor* | 1 | 4 | G | NS | NE |
| *Typhaea stercorera* | 1 | 0 | M | SA | NE |
| *Variimorda villosa* | 1 | 2 | X | SA | NE |
| *Xantholinus linearis* | 1 | 0 | ? | NS | NE |
| *Xyleborinus saxsenii* | 37 | 14 | X | SA | NE |
| *Xylotrechus arvicola* | 0 | 8 | X | SA | LC |

Firstly, with the objective to test if there are any significant differences among treatments regarding the tree species an ANOVA test with a single factor was done considering the number of trees per hectare and the type of treatment where they are found. In the case of understory species, there was no normality in the data so a Kruskal-Wallis test was done instead. The significance level, α, to accept or reject the null hypothesis is 0.05 (5%) for all the cases from now on.

With the purpose of knowing the species' specificity to each treatment, a circular chart was realised with Excel 2016 program, where it was indicated which species were found only in one treatment or in both. Furthermore, the abundance of individuals in each treatment was analysed with a Pareto chart, which organises data in a descending order. In our case, it helps to visually detect which are the species with a greater number of individuals and, therefore, the ones that better represent each treatment. It contains, as well, a line that indicates the accumulated percentage of species in the area. In order to verify if any differences exist among treatments regarding the species richness an ANOVA test of a single factor was done and for individuals' abundance a Kruskal-Wallis test was performed as the normality assumption of the ANOVA test was not fulfilled.

We also studied the species' behaviour in each treatment according to its abundance, having into account the traps where the species were found, by a Principal Component Analysis (PCA), an exploratory analysis which permits to reduce the number of variables losing the least amount of information possible (Terrádez-Gurrea, 2006). This type of analysis will allow us to know if there are any species which better represents one or the other treatment and know which one are those species. Data from 123 species regarding the 7 traps of each treatment (Sustainable logging and Non-intervention) were used, getting a matrix of 123 rows and 14 columns. The advantage of the PCA is that it does not require normality in the data set, but some other assumptions are required such as linearity, a sample size big enough (+150 cases), there should be some correlation among the factors and remove outliers (Statistic Solutions, 2017). The R program version 3.4.3. was utilised, with the package "Rcmdr" and the "FactoMineR" plug-in. Finally, names of the traps were needed to be changed, as shown in Table 7.

Subsequently, a Factor Analysis of Mixed Data (FAMD) was fulfilled to study the behaviour of the individuals according to the forest treatment, beetle species' food regime and the fact those are saproxylic or not. To do so, 890 rows and 4 columns matrix was used. Each row is a beetle species inside a sample, being the sample the content inside the flying trap in a 15 days period (remember that each flying trap provided 3 samples). The columns correspond to the species abundance (number of individuals in a sample), the forest treatment (S or N), the species food regime [defoliator (DE), detritivore (D), seed feeders (G), fungal feeding (M), predators (P), predator-detritivore (PD), xylophagous (X) or they feed of the trees' exudate (E) or vegetation (V)], and its saproxylic (SA) or not (NS) character.

**Table 7**. Name of the traps used in the PCA where each trap is identified with a single number and a letter indicating the type of treatment where are situated. "N" belongs to the non-intervention treatment and "S" belongs to sustainable logging.

| **Name** | | **Transformed name** | |
|---|---|---|---|
| **N** | **S** | **N** | **S** |
| N1.1 | S1.1 | *N1* | *S1* |
| N2.1 | S2.1 | *N2* | *S2* |
| N2.2 | S2.2 | *N3* | *S3* |
| N2.3 | S3.1 | *N4* | *S4* |
| N3.1 | S3.2 | *N5* | *S5* |
| N3.2 | S4.1 | *N6* | *S6* |
| N3.3 | S4.2 | *N7* | *S7* |

# 4. Results

## 4.1. Ecological data

To test any difference among treatments considering the number of tree species per hectare, an ANOVA test with a single factor was fulfilled. The resulting matrix has 6 rows, where each tree species is repeated twice (*Quercus pubescens* variable has been removed because its sample size was too small), and two columns which consist of the treatments where the species are found and the number of trees per hectare. Data come from 18 forestry inventories (10 in S and 8 in N) and they have been transformed adding a unit to each data and using the common logarithm so the normality assumption is fulfilled.

The ANOVA test showed there are no significant differences among treatments according to the abundance of the different tree species ($F = 0.04$; $p = 0.851$).

Regarding the understory species, a Kruskal-Wallis test was performed because even transforming the data using the common logarithm, normality assumption is not accomplished. The matrix in this case has 40 rows, where the herbaceous species are repeated twice as well, and 2 columns, one with the type of treatment where each species is found and the covering value. The covering value come from 21 transects, 7 carried out in N and 14 in S.

The Kruskal-Wallis test also confirms that no significant differences exist regarding the covering percentage of the species in the different treatments ($p = 0.945$).

## 4.2. Individuals' abundance and species richness

In the placed traps in the different treatments as a whole a total of 123 different beetle species has been identified and 4523 individuals of which 1684 were found in treatment N and 2839 in S. The Pareto's diagram shows that the most abundant species in N are (in descending order) *Berginus tamarisci* (Wollaston, 1854), *Crypturgus mediterraneus* (Eichhoff, 1871), *Crypturgus numidicus* (Ferrari, 1867), *Adalia decempunctata* (Linnaeus, 1758), *Orthotomicus longicollis* (Gyllenhal, 1827) and *Ips sexdentatus* (Börner, 1776) (Figure 6, up). In S *C. mediterraneus*, *B. tamarisci*, *C. numidicus* has also been found and also *Carphoborus pini* (Eichhoff, 1882) (Figure 6, down). Species with no more than 20 individuals are grouped together in the "Other" variable.

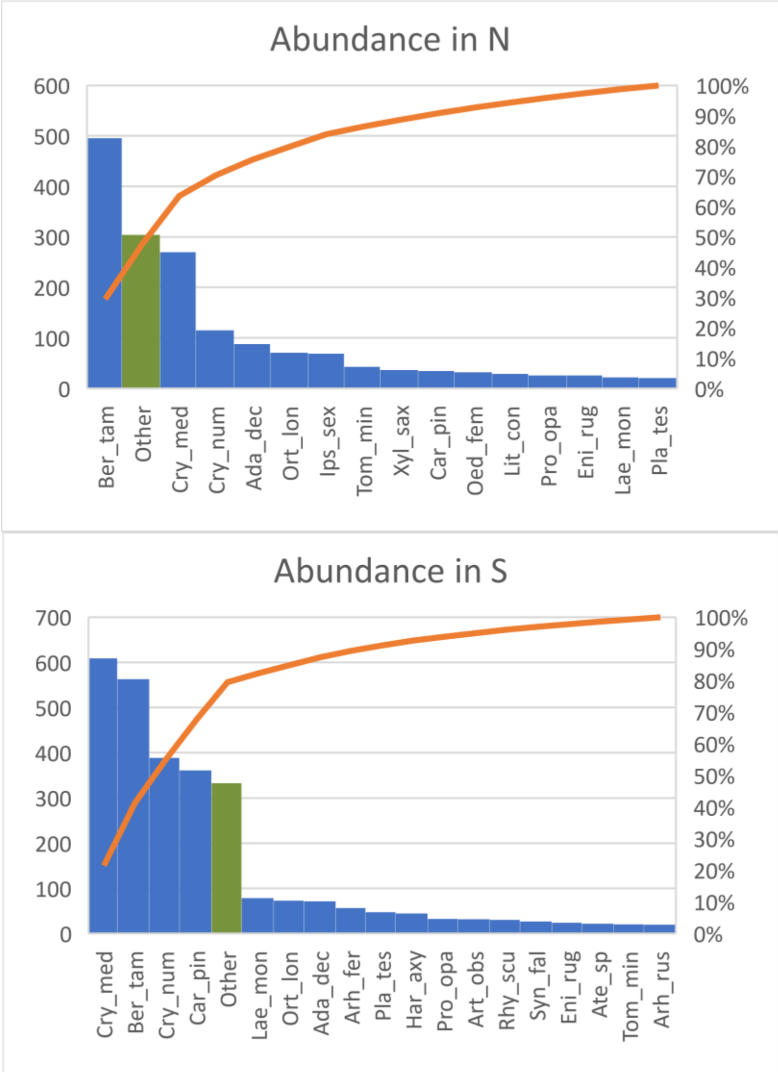


**Figure 6**. Species abundance in treatment N (up) and S (down). Species with less than 20 individuals has been grouped together in the "Other" variable represented in green.

Regarding to species richness, treatment S has a higher number of species than N, being 97 and 95 respectively. Despite this, the difference is only by 2 species.

To verify if any differences according to the abundance among treatments exists, a Kruskal-Wallis test has been performed, because the normality assessment was not achieved so that the ANOVA could not be done. The resulting matrix for the abundance has 246 rows (each species repeated twice) and 2 columns, corresponding to treatment and abundances values. Kruskal-Wallis test show there are no differences in the individuals' abundance according treatments ($p = 0.1769$).

Regarding the species richness a simple ANOVA has been done. It has been necessary to transform data using the normal logarithm to accomplish normality assumption. The matrix for species richness has 42 rows, which are the traps from the three periods, and 2 columns, one for treatment and the other for the number of species found in each trap. In this case, the ANOVA showed differences among treatments ($p = 0.0334$)

### 4.2.1. Species specificity

In the Sustainable logging treatment 28 species exclusive of it were found, 26 in the Non-intervention and 69 species were found in both treatments (Figure 7).

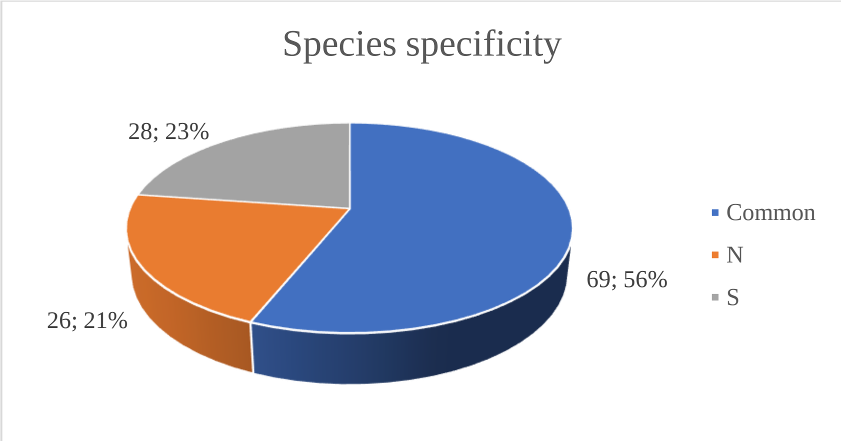


**Figure 7**. Number of species found and percentage of the total number of species found at sustainable logging (S), non-intervention (N) or common to both treatments.

## 4.3. Species behaviour in each treatment according to its abundance

The resultant vectors of the PCA (123 species x 14 traps) (Figure 8) belongs to the number of the traps for each treatment and, as observed, all of them has a similar behaviour as they are in the same positive horizontal axis, which explains a 69.48% of the variance (Dim 1), but differences among vectors are due to the vertical axis, which represents a 10.94% of this variance (Dim 2). In this case sampled individuals are not differentiated between periods.

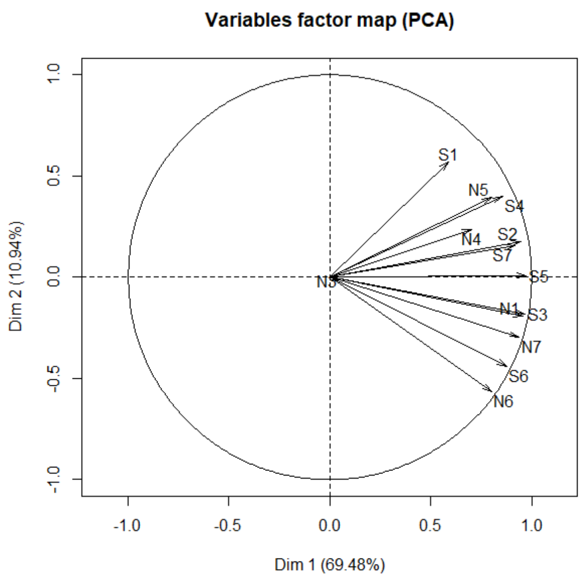


**Figure 8**. Behaviour of the different variables S and N according to the abundance resulting from the PCA.

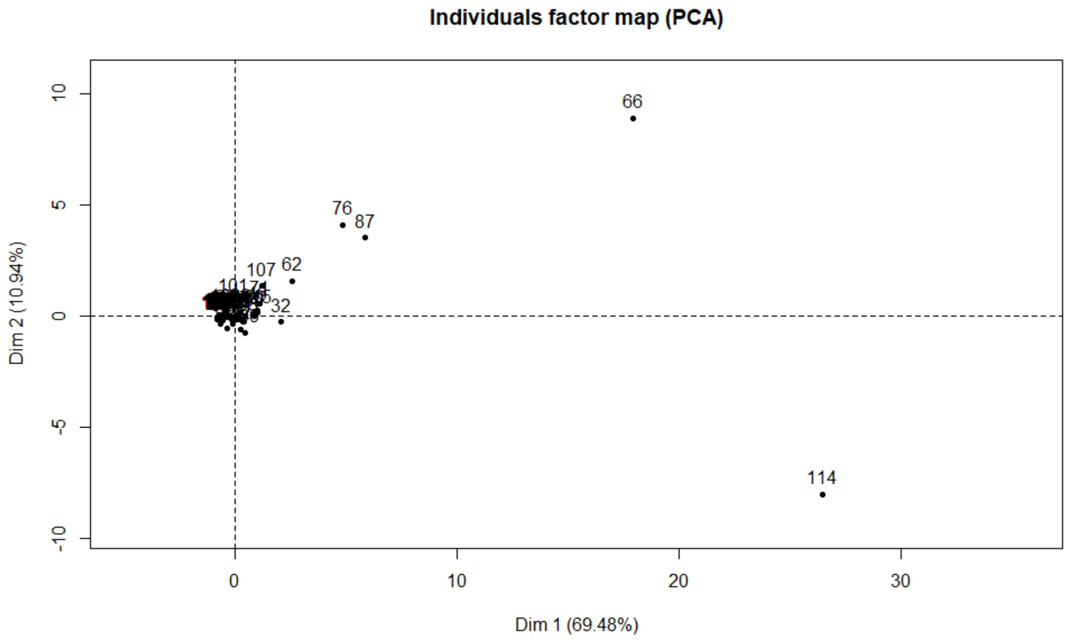


**Figure 9**. Species distribution resulting from the PCA, which are represented by numbers, having into account the behaviour of the variables in Figure 8.

This analysis also generates a graphic where the distribution of the 123 is represented in consonance with the traps of each treatment (N or S) (Figure 9). Most of the species are found in the origin (0,0), indicating they are less abundant and do not have a clear differentiation according to the treatments. Furthermore, there are points out of the origin and, therefore, are more abundant. Besides they are described by the traps vectors in Figure 8; points 66, 76, 87 and 62 adjust on the S1 trap vector, ordered from highest to lowest abundance. Point 32 adjust on the N3 vector and point 114 could adjust on N6, S6 and N7 vectors. If we check the graphical results with the numerical values (Table 8) the distribution of the points on the vectors coincide with the number of individuals, even though for the point 114 can be confusing; in this case the species is abundant for different traps although graphically it adjusts on N6, S6 and N7. This could be because in these traps the species *Berginus tamarisci* is the most representative regarding to the others.

**Table 8**. Numerical values of the abundance of the most representative points, with the pertinent species, in the PCA in each trap located in plots of the different treatments.

| Point | Species | N1 | N2 | N3 | N4 | N5 | N6 | N7 | S1 | S2 | S3 | S4 | S5 | S6 | S7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **66** | *Crypturgus mediterraneus* | 43 | 63 | 18 | 44 | 64 | 4 | 34 | **223** | 42 | 46 | 103 | 75 | 13 | 107 |
| **76** | *Crypturgus numidicus* | 37 | 31 | 0 | 23 | 8 | 1 | 15 | **350** | 12 | 6 | 5 | 10 | 6 | 0 |
| **87** | *Carphoborus pini* | 19 | 4 | 2 | 4 | 0 | 1 | 5 | **198** | 25 | 5 | 46 | 20 | 18 | 49 |
| **62** | *Orthotomicus longicollis* | 5 | 7 | 3 | 13 | 28 | 2 | 13 | **40** | 4 | 11 | 5 | 5 | 2 | 6 |
| **32** | *Adalia decempunctata* | 8 | 4 | **50** | 13 | 3 | 7 | 3 | 21 | 8 | 10 | 1 | 13 | 10 | 9 |
| **114** | *Berginus tamarisci* | **117** | **95** | 25 | 39 | 30 | **86** | **104** | **80** | 44 | **88** | 55 | **97** | **99** | **100** |

## 4.4. Influence of the ecological variables in the beetle species' abundance

In the first place, a FAMD was done having into account the abundance of all the species but there was an unknown food regime which corresponded to *Xantholinus linearis* and only appeared once, so it was removed from the data set.

The x-axis (Dim 1) represents a 16.90% of the variance and it is explained by the "Sapro" variable, where the saproxylic individuals are situated to the right and those non-saproxylic are situated to the left, and the y-axis (Dim 2) represents a 10.20% of the variance and it is explained by the forest treatment (Figure 10).

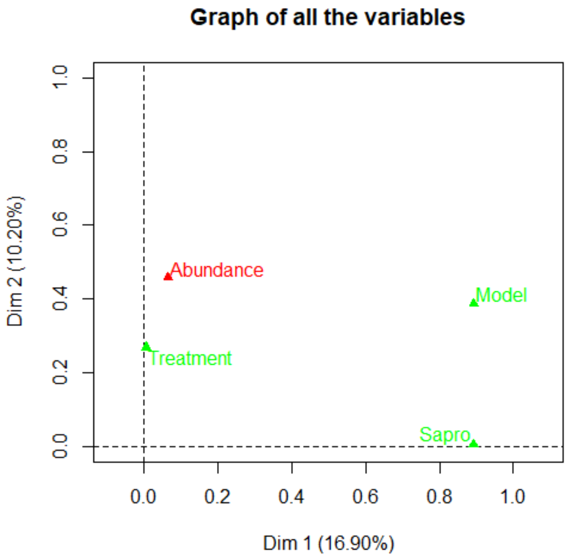


**Figure 10**. Graphic showing which variables better represent the x and y axes in the FAMD. The "Sapro" variable identifies the species with a saproxylic food regime (located on the right) or not saproxylic (left). "Treatment" variable identifies the species found in N, near to the origin point (0,0), or S, distant to (0,0). "Model" variable groups together the species according its food regime although it is not clear which axes better represents this variable, as it has multiple answers.

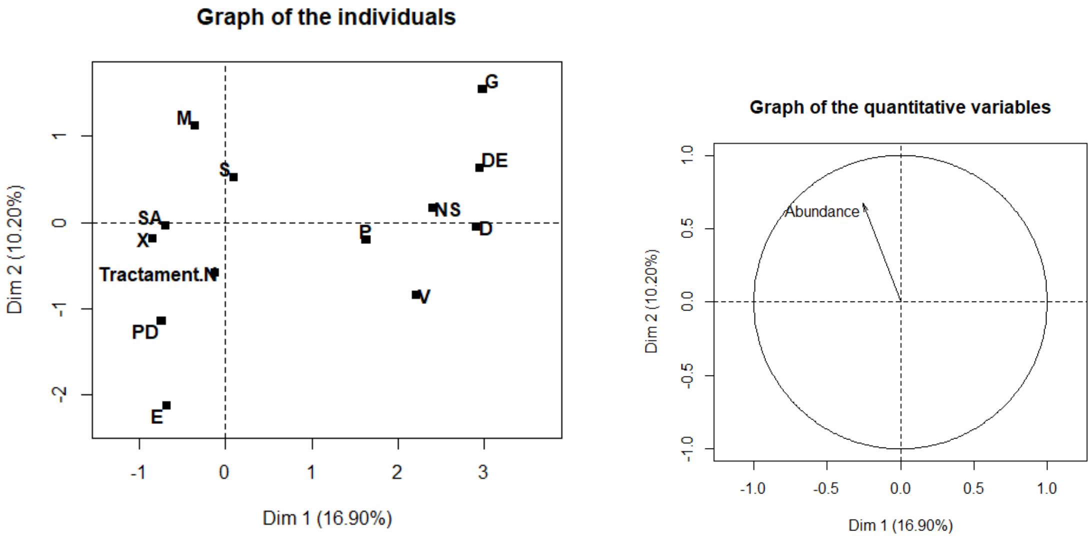


**Figure 11**. Continuation of FAMD results. On the left, the distribution of the food regimes according to forest treatment (S or N) and whether they are saproxylic (SA) or not (NS). Food regimes are represented by defoliator (DE), detritivore (D), seed feeders (G), fungal feeding (M), predators (P), predator-detritivore (PD), xylophagous (X) or they feed of the trees' exudate (E) or vegetation (V). The graphic of quantitative variables (right) points out where the most abundant individuals are located.

The graph of individuals (Figure 11) separates data in one group of non-saproxylic species, NS (G, DE, D, P and V) from another of saproxylic species, SA (M, X, PD and E). Regarding treatments, there are more species in Sustainable logging than in Non-intervention, being M model the most abundant. Finally, X model are clearly saproxylic (SA).

In order to test if there are differences among treatments regarding the beetles' food regime and whether they are saproxylic or not, a three-way ANOVA test (Treatment, Model and Saproxylic) was done. Homoscedasticity assumption was fulfilled but not the normality one though it is not a problem because the sample size is large enough.

**Table 9**. Three-way ANOVA test results. Model, Sapro and Treatment refers to feeding regime, saproxylity and type of treatment S or N, respectively. P-values allows to accept or deny the null hypothesis, $H_o$ (if the p-value > 0.05 $H_o$ is accepted and there are no differences among factors). F-statistics indicates if there is variation among groups (F >1) or not (F = 1). Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1.

| **Variables** | **Degrees of freedom** | **F** | **P-value** |
|---|---|---|---|
| Model | 8 | 1.4705 | 0.16391 |
| Sapro | 1 | 1.2796 | 0.25829 |
| Treatment | 1 | 5.5186 | 0.01904 * |
| Model:Sapro | 2 | 2.8563 | 0.05803· |
| Model:Treatment | 8 | 0.4711 | 0.87695 |
| Sapro:Treatment | 1 | 0.0010 | 0.97496 |
| Model:Sapro:Treatment | 2 | 0.0120 | 0.98807 |

In general, p-values show that there are not significative differences, pointing out that the individuals abundance for each variable and for the interactions is similar. However, there are differences in the treatment variable which means the abundance among treatments differ considerably (Table 9).

These results can be verified in Figure 12, where data from the variables Model and Saproxylic have been grouped together, obtaining MiS variable. In this way we can notice which food regime, distinguished whether they are saproxylic or not, are the most abundant in each treatment according to the number of individuals. In general, there are more saproxylic individuals in S, being XS the most abundant food regime and where the difference is more evident. MS model is the second most abundant with no great differences among treatments. However, PDS is not as abundant as XS or MS but the difference among treatments is important, being 135 in S and 50 in N. The problem in this bar chart in that the results can be only due to one trap where there are lots of individuals, altering the final result.

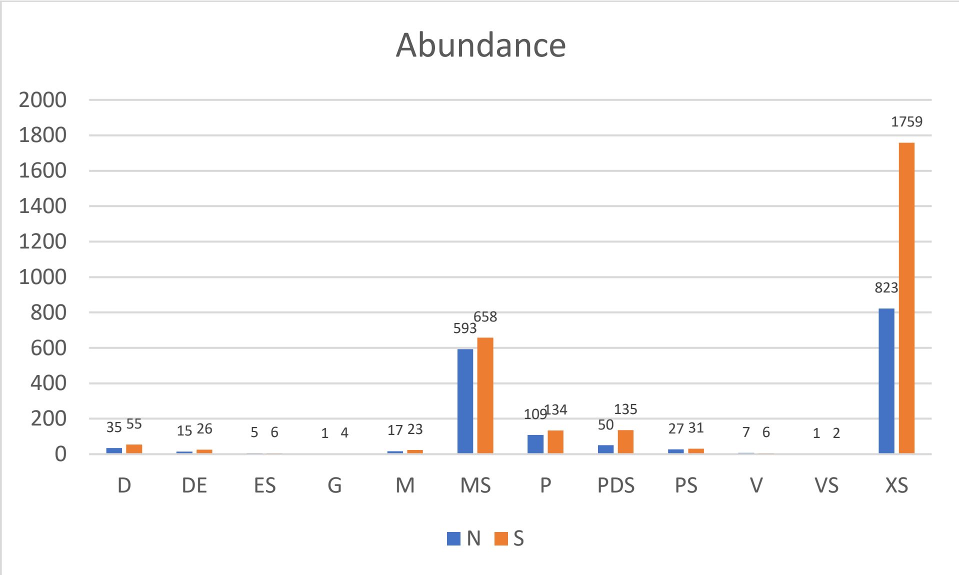


**Figure 12**. Individual abundance according MiS variable, based on Model and Saproxylic variables, and forest treatment (S or N). Defoliator (DE), detritivore (D), seed feeders (G), fungivore (M), predators (P), predator-detritivore (PD), xylophagous (X) or they feed of the trees' exudate (E) or vegetation (V). There are initials accompanied by an S which indicates it saproxylic character.

# 5. Discussion

The obtained results in the beetles sampling in each plot show that there are more individuals in the sustainable logging treatment than in the non-intervention. *Berginus tamarisci* (Wollaston, 1854), *Crypturgus mediterraneus* (Eichhoff, 1871) and *Crypturgus numidicus* (Ferrari, 1867) species are the most abundant in both treatments, even though they have different abundances in each. Otherwise, *Ips sexdentatus* (Börner, 1776) is an outstanding species as it has 69 individuals in the non-intervention but only 5 in sustainable logging, as well as *Carphoborus pini* (Eichhoff, 1882), which has 361 individuals in S and only 35 in N. Those two species are named because they are found in both treatments but with very different abundances. Both of them belong to the Scolytidae family and its main characteristic is that species from this family are xylophagous pests that infect conifers, more specifically pines (López, Romón, Iturrondobeitia, & Goldarazena, 2005). The fact that more individuals of *C. pini* are found in treatment S can make sense as there is a greater number of *Pinus pinea* trees than in N, according to the collected data in the forestry inventories. However, *I. sexdentatus* is more abundant in N even though there are less pines than in S. This species is the most abundant bark beetle in the Iberian Peninsula and it is characterised by infecting those weakened or less robust pines. A possible reason for this abundance difference among treatments is the fact that in sustainable logging dead trees or those affected by fire have been cut down (although some of those logs were left on-site) yet in N dead or moribund trees remained in the same place being more susceptible to being infected by this beetle (López et al., 2005). Despite the difference in number of pines per hectare among treatments, those are not significant and finding more individuals of *I. sexdentatus* may be by chance.

Regarding species richness, the number of species is similar both in non-intervention and sustainable logging treatment, having two more species in S representing a bit more of the half of individuals in N. Nonetheless, statistically there are differences in the species richness from each treatment. The species specificity chart shows that there is also a greater percentage of species that are found exclusively in sustainable logging treatment with a 23% against a 21% in non-intervention. In any case, there is a major proportion of species found in both treatments, being a 56%. Despite the differences according to the individuals' abundance is not significant among treatments, it is clear that sustainable logging treatment has characteristics that favour the presence of beetles, being that more abundant than in non-intervention. A possible cause could be the way in which dead biomass is arranged in S treatment compared to N because of the conducted management.

The fact that a large number of the species are found in both treatments could be explained by various aspects. Regarding the sampling, not having enough space available to fulfil the study influenced in the plot size, which was relatively small (around a hectare), so that those were close to each other. Even though, plots belonging to each treatment were alternated homogenously to reduce the size effect. Looking at the wide range of dispersion of beetles, some of them could have gone to other plots and alter their original composition. In addition, the sampling was done two months after the logging, so beetles could have had no much time to react to this action, even though the less time goes by from the logging the more volatile substances will be emitted from wood. That act as chemical stimulus which attract beetles from other areas nearby the sampling and allows them to find accessible wood easier. Likewise, the less time goes by from the logging the more ecological niches will be which beetles will occupy more easier and with less competition of other organisms. Despite this, there is a considerably high number of specific species in each treatment which means the sampling was successful.

Both sustainable logging and non-intervention treatment were affected by fire and have, if not the same, a similar composition of the flora as shown in the ecological data, as they take part of the same forest. The difference is found in the type of management performed; in S burned trees were cut down, some of them being retired, and in N those were left on-site after the wildfire. Therefore, S will have less amount of wood (31.7 $m^3$/ha versus 84.2 $m^3$/ha in N) but this wood is distributed in standing trees and piles, which favour the presence of beetles (Jonsell, 2008) because the inside wood is more accessible for insects, volatile substances can be spread, like ethanol, which attract other beetles and insects close to the sampling area (Hammond, Langor, & Spence, 2017) and ideal humidity, temperature and, therefore, favourable decomposition state conditions can be found where beetles can live. Hammond et al. (2017), in his study with flying traps, also proved that flying activity of beetles increased where there were open spaces. Regarding understory herbaceous species, the covering values of the different species is similar even though more differences are found in burned branches. In sustainable logging treatment those branches remained in the understory while in the non-intervention most of them remained in the trees. However, neither differences among treatments were found regarding the understory species' covering.

According Vodka, Konvicka, & Cizek (2009) study, saproxylic beetles have preference for sun-exposed wood. Although wildfire burned homogeneously the canopy in both treatments, so that the sun should radiate equally in both, in sustainable logging cut downs and biomass piles have been conducted which can slightly clear the understory yet no significant differences in the plant covering percentage have been found. They also mention that the rarest species are found in sun-exposed places while those generalists take up in shaded stands and prefer feeding on advanced decomposition state wood and depend on shade-tolerant trees, which is not our case. So, knowing the dominant tree species (*Quercus suber* and *Pinus pinea*) tolerate the solar irradiance and the management practices developed in the sustainable logging treatment, our results make sense.

According to the PCA, the variables factor map (Figure 8) show the vectors which represents each of the traps located in each treatment. There are differences between them as they are slightly separated from each other, but it should be pointed out that all of them are orientated to the right, so the current differences are scarce. In this case, the more separated and opposed the vectors are the more differences will be among them but it is not the case so, traps from the different treatments are similar.

Concerning the species, the most representative one in each treatment observed in the PCA coincide with the previous abundance results. Most of the species are found near the origin point showing a low abundance and not being differentiated among treatments whereas a few specific species are more abundant so are away from the origin point and located according to the vector which better represents. The trap where more species individuals are found is S1, which may have certain characteristics that favour the presence of beetles. It could be that the wildfire did not affect as much as in other areas or maybe beetles found more resources (deadwood) and microhabitats.

There is one species, *Berginus tamarisci* (Wollaston, 1854) which could adjust to three different vectors from both treatments (N6, S6 and N7). If we compare these results with the numerical values it is observed that this species is abundant for almost all the traps realised. The fact that it is near to some vectors does not mean it is more abundant in these traps than in the others but it is a very important species to explain the vectors with which it better adjusts and, even being present in the other traps, these can contain other species that explain them more clearly and differentiate them from the other vectors. This species may find optimal characteristics in both treatments and is not affected by the type of forest management. Just as the family to which they belong, Mycetophagidae, they mainly feed on fungus and are found normally under fungus-grown bark, in shelf-fungi and on mouldy vegetative material (Arnett Jr, Thomas, Skelley, & Frank, 2002). Also, *Berginus* species have been observed to feed on pollen (Arnett Jr et al., 2002). In this case, the sampling was done after spring and so the pollen production of the surrounding vegetation could have affected their presence.

In the FAMD two groups are well differentiated according to whether beetles are saproxylic or not regarding to its food regime; on the one hand, food regimes with non-saproxylic species with low abundances and, in the other hand, food regimes with more abundant species, those being saproxylic. The differences in the interaction between these two variables (food regime and saproxility) has not been significant although its p-value is close to the significance level (0.05). A possible reason could be that the non-saproxylic beetles come later to the area and, therefore, doing the sampling one year after the wildfire has influenced in the capture of those beetles, resulting in a low abundance. In further studies it is possible to find more non-saproxylic individuals because new biomass will grow which will be the habitat for those insects.

Regarding to the treatments, sustainable logging has a greater number of species compared to the non-intervention treatment and the most abundant food regimes are mycophagous and xylophagous, the latter being highly saproxylic. Brin, Bouget, Brustel, & Jactel (2011) found in their study a greater abundance of mycophagous and saproxylic xylophagous in small branches and large logs than in large branches and small logs. In addition, they could confirm that branches from oaks and pines provided a suitable habitat for those species and that these trees harbour more threatened saproxylic beetle species than logs do. Thus, the fact that sustainable logging treatment has branches piled up which constitute most of the biomass in this treatment, logs *in-situ* and standing trees favour the presence of these mycophagous and xylophagous species.

The food regime abundance graph, divided whether they are saproxylic or not, shows that the most abundant individuals are the saproxylic, as mentioned before. Even though, in this case the most abundant individuals are the xylophagous saproxylic followed by mycophagous in contrast to the FAMD. A possible explanation is that xylophagous saproxylic beetles (XS) are the most abundant saproxylics (symbolised as SA) so that is why in the FAMD its corresponding point is situated closer to SA point. In the second place there is mycophagous point (MS) which is the second most abundant food regime but it is not the one which better represents the variable SA. In this way, it is justified that its point is far from SA point leading us to believe that it is the most abundant model regarding the others. Lastly, it should be noted that PDS model (saproxylic predator-detritivore) is not one of the most abundant models but there is an important difference among treatments, being more abundant in the sustainable logging. As mentioned in Wikars (1997), wildfires increase predation because they decrease hiding places and generalists predators can spread more easily in the burned areas. If we apply this theory into the fulfilled treatments, in sustainable logging, besides the wildfire which removes part of the vegetation, wood has been retired or accumulated in specific places, resulting a more open area favouring the presence of those predator beetles.

# 6. Conclusion

During years, when a forest was affected by a wildfire burned wood from the logs was harvested and branches were left on the field. A decade ago, approximately, and with the increasing biomass production and wood collection with energetic purposes, the exploitation of burned wood after a wildfire has increased until harvesting the whole trunk (crown included). In this study we wanted to verify which type of management in a Mediterranean forest affected by a wildfire favour saproxylic beetle diversity, following the handbook of Good Practices done in the *Anifog* project. In general, both the individuals' abundance and species richness has been greater in sustainable logging treatment than in the non-intervention one. Anyway, differences have not been significant for the abundance maybe because of the short time from the fire and the proximity and size of the plots. Additionally, the most abundant species resulted to better adjust to the traps in sustainable logging treatment just like those species with saproxylic food regimes. It should be pointed out that any of the species sampled is nowadays in the European Red List of Saproxylic Beetles nor in the "Atlas y Libro Rojo de Los Invertebrados de España".

This has been the beginning of a study that in the future can give more clarifying results upon how to manage a recently burned forest. Nowadays it is necessary to manage considering the species conservation, especially those threatened ones as saproxylic beetles are, but to accomplish this the recovering of the ecosystems must be favoured. Throughout this study I realised that most of the studies and information related to the management of forests after a wildfire were focused on Scandinavian regions and other central European regions. For that reason, I consider it is necessary to continue studying the Mediterranean region as soon as possible to improve the conservational state of this ecosystem.

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