

## EFFECTS OF FIRE ON EURASIAN BADGER'S TROPHIC ECOLOGY IN CORK OAK WOODLANDS OF SW PORTUGAL

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### ABSTRACT

The patterns of food availability and consumption of two social units of badgers, *Meles meles*, were analysed in a post-fire situation in the mountain of Grândola, SW Portugal, comparing with a pre-fire situation. Negative effects of the fire event were detected in the two key-resources – fruits and arthropods. However, the perceived decrease in the availability of food resources in the study area was limited to some of the fire-affected food items since the post-fire year was a fairly productive one. Although there was significant variation between pre and post-fire diets, the already described pattern of a diet consisting mainly of fruits in winter and adult arthropods in spring prevailed. Furthermore, olives were identified as the preferred resource, thus supporting the current theory that in Mediterranean ecosystems badgers are generalist feeders with seasonal specialisations. However, although resource abundance was not affected, the distribution and the richness of the different habitat fragments where they occur changed. Therefore, the fact that no important impacts on badgers' diet were detected cannot guarantee that the species ecology was not affected. The hypotheses of group size reduction and/or expansion of the territory, in order to overcome the constraints associated with trophic resources depletion are discussed in the context of the Resource Dispersion Theory applied to food resources.

Key words: fire, key-resources, Mediterranean landscape, *Meles meles*, trophic ecology.

### RESUMEN

#### *Efectos del fuego sobre la ecología trófica del tejón en un alcornocal del SO de Portugal*

Se ha estudiado la disponibilidad de alimento y la dieta de dos grupos sociales de tejón, *Meles meles*, después de un incendio en el alcornocal de la sierra de Grândola, en el suroeste de Portugal, comparándolo con la situación anterior al incendio. Se han detectado efectos negativos del fuego en los dos recursos clave de la especie: frutos y artrópodos. Sin embargo, la disponibilidad total de alimento en el área de estudio no ha resultado muy deteriorada puesto que el año posterior al incendio ha sido moderadamente productivo. A pesar de las variaciones registradas en la

alimentación tras el incendio, se ha mantenido la tendencia ya verificada de predominio del consumo de aceituna en invierno y de artrópodos en primavera. Además, se concluye que la aceituna es el recurso preferido, comprobándose la teoría en vigor que postula que el tejón es, en ambientes mediterráneos, una especie generalista con especializaciones estacionales. A pesar de que la abundancia de los recursos no ha sido afectada, su distribución y la riqueza de los fragmentos del hábitat favorable para la alimentación, han sido alteradas. Así, la ausencia de impacto en la alimentación no es garantía de que la especie no se haya visto perturbada. Las hipótesis de reducción del tamaño del grupo social y/o aumento del área del territorio para superar las dificultades de la nueva situación nutritiva se discuten en el ámbito de la Teoría de la Dispersión de los Recursos aplicada a los recursos alimentarios.

Palabras clave: ecología trófica, fuego, *Meles meles*, paisaje mediterráneo, recursos-clave.

## INTRODUCTION

Fire is a natural event in most Mediterranean ecosystems (Grove and Rackman 2001), as a consequence of the hot and dry summers (Pausas and Vallejo 1999) that characterize this region since the Pleistocene (Clemente 2002) but also due to increasing human activities after the Neolithic (Clemente 2002). However, fire statistics show that the number of fires, the frequency of large-scale ones and, consequently, the total area burnt drastically escalated after the 80's, both in Portugal (DGRF n.d) and in the overall of the Mediterranean region (Pausas and Vallejo 1999). This is a consequence of both socio-economic changes (e.g., rural areas exodus, replacement of natural vegetation by planted forests of fire-prone species – Grove and Rackman 2001) and climate changes (e.g. increase in average temperature and in rainfall irregularities - Houghton *et al.* 2001 in Clemente 2002). Nonetheless, and in spite of the importance of fires in the dynamics of Mediterranean environments, the knowledge on species adaptations to this phenomenon is still scarce and almost strictly focused on plants. It is, therefore, imperative to identify the impacts of fire on animal species in order to better predict how the increasing frequency of this event will affect animal communities.

The Eurasian badger *Meles meles* (Linnaeus, 1758) is a common species in Mediterranean ecosystems and its trophic behaviour is a key-feature to understand many aspects of the species' ecology such as sociality (Macdonald 1983), density (Kowalczyk *et al.* 2003) or the groups' spatial arrangement (Kruuk 1978). Badger diet has been broadly studied all over the species' vast distribution (e.g.

Skoog 1970 in Kruuk 1978, Kruuk and Parish 1981, Henry 1984, reviewed in Roper 1994, Goszczynski *et al.* 2000), including in Mediterranean landscapes (e.g. Ibáñez and Ibáñez 1977, Kruuk and De Kock 1981, Ciampalini and Lovari 1985, Pigozzi 1991, Revilla 1998, Marassi and Biancardi 2002, Rosalino *et al.* 2005a). Initially the species was classified as omnivorous (Neal 1948 in Kruuk 1978), but soon after this was questioned as a result of some studies in north Europe and UK where the diet is almost exclusively composed by worms (e.g. Kruuk 1978, Kruuk *et al.* 1979, Kruuk and Parish 1981). As new studies were undertaken in other areas of the species' range, results showed a more varied diet. Ever since, several hypothesis have emerged to characterise badger feeding behaviour (Specialist - Kruuk 1989; Local Specialist – e.g. Martín *et al.* 1995; or Facultative Specialist - Fedriani *et al.* 1998) although nowadays, it is almost consensual that the species is a generalist forager (Virgós *et al.* 2005), sometimes with specialisations, either local (e.g. the rabbit in Doñana – Martín *et al.* 1995) or seasonal (Rosalino *et al.* 2005a).

In the Mediterranean region, although with a few exceptions like Doñana (Martín *et al.* 1995) and the Madrid Province Mountains (Virgós *et al.* 2004) in Spain, and Monte Baldo (Kruuk and De Kock 1981) in Italy, adult arthropods and fruits constitute the bulk of badger diet (e.g. Ciampalini and Lovari 1985, Pigozzi 1991, Rodríguez and Delibes 1992, Barea-Azcón *et al.* 2001). In Portugal the studies conducted in Serra de Grândola identified olives as a positively selected resource, complemented by beetles (Coleoptera) – both larvae and adult – crickets (Orthoptera), acorns and pears (Rosalino *et al.* 2005a).

This study is a preliminary approach to the effects of fire on the feeding behaviour of a carnivore species inhabiting the Mediterranean cork oak woodlands. The main aims were to investigate: i) the impact of fire on badger's food availability and ii) how it translates into the species diet composition through iii) the analysis of the relation between the consumption and the availability of the main food categories.

The vulnerability of insects and other invertebrates to fire depends on their location at the time of fire and of fire intensity (Smith 2000), with adult forms burrowing themselves or flying to escape injury, and species with immobile life stages being more vulnerable. So it could be assumed that the main badger invertebrate prey, the mobile beetles, would be affected to a lesser extent than

other invertebrates. However, it has been documented that intense fires, such as those affecting Grândola Mountains, completely remove the ground beetle community from the site, resulting in vacant habitat for colonizing species (Pearce and Venier 2006). Therefore, we hypothesise that both beetle and other invertebrate availability would be negatively influenced by the fire, the result being a decreased availability after the fire event. In what concerns fruit availability, the same pattern of depletion should be expected because, even if trees survived, the crop they were bearing would have been, at least partially, burnt.

## MATERIAL AND METHODS

### *Study Area*

The study area is located in the mountain range of Serra de Grândola (SW of Portugal) and includes the home ranges of two social groups of Eurasian badgers previously radio-tracked (Rosalino *et al.* 2004). About 70% of this area was affected by a fire that occurred in August of 2003.

The area is dominated by cork oak (*Quercus suber*) woodlands – montado de sobro - with patches of riparian vegetation (e.g. *Populus* spp., *Rubus* sp.), olive yards (*Olea europaea*) and orchards (e.g. *Prunus* sp. – peach trees and *Ficus carica* – fig trees), usually located in the vicinity of farm houses dispersed throughout the area. The climate is Mediterranean – with soft winters and hot and dry summers –, with 500 mm of average rainfall (that could reach 800 mm) and 15,6°C of average annual temperature (Santos-Reis and Correia 1999).

### *Methods*

#### *Food availability*

Food availability was assessed between January and June 2004 and was restricted to the two food items that constitute the bulk of badger diet in the study area during the seasons herein studied – fruits (olives and acorns), and insects (adult coleopters, mostly members of the Carabidae Family, and orthopters - Rosalino *et al.* 2005a).

Fruit availability was assessed monthly by counting the number of fruits found on the ground within a 1m<sup>2</sup> square underneath the canopy of 30 cork oaks and 30 olive trees in burnt and unburnt (control) areas.

For counting arthropods, pitfall trapping was used as described in detail in Rosalino *et al.* (2005a). To evaluate the impact of fire a total of three landscape units were sampled – MWSC (Montado Without Shrub Cover), MSC (Montado with Shrub Cover) and BM (Burnt Montado) - both in mid-winter (February) and mid-spring (May). Coleopters were, whenever possible, identified to the species level (Zahradník 1990, Chinery 1997) whilst for Orthoptera identification didn't go beyond the family level (Chinery 1997).

### ***Food consumption***

Diet analysis was based on scats (N= 60, 30 in each season, winter and spring) collected every fortnight between January and June of 2004 in latrines located inside the home-ranges of the two studied groups. These latrines were located both near dens and home-range boundaries. The content of a defecation pit was identified as one scat, and therefore one sample, except when there were variations in colour, texture or shape (Virgós *et al.* 2004). Each month a random sample of 10 scats was selected for laboratory analysis which was performed according to Kruuk and Parish (1981). Scat remains were identified, quantified and classified according the following categories: cereals, plant material (except fruits), fruits, adult arthropods, arthropod larvae, earthworms, gastropods, amphibians, reptiles, birds and mammals.

Results are presented as Frequency of Occurrence (F.O.) and as Percentage of Biomass (P.B.), considered to be the best diet estimators by Korschgen (1980 in Brøseth *et al.* 1997). F.O. was calculated as the proportion of samples in which a certain item was present. P.B. was estimated using digestibility coefficients experimentally measured for badgers (cereals and snakes, Revilla 1998; lizards, Goszczyński *et al.* 2000; all the other categories, Rosalino *et al.* 2003). The exception were earthworms. The mean number of ingested earthworms was extrapolated according to Wroot's (1985) criteria - the number of *chaetae* found in a sample collected from the liquid where the scats were disassembled - and the mean earthworm weight estimate of Goszczyński *et al.* (2000) was used to calculate P.B.

### ***Data Analysis***

Data on food availability (Carvalho 2001, Loureiro *et al.* submitted) and diet (Rei 2001) obtained for the study area in 2001 were used as representative of the pre-fire conditions.

The impacts of fire, season and habitat type (in the case of arthropods) on food availability were assessed by means of a bifactorial ANOVA. Although our data showed considerable heterogeneity of variances and violation of normality assumptions, we decided to use ANOVA since it is a robust test, operating well even in cases of violation of assumptions as long as the sample size is the same and the resulting p-values are very low (Zar, 1999), as in our case. T-tests and Mann-Whitney tests were used to perceive the direction of the detected influences, having the data been tested for normality through the Kolmogorov-Smirnov statistic with a Lilliefors significance level (Zar 1999). In the specific case of Coleoptera, we also tested the family diversity in fire-affected and control areas and measured their overlap. The diversity levels were quantified using the Shannon-Wiener Index ( $H'$  - Krebs 1989) - which varies between 0 (null diversity) and 1 (maximum diversity) - and the overlap was measured by the Morisita Index (MI) – which scores between 0 and 1 for null and maximum overlap, respectively. In order to assess the consequences of fire on the total food availability of the study area (70%) considering the availability patterns found in 2004 and the percentage of the study area that burned (70%), we calculated for each food item the:

$$\text{Post-fire}_{\text{avail}} = 0.70 * (\text{avail}_{\text{burnt area}}) + 0.30 * (\text{avail}_{\text{unburnt area}})$$

To evaluate the post-fire diet diversity we calculated the Shannon-Wiener ( $H'$ ) Diversity Index (Krebs 1989) using P.B. The seasonal diet diversity levels of post-fire (winter vs. spring) as well as the effects of fire (pre-fire vs. post-fire) were then compared using Hutcheson's t statistic (Zar 1999). In addition, and to compare the general patterns of consumption between different seasons and between pre-fire and post-fire conditions, Pianka's Overlap Index ( $O_{jk}$ ) - which varies between 0 (null overlap) and 1 (total overlap) - was calculated. The seasonal variations for each food category as well as the differences due to fire were assessed by means of  $\chi^2$  tests with Yates correction for continuity (Simpson *et al.* 1960), using both P.B. and F.O. results.

Whenever the results respect a restricted temporal scale - winter or spring - there is an subscript w (for winter), s (for spring) or w+s (for winter and spring together).

## RESULTS

### *The impact of fire on food availability*

Fire and season had a negative impact upon the most consumed fruits availability. For acorns both variables, together with their interaction had a great influence in availability ( $R^2 = 0,162$ ;  $F_{\text{fire}} = 11,488$ ,  $df = 1$ ,  $P = 0,001$ ;  $F_{\text{season}} = 5,582$ ,  $df = 1$ ,  $P = 0,018$ ;  $F_{\text{interaction}} = 5,186$ ,  $df = 1$ ,  $P = 0,023$ ). In fact, the availability of acorns in fire-affected areas was significantly lower than that of unburnt areas in both winter ( $U = 3123,5$ ,  $N_{\text{unburnt}} = 108$ ,  $N_{\text{burnt}} = 90$ ,  $P < 0,001$ ) and spring ( $U = 3991,5$ ,  $N_{\text{unburnt}} = 108$ ,  $N_{\text{burnt}} = 90$ ,  $P = 0,001$ ), showing a decline of approximately 98%. As a consequence, the post-fire availability of acorns in the study area became lower than that observed in the pre-fire for both winter ( $U = 3536$ ,  $N_{\text{pre-fire}} = 120$ ,  $N_{\text{post-fire}} = 108$ ,  $P < 0,001$ ) - and spring ( $U = 4066$ ,  $N_{\text{unburnt}} = 120$ ,  $N_{\text{burnt}} = 108$ ,  $P < 0,001$ ).

In what concerns olive availability the same pattern was observed: fire, season and their interaction affected fruit availability ( $R^2 = 0,076$ ;  $F_{\text{fire}} = 9,824$ ,  $df = 1$ ,  $P = 0,002$ ;  $F_{\text{season}} = 9,824$ ,  $df = 1$ ,  $P = 0,002$ ;  $F_{\text{interaction}} = 9,824$ ,  $df = 1$ ,  $P = 0,002$ ). Olive availability was null in fire-impacted areas in winter and spring, therefore being significantly lower than that of non-impacted areas in winter ( $U = 3105$ ,  $N_{\text{burnt}} = N_{\text{unburnt}} = 90$ ,  $P < 0,001$ ) and equivalent to that of spring, which was also null in unburnt areas. In spite of the negative effect of fire on winter olive availability, analysing the total availability in the study area, we find an equivalence between the pre-fire and post-fire situations for both winter ( $U = 3548$ ,  $N_{\text{pre-fire}} = N_{\text{post-fire}} = 90$ ,  $P = 0,065$ ) and spring ( $U = 4005$ ,  $N_{\text{pre-fire}} = N_{\text{post-fire}} = 90$ ,  $P = 0,317$ ).

Regarding arthropods, again fire, season and habitat type influence availability ( $R^2 = 0,226$ ;  $F_{\text{fire}} = 22,636$ ,  $df = 1$ ,  $P < 0,001$ ;  $F_{\text{season}} = 5,689$ ,  $df = 1$ ,  $P = 0,019$ ;  $F_{\text{habitat type}} = 22,209$ ,  $df = 1$ ,  $P < 0,001$ ), but this doesn't hold true for their interaction. Particularizing among arthropod *taxa*, fire, type of habitat and the interaction between season and fire only seem to constrain coleopters abundance ( $R^2 = 0,342$ ;  $F_{\text{fire}} = 16,679$ ,  $df = 1$ ,  $P < 0,001$ ;  $F_{\text{type of habitat}} = 55,632$ ,  $df = 1$ ,  $P < 0,001$ ;  $F_{\text{fire*type of habitat}} = 7,170$ ,  $df = 1$ ,  $P = 0,008$ ). Besides, within coleopters and considering both types of montado together, a significant negative impact of fire was only detected for the number of collected individuals of the Carabidae family in winter ( $U = 297,5$ ,  $N_{\text{unburnt}} = 40$ ,  $N_{\text{burnt}} = 24$ ,  $P = 0,008$ ). However the results are different if we choose to compare MSC/MWSC to BM separately. In fact, and for the order

Coleoptera, BM appears to be significantly poorer than MWSC only in spring ( $U= 105, N_{BM} = N_{MWSC} = 24, P < 0.001$ ). Nevertheless, if we compare it to MSC we find exactly the opposite, i.e., the fire-impacted area is richer than the non-fire impacted area in both winter ( $U= 86, N_{BM} = 24, N_{MSC} = 16, P= 0.003$ ) and spring ( $U= 147.5, N_{BM} = N_{MSC} = 24, P= 0.003$ ). The same was observed when analysing specifically the Carabidae family – this family was more available in MWSC than in BM in winter ( $U= 101.5, N_{MWSC} = N_{BM} = 24, P < 0.001$ ) and spring ( $U= 98, N_{MWSC} = N_{BM} = 24, P < 0.001$ ), but less available in MSC than in BM in spring ( $U= 145, N_{MSC} = N_{BM} = 24, P= 0.002$ ).

The discrepancies obtained in MSC-BM and MWSC-BM comparisons were also detected in the overlap index. In fact, although the values were similar in spring ( $MI_{MSC-BM} = 0.99, MI_{MWSC-BM} = 1.0$ ), in winter the degree of overlap is almost 20% larger for the dyad MWSC-BM ( $MI_{MSC-BM} = 0.67, MI_{MWSC-BM} = 0.85$ ). Although the degrees of overlap were, in general high, BM *taxa* diversity was almost always different from MWSC's or MSC's *taxa* diversity, though not always smaller. In fact BM family diversity was higher than that of MWSC in both spring and in winter and spring together (Table 1).

TABLE 1

MWSC-BM and MSC-BM family diversity comparisons (win stands for winter, spr for spring and win+spr for winter and spring together).

Season	Shannon Wiener Index (H')	Hutcheson statistic
win	MWSC= 0.50, BM= 0.38	t= -7.54, v= 234.94, P< 0.001
win	MSC= 0.67, BM= 0.38	t= -5.06, v= 56.14, P< 0.001
spr	MWSC= 0.13, BM= 0.22	t= -3.83, v= 114.38, P< 0.001
spr	MSC= 0.37, BM= 0.22	t= -1.84, v= 47.12, P>0.05
win+spr	MWSC= 0.41, BM= 0.51	t= -14.13, v= 433.94, P< 0.001
win+spr	MSC= 0.59, BM= 0.51	t= -7.34, v= 78.43, P< 0.001

In what concerns the total availability in the study area in pre-fire and post-fire conditions, the Coleoptera were less available in the post-fire than in the pre-fire in spring (t-test = 4.446, df= 25.084, P< 0.001). Similarly, the availability of the Carabidae was higher in the pre-fire for both winter ( $U= 18, N_1 = N_2 = 24, P < 0.001$ ) and spring (t= 4.694, df= 24.829, P< 0.001).

Regarding Orthoptera availability, fire apparently had no impact contrarily to season ( $R^2 = 0.302$ ;  $F_{\text{season}} = 46.585$ ,  $df = 1$ ,  $P < 0.001$ ). In fact, the availability of Orthoptera in fire-affected areas was similar to that of unburnt areas in both winter ( $U = 464$ ,  $N_{\text{burnt}} = 24$ ,  $N_{\text{unburnt}} = 40$ ,  $P = 0.597$ ) and spring ( $U = 570.5$ ,  $N_{\text{burnt}} = 24$ ,  $N_{\text{unburnt}} = 48$ ,  $P = 0.947$ ). Comparing Orthoptera post-fire availability in the study area with that of the pre-fire situation, we find that although there are no differences in winter ( $U = 273$ ,  $N_{\text{pre-fire}} = N_{\text{post-fire}} = 24$ ,  $P = 0.614$ ), in spring the post-fire levels are above those of pre-fire ( $U = 5.5$ ,  $N_{\text{pre-fire}} = N_{\text{post-fire}} = 24$ ,  $P < 0.001$ ).

### ***The impact of fire on food consumption***

The faecal analysis of post-fire samples revealed the consumption of several different resources, though fruits and adult arthropods represented 65-78% of the ingested biomass and were present in 97-100% of the faecal samples analysed (Figure 1). However, some temporal fluctuations in the importance of each of the food resources were detected.

In terms of P.B., fruits were more important in winter ( $\chi^2 = 1353.98$ ,  $df = 1$ ,  $P < 0.001$ ), when olive consumption represented 40% of the ingested biomass. Inversely, adult arthropods were most important during spring (Figure 1). In fact, during this season the diet included other arthropod, such as Arachnida (spiders and scorpions – P.B. = 0.46%; F.O. = 20%), besides the usual Coleoptera (P.B. = 42.2%; F.O. = 100%, with carabids F.O. reaching 83%), Orthoptera (P.B. = 8,59%; F.O. = 77%) and Chilopoda (P.B. = 1,77%; F.O. = 50%).

Seasonal diet diversity varied (w:  $H' = 0.57$ ; s:  $H' = 0.58$ ), but not significantly ( $t = -1.21$ ;  $v = 7655$ ;  $P > 0.05$ ). The degree of overlap between the two seasons was high ( $O_{ij} = 0.78$ ).

The comparison of pre-fire and post-fire consumption patterns revealed a high similarity for both seasons ( $O_{ij} = 0.91$  in winter and  $O_{ij} = 0.97$  in spring), although there were some significant differences (Figure 1). The variation in fruits' importance was a result of the differential consumption of olives (w:  $\chi^2 = 196.37$ ,  $df = 1$ ,  $P < 0.001$ ; s:  $\chi^2 = 5.72$ ,  $df = 1$ ,  $P < 0.05$ ) and acorns (w:  $\chi^2 = 146.78$ ,  $df = 1$ ,  $P < 0.001$ ; s:  $\chi^2 = 41.4$ ,  $df = 1$ ,  $P < 0.001$ ) (Figure 2). In what concerns adult arthropod *taxa*, differences were mainly due to changes in the ingested biomass of insects, mainly Coleoptera (w:  $\chi^2 = 462.19$ ,  $df = 1$ ,  $P < 0.001$ ; s:  $\chi^2 = 102.5$ ,  $df = 1$ ,  $P < 0.001$ ) and Orthoptera (w:  $\chi^2 = 119.82$ ,  $df = 1$ ,  $P < 0.001$ ; s:  $\chi^2 = 423.6$ ,

df= 1,  $P < 0.001$ ). It also is worthwhile mentioning that in post-fire spring there was a considerable increase of the importance of a food category –cereals - nearly negligible in the pre-fire year.

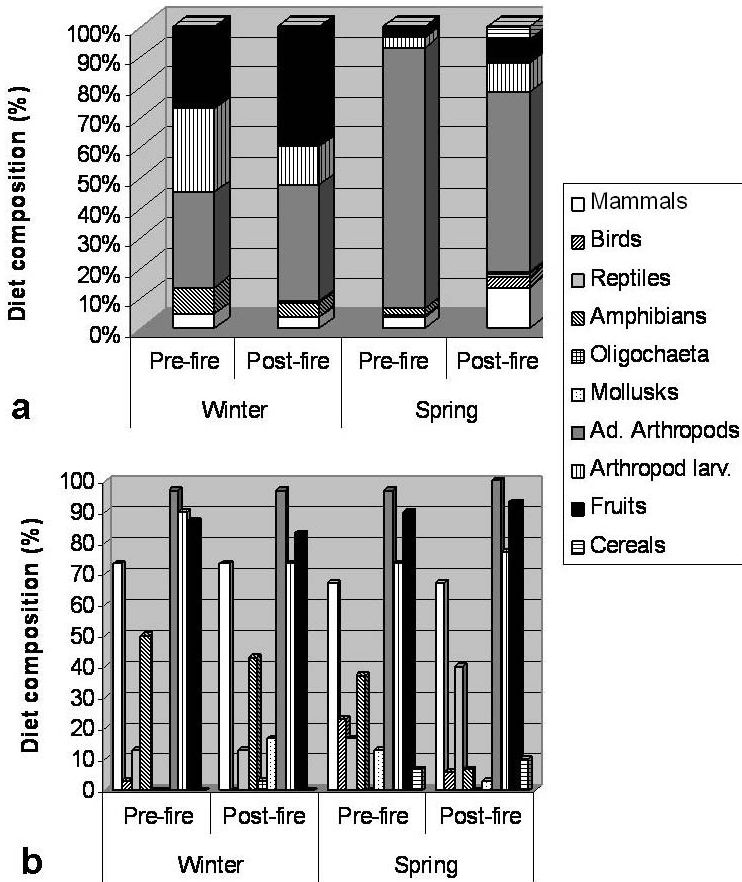


Figure 1. Eurasian badger's prefire and post-fire diet expressed in terms of P.B. (a) and F.O. (b).

*Dieta del tejón antes y después del fuego en P.B. (a) y F.O. (b).*

In what concerns diversity, winter had higher values for the pre-fire conditions ( $H'_{pre-fire} = 0.62$ ,  $H'_{post-fire} = 0.57$ ;  $t = 9.55$ ,  $P < 0.001$ ), and the opposite was true for spring ( $H'_{pre-fire} = 0.27$ ,  $H'_{post-fire} = 0.58$ ;  $t = -31.36$ ,  $P < 0.001$ ). In the overall diet diversity was higher in the post-fire year ( $H'_{pre-fire} = 0.52$ ,  $H'_{post-fire} = 0.63$ ;  $t = -18.71$ ,  $v = 21.341$ ,  $P < 0.001$ ).

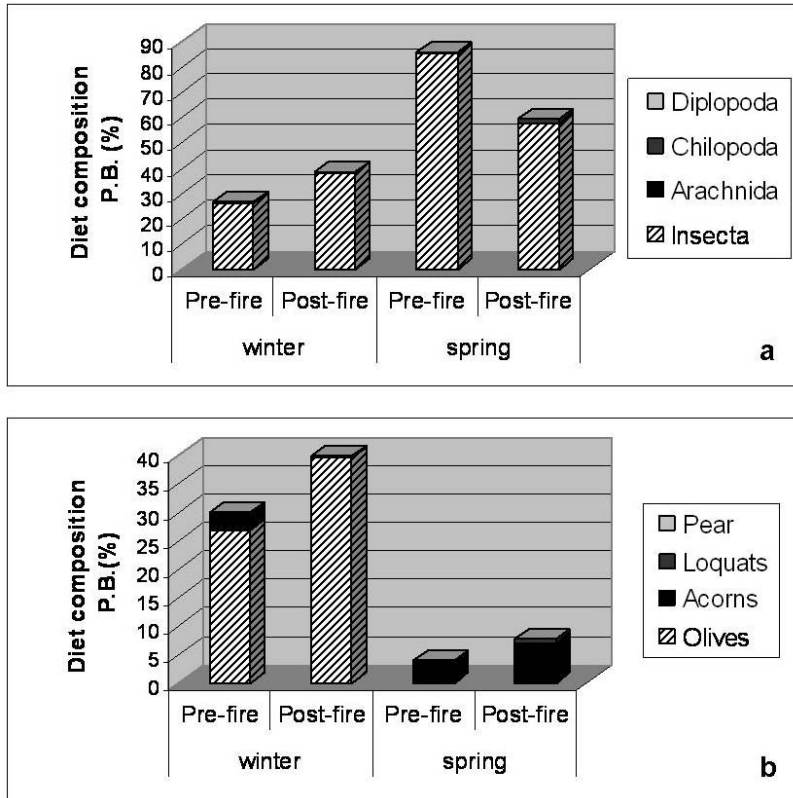


Figure 2 Diet composition in terms of adult arthropods (a) and fruits (b) for the pre and post-fire situations.

*Composición de la dieta en artrópodos adultos (a) y frutos (b) antes y después del fuego.*

### **Consumption vs. Availability**

Comparing availability and consumption we find different scenarios for different food items. Acorns did not show any kind of congruence between availability and consumption, whilst for coleopters the seasonal compatibility was observed only in the pre-fire, and inter-annual compatibility was not observed (Figure 3). As for orthopters a seasonal and almost inter-annual agreement between the variations of those parameters was evident. Olives had an intermediate position, since there was a seasonal congruence between maximum availability and consumption, but the same doesn't hold true when we extended the time frame and considered pre-fire and post-fire levels of availability and consumption.

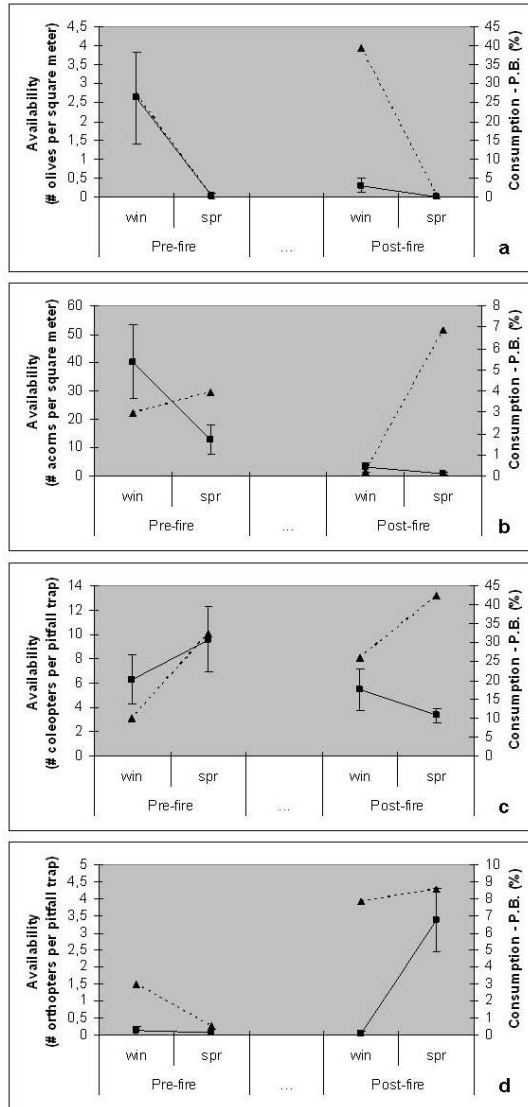


Figure 3. Availability vs. Consumption for olives (a), acorns (b), coleopters (c) and orthopters (d) - availability is represented by black lines while consumption is represented by dotted lines.

*Disponibilidad vs. Consumo de aceitunas (a), bellotas (b), coleópteros (c) y ortópteros (d) - la disponibilidad está representada por las líneas negras y el consumo por las líneas punteadas.*

## DISCUSSION

Our results suggest that the fire that occurred in Serra de Grândola in the summer of 2003, apparently had significant negative effects on badger's food availability, but the species diet remained, overall, similar to that of a pre-fire year.

### ***The impact of fire on food availability***

Concerning food availability our results indicate a high impact of fire on fruit availability of both cork oak trees and olive trees, probably because these already bore fruits in the branches at the time the fire event took place. Therefore, the burnt fruits were not replaced even when the tree survived the fire, hence compromising the success of the on-going fruiting season in terms of the affected trees. The fact that the fire impact was slightly more intense on olive trees than on cork oak trees is probably due to the trees' size difference (adult olive trees are much smaller than adult cork oak trees and, thus, more susceptible to the consequences of fire). Besides, cork oak trees have a special bark - cork (which has been described as a protection against fire in fire-prone habitats as is the case of the Mediterranean montado – Grove and Rackham 2001). Bark together with the tree's larger size probably resulted in a lower mortality for the cork oak trees when compared to that of olive trees, which means the long-term effects of fire are probably different for cork trees and olive trees.

In what concerns arthropods some differences were also observed in terms of availability of burnt and unburnt areas. However, in this case differences cannot, undoubtedly, be considered a consequence of fire. In fact, although the diversity of life strategies has been greatly reduced by considering only the arthropod *taxa* which are the main food items of the badger population in the study area (Rosalino *et al.* 2005a), we can not ignore the “flaws” of the chosen methodology – pitfall trapping. First, it is important to point out that this kind of trapping does not necessarily favour the capture of the most abundant groups, but that of the most mobile ones (Norris and Conroy 1999), which explains the higher capture rates of some groups. Secondly, we can not ignore the fact that fire leads to a phenomenon entitled Habitat Compression, which represents the reduction of the tri-dimensional reality of each habitat – as a result of plant aerial growth – to a bi-dimensional one. This causes an increase in arthropod density (Majer 1980, Whelan *et al.* 1980, O'Dowd and Gill 1984 all in Coy 1994) which, in

most cases, explains the higher capture rate obtained after fire, namely in MSC (but not in MWSC) when compared to BM.

On the other hand, when BM was compared to MWSC, the family Carabidae (and consequently, the order Coleoptera) showed a significantly lower abundance in the burnt situation. Previous studies (Friend 1994, Holiday 1984 in Larsen and Williams 1999) showed similar results for this and other predator *taxa* – there is a decrease of predator density after fire (Coy 1994) as a result of the decline in herbivore prey abundance, which in turn is a response to the exhaustion of food resources (Ross 1965 in Coy 1994).

Assuming that the observed differences in family diversity between fire-affected and control areas can be justified by the fact that most of the coleopters caught were members of the Carabidae family, our results agree with those of a previous study by Friend (1994).

### ***The impact of fire on food consumption***

Although our results suggest that there were negative impacts of fire in food availability, the translation of these results in terms of diet is not straightforward. First, we have to acknowledge that in some cases the fire effects were “softened” (e.g. olives) or “enhanced” (e.g. acorns, coleopters and carabids) by the 2004 higher or lower availability of such pulsed resources (Loureiro *et al.* submitted) when compared to that of 2001. Secondly, not all resources seem to be consumed according to their seasonal and annual availability. In fact, only orthopters were close to a strict cause-effect relation between availability and consumption, true at seasonal and inter-annual time scales. However, orthopters consumption never exceeds 9% of the biomass ingested. The lack of correlation between availability and consumption of acorns had already been observed by Rosalino *et al.* (2005a) at a wider time scale. In fact, Rosalino *et al.* (2005a) concluded that acorns were an avoided resource. Similarly, in their study Coleoptera consumption failed to correlate with availability, a fact that suggests an opportunistic consumption. As for olives, the most consumed food item when available (Rosalino *et al.* 2005a), the inter-annual differences in availability do not seem to be determinants of annual consumption levels. In fact, although the availability peak occurred in pre-fire winter, the consumption peak was observed in post-fire winter. This suggests that either olive availability is not a limiting factor or olives are positively

selected. Rosalino *et al.* (2005a)'s work supports this last assumption, and these authors proposed that badgers are, in Mediterranean habitats, generalist feeders with seasonal specialisms, in this case, upon olives. Thus, olives would be the most consumed food resource when available, even when they are not the most abundant food item (Rosalino *et al.* 2005a). Fedriani *et al.* (1998) had also introduced a similar concept – Facultative Specialist – to explain cases where the diet composition is determined by the availability of a “preferential” resource. In face of our results, we accept this view and propose that atmospheric conditions, probably, also acted as determinants of olive consumption. Therefore, these conditions should be taken into account when comparing availability and consumption seasonally but, especially, annually since the same season in different years may bear important climatic differences. We hypothesise that the olive consumption would be lower when the weather is extreme. In fact, different studies seem to indicate that the frequency (Maurel 1981 in Henry 1984) and the duration (Rosalino *et al.* 2005b) of badger foraging activities are negatively correlated with low temperatures. Moreover, Do Linh San (2004) documented the quick return of badgers to the dens to escape the rain. In our case, weather data indicate that the pre-fire winter (2000-01) was unusually rainy (IM n.d.), with higher than average rainfall values between January and March, while post-fire winter presented an opposite scenario, being unusually dry. As a consequence of the rainy weather, the access to olives was compromised not only as a consequence of the foraging activities having been cut shorter (making it difficult to reach the restricted and dispersed olive patches within the matrix habitat – cork oak woodlands), but also as a consequence of the increase in the degradation rate of the fruits. Thus, the consumption of other food items was, probably, favoured in the pre-fire winter of 2001, such as Coleoptera larvae which, most likely, became more available as the rain softened the soil, making it easier to dig (Pigozzi 1987). This suggests that the consumption of resources other than olives is regulated by olives abundance. For this reason, when analysing badgers consumption vs availability of food resources in Mediterranean areas, it is important to consider the bulk of badgers's diet (olives in our case), since its availability will surely constrain the consumption of alternative prey, independently of their own availability.

This hypothesis is consistent with the theory of Rodríguez and Delibes (1992), who summarized the foraging activity of badgers in the Mediterranean as the active search of cultivated fruits, with the opportunistic consumption of arthropods when accidentally found during foraging bouts. This feeding behaviour, together with the resource spatial spacing, could lead to an erratic or intangible consumption of those alternative resources, a fact to take into account when interpreting food preferences.

At the same time, having the olive availability and consumption patterns as surrogates, and taking into account the post-fire resource availability, we can understand the patterns of post-fire diet. During the post-fire winter of 2004 the consumption of olives was not affected and was complemented mainly by adult arthropods. On the other hand, during post-fire spring, we found that, in the absence of olives, the adult arthropods became the most consumed item, although its consumption did not reach the levels of pre-fire spring. This is probably a consequence of the negative effect of fire on carabids, the most consumed Coleoptera, whose availability in the post-fire year became lower than that of pre-fire. Thus, the deficit of these important prey during post-fire spring was compensated by Orthoptera, as well as by arthropod larvae - which, after the fire, became more abundant again in spring (Coy 1994) - and by several *taxa* of vertebrates and cereals.

Although no important impacts were detected in the characteristic patterns of either availability or consumption of badger food resources, the absence of effects of fire may not be real. Although the availability of resources was only slightly lower during post-fire winter and spring, its distribution was more restricted and scattered. Kruuk (1978) intimately connected badger trophic ecology with the species' social ecology. Accordingly, two scenarios (non-exclusive), not obvious in the diet analysis, may occur after a fire: 1) Decrease in the number of individuals per social unit; 2) Increase in territory size. Unfortunately it wasn't possible to collect data that would allow us to evaluate if any of these situations occurred. However, we suggest that in future studies concerning fire effects on badger's ecology authors consider collecting these kinds of data in order to evaluate the occurrence of these situations, since this is a unique opportunity to test the applicability of Resource Dispersion Hypothesis (Macdonald 1983) to food resources, i.e. if food resources may be considered limiting resources, and so determinants of social unit or territory sizes.

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