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ORIGINAL PAPER

# Fire-created habitats support large mammal community in a Mediterranean landscape

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## Abstract
Large mammals play significant roles in shaping the trophic structure of terrestrial ecosystems and affect the form of vegetation growth in many habitats. We studied large mammal community in a Mediterranean habitat mosaic generated by fires originally dominated by pine forests. We conducted camera-trapping surveys in three study sites with different fire histories, and we recorded eight large mammal species including brown bear (*Ursus arctos*), caracal (*Caracal caracal*), and wild goat (*Capra aegagrus*), which are of conservation importance. The mammal community found in the study sites was functionally diverse, including herbivores, omnivores, carnivores, seed dispersers, soil diggers, main preys, and top predators. The site burned 13 years ago had higher species richness than can be expected from a random pattern, but this was not the case in 30- and >40-year-old sites, showing the importance of relatively younger sites for large mammals. Eurasian badger had more probability to have more abundance in places with more open vegetation while wild goat had higher abundance in more dense vegetation. Young individuals of wild goat, brown bear, and wild boar were also detected in the study sites. The results indicate that burned habitats harbor a phylogenetically and functionally diverse large mammal community in landscapes originally dominated by Mediterranean pine forests. Therefore, these forests continue to retain importance for the large mammals after the fire, and burned habitats should be taken into consideration for the conservation and management plans together with mature forests in Mediterranean ecosystems.

**Keywords** Camera-trapping · Large mammals · Mediterranean Basin · Post-fire habitats · Turkey · Wildlife management

## Introduction

Large mammals play significant roles in shaping the trophic structure of terrestrial ecosystems (Ripple et al. 2014), and they contribute forming the vegetation in many habitats (Bond 2005; Hempson et al. 2015; Bond 2019). Although climate and soil have been long considered as two main drivers of biomes on Earth since the Humboldt's time (Pausas and Bond 2019), recent studies suggest that herbivory by large mammals and disturbances such as fires are also significant drivers of biome boundaries (Dantas et al. 2016; Pausas and Bond 2019). Since large mammals have a significant influence on plant and animal species at lower trophic levels through the cascading effect, their presence or absence in an ecosystem may alter the composition and structure of plant and animal communities (Ripple et al. 2014). Due to their importance for ecosystem structure and function, large mammals have often been important figures for conservation biology. Alteration of natural habitats by the human is one of the most threatening problems for the populations of large mammals (Craigie et al. 2010; Ripple et al. 2014). Although human-mediated disturbances such as logging and recreation have apparent negative effects on the populations of large mammals (George and Crooks 2006; Michalski and Peres 2007), they can possess strategies to deal with fire disturbance with some mechanisms in fire-prone ecosystems (van Mantgem et al. 2015; Pausas 2019).

Fire is one of the main drivers of biodiversity in Mediterranean-type ecosystems (Keeley et al. 2012; Kelly and Brotons 2017; Rundel et al. 2018). Plant species have

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several adaptive traits to cope with fire (Keeley et al. 2011; Tavşanoğlu and Pausas 2018), and consequently, vegetation recovery after a fire is fast in many cases (Kavgacı et al. 2010; Tavşanoğlu and Gürkan 2014). Although the fire response of plant communities is well documented in Mediterranean-type ecosystems, the effect of fire on animal communities has drawn less attention (Pausas and Parr 2018). Animals have fire-response strategies like plants such as resistance, avoidance, intolerance, and crypsis (Pausas 2019). Fire promotes insect populations by creating compositional and structural changes in vegetation (Kaynaş and Gürkan 2008), and by suppressing antagonistic interactions with their predators (Pausas et al. 2018). Habitat heterogeneity created by fire favors bird (Brotons et al. 2005), several reptile species (Santos and Poquet 2010) and small mammal communities (Fox 1982; Kaynaş et al. 2002) by fulfilling habitat requirements for various species (Fox 1982). Moreover, it has been postulated that fire has a unique ecological value for mammal species by increasing their abundance and diversity (Bond 2015).

Post-fire response of large mammal communities has subjected to relatively less number of studies in comparison to other groups in Mediterranean-type ecosystems (Quinn 1994). More recently, large mammals in fire-created habitats have got more attention in Mediterranean ecosystems of California (Turschak et al. 2010; Borchert 2012; Schuette et al. 2014; van Mantgem et al. 2015) and other fire-prone ecosystems of the world (Green et al. 2015; Chia et al. 2016; McGregor et al. 2016; Geary et al. 2018). The Mediterranean Basin, however, remained less studied except for a few recent records of large mammals in burned habitats (Soyumert et al. 2010; Birtsas et al. 2012; Sokos et al. 2016).

Large mammals generally can move to safer and more suitable places next to the burning area during a fire, and consequently, they are mostly free of direct mortality effect of the fire (Quinn 1994). This "fire migration" allows those species to colonize burned sites from nearby habitats as the post-fire succession proceeds (van Mantgem et al. 2015). This post-fire survival method (i.e., exogenous colonization strategy, Pausas 2019) allows animal species to persist at the landscape level and depends on the movement ability of species (Pausas 2019). This information can be critical in developing management and conservation plans for specific large mammal species in Mediterranean habitats, but unfortunately, the lack of knowledge on the status of large mammals in burned habitats limits our ability to integrate fire ecology and large mammal conservation fields in wildlife management plans in fire-prone Mediterranean forests and shrublands.

The aim of our study was to gather novel information on large mammal species in post-fire habitats in the Mediterranean Basin. To reveal whether fire-created habitats support a diverse large mammal community in Mediterranean landscapes, we performed camera-trapping surveys in three sites with different fire histories in a fire-prone Mediterranean forest.

## Materials and methods

### Study area

The study was conducted in Marmaris region of Muğla province in south-western Anatolia, which is one of the most frequently burned areas in Turkey for the last 40 years (36.9° N, 28.2° E, Fig. 1). The original dominant vegetation of the study area is Turkish red pine (*Pinus brutia* Ten.) forests with many shrubs in the understory. Due to recent frequent fires, however, the study area constitutes many habitat patches in various sizes at different stages of post-fire recovery (Tavşanoğlu and Gürkan 2014). This landscape pattern makes the study area an ideal one to test the effect of burned habitat patches on large mammal species. Previous observations showed that the study region has several terrestrial large mammal species with conservation value such as wild goat (*Capra aegagrus*) and caracal (*Caracal caracal*) besides the more widespread ones (İlemin and Gürkan 2010; Soyumert et al. 2010). The climate is a Mediterranean one with dry summers and wet winters. Annual total precipitation is 1211 mm, and the annual mean temperature is 18.7 °C. These climatic conditions make the productivity of the region higher than similar regions in the Mediterranean Basin, resulting in the rapid recovery of vegetation after fire (Tavşanoğlu and Gürkan 2014).

### Site selection and camera-trapping

Camera-trapping surveys were conducted from April 2009 to April 2010 in three study sites (each ~12 $km^2$ in size) with different fire histories: (1) site 1, burned 13 years ago; (2) site 2, burned 30 years ago; (3) site 3, burned more than 40 years ago (Fig. 1). Study sites had distinctive topographical features such as rocky cliffs with abrupt altitudinal changes and valleys formed by streams. They were located close to the coastline; therefore, the elevation ranged from 30 to 650 m. Within this range, the average altitude of established camera-trap stations was 203 m (site 1), 379 m (site 2), and 132 m (site 3). Dominant vegetation before the fires was Turkish red pine forest in all study sites. According to vegetation coverage values obtained by Tavşanoğlu (2008), site 1 is mainly dominated by low shrubs such as *Cistus salviifolius*, *C. creticus*, *Genista acanthoclada*, and *Lavandula stoechas*, whereas in site 2, larger shrubs (*Phillyrea latifolia*, *Erica manipuliflora*, and *Ptilostemon chamaepeuce*) has also significant coverage values in the vegetation beside dominant low shrub species (*C. salviifolius* and *G. acanthoclada*). In the area, long-unburned forests are dominated by *P. brutia* trees and several evergreen large shrub species such as *Quercus infectoria* and *P. latifolia* (Tavşanoğlu 2008; Tavşanoğlu and Gürkan 2014). *P. brutia* regeneration was quite sufficient for 13-year-old site (site 1) although there were no mature individuals reaching the tree layer (Tavşanoğlu 2008). Among the old-burned sites in our study, 30-year-old site (site

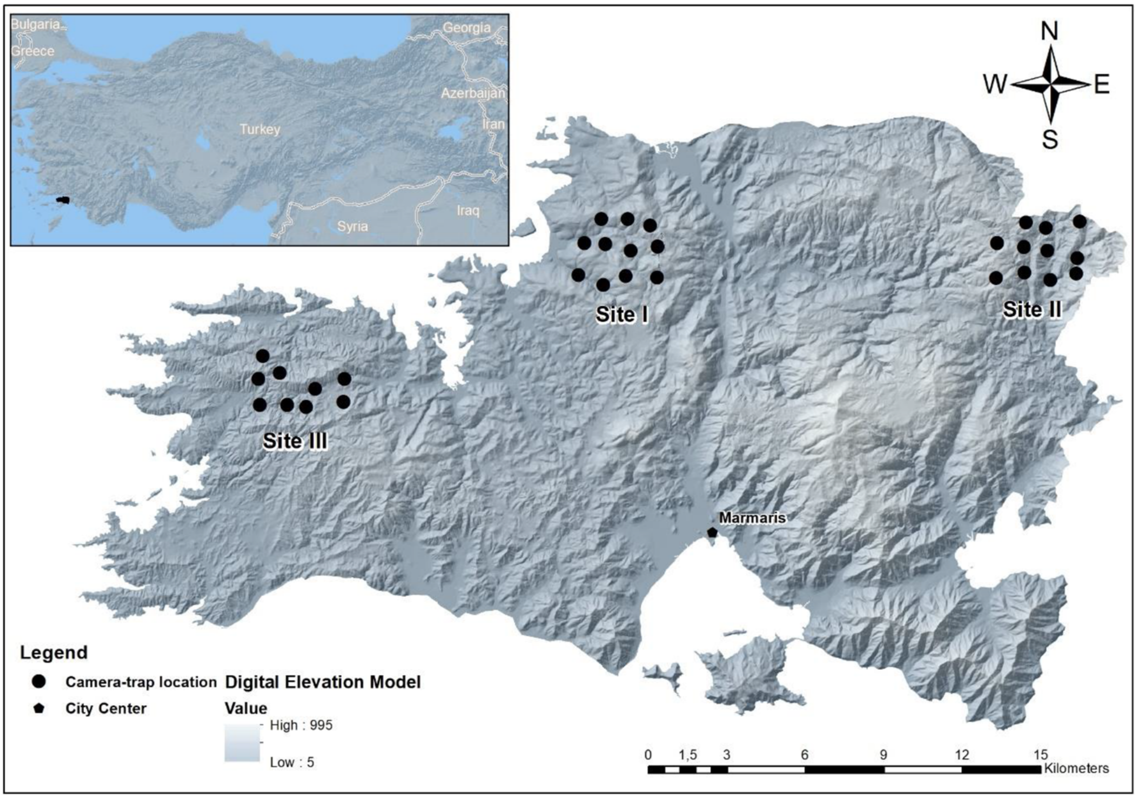


**Fig. 1** The location of the study area and camera-trap stations placed within three study sites

2) had lower regeneration of pines than > 40-year-old site (site 3). The differences in vegetation structure among study sites are mainly due to the post-fire regeneration stage of the plant community of each site but also the success degree of pine (*P. brutia*) regeneration.

Each study site was divided into 1-km$^2$ grids and within each grid, one camera-trap (passive digital CamTrakker) was mounted on a tree at ca. 0.6 m above and parallel to the ground at the closest location to the central point of the grids. Each camera-trap was assigned as a camera-trap station, and the distance between the stations were 1–1.5 km (Fig. 1). The stations were assumed as they cover the mammal activity of the grids at which they were placed. Camera-traps were set up to activate continuously for 24 h to take image records and with motion sensors set to trigger immediately when the movement was detected. No bait or attractant was used at the stations not to affect the systematic camera-trapping surveys. Surveys were conducted with 11 (study site 1 and 2) or 9 (study site 3) camera-traps and 1925 camera-trap nights were obtained with 31 camera-trap stations in total. Systematic camera-trapping surveys were conducted consecutively in the study sites with no time-lap between the survey periods of the study sites (Table 1). At each camera-trap station, four photos were taken through four main directions from the point that camera-trap was established. These photos were later used to determine the vegetation structure of the location of each station.

## Data management and statistical analysis

All records obtained from the camera-traps were classified, and the records belonging to the large mammals (weight > 1 kg) were identified at species level. Information about each capture of mammals such as the date, time and coordinates were recorded in a database. A total of 196 captures belong to all wildlife species were recorded in the database after excluding the photographs of domestic animals, vehicles or humans. Unidentified pictures were classified separately, and only the precise data were included in the results. Non-target wildlife species such as squirrel (*Sciurus anomalus*) or hedgehog (*Erinaceus concolor*) were also eliminated, and the evaluation was conducted using only the records of large mammal species.

Sampling effort, in the unit of camera-trap nights, was calculated by summing up the active days of each camera-trap, and the days when a camera-trap was not functional due to any reason were excluded. The captures from the same station belong to a particular species were filtered for 60 min to be considered as independent events (Tobler et al. 2008). The relative abundance index (RAI) for each species was estimated as the number of independent events per 100 trap-nights (O'Brien 2011; Soyumert et al. 2019), based on the filtered camera-trap records.

The camera-trap stations were clustered into groups according to the time past since last fire occurred at the grid

**Table 1** Sampling effort of camera-trapping in the study sites

| Study site | Time since fire | Survey period | # camera-trap stations | # camera-trap nights |
|---|---|---|---|---|
| Site 1 | 13 years | April 2009–June 2009 | 11 | 391 |
| Site 2 | 30 years | June 2009–October 2009 | 11 | 822 |
| Site 3 | > 40 years | November 2009–April 2010 | 9 | 712 |
| Total | | April 2009–April 2010 | 31 | 1925 |

(Table 1), and we documented the large mammal species presence and relative abundance (i.e., RAI) at the three study sites, as site 1 that burned 13 years ago, site 2 that burned 30 years ago, and site 3 that burned more than 40 years ago. We tested whether species richness in each study site differs from the expected random pattern by performing a $\chi^2$ analyses.

To determine vegetation structure of the locations that camera-traps were placed, we used photos taken during the establishment of camera-traps. First, we recorded the occurrence of different vegetation layers (i.e., mature tree layer, young tree/large shrub layer, shrub layer, and grassy/open patch) for each photo. Then, we assigned each layer a score weighing their contribution to the complexity of vegetation structure, such that 4, 2, 1, and − 1 for mature tree, large shrub, shrub, and grassy layers, respectively. Finally, we created a vegetation index by averaging values from four photos for each camera-trap locations in which obtained by summing vegetation layer scores. By this way, relatively open habitats has lower vegetation index values, in contrary more complex or taller vegetation get higher values.

To understand whether vegetation structure has an effect on the species presence and abundance, we performed a two-staged modeling approach as described by Soyumert et al. (2019). For each species, the association between the vegetation index and species presence and abundance was tested using generalized linear mixed models (assuming a binomial error distribution) and linear mixed models considering study site (therefore, also the season) as the random factor. Results of these analyses were obtained by performing a likelihood ratio test. Before linear mixed model analyses, data normality was checked and a logarithmic transformation was performed if needed. The analyses were conducted using lme4 (Bates et al. 2015) and nlme (Pinheiro et al. 2019) packages implemented in R statistical software (R Core Team 2019).

## Results

We detected eight large mammal species with 144 independent captures in total as a result of the camera-trap surveys (Table 2, Fig. 2). These species are found at different parts of the phylogenetic tree of mammals and belong to three taxonomic orders and seven families (Table 2). Among the recorded species, brown bear (*Ursus arctos*), caracal (*Caracal caracal*), and wild goat (*Capra aegagrus*) are of regional conservation importance in Turkey and the Mediterranean Basin (IUCN Red List 2018) (Table 2). The mammalian community found in the study sites were also functionally diverse, including herbivores, omnivores, carnivores, seed dispersers, main preys, top predators, and soil diggers (Table 2).

The study sites differed in their species composition, as only four among the eight large mammal species were recorded in all habitats representing different post-fire successional stages (Table 3). The site burned 13 years ago (site 1) had higher species richness than can be expected from a random pattern ($P < 0.005$, Table 3), but the number of species detected was not higher than expected in older sites ($P > 0.05$, Table 3). Eurasian badger had more probability to have more abundance in places with more open vegetation ($P < 0.05$, Table 3) while wild goat had higher abundance in more dense vegetation ($P < 0.05$, Table 3). Other species did not show a significant pattern in relation to the vegetation structure ($P > 0.05$, Table 3).

In addition to adult individuals of the detected large mammal species, we also captured records belonging to young individuals of wild goat ($n = 2$), brown bear ($n = 1$), and wild boar ($n = 12$) in study sites. Wild boar piglets were detected in both site 1 ($n = 10$) and site 2 ($n = 2$), while the wild goat kids were detected in site 2, and brown bear cubs (two individuals in one photograph) in site 3. These records indicate the presence of breeding individuals of those species in burned habitats.

## Discussion

Our results reveal that burned habitats harbor a phylogenetically and functionally diverse large mammal community in landscapes originally dominated by Mediterranean pine forests. The camera-trap records indicate that large mammal species do not avoid the burned areas in Mediterranean environments, contrary, they effectively use these habitats and burned habitats support large mammal populations in the study region. The presence of breeding individuals of brown bear, wild goat, and wild boar in the study sites also suggests that fire-created habitats host viable populations of large mammal species in the region.

The brown bear individuals recorded in the present study are belong to one of the southernmost populations of the

**Table 2** Detected large mammal species, their status according to the IUCN red list, and their functional role in the ecosystem. "Med." refers to IUCN Status according to the Mediterranean Regional Assessment of IUCN Red List of Threatened Species (IUCN Red List 2018). VU vulnerable, NT near threatened, LC least concern, Hb herbivore, Om omnivore, Cr carnivore, TP top predator, Dg soil digger, Ga gallery-type nesting in the soil, SF selective feeding, IP important prey, SD seed disperser

| Order/family | Latin name | Common name | IUCN status global/Med. | Functional role |
|---|---|---|---|---|
| Artiodactyla | | | | |
| Bovidae | *Capra aegagrus* | Wild goat | VU/VU | Hb, SD, SF |
| Suidae | *Sus scrofa* | Wild boar | LC/LC | Om, SD, Dg |
| Carnivora | | | | |
| Ursidae | *Ursus arctos* | Brown bear | LC/VU | Om, TP, SD |
| Felidae | *Caracal caracal* | Caracal | LC/NT | Cr, TP |
| Canidae | *Vulpes vulpes* | Red fox | LC/LC | Cr |
| Mustelidae | *Meles meles* | Eurasian badger | LC/LC | Cr, Dg, Ga |
| Mustelidae | *Martes foina* | Stone marten | LC/LC | Cr |
| Lagomorpha | | | | |
| Leporidae | *Lepus europaeus* | Brown hare | LC/LC | Hb, SD, IP |

species in the world (McLellan et al. 2017), and this population is one of the most isolated populations of the species in Anatolia. For this isolated brown bear population in our study area, the conservation status has been assessed as critically endangered (CR) for Turkey (Ambarlı et al. 2016). Since our records reveal that brown bears are capable of using burned habitats in Mediterranean forests together with their cubs, it is necessary to constitute an effective conservation plan for brown bear populations across the Mediterranean Basin considering the fire-created habitats. A similar isolation problem is also valid for the caracal population in the study region, which is located at the south-western Anatolia that holds the only population of caracal in Turkey without any connection with other populations of the species throughout its geographical range (Avgan et al. 2016). Since the current information about the relationship between caracal and wildfire is very limited, documenting the presence of a caracal population in a burned habitat is important as the species has a distribution in fire-prone ecosystems globally (Avgan et al. 2016). For wildlife managers, therefore, it is critical to recognize the importance of burned habitats for large mammals in Mediterranean forests for better conservation implementations.

In Mediterranean ecosystems, both plants and animals have developed several fire-response strategies to survive or re-colonize post-fire habitats (Pausas 2019). Herbivore large mammals benefit the appearance of fire-created habitats as

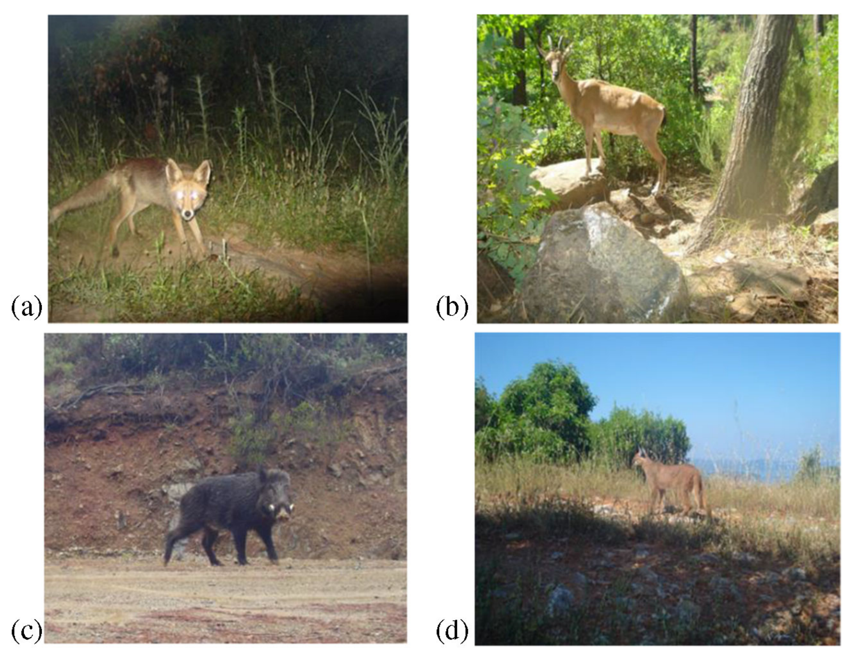


**Fig. 2** Camera-trap record samples for large mammal species detected in the study region. **a** Red fox. **b** Wild goat. **c** Wild boar. **d** Caracal

**Table 3** Number of independent records of large mammal species in study sites. Summary of the analyses testing the effect of vegetation on species presence (generalized linear mixed models, GLMM) and RAI values (linear mixed models, LMM) are also provided. Results of these analyses were obtained from likelihood ratio tests. Likelihood ratio (*LR*), $\chi^2$, and associated *P* values are provided (bold, if $P < 0.05$). Note that LMM analysis could not be performed for brown bear due to low number of detections. The $\chi^2$ analysis at the bottom shows the results of the $\chi^2$ test comparing the observed versus expected species richness values in each site

| | Number of independent records | | | | Vegetation index statistics | | | |
|---|---|---|---|---|---|---|---|---|
| | Sites and post-fire age | | | | GLMM | | LMM | |
| Species | Site 1 (13 years) | Site 2 (30 years) | Site 3 (> 40 years) | Total | $\chi^2$ | *P* | LR | *P* |
| Wild goat | 0 | 9 | 0 | 9 | 4.39 | *0.036* | 4.92 | *0.027* |
| Caracal | 2 | 1 | 8 | 11 | 0.20 | 0.654 | 0.76 | 0.384 |
| Brown hare | 12 | 10 | 6 | 28 | ~ 0 | 0.992 | 1.72 | 0.189 |
| Stone marten | 5 | 2 | 0 | 7 | 0.31 | 0.576 | 3.33 | 0.068 |
| Eurasian badger | 3 | 4 | 1 | 8 | ~ 0 | 0.944 | 5.27 | *0.022* |
| Wild boar | 32 | 17 | 24 | 73 | 3.79 | 0.052 | 0.24 | 0.625 |
| Brown bear | 1 | 0 | 1 | 2 | 0.01 | 0.825 | – | – |
| Red fox | 2 | 4 | 0 | 6 | 0.75 | 0.386 | 3.31 | 0.069 |
| Total records | 57 | 47 | 40 | 144 | | | | |
| Species richness | 7 | 7 | 5 | 8 | | | | |
| $\chi^2$ | 7.7 | 1.4 | 0.4 | | | | | |
| *P* | *0.005* | 0.234 | 0.504 | | | | | |

they detect predators easier in such environments than in the unburned forests (Jaffe and Isbell 2009), and they can find more food (i.e., grasses, etc.) due to the increased forage quantity and quality (Romme et al. 2011). Here in the present study, wild goat, the largest herbivore in the region, has been detected only in the site 2 which burned 30 years ago. The habitat use of wild goat is related with steep slopes and rocky areas (Esfandabad et al. 2010; Sarhangzadeh et al. 2013), and this study site may offer more appropriate habitat conditions for wild goat as it has the highest elevation around the region and include many rocky areas and relatively steepy slopes. More studies are needed to reveal how habitat structure and fire interact to shape the distribution of the wild goat.

Important prey species such as brown hares increase during the early years of the post-fire succession in Mediterranean forests (Sokos et al. 2016). In our study sites, brown hare is one of the most common large mammal species; possibly supporting the presence of predator species (such as caracal; Mengüllüoğlu and Ambarlı, 2019) in burned areas, since it is known that predator large mammals benefit the increased visibility and ability to move long distance for hunting in burned habitats (Pausas and Parr 2018), and the increased number of prey (Torre and Diaz 2004; Rollan and Real 2011). Evidence of habitat use by large mammals in burned sites in our study also supports these conclusions.

The diversity in the functional roles of the detected large mammal species in our study is associated with their potential contribution to the post-fire recovery of the ecosystem (Table 2). They are found at diverse trophic levels as herbivore, carnivore, and omnivore; at the same time, some of the species also have major roles as being the top predator or main prey in the food web of the studied ecosystem. The foraging behavior of wild boar and Eurasian badger by digging the soil surface to reach their food resources such as plant roots and invertebrates may promote the germination of seeds in the soil seed bank and seedling establishment with several mechanisms as revealed for many digging large mammals worldwide (Chambers and MacMahon 1994; Fleming et al. 2014). Active dispersal of seeds by large mammals by both epizoochory and endozoochory (Couvreur et al. 2008; Karimi et al. 2018) may contribute to the distribution of seeds in habitat patches in a heterogeneous post-fire regenerating ecosystem. As indicated by Torre and Diaz (2004), preying success of carnivores on small mammals is evident to change due to the fire-related habitat alteration resulted by changes in vegetation cover. Since being at the top of the trophic level, a change in the population size of the carnivorous large mammals has a cascading effect in the ecosystem (Nichols et al. 2009), and the presence of large carnivores in burned sites can be used as an indicator for a successful habitat recovery after fire in Mediterranean-type ecosystems.

Consequently, the existence of post-fire habitat patches has important implications for the conservation of large mammals in frequently burned Mediterranean ecosystems. The burned habitats are important for large mammals because they (1) create new food resources since many species—both animals and plants—that can be consumed by large mammals appear at different post-fire recovery stages, (2) decrease inter- and intra-specific competition by increasing the number of food sources, (3) maintain landscape heterogeneity and habitat diversity, and (4) provide a good connection between unburned habitat patches.

In conclusion, habitats created by fire disturbance in Mediterranean pine forests support large mammal occurrence, and burned Mediterranean habitats should be considered in the conservation and management plans of large mammals beside mature forests.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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