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Mesocarnivore site occupancy in cork oak landscapes: influence of management regimes

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Resumo

A coexistência de espécies simpátricas é o foco de diversos estudos ecológicos. Em teoria, duas espécies semelhantes não podem coexistir no mesmo local, uma vez que irão competir pelos mesmos recursos e, portanto, a espécie mais forte irá prevalecer sobre a espécie mais fraca. Desta forma, a competição é uma das forças motrizes na estruturação e organização das comunidades de carnívoros. No entanto, na prática existem algumas nuances sobre esta teoria ecológica, sendo a principal a partição de nicho. Frequentemente nas comunidades de carnívoros se encontram mecanismos de segregação multidimensionais entre espécies simpátricas que traduzem a partição de nicho, quer seja uma partição espacial, temporal ou trófica. A segregação espacial é aquela que melhor se conhece entre espécies de carnívoros, no entanto, também temporalmente e a nível trófico as espécies podem diferir, sendo que se espera que tal aconteça ao longo de pelo menos um dos eixos. Os carnívoros são um grupo com uma grande diversidade, as espécies diferem entre si na morfologia, hábitos, preferências alimentares e de habitat. Desta forma, os carnívoros são um grupo com alguma plasticidade na resposta às condições ambientais e do ecossistema, tendo as espécies a possibilidade de ocupar diversos nichos, sempre considerando os seus requisitos ecológicos. Por outro lado, os carnívoros são um importante indicador do bom estado do ecossistema, pois sendo na sua maioria predadores têm um papel estrutural e regulador nas cadeias tróficas, baseado na comum interação predador-presa. Através de cascatas tróficas os carnívoros podem controlar as populações de presas, isto evita que se atinjam valores populacionais prejudiciais para o ecossistema no geral, incluindo para o Homem. No entanto, as cascatas tróficas funcionam também no sentido inverso, colocando os carnívoros numa posição de vulnerabilidade, pois qualquer alteração em níveis tróficos inferiores irá também afetar estas espécies. Isto torna-se especialmente preocupante quando existe uma redução significativa de presas habituais, provocando por consequência redução das populações de carnívoros. Para além da função estrutural, os carnívoros prestam outros serviços bastante importantes aos ecossistemas. Apesar de predadores, muitas vezes estas espécies recorrem a outros itens alimentares, especialmente frutas quando estas estão mais disponíveis no habitat. Deste modo, os carnívoros têm um papel relevante na dispersão de sementes, sendo que muitas vezes as depositam bastante longe do seu local de origem e muito frequentemente em áreas abertas com elevadas taxas de germinação. Muitas vezes este taxa funciona também como controlo de reservatórios de agentes patogénicos, uma vez que algumas das espécies reservatório constituem presas de carnívoros. Contribuem assim para a redução do risco de contaminação para espécies domésticas e até para o Homem.

A agricultura e práticas florestais são cada vez mais a fonte de destruição e fragmentação do habitat, uma das principais causas do declínio da biodiversidade. Com o aumento da população mundial, estas atividades de origem antropogénica cada vez mais têm posto em causa a persistência da biodiversidade. Atualmente, vários fatores ameaçam a biodiversidade de forma a comprometerem a sua subsistência, entre eles: a degradação e perda de habitat, vários tipos de poluição, sobre-exploração dos recursos naturais, introdução de espécies invasoras, catástrofes naturais, perturbações antropogénicas e caça e perseguição ilegal de espécies. Os carnívoros são um grupo especialmente suscetível a conflitos com o Homem, sendo que podem competir pelos mesmo recursos, causando muitas vezes casos de perseguição ilegal das espécies. Ameaças como a degradação do habitat pela agricultura, a sobre-exploração de recursos naturais ou outras atividades antropogénicas, bem como as catástrofes naturais, afetam as espécies pela diminuição de recursos disponíveis, assim como da sua qualidade. Isto acontece também na presença de espécies invasoras, que competem com as espécies nativas pelos mesmos recursos.

Os ecossistemas mediterrânicos têm para além de um importante valor natural, também um valor cultural incutido, pois foram ao longo de várias décadas o resultado da interação do Homem

com a vida selvagem. Esta interação por vezes ocorre pacificamente e de forma estável e noutras ocasiões de uma forma mais conflituosa, como referido anteriormente. O montado de sobro é um biótopo típico do mediterrâneo que evidencia o papel do Homem na modelação da paisagem. Sendo um habitat modificado, o montado de sobro é constituído por uma camada arbórea de sobreiros (*Quercus suber*) e/ou azinheiras (*Quercus rotundifolia*), complementada com subcoberto diverso, mais ou menos denso, dependendo dos locais e das atividades antropogénicas desenvolvidas. O montado é um sistema agro-silvo-pastoril, que integra a produção animal, extração de cortiça e cultivo de cereais, bem como outras atividades agrícolas e florestais. Simultaneamente, providencia vários benefícios estéticos e recreativos, serviços de ecossistema, assim como um habitat adequado a várias espécies. Muitas vezes encontramos no montado manchas de outros biótopos, nomeadamente plantações como os pinhais ou eucaliptais, áreas de matagais mediterrânicos ou galerias ripícolas. A combinação dos diferentes habitats cria heterogeneidade na paisagem o que, de uma forma geral, beneficia os carnívoros e outra biodiversidade.

Em Portugal, as zonas de montado encontram-se mais a Sul do país e contam com 10 das 14 espécies de mesocarnívoros, ou seja, carnívoros de porte médio-pequeno (< 15kg). Apesar da coexistência das espécies de carnívoros com os humanos em áreas semi-naturais, mudanças atuais na intensidade de gestão têm ocorrido como duas tendências. Por um lado, a intensificação das práticas agrícolas e pecuárias e consequentemente aumento de diversas perturbações antropogénicas nestas áreas. Por outro lado, o abandono de áreas anteriormente usadas para usos tradicionais do solo, que consistiam em sistemas de pousio e rotação, mas geralmente associadas a pouca intervenção humana. Isto poderá levar a uma alteração das comunidades de carnívoros em sistemas agro-silvo-pastoris, uma vez que estamos perante práticas que originam modificações na paisagem e usos do solo.

Desta forma, o principal objetivo deste estudo é perceber de que forma é que as opções de gestão têm um papel estruturante nas comunidades de carnívoros. Para tal foram analisadas duas áreas próximas geograficamente e com características ambientais e ecológicas semelhantes, o que pressupõe também comunidades de carnívoros semelhantes. Uma das áreas, a Companhia das Lezírias S.A., é a maior exploração agro-silvo-pastoril do país, contando com variadas atividades de produção e uma grande intervenção humana no habitat, originando várias alterações nos usos do solo. Em alternativa, a outra área de estudo é o Campo de Tiro de Alcochete, que é uma base militar pertencente à Força Aérea Portuguesa e onde ocorrem diversos exercícios militares. No entanto apesar desta fonte de perturbação, esta área apresenta poucas opções de gestão, mantendo o uso do solo mais estável e natural do que a área anterior. Previu-se inicialmente, que de uma forma geral, a heterogeneidade da paisagem beneficie a comunidade de carnívoros, ao contrário de todas as atividades que impliquem um ecossistema mais homogéneo. Por outro lado, atividades que promovam uma redução significativa do subcoberto esperam-se que prejudiquem as espécies pela perda de recursos alimentares e de abrigo, ao contrario de atividades que mantenham o subcoberto. Atividades agrícolas devem favorecer espécies mais generalistas como a raposa, o sacarrabos e o texugo que beneficiam de recursos alimentares providenciados por estas, contrariamente às espécies menos generalistas, tal como a geneta e fuinha. Finalmente, maior intensidade de gestão prevê-se que prejudique mais espécies como a fuinha e geneta, que requerem ambientes menos modificados em comparação com a raposa e o sacarrabos.

Para testar estas hipóteses utilizei dados adquiridos em 2013 e 2014 referentes à Companhia das Lezírias e recolhi um conjunto semelhante de informação no Campo de Tiro de Alcochete. Para tal, foram instaladas estações de foto-armadilhagem para amostrar espécies de carnívoros por toda a área de estudo. A amostragem decorreu entre Novembro de 2016 e Maio de 2017.

Foram estabelecidas 66 estações de armadilhagem fotográfica ao longo de toda a áreas, sendo que a amostragem foi dividida em três fases, cada uma com 22 quadrículas amostradas. No total, cada quadrícula foi amostrada três vezes o que resultou num total de 45 dias de amostragem em casa estação. Simultaneamente, foram recolhidas variáveis potencialmente explicativas dos padrões de ocupação e de intensidade de uso do habitat pelas espécies. Estas variáveis pertencem a três categorias cruciais na sobrevivência dos carnívoros: habitat, presas e perturbação. As variáveis foram medidas em *buffers* com raio de 350m em redor do local exato de instalação de cada câmara. Todos os dados referentes ao Campo de Tiro, tanto de capturas de carnívoros como as variáveis correspondentes a cada estação de amostragem, foram aplicados em modelos de ocupação e de intensidade de uso do habitat, *single season single species* e *N-mixture*, respetivamente.

Em cerca de 6 meses de amostragem, que equivaleram a 2874 dias de foto-armadilhagem, foi obtido um total de 505 capturas independentes de carnívoros. Isto é, foram consideradas capturas independentes todas as ocasiões em que um indivíduo da mesma espécie era fotografado com pelo menos 30 minutos de intervalo, a não ser que fosse possível distinguir mais do que um indivíduo. A comunidade de carnívoros do Campo de Tiro tem ocupações *naïve* iguais ou superiores a 30%, o que significa que estamos perante uma comunidade saudável, com espécies relativamente bem distribuídas pela área. A raposa é a espécie melhor distribuída (ocupando 85% da área de estudo), seguida do sacarrabos, depois a fuinha, a geneta e por fim o texugo, com menor ocupação da área de estudo. Tendo em conta os resultados obtidos na Companhia das Lezírias, a raposa, o sacarrabos e o texugo têm maiores valores de ocupação *naïve* nesta área, pelo contrário a geneta e fuinha estão melhor distribuídas no Campo de Tiro. Os resultados dos modelos comprovam as diferentes preferências das espécies de carnívoros, o que se traduz na existência de partição de nicho. Os modelos gerados para as duas áreas evidenciam que na área com maior perturbação pelas opções de gestão, a Companhia das Lezírias, o habitat torna-se o mais significativo na distribuição e abundância das espécies. Opostamente, numa área mais homogénea e com poucas opções de gestão, o Campo de Tiro, são as fontes de perturbação que aparentam ser as variáveis mais relevantes na ocupação das espécies. A comparação dos resultados em ambas as áreas permite inferir que de facto as opções de gestão têm um papel importante na estrutura e organização das comunidades de carnívoros. Isto porque, em áreas próximas e similares onde as comunidades de carnívoros eram expectáveis que fossem semelhantes, a intensidade de gestão origina diferenças na composição das mesmas, bem como resulta na exploração de diferentes nichos pelas mesmas espécies em ambas as áreas. Apesar das diferenças encontradas nas opções de gestão, ambas as áreas de estudo apresentam um mosaico de habitats heterogéneo. Isto parece beneficiar a comunidade de carnívoros uma vez que estes se encontram de uma forma geral, bem distribuídos e em abundância tanto numa área como noutra. No entanto, os resultados obtidos também revelam a importância dos matos mediterrânicos no subcoberto, ao se detetar um efeito negativo do pastoreio na intensidade de uso do habitat pelas espécies, tanto na Companhia das Lezírias como no Campo de Tiro. Adicionalmente, as espécies mais generalistas ocorrem em maior abundância na Companhia das Lezírias, onde as práticas agrícolas providenciam novas e diferentes fontes de alimento. Por outro lado, as espécies menos generalistas apresentam maior abundância no Campo de Tiro de Alcochete uma área com menos práticas agrícolas.

A relevância deste trabalho prende-se pelo conhecimento científico que adiciona àquilo que já era conhecido sobre a influência antropogénica nos carnívoros e como as suas comunidades respondem. Verificou-se que frequências e intensidades distintas nas atividades de gestão têm diferentes implicações na paisagem e consequentemente na comunidade de carnívoros, afetando as espécies de diferentes formas. Com os resultados obtidos pretende-se também criar políticas

de gestão para os sistemas mediterrânicos semi-naturais, com vista à conservação das espécies de carnívoros. A tomada de decisão sustentada por dados científicos e robustos, torna-se cada vez mais importante e deve ser considerada em áreas com uma grande incidência de opções de gestão.

Palavras-chave: comunidades de carnívoros, partição de nicho, montado, opções de gestão

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General introduction

An ecological community is a group of populations of different species that share the same geographic area. The organization of ecological communities is based on two major driving forces – energy transfer and competition (Hairston 1964). The first refers to the transference of energy along food chains (Paine 1966). Energy is essential to species survival because it is the base of all metabolism, physiology, movements and life activities. From one trophic level to another some energy is always lost, so the balance between the energy gained and the energy spent during the daily routine is crucial to individuals and species and consequently influences the structure of communities. On the other hand, it is known that competition for resources is a powerful driver of ecological community assembly (Schoener 1983). The competitive exclusion principle suggests that ecologically similar species cannot co-occur in the same area (Hardin 1960), where the stronger species prevail over the weaker one (Fedriani et al. 2000). Nevertheless, in nature coexistence of sympatric and similar species is observed, specifically due to a mechanism denominated as niche partitioning. The concept of niche is often recognized as the frequency distribution of utilization of occurrence along dimensions (Schoener 1974). This segregation of the niche axis in multidimensional space aims to minimise species overlap, essentially among three axes – spatial, trophic and temporal (Schoener 1974). This means that similar species can coexist in specific conditions, namely if they partition their use of resources in time, across spatial heterogeneity and across different resource uses.

Globally, anthropogenic factors are known drivers of major environmental changes, such as climatic fluctuations and ecosystem transformations, that lead to biodiversity loss (https://www.millenniumassessment.org/en/About.html#1). One of the main consequences for fauna is the destruction and fragmentation of the habitat that results both in the decrease of suitable patches for the species persistence and impedes genetic flow (Jackson & Fahrig 2011). The decreased habitat availability is originated mostly by agriculture, forestry exploitation and infrastructure construction. To adapt to changes in habitat and being able to coexist in limited space, species may reorganize their distribution and the resources they use. Sometimes, moderate levels of habitat change create mosaic landscapes with different patches, which might be beneficial for some species that could take advantage of the resulting habitat heterogeneity (Dotta & Verdade 2007). This is supported by the intermediate disturbance hypothesis (Wilkinson 1999). Townsend and Scarsbrook (1997) state that in one extreme, intensively disturbed habitats hold low species richness because species colonization in short intervals between disturbances is difficult. On another hand, areas with low disturbance are also low in species richness because competition by superior species is high (Townsend & Scarsbrook 1997). According to Townsend and Scarsbrook (1997), the highest richness levels are achieved in areas with intermediate levels of disturbance, because they allow the coexistence of rapid colonizers and competitive species.

The Mediterranean basin is a region that has been highly humanized for millennia (Blondel 2006), and are the result of an old interaction between human populations and nature being today considered as part of the region cultural heritage (Blondel 2006). Mediterranean regions are also considered one of the global biodiversity hotspots (Myers et al. 2000), as they hold high levels of diversity and endemism, creating unique and rich ecosystems. The typical Mediterranean climate has dry and hot summers and rainy and cold winters, which also occurs in other areas of the globe such as California, Chile, South Africa and Australia. The Mediterranean-type ecosystems are a priority for species and ecosystem conservation. Despite their biological and ecological relevance, these ecosystems are however exposed to several human pressures at increasing levels, namely the expansion of agriculture and urbanization (Blondel 2006). The anthropogenic activities are expected to interfere in natural communities, altering their organization, in some cases benefiting species while in other prejudicing them.

A good example of human-nature interaction is the cork oak (*Quercus suber*) *montado* which is a semi-natural system that integrates different anthropogenic activities and simultaneously maintains a diverse fauna (e.g. Pinto-Correia 1993). This system is adapted to Mediterranean climate and it is considered a flexible model of management for renewable natural resources (Carrión et al. 2000). It is composed by individual or groups of trees, with a typical understory either with low density of shrubs or with well-developed shrubs. The management options of this landscape include diverse economic activities (Pinto-Correia 1993; Pinto-Correia et al. 2011). Every nine years, cork, the tree bark, is extracted from the tree. Cork is commercialized around the world and it is very popular due to its resistance, being used to make bottle stoppers, flooring, insulation material, clothes, accessories and decorative objects (Bugalho et al. 2011). The understory is also managed either by livestock or using mechanical procedures (Mangas et al. 2008). Different economical profitable plantations can also be found in this semi-natural system, for instance orchards, olive groves or cereal crops (Pinto-Correia 1993). The cereal cultivation is important not only to commercialize but also to feed the livestock. *Montado* is considered a high value nature (HVN) farmland, due to the highly varied resources and conditions that provide for animal and plant species (Paracchini et al. 2008). This habitat hosts a rich fauna composed by species with high conservation importance (Santos-Reis & Correia 1999), where carnivores are included and must be preserved because of their diversity.

Carnivore mammals are an animal guild extremely sensitive to environmental changes, in particular those of anthropogenic origin (Woodroffe 2000). These species are most of the times predators, so disturbances in lower trophic levels will affect carnivores through bottom-up trophic cascades (Carpenter & Kitchell 1993). Besides, their role in top-down regulation of trophic structures represents an important function in maintaining ecosystem health (Ruiz-Olmo 2012). Carnivores are difficult species to study especially because of their secretive and nocturnal habits, as well as the low densities that they live in the wild (Ruiz-Olmo 2012). Associating to the difficulty to investigate carnivore species, their sensitivity to environmental changes, make them a very vulnerable guild and susceptible to extinction scenarios. Their importance is also recognized in the ecosystem services that they provide, such as, regulation and maintenance functions, for instance as pest controllers (e.g., in outbreaks of prey populations), as seed dispersers or as pathogens reservoirs (Ruiz-Olmo 2012). Some carnivore species are able to change their diet, not being exclusively predators, to adapt to human-shaped landscapes and the resources they provide (Rosalino & Santos-Reis 2009). On the other hand, carnivores are often persecuted by humans either directly via hunting or illegal poaching or via habitat loss. With the continuous growth of human population, it gets worse, once increasing resources are necessary to support all the human needs.

Land cover changes and management activities are expected to alter the original carnivore communities in managed landscapes (Banks et al. 2008). Nonetheless, the human activities of the traditional *montado* create heterogeneity that might be beneficial to carnivore species (Dotta & Verdade 2007), also contributing to their ecological requirements. The mentioned heterogeneity can be related not only to different patches of habitat but also to different food resources (Verdade et al. 2011), which potentially optimize carnivores coexistence. It is reasonable that generalist species remain present and abundant even in areas with more disturbance once they adapt easily to changes (Pita et al. 2009; Verdade et al. 2011) On the contrary, specialist species are expected to prefer areas with low human intervention, meaning with lower management intensity, once allow them to explore niches with restricted set of conditions as demonstrated by Peers et al. (2012).

While there is a body of research on understanding which are the main environmental factors shaping carnivore communities (Pita et al. 2009; Long et al. 2011; Sarmento et al. 2011; Pereira et al. 2012; Soto & Palomares 2015; Curveira-Santos et al. 2017), few focused on the effects of management options. In African landscapes, the gradient between protected and humanized areas is the most studied type of disturbance and it seems to have an important role structuring carnivore communities (Burton et al. 2012; Msuha et al. 2012; Schuette et al. 2013; Kiffner et al. 2014; Farris et al. 2015; Rich et al. 2016). Agricultural practices, livestock production and hunting being the most harmful factors to native carnivores (Burton et al. 2012; Msuha et al. 2012; Schuette et al. 2013; Kiffner et al. 2014; Farris et al. 2015; Rich et al. 2016). In Mediterranean systems, several factors might affect organization of carnivore communities namely agricultural and forestry practices, livestock production, increasing urbanization and infrastructures construction (Pita et al. 2011; Sarmento et al. 2011; Pereira et al. 2012; Soto & Palomares 2015; Curveira-Santos et al. 2017), but no comparison exists between ecologically similar areas with distinct management regimes at a local scale.

This study focus on testing how different management options might affect the structure of carnivore communities. We compare two areas geographically close and with similar carnivore communities but with distinct management regimes. The study is presented using an article format in order to be submitted for publication at the Conservation Biology journal given the conservation focus both on the local carnivore community and the *montado* long-term sustainability.

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1. Abstract: *The coexistence of sympatric mesocarnivore species maybe possible due to niche partitioning mechanisms. Co-occurring species segregate along different niche dimensions, through different habits and preferences. In this way mesocarnivores can minimize competitive interactions as well as adapt to ecosystem changes. The cork oak (*Quercus suber*)* montado *is a semi-natural Mediterranean system, where the constant human intervention has been shaping the landscape and its features over time, for instance by varying land uses and understory structure. Associated with this, management options for agricultural, forestry and livestock raising practices promote habitat diversification. The mosaic of different habitat patches provides resources to several species, including carnivores, and this heterogeneity allows them to fill in different niches. To understand how carnivores respond to landscape changes induced by management options at the farm level, two similar mesocarnivore communities were assessed. These communities inhabit adjacent areas within a cork oak woodland matrix, however subjected to different management and consequently different anthropogenic disturbances. Using a camera trapping approach and ecological modelling procedures, I evaluated the occupancy (presence/absence data) and intensity of habitat use (use frequency) patterns of five mesocarnivore species: red fox (*Vulpes vulpes*), stone marten (*Martes foina*), European badger (*Meles meles*), common genet (*Genetta genetta*), Egyptian mongoose (*Herpestes ichneumon*). Simultaneously environmental variables that represent three categories needed for carnivores survival: habitat, preys and disturbance factors, were measured. All five species were present in the two study areas, with a total of 505 captures during 2874 trap-days, which can be translated in 17.6 captures per 100 days. Habitat use intensity was best explained by environmental variables than space occupancy patterns. In general, in the intensively managed area, habitat variables measuring the effects of human intervention were more important predictors of carnivore habitat use intensity, for instance riparian vegetation and* montado *with different shrubs density. On the other hand, carnivore species in the area with less intensive management respond firstly to disturbance sources like for example livestock and wild boar abundances and military activities. These results suggest that management options have an important role in structuring mesocarnivores community. Individually each species responded differently to the considered factors, promoting segregation along space and therefore coexistence.*

Keywords: carnivore communities, niche partitioning, *montado*, management options

According to Conservation Biology rules

2. Introduction

2.1. Cork oak ecosystem and the impacts of management options

Anthropogenic factors are the drivers of significant environmental changes, namely increasing climatic fluctuations, ecosystem instability, and global biodiversity loss (Forester & Machlist 1996; Karl & Trenberth 2003; Ives & Carpenter 2007). With the growth of human population over the last century, natural resources have been more exploited and some became depleted, which may cause a conflict with wildlife whenever those resources are also needed for its survival. Agriculture is considered one of the driving forces changing natural ecosystems, because of the need for more and better food resources for human consumption as well as for livestock (Meyer &Turner II 1992). Agriculture has been affecting both the spatial and temporal structure of the landscape (Wiens 2000). The intensification of agriculture sometimes leads to monocultures, often harmful to species, both due to habitat loss and lower variety of food resources, also frequently associated with the use of agrochemicals (Verdade et al. 2011). In Europe, agricultural activities and forestry production have been the main causes of habitat fragmentation, acting as barriers to dispersal and reducing genetic flux (Jackson & Fahrig 2011), therefore compromising the survival of species. For example, some species of steppe birds, such as the Montagu's Harrier (*Circus pygargus*) or the Great Bustard (*Otis tarda*) are dependent on agricultural areas (Paracchini et al. 2008).

The Mediterranean basin is one of the most biodiverse areas of the world, with large numbers of endemic species (Myers et al. 2000), and also considered a rich area in natural and cultural landscapes (Naveh 1998). It means that in spite of the potential for conflicts between humans and wildlife, their coexistence was maintained along millennia (Blondel 2006), even if sometimes and in some places in an unbalanced way (e.g. Lozano et al. 2003). Scrublands are an important component in Mediterranean ecosystems; they are composed of a mixture of several sclerophyllous shrubs, tree species and abundant rocks (Mangas et al. 2008). The Mediterranean climate favours natural fires (Pausas 2004; Blondel 2006), that in general are frequent and intense (Moreno et al. 1998). For instance, Pausas (2004) refers that in the period 1974 - 2000 the area burned varied between 10000 and 16000 hectares per year. Often these affect human interests such as pine plantations, urbanizations or croplands (Prodon et al. 1984; Prodon 1987; Terradas 1996). Since the shrubs are potentially enhancing factors for these fires, shrub removal over large areas is used to control ignition potential (Terradas 1996; Camprodon 2001). Traditionally shrub removal was progressive by cattle grazing; however nowadays it is done using machine power and much more aggressive, with the destruction of vast scrubland areas, for instance in plantation forests (Mangas et al. 2008).

Cork oak (*Quercus suber*) woodlands, a Mediterranean ecosystem called *montado* in portuguese, are the best example of an agro-silvo-pastoral system that integrates animal production, cork harvesting and cereal cultivation, while hosting high biodiversity and providing recreational and aesthetical benefits (Bugalho et al. 2011). This land use results from the transformation of the indigenous macquis (Pinto-Correia 1993) and represents a model of management for renewable natural resources which is flexible and adapted to the Mediterranean climate (Carrión et al. 2000). This climate is characterized by hot and dry summers and cold and humid winters (Lionello et al. 2006). Nowadays, *montado* is composed by individual or groups of trees, generally cork or holm oaks (*Quercus rotundifolia*), but it also includes patches with orchards, olive groves (*Olea europaea*) or even other oaks (*Quercus pyrenaica* and *Quercus faginea*) (Pinto-Correia 1993; Rosalino et al. 2009; Gonçalves et al. 2012). The heterogeneity of the *montado* landscapes is enhanced if we further consider the composition and structure of the shrubby vegetation. Usually the density of shrubs is controlled, by direct removal or by animal grazing (Pinto-Correia & Mascarenhas 1999); nevertheless, some dense patches can be found in areas with less accessibility (Gonçalves et al. 2012). These shrubs are dominated by species such as strawberry tree (*Arbutus unedo*), rock rose (*Cistus* spp.), false olive (*Phyllirea angustifolia*), or heath (*Erica* spp). (Mangas et al. 2008; Canteiro et al. 2011).

In the Iberian Peninsula historical humanization and traditional land-uses practices have created landscape heterogeneity that benefits biodiversity (Plieninger et al. 2006). The traditional farmlands are characterized by rotation agricultural systems that require frequent human interventions on the farm/agroforestry system (Navarro & Pereira 2012). These farming systems are known for the low nutrient input and low output per hectare (Plieninger et al. 2006), usually associated to “low-intensity land uses systems” (Bignal & McCracken 1996) Their maximum extension on Europe, was reached in the second part of the 19th century, and in the 20th century the progress of technology induced a decrease in the traditional uses of the land (Plieninger et al. 2006; Henle et al. 2008). Currently in Portugal, there are two concurrent states where some farmlands, powered by rural exodus, are being abandoned and encroached by shrubs; while in other farmlands, there is intensification of land uses with higher grazing pressure or intensive crop farming (Henle et al. 2008; Costa et al. 2011). While the first state allows the growth of shrubs and succession, the latter one does exactly the opposite, decreasing shrub vegetation and, to some extent arresting succession.

The economic sustainability of the *montado* has been based on a diversity of products (Pinto-Correia et al. 2011). For instance, the cork production in Portugal is recognized globally, comprising 33% of the world cork oak area and 54% of the mean annual world cork production (Ribeiro et al. 2010). Cork extraction occurs every nine years, without the removal of any tree during the process. All around the world, cork is frequently used to produce many objects of daily life, such as cork stoppers, wardrobe, decoration, and other. *Montado* also supports production activities of cereal crops cultivated in long rotations, combined with fallowing, and extensive livestock grazing (Gaspar et al. 2007). Although livestock has been shaping the Mediterranean landscapes over time, in the past years there has been an increase in livestock numbers per unit of area. In this system, livestock has diverse functions: prevents the colonization of pasture lands by shrub species, improves croplands quality and soil fertility, and accelerates nutrient recycling (Moreno & Pulido 2009). Raising sheep, goats, and the Iberian pig was the traditional activity. Nevertheless, we are today facing some changes in livestock management, namely abandonment of rotation systems, increase of time spent in the same patches, replacement of traditionally used species for bovines, and the increase of livestock units above sustainable levels (Olea & Miguel Ayanz 2006). At moderate levels, the presence of cattle in oak woodlands has the positive consequence of controlling shrub vegetation, but increasing numbers could be prejudicial for native wildlife species, reducing some food resources and causing habitat disturbance.

Currently, the *montado* is often interspersed with planted forest patches that are explored economically. Nowadays, plantation forests cover about 11% of the total forested area in the Mediterranean basin (Blondel et al. 2010). In Portugal, the main plantation species is eucalyptus (*Eucalyptus globulus*), an exotic tree that occupies about 26% of the country’s forested area (ICNF 2013). However, fast growing plantations impoverish even more the soils. In addition to the reduced diversity in the canopy, these plantations also promote a decrease of diversity in the understory (Fabião et al. 2007). In order to be profitable, eucalyptus plantations are generally under intensive management and high levels of perturbation.

2.2. The role of carnivores in ecosystems and their importance as biological models

Carnivores, i.e. mammalian species included in the Order Carnivora, have high ecological value and are sensible to perturbation which affects community composition, species distribution and occupancy patterns (Verdade et al. 2011; Ruiz-Olmo 2012). Carnivores are flagship species, that is, popular species serving as symbols to promote the conservation awareness and action (Heywood 1995) due to the empathy that they cause in people. Because of their large area requirements in comparison to other taxonomic groups, carnivores are also umbrella species with a key role in ecosystems (Mangas et al. 2008), which means that they serve as a "protective umbrella" to several co-occurring species (Fleishman et al. 2000). Carnivores also have the ability of directly or indirectly control the availability of resources to other organisms, especially through the physical modification, maintenance or creation of habitat; this concept is called ecosystem engineering (Fleishman et al. 2000). Carnivores as a group show high plasticity (Ruiz-Olmo 2012), with varied body size, habitat and food preferences, as well as their life strategies or even their behaviours. However, they are also considered like a homogeneous model based on their role as predators (Ewer 1973). Mammals have a strong influence on ecosystem dynamics, in terms of trophic interactions as they can act as prey or predators (Sinclair 2003).

In the Mediterranean basin, most species are mesocarnivores, term which refers to small and medium-sized species (< 15kg) (Roemer et al. 2009). Given their smaller size and ability to thrive in diverse habitats, mesocarnivores are usually more abundant than large carnivores and ecologically more diverse; yet their impact within communities is generally assumed to be relatively minor (Roemer et al. 2009). Roemer and collaborators (2009) state that in many situations, mesocarnivores may be fundamentally important drivers of ecosystem function, structure and dynamics, especially in three different occasions: (1) when larger carnivores are absent, (2) on island ecosystems or other communities with relatively simple composition, and (3) where they represent non-native introductions. So, with the decline of apex predators in many ecosystems around the world, mesocarnivores are more and more filling ecological roles previously taken by large carnivores (Roemer et al. 2009), mostly in trophic organization. In Portugal, the cork oak ecosystem supports about 70% of the medium-sized carnivore species, i.e. 10 out of 14 species (Rosalino et al. 2005c).

In general, a diverse mammalian community represents a healthy ecosystem (Miller et al. 2011). Among the several ecosystem services provided by carnivores, there are three that stand out. Firstly, carnivores usually perform the function of ecosystem regulators, essentially controlling prey densities. This is a typical prey-predator interaction, where there is a mutual dependence (Ruiz-Olmo 2012). Carnivores act as top-down regulators of lower trophic levels, both for mesopredator (i.e. performing as superpredators) and for herbivore populations (Prugh et al. 2009; Ruiz-Olmo 2012). Secondly, another relevant service performed by carnivores is seed dispersal (Roemer et al. 2009; Rosalino et al. 2010; Ruiz-Olmo 2012). Many carnivores become secondarily generalists (Ruiz-Olmo 2012), resorting to the most abundant food resources; they often consume fruits when seasonally available in the habitat. Current data from Mediterranean Europe, demonstrated the relevant role of fruits on the diet of most mesocarnivores, with more than 25% of food consumption (Rosalino & Santos-Reis 2009). Jordano et al. (2007) found that mesocarnivores, tend to move seeds as far as 1km (most of the times between 650 and 700m), and usually deposit them in open habitats, where the germination rates are predicted to be higher. According to this author, this contrasts with birds, known as main dispersers; small passerines disperse seeds to less that 51m and deposit them in covered habitats and medium-sized birds take the seeds far than 110m, to open habitats (Jordano et al. 2007). Thirdly, in many cases carnivores act as controllers of reservoirs for pathogens and parasites, since these species are often carnivores' preys. This fact allows the control of diseases, reducing the risk of contamination in domestic species and even to humans (Roemer et al. 2009; Ruiz-Olmo 2012).

Human interests sometimes collide with carnivore's co-existence, especially in what concerns to the competition for the same resources (e.g. food or space) (Woodroffe 2000). The increase of human population and with all the associated activities, there are frequent conflicts with carnivores which originate species illegal persecution, as reported for the European wildcat (*Felis silvestris*) (Lozano et al. 2003). All these factors make carnivores a group with high vulnerability to local extinctions (Woodroffe 2000; Crooks 2002), with an increased need of conservation actions and decisions. Such decisions are based on the regulation function of these mammals, because any change in their community will affect other groups of animals, specifically if these changes elicit trophic cascades, i.e. when the increase or decrease of the abundance in one trophic level affects inversely other trophic level of the food web (Carpenter & Kitchell 1993).

Studies about mesocarnivores are increasingly important, not only focused on single species but also in their communities. Reliable estimates of species abundance and community structure are essential to inform and support decision-making processes (Jimenéz et al. 2017). However, carnivores are not easy to study because of their secretive and conspicuous habits, therefore the most common methods to measure abundance are hard to implement. Currently, noninvasive methods (e.g. camera trapping, search of tracks and signs, hair traps and others) have been used with high rates of success (Silveira et al. 2003). In addition, carnivores usually have large home ranges and low densities (Crooks 2002; Ruiz-Olmo 2012), making it difficult to study them.

2.3. Structure of carnivore communities and effects of managed landscapes

The structure of carnivore communities is based on various relationships among species and habitats, as well as intra and interspecific competitive interactions (Prugh et al. 2009). Carnivore communities' organization is determined by the apex predator regulation, the interaction among sympatric competitors and bottom-up regulation from availability of food resources and habitat suitability (Curveira-Santos et al. 2017). Furthermore, it is often a function of resource use and interspecific interactions between community members (Schoener 2009). Today many sympatric carnivore species persist in Mediterranean ecosystems and more and more studies have been addressing this issue, the species coexistence and the processes behind it, but most of them focus on natural areas. Sarmento et al. (2011) argued that sympatric mesocarnivores species occupancy responds differently to behavioural factors, density and local environmental factors. Other studies demonstrated that ecologically similar species can coexist in the same area, favoured by habitat diversity (Pereira et al. 2012), and, especially for specialist species, fine-scale habitat can be the key for coexistence (Soto & Palomares 2015). According to Monterroso et al. (2014) temporal partitioning is another important factor to consider in carnivore coexistence, mainly with increasing community complexity, where asynchronous peaks are possible.

Usually, coexistence of two similar species results in the prevalence of the stronger species and the local or global extinction of the weaker species (Fedriani et al. 2000). This is because competition drives community organization and structure (Schoener 1983) According to Schoener (1983) there are two mechanisms of interspecific competition: (1) exploitative competition, which consists in individuals using resources so that they deprive others from their benefits and (2) interference competition, that means direct interaction between individuals, such as by fighting, spread toxins, etc. The interference competition sometimes could lead to an extreme case which is called intraguild predation. Interspecific killing is known to have direct and indirect consequences on population and community structure (Palomares & Caro 1999). Because of such competitive interactions, Hardin (1960) defined the competitive exclusion principle, which states that two species with similar ecology cannot live together in the same place.

Nevertheless, sympatric and ecologically similar species may be able to coexist through a process named niche partitioning. This is a differential and multidimensional process that reduces resource overlap (Schoener 1974). This process is based on three main segregation dimensions: (1) spatial, (2) trophic, and (3) temporal; and it has been studied particularly in mammalian carnivore guilds, due to the strong competitive interactions among them (Schoener 1974). Many ecologists defined niche concept based on the number of times of occurrence along dimensions (Schoener 1974), while others considered it the set of necessary conditions to support the vital activities of an organism (Alley 1982). Spatial segregation seems to have an important role in the competition interactions between species (Fedriani et al. 2000). Space is differently used through distinct behaviours of avoidance and habitat selection by each species (Fedriani et al. 2000; Pereira et al. 2012). That choice considers the ecological requirements of each species associated with their habitat suitability and carrying capacity. However, at a larger scale species could share same habitats whereas, locally they can use resources differently, reducing overall competition (Pereira et al. 2012). Despite co-occurrence of carnivores in some habitats, interfering carnivores may relax the effects of interspecific competition by temporal segregation.

The time axis of niche partitioning is also found in the carnivore guild. Temporal segregation is especially noted in the asynchrony in the diel cycle and activity patterns of carnivore species (Monterroso et al. 2014). For instance, in cases when asymmetrical competition occurs, the subordinate species adjusts its behaviour to minimize agonistic encounters with the superior competitor (Monterroso et al. 2014). This dimension reveals to be particularly important when species have a high overlap across the two other dimensions (spatial and trophic), because it allows the exploitation of same resources, like habitat and prey, at different times (Curveira-Santos et al. 2017). Along the temporal dimension, species could have enough plasticity for the adjustment of the activity patterns to local conditions to increase its fitness and reduce competition (Monterroso et al. 2014).

Lastly, the trophic differentiation is a relevant axis since the strong prey-predator interaction is one of the most important in niche selection (Fedriani et al. 1999). This segregation is based on different choices for food resources and on consumption of variable food items along the year, depending on their availability in the habitat (Rosalino et al. 2005a) and the level of diet specialization of the species. In case of generalist species, it is easier change among food sources and consume an alternative food item, in the other hand, for the specialist species trophic niche differentiation is harder.

Agricultural conversion may trigger the use of new resources by species, specifically those related to human activities such as pet food, crops and crop pests (Verdade et al. 2011). However, associated with agricultural practices there are additional potential impacts to carnivores, for example increased exposure to feral predators (e.g., feral cats and dogs) and to edge effects, which may alter community composition and species abundance (Banks et al. 2008) and their interaction balances. Some authors suggest that mesocarnivores are adapting to take advantage of trophic resources created by agroecosystems (Verdade et al. 2011). For generalist mammalian predators, farmlands seem to be a source of food, not only more diverse but also more accessible than in natural habitats, and thus carnivores may be able to reach higher densities (Pita et al. 2009). In addition, farmlands provide resources such as fruits and vegetables and they also contribute to maintain small mammals' populations. On the other hand, farmlands may hinder specialist species that do not adapt well to change. Besides the direct effects, other indirect consequences may affect populations in farmlands, such as the increase of invasive and commensal species, that often compromises the survival of native species, because of the potential changes in competition and predation interactions (Shapira et al. 2008).

Traditional land uses often destroyed understory and reduced drastically its density, resulting in decreases in shelter against weather conditions (Mangas et al. 2008) and predators, as well as decreased conditions for the persistence of prey populations, which affect community organization. Today there are still management practices that might have these consequences, reducing refuge conditions and prey populations, for example eucalyptus' plantations with low shrub cover that are characterized by low food availability (Rosalino et al. 2005c; Pereira et al. 2012), affecting the behaviour of species and their interspecific interactions, resulting in a bigger foraging effort and greater exposures to predation risk (Cruz et al. 2015). Forest plantations might also be a source of alternative food and breeding resources, particularly when the forest patches are interspersed with open landscapes, as in the Iberian Peninsula (Gehring & Swihart 2003; Baker & Harris 2006). Plantation forests in some situations may require reduced human intervention for long periods and because of that it can be a safe place for carnivores (Pita et al. 2009).

In the Mediterranean region, scrublands provide shelter and are usually positively associated with carnivore richness. Providing cover for predatory activities, shelter and minimizing predation risk, shrublands should be seen as a key element in carnivore conservation (Mangas et al. 2008). Besides the refuge, other studies emphasized the relevant role of scrubs or mosaic of scrubs as a source of food for medium-sized carnivores (Virgós & Casanovas 1997; Revilla et al. 2000; Lozano et al. 2003). This might explain the higher carnivore richness in areas with a mixture of trees and tall shrubs, contrasting with areas with low shrub cover (e.g. *montado*, pine or eucalyptus plantations and open areas resulting from eucalyptus removal) (Mangas et al. 2008). Further shrub removal to prevent fires does not consider potential effects to mesocarnivores that depend on scrublands (Mangas et al. 2008).

The conservation of mammalian carnivores is difficult due to multiple socio-economic and conservation interests involved, demanding constantly new information about population status and impacts of management interventions (Jiménez et al. 2017). Therefore, the quality of the data is crucial to develop robust studies to help follow an adaptive management framework, as well as to build support and knowledge for good management decisions and policies (Jiménez et al. 2017).

2.4. Study aims and hypotheses

This study aims to understand how local-level management options might influence the structure of mesocarnivore communities. To do so I used occupancy and habitat use intensity models to determine carnivore species likelihood of presence and abundance, to understand carnivore distribution over space and habitat use intensity, and determine which factors might be influencing it. This aim was achieved by comparing data collected in Campo de Tiro with data previously available to Companhia das Lezírias S.A. using a similar approach. These areas were chosen because they represent different management options in the same ecosystem-type and at close proximity, meaning that other physiographic factors that could induced the variation in the carnivore communities are under control. Campo de Tiro de Alcochete has lower human intervention and Companhia das Lezírias S.A. represents an area with strong human intervention, where the natural succession of vegetation is often interrupted by management activities.

My hypotheses are as follows: (1) the landscape heterogeneity resulting from the management activities promotes higher resource diversity and a more diverse and abundant carnivore community, (2) anthropogenic activities that decrease understory height and/or density affect negatively the carnivore community, (3) agricultural practices increase food availability which benefits generalist carnivore species and (4) management options that cause land use changes are detrimental to less generalist carnivore species.

3. Study areas

The two study areas (Fig. 1) selected to test above mentioned hypotheses are: Campo de Tiro de Alcochete (CT), where field work was conducted between November 2016 and May 2017, and Companhia das Lezírias S.A. (CL) where data was collected previously (November 2013 – March 2014; Curveira-Santos et al. 2017 study (Fig. 1).

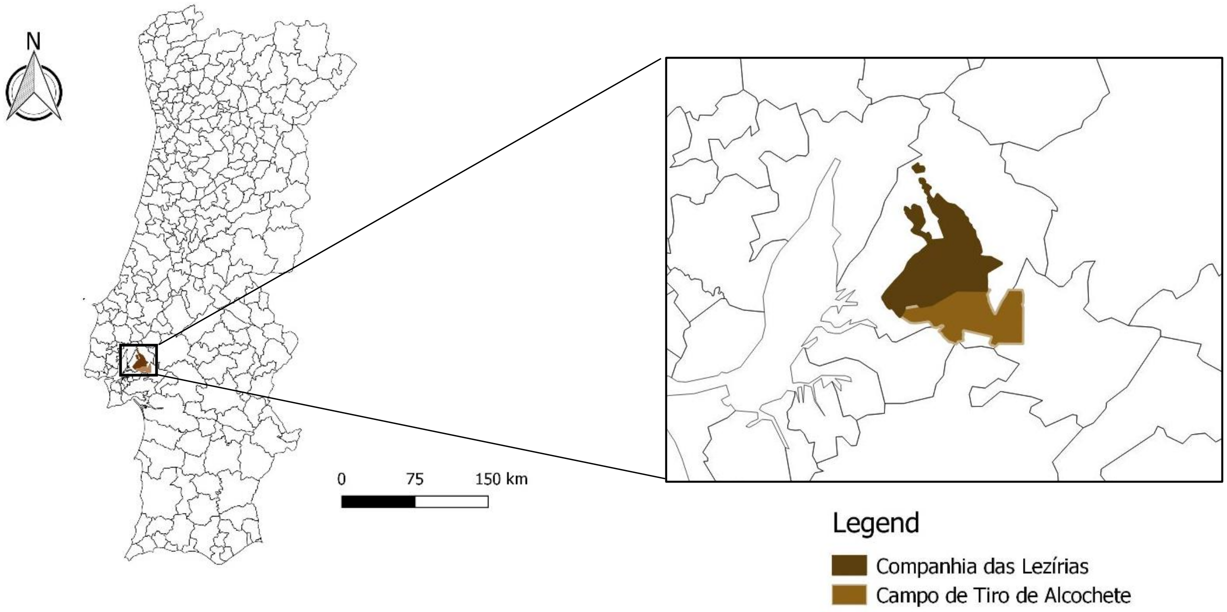

Figure 1 – Locations of the two study areas and limits of Portugal counties.

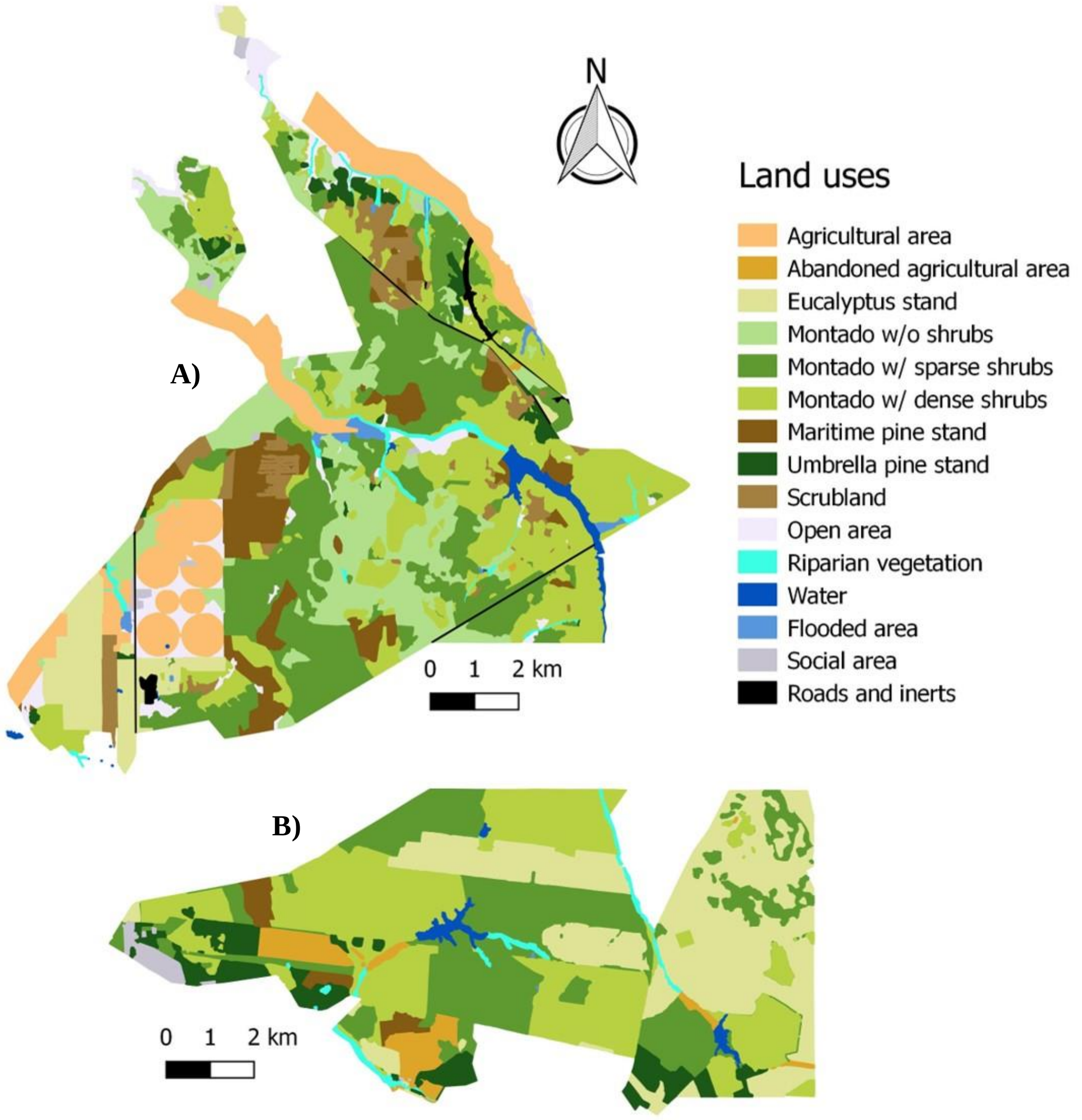

Figure 2 – Study areas and main land uses. A) Companhia das Lezírias S.A. (CL) and B) Campo de Tiro de Alcochete (CT).

Campo de Tiro is a military unit integrated in the Portuguese Air Force, firstly installed in 1904 with the purpose of being an artillery shooting area. Currently, its mission is to provide the Air and other Military Forces a safe area for military training and experiments with real armament, as well as safe storage for war material (http://www.emfa.pt/www/mobile/unidade-26-campo-de-tiro). With an extension of 7500 hectares, this area is inserted in the sedimentary basin of Tagus and Sado Rivers, located south of Tagus River. Characterized by Mediterranean climate, includes three artificial dams (Vale Michões, Claudina and Areeiro) and also some ground depressions that form temporary ponds, through the accumulation of water during the rainy winters. This mostly happens because of soil type, that is generally sandy in the surface and clayey in depth, hindering water drainage (FAP 1998). The all area is mostly flat with a mild slope, averaging 3% (FAP 1998).

Campo de Tiro is mostly a forested area, with the cork oak (*Quercus suber*) *montado* as the main habitat but we can also find pine stands, more specifically of maritime pine (*Pinus pinaster*) and umbrella pine (*Pinus pinea*), as well as eucalyptus (*Eucalyptus globulus*) plantations (Fig. 2). Shrublands are dominated by halimium (*Halimium* sp.), gorse (*Ulex* spp.), false olive (*Phillyrea* spp.), rock rose (*Cistus* spp.) and common heather (*Calluna vulgaris*). The eucalyptus stands are the biotope with less understory cover, and on the other hand, areas of *montado* with some maritime pine mixture appear to have the highest level of understory. Scattered in the area and associated with water lines there are well-developed riparian vegetation patches, including species as willows (*Salix alba*), ashes (*Fraxinus angustifolia*), alders (*Alnus glutinosa*), hawthrons (*Crataegus monogyna*) and blackberries (*Rubus sp*.). In general, the area has few urban areas and many of them currently abandoned (Miravent 2000).

This military unit is a reference site that supports both operational activities and the sustainable management of natural resources and biodiversity. Habitat management activities occurring in this study area are few and mostly related to forestry. The most managed habitat are eucalyptus plantations, with the removal and replantation of trees in short time intervals. Other activities, occurring usually every year, are cork extraction in different patches and pine nut harvest. Nowadays all the old farms inside the area are abandoned, but we still can found olive groves and old agricultural fields, currently without any human intervention allowing natural succession along the years. The livestock in Campo de Tiro includes sheep (ca. 550 units) and goats (ca.15 units), which can freely explore all area during daytime.

The anthropogenic activity that stands out the most in Campo de Tiro is the military operational activity, that consist in: (1) operational training of aerial shooting and bombardment, performed by both national and international Air Forces, (2) the instruction of Military Forces specifically, dominating fires and tactical exercises of combat, (3) the dismantling and destruction of military explosives' munitions, (4) testing of the Military Forces war material, and (5) collaboration with defense industries by providing them safe areas to tests and demonstrations (http://www.emfa.pt/www/mobile/unidade-26-campo-de-tiro). However, the military exercises do not occur throughout all the area but in specific locations, designed purposely for these objectives. According to FAP (1998), these places occupy about 1.440 ha, which represents 20% of Campo de Tiro (Miravent 2000). Most of these areas are continuous, excepting three scattered locations.

Companhia das Lezírias S.A. is located right next to Campo de Tiro being separated just by the road N119 (Fig. 1). The habitat matrix is very similar to CT, being composed by cork oak *montado* interspersed with diverse patches such as pine (*Pinus pinaster* and *Pinus pinea*) and eucalyptus stands (Fig. 2). Like in Campo de Tiro, there are also depressions that originate temporary ponds and a dam (Vale Cobrão) with permanent water though it reduces significantly during the dry season. The understory and the riparian vegetation have the same composition as in CT. In CL 11km of riparian arboreal and shrubby and well-developed vegetation are present (Gonçalves et al. 2012). Considering the proximity and similarity between the two areas, the factors that usually induce variation (e.g. climate, slope, dominant habitat, soil and other physiographic variables) within distinct areas, are controlled and the major source of variability between CL and CT are management-related.

The area of Companhia das Lezírias is separated in two different geographic cores: "Lezíria", the humid area, with 8.000 hectares and "Charneca", the drier area, with an extension of 10.000 hectares (http://www.cl.pt/htmls/pt/empresa_apresenta.shtml), where this study was carried. Since CL foundation, in 1836, Charneca do Infantado has been intensively managed, but initially it was used essentially for silviculture and pastoral practices (Curveira-Santos et al. 2017) which, associated with the current agricultural practices and new exploitation activities, make this area a heterogeneous and complex mosaic of several habitats, some with an anthropic origin. Nowadays, the main activities in Charneca are agricultural productions, forestry exploitation and animal raising (http://www.cl.pt/htmls/pt/empresa_apresenta.shtml). The agricultural activities are mainly at vineyards, rice plantations and olive groves (CL 2015). Other productions also occur, but on a smaller scale. Another relevant management option about Charneca is the bovine livestock production regime. Livestock units spend most of the time in forested areas (5500 ha) of Charneca, specifically from September/October to February/March, what corresponds to the winter season, when Lezíria is flooded, and often reach values between 0,5 and 1,1 heads/ha (Gonçalves et al. 2012).

Table 1 – Land uses and management options in both study areas: Campo de Tiro (CT) and Companhia das Lezírias (CL). *the agricultural areas on CT are abandoned without any intervention contrary to CL.

		CT	**CL**
	Total extension	7.500 ha	18.000 ha
	Permanent water points (dams)	3	1
	Slope	Mild	Mild
Land cover/uses	Montado/mixture	56%	38%
	Maritime pine stands	1%	5%
	Umbrella pine stands	7%	3%
	Eucalyptus stands	28%	2%
	Agricultural areas	5%*	35%
	Urban/Rural areas	1%	2%
	Riparian vegetation extension	ca. 11.000 m	ca. 24.000 m
Main management options	Livestock	Sheep and goats	Cows and pigs
	Vineyards	Absent	Present
	Olive groves	Absent	Present
	Rice plantations	Absent	Present
	Corn plantations	Absent	Present
	Honey production	Present	Present
	Cork extraction	Every year in different patches	Every year in different patches
	Pine nut harvest	Every year in umbrella pine stands	Every year in umbrella pine stands
	Wood extraction	Only in trees that are already dead or sick, excepting eucalyptus that are cut after 3 reforestations	Cut of cork oak, pine and eucalyptus in different patches
	Shrubs removal	Every year around the limiting fence	Every year in different patches
	Game	Wild boar and red fox	Wild boar, red fox, mongoose, rabbit and hare
	Horse raising	Absent	Stables and instruction
	Military activities	Shooting, explosions, bombardments and controlled fires	Absent
	Recreational activities	Aeromodelling, sport fishing, scouts camping, other outdoor activities (e.g. picnics, peddy-papers, cross-country runs)	EVOA, field trips (e.g. school trips and others) and bungalows accommodation

4. Methods

Carnivore surveys were carried by camera trapping. Traps were set with a regular distribution pattern along the two study areas. At each trapping location, a buffer of 350 meters was set and environmental parameters were measured that are proxies to relevant ecological requirements. The approaches followed in both study areas were similar to minimise methodological bias. The following trapping protocol refers to the sampling in Campo de Tiro de Alcochete as details for sampling at Companhia das Lezírias can be found in Curveira-Santos (2014). The selected environmental variables were included in modelling procedures associated to carnivore information using two types of models: (1) occupancy models - single season single species - that consider the presence of the species in the area, and (2) habitat use intensity models – N-mixture – based on the intensity of use as a proxy of species abundance in sampling stations.

4.1. Camera trapping protocol

The monitoring of the mesocarnivore community was carried from November 2016 to May 2017, using a camera trapping protocol. The use of this technique in conservation and ecology studies has been increasing in the last decade (McCallum 2012), because camera trapping is a powerful and non-invasive method for collecting information on elusive species, such as carnivores that are usually nocturne, scarce and difficult to detect (Ferreras et al. 2017).

The sampling grid followed a regular pattern. I used QGIS Software to divide the study area into a grid of 1x1km, which included 66 grid cells and each grid cell was used as a sampling station, covering the total extension of Campo de Tiro de Alcochete. Each station included one passive infrared camera model Moultrie M-990i Trail Camera and lure, composed with sand used by cats and *Valeriana officinalis* (Monterroso et al. 2011). Since only 22 cameras were available to the study, the 66 grid-cells were separated in three different sub-areas (A1, A2 and A3) with 22 grid-cells that were sampled simultaneously for a period of 15 consecutive days. After sampling the total of 66 stations, the procedure was repeated 2 more times. Thus, each station was active during 45 days (15 days+15days+15days).

After locating the central point of each grid-cell, a buffer of 100m was searched to select the best place to set the camera considering the animal trails. This strategy was followed to avoid spatial autocorrelation between stations, distancing an average of 996.6m [SE=108.8m, min=570.1m, max= 1044m]. The cameras were attached to trees, about 30-40cm above the ground, to meet the dimensions of the target species. Each camera was programmed with the sensor in high sensitivity; once triggered it captured a burst of three sequential photos and a delay of 10 seconds between each burst of photos was chosen. To ensure data independence, a single capture was considered every time that photographs of the same species were taken during an interval of 30 minutes, unless it was possible to distinguish more than one individual (Curveira-Santos 2014).

Previous data from Companhia das Lezírias S.A. was used (Curveira-Santos 2014). The field work at CL was carried between November 2013 and February 2014, and the protocol was similar except in the use of a stratified approach based on land cover representativeness of main habitat types, the number of sampling stations (52 at CL) and time at CL stations that stayed permanently active during 5 months (Curveira-Santos 2014).

4.2. Characterization of sampling stations

According to literature that describes ecological requirements of mesocarnivores species which distribution includes the study areas' region (Cavalini & Lovani 1991; Lucherini et al. 1995; Rosalino & Santos-Reis 2002; Virgós et al. 1999; Mangas et al. 2008; Santos & Beier 2008; Rosalino et al. 2009; Santos & Santos-Reis 2010; Curveira-Santos et al. 2017), a set of environmental predictor variables (covariates) were selected and measured in each sampling station within a 350m radius buffer (Curveira-Santos 2014). This buffer was chosen as in Curveira-Santos (2014), reflecting the smallest core-area of the species composing the target community. The smallest core-area was from the common genet (0.34km^2 - Santos-Reis et al. 2004).

Environmental covariates were divided into three major categories that represent their ecological functions: (1) HABITAT, (2) PREY and (3) DISTURBANCE (Table 2).

Table 2 – Environmental variables collected to assess mesocarnivores occupancy and intensity of habitat use patterns, and its description.

	Covariate	**Abreviation**	**Unit**	**Description**
HABITAT	Montado with dense shrubs	MDS	Proportion (%)	Cork oak patches or mixed patches of *Quercus suber* with *Pinus pinaster* or *Pinus pinea* (less frequent), with dense and high to intermediate understory dominated by *Halimiun sp., Ulex sp.* and *Cistus salvifolius.*
	Montado with sparse shrubs	MSS	Proportion (%)	Cork oak patches or mixed patches of *Quercus suber* with *Pinus pinaster* and *Pinus pinea* (less frequent) with sparse and short understory dominated by *Cistus salvifolius* and *Cistus crispus.*
	Maritime Pine stand	MP	Proportion (%)	*Pinus pinaster* stands with different stages of development and frequently with short to medium height understory, mostly composed by *Halimiun sp., Calluna sp., Erica sp* and *Ulex sp.*
	Umbrella Pine stand	UP	Proportion (%)	*Pinus pinea* stands with different stages of development and frequently with short to medium height understory, mostly composed by *Cistus sp., Halimium sp.* and *Ulex sp.*
	Eucalyptus stand	EU	Proportion (%)	*Eucalyptus globulus* plantations from varying ages, usually with little or totally absent understory.
	Abandoned agricultural area	AGRI	Proportion (%)	Different types of old agricultural areas without human intervention nowadays, mostly composed by herbaceous species.
	Riparian vegetation	RIP	Proportion (%)	Strips adjacent and along the water lines with dense and specific vegetation.
	Landscape diversity	LDiv	0 - 1	Simpson's Landscape Diversity Index, that reflects the diversity of patches in each buffer of sampling stations.
PREY	Small mammals	SMam	Abundance categories (0 – 9)	Abundance categories relating with the levels of small mammals' abundance among the different habitats.
DISTURBANCE	Wild boar Abundance	Ss	Captures/day	Index of relative abundance of wild boar in each camera trap.
	Fallow deer Abundance	Dd	Captures/day	Index of relative abundance of fallow deer in each camera trap.
	Livestock Abundance	Liv	Captures/day	Index of relative abundance of livestock in each camera trap, including sheep and goats.
	Roads extension	Roa	Meters	Extension of the roads inside each buffer of sampling stations.
	Military activity	MAct	Frequency categories (0 – 5)	Frequency categories of military activities in each station along whole sampling period.

The HABITAT covariates reflect land cover characteristics and were all collected using QGIS software (version 2.14.14). Land cover characteristics were extracted from land-use maps elaborated by Campo de Tiro that were updated using aerial photographs and during the field work to record changes in the landscape. For each camera trapping station, I estimated the proportion of the buffer area covered by each habitat, calculating the area of each patch in the buffer (Fig. 3). I used Principal Component Analysis (PCA) (Zuur et al. 2007) to reduce the dimensionality of habitat covariates, so the scores of the resulting main principal components were incorporated in the modelling process. Similarly to Curveira-Santos et al. (2017), riparian vegetation was included separately in the models because of its ecological relevance for mesocarnivores' community (Matos et al. 2009; Santos et al. 2011). I used the Simpson's Landscape Diversity Index ($SLDI=1-\sum pi^2$) to estimate landscape diversity, a proxy for heterogeneity. This index is based on the proportion of each habitat in the buffer (pi) and that refers specifically to patch diversity among each buffer. It ranges from 0, when only one type of habitat is present, to 1 that corresponds to the patch richness.

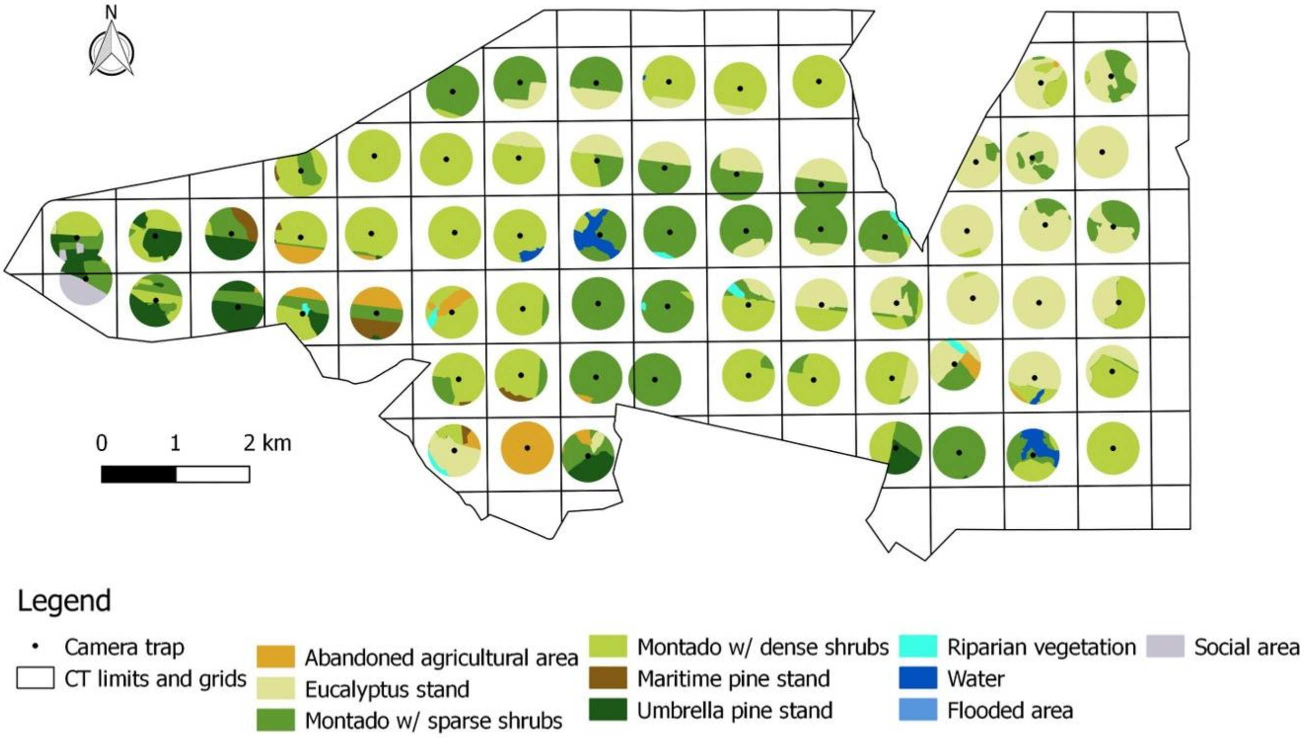

Figure 3 – Campo de Tiro and grid-cells limits associated to the camera trap stations and correspondent 350m buffers with the habitat cover.

PREY variables were selected based on previous studies which identified the main prey species to target community, namely European rabbits (*Oryctolagus cuniculus*) and small mammals (Fedriani et al. 1999, Rosalino & Santos-Reis 2002, Santos et al. 2007). First, I calculated the Relative Abundance Index (RAI) of European rabbit in the study area, but this covariate was not included in the modelling procedure because rabbits were only present in 3 sampling stations. Therefore, I only used the abundance of small mammals. Due to the lack of data on this group in Campo de Tiro, abundance levels corresponding to each type of habitat were defined based on previous knowledge and literature (Gonçalves et al. 2012) and considering the quality of potential resources to small mammals in each habitat. For each sampling station, an average abundance value was estimated by multiplying abundance in a given habitat type by its area within the buffer.

The negative impact of human activities in ecosystems is currently known, so DISTURBANCE is an important factor that has been shaping the landscapes as well as carnivores' communities. The major anthropogenic disturbance in Campo de Tiro are the military activities that could affect carnivores in many ways, for instance the noise produced, the land cover changes or even by direct killing because of the impact. This covariate was assessed by attributing a score to each security area (i.e. areas defined for different types of military exercises along the study area), based on military activities frequency along the whole sampling period (0 – 0 days; 1 – 1 to 20 days; 2 – 21 to 40 days; 3 – 41 to 60 days; 4 – 61 to 80; 5 – more than 80 days). For each sampling station, an average value was calculated reflecting the proportion of each security area inside the buffer. The extension of roads within each buffer was included as a variable.

All covariates were compiled using different tools of QGIS software (version 2.14.14). The presence of livestock is an important source of disturbance to carnivore communities (Curveira-Santos et al. 2017), so it was also considered in the modelling process. In the study area, livestock is composed mainly by goats (*Capra hircus*) and sheep (*Ovis aries*) and it was assessed during camera trapping and it was included in the models as captures/day as a measure of relative abundance. Moreover, wild species can also cause perturbation in carnivores (Lozano et al. 2007). In this area, wild species include wild boar (*Sus scrofa*) and the fallow deer (*Dama dama*). The pressure by these ungulates was estimated as captures/day in camera trapping, similarly as to the livestock.

The relationship between environmental variables was evaluated through pairwise correlations, using Spearman's correlation coefficient. This is an important step to avoid multicollinearity between predictor variables included in the models. We considered the presence of correlation when the coefficient between two covariates was equal or higher than 0.7 (Santos et al. 2016b). All analyses were performed in using statistical software R (version 3.4.1, Core Team 2017).

4.3. Occupancy and modelling habitat use intensity

To evaluate the influence of environmental factors on mesocarnivore community structure, two different models were applied. Single season single species occupancy models were used to estimate the probability of a species existence in each place, i.e. its occupancy (Ψ) (MacKenzie et al. 2002). A binary code was established, 0 when the species is absent and 1 when it is present. On the other hand, I also used N-mixture models, which reflect the intensity of habitat use (λ) and the covariates that main explain it (Royle 2004; Joseph et al. 2009). Both type of models incorporate the probability of detection (ρ), meaning that it considers imperfect detection (i.e. $\rho < 1$) associated with the methods used (MacKenzie & Bailey 2004). This allows avoiding the underestimates of this parameter and produce a reliable result taking into account the false negatives, when a species is present but it was not detected, once the detection probability depends on the species and local environmental conditions (MacKenzie & Bailey 2004). Occupancy and N-mixture models were done to all target species, except for the red fox; due to its wide distribution and presumed high abundance in the area the occupancy model was not possible to do.

The species camera-trap histories were divided into 6 periods of 7 days each. Each period is a replicate and this allows to assume a closed population during the sampling period, which is crucial in single season modelling. The covariates were all normalized by dividing the difference between the index at a given location and the mean index value by the index standard deviation (z-scores) (Santos et al. 2016b), in order to be comparable and easier to interpret, what would not be possible if they were in distinct units.

Both occupancy and N-mixture models have the same two-step approach. First, covariates were assessed for their influence in the probability of detection for each species, while keeping the other parameter constant (probability of occupancy Ψ or habitat use intensity λ). Not all covariates were tested in this step, only those with ecological importance to carnivores' detection as for example the habitat variables (PC1, PC2, PC3 and riparian vegetation), wild boar abundance and the military activities. Second, for each species, the covariate that best explained its probability of detection was fixed and combined with either occupancy or intensity of habitat use parameters. To create the candidate models, partial hypotheses were defined, i.e. all the HABITAT variables were tested individually to each species as well as the DISTURBANCE ones. The covariate related to PREY was not considered at this stage given the fact that was a single variable. To derive the final models the variable for probability of detection was fixed, and a set of different combinations with the covariates identified as significant to occupancy or intensity of habitat use during the previous procedure (HABITAT, DISTURBANCE) were tested and PREY also included.

Before selecting the best models, I tested for goodness-of-fit of the whole global candidate models, as described by MacKenzie and Bailey (2004). This is based on the Pearson chi-square statistic and estimates an overdispersion parameter ($\hat{c}$) that indicates if the model is an adequate description of the data (i.e., when $\hat{c}$ approximates 1) or not (MacKenzie et al. 2006). The overdispersion parameter allows rectifying the models, fitting them to the data by adjusting the $\hat{c}$ value during the modelling process, if necessary. To rank both the models from partial hypotheses and the global models, we used the Akaike Information Criterion (AIC) with the correction for small samples (AICc) (Burnham & Anderson 2002). Global models were ranked by its ΔAICc, which is a value of difference ($\Delta_i = AIC_i - AIC_{min}$) that allows an easy and quick comparison of all ranked models, basically it is a level of empirical support of the model *i*. Those models with $\Delta AICc \leq 2$ were considered non-differentiable and the best fitting to the data and their variables good predictors of occupancy or intensity of habitat use. I also calculated AICc weights, and if a given model had AICc weight>0.9 it was considered a single top ranked model, this means, the most parsimonious model of the set. In the cases of more than one model ranked as the best, model averaging was used to calculate the coefficients of the most explanatory covariates and the confidence intervals (Burnham & Anderson 2002), limited with 90% of confidence.

Modelling procedures were carried out with the "unmarked" package of R software, using occu and pcount functions respectively for occupancy and N-mixture models; for AIC ranking, test of goodness of fit and model averaging we used the "AICcmodavg" package.

Besides the ecological modelling, were calculate naïve occupancies for each species, that result from the proportion between the camera-trap stations where species were recorded and the total of sampling stations.

5. Results

5.1. Mesocarnivores capture success and naïve occupancies at Campo de Tiro

The carnivore community was composed by five mesocarnivore species: red fox, stone marten, European badger, common genet and Egyptian mongoose. During the sampling period, a total of 505 independent captures of targeted mesocarnivore species were performed in CT area, along 2874 effective trap-days (Table 3). This results in an average capture rate of 17.7 captures per 100 trap days (1 capture per 5.7 trap days), ranging from 6.4 (red fox) to 1.6 (stone marten) (Table 3). The most widespread species was the red fox with a naïve occupancy of 0.85 (56 out of 66 sampling points) followed by the mongoose with 0.68 (45 out of 66 sampling points) (Table 3). The other three species showed a narrower distribution as they had naïve occupancies <0.5. The common genet, stone marten and European badger exhibit naïve occupancies of 0.44 (29 trap stations out of 66), 0.47 (31 out of 66) and 0.30 (20 out of 66), respectively (Table 3).

Table 3 – Camera trap effort and mesocarnivores captures in Campo de Tiro, between November 2016 and May 2017.

Camera trap effort	**Trap stations**	**Trapping days (TD)**	**Mean TD per station**	**Carnivores captures**		**Independent captures**	**RAI**	**Naïve occupancy**
	66	2874	44		*Red fox*	184	6.40	0.85
					Mongoose	162	5.64	0.68
					Genet	64	2.23	0.44
					Badger	49	1.70	0.30
					Stone marten	46	1.60	0.47
					All	505	17.67	1

5.2. Characterization of sampling stations at Campo de Tiro

The Principal Components Analysis explained 72% of habitat data variability (Table 4). The first Principal Component (PC1) explained 28%, and separated *montado* with dense shrub (positive loadings) from *montado* with sparse shrubs (negative loadings) (Table 4). The PC2 represents 24% of the variation and distinguishes eucalyptus stands (positive loadings) from both types of pine stands (negative loadings) (Table 4). At last, PC3 represents 20% of variability and contrasts the abandoned agricultural areas (negative loadings) with *montado* with sparse shrubs (positive loadings) (Table 4).

No covariate was removed because there were no significant pairwise correlations, despite the high correlation between small mammals and PC1 (r= 0.62), which was close to the significance threshold.

Table 4 – Principal Component Analysis (PCA) results with the loadings of main habitats in each first three Principal Components (PC) and the variance that they explained.

	PC1	**PC2**	**PC3**
Montado w/ dense shrubs	0.74	-0.06	0.19
Montado w/ sparse shrubs	-0.63	-0.14	0.37
Maritime pine stand	-0.11	-0.48	-0.44
Umbrella pine stand	-0.08	-0.44	0.24
Eucalyptus stand	-0.19	0.65	-0.41
Abandoned agricultural area	0.02	-0.36	-0.64
Proportion of variance	0.28	0.24	0.20
Cumulative proportion	0.28	0.52	0.72

5.3. Mesocarnivores occupancy and habitat use intensity patterns at Campo de Tiro

Environmental variables were included in both models for each species, though with distinct combinations (Table 5). The N-mixture models results seem to be better supported than occupancy models because resulted in more predictor factors with significance to habitat use intensity by species (Table 6).

Generally, species distribution and habitat use intensity were influenced by different habitat characteristics and disturbance sources. Red fox and stone marten do not seem to be significantly affected by any of the predictor variables considered. Mongoose intensity of habitat use appears to be negatively dependent on livestock abundance, while this variable has a positive effect on badger intensity of use. Additionally, habitat use intensity for badger is also affected positively by wild boar abundance. On the other hand, genet abundance is mainly positively influenced by two types of disturbance, wild boar abundance and military activities frequency, and by riparian vegetation covariate.

Table 5 – Model selection (ΔAICc≤2) results for both occupancy and n-mixture models for the five targeted mesocarnivores, considering the covariates that are influencing their occupation and intensity of habitat use patterns in Campo de Tiro.

Species	Models type	Candidate models	K	AICc	ΔAICc	AICcwt
Red fox	N-mixture	ρ (MAct) λ (SMam)	4	679.18	0.00	0.58
		ρ (MAct) λ (Ss+ SMam)	5	681.49	2.31	0.18
		ρ (MAct) λ (PC1+ Ss)	5	681.57	2.39	0.18
		ρ (MAct) λ (PC1+ Ss+ SMam)	6	683.90	4.73	0.05
Mongoose	Occupancy	ρ (PC2) Ψ (Liv+ SMam)	5	408.37	0.00	0.64
		ρ (PC2) Ψ (LDiv+ PC2+ Liv)	6	410.76	2.39	0.19
		ρ (PC2) Ψ (LDiv+ PC2+ Liv+ SMam)	7	413.11	4.74	0.06
		ρ (PC2) Ψ (SMam)	4	413.14	4.77	0.06
		ρ (PC2) Ψ (LDiv+ PC2)	5	413.95	5.58	0.04
		ρ (PC2) Ψ (LDiv+ PC2+ SMam)	6	416.18	7.81	0.01
	N-mixture	ρ (PC2) λ (Liv+ SMam)	5	625.82	0.00	0.55
		ρ (PC2) λ (LDiv+ PC2+ Liv)	6	626.74	0.92	0.35
		ρ (PC2) λ (LDiv+ PC2+ Liv+ SMam)	7	629.22	3.40	0.10
		ρ (PC2) λ (SMam)	4	636.20	10.39	0.00
		ρ (PC2) λ (LDiv+ PC2)	5	637.20	11.38	0.00
		ρ (PC2) λ (LDiv+ PC2+ SMam)	6	639.58	13.77	0.00
Badger	Occupancy	ρ (PC3) Ψ (Ss)	4	183.71	0.00	0.39
		ρ (PC3) Ψ (Liv)	4	184.01	0.30	0.34
		ρ (PC3) Ψ (Ss+ Liv)	5	184.94	1.23	0.21
		ρ (PC3) Ψ (Ss+ Liv+ SMam)	6	187.34	3.62	0.06
	N-mixture	ρ (PC3) λ (Ss+ Liv)	5	304.01	0.00	0.52
		ρ (PC3) λ (Ss)	4	304.97	0.96	0.32
		ρ (PC3) λ (Ss+ Liv+ SMam)	6	306.43	2.42	0.16
		ρ (PC3) λ (Liv)	4	315.31	11.30	0.00
Genet	Occupancy	ρ (.) Ψ (RIP)	3	273.31	0.00	0.18
		ρ (.) Ψ (Roa+ MAct)	4	273.35	0.05	0.17
		ρ (.) Ψ (Roa+ Ss+ MAct)	5	273.42	0.11	0.17
		ρ (.) Ψ (RIP+ Roa+ Ss+ MAct)	6	273.93	0.62	0.13
		ρ (.) Ψ (Ss)	3	274.05	0.74	0.12
		ρ (.) Ψ (Roa+ Ss+ MAct+ SMam)	6	275.31	2.01	0.06
		ρ (.) Ψ (RIP+ SMam)	4	275.31	2.01	0.06
		ρ (.) Ψ (RIP+ Roa+ Ss+ MAct+ SMam)	7	275.39	2.08	0.06
		ρ (.) Ψ (SMam)	3	276.50	3.19	0.04
	N-mixture	ρ (.) λ (Ss)	3	342.25	0.00	0.23
		ρ (.) λ (RIP)	3	342.30	0.05	0.23
		ρ (.) λ (RIP+ Roa+ Ss+ MAct)	6	343.76	1.50	0.11
		ρ (.) λ (Roa+ Ss+ MAct)	5	343.87	1.61	0.10
		ρ (.) λ (RIP+ SMam)	4	344.39	2.13	0.08
		ρ (.) λ (Roa+ Ss+ MAct+ SMam)	6	344.73	2.48	0.07
		ρ (.) λ (SMam)	3	344.77	2.51	0.07
		ρ (.) λ (Roa+ MAct)	4	344.85	2.60	0.06
		ρ (.) λ (RIP+ Roa+ Ss+ MAct+ SMam)	7	345.04	2.79	0.06

Species	Models type	Candidate models	K	AICc	ΔAICc	AICcwt
Stone marten	Occupancy	ρ (MAct) Ψ (PC2+ PC3)	5	215.08	0.00	0.51
		ρ (MAct) Ψ (PC2+ PC3+ SMam)	6	217.52	2.43	0.15
		ρ (MAct) Ψ (Ss+ Dd+ SMam)	6	217.94	2.86	0.12
		ρ (MAct) Ψ (SMam)	4	218.46	3.37	0.09
		ρ (MAct) Ψ (PC2+ PC3+ Ss+ Dd+ SMam)	8	218.56	3.48	0.09
		ρ (MAct) Ψ (Ss+ Dd)	5	220.03	4.95	0.04
	N-mixture	ρ (MAct) λ (PC2+ PC3)	5	243.46	0.00	0.36
		ρ (MAct) λ (SMam)	4	244.36	0.90	0.23
		ρ (MAct) λ (Ss+ Dd)	5	244.49	1.04	0.22
		ρ (MAct) λ (PC2+ PC3+ SMam)	6	245.85	2.39	0.11
		ρ (MAct) λ (Ss+ Dd+ SMam)	6	246.85	3.39	0.07
		ρ (MAct) λ (PC2+ PC3+ Ss+ Dd+ SMam)	8	249.60	6.14	0.02

The goodness-of-fit test indicated that all the candidate models were adequate to the data, with ĉ values near to 1.

5.3.1. *Species occupancy patterns*

Stone marten

For stone marten, the detection probability was mostly negatively influenced by military activities, however this is not a significant relation, since this covariate was not well-supported in a 90% confidence interval. For the occupancy of this species, only one model resulted as the best (ΔAICc≤2) and included only habitat variables, namely PC2 and PC3 (Table 5). Both principal components had a positive relation with the species occupancy, it means that pine stands and abandoned agricultural areas had a negative influence, and the eucalyptus stands and *montado* with sparse shrubs a positive effect (Table 6).

European badger

European badger detection probability is not significantly associated with any tested environmental factor. This parameter was best modelled by PC3, which suggests the negative effect of abandoned agricultural areas in contrast with positive effect of *montado* with sparse shrubs. But it is not a well-supported because the β coefficient confidence interval overlaps zero. Three models had ΔAIcc≤2 to the occupancy patterns, though not be a single top ranked model, the best one was explained by the wild boar abundance (Table 5). Through model averaged we conclude that the variables included in the best models had a positive effect, namely the wild boar abundance as well as the abundance of livestock (Table 6). However, considering the β coefficients and the confidence intervals none variable was a good predictor to this species presence, so the conclusions about its occupancy patterns can be weak and with low reliability (Table 6).

Common genet

The best model that reflects the common genet detection probability was the null model. In spite of no variable apparently describing the detectability of this species, this parameter was still included in the occupancy models, without any covariate explaining it. In the set of candidate occupancy models, five models had ΔAICc values lower than 2 (Table 5). None of them emerged as a single top ranked model (AICcwt >0.9), but the most parsimonious was the model only with the riparian vegetation variable (Table 5). Model averaging resulted in occupancy being influenced positively by all variables tested: roads extension, wild boar abundance, military activities and riparian vegetation (Table 6). Nevertheless, the β coefficients to 90% confidence intervals overlapped zero according to model averaging estimates, so there is low confidence in the influence of these covariates (Table 6).

Egyptian mongoose

Egyptian mongoose detection relates negatively with eucalyptus plantations and positively with pine stands. The detection probability of the mongoose was mostly associated with PC2, which is negatively related to this species and also well-supported by the 90% confidence interval. Mongoose occupancy retrieved only one most parsimonious model ($\Delta AICc \leq 2$), composed by the livestock abundance and small mammals' variables (Table 5). Livestock variable seems to influence negatively the species while small mammals had a positive effect (Table 6).

5.3.2. *Species patterns of habitat use intensity*

Red fox

Detection probability for this species was mainly described by the positive influence of military activities. Only one model had $\Delta AICc \leq 2$, emerging as the best model to explain the intensity of habitat use (Table 5). It had a single variable, the abundance of small mammals (Table 5).

Stone marten

The stone marten detection probability was best modelled as a function of the military activities, describing a positive and significant relation. Contrary to what resulted in the occupation model, in this case it is a good predictor of this species' detection. The best model to explain the intensity of habitat use only included habitat variables, PC2 and PC3 scores, but a total of three models emerged with $\Delta AICc \leq 2$, but none was a single top ranked model (AICcwt >0.9) (Table 5). The model averaging showed that all the tested variables were positively associated with the stone marten abundance but none of them were a good predictor (Table 6). These covariates that hamper conclusions on intensity of habitat use by this species, were: PC2, PC3, wild boar, fallow deer and small mammals (Table 6).

European badger

Detection for badger is positively related with the *montado* with sparse shrubs and negatively with the old agricultural areas. For the abundance models, the covariate that best explained the European badger detection probability was also the PC3 score, with a positive association. However, this time this is considered a good predictor of the detection parameter, since the β coefficient 90% confidence interval did not overlap zero. From the set of candidate models two of them were ranked with $\Delta AICc \leq 2$, but the best one was the model with the variables related to wild boar and livestock abundance (Table 5). The model averaged was assessed and, either the wild boar variable and the livestock one, reflected a positive and significant effect on intensity of habitat use by badger (Table 6). These two covariates were good predictors, because the β coefficients were well-supported (Table 6).

Common genet

As in the occupancy model, the best function to explain the genet detection probability was the null one. On the other hand, in what concerns intensity of use four models from the set were ranked with ΔAICc≤2, and the most parsimonious just included the wild boar variable (Table 5). Nevertheless, as any model came up as a single top ranked model (AICcwt >0.9) (Table 5), the model averaged procedure was applied. The covariate related to roads extension seems to positively affect the common genet abundance, but the β coefficient confidence intervals overlapped zero, so any conclusions could be made about the influence of this factor (Table 6). However, the wild boar abundance, the military activities and the riparian vegetation, also having positive effect on the intensity of habitat use by this species were well-supported, as β coefficients confidence interval did not overlap zero (Table 6).

Egyptian mongoose

Mongoose detection explanatory variable obtained by the models was not significant. As in the occupancy model, the detection probability was best modelled as a function of PC2, with which it relates negatively although, in this case it is considered a poor predictor because the β coefficient 90% confidence intervals overlapped zero. Two models were ranked as the best models (ΔAICC≤2) (Table 5). The most parsimonious was the model including livestock and small mammals abundances, followed by the one which includes PC2 and landscape diversity, according to their ΔAICc scores (Table 5). Since none of them showed a high AICc weight (Table 5), the model averaging procedure was applied to understand the effect of each factor individually. All the covariates related to mongoose intensity of habitat use had a negative effect on species, excepting small mammals that denoted a positive effect (Table 6). Despite that, small mammals, PC2 score and landscape diversity had β coefficient confidence intervals overlapping zero, so they were bad predictors to this species preferences (Table 6). Livestock negatively influenced the intensity of habitat use, because β coefficient confidence interval did not overlapped zero (Table 6).

Table 6 – Model averaged results: β coefficients, standard error (SE) and 90% confidence intervals (CI) for covariates used in best models of the five targeted mesocarnivores, both for occupancy and n-mixture models. * identifies the well-supported covariates, with CI not overlapping zero.

		Red fox	***Mongoose***	***Badger***	***Genet***	***Stone marten***
Occupancy Ψ	Intercep		1.76±0.59 [0.79; 2.73]*	-0.53±0.47 [-1.3; 0.24]	-0.08±0.45 [-0.83; 0.66]	32.13±101.96 [-135.58; 199.85]
	PC2					8.62±40.15 [-70.08; 87.31]
	PC3					28.45±83.28 [-134.78; 191.68]
	RIP				12.14±72.29 [-129.54; 153.82]	
	Liv		-0.91±0.47 [-1.82; 0.01]	3.8±7.87 [-11.61; 19.22]		
	Ss			0.83±0.67 [-0.47; 2.14]	0.62±0.5 [-0.35; 1.6]	
	Roa				0.69±0.53 [-0.35; 1.73]	
	MAct				0.55±0.38 [-0.2; 1.3]	
	SMam		0.23±0.44 [-0.64; 0.44]			

		Red fox	***Mongoose***	***Badger***	***Genet***	***Stone marten***
Intensity of habitat use λ	Intercep	4.26±0.43 [3.56; 4.97]*	1.47±0.35 [0.9; 2.04]*	0.22±0.47 [-0.55; 1]	0.03±0.33 [-0.52; 0.58]	3.8±1.03 [2.1; 5.5]*
	PC2		-0.19±0.25 [-0.6; 0.22]			0.32±0.22 [-0.04; 0.67]
	PC3					0.19±0.23 [-0.2; 0.57]
	RIP				0.21±0.12 [0.01; 0.42]*	
	LDiv		-0.11±0.1 [-0.27; 0.06]			
	Liv		-0.59±0.23 [-0.96; -0.21]*	0.22±0.1 [0.04; 0.39]*		
	Ss			0.55±0.14 [0.32; 0.78]*	0.23±0.12 [0.03; 0.43]*	0.21±0.14 [-0.02; 0.45]
	Dd					0.11±0.16 [-0.16; 0.37]
	Roa				0.05±0.17 [-0.22; 0.33]	
	MAct				0.25±0.15 [0; 0.49]*	
	SMam	0.02±0.08 [-0.11; 0.16]	0.03±0.1 [-0.14; 0.2]			0.01±0.18 [-0.28; 0.31]

5.4. Comparison between Campo de Tiro and Companhia das Lezírias habitat use by mesocarnivores

Species-level estimates, here not interpreted as a measure of abundance but as a relative measure of intensity of habitat use, were compared among study areas. Apparently, habitat variables are more relevant in CL than in CT, while in the later disturbance variables seem to be more important predictors (Table 7).

Table 7 – Predictor variables from the best models for CT and CL, and their relations with the species intensity of habitat use. For detailed information at CL data and results see Curveira-Santos et al. (2017). *identifies the well-supported covariates, with CI not overlapping zero.

	CT		**CL**	
	Predictor variable	**Relation with habitat use intensity**	**Predictor variable**	**Relation with habitat use intensity**
Red fox	SMam	+	Rabbit* Liv* PC1* PC2 PC3	+ - + - -
Mongoose	PC2 Liv* SMam LDiv	- - + -	PC1* PC2 Liv Rabbit* LDiv*	- + - + +
Badger	Ss* Liv*	+ +	PC1* Liv* LDiv	- - -
Genet	RIP* Ss* Roa MAct*	+ + + +	RIP* Liv	+ +
Stone marten	PC2 PC3 SMam Ss Dd	+ + + + +		

Despite the high similarity between the mesocarnivore communities in both areas, some differences could be found. First, in the composition, since in CT any feral cats were recorded while in CL this species was often observed. Secondly, the intensity of habitat use, here used as a proxy for relative abundance, varied between the different species present in both areas. The RAI parameter, which corresponds to captures per 100 days, are higher in CL to red fox and badger, while is lower for the common genet, mongoose (Table 8) and the stone marten. The stone marten and the badger were the two species that showed more contrasting results among areas, the first being much more captured in CT and the opposite for the badger (Table 8). Considering naïve occupancies, results demonstrate higher occupancy of red fox, mongoose and European badger in CL while genet and stone marten are better distributed in CT.

Table 8 – Relative Abundance Index (RAI) and Naïve Occupancy of targeted mesocarnivore species in CT and CL.

Species	**RAI**		**Naïve Occupancy**	
	CT	CL	CT	CL
Red fox	6.40	9.59	0.85	0.95
Mongoose	5.64	4.66	0.68	0.80
Genet	2.23	1.49	0.44	0.36
Badger	1.70	8.53	0.30	0.82
Stone marten	1.60	-	0.47	<0.30
Feral cat	-	0.29	-	0.29

6. Discussion

This study was set to test the hypotheses that (1) the landscape heterogeneity resulting from management activities promotes higher resource diversity and a more diverse and abundant carnivore community, (2) anthropogenic activities that decrease understory height and/or density affect negatively the carnivore community, (3) agricultural practices increase food availability which benefits generalist carnivore species and (4) management options that cause land use changes are detrimental to less generalist carnivore species. All hypotheses were supported by the results obtained (both with fieldwork conducted at Campo de Tiro and with the comparison with Companhia das Lezírias results), although at the species level some responded more clearly than other. In this sense, the main aim of the study was reached, since the obtained results evidenced the structuring role of management regimes in carnivore communities.

Companhia das Lezírias (CL) is the area with more human influence due to higher management intensity. The agricultural and forestry practices, as well as the livestock stocking rate and rotation regime, induce frequent changes in the landscape, often in short intervals of time. In comparison, at Campo de Tiro (CT) human disturbance is lower in view of a more moderate management regime resulting in a more homogenous landscape over time. The comparison between the two study areas translates therefore the influence of the management options in similar carnivore communities. Occupancy of mesocarnivores at CT was very species specific and no single variables appeared to be good predictor of community composition. Inversely, for intensity of habitat use, here used as a proxy for relative abundance, covariates gave a better support to the resulting models and form the basis of this discussion.

The landscape heterogeneity hypothesis suggests that heterogeneity leads to more diverse and abundant carnivore communities, and my results corroborate this expectation. Despite CL being an area more intensively managed comparatively to CT, both areas represent heterogenous landscapes and hold rich and abundant carnivore communities, proving to be composed by the expected mesocarnivore species inhabiting the region taking into consideration the known range of the species (Cabral et al. 2005). Nevertheless, specificities related with the disturbance level has also an influence on community organization. For instance, in CL, besides the wild carnivore species common to both areas, we found feral cats roaming freely in the area that were absent in CT. This is related with the higher humanisation on CL. Feral cats are domestic cats that are not strictly dependent of humans but are associated to human settlements, depending of human care, at an initial period of their life, and the resources they provide (Hawkins 2005). As for the wild species, the obtained result that evidences most the importance of landscape heterogeneity, was the positive effect of landscape diversity on mongoose relative abundance. This fact was also illustrated for this species in literature (e.g., Pereira & Rodríguez 2010).

Most management practices in agroforestry systems imply the reduction of understory, either in density or height. According to Mangas et al. (2008), the shrublands are a very important habitat in Mediterranean ecosystems, conferring shelter and food to carnivore species. Consequently, the shrubs decrease originated by anthropic activities is considered prejudicial to mesocarnivores, even if affecting the individual species differently. Likewise, the obtained results corroborate the hypothesis of the negative impact of understory reduction on species. Livestock grazing, that reduces significantly the understory layer, has a negative impact on red fox and badger relative abundances in CL and on Egyptian mongoose relative abundance in CT. For red fox, in CL it was also observed a negative association of the species relative abundance with the *montado* with sparse shrubs, what relates with livestock stocking rates. Despite its habitat generalist character, the red fox showed a preference for patches with dense shrubs. Curveira-Santos et al. (2017) associated this to the high abundance of small mammals in these patches, an important prey of fox diet (Santos et al. 2007). However, in what concerns the influence of livestock in European badgers, contrasting results were found in both study areas. In CL, a negative effect of this variable was detected and this can be associated to high stocking rates and what Mullen et al. (2013) stated - badger avoidance behaviour for areas with cattle, during foraging activities. Also, Woodroffe et al. (2016), described that in spite of badgers prefer cattle pastures habitats, they avoid the bovines. But in CT, we found a positive interaction between species intensity of habitat use and the abundance of livestock, what can be presumably justified by two main issues. On the one hand, the livestock production is less intensive in this area, and on another hand, the animals are closed during the night until the next morning, which coincide with the period of greater badger activity. In this perspective, badger do not need to avoid the animals as in CL, since they are not in the field. Besides, there is accumulation of livestock excrement during the day, that attracts large concentrations of coprophages insects. Currently, in Mediterranean semi-natural systems, insects are the main source of protein in badger diet (Rosalino et al. 2005a), what makes them a relevant food item and associate this species to livestock producing areas, especially when raised at moderate numbers as found in CT. The same pattern was observed with wild boar, living in CT in high abundance and constituting an important food source to badgers. However, badger habitat preference in CL, did not corroborate the hypothesis of negative impact of reduced understory on species, since the relative abundance of the species was positively affected by *montado* with sparse shrubs, agreeing with Hipólito et al. (2016) findings, that badger sett locations are preferentially found among patches with sparse or no shrubs, as well as with that of Rosalino et al. (2004), who demonstrated that badgers do not show avoidance behaviour for areas with recent understory removal. Additionally, in CT, badger detectability was related positively with *montado* with sparse shrubs. This association can be due to the species morphology (short legs), being more easily detected in these areas than in areas with denser and taller shrubs. Another explanation can be the fact that, although livestock roam freely during the day in CT, they usually occupy areas with low density of shrubs. Once European badger is associated with livestock, and livestock uses areas with less understory cover, the probability of detecting the species in this habitat is high. Inversely, in the case of mongooses, that prefer extensive areas of shrublands being rarely found in open areas (e.g., Sarmento et al. 2011), the reduction of understory affects negatively its presence and this is reflected in the avoidance of areas with livestock. This habitat preference relates with the species food preferences in Mediterranean ecosystems - small mammals (Palomares & Delibes 1993), that show higher richness and abundance in habitats with dense shrubs (Muñoz et al. 2009; Gonçalves et al. 2012; Curveira-Santos et al. 2017). Generally, in CL, habitat variables are more relevant to species relative abundance than in CT. Due to the high anthropic disturbances, related to agricultural productions, forestry plantations, livestock raising and all the activities behind, the habitat is always changing which often include the understory reduction. So, mesocarnivores need to adapt to these changes and to potential lower quality of the available patches, being this one of the most important variables in community organization along space. On the other hand, in CT, as habitats are relatively stable and provide good conditions of shelter and food due to shrub development, species can maintain their habitat preferences over the time. In this case, the most key factors in species intensity of habitat use are the disturbance sources, either with an anthropic origin or not.

The obtained results show that in CL, red fox and badger have higher relative abundances than in CT. Justification can be based on agricultural practices, more present in CL, that provides different food resources to carnivores, which can benefit the more generalist species that are able to base its diet in another food items, beside vertebrate preys (e.g., Rosalino et al. 2005a). Egyptian mongoose in spite of being more abundant in CT, its occupancy is higher in CL where it is best distributed. This demonstrates that mongoose benefits with landscape heterogeneity, usually translated in higher extent of each ecotone that give advantage to the species. On the other hand, the higher abundance observed in CT can be a result of the methodology used. Since it was used the intensity of use as a proxy for relative abundance, may be less individuals that are using more intensively a certain area, but it is not possible distinguish them through the photographs, which can be causing this result. Species composing the target communities are commonly known as generalist species, but two of them – common genet and stone marten – challenge the generalist-specialist paradigm by demonstrating better performance over a restricted set of variables (namely those related with habitat cover), contrarily to the red fox, the badger and the mongoose that performed similarly across most variables. Comparable results were obtained by Peers et al. (2012) when comparing the Canada lynx and the bobcat. On the other hand, the European badger, that is species that uses fruits as one of its main food resource (Rosalino et al. 2005a), show higher relative abundance at CL, with a significant difference from values observed in CT. This difference between areas can be justified not only by the increase of food resources in CL farmlands, but also by the bad conditions of CT to badger settlement capacity as a consequence of military activities there occuring. As stated by Rosalino et al. (2005b), the abundance of European badger can be regulated by the presence of good locations to construct their dens (commonly named setts). Considering that badgers are selective over the environmental factors influencing their setts, they just settle when finding the perfect conditions for reproduction. As setts are underground complex galleries, at CT the sound and the impacts on soil caused by military activities (i.e. explosions and bursts) can be impeding their construction and the reason of the low presence of the species in this study area.

Less generalist species should be harmed in areas with significant and intensive management. Due to their more specialist character, the adaptation to new conditions is hampered as a result of the landscape change dynamics. This hypothesis relates to the one mentioned in the paragraph above, about the food resources provided by agriculture. The higher relative abundance of common genet and stone marten in CT than in CL reflects exactly this hypothesis. In CT, these species face a more homogenous habitat with less alterations and human interventions along time. This fact probably allows them to maintain their preferences, using the same resources that they are used to. The variation in species relative abundances and occupancies is due to the different levels of disturbance between both areas.

The species of the targeted communities co-occur in both study areas, what is apparently possible by their different preferences for the measured habitat variables, evidencing the partitioning of spatial niches. Besides the species habitat preferences already mentioned (red fox, Egyptian mongoose and European badger), also spatial segregation evidences were found to common genet in this study results. Despite the known flexibility in the common genet habitat choice (Calzada 2002), the riparian vegetation patches have an important ecological role as described in Santos-Reis et al. (2004) and also found in this study, for both areas. In general, this habitat provides shelter and food resources to carnivore species, having a great relevance not only for genet but also for the other species (Matos et al. 2009; Santos et al. 2011), that usually use these patches during its daily movements and activities (Pita et al. 2009; Rosalino et al. 2009), for instance foraging. However, it seems to be more important to the common genet which, as described by Curveira-Santos et al. (2017), can be the only species using riparian corridors full time, highlighting the segregation along the space, since none of the other species is so strongly related with this habitat. Riparian corridors are usually composed by dense vegetation which offers refuge to genets, either to protect it from human disturbances and predators or providing calm resting places. Besides, it also promotes high abundance of small mammals that is the major prey on the diet of this species (Virgós et al. 1999; Rosalino & Santos-Reis 2002). The positive association of genet with wild boar abundance can be merely a coincidence or the result of common habitat preferences in managed and hunting areas (Barros 2016). Genet relative abundance at CT appears to be positively related to frequency of military activities, contrary to what was expected. A possible explanation it is the characteristics of the areas with more military activities, usually deprived from vegetation and with low tree cover. Considering this, genets should avoid these areas where are more exposed, and pass quickly through them finding shelter in the closer areas with more understory and better conditions to refuge. This can be related to camera traps installation, once that military activities often originate explosions and shooting, the camera stations were placed in the edge of the open areas to avoid material damages. Thus, the hypothesis is that the locations of the camera traps coincided with the areas where genets took refuge after quickly crossing the open areas where military activities occurred.

No evidences of habitat preferences were found for stone marten in the present study. However, this species has frequently climbing behaviours taking advantage of both horizontal and vertical dimensions of the landscape (Padial et al. 2002). Bearing this in mind, previous studies demonstrated high association of stone marten with habitats with denser tree cover, for instance oak forests and well-developed pine stands (Santos & Santos-Reis 2010; Sarmento et al. 2011). Moreover, this species can present some overlap in habitat choice with mongooses and red fox, because small mammals are also a relevant item in stone marten diet and so oftentimes select patches with shrubby vegetation (Santos & Santos-Reis 2010; Sarmento et al. 2011). The only significant predictor variable for this species detectability in the study, was the military activities that showed a positive effect. It is reasonable that stone marten detection increases in areas with more military activities because, derived from the human movements, roads and the military exercises itself, these locations tend to be open areas, without trees or even understory layer, facilitating the photographic capture.

Rabbit abundance in CL represented a positive effect on carnivores, especially on red fox and mongoose intensities of habitat use (Curveira-Santos et al. 2017). On the other hand, prey variable used in CT (i.e. small mammals predicted abundance) does not appear to have a considerable influence. However, it must be noticed that prey variables in CT might have been underestimated. Other authors described the importance of preys in the targeted species distribution and abundance (Lovani et al. 1994; Rosalino & Santos-Reis 2002; Carvalho & Gomes 2004; Santos et al. 2007; Sarmento et al. 2011), but due to lack of robust information on small mammals and rabbits in CT it was not possible to draw conclusions about its effect. Initially, an index of rabbit abundance was calculated but it was verified that this species was present in few places in the study area (i.e. 3 out of 66), what originated its removal from models. Additionally, this prey was mostly present close to social areas, maybe because of food availability. Besides their low densities in the area, its proximity to human infrastructures can make carnivores use other food resources to avoid social areas. This fact also can be analysed considering the climacteric conditions of the sampling years (Appendix III). European rabbit, being herbivorous, may have benefited during the sampling years in CL of the higher precipitation rates found than incompared to the current sampling year. With the precipitation, the primary productivity increased (Rosenzweig 1968) and consequently promoted more food resources for this species. This pattern is also valid to small mammals, however the variable related to this prey was removed from modelling procedures in CL analyses and it was not significant in CT. Nevertheless, Santos et al. (2007) stated that populations of Mediterranean carnivores had to adapt their feeding habits over time, and nowadays species explore the available resources, being most of the times more omnivorous to subsist.

Studies focusing management options and its impacts on carnivore communities are increasingly relevant, especially now, a time that landscapes are constantly being shaped by human intervention, but there are few dedicated to this topic. Msuha et al. (2012) and Kiffner et al. (2014) studied mammal communities effects, including carnivore species, in three distinct areas with different levels of anthropic disturbance. Both study areas were in Tarangire-Manyara ecosystem in Tanzania and results obtained for carnivores were similar: they showed little changes in protected zones and grazing areas, contrary to cultivated areas where species richness was lower. In Mole National Park in Gana, Burton et al. (2012) inferred the response of carnivores to hunting, habitat and prey variables. Authors concluded that neither hunting or edge proximity had a significant impact on species as they expected originally; species occupancy patterns were mainly positively associated to small preys and just riverine habitats had significant interactions (positive and negative) with carnivores. Shuette et al. (2013) in Kenya, and Rich et al. (2016) in Botswana, tested both anthropogenic and environmental predictors in local mammal communities. The first one just focused carnivore community and observed that apex predator occupancies were lower in areas with more anthropic disturbances. Additionally, stated that a diverse carnivore community can subsist in a heterogeneous landscape caused by seasonal variation in human land use. In the latter study, authors verified a positive effect of grasslands/floodplain cover in carnivores. At last, a project carried in Madagascar (Farris et al. 2015) found evidences of differences in native and exotic carnivore species as responses of anthropogenic disturbances; with habitat degradation, native species decrease their occupancies while exotic species increase.

Overall, the present study supports the idea that managed areas can still hold healthy carnivore communities, maintained by the landscape heterogeneity. However, depending on the disturbance level, different impacts could affect carnivores. When in presence of prominent level of human intervention causing landscape changes, species could have to reorganize their occupancy patterns and adapt to available resources. In a case of low management intensity and human disturbance that however promotes heterogeneity, carnivores often specialize in a restricted set of variables, promoting niche portioning that facilitates co-existence. Consequently, sympatric carnivores' coexistence is favoured in human-shaped landscapes, because of the different segregation options along the distinct available patches. Mediterranean ecosystems, and specifically cork oak woodlands, are usually under great anthropogenic pressure and adequate management options are crucial to maintain biodiversity. To allow carnivores communities persistence and coexistence mechanisms, it is also important to improve decision-making involved in management options, creating appropriate policies not only for the species but also focusing the environmental conditions.

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Conclusion

This study contributes firstly to increase our scientific knowledge about the occupancy and intensity of habitat use patterns of carnivore communities inhabiting managed landscapes and secondly to understand how anthropic disturbance resulting from management options at the landscape level can influence these communities. Results obtained suggest that management regimes have an important structural role in carnivore communities' organization. As proposed initially, our findings corroborate the hypothesis that heterogeneity resulted promoted by human activities provides novel resources to carnivores, contributing to the persistence of their populations. The agro-forestry practices in the study areas favor the most generalist mesocarnivore species because they increase the availability of food resources and refuge, illustrated here mainly by the patterns of intensity of use by the European badger. Many management activities result in understory reduction, which we verified negatively affecting the community, specifically the mongoose, the fox and the badger. Higher relative abundances of less generalist species on CT than in CL indicate that anthropic activities intensity matters because of the frequent changes on the landscape.

The lack of robust information on prey populations was a constrain in the modelling procedures as food is known to be a major structuring factor in animal communities. The extreme rarity of rabbit was notable in both areas, and time constrains prevented the collection of data on the status of small mammals populations in CT. However, information gathered at CL, with similar habitat types and in close proximity, allowed us to rank the habitats in terms of potential relative abundance of small animals.

The approach followed in this study was innovative in terms of past knowledge relatively to the influence of anthropogenic activities on mesocarnivore communities, since proximity and land cover similarities between the areas compared, allowed to control other factors (apart from management options) that could induce variability among the two communities. Additionally, most previous studies about human influence on mesocarnivore communities were developed in protected areas, where human disturbance is often controlled and lower, contrarily to present the study.

In the future, it would be interesting to replicate this study, in more areas representing a gradient of human disturbance due to different management options and in different environmental conditions. This way more information would be available to support decision-making in management options that should be optimized in order to focus not only the economic sustainability of the system but also the carnivores conservation.

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Appendices

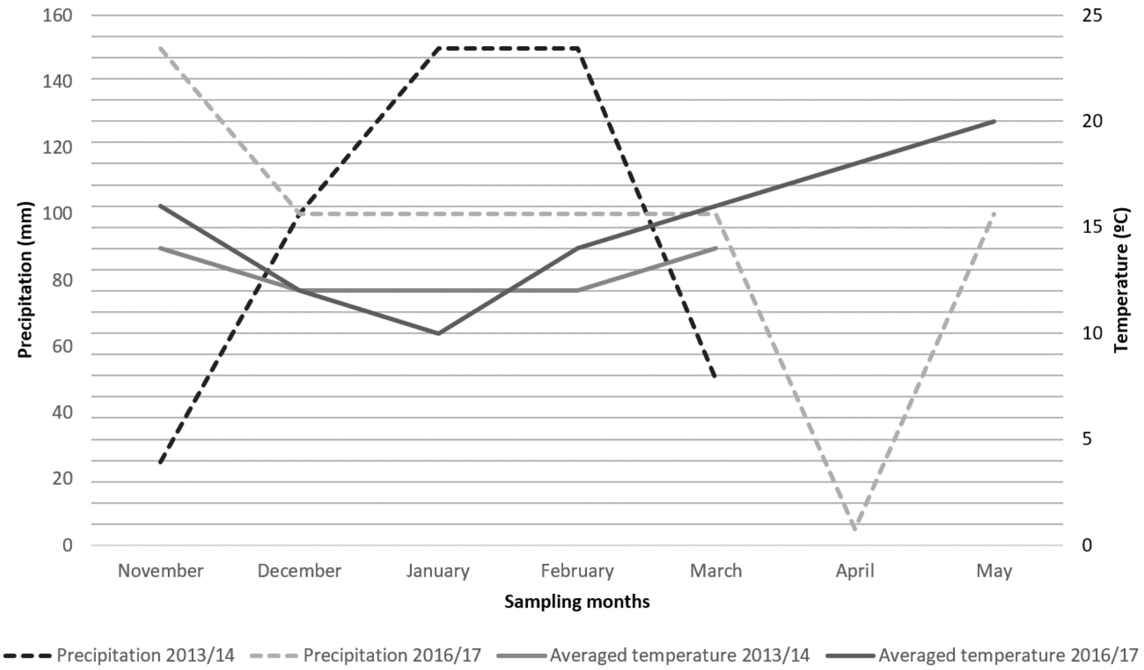
Appendix I – Model selection (ΔAICc≤2) results for detectability models for the five targeted mesocarnivores, considering the covariates that are more relevant to species detection probability in Campo de Tiro.

Species	Candidate models	K	AICc	ΔAICc	AICcwt
Red fox	ρ (MAct)	3	436.82	0.00	0.40
	ρ (.)	2	438.23	1.41	0.20
	ρ (PC2)	3	439.04	2.22	0.13
	ρ (RIP)	3	440.12	3.30	0.08
	ρ (Ss)	3	440.33	3.51	0.07
	ρ (PC1)	3	440.34	3.52	0.07
	ρ (PC3)	3	440.41	3.59	0.07
Mongoose	ρ (PC2)	3	411.24	0.00	0.80
	ρ (MAct)	3	415.03	3.79	0.12
	ρ (PC1)	3	418.03	6.79	0.03
	ρ (Ss)	3	418.16	6.92	0.02
	ρ (.)	2	418.93	7.69	0.02
	ρ (RIP)	3	420.35	9.11	0.01
	ρ (PC3)	3	420.77	9.53	0.01
Badger	ρ (PC3)	3	183.20	0.00	0.49
	ρ (Ss)	3	185.33	2.12	0.17
	ρ (.)	2	185.90	2.70	0.13
	ρ (PC2)	3	187.03	3.83	0.07
	ρ (MAct)	3	187.66	4.45	0.05
	ρ (PC1)	3	187.80	4.60	0.05
	ρ (RIP)	3	188.04	4.84	0.04
Genet	ρ (.)	2	274.61	0.00	0.27
	ρ (PC3)	3	274.92	0.31	0.23
	ρ (RIP)	3	276.21	1.61	0.12
	ρ (MAct)	3	276.40	1.80	0.11
	ρ (Ss)	3	276.74	2.14	0.09
	ρ (PC1)	3	276.77	2.17	0.09
	ρ (PC2)	3	276.79	2.19	0.09
Stone marten	ρ (MAct)	3	216.19	0.00	0.27
	ρ (.)	2	216.37	0.18	0.25
	ρ (PC3)	3	217.97	1.78	0.11
	ρ (PC2)	3	218.15	1.69	0.10
	ρ (Ss)	3	218.17	1.98	0.10
	ρ (PC1)	3	218.52	2.33	0.08
	ρ (RIP)	3	218.52	2.33	0.08

Appendix II - Camera trap effort and mesocarnivores captures in Companhia das Lezírias, between November 2013 and March 2014 (Curveira-Santos et al. 2017).

Camera trap effort	**Trap stations**	**Trapping days (TD)**	**Mean TD per station**	**Carnivores captures**		**Independent captures**	**RAI**	**Naïve occupancy**
	52	6496	125		*Red fox*	623	9.59	0.95
					Mongoose	303	4.66	0.80
					Genet	97	1.49	0.36
					Badger	554	8.53	0.82
					Feral cat	68	1.05	0.29
					All	1645	25.32	1

Appendix III – Comparison between the sampling periods (CL: 2013/14 and CT: 2016/17) based on climacteric data, specifically the mean air temperature and total precipitation.



Appendix IV – Examples of camera trap stations

Sampling station on a pine stand and close to riparian vegetation

Sampling station on a *montado* patch with dense shrubs

Sampling station on a *montado* patch with sparse shrubs

Appendix V – Camera trap photographs of the targeted mesocarnivores species

Red fox (*Vulpes vulpes*)

Egyptian mongoose (*Herpestes ichneumon*)

European badger (*Meles meles*)

Common genet (*Genetta genetta*)

Stone marten (*Martes foina*)