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Ecology of carnivorous species in urban ecosystems: Are they adapted?

Dissertação de mestrado, orientada pelo Professor Doutor José Paulo Sousa e pela Doutora Joana Silva Alves e apresentada ao Departamento Ciências da Vida da Faculdade de Ciências e Tecnologias da Universidade de Coimbra

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Ecology of carnivorous species in urban ecosystems: Are they adapted?

Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau Mestre em Ecologia, realizada sob a orientação científica do Professor Doutor José Paulo Sousa e Doutora Joana Silva Alves (Universidade de Coimbra)

Stefan Martins Ribeiro

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Resumo

Com o atual crescimento das populações humanas, principalmente em zonas urbanas, o crescimento das áreas urbanas atingiu proporções nunca antes vistas. Este processo tem levado à destruição e fragmentação dos habitats e, consequentemente, à criação de habitats com novas características. Existe, então, a necessidade de estudar o impacto que o crescimento urbano provoca nas populações selvagens existentes nesses locais (parques e jardins urbanos). Perceber quais são os fatores que modificam a densidade e diversidade das populações de mamíferos é essencial para selecionar politicas de gestão ao nível da conservação da biodiversidade. O presente estudo visa avaliar o nível de adaptação dos carnívoros presentes nos dois locais de estudo (Jardim Botânico da Universidade de Coimbra e Mata Nacional do Choupal), bem como a densidade dos micromamíferos (presas). A foto-armadilhagem, capturas de micromamíferos e a análise de excrementos foram as técnicas utilizadas para a realização deste estudo. Considerando os resultados obtidos nos dois locais, foram observados maiores valores de diversidade e densidade no Choupal (peri-urbano). O Jardim Botânico (urbano) tem baixos valores de densidade de micromamíferos e uma quase inexistência de carnívoros. Os resultados de densidade registados no Choupal permitiram perceber que os habitats urbanos podem possuir densidades mais altas comparativamente às obtidas em zonas rurais. Relativamente ao nicho ecológico, a maior sobreposição de nicho foi registada entre a raposa e o texugo, o que indica que estas espécies podem coexistir e dividir os recursos disponíveis.

Conclui-se que a fragmentação nos habitats, provocada pelo desenvolvimento urbano, pode provocar isolamento e perda de recursos, afectando populações selvagens. Estas alterações irão provocar mudanças nas estruturas populacionais, causando diferenças na adaptação das diferentes espécies, o que poderá levar à perda de biodiversidade. São então necessários mais estudos em ecologia urbana, de forma a propor acções para mitigar estes efeitos, como por exemplo a criação de corredores ecológicos, para que se permita a movimentação das plantas e animais entre os diferentes fragmentos.

Palavras-chave: adaptação; carnívoros; Jardim Botânico da Universidade de Coimbra; Mata Nacional do Choupal; micromamíferos; fragmentação; ecologia urbana.

Abstract

With the current growth of human populations, mainly in urban zones, the growth of areas occupied by cities has reached proportions never seen before. This process has been leading to the destruction and fragmentation of habitats and, consequently, to the appearance of habitats with new characteristics. Therefore, there is a need to study the impact that urban growth causes on wild populations that live in those spaces (parks and urban gardens). Understanding which factors modify the density and diversity of mammal populations is essential to select management policies regarding conservation of biodiversity. The present study aims to evaluate the level of adaptation of carnivores represented in both places where this study was undertaken (Botanical Garden of University of Coimbra and Choupal National Forest) and the density of small mammals (preys). Camera-trapping, life trapping and scats analysis were the techniques chosen to perform this study. Considering the results obtained in both places, higher values of diversity and density were observed in Choupal National Forest (peri-urban). Botanical Garden (urban) showed lower values of density of small mammals, and almost a total inexistence of carnivores. Density estimates obtained for Choupal allowed to understand that urban habitats may possess higher densities, when compared to the ones obtained in another studies carried out in rural areas. Regarding ecological niches, the higher overlap was observed between the Red fox and European badger, which indicates that these species are able to coexist and share the available resources.

It is then possible to conclude that habitats' fragmentation, caused by urban development, may lead to isolation and loss of resources, affecting wild populations. These changes will lead to alterations in population structures, causing differences in the adaptation of the different species, which may cause loss of biodiversity. More studies in urban ecology are needed, to propose actions capable of mitigating these effects, as the creation of

ecological corridors to allow the movement of plants and animals between different patches.

Key words: adaptation; carnivores; Botanical Garden of the University of Coimbra; Choupal National Forest; small mammals; fragmentation; urban ecology.

CHAPTER 1- *General Introduction*

1.1 Urban ecology

1.1.1 Why urban ecology?

Ecology, in general, studies the relationship between organisms and communities, and their relationship with the environment where they live. However, due to all the changes that our planet is suffering, by natural and/or anthropogenic causes, the habitats commonly used by several wildlife species are being degraded or fragmented.

Due to this fact, it becomes crucial to study the impact that these changes may have in the population ecology and the behaviour of wild species. Currently, one important aspect to consider is the growth of cities, which is happening at a very fast rate. Back in 1900, only 10 % of the world population lived in large city areas, whereas today this percentage has risen to more than 50%. Over the next 50 years, it is expected that 95% of the net increase in human population will take place in urban areas. In developed countries 80% of its total population will live on urban areas (Grimm, 2008).

The clustering of human populations leads to really big-city sizes, which leads to a high production of materials for human consumption, land use changes, water systems and urban waste discharges that will affect biogeochemical cycles, climate and the environment as a whole. However, these changes are not limited to cities, because the inhabitants of the urban areas depend on the capacity of production of the ecosystems far beyond the city limits. So, the affected area it is much bigger that the real size of the city, leading to a huge ecological footprint of the human populations living in big cities (Grimm, 2008). Compared to the “natural” ecosystems with a typical energy budget ranging between 1.000 and 10.000 Kcal per square meters per year, cities in an industrialized country can have an energy budget ranging between 100.000 and 300.000 Kcal per square meter per year (Odum, 1997).

Data from the Living Planet Report 2014 (McLellan *et al*., 2014), shows that more than 10.000 representative populations of mammals, birds, reptiles, amphibians and fish, have declined by 52% since 1970, and these are the living forms providing the services of the ecosystems that support the life on Earth.

Earth is suffering from exhaustion in terms of the exploitation of its resources, having reached a point where it does not have biological capacity to renew what is removed (Pollard *et al*., 2010). By exploiting the ecosystems far beyond their carrying capacity, we are risking the future of the new generations. To revert this trend, it is essential that conservation and sustainable development work together (McLellan *et al*., 2014). So it is of utmost importance to study how wild species are adapting to the current increase of the urban areas. Studies in urban ecology are not only focused in cities, but also in other areas where the anthropogenic pressure and human settlements are enough to cause impacts on the wildlife (McIntyre, 2000).

1.1.2 Work done so far

Despite some studies on urban plant species, and a few isolated works about urban wildlife in Europe, a systematic research on urban ecology of animal species in and around cities only began in the 70s (Sukopp, 2002). Since then, several journals have focused their aims exclusively on this topic (e.g. Journal of Urban Ecology - Oxford; Urban Ecosystems - Springer), and on research developed by some high-profile government projects, such as the Long-Term Ecological Research in the United States (Grimm *et al*., 2000), and the Australian Research Centre for Urban Ecology.

Despite the status of urban ecology as an emergent field of research, relatively little is known about historical and recent trends in urban wildlife research. Magle *et al.* (2012) show that only 14 papers were published before 1991, and between 1991-2000 this number increased to 128. From 2001 to 2010, 429 studies were published in urban wildlife studies. From the 571 studies published until 2010, only 118 (20.7%) were performed in Europe and 291 in America (51%), and from the 118 studies made in Europe, only 29 (24.6%) included wild mammals. Moreover, from all the papers published until 2010, only 178 intended to study the conservation of urban wildlife. So, it is quite notorious the lack of information about this research field, and even more about the urban wildlife of Europe (Magle *et al.*, 2012).

1.1.3. What is urban ecology?

Urban ecology has greatly modified the discipline of ecology, integrating the theory and methods of natural and social sciences to study the patterns and processes of urban ecosystems (Grimm, 2008). Since in these systems it is not possible to take into account only the natural features of the site, it is essential to consider also the anthropogenic or social characteristics of the study areas, making the urban ecology a multidisciplinary science (McIntyre, 2000).

Urban ecology has to deal with the fact that changes in some natural processes will have impact in the ecology of wildlife populations. Possible modifications could be the alteration of the landscapes, habitat fragmentation and human pressure (Alberti, 2005).

1.1.4. Complex urban areas

Urban areas are heterogeneous places with dynamic and complex landscapes that are characterized by their own unique challenges. Urbanized areas differ greatly from rural ones, in aspects like microclimate (urban areas are warmer and have greater precipitation), hydrology (increased runoff), and soils (higher concentrations of heavy metals and organic matter) (Alberti, 2005).

Moreover, urban landscapes are also different in terms of patch dynamics (Wu and Loucks, 1995; Pickett and Rodgers, 1997). Urban development affects the patch structure by altering the size, shape, interconnectivity, and composition of the natural patches (Alberti, 2005). By changing the ecological conditions through physical changes, it is expected that urban patterns will generate differential ecological effects (Forman and Godron, 1981), which ultimately will have huge implications in biodiversity.

Wilson (1992) highlighted that some anthropogenic activities affect wildlife populations, and it is possible to include them in four categories: over exploitation, habitat destruction, the introduction of non-native (alien) species, and the spread of diseases carried by alien species. The use of resources in urban areas is particularly higher, when compared to rural areas, which can lead to an over exploitation of the resources. The introduction of non-native (alien) species by humans (Vilisics and Hornung, 2009) can augment the risk of transmission of diseases due to the new illnesses brought by the referred species. Another aspect to be considered is the habitat destruction and fragmentation through the construction of anthropogenic infrastructures (e.g. roads, buildings). Tabarelli and Gascon, (2005), Tilman *et al*., (2001) and Wilcove *et al*., (1998) indicate that one of the greatest threats to the biodiversity of the planet is exactly the habitat fragmentation.

Habitat fragmentation is defined as a process in which "a large expanse of habitat is transformed into a number of smaller patches of smaller total area, isolated from each other by a matrix of habitats unlike the original" (Wilcove *et al*., 1986). This definition of habitat fragmentation, implies three effects on habitat patterns: 1) reduction of the habitat available; 2) increased number and isolation of patches and 3) decrease of the size of the patches (Fahrig, 2003).

The most obvious effect of the process of fragmentation is the removal of habitat, either by habitat loss and formation of small and isolated patches, or by changes to the properties of the remaining habitat, creating new types of habitats (van den Berg *et al.*, 2001). However, these changes will result in the isolation of the populations, changes in the genetic flows, intensification of competition, changes to the structure and quality of habitats, and ultimately species extinctions (Fahrig, 2003). So, these smaller patches (*e.g.* urban green areas) have major problems, like the edge effect (Chen *et al*., 1992), reduced connectivity with other areas (Collinge, 1996) and the intensification of competition, due to lower availability of resources, and the introduction of non-native species (better competitors). Consequently, populations of native species in isolated and smaller patches tend to decrease in size, which has consequences in the ecosystem services (Harris, 1984; Soule *et al*., 1988). Habitat fragmentation is happening in all types of habitats, but it is especially pronounced in urban areas, by the introduction of biogeographic barriers (*e.g.* roads, canals) (Rondinini and Doncaster, 2002).

When attempting to predict interspecific differences in responses to habitat fragmentation, ecological and behavioral attributes play an important role (Gehring and Swihart, 2003). The sensitivity of each species to fragmentation results from its ability to move through a changed landscape. The costs of movement can vary among species, and depend on its skills to cross a potentially hostile matrix of the surrounding patches and on the suitability of the wildlife corridors into facilitating movements between patches (Laurance, 1995; Nupp and Swihart, 2000).

1.1.5. Wildlife corridor and "Hot-spots"

Wildlife corridors connect larger areas of wildlife habitats facilitating the movement of animals and plant seeds and reducing the adverse effects of habitat fragmentation. In urban areas, these structures do not have just an ecological function; other purposes like recreation, culture and aesthetics are also significant (Ahern, 1995). We can define wildlife corridors as linear structures of the landscape that link fragments that have been connected before (Soulé, 1991; Saunders *et al.*, 1991). These corridors can be used as a conservation tool (Beier and Noss, 1998), since the preservation of vegetation corridors between isolated habitat patches is expected to moderate the negative effects of habitat fragmentation by maintaining landscape connectivity (Lindenmayer and Nix, 1993; Lindenmayer, 1994). In ecological studies of habitat fragmentation, the term 'corridor' generally refers to a linear landscape element composed by native vegetation, which links two or more patches (Harris and Scheck, 1991), and facilitates the movement of plants and animals among habitat fragments, which may allow more species to exist, and populations to persist longer than it would be expected based solely on fragment size (Bennett, 1999).

The existence of vegetation corridors between isolated habitat fragments may modify patterns of species richness and composition by increasing the effective size of the fragments. This is very important in urban areas because green parks are the fewer places that can be inhabited by wild species, giving to the green parks the possibility of being "hot-spots" of diversity in the urban context. However, the importance of urban green parks exceeds the preservation of animal and plant diversity, including relevant aspects like modelling the physical appearance of the city, leisure, ability to connect urban citizens with their environment (Orr, 1993), and also providing ecosystem services. Ecosystem services like food, water, wood, air purification and pollination, which are the basis of all human activity, are critical to maintain the human welfare, and the economic and social development (Sandler, 2010).

1.1.6 Comparison between urban and rural populations

Considerable changes in ecology of the populations, who are adapting to urban areas, are expected when compared with populations living in rural areas. In urban areas, wildlife populations will have to live at much higher densities, due to the space limitations of suitable sites, which are only small gardens or small forest patches. Other changes include a reduced migratory behaviour, when occurs, because chances of surviving during winter in cities are higher; longer mating season due to sedentary life and favourable microclimate and availability of resources; greater longevity, due to greater winter survival, favourable climate and available food (anthropogenic food), but this longevity can also be reduced due to accidental death by car accidents; different circadian rhythms due to artificial light, and to avoid contact with humans; and changes in foraging behaviour, due to the presence of anthropogenic food and possible lack of preys (Luniak, 2004).

The described ecological and behavioural modifications may lead to loss of biodiversity in urban areas, because species with greater plasticity will adapt better, gaining space and increasing its density, while the species with lower ability to adapt will disappear

(Agrawal, 2001). The species introduced by humans (alien species) are also a major problem, because they can become invasive species. In the Iberian Peninsula, several species of *Acacia* were introduced in the 19th century, and nowadays it invaded a huge part of the national territory (González-Muñoz *et al*., 2012).

1.2 Study species

The Portuguese mammal fauna can be considered a rich and diversified community (Santos-Reis and Mathias, 1996), and in comparison with other European countries, the Iberian Peninsula has a great richness of carnivorous mammals, with sixteen species appearing frequently in sympatric situations (Padial *et al*., 2002).

Carnivores are mammals with predatory habits, predominantly feeding on other animals, or in some cases omnivores. They live in different types of habitats/biomes, such as the Mediterranean, savannah and rainforest. They usually produce a single litter annually, but some exceptions can be pointed out (with more than one per year or with gaps of 2-3 years between litters). Most are adapted for terrestrial life, with well-developed hearing and sense of smell.

1.2.1 Ecology and Behaviour of carnivorous

Red fox *Vulpes vulpes* (Linnaeus, 1758) has crepuscular or nocturnal activity and has the widest geographical range of any member of the order Carnivora. Distributed across the entire northern hemisphere, from the Arctic Circle to Northern Africa, Central America, and the Asiatic steppes (covering nearly 70 million km^2), it is classified as Least concern by the Red Book of Portuguese Vertebrates - ICNF and The Red List of Threatened Species - IUCN. The occupied habitats are so diverse as tundra, desert and forest, as well as urban areas. Natural habitat is a dry, mixed landscape, with an abundant "edge" of scrub and woodland. The diet can be quite diversified, but small mammals and lagomorphs are the main preys, but in is some situations, red foxes can also feed on fruit, insects and birds (Pires, 2001). In the northern hemisphere, the breeding season occurs between February and April (Fox, 2007). The major threats for red fox populations include habitat degradation, loss, and fragmentation. However, the red fox versatility and eclectic diet are likely to ensure their persistence despite changes in landscape and prey availability (Hoffmann and Sillero-Zubiri, 2016).

European Badger *Meles meles* (Linnaeus, 1758) is a crepuscular and nocturnal species with a very wide distribution, and can be found throughout all Europe except in Northern Scandinavia. It is classified as Least concern by the Red Book of Portuguese Vertebrates - ICNF and The Red List of Threatened Species - IUCN. The favourite habitat of the species are deciduous forests with clearings, or open pastureland with small patches of woodland. Nevertheless, it is also found in mixed and coniferous woodland, scrublands, suburban areas and urban parks. It is an opportunistic forager that feeds on a wide variety of food (omnivorous diet), including fruit, cereal crops, invertebrates, bird eggs, carrion, and live vertebrate prey such as hedgehogs, moles, and rabbits. Eurasian badgers breed all year, however, late winter / early spring (February - May) and late summer / early autumn (August - October) are the peaks of breeding activity (Wang, 2011). Loss of suitable habitat and habitat fragmentation are the major threats for the species (Kranz, 2016).

Stone marten *Martes foina* (Erxleben, 1777) is a widespread species that has nocturnal and crepuscular activity, and can be found from Iberian Peninsula to central and southern Europe, and in the Middle East, and central Asia. The Red Book of Portuguese

Vertebrates - ICNF and The Red List of Threatened Species - IUCN classifies the species as Least Concern. The preferential habitat types of the species in the Iberian Peninsula are cork woodlands, riparian galleries, pasturelands, orchards (Santos and Santos-Reis, 2010) and other cultivated fields like olive-yards and vegetable-gardens (Santos- Reis *et al*., 2005) and scrublands (Rondinini and Boitani, 2002). The main sources of food of stone marten are small mammals, birds and fruits (Delibes, 1978). In terms of reproduction, the copulation takes place in midsummer, but the blastocyst only begins to develop in February and the birth occurs one month later (March) (Carter, 2004).

Common genet *Genetta genetta* (Linnaeus, 1758) is a nocturnal and crepuscular animal that lives in the North of Africa and in the Iberian Peninsula and also in some parts of France (Delibes, 1999; Gaubert *et al*., 2008). It is classified as Least Concern by Red Book of Portuguese Vertebrates - ICNF and The Red List of Threatened Species - IUCN. It is a generalist species that prefers all types of wooded habitats (deciduous and evergreen), and avoids open habitats and is commonly found close to humanised areas (Gaubert *et al*., 2015). The diet consists mainly in small mammals, but this species also eats small birds, other small vertebrates, insects, and fruits (Delibes and Gaubert, 2013). This species has the peak of the breeding season in February and March.

Egyptian Mongoose *Herpestes ichneumon* (Linnaeus, 1758) has diurnal activity and is present in almost all African Continent, but it is also found from the Sinai Peninsula to the south of Turkey (Delibes, 1999), and in southern and central Portugal (Borralho *et al*., 1996) and south-western Spain (Delibes, 1999). The species is classified as Least Concern by Red Book of Portuguese Vertebrates - ICNF and The Red List of Threatened Species - IUCN. In terms of habitat preferences, this species prefers habitats that have understory, with a clear preference for riparian habitats (Delibes, 1999). However, the Egyptian mongoose may also live in urban areas. Despite their generalist omnivorous diet , rabbits, small mammals, birds and reptiles represent almost the total of the prey items consumed (Delibes, 1984). The gestation is approximately 11 weeks, and cubs born in July or August in the Iberian Peninsula (Hinton and Dunn, 1967).

Besides the carnivorous species, domestic species as the cat (*Felis catus*) and the dog (*Canis lupus familiaris*) may also coexist in the same places.

1.2.2. Main preys

Due to their small home ranges, small mammals often persist in green spaces, parks and even in residential gardens of urban areas (Mahan and O'Connell, 2005), and they play an important role in food webs, because they influence the presence or absence of other wildlife due to competitive interactions. Additionally, they act as prey to other animals such as carnivores, birds and reptiles (Ekernas and Mertes, 2006). They may also be valuable indicators of habitat quality. The distribution and abundance of small mammals is affected by the available resources, the evolutionary history, the degree of specialization, as well as the interaction between species (Fuente, 1992). They have been used as model organisms in conservation biology and ecology, to study how larger species are responding to disturbance (Barrett and Peles, 1999; Wolff, 1999). In the study area, the insectivorous species include hedgehog *Erinaceus europaeus* (Linnaeus, 1758), greater white-toothed shrew *Crocidura russula* (Hermann, 1780) and the spanish shrew *Sorex granarius* (Miller, 1910). In rodents, it is included red squirrel *Sciurus vulgaris* (Linnaeus, 1758), lusitanian pine vole *Microtus lusitanicus* (Gerbe, 1879), field vole *Microtus agrestis* (Linnaeus, 1761), house mouse *Mus musculus* (Linnaeus, 1758), algerian mouse *Mus spretus* (Lataste, 1883), wood mouse *Apodemus sylvaticus*

(Linnaeus, 1758), brown rat *Rattus norvegicus* (Berkenhout, 1769) and black rat *Rattus rattus* (Linnaeus, 1758). One lagomorph is also present, the rabbit *Oryctolagus cuniculus* (Linnaeus, 1758) (Santos-Reis and Mathias, 1996). These species, are classified as Least Concern by the Red Book of Portuguese Vertebrates- ICNF and The Red List of Threatened Species- IUCN.

1.3. Concepts in ecology of carnivorous

1.3.1 Ecological niche

The position and role that a species plays in its environment can be defined as ecological niche. A species' niche is characterized by the relationships that it establishes with the biotic and abiotic factors of its environment (Wittaker *et al.* 1973). Additionally, it has an essential role in meeting the species' needs for food and shelter, survival and reproduction. It is then fundamental to characterize the niche breath (variety of resources or habitats used by species), which provides a measure of species behavioural plasticity, to understand the differences between the ecological niche of each species (Gehring and Swihart, 2002).

Lomolino *et al*. (2009) refer that species distributions and their dynamics overtime result from properties of the species, environmental variation and interactions between the two. In particular, the abilities of some species to modify their environments and change the range dynamics of another species. Interactions between species in communities are very important because they determine qualitative and quantitative community composition (Delibes, 1983). For instance, Mulder (1990) stated that the red fox can be an important limiting factor for small mustelid populations, like the stone marten or the european badger. Different patches in landscape usually support sufficient resources that allow sympatry of species within the same trophic level (Levin, 1974), and increase the persistence of predator–prey interactions (Fahrig, 2003). Connell (1980) stated that for species to coexist, they should exhibit a relatively low overlap in resource utilization, differing in their ecological requirements (Pianka, 1974). So, niche overlap is privileged when specialist and generalist species are present, and when the resources are abundant, like stated in the competition theory (Fedriani *et al*., 1999).

1.3.2 Predator-prey models

It is commonly known that populations of organisms suffer alterations overtime. This idea is implied in ecological research, which documents the fluctuations in population densities of several organisms, namely algae, invertebrates, fish, frogs, birds, and mammals. The availability of resources is crucial to understand the referred fluctuations, because when resources are limited, individuals tend to compete to gain access to them. This process will eventually lead to the populations' decline. Bottom-up control (population of preys control the population of predators) is important to regulate the population around its carrying capacity (maximum population size that the environment can sustain). Furthermore, the inverse relationship has also a huge influence, by the process of top-down control (population of predators control the population of preys). These two types of population control are considered basal, because they have been promoting changes in populations overtime (Stevens, 2010).

1.4 Study sites

1.4.1 Location, climate, topography

The Botanical Garden of University of Coimbra and the Choupal Nacional Forest are two green parks located in Coimbra city, in the Central Region of Portugal. This region has a Mediterranean climate with Atlantic influence, classified as mesothermal sub-humid climate (Silva, 1995; Tavares, 1999). The mean temperatures range from 10º C in the winter and around 22º in summer, with an annual precipitation of around 922mm. Coimbra is crossed by the Mondego river which rises at Serra da Estrela at an altitude of 1500m. With an extension of 227 Km, the Mondego river flows into the Atlantic Ocean at Figueira da Foz.

Choupal Nacional Forest (40º13'N, 8º26'W) is limited on the north part by an irrigation canal and on the south by the Mondego river, and has a total area of 79 hectares. Botanical Garden of University of Coimbra (40°12'N, 8°25'W) is located near to the Department of Life Sciences (FCTUC) in centre of the city, limited by stone walls, and has 13 hectares.

1.4.2. Land cover and Fauna

Choupal Nacional Forest has a mixed forest of hardwoods, mostly deciduous where eucalyptus (*Eucalyptus sp.*), maples (*Acer negundo, Acer pseudoplatanus*) and laurel (*Laurus nobilis*) are the dominant species. Other species like oak tree (*Quercus robur*), black poplar (*Populus nigra*), willow tree (*Salix atrocinerea, Salix alba*) and the invasive "mimosa" (*Acacia dealbata*) are also very represented. Another species like narrow-leafed ash (*Fraxinus angustifolia*), common alder (*Alnus glutinosa*), Mediterranean hackberry (*Celtis australis*) are also found. Almost all ground is covered with the invasive species *Tradiscantia* sp.. The study area also encompasses a variety of birds (65 species identified) such as black kite (*Milvus migrans*), grey heron (*Ardea cinerea*), common moorhen (*Gallinula chloropus)* and mallard (*Anas platyrhynchos*), which can be seen as examples of the great faunal diversity. Mammals like red fox (*Vulpes vulpes)*, boar (*Sus scrofa*), european badger (*Meles meles*) and the aquatic mammal european otter (*Lutra lutra*) have also been identified. (ICNB, 2010).

Botanical Garden of University of Coimbra can be divided in two zones, the garden and the forest. The forest occupies 2/3 of the total of Botanical Garden and it is occupied by a dense vegetation where different areas can be found, such as a bamboo grove of the species *Phyllostacys bambusoides*, an area dominated by the presence of laurel (*Laurus nobilis*), several species of eucalyptus, the cold greenhouse, a collection of monocots, among many other plant species. The garden area is much more humanized; hedges of the species *Buxus sempervirens* are well-represented and species like *Chamaerops humilis, Latania chinensis and Archontophoenix cunninghamiana* and some araucaria species (*Araucaria bidwilli* and *Araucaria columnaris*) are also present (Tavares, 2011). The fauna species were not frequently studied. A record of the presence of the red squirrel exists, but currently that species is not observed in the referred site. The reasons for its disappearance are unknown.

1.5 Objectives

The growth of urban areas is leading to the fragmentation and destruction of the natural habitats, promoting the rise of new types of habitats, which makes important to study of how wildlife populations are adapting and behaving to urban environments. This study focuses on study the carnivorous populations (population size, densities) in two different habitats with diverse anthropogenic pressures and localizations, i.e. the Botanical Garden of University of Coimbra, a central urban area, and the Choupal Nacional Forest, a peri-urban area. To accomplish the main goal, the diversity of mammals in the study areas will be assessed, as well as the population densities of both carnivore and small mammal species. To better understand what changes are occurring in wildlife populations living in urban areas, these results will be compared with those from studies in rural areas.

Differences in population densities and diversity are expected, with a higher density (due to the small sizes of patches), and lower diversity of species in urban areas. In terms of niche overlap, species with identical ecological behaviour would present a higher niche overlap.

CHAPTER 2 - *Carnivore species in urban ecosystems: Are small urban parks capable of maintaining carnivore populations?*

2.1 Introduction

With the current growth of human populations, and the exponential migration to the urban areas, the cities are expanding in a way that has never been seen before. This growth is leading to the natural habitats destruction and fragmentation, creating new ones. These habitats (urban parks) will have different characteristics, as the size, number of patches and isolation (Wilcove *et al.*, 1998; Tilman *et al.*, 2001; Fahrig, 2003; Tabarelli and Gascon, 2005).

The existence of green spaces in urban areas is essential for biodiversity, not only because they are considered one of the few adequate places for supporting wild species' lives, but also because they provide ecosystem services like food, water, wood, air purification and pollination, which are indispensable for economic and social development (Sandler, 2010). However, these spaces are becoming threatened because of cities growth, which leads to the idea that it is crucial to build management strategies that highlight the importance of biodiversity.

Between urban and rural areas, some major differences can be pointed out, namely in what concerns to climate, hydrology and soil constitution. Urban areas are known for their greater precipitation, higher concentration of heavy metals and organic matter and warmer weather, when compared to rural areas (Alberti, 2005). Patches' structure may also be physically modified (in size, shape, interconnectivity and composition) changing the patches' dynamics, and consequently modifying the ecological conditions, which might cause impact on biodiversity (Forman and Godron, 1981).

Urban areas are rich and complex areas that allow the coexistence of species. Different patches may have enough resources to be inhabited by species of the same trophic level, which increases the maintenance of the interaction between predator and prey. Species that coexist in the same space have different ecological necessities, which leads to the privilege of niche overlap between specialist and generalist species (Fedriani *et al.*, 1999).

The study of carnivores is highly important, because these animals are keystones for the maintenance of ecosystem balance through top-down regulation process. This happens due to the fact that herbivores reduce the biomass of plants, but in turn, herbivore biomass is held in check by carnivores.

Red fox *Vulpes vulpes*, european badger *Meles meles*, stone marten *Martes foina*, common genet *Genetta genetta* and egyptian mongoose *Herpestes ichneumon* are carnivore species abundant in the Iberian fauna and they are considered ‘‘low concern’’ in terms of conservation status (Cabral *et al*., 2005). The red fox presents a generalist/opportunistic behaviour in habitat use (Pereira *et al.*, 2012), using diverse biomas as tundra, desert and forest, generally selecting heterogeneous areas (Cavallini and Lovari, 1994; Cagnacci *et al*., 2004). The european badger has a very wide distribution, with preference in deciduous woods with clearings, or open pastureland with small patches of woodland (Cabral *et al*., 2005), while the stone marten is a generalist species (Virgós and García, 2002; Santos and Santos-Reis, 2010) typically found in cork woodlands, riparian vegetation, pasturelands, orchards (Santos and Santos-Reis, 2010) and in other cultivated fields like olive-yards and vegetable-gardens (Santos- Reis *et al*., 2005) and scrubs (Rondinini and Boitani, 2002). The common genet is also a generalist species, but it prefers all types of wooded habitats (deciduous and evergreen), avoiding open habitats (Cabral *et al*., 2005). Finally, the egyptian mongoose can be found in Mediterranean maquis, with a clear preference for humid, riparian habitats (Delibes, 1999). Literature highlights that all these species may be found in urban areas (Huck *et al*., 2008; Duduś *et al*., 2014).

Small mammals play a truly important role in what concerns food webs, because they are the main prey of species from the higher trophic level. It is then fundamental to take in consideration the small mammals when studying carnivores' populations (Ekernas and Mertes, 2006).

The main purpose of this study is to evaluate the different carnivorous populations (population estimate, density) in two different green spaces with different locations and anthropological pressures: Choupal Nacional Forest and Botanical Garden of University of Coimbra.

To fulfil the ultimate purpose of this study, mammals' diversity was studied, as well as the density of small mammals and carnivores. To achieve a better comprehension of the differences between these populations, our results were compared with the ones obtained in rural areas. It is then expected that, compared to rural populations, urban carnivores' populations will present a higher density, due to the small size of suitable habitats, and lower diversity.

2.2 Methods

2.2.1 Study area

The study area is located in Coimbra city, Central Portugal, and it is composed by two different green urban areas: Choupal Nacional Forest (40° 21' N, -8° 44' W) and Botanical Garden of the University of Coimbra (40° 20' N, -8° 42' W) (Figure 1). The climate of this region is predominantly Mediterranean, with some Atlantic influences (Archibold, 1995), hot summers (mean temperature 22°) and mild winters (mean temperature 10°). Annual rainfall is on average about 922mm, mostly concentrated in January and February.

The Choupal National Forest is a forest area with 79 ha. Located near the city limits, it is limited at north by an irrigation canal and at south by the Mondego river. It is composed by a mixed forest of hardwoods, mostly deciduous, where eucalyptus (*Eucalyptus sp.*), maples (*Acer negundo*, *Acer pseudoplatanus*) and laurel (*Laurus nobilis*) are the most abundant. The ground is covered with *Tradiscantia* sp.. (ICNB, 2010). The Botanical Garden of the University of Coimbra is a wall fenced area with 13 ha, located in the downtown of Coimbra. It can be divided into two strata, the garden and the forest. The forest is occupied by a dense vegetation where very different areas can be found, such as a bamboo grove of the species *Phyllostacys bambusoides*, a zone dominated by the presence of laurel (*Laurus nobilis*), several species of eucalyptus, among many other plant species. The garden area is smaller, with species like *Chamaerops humilis, Latania chinensis and Archontophoenix cunninghamiana,* as well as some araucaria species (*Araucaria bidwilli* and *Araucaria columnaris*) (Tavares, 2011).

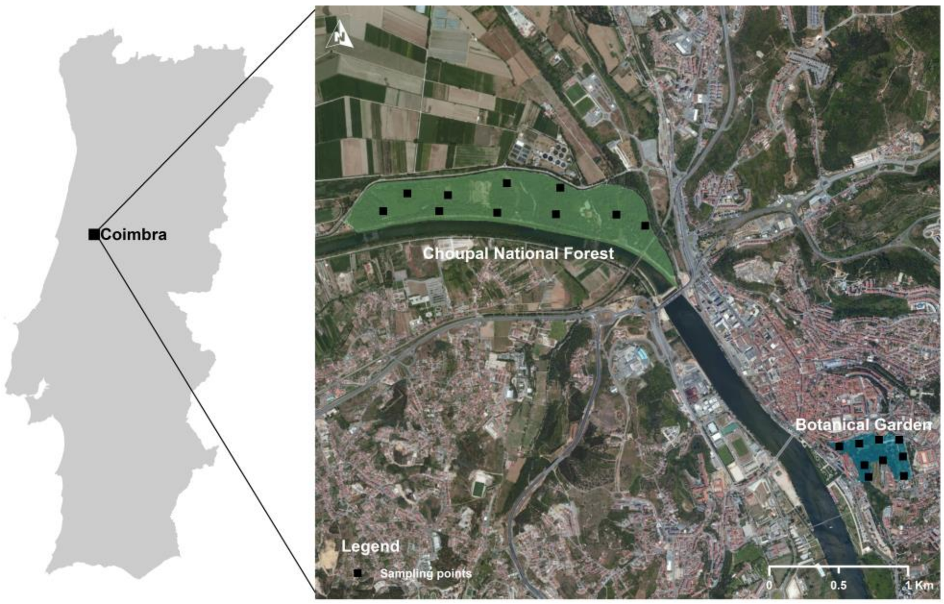

Figure 1: Map of the study area in mainland Portugal, highlighting the city of Coimbra with the Choupal Nacional Forest in green and Botanical Garden of University of Coimbra in blue. Black squares indicate the stations were camera-trap and live-trapping was conducted.

2.2.2 Data collection

2.2.2.1 Camera-trapping surveys

Each sampling point (total 19 points, 10 in Choupal Nacional Forest and 9 in Botanical Garden of the University of Coimbra) was surveyed during 49 days (49 trap-nights), 7 days per month, between October 2015 and April 2016.

Five Bushnell® Trophy Cams HD Max (8MP) were used in a rotation scheme, set to a time interval of 1s and to take three photos at each contact. The date and time were recorded in all photos. Each camera was equipped with an 8 GB SD card that allowed storing about 5,600 photos (with 8 MP resolution each), which corresponds to 1,860 shots approximately, and eight AA alkaline batteries that provide 6 months of continuous work.

Cameras were placed at a height of 0.25 to 0.5 m and at a 1 to 2 m distance from the bait. A mixture of sardine, flour, vegetable oil and dog food were used as bait in the trap-stations. Vegetation within the range of the infra-red (PIR) motion sensor and/or within the field of view of the cameras was removed to avoid false shots and to increase the quality of the photos.

The camera traps were placed uniformly within each area in order to ensure an even sampling effort. The mean distance ± SD to the nearest camera was 190 ± 37 m (min: 132 m; max: 223 m) for the Choupal National Forest and 134 ± 35 m (min:90 m; max: 216m) for the Botanical Garden.

Common genets, red foxes, badgers and mongooses were individualized using pelage patterns and natural body marks. Photos that do not have sufficient quality to understand pelage patterns or any other particular marks were not considered for individual recognition.

2.2.2.2 Live-trapping surveys

Live-trapping and marking of small mammals were performed between November 2015 and April 2016, three nights per month in each study site (Choupal Nacional Forest and Botanical Garden of the University of Coimbra). The capture-recapture method was executed only during three consecutive nights due to the fragility of the species under study (Gurnell and Flowerdew, 1982).

The sampling points were the same used for camera-trapping (10 in Choupal Nacional Forest and 9 in Botanical Garden of the University of Coimbra). In each sampling point a total of 9 Sherman traps (23 x 7.5 x 9 cm; Sherman Co., USA) were used. The Shermam traps were placed in a grid of 3x3 traps with each trap spaced 10 m apart. We used a total of 90 traps in Choupal Nacional Forest and 81 traps in Botanical Garden of the University of Coimbra. All traps were baited with a mixture of sardine, seeds, flour and vegetable oil, cotton was also used to provide thermal protection. Whenever was possible, the traps were set under the cover of shrubs or dense herbs to conceal them and to provide some thermal protection (Torre, 2010).

Small mammals caught were identified to the species. All the animals were individualized by shaving unique patterns in the hair. The weight, body length, tail length and hind-paw length of all animals was also recorded. The animals were released in the same place of the capture.

2.2.2.3 Scats surveys

Scats surveys were carried out, on a monthly basis, between October 2015 and April 2016. The scats surveys were performed systematically in all the network of available transects (roads, paths and trails) of each study site. The exact localizations of the scats, along the transects, were recorded using a GPS (Garmin® GPS 60). After field collection, all the collected scats from the transects, were air-dried and stored at -20ºC in individual plastic bags for further analysis (Davison *et al*., 2002).

Whenever possible the scats were identified to the species. The criteria used to distinguish scats of the different species included shape, size and odour. All the scats where the species identification was uncertain were not considered.

2.2.3 Data analysis

The analysis of capture-recapture data was performed using two different models, being them the conventional non-spatially closed capture-recapture model and the spatially explicit closed capture-recapture model. The models were used to estimate population size, density and capture probability. The closure test of CAPTURE was performed to verify if the population under analysis is demographically closed (Otis *et al.*, 1978).

CAPTURE software (Otis *et al*., 1978; Rexstad and Burnham, 1991) was used to preform non-spatial closed capture-recapture models. Eight fundamental, non-spatial, capture-recapture models for closed populations were used. The null model (M_0) assumes that the capture probability is constant across individuals and time. The other seven models consider that different sources of variation, namely time, behaviour, heterogeneity, or its combinations, can influence the capture probability. The model selection algorithm of CAPTURE was used to select the most appropriate model (model score equal to one corresponds to the best-fit model) (Otis *et al.*, 1978; Rexstad and Burnham, 1991). The chosen model was then used to estimate the probability of capture, the estimated population size of the different species, the corresponding standard error and 95% confidence intervals.

The spatially explicit capture-recapture model, in addition to individual animal capture histories use the spatial information from capture locations in the density estimation (Athreya *et al.*, 2013). Spatially explicit capture-recapture models assume that home ranges of the species are circular and stable during the survey, that the activity centres are randomly distributed (as a Poisson process), and that the probability of capture of an individual decreases with increasing distance from the activity centre following a predefined function (Efford, 2004; Royle, 2008). R software (R 3.2.3, R Core Team 2015) with secr package (Efford, 2016) was used to fit the spatially explicit capture-recapture model. The fitted spatial explicit model was used to estimate the population size and the density of the captured species, and its standard error and 95% confidence intervals.

The biodiversity of mammal species in the two study sites was evaluated using different diversity indexes, namely the species richness (S), Shannon index (H'), Pielou's evenness (J') and Margalef index (D_{Mg}). The S is simply the number of species. The Shannon index (H') was calculated as:

$$H' = -\sum_{i=1}^{S} p_i \,.\ln p_i$$

where p_i is the proportion of individuals of the i species, ln is the natural log. The Pielou's evenness (J') was calculated as:

$$J' = \frac{H'}{H'max}$$

where the H' is the Shannon index, and the $H'max$ is the maximum value of H'. The values of J' range between 0 and 1, close to 1 the species are present in similar quantity, close to 0 means that a dominant species is present. The Margalef index (D_{Mg}) was calculated as:

$$D_{Mg} = \frac{(S-1)}{lnN}$$

where N is the total number of individuals in the sample and S is the number of species. Values D_{Mg} lower than 2.0 indicate areas with low diversity and values of D_{Mg} above 5.0 indicate areas with a great biodiversity. Diversity indexes were calculated using the Past software (Hammer *et al*., 2001).

Multivariate data analysis was made with a presence/absence data of the mammal species recorded with the three techniques used (camera-trapping, live-trapping and scats). Principal Components Analysis (PCA) was performed in order to find what species contribute most for the differences between these two sites.

The overlap of the resources used among the four carnivores was analysed at station level, *i.e.* camera-trap level. Pianka's index of niche overlap was used to measure the overlap:

$$O_{jk} = \frac{\sum_{i=1}^{l} o_j \cdot o_k}{\sqrt{\sum_{i=1}^{l} o_j^2 \cdot \sum_{i=1}^{l} o_k^2}}$$

where o_j is the resources used by specie j and o_k is the resources used by specie k, that is a symmetric measure of overlap between species, ranging from 0 and 1 (*i.e.* no resources used in common to complete overlap of resource use).

2.3. Results

2.3.1. Captured species

Sampling effort of the camera-trap resulted in a total of 552 photos, 289 photos in Choupal and 263 photos in the Botanical Garden. Of these 552 photos, 285 photos are from carnivores, divided into four species (Table 1), and 267 are from small mammals, divided into three species (Table 2).

Table 1 - Number of cameras and photos of carnivore species (red fox, common genet, European badger, Egyptian mongoose) in the two study sites.

	Number of cameras		Number of Photos			
			Red fox	Common genet	European badger	Egyptian mongoose
Botanical Garden	3	Garden	0	7	0	0
	6	Forest	0	1	0	0
Choupal	10		263	2	11	1

Table 2 - Number of cameras and photos of other mammal species (hedgehog, black rat and red squirrel) in the two study sites.

	Number of cameras		Number of Photos		
			Hedgehog	Black rat	Red squirrel
Botanical Garden	3	Garden	66	2	0
	6	Forest	164	31	0
Choupal	10		0	0	12

In live-trapping, the trapping effort enabled 191 captures of 143 individuals, divided into 153 captures of 113 individuals in Choupal and 39 captures of 21 individuals in the Botanical Garden (Table 3).

Table 3 - Number of live-trap captures and different individuals per species and study site.

	Choupal		Botanical Garden			
			Garden		Forest	
Species	Nº Captures	Individuals	Nº Captures	Individuals	Nº Captures	Individuals
Apodemus sylvaticus	83	62	3	3	5	3
Microtus agrestis	7	5	0	0	0	0
Mus musculus	1	1	6	5	0	0
Mus spretus	6	3	1	1	11	9
Crocidura russula	52	39	0	0	1	1
Erinaceus europeus	0	0	4	2	8	6
Sorex granarius	3	3	0	0	0	0

In Choupal, were collected 13 scats of red fox, 3 of otter and 1 from stone marten. On the other hand, in Botanical Garden, 1 scat of stone marten was collected, as well as 12 of hedgehogs and 3 of weasel (Table 4).

Table 4 - Number of scats identified for red fox, beech marten, least weasel, otter and hedgehog in the two study sites.

	Choupal	Botanical Garden	
		Garden	Forest
Red fox	13	0	0
Beech marten	1	1	0
Least weasel	0	0	3
Otter	3	0	0
Hedgehog	0	0	12

2.4.2. Population estimate: size, density

Closure test results were consistent with the assumption that the red fox and european badger populations are closed [z = -1.24; P = 0.107 and z = 0.30; P = 0.618 (Table 4)]. The discriminant function analysis in CAPTURE software indicted that the null model (M_0) was the best fit to our data. In Choupal forest, the population size estimated with the non-spatial closed capture-recapture models was 5.0 ± 0.02 individuals for red fox and 3.0 ± 0.49 individuals for european badger. The captures probability was 0.74 and 0.33 for red fox and european badger, respectively. The spatially explicit capture-recapture model sestimated a population size of 5.0 ± 2.4 red foxes and 3.3 ± 1.4 european badgers, resulting in estimated densities of 0.056 ± 0.026 animals/ha for red fox and 0.037 ± 0.016 individuals/ha for european badger (Table 5).

Table 5 - Population and density estimates, capture probability and closure test using non-spatial closed capture-recapture models and spatially explicit capture-recapture models for red fox and european badger in Choupal National Forest

	Vulpes vulpes	*Meles meles*
Population estimate[1]	5.0 ± 0.02 (5.0 - 5.3)	3.0 ± 0.49 (3.0 - 5.1)
Capture probability (per occasion)[1]	0.74	0.33
Density estimate (animal/ha)[2]	0.056 ± 0.026 (0.023 - 0.134)	0.037 ± 0.016 (0.016 - 0.082)
Population estimate[2]	5.0 ± 2.4 (2.1 - 12.0)	3.3 ± 1.4 (1.5 - 7.3)
Closure test	z=-1.24; P=0.107	z=0.30; P=0.618

Based on: [1]Non-spatial closed capture-recapture model; [2]Spatially explicit capture-recapture model

Temporal population and density estimations were also evaluated for three species (red fox, wood mouse and greater white-toothed shrew) in Choupal forest. The temporal estimates of the non-spatial close capture-recapture models for the red fox's population size varied between 2.0 ± 0.0 (November and March) and 4.0 ± 0.1 (October, January and February). The capture probability diverges between 0.52 in December and 0.86 in March. The temporal spatially explicit capture-recapture models estimates are similar to the estimates of the non-spatial models. The highest population size and density was obtained in October, January and February (N=4.0 ± 2.1 and D= 0.045 ± 0.024) whereas November and March have the lowest values (N=2.0 ± 1.6 and D= 0.022 ± 0.018) (Table 6).

Table 6 – Temporal population and density estimates, and capture probability using non-spatial closed capture-recapture models and spatially explicit capture-recapture models for red fox in Choupal National Forest.

	Population estimate[1]	Capture probability (per occasion)[1]	Density estimate (animal/ha)[2]	Population estimate[2]
October 2015	4.0 ± 0.1 (4.0 - 4.5)	0.57	0.045 ± 0.024 (0.017 - 0.119)	4.0 ± 2.1 (1.5 - 10.7)
November 2015	2.0 ± 0.0 (2.0 - 2.4)	0.64	0.022 ± 0.018 (0.006 - 0.089)	2.0 ± 1.6 (0.5 - 8.0)
December 2015	3.0 ± 0.1 (3.0 - 3.6)	0.52	0.034 ± 0.021 (0.011 - 0.104)	3.0 ± 1.9 (1.0 - 9.3)
January 2016	4.0 ± 0.1 (4.0 - 4.6)	0.54	0.045 ± 0.024 (0.017 - 0.119)	4.0 ± 2.1 (1.5 - 10.7)
February 2016	4.0 ± 0.1 (4.0 - 4.4)	0.64	0.045 ± 0.024 (0.017 - 0.119)	4.0 ± 2.1 (1.5 - 10.7)
March 2016	2.0 ± 0.0 (2.0 - 2.2)	0.86	0.022 ± 0.018 (0.006 - 0.089)	2.0 ± 1.6 (0.5 - 8.0)
April 2016	3.0 ± 0.1 (3.0 - 3.5)	0.57	0.034 ± 0.021 (0.011 - 0.104)	3.0 ± 1.9 (1.0 - 9.3)

Based on: [1]Non-spatial closed capture-recapture model; [2]Spatially explicit capture-recapture model

The population estimates of the wood mouse (Table 7) and the greater white-toothed shrew (Table 8) show temporal fluctuations during the studied period. The estimates of wood mouse range from 9.0 ± 2.7 in February and 48.0 ± 27.4 in April. Regarding, the greater white-toothed shrew, it was not possible to calculate estimates for all study months due to the low number of captures. The capture probability ranged between 0.37 (February) and 0.13 (April) for the wood mouse and from 0.16 (April) to 0.67 (January) for greater white-toothed shrew. The density of the wood mouse varies between 1.22 ± 7.73 (December) and 2.78 ± 16.95 individuals/ha (April). The density for greater white-toothed shrew ranged from 0.03 ± 0.04 (November) to 0.22 ± 0.06 individual/ha (April).

Table 7 - Temporal population and density estimates, and capture probability using non-spatial closed capture-recapture models and spatially explicit capture-recapture models for wood mouse in Choupal National Forest.

	Population estimate[1]	Capture probability (per occasion)[1]	Density estimate (animal/ha)[2]
November 2015	11.0 ± 3.6 (8.0 - 29.8)	0.33	1.34 ± 8.48 (0.03 - 58.61)
December 2015	11.0 ± 4.8 (7.0 - 45.6)	0.27	1.22 ± 7.73 (0.03 - 53.36)
January 2016	16.0 ± 4.1 (12.0 - 37.5)	0.33	2.23 ± 13.69 (0.05 - 94.60)
February 2016	9.0 ± 2.7 (7.0 - 22.9)	0.37	1.32 ± 8.36 (0.03 - 57.71)
March 2016	20.0 ± 5.2 (14.1 - 42.8)	0.32	2.47 ± 15.16 (0.06 - 104.70)
April 2016	48.0 ± 27.4 (21.1 - 249.4)	0.13	2.78 ± 16.95 (0.07 - 117.08)

Based on: [1]Non-spatial closed capture-recapture model; [2]Spatially explicit capture-recapture model

Table 8 - Temporal population and density estimates, and capture probability using non-spatial closed capture-recapture models and spatially explicit capture-recapture models for greater white-toothed shrew in Choupal National Forest.

	Population estimate[1]	Capture probability (per occasion)[1]	Density estimate (animal/ha)[2]
November 2015	1.0 ± NA (NA - NA)	NA	0.03 ± 0.04 (0.00 - 0.22)
December 2015	NA ± NA (NA - NA)	NA	0.07 ± 0.04 (0.03 - 0.18)
January 2016	6.0 ± 0.5 (6.0 - 8.0)	0.67	0.09 ± 0.04 (0.04 - 0.20)
February 2016	NA ± NA (NA - NA)	NA	0.04 ± 0.03 (0.01 - 0.14)
March 2016	11.0 ± 3.5 (9.0 - 71.4)	0.28	0.13 ± 0.05 (0.07 - 0.26)
April 2016	34.0 ± 17.1 (17.2 - 165.4)	0.16	0.22 ± 0.06 (0.12 - 0.38)

Based on: [1]Non-spatial closed capture-recapture model; [2]Spatially explicit capture-recapture model

In the Botanical garden, it was only possible to roughly calculate estimates for common genet and cats due to the low number of captures. The population size estimated with non-spatial closed capture-recapture models was 1.0 ± 0.00 for common genets and 3.4 ± 0.40 for cats. The captures probability was 0.83 for common genets and 0.58 for cats. The spatially explicit capture-recapture models estimate a population size of 1.0 ± 1.3 common genets and of 3.6 ± 0.4 cats. The densities for common genet and cat was 0.033 ± 0.043 and 0.114 ± 0.012 individual per hectare respectively (Table 9).

Table 9 - Population and density estimates, capture probability and closure test using non-spatial closed capture-recapture model and spatially explicit capture-recapture model for common genet and cat in Botanical Garden.

	Genetta genetta	*Felis catus*
Population estimate[1]	1.0 ± 0.00 (1.0 - 1.3)	3.4 ± 0.40 (2.0 - 5.8)

Capture probability (per occasion)[1]	0.83	0.58
Density estimate[2] (animal/ha)	0.033 ± 0.043 (0.005 - 0.231)	0.114 ± 0.012 (0.016 - 0.390)
Population estimate[2]	1.0 ± 1.3 (0.1 - 7.2)	3.6 ± 0.4 (0.5 - 12.2)
Closure test	NA	z=-2.24; P=0.01

Based on: [1]Non-spatial closed capture-recapture model; [2]Spatially explicit capture-recapture model

2.3.3 Diversity of mammal species

Globally, the Choupal forest presented a species richness ranging from 5 to 9 (Table 10), with *Vulpes vulpes* and *Apodemus sylvaticus* as the two main species. In terms of carnivore species, a maximum of 3 species were detected by camera-traps, plus two carnivore species identified from scats (*Martes foina* and *Lutra lutra*). In the Botanical garden, the number of species detected by camera-traps and live-trapping ranges from 3 to 7 (Table 10), with other two species detected from scats, *Martes foina* and *Mustela nivalis*. In Choupal Nacional Forest, the diversity was higher in April (S=9; H'=1.349; D_{mg}=1.778), whereas in the Botanical garden February had the higher diversity values, when compared to the other months (Table 9). In both sites the diversity fluctuates over the studied period.

Table 10 – Diversity indexes (Species richness, Shannon index, Pielou's index and Margalef index) of mammal species in Choupal National Forest and Botanical Garden in different months, using data from camera traps and live-trapping.

		S	H'	J'	Dmg
Choupal	November 2015	7	1.118	0.703	1.595
	December 2015	5	0.9	0.632	1.033
	January 2016	6	1.089	0.608	1.122

	February 2016	5	0.926	0.575	0.948
	March 2016	6	1.325	0.739	1.231
	April 2016	9	1.349	0.635	1.778
Botanical Garden	November 2015	3	0.438	0.398	0.572
	December 2015	4	0.281	0.203	0.647
	January 2016	5	0.658	0.409	0.945
	February 2016	7	1.49	0.766	1.688
	March 2016	5	0.752	0.467	1.084
	April 2016	4	0.773	0.558	0.756

The PCA clearly shows the differences in species occurrence in both study sites. The PCA biplot (Figure 2) explains 52% of the total variance in the species composition, and is quite evident from the separation between the samples from the Choupal forest and the Botanical garden. The main species that are contributing for the separation between the two study sites are the presence of *Vulpes vulpes* and *Apodemus sylvaticus* in Choupal forest and the high presence of *Erinaceus europaeus* in the Botanical garden (Figure 2).

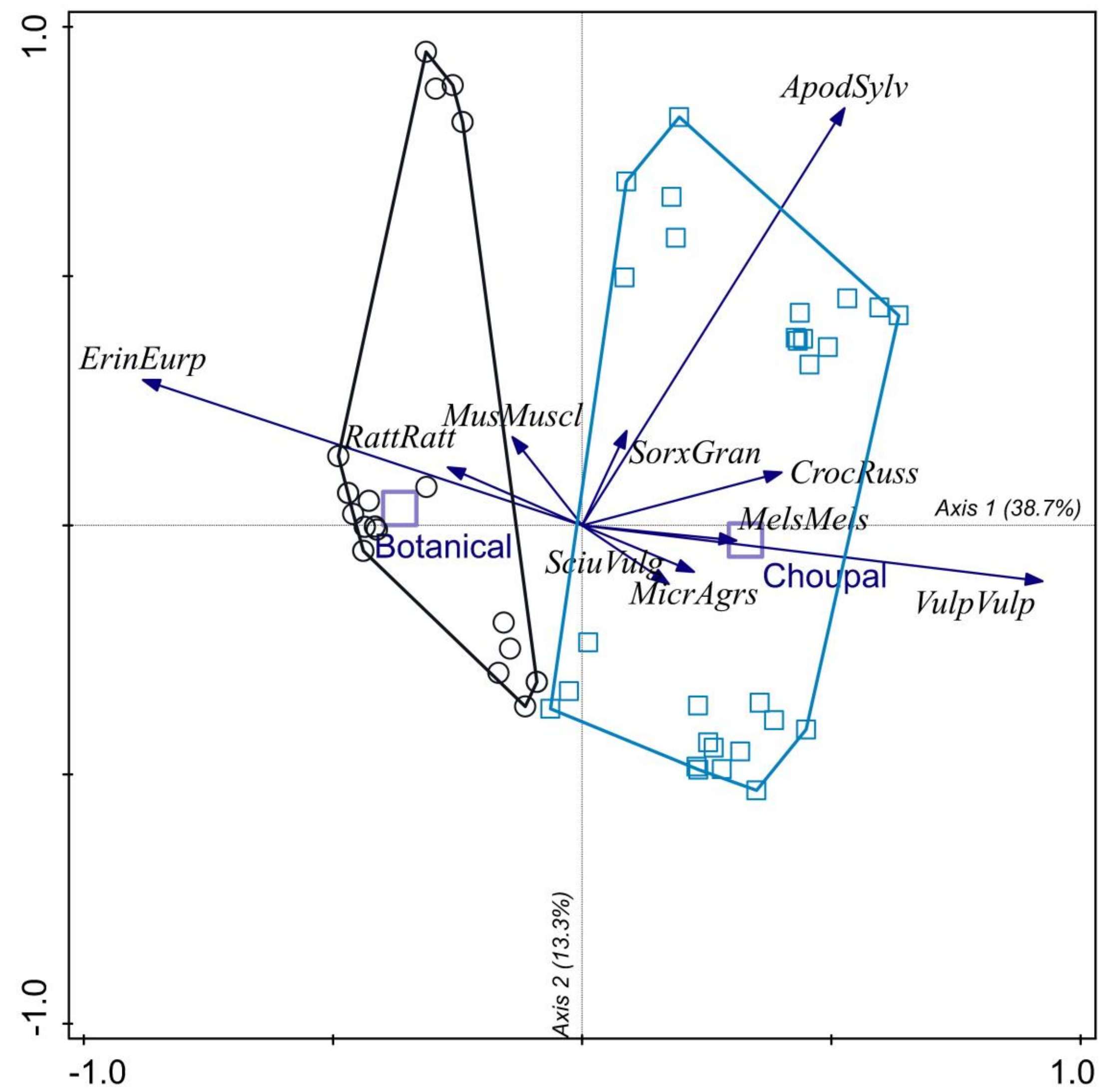

Figure 2 - Principal Component Analysis (PCA) biplot of all the species detected in Choupal Nation Forest and in the Botanical Garden. Arrows represent the species, black circles Botanical garden samples, small blue squares Choupal forest samples, big squares represent the centroids. Only the 10 most representative species are show.

2.3.4. Niche overlap

The results of niche overlap at the station level show a highest overlap between red fox and european badger (Table 11).

Table 11 - Pianka's index of niche overlap at station scale among four carnivores (red fox, common genet, egyptian mongoose and european badger) of Choupal Nacional Forest.

	Red fox vs Common genet	Red fox vs Egyptian mongoose	Red fox vs European badger
Station Scale	0.2	0.1	0.6

2.3.5. Circadian rhythms

In Choupal, red fox and european badger have a crepuscular and nocturnal activity. The highest level of activity of both species was between 18:00h and 06:00h (Figure 3a,b). Red squirrel has a diurnal activity pattern, showing higher activity between 06:00h and 18:00h (Figure 3c). In the Botanical garden, the common genet, hedgehog and black rat were more active between 18:00h and 06:00h (Figure 4a,b,c), whereas the cat presented activity throughout the entire day (Figure 4d). For the other species observed in camera-trap, the patterns of activity are not presented due to the small dataset.

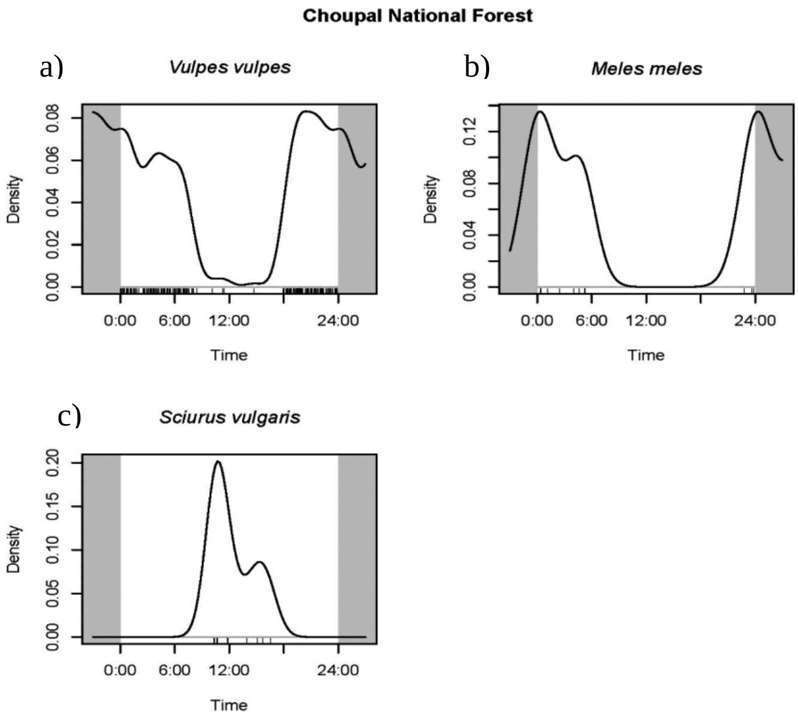

Figure 3 – Fitted kernel density curves for patterns of activity of the mammals observed in Choupal Nacional Forest. a) red fox; b) european badger; c) red squirrel.

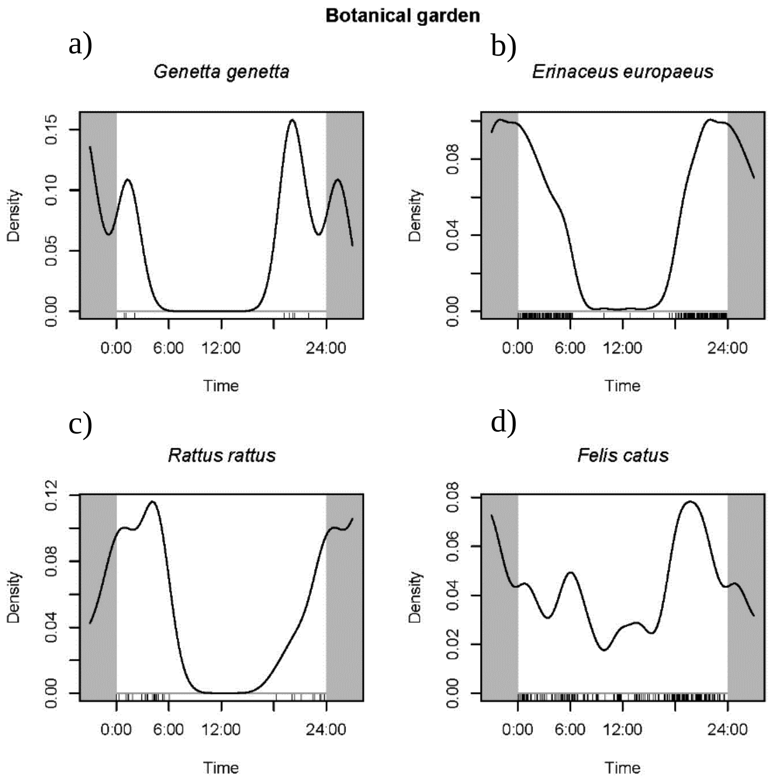

Figure 4 – Fitted kernel density curves for patterns of activity of the mammals observed in Botanical Garden of University of Coimbra. a) common genet; b) hedgehog; c) black rat; d) cat.

2.4. Discussion

Wild mammal carnivores have a key role in ecosystems as predators, competitors and umbrella species, and thus any changes in the abundance of carnivore species or in the composition of their communities could induce further changes at the ecosystem level (Treves and Karanth, 2003; Roemer *et al*., 2009). As so, it is essential to build effective land management policies, where biodiversity conservation is a keystone (Pereira *et al*., 2012). Small to medium-sized carnivores, are particularly affected by the urbanization process, due to their sensitivity to habitat fragmentation, low population densities, and large territory requirements (Roemer *et al*., 2009; Bateman and Fleming, 2012).

Considering the diversity and density of mammals, in the Choupal National Forest, the number of species detected and their densities are higher when compared to the Botanical Garden, as expected. In fact, being the Choupal forest a peri-urban area, its connectivity with rural and natural areas is much higher than in the Botanical garden. The small mammals' densities are also higher in Choupal.

The densities obtained for red fox and european badger in Choupal forest were higher when compared with the results obtained in other studies in rural areas (Sarmento *et al*., 2009; Eira, 2003; Kowalczyk *et al*., 2000; Rosalino *et al*., 2004). These results corroborate with Luniak (2004) and with our predictions, which state that the densities in urban areas are higher, due to the aggregation of all animals of the population on smaller habitats patches. On a monthly basis, the population size of red fox presents solely slight changes throughout months, which could result from fluctuations on the presence or absence of preys (Sidorovich *et al*., 2005). Considering our results in terms of abundance of small mammals, the abundance of red fox does not seem to follow the trend observed for *Apodemus sylvaticus* and *Crocidura russula*. This may be simply the result of a quite stable number of red foxes using the Choupal area, are not fluctuating considerably with changes in the abundance of small mammals. Even so, more studies are necessary to fully understand the temporal patterns of mammal abundance in this peri-urban area.

The differences observed from the results of live-trapping show clearly that in the Choupal forest the abundance and diversity of small mammals is higher than the obtained in the Botanical garden, with the wood mouse and the greater white-toothed shrew as the two main species of small mammals. The dominance of the wood mouse in urban areas was already shown by Dickman and Doncaster (1987). This is an expected result due to the characteristics of this species, that have a broad diet (seeds, fruits, nuts, snails and arthropods (Watts, 1968)) and flexible habitat use. The results obtained in November (late Autumn) were lower than expected, considering the biology of small mammals, but it can be a consequence of the meteorological conditions because the rain season started latter than usual, just in January. Since we were not able to start the captures of small mammals in October, our results only reflect one month and not Autumn as a complete season.

Regarding the Botanical Garden, the low densities of small mammals encountered in this area may be due to: (1) High densities of cats (*Felis catus*), which may have a huge impact on the populations of small mammals (Courchamp *et al*., 2002); (2) Lack of available food, since rodents feed mainly on seeds and small plants, and the flora present in this urban area is composed by several exotic species that may not provide enough food for rodents; (3) Treatment of surrounding areas with rodenticides, leading to a lower population density in what concerns all the small mammals. The black rat (*Rattus rattus*) was not captured in the live-traps but was observed in camera-trap photos, which may be a constrained of the size of the traps used in this study.

Considering the results obtained by both methods of population estimates, the results of are concordant, with the Spatially explicit capture-recapture models providing higher confidence intervals, because it takes into account the distribution of animals in space and area effectively sampled (Sollmann, 2011).

The diversity of mammals observed at the study sites was very low comparatively with the results obtained in some rural areas (Pita *et al*., 2009). When comparing our study areas, the diversity is lower in Botanical Garden in all taxonomic groups. This result is in line with that observed by Prugh *et al*., (2008), which states that smaller areas usually have lower diversities. Moreover, since the Botanical Garden is located in a central area of the city of Coimbra, its connectivity to rural and natural areas is lower than verified in Choupal forest, and the wildlife corridors available are also scarce. Another important feature that is limiting the presence of wildlife species in the Botanical Garden is the fact that this area is fenced by a stone wall, with a limited number of entrances (3 gates and 2 small holes), and most of them of sizes smaller than required for medium-size carnivores.

The evenness of both study sites was low, because the population of carnivorous in Choupal is clearly dominated by red fox, and the main mammal species in the Botanical garden is the hedgehog. According to Kurki *et al*., (1998), red fox increases its density with habitat fragmentation, which can be explained by its plasticity, that enables them to live in a wide variety of habitats, exhibiting opportunistic feeding behaviours as a key factor to be successful in colonizing urban areas (Doncaster *et al*., 1990; Contesse *et al*., 2004). As so, red fox seems to be better adapted to changes in habitat than other species of carnivores. In Botanical Garden, the absence of more terrestrial carnivores and the physiological strategies of the hedgehog to reduce their probability of being predated, turn possible the occurrence of higher densities of this species.

The PCA shows that the hedgehog and red fox were the species that mostly contributed for the graphical segregation of both study areas, which represents clearly the species occurrence in each study site. Moreover, and since the PCA results from presence/absence data obtained by the three methods employed (camera-traps, live-trapping and identification of faeces collected in linear transects), it provides a more complete picture regarding the biodiversity of both study areas.

Virgós *et al*., (2002) showed there are three crucial factors to explain the habitat/fragment use, which are the fragment size, the geographic location and the vegetation type. If we compare the two study sites, the areas have huge differences in all three aspects, with Choupal having 79 hectares in contrast with the 13 hectares of the Botanical Garden. The Botanical Garden is located in the central area of Coimbra (urban), and it is bounded by walls, which difficult or makes impossible the access of larger animals like red fox or european badgers, whereas Choupal forest is located in a more remote area (peri-urban), far from the city centre and with clear paths to the agricultural areas. The vegetation type is also rather different, with Choupal presenting a more autochthonous vegetation and the Botanical Garden having a more diverse flora with many exotic species. Goldyn *et al*., (2003) observed that red fox forages in habitats with a high availability of rodents, like the wood mouse (*Apodemus sylvaticus*), that constitutes its main prey (Carvalho and Gomes, 2004) and requires larger vital areas. So, the lack of preys together with the small size of the patch and the isolation, makes the Botanical garden an urban area not suitable for larger carnivores like red fox and european badger. Only mid-sized carnivores, like common genet, stone marten and weasel, can use this structure by using their physiological characteristics and arboreal abilities (*i.e.* can cross the wall by small holes or by trees tops).

Red fox and european badger have a higher niche overlap, which is in agreement with the results obtained by Fedriani *et al*. (1999). Both species are generalists in terms of habitat (Ginsberg and Mac-Donald, 1990), but present different feeding habits that enable them to exploit the same territory. According to Neal (1986), the badgers' food usually consists of vegetables and small and easily captured animals, such as worms and insects, and it rarely captures small mammals, while the red fox is an omnivorous species that feeds mainly on small mammals (Fedriani *et al*., 1999). This result shows that the Choupal forest has enough resources to enable the coexistence of these two species. The low niche overlap between genets and red fox in Choupal forest can be due to a lack of detection of the first species in the camera-traps. In fact, due to the tree height, it is possible for the genets to explore the same areas but at a different altitudinal level, making use of their arboreal skills, and avoiding competition with bigger species like red fox or european badger, which are potential predators and/or competitors (Pereira *et al*., 2012).

Observing the patterns of activity, we conclude that the carnivorous in Choupal have crepuscular and nocturnal habits, to avoid human contact, which is in agreement to the results obtained by Kowalczyk *et al*., (2003) and Díaz-Ruiz *et al*., (2015). On the other hand, the activity pattern of the red squirrel was diurnal, which happens to avoid unnecessary interactions with natural predators. In Botanical garden, common genet, hedgehog and black rat have also crepuscular and nocturnal habits. In this area, all the wild species presented a nocturnal activity, contrasting with the patterns obtained for cats, which were active all day, increasing its impact on wild populations.

Looking at the results, we can assume that the carnivorous species are well adapted to the Choupal national forest. According to our results, the carnivorous species cannot live permanently in the Botanical garden due to lack of resources, but carnivorous with arboreal abilities can cross this area. In the Choupal national forest, the red fox and the european badger are the two species better adapted due to their plasticity.

The results obtained in Botanical garden are an example of the impact of urbanization in green areas, where the fragmentation of the habitats leads to a decrease of diversity and species abundance. Depending on the purposes defined to the green urban areas, it could be important to implement actions to improve the biodiversity of the urban habitats, like in the Botanical garden. Wildlife corridors could be one of the solutions, creating connections with other green areas, and facilitating the movement of plants and animals among habitat patches, mitigating the effects of fragmentation (Corsi *et al*., 1999; Angold *et al*., 2006).

This study goes in line with Arroyo-Rodriguez *et al.* (2013) and Gortat *et al*. (2014), which highlight the impact of habitat fragmentation in the composition of wild populations and the differences between urban and rural populations. However, from our knowledge this is the first study of carnivorous species conducted in urban areas in Portugal, which highlights the importance of our results. Nevertheless, due to the limitations associated to the field work, new studies are necessary to fully understand how carnivorous species are adapting to urban areas in Portugal. Firstly, the data collection period (6 months) does not allow us to make conclusions to all seasons. Another constrain is associated with the intrinsic limitation of the field methods, which can lead to the underestimation of some species. The beech marten, least weasel and otter are species that, due to their characteristics, were only detected in the scats surveys.

More studies about this research topic are needed to evaluate the importance of the urban green areas to wildlife preservation, and the implications of possible interventions. For instance, promoting wildlife corridors will slow the effects of fragmentation by increasing the movement of the animals among isolated populations (Gilbert *et al*., 1998), preventing local extinctions (Reed, 2004), retaining genetic diversity (Mech and Hallett, 2001), and maintaining ecological processes (Haddad and Tewskbury, 2006). However, the presence of some risks is also notorious, namely the spread of exotic and invasive species.

Conserving and enhancing urban biodiversity has also unique implications for human well-being, public health, and for making citizens aware of the importance of biodiversity conservation (Miller, 2005; Goddard *et al*., 2010).

CHAPTER 3 – *General Conclusions*

3. General Conclusions

The main goal of this study was to evaluate how carnivorous species are adapting to two green areas of Coimbra, Botanical Garden of University of Coimbra and Choupal Nacional Forest, as well as the diversity of mammals observed in these sites. To evaluate that, we estimated the population size and density of the carnivore species and their main preys, the small mammals. By comparing the two study sites, it is possible to understand which environmental variables constitute important factors that determine the suitability of habitats for carnivores. Connectivity with rural and/or natural areas, patch size and availability of preys are three essential ones.

The results show a great difference in densities and diversity of species between the two study sites. In Choupal, the presence of six species (red fox, european badger, common genet, egyptian mongoose, otter and beech marten) was detected, and in Botanical Garden just the genet, weasel and stone marten were identified. This result proves that the Botanical garden does not have the essential characteristics to held stable populations of carnivores, mainly due to isolation and smaller size (lower than the home range of carnivore species) and low availability of prey.

Although the higher abundance of small mammals in the Choupal forest was expected due to the characteristics of the local, the low abundance and diversity of this group in the Botanical Garden was a surprise. Our results are not conclusive in terms of the reasons for the low densities, but it could be due to a combination of factors like the high densities of cats, the availability of food and the rodenticides applied in the surroundings.

Analysing our results, we can conclude that the Botanical garden is a very fragmented area, isolated and without natural resources for the carnivorous species. Although also fragmented, Choupal it is not so isolated, having large connectivity in its north and west boundaries with agricultural areas, and in the south with Mondego river. The carrying capacity of the Choupal is also higher compared with the Botanical Garden, due to the patch size and the abundance of prey.

The red fox and the european badger are the two carnivorous species that are more well adapted to the Choupal national forest. In Botanical garden, carnivorous species do not seem to be capable of using the space in a more permanent fashion.

The results obtained show that more studies are needed to understand the need for creating solutions to mitigate the effects of fragmentation made by urban development in areas like Coimbra.

The present study focuses on the mammal populations, especially in the carnivorous living in two green areas of Coimbra city, bringing new knowledge in the understanding of the impact of the urbanization for these wild species. Since this is the first study focused in urban ecology of carnivorous in Portugal, more studies are needed to understand the impact of the urban development in the ecology and evolution of these species. However, this approach and results bring new insights and new research perspectives for urban ecology research.

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