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INTEGRATING ANTHROPIC FACTORS INTO WILDCAT *Felis silvestris* CONSERVATION IN SOUTHERN IBERIA LANDSCAPES

JOAQUIM PEDRO SANTOS MÊRCES FERREIRA

DOUTORAMENTO EM BIOLOGIA

(BIOLOGIA DA CONSERVAÇÃO)

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Tese co-orientada por:
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NOTA PRÉVIA

Na elaboração desta dissertação foram usados resultados de trabalhos já submetidos para publicação em revistas científicas internacionais indexadas. Uma vez que estes trabalhos foram realizados em colaboração com outros investigadores, e de acordo com o previsto no nº 1 do artigo 41º do Regulamento de Estudos Pós-Graduados da Universidade de Lisboa, publicado no Diário da República II série nº 209 de 30 de Outubro de 2006. O candidato esclarece que liderou e participou integralmente na concepção dos trabalhos, obtenção dos dados, análise e discussão dos resultados, bem como na redacção dos manuscritos dos artigos I a IV.

Lisboa, Maio de 2010

Joaquim Pedro Santos Mercês Ferreira

“O grito verde que anda”.

Francisco. Chico. Chico Mendes.
Seringa. Seringueiro. Seringal.
Legião de homens e sonhos.
Verde rompendo o verde.
Punhal aceso na memória
da água, da pedra, da madeira.
Dos homens?
A sumaúma, a seringueira,
a pedra do monte Roraima,
o sangue que mina do tronco
nos seringais de Xapuri indagam:
onde a sombra exilada de Chico Mendes?
Organizador dos ventos gerais
que combatem depois das cercas,
de todas as cercas da terra...
Chico: um grito verde que não cessa.

(Pedro Tierra)

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Abstract

The European wildcat *Felis silvestris* is a threatened species in Europe, where suitable management of forests has been considered crucial for its conservation. However, this recommendation may not be general due to the lack of studies that test this hypothesis in the Mediterranean area, where landscapes are very different from those of central-north Europe. Nowadays, the European wildcat is distributed in Europe in a number of fragmented populations threatened by destruction of their natural habitats, persecution and crossbreeding with free-ranging domestic feral cats. The conservation of wildcat in the constantly changing, human-altered landscapes of Southern Iberia requires therefore a clear understanding of the species limits and capabilities in these environments. My thesis focused on wildcat ecological requirements and constrains imposed by human-related activities. In natural areas the wildcat constrains are link to human actions and activities. First step was to build a model that incorporates the advantages of correlative and mechanistic models to develop large-scale determinants that express the local individual requirements for wide range wildcat distribution. The results obtained suggest the importance of small mammals as prey for the species, as well the negative influence of human disturbance. Human disturbance is reflected in changes in the land use, direct persecution and the expansion and dimension of domestic cat populations. The presence of domestic species in natural areas often represent a conservation problem due to competition with and predation of wild species, because they act as reservoirs for many diseases and even due to the potential hybridization with the wild ancestor types. The impact of domestic cats depends on where they can be found and on the factors controlling their numbers and space use. In this Thesis were described the patterns of presence, abundance, spatial behaviour and human constraints (food resources) associated to domestic cats. Human activities and domestic cat population structure, that implies different scenarios for wildcat conservation, were discussed in the last Chapter of this Thesis.

Key-words: domestic cat *Felis catus,* European wildcat *Felis silvestris,* People and cats distribution, wildcat conservation

Resumo

Nas últimas décadas verificou-se uma preocupação crescente com as questões ambientais globais, resultantes da degradação do meio ambiente, como consequência da utilização de práticas não sustentáveis no uso dos recursos naturais, levando à perda acelerada da diversidade biológica. Cerca de 44% de todas as espécies de plantas vasculares e 35% de todas as espécies de quatro grupos de vertebrados (anfíbios, répteis, aves e mamíferos), estão confinadas a 25 "hotspots" de biodiversidade que ocupam apenas 1,4% de toda a superfície da Terra. Entre estes "hotspots" está a bacia Mediterrânica, sendo parte significativa dessa área a metade sul da Península Ibérica. No Mediterrâneo, ocorrem 38 espécies de mamíferos, alguns endémicos com destaque para o lince Ibérico *Lynx pardinus*, o felino mais ameaçado do Mundo. Localizada na parte mais ocidental do Mediterrâneo, a Península Ibérica caracteriza-se por ter estações do ano bem marcadas, com verões quentes e secos, e invernos amenos e chuvosos. Em termos gerais, apresenta dois grandes planaltos no centro, dominados por agricultura extensiva de cereais, intercalados por manchas de vegetação esclerófita, constituídos na sua maioria por sistemas agro-florestais. No Norte e Noroeste da Península Ibérica, as florestas folhosas e mistas são a vegetação dominante, intercaladas por parcelas de pastagens, dando origem a uma diversificada comunidade de predadores e presas. O gradual desaparecimento da floresta original, substituída pelo aumento da área ocupada por matos e matagais, em combinação com a diversificação da paisagem ao longo do tempo, afectou não só a distribuição das espécies, mas também a sua diversidade genética. Durante a segunda metade do século XX, as áreas rurais da Península Ibérica sofreram uma emigração em massa para as cidades, com o abandono dos tradicionais usos agrícolas. A causa desse abandono foi a intensificação da agricultura em áreas planas, devido ao aumento da produtividade causada pela mecanização, uso de fertilizantes químicos e novos mecanismos de irrigação. Estas alterações levaram à redução da área de distribuição e efectivo populacional de numerosas espécies, algumas das quais se encontram actualmente distribuídas por populações fragmentadas e de pequena dimensão. Com uma ampla distribuição no passado o gato bravo Europeu *Felis silvestris* distribuía-se por todas as regiões florestadas da Europa, do Cáucaso e da Ásia. Actualmente ocorre em populações fragmentadas de Portugal, Espanha, França, Itália e Alemanha, Balcãs, Cárpagos, Cáucaso e Ásia, além de algumas populações insulares, na

Escócia e Sicília. Por causa do declínio em várias áreas da sua distribuição na Europa, o gato bravo encontra-se limitado às zonas montanhosas de baixa e média altitude, com pouca perturbação humana, onde se encontra associado a ambientes florestais (zona Atlântica) ou com coberto arbustivo (zona Mediterrânea). Nas zonas Mediterrâneas da Península, as áreas de mosaico constituídas por um misto de pastagens intercaladas com manchas de matos, para além da grande disponibilidade de presas (especialmente coelho bravo *Oryctolagus cuniculus*) também proporcionam abrigo e refúgio. Apesar dos micromamíferos serem a base da alimentação do gato bravo na maioria da sua área de distribuição, em ambientes mediterrâneos são substituídos como presa-base pelo coelho bravo. De entre os factores de ameaça, para além daqueles que são comuns a outras espécies de carnívoros, como a perda de habitat, diminuição das populações presa, e perseguição humana através do controlo de predadores associado à actividade cinegética, acresce aqueles que têm que ver com a expansão das populações de gato doméstico *Felis catus* em áreas naturais. De facto, a hibridação introgressiva com o gato doméstico é referida como a mais grave ameaça à conservação do gato bravo. No entanto, e ao contrário de outras regiões da Europa, as populações de gato bravo na Península Ibérica apresenta baixos níveis de hibridação, conferindo-lhes um alto valor de conservação. A presença de gatos domésticos em áreas naturais muitas vezes representa um problema de conservação, também, devido à competição e predação de espécies selvagens, para além das suas populações funcionarem como reservatórios para muitas doenças. Sabendo que o sucesso do gato doméstico em colonizar novas áreas está associado à expansão humana, torna-se importante avaliar a relação entre o gato doméstico e o homem em áreas naturais importantes para a conservação do gato bravo, confrontando essa análise com o que se conhece da ecologia espacial e trófica do gato doméstico em toda a sua área de distribuição. Deste modo, esta Tese focou os requisitos ecológicos do gato bravo e os constrangimentos relacionados com a presença humana e as suas actividades, em quatro capítulos (Caps. 3, 4, 5 e 6) correspondentes a quatro artigos científicos. No capítulo 3, foi feita a avaliação dos principais descritores da distribuição de gato bravo em Espanha (uma vez que não existe informação em Portugal para se poder fazer essa análise). Para tal, foram construídos modelos para a zona Atlântica, Mediterrânica e Espanha Continental usando um conjunto de descritores baseados na informação a uma escala mais fina. De onde resultou que, os descritores mais relevantes para o gato bravo à escala mais fina mantêm-se à grande escala (Espanha), e em diferentes biomas: Atlântico e Mediterrâneo. O número de espécies de micromamíferos e a diferença de altitude (este descritor está indirectamente associado à ocupação humana) são as variáveis mais importantes para descrever a distribuição de gato bravo na Peninsula Ibérica. Nesta perspectiva, a presença humana é uma questão-chave nas estratégias de conservação do gato bravo, o que justifica o investimento no conhecimento sobre as interacções entre os primeiros, os gatos domésticos e, consequentemente, os seres humanos. No capítulo 4, foi usada a informação da presença de gatos domésticos em 128 herdades da Zona Especial de Conservação de Moura-Barrancos para analisar os factores ambientais e humanos que afectam a presença e o número de gatos em cada herdade, com recurso à utilização de modelos lineares generalizados. Para além disso, foi feito o rádio seguimento de oito gatos domésticos (5 machos e 3 fêmeas), cuja informação relativa ao tamanho das suas deslocações diárias foi relacionado com um grupo de variáveis independentes (sexo, estação do ano, habitat, factores humanos) recorrendo à utilização de modelos generalizados mistos. Como resultados mais relevantes deste trabalho salienta-se a dependência do gato doméstico em relação à ocupação humana, estando a sua abundância associada aos recursos alimentares fornecidos pelas pessoas. Em relação à dimensão dos seus movimentos diários estes reflectem uma relação negativa com a presença de outros carnívoros, em particular com a raposa *Vulpes vulpes*. No capitulo 5, foi feita a análise ao conteúdo de 407 excrementos de *Felis sp* recolhidos em nove latrinas situadas no, e perto, do Sítio Moura-Barrancos, sendo as mesmas caracterizadas de acordo com a sua distância a casas. Com recurso a análise multivariada os excrementos foram agrupados com base na diferença dos itens que os constituem. Os restos da alimentação humana, associados aos excrementos recolhidos em latrinas perto de casas, e o consumo de coelho bravo, associado às latrinas afastadas de casas, deram o contributo mais significativo para a diferenciação dos grupos de excrementos. O mesmo tipo de abordagem e análise foi feita com recurso a uma revisão bibliográfica de estudos (n=57) sobre a ecologia trófica do gato doméstico no Mundo, que revelaram similitudes entre as zonas urbanas e naturais, em oposição às ilhas. Em ambas as análises, escala da área de estudo e mundial, ficou expressa a dependência do gato doméstico pelos recursos alimentares disponibilizados pelo homem. No capítulo 6, foram utilizados vinte cinco artigos publicados com informação sobre a prevalência de seis agentes virais (FcoV – Coronavírus Felino, FIV - Imunodeficiência Felina, FeLV – Leucémia Felina, FPV – Panleucopénia Felina, FCV - Calicivírus Felino e FHV – Herpesvírus Felino) nas populações de gato doméstico, gato bravo, gato do deserto *Felis Margarita* e o gato

leopardo de Iriomote *Felis irimotensis* em trinta e seis áreas distribuídas por cinco continentes. Para entender a influência do ambiente (ilhas, áreas naturais, rurais e urbanas), da espécie, e da prevalência de cada um dos seis agentes virais na ocorrência de cada um dos seis vírus, foram utilizados modelos lineares generalizados, em que a variável dependente corresponde à presença/ausência de cada tipo de vírus por amostra. O ambiente e a espécie estiverem presentes nos melhores modelos para FIV, FCoV e FPV, enquanto a prevalência de outros vírus foi significante para os modelos de FeLV, FCV e FHV. A prevalência de FIV aparece correlacionada com a sociabilidade da espécie, com incidência para as zonas rurais e urbanas. A ocorrência de FIV e FeLV, que necessitam do contacto para a propagação, afecta a ocorrência de outros vírus.

Finalmente, no capítulo 7 (discussão) faz-se um resumo das implicações para a conservação do gato bravo mediante vários cenários de ocupação humana em áreas naturais, de acordo com os impactos das suas actividades (agricultura, pecuária e cinegética) e presença /abundância de gatos domésticos.

Palavras-chave: gato doméstico *Felis catus*, gato bravo *Felis silvestris*, Modelação ecológica, Ecologia trófica, Ecologia espacial, Conservação, Leucemia felina (FeLV), Imunodeficiência felina (FIV), Impacto do Homem em áreas Naturais Mediterrânicas

***PART I** - INTRODUCTION*

Chapter 1

General Introduction

1. General Introduction

1.1 HUMAN PRESENCE AND NATURAL VALUES IN THE IBERIAN PENINSULA

Conservation of natural values is one of the major concerns in the modern world. It does not merely deal with the preservation of endangered species, but also with dramatic changes in ecosystems and landscapes (Deem *et al.* 2001). In recent years the concept of biodiversity is gaining popularity, with the ecosystems as the principal conservation targets, combining genetic diversity within populations, community structure (species richness and composition), and landscape heterogeneity. In this context, the Mediterranean Basin is one of the richest places in the world in terms of animal and plant species and was recognized as one of 34 biodiversity hotspots with almost all taxa exhibit high levels of diversity, at both the specific and subspecific levels (Mittermeier *et al*. 2004).

Contrasting with most taxa, the mammal fauna of the Mediterranean is largely derived from the Eurasian and African biogeographic zones and therefore exhibits relatively low levels of endemism, once most species tend to have very wide ranges (Temple and Cuttelod 2009). However, in the Mediterranean thirty eight carnivore species can be found, two of which endemic with the highlight towards the world's most endangered felid - the Iberian lynx *Lynx pardinus* (Temple and Cuttlelod 2009). The evolutionary mechanisms of such diversification have been related to conditions and opportunities ultimately generated by the environmental and historical peculiarities offered by the geographic location and configuration of the Mediterranean areas (e.g. insularity, peninsula-rich shoreline, climatic seasonality, habitat heterogeneity, etc) (Garcia-Barros *et al.* 2002). Located in the West of the Mediterranean region, the Iberian Peninsula is characterized by well-marked seasons, with dry and hot summers and wet and mild winters. Broadly, the region encompasses two plateaus in the centre, dominated by extensive cereal farming interspersed by patches of sclerophylous vegetation, agro-forestry systems and some formations of Mediterranean scrubland and forest. Dividing and surrounding these plateaus, several mountain systems are found, where large areas of Mediterranean scrublands and forests are preserved. In North and Northwest Atlantic areas of Iberia, the mixed and broad-leaved forests of deciduous species are the dominant vegetation, with imbibed patches of pastureland, allowing for a rich community of predators and prey in these landscapes. All these landscapes are the result of millenary transformations, product of the interaction between natural, antropic, and historical factors, as these ecosystems have experienced a long and intense history of human influence (Blondel 2006). Early hominids (eg, *Homo erectus*) migrated out of Africa, through Mediterranean lands, into Europe and Asia. Thereafter, modern humans colonized the Mediterranean Basin (Mannion 1999) *c*. 10 000 years ago. This was a turning point in cultural and environmental history. Humans domesticated certain plants and animals, such as wheat, barley, sheep, cattle and goats, and the ecosystems were subject to modification. Land management was in the context of a self-sufficient economy in which exchanges with the outside world were scarce (ovine transhumance and few agricultural and metal imports), leading to a highly humanised landscape with great ecological and cultural diversity (Crowling *et al.* 1996, García-Ruiz and Valero 1998). The progressive replacement of deciduous broad-leaved forests by evergreen sclerophyllous forests and scrubland, in combination with increasing habitat patchiness over time, affected both the distribution of populations and species and their genetic diversity (Blondel 2006).

1.1.1 Effects of landscape humanisation on wildlife

During the second half of the 20th century, the rural areas of the Iberian Peninsula suffered the massive emigration of people towards cities and the consequent abandonment of traditional agricultural uses, with the consequent decrease in livestock numbers (Lasanta *et al.* 2006, MacDonald *et al.* 2000). The cause of this marginalization was the intensification of agriculture in flat areas, due to an increased productivity caused by mechanisation, use of chemical fertilisers and irrigation mechanisms (Preiss *et al.* 1997, Macdonald *et al.* 2000). As a consequence, the agricultural production in mountainous areas was less competitive, with higher production costs because of smaller property sizes, higher complexity in property structure, higher difficulty in using machinery and lower soil fertility. At this point, conflicts between people and wildlife, particulary predators intensified because of competition for shared, limited resources due to landscape changes (Odden *et al.* 2002, Graham *et al.* 2005, Kaartinen *et al.* 2009). This includes deforestation, intensification of pastoral agriculture, loss of arable agriculture, disturbance of natural fire regimes, mining, urbanization, tourism, pollution and the introduction of alien species (Perevolotsky and Seligman 1998, Rodriguez and Delibes 2004, Oliveira *et al.* 2008). The actual landscape of Iberia is therefore the result of a subtle interaction between ecological and anthropogenic processes occurring at each successional stage, and many species opportunistically took advantage of the gradual changes induced by people in the landscape, becoming hostages of agricultural and grazing activities. At this stage and over time, people conducted small shrub removal to facilitate cattle grazing or accede to new exploitation areas, contributing to shape a highly diverse landscape. For species, such as the wolf *Canis lupus signatus*, some large ungulates are reduced due to hunting and habitat changes (Graham *et al.* 2005), but this was compensated with the abundance of live livestock and their carcasses (sheep, goats, Iberian pigs and cattle) and increased populations of wildboard *Sus scrofa* and roe deer *Capreolus capreolus* (Vos 2000). The traditional farming system, therefore, beyond promoting heterogeneity in the landscape, represented an important food resource for large predators and scavenging species (Vos 2000, Lasanta *et al.* 2006). European rabbits are native to the Iberian Peninsula (Monnerot *et al*. 1994), and from the late Pleistocene until Classic Antiquity, they were mostly restricted to the place of origin. Because of that, in Iberian Mediterranean ecosystems, rabbits are a keystone species for approximately 40 Iberian predators (Delibes-Mateos *et al*. 2008), including two highly endangered species: the Iberian lynx and the Spanish Imperial eagle *Aquila adalberti*.

1.1.1.1 Interactions between people and carnivores

The traditional agriculture practices promoted the existence of edges between different types of habitat, with particular relevance when it relates to pastures and high-cover vegetation. Many game species, like rabbits and red-legged partridges *Alectoris rufa*, use this mosaic landscape and are followed by a diversity of predators. Responding to these sustainable rural activities, several carnivore species became directly or indirectly linked to the landscape changes made by man that influenced their population trends. In fact, of the 15 species of existing Iberian carnivores (Temple and Cuttelod 2009), six (red fox *Vulpes vulpes*, common genet *Geneta geneta*, Egyptian mongoose *Herpestes icnheumon*, European badger *Males males*, stone marten *Martes foina* and weasel *Mustela nivalis*) managed to adapt to these changes, in some cases even taking advantage of the opportunities provided by human activities (Treves and Karanth 2003). Inversely, for other carnivore species, human activities had a strong negative impact on their populations, especially for those highly sensitive to disturbance, like brown bear *Ursus actus*, the Iberian Lynx and the European wildcat *Felis silvestris* (Rodriguez and Delibes 1990, Stahl and Artois 1994, Naves *et al.* 2003). Not all human activities, and/or its intensity, had equal effects on sensitive carnivores and if some clearly promoted population reductions (e.g persecution, shelter reduction) (Villafuerte *et al.* 1998, Rodriguez and Delibes 2004), other favoured some species expansion by providing additional food resources. Traditional agricultural practices, for instance, increased the landscape mosaics, promoting the diversity and abundance of prey, and generated new opportunities for carnivores (Lozano *et al.* 2003). Even some of the more sensitive medium-sized carnivores (such as Iberian lynx and wildcat) compensate the impact of human disturbance with prey resources offered in these traditional small-scale agricultural landscapes, such as wild rabbits (*Oryctolagus cuniculus*) and rodents. Recent studies reinforce the association between Mediterranean vegetation and carnivore's requirements, directly as shelter and indirectly through its relation with food resources availability (Moreno and Villafuerte 1995, Lozano *et al.* 2003, Fernández *et al.* 2006). For example, the wildcat and the Iberian lynx are known to use habitat ecotones as foraging areas due to their higher rabbit abundance (Lozano *et al.* 2003, Fernández *et al.* 2003, Fernández 2005, Fernández *et al.* 2006) or rodents in forest edges (Biró *et al.* 2004, Klar *et al.* 2008). However, extensive activities such as those related with the plantation of production forests (e.g. eucalyptus) or that of cereals, may have caused local extinctions or, at least, significant population size reductions (Andren 1994, Inchausti *et al.* 2005).

1.1.1.2 People - carnivore conflicts

Livestock predation by mammalian large carnivores is one of the most frequent sources of conflict between humans and wildlife throughout the world (Graham *et al.* 2005, Kaartinen *et al.* 2009). Perceived economic losses due to livestock depredation often lead to retaliatory responses by agro-pastoralists. For example, the main problem faced by Iberian wolf conservation is the high level of livestock depredation throughout the Iberian Peninsula (Petrucci-Fonseca 1990, Reig *et al.* 1985, Cuesta *et al.* 1991, Vos 2000). In the case of the brown bear, forestry and agricultural practices and intensive grazing led this carnivore to prey on livestock and, because of cattle abundance and foraging competition, the conflict increased (Clevenger *et al.* 1994, Naves *et al.* 2003). Roads and other infrastructures represent the new impacts on species, with great relevance in carnivore populations (Ferreras *et al.* 1992). In fact, there is a close relationship between the occurrence of preferred carnivore habitats and low human disturbance levels with the number of carnivore fatalities, and the vulnerability of some species to particular features of roads. As the road network extends across the landscape and traffic volumes intensify, researchers have documented that roads and traffic may affect some carnivore populations in three general ways: they may increase mortality, limit mobility including access to resources, and decrease the habitat amount and quality (e.g. Trombulak and Frissell 2000, Grilo *et al.* 2009). Because carnivores have small populations, tend to live at low densities and occupy large home-ranges, they are particularly vulnerable to roads expansion. Road mortality is a major threat for European wildcats (Klar *et al* 2009) and roads may also have a repulsive effect on wildcats influencing their habitat selection (Klar *et al.* 2008).

Several decades ago in the Iberian Peninsula, hunting was an important cultural and social activity, which was mostly non-commercial. The number of private areas devoted to big game hunting is increasing in Portugal and Spain. Management of these areas may thus neglect smaller hunting species (e.g., wild rabbits, Iberian hares *Lepus granatensis* and red legged partridges), and especially in the case of intensively exploited areas (Rodríguez and Delibes 2004, Lozano *et al.* 2007), where modern agriculture change the original landscape matrix to a homogeneous landscape of irrigated crop fields or promotes large scrubland extensions for big game. Nevertheless, in many areas the small game hunting still is an important activity, particularly in poor rural areas, and plays an important socio-economic role, generating income and providing employment and recreation, particularly in rural areas, leading to new problems for carnivore populations. Besides habitat modification and release of farm-reared game, the most common game management practices in small game areas include legal and illegal predator control (Virgós and Travaini 2005, Beja *et al.* 2008). This practice was more intensive in the past, with the state-sponsored campaigns to eliminate predators during late 1930s to late 1960s in Portugal and from 1950s to the mid 1970s in Spain (Villafuerte *et al.* 1998, Beja *et al.* 2008), resulting in drastic population declines and regional extinctions (Garzón 1974). The use of poison, snares and traps was widespread, resulting in the strong decline of some carnivore species (Rodriguez and Delibes 1990, Duarte and Vargas 2001, Álvares 2003). Although state-supported and legal killing ended in the mid-1970s, this activity continues, both through legal methods (shooting or trappings of Egyptian mongooses and red foxes in Portugal and red fox in Spain) and illegal and non-selective techniques. (Duarte and Vargas 2001, Virgós and Travaini 2005, Beja *et al.* 2008).

1.1.1.3 Role of domestic carnivores as reservoirs of infectious agents to wildlife

The expansion of agriculture and livestock production near or inside natural areas promotes contact between human populations and their livestock with wild carnivores (Macdonald *et al.* 2000). This close contact facilitates the spread of infectious agents and parasites to new hosts and environments, thus establishing new relationships between hosts and parasites, and new ecological niches in the chain of disease transmission (Altizer *et al.* 2003). The host-pathogen relationship has therefore suffered an imbalance caused mainly by environmental changes due to human activity (Daszak *et al.* 2000, Deem *et al.* 2001), frequently associated with the introduction of pathogens into wild populations and changes in the host's susceptibility to infections (Grenfell and Dobson 1995). Incidence itself depends on the relation between population size, density, and rate of contact for efficient disease transmission. An important factor is the social organisation of domestic hosts, that can influence parasite prevalence and population dynamics. For example, although the prevalence of FeLV increased with group size in domestic cats, FIV prevalence decreases with increasing group size (Fromont *et al.* 1997). FeLV transmission is enhanced in larger groups with non-aggressive contacts. FIV is transmitted by biting and occurrs almost exclusively among adult males that fought to maintain dominance hierarchies. Some epidemics originated in reservoir species caused important declines in endangered species. Examples of this are the canine distemper outbreak in the last remaining wild colony of black footed ferrets *Mustela nigripes* in 1985, that was transmitted by feral dogs and killed over 70% of the population, (Thorne and williams 1988), the canine distemper epidemic of 1994 in the Serengeti lion *Panthera leo* population, transmitted by domestic dogs from people populations adjacent to Massai Mara national park that caused mortality in approximately 30% of individuals (Roelke-Parker *et. al* 1996), and the decline of African wild dog population *Lycaon picus*, during a canine distemper epizootic in domestic dogs in the Serengeti (Alexander and Appel 1994). Beyond virus, bacterial infections are also important causes of mortality in wild carnivores. In felids, the infected carcasses (cape buffalo, deer, fallow deer or wild board) with bovine tuberculosis are considered to be the primary route of infection by *Mycobacterium bovis.* In some regions of Kruger National Park, up to 90% of the lions have been exposed to tuberculosis and the disease has spread to cheetahs and leopards presumably due to scavenging of buffalo carcasses (Keet *et al.* 1996). In southern Iberian Peninsula, there is a high prevalence of tuberculosis in wild ungulates and wild boards related to the high density of animals in hunting or protected areas (Gortázar *et al.* 2008). However, the potential role of wild animals in the maintenance and spread of *M. bovis* infection in domestic livestock is of particular importance in countries where eradication programs have substantially reduced the incidence of bovine tuberculosis but sporadic outbreaks still occur. The best-known examples are the European badger in the United Kingdom and the Republic of Ireland (Nolan and Wilesmith 1994, Gallager and Clifton-Hadley 2000) and the possum *Trichosurus vulpecula* in New Zealand (Coleman and Cooke 2001). Transmission of infectious agents from cattle to wildlife (and vice versa) may have several routes. First, the territories of wild and domesticated animals overlap because they share feeding grounds and drinking ponds, and crowding of animals at watering ponds, may facilitate close contact and thus may lead to increased transmission by the respiratory route (Aranaz *et al.* 1996, Cosivi *et al.* 1998). Second, the persistence in infected animals after death may be a source of infection for scavengers, providing the large dose of microorganisms needed for infection by the alimentary route (Aranaz *et al.* 1996).

1.2 THE EUROPEAN WILDCAT

1.2.1 Distribution and spatial ecology

With a wide distribution in the past, the European wildcat probably covered all the forested regions of Western, Central and Southern Europe, Caucasus and Asia (Stahl and Artois 1994). Extinction events in many areas of its range, which took place between the end of the eighties and the early twenties, led to the decline and fragmentation of the original population and justify the present high vulnerability faced by the species. Thus, the wildcat is now only present in less populated and relatively isolated areas (Portugal, Spain, France, Italy, Belgium, Germany), the Balkans, Carpathians, Caucasus and Asia, in addition to a few island populations in Scotland, Sicily, and probably Corsica (Stahl and Léger 1992). Because of the species decline in several areas of its European distribution, the wildcat is now limited to mountains of medium and low altitude with little human disturbance (Stahl and Artois 1994). The species habitat requirements are still not well known but several evidences link the wildcat to high understorey vegetation cover (Lozano *et al.* 2003, Mangas *et al.* 2008), although it also uses riparian galleries along the rivers and stream valleys, among other high-cover habitats, as well as rocky areas, (Klar *et al.* 2008, Monterroso *et al.* 2009). In the Mediterranean environments, at landscape level the species seems mainly associated to mosaics of scrubland and pastureland and at the microhabitat level to high shrub cover (Lozano *et al.* 2003). Like most felines wildcats are solitary and largely nocturnal resting in hidden thickets, dens or forests by day and patrolling and hunting at night

(Sandell 1989). Males and females come together solely to mate in mid-winter and for the rest of their lives the cats are alone (Sandell 1989). Although physical encounters are rare, wildcats regularly communicate with each other through scent, and territorial boundaries are marked with faeces or sprays (Stahl and Leger 1992). The wildcat home range size varies along its distribution range and even locally in the same region, with values ranging between 1.95 and 50.17 km^2 for males and 0.69 to 13.85 km^2 for females (Stahl and Artois 1994, Biró *et al.* 2004, Monterroso *et al.* 2009).

1.2.2 Food requirements

Despite consuming a large diversity of prey, from insects to rabbits, the stable prey species for the wildcat in most of its range are small mammals (Condé *et al.* 1972, Sládek 1973, Hewson 1983, Sarmento 1996, Moleón and Gil-Sánchez 2003, Carvalho and Gomes 2004). However, in Mediterranean-type environments, such as those found in the centre and south of the Iberian Peninsula, wild rabbits appear as the main prey for the wildcat (Ferreira 2003, Malo *et al.* 2004, Lozano *et al* 2006).

1.2.3 Main threats

In 1992, the European Council underlined two main threats that relate to the extinction risk for wildcat: habitat destruction, resulting in population fragmentation and isolation (Stahl and Artois 1994, Nowel and Jackson 1996, Lozano *et al.* 2003, Klar *et al* 2008), and hybridisation with domestic cat, which may threaten the status of wildcat as a genetically distinct species (Hubbard *et al.* 1992). The intense land-cover transformation of Central European landscapes has left forests as almost the only sheltering vegetation, decreasing the amount of available habitat for the wildcat and the distance to human-related land use types like settlements, single houses and roads (Klar *et al.* 2008). For example, Langley and Yalden (1977) stated that wildcat population decline in the British Isles was a consequence of deforestation, despite claiming that wildcat was not a typical forest species. This reduction of vegetation cover in large areas had consequences to wildcat populations that resulted in the disappearance of the species in several European areas and population isolation in the regions with more conservation value (Stahl and Artois 1994). This situation promotes the contact with domestic cats and, as consequence, introgressive hybridization occurs (Nowell and Jackson 1996). Extensive hybridization was described in Hungary and Scotland (Beaumont *et al.* 2001, Daniels *et al.* 2001, Pierpaoli *et al.* 2003), contrasting with the low levels of hybridization found in wildcat populations of Iberia, Germany and Italy (Randi and Ragni 1991, Lecis *et al.* 2006, Oliveira *et. al* 2008) that therefore have high conservation value and should be actively protected (Pierpaoli *et al.* 2003). Many encounters between wildcats and domestic cats are agonistic, with wildcats sometimes killing the latter and this could be a barrier to hybridization (Hubbard *et al*. 1992). Another important threat to wildcat is predator control activities, especially in small game hunting areas (Virgós and Travaini 2005).

1.3 THE DOMESTIC CAT

1.3.1 Domestication, range expansion and "feralization"

Domestic cats have accompanied humanity in all phases of exploration and colonization, and have been accidentally or deliberately introduced to many terrestrial ecosystems of the world (Kirkpatrick and Rauzon 1986, Fitzgerald and Turner 2000). In rural areas, the available food is less than in urban and suburban areas and cats depend greatly on people to feed them. Cat populations exhibit varying degrees of dependence on people. *Stray cats* - cats found in and around cities, towns and rural properties depending on some resources provide by people. *Feral cats* – cats that live and reproduce in the wild and survive by hunting or scavenging. People satisfy none of their needs intentionally. Recruitment to the stray and feral groups from the domestic population constantly occurs from the pet population. However, it is important to remember that all are domestic species *Felis catus* and that stray and feral cats are simply an introduction of that domestic species to the urban, suburban and natural environment.

1.3.2 Distribution and population numbers

Domestic cats, as dogs, are the carnivore species with a wider distribution range, occurring in all continents, and are currently one of the biggest problems and challenges of wildlife conservation (Macdonald and Thom 2001). In contrast with wildcats, domestic cats easily find food and shelter in human settlements (Barratt 1997, Germain *et al.* 2008). It is in populate cities, with an inexhaustible source of food that domestic cats reach unimaginable numbers; for example in the streets of the United States there are about 30 million ‘stray’-‘feral’ cats (Grimm 2009). There are however large variations in the relation between people and domestic cats, from urban to rural areas where they have total freedom of movement and probably less control by man. Human settlements can be quite diverse in their resource availability for domestic cats (Bradshaw *et al.* 1999): large villages and cities concentrate human structures and support higher human densities and consequently of cats, while rural villages and farms show a more dispersed pattern of occupation with lower rates of human population distributed over a larger area and less cats. Free-ranging domestic cats live close to human settlements, and their home-range size varies with human density and with food availability and distribution (Liberg and Sandell, 1988). At very low densities (less than 10 cats km^{-2}), as in low humanised natural-rural areas, the cats home ranges are larger and the intra-specific encounters are uncommon (Kerby and Mcdonald 1988); in high-density areas these environments favour the contact between domestic cats and other carnivore species. Size and stability of domestic cat populations depend therefore on a local combination of favourable environmental variables providing food and refuge that allow, on average, a positive population growth. Other important factors for domestic cats population growth are the interactions with other local species (mainly predation and competition), the dispersal abilities of the species between the population groups (Soberon and Peterson 2005, Soberon 2007) and disease dynamics.

1.3.3 Main impacts on wildlife

In many cases, domestic cats have adapted with great success to the ecosystem where they were introduced and have become dominant predators, as documented in many islands (Nogales and Medina 1996), where their impact is quite relevant particularly on breeding seabird colonies (Matias and Catry 2008) and endemic species (Rodriguez-Moreno *et al.* 2007). In addition to the predatory impact on other species, this successful invader acts as reservoir in the transmission of numerous diseases (Artois and Remond 1994, Courchamp *et al.* 1995, Fromont *et al.* 1997, Daniels *et al.* 1999). An extreme example of this impact is that of the Iberian lynx, the most endangered feline of the world, which transmission of feline leukemia virus (FeLV) may be explained by close contacts with domestic cats (Jessup *et al.* 1993, Millán *et al.* 2009). Another motif of concern, as already mentioned (see 1.3.3), is introgressive hybridization with wildcats. Much of the hybridization probably occurr in rural areas where the contact between the two species is more common. In fact, urban domestic cats consistently occupied smaller home rangers than rural domestic ones (Devillard *et al.* 2003), and wildcat males probably mated with female domestic cats.

1.4 AIMS AND STRUCTURE OF THE THESIS

The European wildcat is a threatened species in most Europe, particularly in the central-north areas where suitable management of forests was considered crucial for its long-term conservation (Stahl and Artois 1994). However, this recommendation may not apply at the global level due to the lack of studies that support this assumption in the Mediterranean region, where landscapes and the presence of people in natural areas are very different from those in central-north Europe. No study has specifically addressed the indirect effects of anthropogeneity (land use, hunting, cattle raising and "ferality" of domestic carnivores such as cats) on wildcat conservation. The conservation of wildcat in the constantly changing, human-altered landscapes of Southern Iberia requires therefore a clear understanding of the species limits and capabilities in these environments. People provide food and shelter for domestic cats and persecute carnivore species, like wildcat, during predator control campaigns. Domestic cat populations are formed by small family groups around farms or/and in near villages, where they can reach high densities, compared to nearby wildcat population densities. The domestic cat is then a host of, and the main vehicle for the transmission of disease into the wildcat, if the probability of contact between the two species is high. Once wildcat populations do not reach high densities of individuals the inverse transmission is less probable. The same occurs with hybridization between the two species, probably as result of domestic males moving into natural areas (dashed arrows in Figure 1 represents these scenarios).

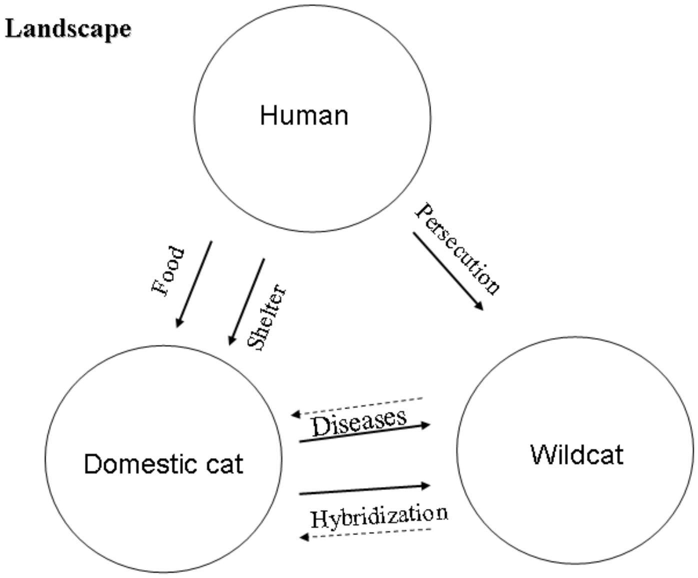

Figure 1.1. Wildcat, domestic cat and human interactions in natural-rural areas.

My thesis focused on wildcat ecological requirements and constrains imposed by human-related activities. In natural-rural areas the wildcat constrains are clearly linked to human actions and activities, which determine the size and distribution of domestic cat populations, which will have an impact on wildcat-domestic cat interactions (Figure 1). To achieve these general objectives, habitat evaluation and ranking schemes, as well as GIS-based modelling procedures, were combined with conventional and recent techniques in the study of wildlife ecology of carnivores (trapping, radio-tracking and photo-trapping). To analyse the data I applied statistical modelling and developed distribution (wildcat and domestic cat) and spatially explicit models (domestic cat) to understand how species interact with landscape, human presence, other carnivores and prey.

The thesis is organised in five Parts that include seven chapters, including four independent papers submitted for publication in peer-reviewed journals (Chapters 3 to 6) plus the general introduction (Chapter 1), the study area description (Chapter 2) and a summary of the main findings supporting the discussion of its implications to wildcat conservation (Chapter 7).

PART I - **INTRODUCTION**

In this part, was made a general introduction (chapter 1) about the topic and aims of this thesis. The study area (chapter 2) was also described in this section.

PART II – **LARGE SCALE REQUIREMENTS OF WILDCAT**

In this part, that includes chapter 3, the main wildcat requirements at large scale are analysed, including prey availability, vegetation cover and human disturbance, based on regional/local species knowledge:

Chapter 3 - Ferreira JP, Fernández N, Santos-Reis M and Revilla E (submitted). Large scale determinants of European wildcat distribution on Mediterranean and Atlantic areas. *Ecography*

PART III – **HUMAN INFLUENCE IN RURAL POPULATIONS OF DOMESTIC CATS.**

In this part the main goal was to understand the role of man in the maintenance of domestic cat populations in natural-rural areas. To achieve this we focus on domestic cat distribution, spatial ecology and trophic regime relatively to human presence and land use:

Chapter 4 - Ferreira JP, Leitão I, Santos-Reis and Revilla E (submitted). Cats without frontiers? Environmental and human controls of domestic cats in natural areas. *Jounal of Applied Ecology*.

Chapter 5 **-** Ferreira JP, Leitão I, Maldonado C, Santos-Reis S and Revilla E (final stage of preparation). Different cats, different places, different diets?

PART IV – **DOMESTIC CATS AS DISEASE RESERVOIRS TO WILDLIFE: THREATS TO WILDCATS IN NATURAL-RURAL AREAS**

In this chapter a review of feline-associated virus was performed at worldwide level and prevalence related with environment-type (natural, rural, urban or island), carnivore species and other virus occurrence at population level:

Chapter 6 **-** Ferreira JP, Maldonado C, Santos-Reis S and Revilla E (in prep). Virus Prevalence in cat populations: Implications for wildlife conservation, wildcats in particular.**.**

PART V **- DISCUSSION. LESSONS FOR WILDCAT CONSERVATION**

In this part, that include chapter 7, was made a general resume of the main findings of this thesis, as well proposals for wildcat conservation.

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Chapter 2

Study area

2. Study Area

This thesis was conducted at two spatial levels. One corresponds to a large-scale analysis, using the Iberian Peninsula as the study area (Paper I), and another at a finer-scale, concentrating in a natural area of south-eastern Portugal. (Papers II and III)

Iberian Peninsula

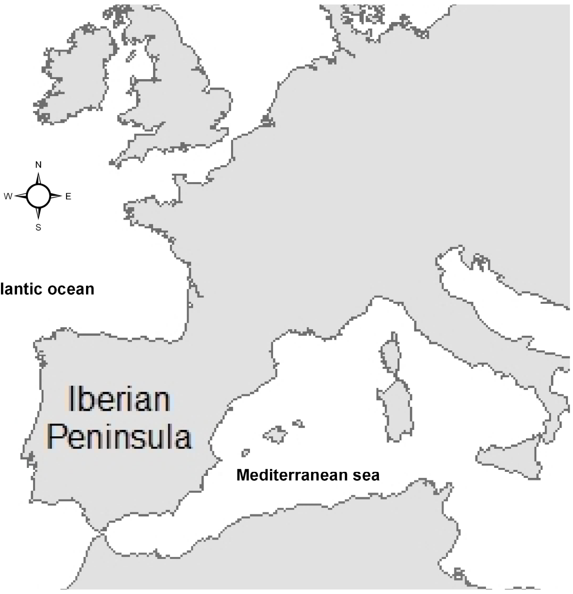

Figure 2.1 – Iberian Peninsula location

The Iberian Peninsula is located in the extreme southwest of Europe, being bordered by the Mediterranean Sea at the southeast and east, and by the Atlantic Ocean on the north, west and south-west (Figure 2.1). The mountain system of the Pyrenees, form the northeast edge of the peninsula, separating it from the rest of Europe. In spite of its relatively small size, the Iberian Peninsula is not a homogeneous area neither in terms of climate nor in terms of vegetation. Its geographical location, exposure to marine influences, and hydrographic and orographic peculiarities, together with an ancient human occupation, originated a diverse mosaic of landscapes variying from arid to alpine - type ecosystems (Castro *et al.* 1997). In fact, Iberian Peninsula encompasses two major biogeographic regions: the Mediterranean, occupying the majority of the territory, and the Atlantic, more localized in the northern and north-western edges (Figure 2.2).

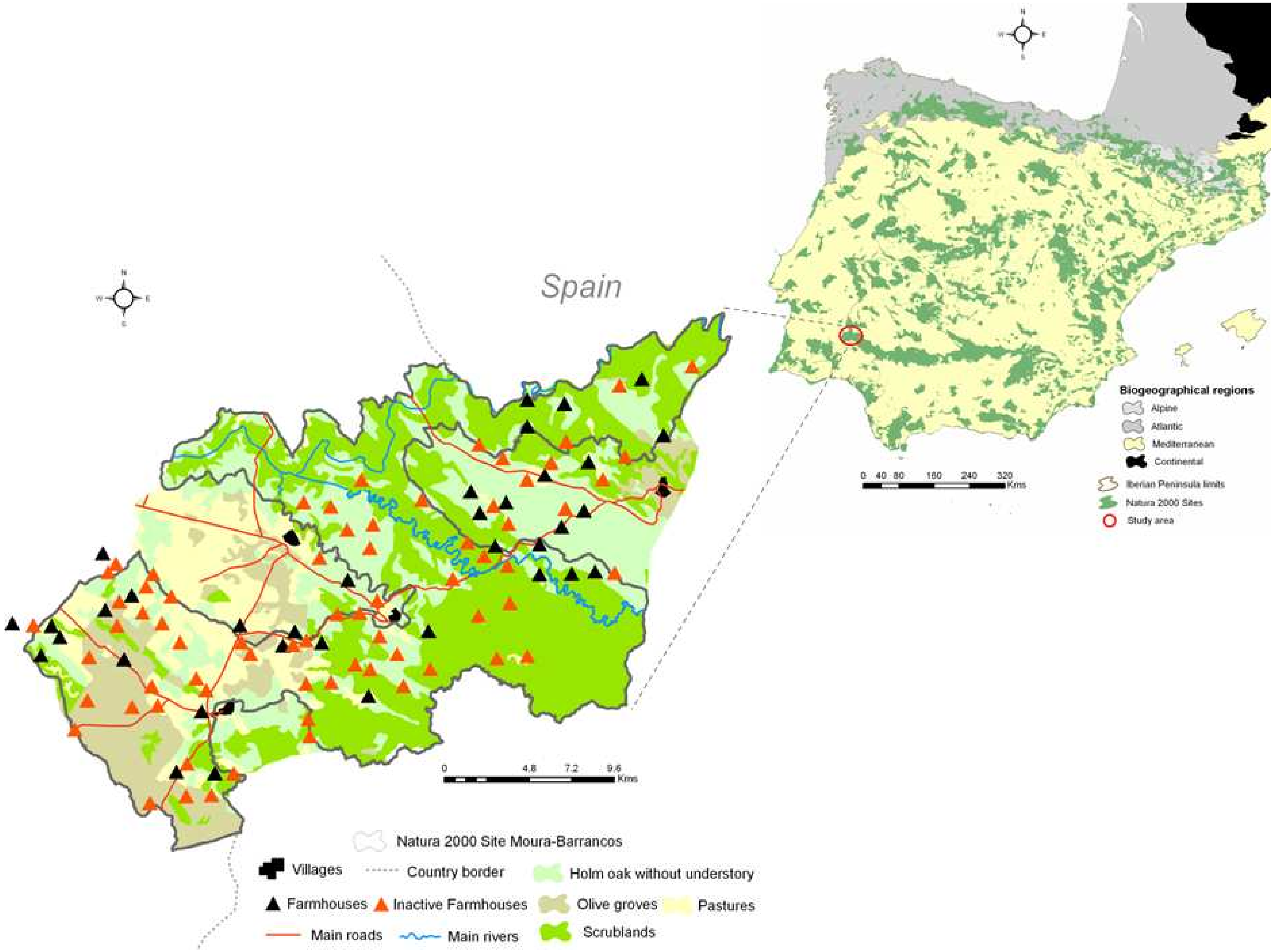

Figure 2.2**.** Study areas used at the two scales of analysis (Iberian Peninsula and Moura-Barrancos region, including the Natura 2000 Site).

Mediterranean area of Iberian Peninsula - The Mediterranean-type area, which occupies most of Iberian Peninsula, is characterized by well-marked seasons with dry, hot summers and wet, mild winters (Castro *et al.* 1997). Broadly, this area encompasses two plateaus in the centre, dominated by extensive cereal farming interspersed by sclerophylous vegetation, agro-forestry systems and some formations of Mediterranean scrubland and forest. Several mountain systems are found dividing and surrounding these plateaus, where large fragments of Mediterranean scrublands and forests are preserved. Forests are typically dominated by *Quercus* spp., mainly holm oak *Quercus rotundifolia*- or coniferous mainly pines *Pinus* spp (Castro *et al.* 1997). In these systems, wild rabbits are abundant and represent a key-prey for many carnivores and raptors, including the wildcat, (Malo *et al.* 2004, Moreno *et al.* 2004, Lozano *et al.* 2006). Other preys inhabiting the region include small mammals (13 species of insectivores and rodents, according to (Palomo *et al.* 2007). Besides wildcat, 10 other species of carnivores can be found in this region, including two top-predators: the Iberian wolf and the Iberian lynx.

Atlantic area of Iberian Peninsula - The Atlantic-type area occupies the mountainous areas of northern Spain and the north-western corner of Portugal, being relatively wet, with mild winters, warm summers and regular precipitation throughout the year. In contrast to the Mediterranean areas, natural landscapes are dominated by mixed and broad-leaved forests of deciduous species. The agriculture is mainly restricted to altitude pastures, occurring in patches that are imbibed in a diversified matrix of forested areas. Topography is rough, limiting human occupancy in many areas. The structure and diversity of the landscape promotes a rich community of small mammals (21 species of insectivores and rodents – Palomo *et al.* 2007), which is followed by an also diverse guild of carnivores (13 species – wildcats and wolves included). Wildcats in the Atlantic region feed mostly on small mammals, and are less dependent of the wild rabbit that lives at lower density and does not constitute a key- prey for predators.

Moura-Barrancos Natura 2000 Site

The finer-scale research was conducted in a natural area of Guadiana river basin, characterized by a Mediterranean landscape. Located in the southeast of the Portuguese-Spanish border, between 38º13’N - 37º57’N and 7º24’O - 6º59’O, the Moura-Barrancos Natura 2000 Site has an overall area of 43309 ha (10000 ha of an evolving agro-forestry system) dominated by holm oak woodlands, scrubland patches and rocky areas along the main valleys (Figure 3). Rivers, streams and creeks, with intermittent character, flow through scrubland areas of Mediterranean sclerophylous vegetation mixed with rocks. Besides other natural values, the Moura-barrancos site was created because it was one of the last strongholds of the Iberian lynx in Portugal (Pires and Fernandes 2003). Included in Mediterranean region, the site as a climate is characterized by mild winters and extremely hot summers (Carmel and Flather 2004), with average temperatures between <18 and >22°C, respectively (Chicharo *et al.* 2001). Annual precipitation levels vary between 400–600 mm (Chicharo *et al.* 2001). Land-use is dominated by an agro-silvo-pastoral system, characterized by the combination of open tree cover with cattle grazing underneath. The human population density is low (between 10.7 and 17.1 hab/km^2) concentrated in five small villages. Human settlements are concentrated in villages and several farmhouses can be found scattered throughout the landscape, although most currently abandoned. Human activity is restricted to cattle raising, agriculture and game hunting. These conditions offer a very suitable habitat for wildcats, due to the presence of well preserved vegetation patches and connectivity elements (e.g. river valleys) along the landscape. Because of human occupancy, that translates into the presence of stray-feral cats, the landscape context presents the ideal conditions for hybridization events with wildcats.

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PART II – *LARGE SCALE REQUIREMENTS OF WILDCAT*

Chapter 3

LARGE SCALE DETERMINANTS OF EUROPEAN WILDCAT.

DISTRIBUTION ON MEDITERRANEAN AND ATLANTIC AREAS

Paper I

LARGE SCALE DETERMINANTS OF EUROPEAN WILDCAT DISTRIBUTION ON MEDITERRANEAN AND ATLANTIC AREAS.

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Submitted to ***Ecography***

Large scale determinants of European wildcat distribution on Mediterranean and Atlantic areas.

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Abstract

Mechanistic and correlative models presents some problems, related with the scale of application, either because of the local/regional species linkage variables changed along biomes and global predictors have problems of interpretation. A set of models were run in two different biomes, Atlantic and Mediterranean, and in all Continental Spain using a group of descriptors based on fine scale information. The approach incorporated the advantages of correlative and mechanistic models to develop large-scale determinants that express the local individual requirements for wide ranging species occurring in distinct biomes. The best accuracy models revealed that the effects of the relevant descriptors at fine scale studies still appear at large scale, and in distinct biomes. To address this, was selected the European wildcat that has a large geographical range and some ecological tolerance, but suffering a constrained in its distribution range. The generalized idea that the European wildcat shows different requirements along its distribution range, and that differences are stronger across biomes, mainly between temperate forest and Mediterranean vegetation were not observed at large scale using information from fine-scale. The more important descriptors for wildcat presence, the number of small mammals and elevation range, in Atlantic and Mediterranean biomes still occur in Continental Spain. This is the first large scale modeling that analyses the main wildcat requirements, including prey availability, vegetation cover and human disturbance, based on regional/local species knowledge.

Key words: Large-scale modelling, mechanistic and correlative models, wildcat, *Felis silvestris*

3.1. INTRODUCTION

Understand the relationships between the distribution of species and environmental variability is one of the biggest issues in ecological research. The quantification of species-environment relationships not only represents the core of predictive geographical modelling in ecology: also, it has important applications in conservation practice (Guisan and Zimmermann 2000, Schadt *et al.* 2002). Species distributions respond to ecological processes operating simultaneously over a wide range of scales, from the spatial scale of individual movements to the scale of variability in species-level environmental constrains, e.g. climate (Karl *et al.* 2000, Fernández *et al.* 2003). Several authors have identified correlative models as more appropriate at global, regional and landscape scales than mechanistic models, which seem to be more accurate at finer spatial scales (Guisan and Zimmermann 2000, Johnson and Omland 2004, Helmuth *et al.* 2005). Nevertheless, the two model approaches presents some difficulties: the local scale of mechanistic models have problems in application across areas of distinct biomes and the correlative approaches, with large scale application, have problems of interpretation as a consequence of predictors changes across biomes. Many distribution models have been performed based on limiting factors at large spatial scales, like climatic variables (Thuiller *et al.* 2004), not incorporate individual selection requirements. Other models linkage the species distribution, at fine resolution, to variables that are assumed to be relevant to individuals presence (Engler *et al.* 2004, Pearce *et al.* 2001). Nevertheless, the significance of those variables in terms of individuals requirements (resources) or limited population (ie mortality factors) is not always clear.

Regional scale predictive modelling is being used increasingly to identify the factors conditioning species distribution and to provide primary information for regional conservation programs (Mladenoff *et al.* 1999, Schadt *et al.* 2002, Naves *et al.* 2003, Klar *et. al.* 2008). These models are generally developed to test various hypotheses, as to how environmental factors control the distribution of species and communities (Guisan and Zimmermann 2000). Some models correlate environmental abiotic variables influencing species ecology with presence/absence data distribution to identify suitable areas for the species (correlative approach), while others considered to underlie the observed correlations with environmental attributes (mechanist approach) by using a detailed knowledge of the target species (Robertson *et al.* 2003).

Moreover, the distribution of a species is an expression of the regulatory mechanisms acting at the individual level, regarding species as requiring a set of resources and conditions in order to function (Fernández *et al*. 2003). This approach explicitly takes into account functional relationships between species and essential resources and/or conditions in their environment rather than using general vegetation types as surrogates for species habitat (Vanreusel and Van Dyck, 2007).

With detailed knowledge at fine scale of target species, namely data on individual requirements (resources) and population limitations (e.g., mortality factors), we can formulate hypothesis that the species distribution reflects the regulatory mechanisms acting at the individual level. The distribution of these requirements can explain the distribution of a species, knowing that other factors, like historical and geographical, also play an important role in species distribution range (Gaston and Fuller 2009).

Thus the main goal is to test the hypothesis: Can species distribution at large scale to be model using fine scale information, knowing that species requirements vary across biomes?

For that was choosing a European Wildcat *Felis silvestris*, a species with a large geographic range, occurring in different biomes, but had suffered a contraction in their historical range.

The widespread decline of wildcat populations between late eighteenth and early twentieth centuries, results in the fragmentation and extinction of many populations of Western and Central Europe (Stahl and Leger 1992). Previous studies indicate that the species selects areas with low density of humans, settlements and transport infrastructures (Klar *et al.* 2008, Monterroso *et al.* 2009) (Szemeyhy 1992, Klar *et al.* 2008) (Klar *et al.* 2008, Santos *et al.* 2008, Monterroso *et al.* 2009) and dense vegetation cover (Lozano *et al.* 2003, Sarmento *et al.* 2006, Klar *et al.* 2008, Santos *et al.* 2008). Few studies exist in Mediterranean landscapes, where the species seems mainly associated to mosaics of scrubland and pastureland (Lozano *et al.* 2003). Regarding resource requirements, wildcats consume a large diversity of prey but small mammals are dominant in their diet in most areas of its distribution range (Condé *et al.* 1972, Sládek, 1973, Hewson 1983, Sarmento 1996, Moleón and Gil-Sánchez 2003, Carvalho and Gomes, 2004). However wild rabbits (*Oryctolagus cuniculus*) become the main prey in most of the Mediterranean environments, such as the central and southern regions of the Iberian Peninsula (Malo *et al.* 2004, Gil-Sanchez *et al.* 1999, Lozano *et al* 2006, Monterroso *et al.* 2009).

To accomplish the proposal goal was test if habitat factors operating at the level of individuals explain broad-scale distribution patterns of the wildcat. The fine scale variables that had great influence in species presence were included in more general descriptors that can be interpretive across the species distribution range. For this, was assessed the agreement between predictions from resource-based habitat selection models and the broad-scale species distribution in Spain. The fine scale descriptors directly linked to resource requirements by individuals were used to create broader descriptors: vegetation cover, food availability and human disturbance to evaluate the following hypotheses:

H_1) Prey diversity (small mammals and wild rabbits) is the single explanatory factor of wildcat distribution; H_2) Prey (small mammals and wild rabbits) and human disturbance interact; H_3) Prey (small mammals and wild rabbits) and vegetation cover providing refuge/shelter are the limiting factors, human disturbance being not important; H_4) All three factors are equally. These descriptors reflect the more important variables for wildcat in fine scale studies, with special relevance for prey availability that is reference for most autors (Lozano *et al.* 2006). The human disturbance seems to play as well an important role in wildcat distribution (Klar *et al.* 2008, Santos *et al.* 2008, Monterroso *et al.* 2009).

Moreover, we explored whether a single correlative-mechanistic hybrid model may predict the species distribution across distinct biomes. The wildcat explore different resources in the various biomes where occurs. In Atlantic areas the wildcat prey mainly rodents while in Mediterranean the main prey is the rabbits (Lozano *et al.* 2006). The habitats preferred by the species in Atlantic areas are mixed and broad leave forest selecting the sclerophylous vegetation in the Mediterranean (Klar *et al.* 2008, Lozano *et al.* 2003).

The evaluation of model performance in distinct biomes was necessary to evaluate the effects of the various descriptors, and related hypothesis, with wildcat distribution range. The challenge is to incorporate the advantages of both approaches to develop large-scale models that express the local requirements for wide-ranging species occurring in distinct biomes.

3.2 METHODS

3.2.1 *Study area*

The wildcat distribution in the Iberian Peninsula was study, which includes a representation of two biomes: Atlantic and Mediterranean. The Mediterranean region, which occupies most of the continental Spain, is characterized by well-marked seasons with dry, hot summers and wet, mild winters. Broadly, the region encompasses two plateaus in the centre, dominated by extensive cereal farming interspersed by sclerophylous vegetation, agro-forestry systems and some formations of Mediterranean scrubland and forest. Several Mountain systems are found dividing and surrounding these plateaus, where higher fragments of Mediterranean scrublands and forests are preserved. Forests are typically dominated by *Quercus* spp. manly holm oak *Quercus Rotundifolia*- or *Pinus* spp. Various studies have shown that wild rabbit are a key-prey for wildcats in these systems. Other preys include smaller mammals: 13 species of insectivorous and rodent mammals are present in the Mediterranean region. The Atlantic region occupies the mountainous areas of Northern Spain, being relatively wet, with mild winters, warm summers and more regular precipitation throughout the year. In contrast to Mediterranean areas, mixed and broad-leaved forests of deciduous species are dominant in natural areas. The agriculture are mainly pastures patches that imbibed in a diversify matrix with associated forest areas, to these landscape structure is associated a rich community of small mammals. Topography is rough limiting human occupancy in many areas. Wildcats in the Atlantic region mostly feed on small mammals, which constitute a richer community of 21 insectivorous and rodent species bellowing to groups usually predated by carnivores. Wild rabbits are at low population densities and do not constitute a significant prey in Atlantic ecosystems.

3.2.2 Wildcat distribution data

Distribution data of wildcat was compiled on the basis of a 10x10km UTM (Universal Transverse Mercator) grid. For Spain was used data from the National Atlas of Mammals CITA, which congregates data collected after 1980 originating from published information, museum collections, research centres, universities, besides a questionnaire addressed to technicians belonging to the Natural Areas Network (for more details see Palomo *et al.* 2007). Each evidence of presence was criteriously evaluated and excluded when considered not reliable. As for Portugal, a similar effort was made using data from Natural history Museum of Lisbon and Instituto de Conservação da Natureza e Biodiversidade (ICNB) data base. The sampling effort could result different is diluted once only 335 of the total 5327 squares for Spain include more than one evidence of wildcat presence.

3.2.3 Predictors of wildcat distribution

The four hypothesis established reflected the known information collected at fine scale, most according the individual selected resources, like habitat selection and diet of the wildcat studies. Base on these data we built tree main descriptors (food availability, Vegetation cover and human disturbance) that could surrogates the influence of fine scale variables in species distribution at large scale, with the ultimate goal to model wildcat distribution in different biomes (Atlantic and Mediterranean) and in all Continental Spain, using a common simple predictors derived from local level of information.

3.2.3.1 Food descriptors

Wildcats consume a large diversity of prey, but the stable prey species in most locations are the small mammals (Lozano *et al.* 2006). With the exceptions of Scotland and the most of the Mediterranean areas of Iberian Peninsula were the rabbit abundances are high, the rodents and insectivorous (except bats) mammals represents the stable prey for wildcat along is distribution range (Condé *et al.* 1972, Sládek 1973, Hewson 1983, Sarmento 1996, Moleón and Gil-Sánchez 2003, Carvalho and Gomes 2004, Malo *et al.* 2004). In fact, the marked Mediterranean Iberia the rabbits represents the stable prey for wildcat (Aymerich 1982, Sarmento 1996, Malo *et al.* 2004, Lozano *et. al.* 2006). The higher trophic diversity in wildcat diet in Mediterranean climates is closely associated with the wild rabbits consumption in opposite with lower trophic diversity in high latitudes were the rodents are more consumed (Lozano *et al.* 2006). These corroborates the idea that the rodents are more “staple-key-prey” than wild rabbits, witch is accomplish the consumption of more secondary preys. The availability of a higher number of species (mainly Microtinae) enables greater independence from fluctuating population of prey species. Suggesting that the number of small mammals species determines the presence of wildcat, with exception for Mediterranean areas were the diversity of rodents is lower and the rabbits abundance is very important for the feline occurrence, these two main prey were considered as represent the food resources.

The small mammals diversity (Sm_N) represents the number of species of Insectivorous and Rodents presents in each 10x10 km squares of Spain. The Insectivorous species belong to Soricomorpha Order, with the exception of Pyrenean desman *Galemys pyrenaicus* and *Neomys* Genus that were not incorporated, once they are not referred as wildcat prey. In Rodentia Order, and for similar reason, the Alpine marmot *Marmota marmota* was excluded. The rodents, insectivores and wild rabbit presence/absence data were obtained from the Spanish Atlas (Palomo *et al.* 2007). The rabbit (Rb_p) presence, once data of species abundances for all 10x10km of Spain has not available, is an important food descriptor in most areas of Mediterranean Spain.

3.2.3.2 Vegetation descriptors

Apparently the type of vegetation cover is not a determinant factor in the distribution of wildcat; this follows from the fact that the species be more generalist in the use of the habitat and not strictly forestry, according to fine scale studies (Stahl and Artois 1994, Lozano *et al.* 2003, Sarmento *et al.* 2006 Monterroso *et al.* 2009). Nevertheless, fine scale studies suggest that wildcat preferential use broad leave and mixed forest (Ragny 1981, Stahl and Artois 1994, McOrist and Kitchener 1994, Klar *et al.* 2008) in high latitudes, like Spanish Atlantic biomes and scrubland in Mediterranean regions (Lozano *et al.* 2003, Sarmento *et al.* 2006, Monterroso *et al.* 2009). So, we aggregated the vegetation types selected at fine scale by wildcat individuals in the two differentiate biomes; Forest types from Atlantic and scrubland in Mediterranean, in one major vegetation descriptor representing the vegetation cover as explanatory factor of wildcat distribution.

To test the hypothesis of the relevance of habitat quality in wildcat distribution was included a set of land use/land cover variables derived from the Corine Land Cover 2000 map, representing a more fine-scale (scale 1:100 000. 150 m positional accuracy and with 25 ha minimum mapping unit) (EEA 2005) than the UTM 10x10 Km square. According to the wildcat favourable vegetation types the original eighteen Corine Land Cover classes were reclassified in Vegetation Cover (Veg_cover) integrates 5 classes: including Broad-leaved Forest, Coniferous Forest, Mixed Forest, Transitional Woodland/Shrub and Sclerophylous Vegetation (Table 3.1).

3.2.3.3 Human disturbance predictors

Because of the decline of their populations in several areas of its European distribution, the wildcat is limited to mountainous areas of medium and low altitude, undisturbed by human activities (Stahl and Artois 1994, Heltai *et al.* 2006). The importance of elevation range as a positive predictor of threatened species richness globally may result from influence of topography on the occurrence of species at fine scale (Jetz *et al.* 2004, Monterroso *et al.* 2009) and their inherent associated vulnerability (Manne *et al.* 1999). Alternatively, in some cases this occurrence may result from range contractions from human-impacted lower elevation areas leaving remnant populations in more mountainous regions. Nevertheless, the number and distribution of households and human settlements can differ from people density. These human structures changed in shape distribution: large villages and cities concentred the human settlements and highest values of people density, or a dispersal occupation with lower rates of human population but distributed by a largest area represents different disturbance scenarios for the wildcat. In both cases the elevation range represents areas with lowest people densities and human settlements. Other human impacts are related with habitat destruction (Santos *et al.* 2008, Klar *et al.* 2008, Monterroso *et al.* 2009) and road kill/disturbance (Vogt 1985, Klar *et al.* 2008, Klar *et al.* 2009). Fine-scale monitoring showed that wildcats were aware of roads as an obstacle and only a limited number of major roads can be tolerated within a wildcat home range (Klar *et al.* 2009).

As human disturbance descriptors we used, besides the land cover of NNA classes, the roads length (Road_l) and the elevation Range (Elev_range) that indirectly reflects the human presence. The Non Natural Areas (NNA) integrates the 13 sub-classes of the Artificial Areas Class of Corine Land Cover 2000. Roads length, correspond to the length of highways and main roads in each 10x10 km square at the 1/10000 scale.

Elevation range was obtained from the difference between maximum and minimum of altitude in each 10x10Km square, using raster data with a geographic accuracy of 1000m (Table 3.1). The data with land use, roads and elevation maps were clipped to 10x10 km UTM grid of Spain. ArcView 3.2, and its extensions Spatial Analyst, Patch Analyst and 3D Analyst, were the GIS software applications used.

Table 3.1**.** Denomination and description of the variables used in wildcat logistic regression models.

Variable group	**code**	**Data type/source**	**Data type**	**Data Range (min-max)**			**Units**
				Spain	Mediterranean	Atlantic	
Food availability	*Sm_N*	Small mammals diversity (1)	Discret	(0 - 21)	(0 - 20)	(0 - 21)	
	Rb_p	Rabbit Presence (1)	(0,1)	(0 -1)	(0 -1)	(0 -1)	
Vegetation cover	*Veg_cover*	Coniferous forest (km^2) (2)	Continuous	(0 - 1,66)	(0 - 1,66)	(0 - 0,194)	km^2
		Mixed forest (km^2) (2)	Continuous	(0 - 1,08)	(0 - 0,214)	(0 - 1,08)	km^2
		Broad leaved forest (km^2) (2)	Continuous	(0 - 1,57)	(0 - 1,57)	(0 - 0,93)	km^2
		Sclerophylous vegetation (km^2) (2)	Continuous	(0 - 0,72)	(0 - 0,72)	(0 - 0,074)	km^2
		Transitional woodland/shrub (km^2) (2)	Continuous	(0- 0,25)	(0 – 0,25)	(0 – 0,112)	km^2
Human disturbance	*NNA*	Non natural areas (km^2) (2)	Continuous	0 - 8,25)	(0 - 8,25)	(0 - 0,22)	km^2
	Road_l	Roads length (Km) (3)	Continuous	(0 - 696)	(0 - 696)	(0 - 620)	km
	Elev_Range	Elevation Range (m) (4)	Continuous	(0 - 2216)	(0 - 2216)	(0 – 2067)	m

Table 3.2. **Relevant references and information used to support wildcat occurrence hypotheses.**

Hypotheses	Authors / Date	Scale	Geographic Region	Altitude (m)	Main habitat	Study aims	Results
H1. Food availability	1) Aymerich 1982 2) Carvalho and Gomes 2004 3) Sarmento 1996 4) Molen and Gil-Sánchez 2003 5) Gil-Sánchez 1999 6) Malo et al. 2004 7) Stahl and Leger 1992 8) Lozano et al. 2006	1) Central Spain 2) PGNP Portugal (4606 ha) 3) SMNR Portugal (200km2) 4) Sierra Nevada Spain 5) PNSH Spain (3500 ha) 6) Central Spain (2916km2) 7) Europe 8) Continental scale	Mediterranean Atlantic Mediterranean Mediterranean Mediterranean Mediterranean Medt. and atlant. Medt. and atlant.	800-1400 700-2300 650-750 700 -1700	1) Sclerophylous vegetation 2) Low scrubland. Forest mosaic 3) Scrubland and Forest 4) Forest 4) Olive groves and sclerophylous vegetation 5) Pyrenean oak forest and Sclerophylous vegetation 6) Low scrubland. Forest mosaic	1) Diet 2) Diet 3) Diet 4) Diet 5) Diet 6) Diet 7) Ecological 8) ALL 9) Diet	1) Small mammals and rabbits 2) Small mammals and rabbits 3) Small mammals 4) Small mammals 5) Small mammals and rabbits 6) Facultative specialization Small mammals / rabbits 7) Small mammals 8) Facultative specialization Small mammals / rabbits
H2. Food + human disturbance	1) to 8) plus 9) Mermod and Liberek 2002 10) Monterroso et al. 2009	Jura Mountains Suisse	- Mediterranean	500-1300	Pastures and forest	Snow cover and wildcat movements Spatial ecology	9) Selection high altitude with few human settlements and prey availability 10) Human disturbance and rabbit abundance
H3. Food + vegetation cover	1) to 10) plus 11) Lozano et al. 2007 12) Lozano et al. 2003	10) MonfragueNP Spain (17 852 ha) 11) Central Spain (2916km2)	Mediterranean Mediterranean	250-470 500-2000	Sclerophylous vegetation Sclerophylous vegetation	10) Large game species/rabbits populations 11) Habitat selection	11) Lack of prey associated to large game species density 12) Importance of scrub–pastureland mosaics
H4. Food + human disturbance + vegetation cover	1) to 12) plus 13) Klar et al. 2008 14) Biró et al. 2004 15) Sarmento et al. 2006 16) Santos et al. 2008	12) Germany 13) Hungary 14) SMNR Portugal (200km2) 15) Guadiana river (Portugal)	- - Mediterranean Mediterranean		12) Lowland Forest 13) pine forest. oak forest 14) Scrubland and forest 15) Pastures. Sclerophylous vegetation	12) Habitat models 13) Wildcat/domestic cat home ranges 14) space and habitat selection 15) Large Dam impacts. After and before implementation	13) Wildcat Habitat affected by human disturbance and habitat loss 14) Habitat loss and fragmentation. competition with domestic cats 15) Broad leave and mixed forest. low human density. prey availability 16) Wildcat highly vulnerable to large dam construction (habitat loss. human disturbance. prey availability)

Following hypotheses:

H_1) Prey diversity (small mammals and wild rabbits) is the single explanatory factor of wildcat distribution; H_2) Prey (small mammals and wild rabbits) and human disturbance interact; H_3) Prey (small mammals and wild rabbits) and vegetation cover providing refuge/shelter are the limiting factors, human disturbance being not important; H_4) All three factors are equally (Figure 3.1 and Table 3.2).

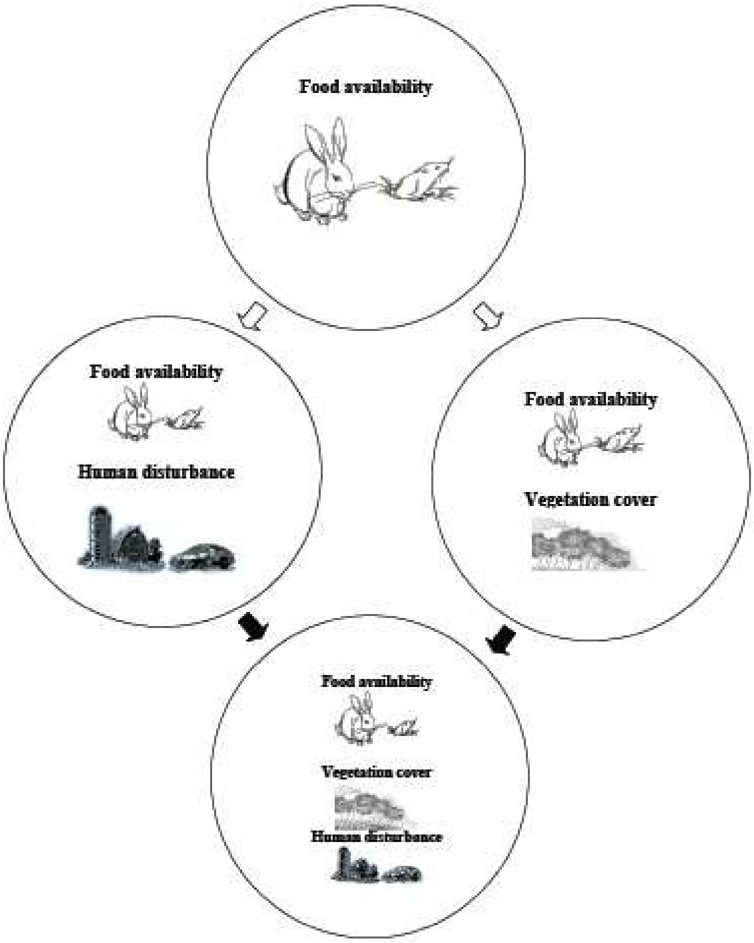

Figure 3.1**.** Model designed based in four hypotheses in order two 3 main factors: food availability, Vegetation cover and Human disturbance. Considering the Food availability fundamental to wildcat presence and are present in the 4 hypotheses

3.2.4 Data analyses

Binary logistic regression was performed using the four hypotheses based on food, habitat and human disturbance descriptors to model of wildcat occurrence in Continental Spain and in the Atlantic and Mediterranean biomes. To accomplish that was used a training data sets that corresponded to a random subsets (n=2559, 1280 presences and 1279 absences) (n=2052, 1025 Presences and 1027 absences) and (n=507, 255 Presences and 252 absences). The variables strongly correlate were excluded from the analysis, when $r_s > 0.7$, considering in the selection their correlation with wildcat presence and biological meaning. The Regression modelling performed using SAS (SAS Institute Inc. 2004) generate 22 models: 6 for Continental Spain and 6 and 10 for respectively Mediterranean and Atlantic Spain biomes (Table 3.3). Candidate models were then confronted according to the Akaike Information Criterion (AIC) to assess model fit to the distribution data (Burnham and Anderson, 2002). Briefly, under this approach each hypothesis is represented by one or several competing statistical models which are formulated a priori based on biological knowledge, and AIC provides an objective tool to rank these models and thus quantify the evidence for each hypothesis (Burnham and Anderson 2002).

The predictive accuracy of the most parsimonious models was evaluated from Receiver Operating Characteristic (ROC) plots after plotting sensitivity values (true positive fraction) on the *y*-axis against their equivalent (1-specificity) values (false positive fraction) for different thresholds in *x* (Liu *et al.* 2005). The AUC measure from ROC curve is considered useful for comparing the performance of wildcat presence-absence model in a threshold-independent fashion (Fielding and Bell 1997). The ROC procedure offers a way of identifying an optimum probability threshold by simply reading the point on the curve at witch the sum of sensitivity and specificity is maximized (Zweig and Campbell 1993). For this, was examined the model sensitivity (i.e., the probability of wildcat presence) and the specificity (probability of detecting only absences).

3.3. RESULTS

Models results (Table 3.4) for Continental Spain and for Mediterranean and Atlantic Spain biomes revealed that the number of small mammal species and elevation range had the highest and positive contribution for wildcat presence in Spain. In Atlantic biome elevation range was the most important predictor of wildcat presence. The importance of rabbit differed between Atlantic and Mediterranean biomes: it was positively correlated with wildcat presence in Spain and in the Mediterranean biome but not in the Atlantic when considered separately. Vegetation cover had positive (but less important) contribution for wildcat presence in the Continental Spain and in both biomes. Mediterranean and Atlantic. Non natural areas contributed negatively in Spain and Mediterranean areas but were positive in the Atlantic biome. Road length also contributed negatively to wildcat presence in Spain but not in Atlantic areas (Figure 3.3 and Table 3.4). The application of the bests models for Continental Spain and Atlantic and Mediterranean biomes included tree common variables: Sm_N, Elev_range and Veg_cover (Table 3.4). In fact, the crosstab (Table 3.5) of best models accuracy in Continental Spain and the Mediterranean and Atlantic biomes show very similar performances.

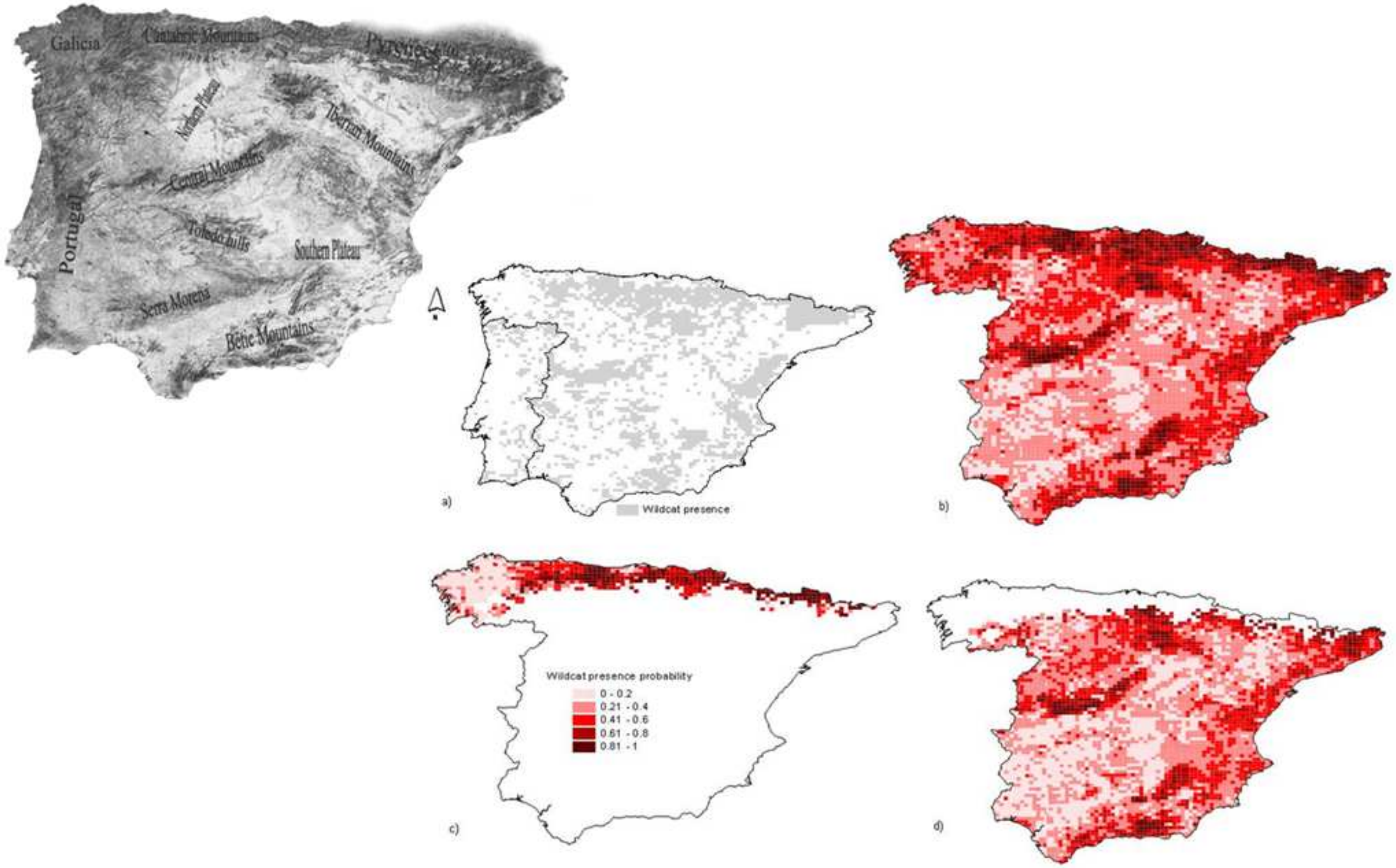

Figure 3.2**.** Wildcat data distribution in the Iberian Peninsula (10x10km UTM squares) a). For Spain data was compiled from Atlas and Libro Rojo de los Mamiferos Terrestres de España (Palomo *et al.* 2007) and for Portugal in the frame of the Livro Vermelho dos Vertebrados de Portugal (Cabral *et al.* 2005). b) Wildcat presence probability at each UTM 10x10 km square in Iberia Peninsula, c) Atlantic and d) Mediterranean Spain, as result of logistic regression best models (H_{42}, MH_{41}, AH_{43}), respectively.

Table 3.3**.** Summary of models for predicting wildcat distribution in four groups corresponding to different hypotheses, based on a mechanistic approach, of potential factors affecting wildcat occurrence. Each hypothesis is represented by an alternative statistical model, and Akaike Information Criterion (AIC) provides an objective tool to rank the models. A total of 22 models were run. The best models present lowest AIC value (Burnham and Anderson, 2002).

Models	***Hip.***	***Predicted Probabilities***		Deviance	***AIC***	***Weighted AIC***
		% conc.	***%disc.***			
Spain						
Null Model						
Intercept only	H0			3548.14	3549.52	0.00
Food availability	H1					
Sm_N+ Rb_p	H11	68.0	28.5	3216.30	3222.85	0.00
Food availability and human disturbance	H2					
Sm_N + Rb_p + NNA + Road_l + Elev_range	H21	74.9	24.9	3011.62	3023.09	0.109
Sm_N + Rb_p + Road_l + Elev_range	H22	74.9	24.9	3012.44	3021.91	0.197
Food availability and vegetation cover	H3					
Sm_N + Rb_p + Veg_cover	H31	70.6	29.0	3189.73	3118.37	0.00
Food availability. human disturbance and vegetation cover	H4					
Sm_N + Rb_p + NNA + Road_l + Elev_range + Veg_cover	H41	75.0	24.8	3008.00	3021.53	0239
Sm_N + Rb_p + Road_l + Elev_range + Veg_cover	H42	75.0	24.8	3008.70	3020.25	0.453
Mediterranean Spain						
Null Model						
Intercept only	MH01			2843.90	2846.67	0.00
Food availability	MH1					
Sm_N + Rb_p	MH11	67.4	28.6	2588.92	2595.07	0.00
Food availability and human disturbance	MH2					
Sm_N + Rb_p + NNA + Road_l + Elev_range	MH21	74.1	25.6	2437.64	2454.24	0.08
Sm_N + Rb_p + Road_l + Elev_range	MH22	74.1	25.7	2443.64	2454.96	0.05
Food availability and vegetation cover	MH3					
Sm_N + Rb_p + Veg_cover	MH31	71.0	28.5	2540.20	2563.75	0.00
Food availability. human disturbance and vegetation cover	MH4					
Sm_N + Rb_p + NNA + Road_l + Elev_range + Veg_cover	MH41	74.5	25.3	2426.27	2450.98	0.41
Sm_N + Rb_p + Road_l + Elev_range + Veg_cover	MH42	74.4	25.3	2432.12	2451.57	0.30
Atlantic Spain						
Null Model						
Intercept only	AHO			700.2	704.83	0.00
Food availability	AH1					
Sm_N + Rb_p	AH11	74.6	23.0	590.33	597.63	0.00
Food availability and human disturbance	AH2					
Sm_N + Rb_p + NNA + Road_l + Elev_range	AH21	85.3	14.6	481.84	496.76	0.01
Sm_N + Rb_p + Road_l + Elev_range	AH22	85.2	14.7	484.97	495.86	0.02
Sm_N + Rb_p + Elev_range	AH23	85.2	14.7	485.84	494.87	0.04
Sm_N + Elev_range	AH24	85.0	14.9	487.23	494.33	0.05
Food availability and vegetation cover	AH3					
Sm_N + Rb_p + Veg_cover	AH31	75.9	23.6	587.64	597.05	0.00
Food availability. human disturbance and vegetation cover	AH4					
Sm_N + Rb_p + NNA + Road_l + Elev_range + Veg_cover	AH41	85.7	14.2	477.60	492.72	0.11
Sm_N + NNA + Road_l + Elev_range + Veg_cover	AH42	85.6	14.3	478.00	491.18	0.23
Sm_N + NNA + Elev_range + Veg_cover	AH43	85.6	14.3	479.00	490.33	0.36
Sm_N + Elev_range + Veg_cover	AH44	85.4	14.5	482.00	491.87	0.17

Table 3.4**.** Variables included in best models and their coefficients (β), standard errors (SE), Wald test values and significance (*P*). Variable codes as in Table 2.

Models/variables	**Estimate**	**S.E.**	**Standardize Estimate**	**Order Std. Est.**	**Wald**	***P***
Spain Model						
(intercept)	- 2.0018	0.1194			281.326	<.0001
Sm_N	0.1342	0.0103	0.3517	1	169.863	<.0001
Rb_p	0.6979	0.0969	0.1841	3	51.869	<.0001
Road_l	- 0.0012	0.0005	- 0.0592	4	5.692	0.0170
Veg_cover	0.0007	0.0004	0.0443	5	2.210	0.1371
Elev_range	0.0016	0.0001	0.3497	2	149.387	<.0001
Mediterranean Spain Model						
(intercept)	- 1.8493	0.1289			250.885	<.0001
Sm_N	0.1327	0.0128	0.3161	1	106.683	<.0001
Rb_p	0.7042	0.1136	0.1782	3	38.424	<.0001
NNA	- 0.0001	0.0001	- 0.0430	5	2.493	0.1143
Road_l	- 0.0011	0.0006	- 0.0537	6	3.812	0.0509
Veg_cover	1.2901	0.0006	0.0878	4	4.526	0.0334
Elev_range	0.0016	0.0002	0.2988	2	81.966	<.0001
Atlantic Spain Model						
(intercept)	- 3.8576	0.3621			113.516	<.0001
Sm_N	0.1815	0.0220	0.5796	2	67.900	<.0001
NNA	0.0103	0.0069	0.1509	3	2.232	0.1352
Veg_cover	0.0017	0.0008	0.1275	4	4.116	0.0425
Elev_range	0.0028	0.0003	0.7056	1	81.052	<.0001

Table 3.5**.** Crosstab of models accuracy between Spain i), Mediterranean ii) and Atlantic iii) areas.

Models	**Spain**			**Mediterranean**			**Atlantic**		
	Predicted Probabilities		AUC	Predicted Probabilities		AUC	Predicted Probabilities		AUC
	% Concord.	% Discord.		% Concord.	% Discord.		% Concord.	% Discord.	
H42-Spain	75.9	23.8	0.761	75.2	24.5	0.746	85.7	14.2	0.857
MH 41-Mediterranean	76.0	23.9	0.762	74.3	24.5	0.746	85.9	13.9	0.853
AH43-Atlantic	75.5	24.3	0.770	74.8	24.9	0.742	85.6	14.3	0.855

3.3.1 Model evaluation

The best models for Continental Spain and Mediterranean and Atlantic Biomes (H$_{42\text{ – Spain}}$; MH$_{41\text{ – Mediterranean}}$; MH$_{43\text{ – Atlantic}}$) were used in classification prognoses (Table 3.5). AUC scores were 0.751 ± 0.009 for Spain, 0.746 ± 0.011 for the Mediterranean biome and 0.857 ± 0.016 for the Atlantic biome, indicating a good predictive power for Atlantic and fair for Continental Spain and Mediterranean biome (Swets 1988) (Figure

3.4). The *P* value that maximized correct prognoses for Continental Spain (68.5%) was 0.46 that correctly classifies presences (75.9%) and absences (61.2%). The same *P* value maximized the correct prognoses for Mediterranean biome (67.7%) that classifies 75.8% of presences and 59.6% of absences. The *P* value for the best model for Atlantic biome was 0.5 with 77.9% of correct prognoses (79% presences and 76.9% of absences) (Figure 3.4). The classifications accuracy of the most parsimonious models for Continental Spain and Mediterranean and Atlantic biomes were then tested in independent data samples (i.e. n=1085, 542 Presences and 543 absences – Spain; n=982, 491 Presences and 491 absences – Mediterranean; n=507, 252 Presences and 255 absences – Atlantic) reserved for model evaluation purposes. The classification on these new samples, to corresponding cut off's, did not differ significantly from the training data sets and prognoses 69.8% of correct classifications for Continental Spain, 74.1% for Mediterranean and 83.9% for Atlantic biomes. Respectively, the Spearman correlation between prediction and wildcat presences correlated significantly, $r_s = 0.429$, 0.415 and 0.552, $P = 0.01$ (Figure 3.4).

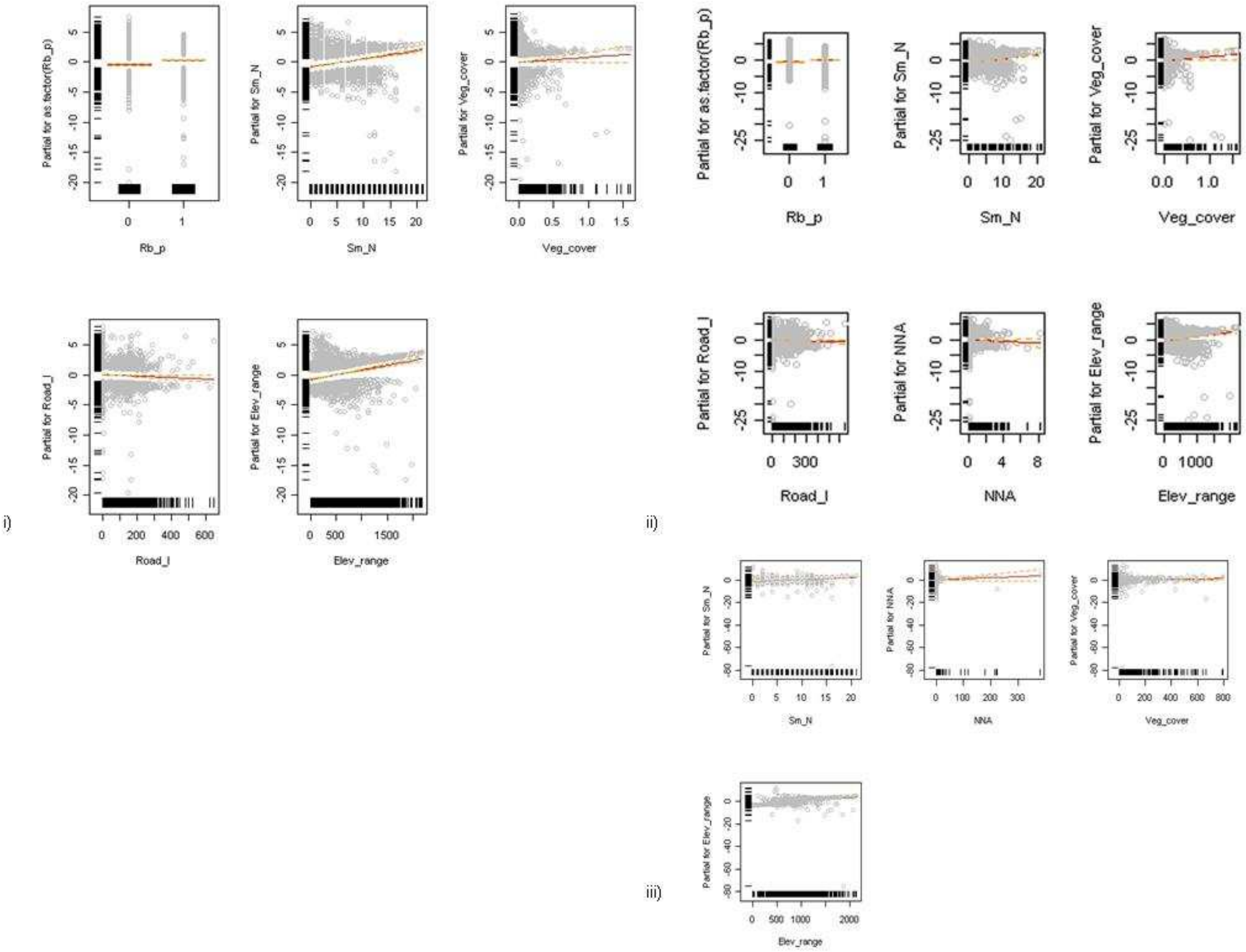

Figure 3.3**.** Partial contribution of individual best models variables to predict wildcat presence in Spain i), Mediterranean ii) and Atlantic iii). The most important variables related to wildcat occurrence were the Number of Small mammals species (Sm_N) and Elevation range (Elev_range) with a positive contribution for best models (H_{42}, MH_{41}, AH_{43}), respectively.

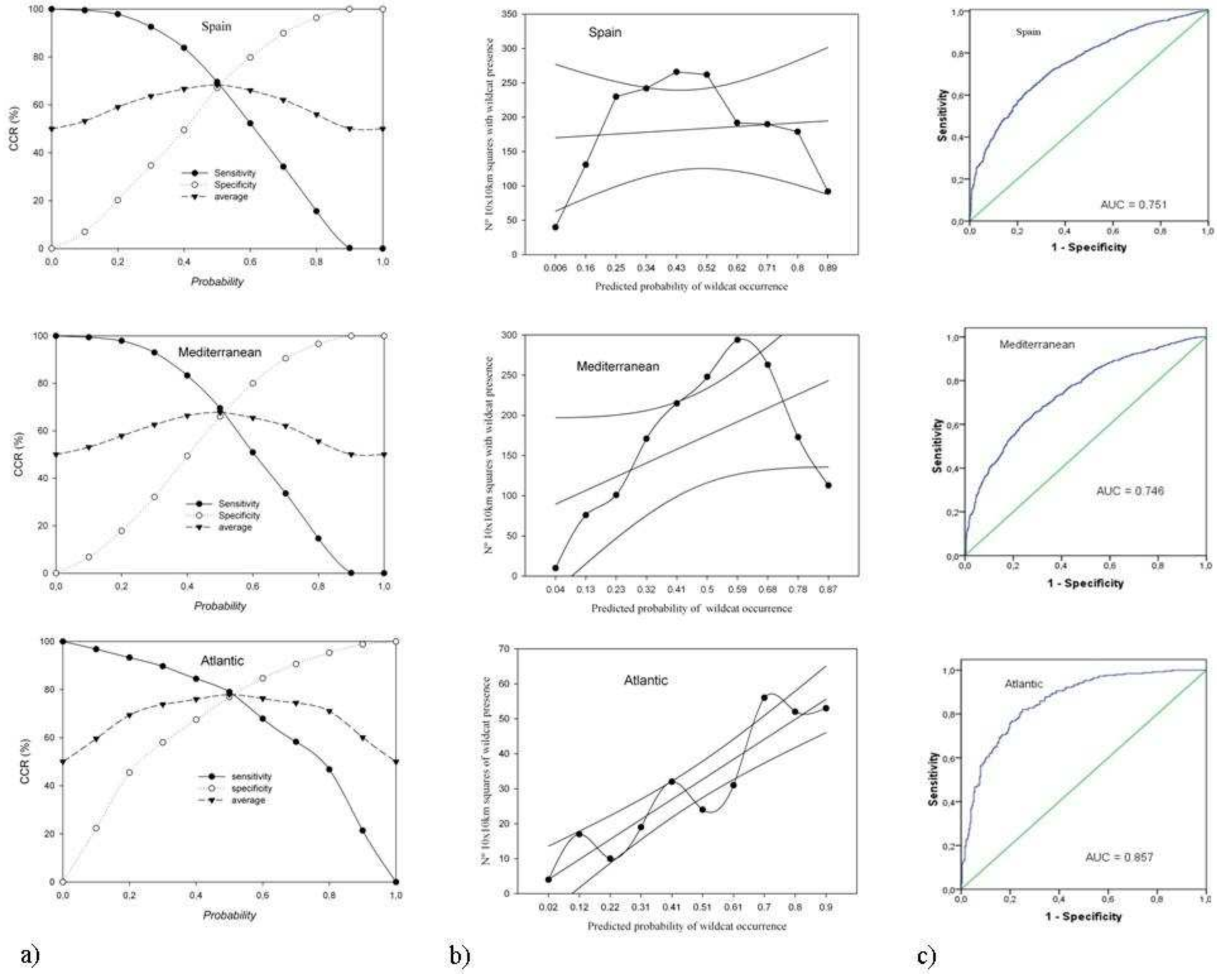

Figure 3.4. a) Correct classifications rates (CCR) at different cutt-off points at 0.2 intervals, b) Comparison of presence and predicted occurrence of wildcat in 10x10km squares at 0.1 intervals and c) ROC curve for best models (H_{42}, MH_{41}, AH_{43}), respectively.

3.3.2 Mapping wildcat presence probability

The probabilities of wildcat occurrence in Continental Spain show a highly fragmented pattern, with the species mostly restricted to Cantabrian, Basque and Pyrenees mountain range in North Atlantic regions, Central and Iberian mountains around the Northern plateau, and Subbetic and Penibetic mountains in southeast Spain (Figure 3.2b). Discordance is observed when comparing the resulting maps using presence probability and the true presences, mainly in South Mediterranean regions, where the highest values of occurrence probability were scarce and fragmented. (Figure 3.2 a and b).

In Mediterranean biome the probabilities shape clearly show a more negative scenario for wildcat presence, with the areas of central Spain presenting lowest classes of probability (Figure 3.2 d). For the Atlantic Spain the wildcat occurrence probability show high values in all his range with the exception of Galicia region (Figure 3.2 c).

3.4. DISCUSSION

A set of models were run in two different biomes, Atlantic and Mediterranean, and in all Continental Spain using a group of descriptors based on fine scale information. The approach was to incorporate the advantages of correlative and mechanistic models to develop large-scale determinants that express the local individual requirements for wide ranging species occurring in distinct biomes. To address this, was selected the European wildcat that has a large geographical range, some ecological tolerance, but suffering a constrained in its distribution range (Stahl and Artois 1994). First step was to list all relevant information about the species, analyzed identical features between same types of descriptors and built new predictors. In fact, the mechanistic and correlative models presents some problems, related with the scale of application, either because of the local/regional species linkage variables changed along biomes and global predictors have problems of interpretation (Guisan and Zimmermann 2000, Johnson and Omland 2004, Helmuth *et al.* 2005). The success of developed models that incorporates advantages of correlative and mechanistic model approaches depends greatly of detailed biological information on target species. Nevertheless, large-scale approaches may disregard landscape patterns important for regional conservation of the species habitat, which can be found at fine-scale (Fernández *et al.* 2003). This is particularly for habitat models, once the large-scale don't reflect the landscape structure features selected at individual home range level that high probably correlates with prey resources. The relation between fine scale landscape predictors and prey density can be interpreted as a likely mechanism to explain habitat quality at a higher level (Fernández *et al.* 2003). The inclusion of prey predictors in this model approach revealed the importance of fine scale landscape features through the weak predictive power of large types of vegetation. At large scale model this kind of landscape detailed is not available, so was taken to incorporate a predictor that relates to main prey resources.

What are the main factors that affect wildcat distribution in Spain using a "hybrid" mechanistic-correlative model approach?

Wildcat natural history and behaviour obtained from ecological research at fine scale suggests the importance of small mammals as prey for the species, as well the negative influence of human disturbance. In fact, recent study performed at fine scale in south of Portugal (Monterroso *et al.* 2009), reveal that that topographic unevenness were also considered key features for wildcat distribution, and with prey availability explained up 85% of species occurrence in the study area (Monterroso *et al.* 2009).

The generalized idea that the European wildcat shows different requirements along its distribution range, and that these differences are stronger across biomes, mainly between temperate forest and Mediterranean vegetation (Stahl and Artois 1994, McOrist and Kitchener 1994, Lozano *et al.* 2003, Biró *et al.* 2004), were not observed at large scale using information from fine-scale. It is true that, Atlantic areas have a distinct habitat composition from Mediterranean biome, the vegetation types are clearly different, such as the minor extend of agriculture areas, opposed to large extensions of agriculture fields in Mediterranean. The positive relation of Non natural with wildcat presence in output models of Atlantic biome, in contrast with a negative association of this variable in Mediterranean areas; reflect the expression of this descriptor in different biomes at large scale. The differences reflect the importance of habitat variables to prey availability, with the smallest patches of pasture in the Atlantic linkage to rodent availability and the largest extension of agriculture fields in Mediterranean with the lower rabbit density. Once the prey availability predictors were included in the model construction the influence of habitat as descriptors of wildcat presence decreased.

In fact, the more important descriptors (Sm_N and Elev_range) for wildcat presence in Atlantic and Mediterranean biomes still occur in Continental Spain. This is the first large scale study that analyses the main wildcat requirements, including prey availability, vegetation cover and human disturbance, based on regional/local species knowledge. The inclusion of food resources is a very important step, once these reveal the true relation between wildcat and its habitat, as well as species-prey type selection. Apparently the type of vegetation cover is not so important in the distribution of the wildcat; this is reinforced by the fact that the species is more habitat generalist than first suspected, not behaving as strictly forestall (Stahl and Artois 1994, Sarmento 1996, Lozano *et al.* 2003, Sarmento *et al.* 2006). Lozano *et al*. (2003) refers the relevance of scrublands for wild-living cats, in particularly the scrub-pastureland mosaic landscape were wild rabbits are more abundant, and high shrub cover at a microhabitat scale, rather than forests at a macro habitat scale. But for a species more generalist in the use of habitat types, the vegetation predictors many times are linkage to prey availability, not reflect the real importance for species occurrence. Klar *et al.* (2008) refer the importance of forest for the wildcat, referring that alone does not fully explain the species habitat use, once the riparian areas within forest, as edge habitats often provide higher diversity and abundance of small prey mammals than the interior forest. The relationship between prey availability and vegetation structure, namely the importance of pastures – scrubland mosaics for the wild rabbit in Mediterranean areas of Iberian Peninsula (Lozano *et al.* 2003) is a good example how the wildcat presence is indirectly relate to vegetation type, as consequence of main prey-vegetation link.

The marked Mediterranean areas, dominated by sclerophylous vegetation, are usually related with a main "single-key-prey" - wild rabbits (Malo *et al.* 2004, Gil-Sanchez *et al.* 1999, Lozano *et al* 2006, Monterroso *et al.* 2009), inversely to Atlantic regions, mainly covered, by mix and broad leaved forests, in which "grouped-key-preys – small mammals", are more available. These leads to a fundamental issue, that is the role of habitat, nearest related to prey availability and composition, and the main difference between Atlantic and Mediterranean areas, since both vegetation types provide good conditions for sheltering (Stahl and Artois 1994, Revilla *et al.* 2001, Lozano *et al.* 2003, Sarmento *et al.* 2006). In fact, habitat edges define a transitional line between different types of habitat, particularly relevant when relating to pastures and cover vegetation. Many rodents, birds and wild rabbits use these ecotones, and they are followed by a diversity of predators. Nevertheless, the importance of small mammals for the wildcat, well marked in Atlantic areas, still occurs in Mediterranean areas, where these prey represents the most relevant predictor for species occurrence, opposed to the idea of rabbit specialization in Mediterranean areas. Probably the wildcats take advantage of local wild rabbit's abundance.

Besides food and shelters, human disturbance is very important to explain the shape pattern of wildcat occurrence. In fact, the elevation up to a certain range can ensure optimal conditions for wildcat: low disturbance, food and shelter resources. In the Atlantic Spain elevation range represents the most relevant descriptor for wildcat presence, suggesting that these mountains region probably protected the species from the human activities, these explain the high level of shape probability for wildcat occurrence in this area. This importance appears reflected in Mediterranean areas where the mountains show high probability for species presence. Mermod *et al.* (2002), suggest that the European wildcat in Switzerland uses high elevations in summer for two reasons: they are able to obtain food resources and there are fewer human settlements. Alternatively, in some cases this occurrence may result from range contractions from human-impacted lower elevation areas leaving remnant populations in more mountainous regions. Nevertheless, the number and distribution of households and human settlements can differ from people density. Large villages and cities concentring human settlements and highest values of people density, or a dispersal occupation with lower rates of human population but distributed by a largest area, represents different disturbance scenarios for the wildcat.

Wildcat conservation implications

Broad scale predictors of wildcat distribution are essential to address global conservation strategies, with the ultimate goal of a defined action plan for the species in the Iberian Peninsula. The large scale results confirm the variety of habitats used by the wildcat, and this probably reflects the foraging behaviour on the search for small mammals and rabbits. Nevertheless, fine scale studies should still be performed; in fact the fine scale landscape analysis is very relevant to understand patterns of breeder abundance, and consequent local habitat management (Vanreusel and Dyck 2007, Fernández *et al.* 2003). The conservations measures for the wildcat must promote prey availability; which is dependent of natural vegetation and low levels of agricultural intensification. Over decades, in rural areas, people conducted small-scale shrub clearing by cattle grazing or by facilitating access to exploitation areas, resulting in a highly diverse landscape matrix. These landscape mosaics promote prey availability, specially rabbits and rodents (Bolger *et al.* 1997, Lozano *et al.* 2003). The modern world changes in agriculture practices, transforming natural and small diverse agriculture patches into large monocultures, reduced the prey availability for the wildcat. The same situation occurs when large amounts of private areas are devoted to big game hunting, with a landscape matrix dominated by shrubs and high density on big game species, lead to decreasing prey abundance, especially rabbits (Delibes-Mateos et *al.* 2008, Lozano *et al.* 2007). Environmental measures aiming wildcat conservation have to focus on the increase of prey, specially rodents and rabbits. Global changes, like land-use and climate change, could promote the contraction range for rodents species and irregular oscillations in their populations abundance, especially those with high level of specialization, depending on specific conditions to occur. This will pronounce a particular impact for species that have rodents as key-prey; witch is the case of wildcat. Another important aspect is the role of human disturbance, still poorly known, but probably highly complex, once they reflect direct (persecution) and indirect human-wildcat interactions (habitat fragmentation, domestic cats hybridization). Understand these interactions and the level how they affect the wildcat occurrence is highly priority in species conservation. The present work can be used as a powerful tool to assess the conservation value of sites for the wildcat occurrence in Iberia Peninsula and contribute to effective conservation planning for the species.

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PART III *- HUMAN INFLUENCE IN RURAL POPULATIONS OF DOMESTIC CATS.*

Chapter 4

Cats without frontiers?

Environmental and Human Controls of Domestic Cats in Natural Areas.

Paper II

CATS WITHOUT FRONTIERS? ENVIRONMENTAL AND HUMAN CONTROLS OF DOMESTIC CATS IN NATURAL AREAS.

Joaquim Pedro Ferreira, Inês Leitão, Margarida Santos-Reis, Eloy Revilla Submitted to *Jounal of Applied Ecology*

Cats without frontiers? Environmental and human controls of domestic cats in natural areas

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Abstract

Domestic cats ranging freely in natural areas are a conservation concern due to competition, predation, disease transmission or hybridization with wildcats. There is little information on the factors affecting their numbers and space use in natural areas, impairing our ability to design effective control policies. We describe the patterns of cat presence, abundance and space use and analyse the associated environmental and human constraints in a well-preserved Mediterranean natural area with small scattered local farms. We failed in detecting cats in areas away from human settlements (trapping effort above 4000 trap-nights), while we captured 30 individuals near farm houses. We identified a total of 130 cats, all of them in farms still in use by people (30% of 128 farms). All cats were free-ranging and very wary of people. The main factor explaining the presence of cats was the presence of people, while the number of cats per farm was mostly affected by the occasional food provisioning with human refuse and the presence of people. The home ranges of eight radiodiotagged cats were centred at farms. Males went furthest during the mating season (3.8 km on average, maximum 6.3 km), using farms as stepping stones in their mating displacements (2.2 km of maximum inter-farm distance moved). All cats showed a strong preference for human settlements, followed by areas at less than 200 m from roads and with a lower slope. In their daily movements cats notably avoided entering areas with high fox density.

Synthesis and applications. Contrary to our expectations, we failed in detecting cats living independently of people. The presence, abundance and space use of cats was heavily dependent on human settlements. Any strategy aiming at reducing their numbers in natural areas should limit the presence of people and avoid any access to human refuse. The number of individuals moving into well preserved areas can be controlled by increasing the distance between settlements and by preserving the community of native carnivores. When controlling human presence is not possible, the alternative would be neutering and vaccinating the cats, especially males.

Key-words: feral cats, Iberian lynx, wildcat, presence and abundance, space use, movement patterns, carnivore interactions, invasive species

4.1. INTRODUCTION

The presence of domestic species in natural areas often represents a conservation problem due to competition with and predation of wild species, because they act as reservoirs for many diseases and even due to the potential hybridization with the wild ancestor types (Gittleman *et al*. 2001). The domestic cat *Felis catus* is no exception and is currently considered a major conservation problem. It is the carnivore species with a wider distribution range, being present in all continents and in many islands, including several subantartic islands (Kirkpatrick and Rauzon 1986, Matias and Catry 2007, Bergstrom *et al.* 2009). Cats have accompanied humankind in all phases of exploration and colonization, and have been accidentally or deliberately introduced to most of the terrestrial ecosystems of the world (Fitzgerald and Turner 2000). In some cases, they have adapted with great success to new environments such as island ecosystems where they became a successful invader being today dominant predators that cause a very relevant impact on breeding seabird colonies and endemic species (Rensburg and Bester 1988, Nogales *et al*. 2004). In mainland areas, house cats also have a record as a subsidised exotic predator of native species (Woods *et al.* 2003). In addition to their predatory impact, domestic cats act as reservoirs in the transmission of numerous diseases to other species (Artois and Remond 1994, Daniels *et al.* 1999). In the case of the Iberian lynx, the most endangered feline of the world, the transmission of Feline Immunodeficiency Virus (FIV) and Feline Leukemia Virus (FeLV) by domestic cats may become a serious threat to their populations (Meli *et al.* 2009, Millán *et al.* 2009). A recent outbreak of FeLV in one of the two surviving Iberian lynx populations resulted in the infection of 13 individuals (24% prevalence) and in the subsequent death of 6 of them. The phylogenetic analyses of the virus strains indicated that the infection most likely originated from the domestic cats invading the lynx habitats (Meli *et al.* 2009). In contrast to the reservoir role of the domestic cat, FeLV was highly virulent to lynxes. Another major problem of free ranging domestic cats is introgressive hybridization with wildcats *Felis silvestris* (Randi and Ragni 1991, Hubbard *et al.* 1992). Extensive hybridization has been described in Hungary and Scotland, contrasting with occasional interbreeding in Italy and Germany (Beaumont *et al.* 2001, Daniels *et al.* 2001, Pierpaoli *et al.* 2003, Oliveira *et al.* 2008). Much of the hybridizations probably occurred in areas where the contact between the two species is more common. The impact of domestic cats depends on where they can be found and on the factors controlling their numbers and space use. Pet cats are found in large numbers in urban and suburban areas around the globe. However, the main conservation threats are posed by cats whose needs are not satisfied by people (at least not intentionally). Stray and feral cats live and reproduce with little or no human intervention and survive by scavenging or hunting. The almost unlimited food supplies that cities provide allow for the presence of vast numbers of feral cats; for example about 30 million cats are estimated to live in the streets of the United States (Grimm 2009). The number of feral cats follows the gradient of availability of human-related food resources form urban and suburban to rural areas, where the availability is much lower than in cities. Within this gradient, cat populations exhibit varying degrees of dependence on humans, and it is generally assumed that feral cats can live and reproduce freely in well preserved natural areas (Paltridge 2002, Biró *et al.* 2004, Phillips *et al.* 2007). The most dangerous domestic cats are precisely those living or expending time in natural areas, where they have an easier access to rare or endangered prey, may get in contact with wild endangered carnivores and may interbreed with wildcats. In this paper we investigate the factors associated with 92 the presence, abundance and space use by domestic cats in a gradient between a well-preserved natural area and a rural area with very low human density distributed in isolated farm settlements within a heterogeneous Mediterranean landscape in the South of the Iberian Peninsula. The area is representative of well preserved Mediterranean habitats where wildcats can still persist and where reintroduction programs of Iberian lynx are expected to be implemented (Anonymous 2008). We aim at describing the patterns of occurrence and abundance of domestic cats, as well as to evaluate home range, movements and habitat use and the environmental and human constraints associated to them. A priori, we expected that cats will be heavily dependent on human-related descriptors for individuals inhabiting near human settlements, while environmental features, such as those describing the availability of food and/or protection, should become much more relevant for cats living independently far from settlements. The information on those human and environmental determinants should prove useful when managing populations of domestic cats in the most sensitive natural areas.

4.2. METHODS

4.2.1. *Study area*

The study was carried out in Moura-Barrancos Natura 2000 site (43,309 ha) and part of a Bird Special Protection Area, encompassing the agroforestry areas around the village of Barrancos in the Southeast Portuguese-Spanish border (between 38º13’N - 37º57’N and 7º24’O - 6º59’O, Figure 4.1). This landscape is a typically well-preserved Mediterranean forested area, dominated by holm oak woodlands (*Quercus rotundifolia*), patches of sclerophylous scrubland and rocky areas and boulders along the main rivers and streams. Elevation ranges between 200 and 400 m. There are no villages within the Natura 2000 site and human settlements are reduced to isolated traditional farm houses. The climate is characterized by dry and hot summers and cold winters. Human activity is restricted to cattle rising, traditional agriculture and game hunting in an agro-silvo-pastoral system characterized by a heterogeneous combination of patches with open tree cover for cattle grazing (montado or dehesa) and shrubby forest patches. Moura-Barrancos Natura 2000 study site belongs to two municipalities: Barrancos, with a single village occupied by about 1,800 people (with a municipal density of 10.7 inhabitants/km^2) and Moura, that encompasses five small villages close to the study area (17.1 inhabitants/km^2). The study area offers a very suitable habitat for wildcats and the gradient between no human occupation to isolated farm houses offers a landscape context where hybridization between wild and domestic cats might occur. The Natura 2000 site was created, among other reasons, because it was one of the last strongholds of the Iberian lynx in Portugal (Pires and Fernandes 2003).

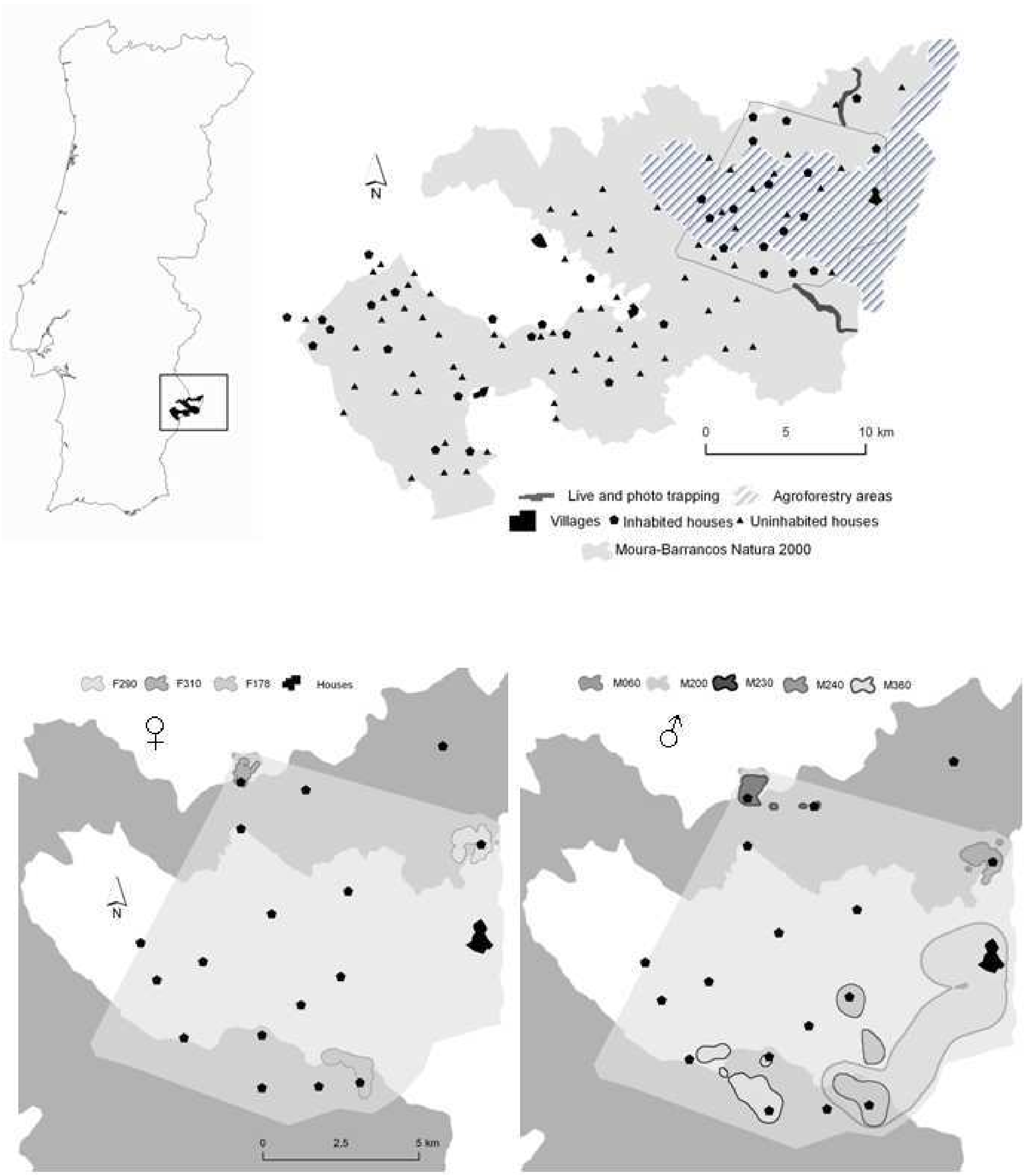

Figure 4.1. Study area defined by the Moura-Barrancos Natura 2000 site and the surrounding agroforestry area. The outline represents the minimum convex polygon encompassing all radiolocations of marked cats, and is presented below in detail to show the home ranges of the domestic cats (95% Kernel isolines) of males (right) and females (left). The largest patch of houses in the East is the village of Barrancos.

4.2.2. *Distribution of domestic cats*

4.2.2.1 Live-and photo-trapping

In order to estimate the presence of cats we implemented a live-trapping program both in scrubland areas and at farm houses. In the first case we selected areas with potentially high quality for wildcats in a range of distances to the nearest farm house (with a range of 1.3 to 4.5 km to the nearest house). Trapping occurred between February and July 2006 and March and July 2007 with 14 box-traps (model 608, Tomahawk Live Trap Co., Wisconsin, United States of America). Traps were baited with a live pigeon to maximise the capture probability of both domestic and wildcats. The pigeon was fed and protected inside the trap to avoid being captured by cats. We located box-traps in places 140 with thick vegetation or rocky cover, separated by 300-500m of distance. Traps were checked daily after sunrise. Additionally, we performed two campaigns of phototrapping in the same areas. In the first site we used nine cameras (Cam TrakkerTM 143 , Watkinswille, GA, USA) from March to May 2006, while in the second area we used 11 cameras from May to August 2006. Cameras were also baited with a protected pigeon. The trapping campaign at farms occurred in January and May 2007 in 10 farms within our study area. Live trapping was carried out around households using five traps per farm. Traps were baited with fresh fish and were checked twice a day (sunrise and sunset). The animals captured were weighted after being anaesthetized with an intra-muscular injection of medetomidine hydrochloride (Domitors, Espoo, Finland; 0.1mgmL-1150) and ketamine hydrochloride (Imalgenes, Lyon, France; 1 gmL-1151) in a 2:1 proportion. After handling, 0.08 mg/kg of Antisedan was administered for reversal. The age (young/adult) of animals was estimated from body weight and dentition. We considered adults those animals with full adult dentition and a weight above 2.5 kg or 3.5kg for females and males respectively (Liberg *et al*. 2000).

4.2.2.2 Cat presence and abundance at farms

We identified all farms inside our study area and evaluated the presence and number of cats during survey visits. We complemented this information with interviews to the owners/workers to obtain information on their use of the farm, the number and type of non seen cats and on their relationship with cats (including food provisioning). We used a ground-validated 1:5,000 orthophoto (year 2005) to build the digital cartography on land cover. We considered three land cover classes: human settlements, corresponding to the building areas in farms and other human settlements; natural vegetation, including sclerophylous vegetation, coniferous forests and riparian vegetation, and agro-forestry areas, which consisted in the oak montado-dehesas without understory and olive groves (Table 4.1). Additionally, we used a digital elevation model (DEM) in raster format (10 m resolution) obtained from a 1: 25,000 vectorial topographic map. Slope was derived from the DEM using second-order finite differences, and ranged from 0 to 41º. Roads and rivers were digitised from 1: 250,000 maps, corresponding to the length of paved roads and main rivers. Environmental and human-related variables were determined within a circle centred at each farm with an area of 1km^2 (Table 4.1).

4.2.3. *Analyses*

We analysed the environmental and human-related factors affecting the presence of cats at farms using generalised linear models with a binomial error distribution and a logit link function in R software. We considered that two variables were strongly correlated when rs > 0.7, using only the one with a higher correlation with the dependent variable. In total we generated 17 a priori models of cat presence at farms based on three groups of hypotheses depending on the combination of variables: 1) human influence; 2) environmental variables; or 3) a combination of both (Table 4.2). In the case of cat abundance we used a Poisson distribution with a log link. Following the same procedure we generated 16 candidate models (Tables 4.1 and 4.2). We used the Akaike Information Criterion (AIC) to rank the models according to their capacity to parsimoniously describe the data (Burnham and Anderson 2002).

Table 4.1**.** Variable types, codes, range values, definitions and variables used in each data analysis

Variable types	Code	Range values	Definition	Variables used in data analysis		
				Presence and abundance	Daily movement	Habitat selection
Environmental features						
Elevation range	Elev_range	(20-210)	Max. – min. altitude in 1km radius (%) **A**		X	X
Nº elevation curves crossed	Elevcurves_c	(0-68)	Number of elevation curves crossed	X	X	
Mean_slope	Slope	(1.55-15.26)	Mean slope in 1km radius (%) **A**	X		X
Slope range class	Slope_r	1-2	1: slope range 0-13.5; 2: slope range >13.5			X
Natural Vegetation cover area	Natveg	(0-75, 29)	Cover measure in 1km radius (%) **A**; home ranges **B**	X	X	X
Number of patches of natural vegetation crossed	Natveg_c	(0-4)	Number of vegetation cover patches crossed		X	
Agro-forestry area	AGF	(25-95, 64.4)	Cover measure in 1km radius (%) **A**; home ranges **B**	X	X	X
River length	River_l	(0-7174)	River with (m)	X		
Nº rivers crossed	Riv_c	(0-3)	Number of Rivers crossed		X	
Presence of other carnivores						
Red fox (*Vulpes vulpes*)	VV	(0-88%)	Average of Kernel Probability isolines crossed		X	
Badger (*Meles meles*)	MM	(0-95%)	Average of Kernel Probability isolines crossed		X	
Stone marten (*Martes foina*)	MF	(0-95%)	Average of Kernel Probability isolines crossed		X	
Common genet (*Geneta geneta*)	GG	(0-95%)	Average of Kernel Probability isolines crossed		X	
Egyptian mongoose (*Herpestes ichneumon*)	HI	(58-83%)	Average of Kernel Probability isolines crossed		X	
All species combined	carn	(65-95%)	Average of Kernel Probability isolines crossed		X	
Human features						
Human settlements area	House	(1.1-34, 1.3)	Cover measure in 1km radius (%) **A**; home ranges **B**	X	X	X
Number of human settlements crossed	House_c	(0-2)	Number of crossed		X	
Human presence	People	(0-1)	Absence or Presence through inqueries	X		X
Minimum distance to human settlements	MDH	(147-3373)	Distance to nearest farm with	X		
Minimun distance to human settlements with cats	MDCH	(245-6630)	Distance to nearest farm with cats	X		
Number of roads crossed	Roads_c	(0-3)	Number		X	
Road length	Road_l	(0-3916)	Road width (m)	X		
Distance to nearest road	Road_d	1-2	1: distance to road <200m; 2: distance to road >200m			X
Feeding domestic cats	Cats_feed	(0-1)	Human provision, or not, of food to the cats	X		

4.2.3.1 Domestic cats space use

In order to describe the patterns of space use and the factors associated 187 with it we radio tagged eight domestic cats captured at four farms in 2007. All the farms are well preserved game areas (Figure 4.1): Noudar Castle (NC), which with 980 ha is located inside the Natural Park; Coutada Frades (CF) with 468 ha and Contenda Forest Area (CFA) with 5309 ha, and Russianas (RUS) with 1480 ha, both of which are partially devoted to grazing. The eight cats (5 males, 3 adults and 2 subadults; 3 adult females) were fitted with radio-collars with activity sensors (Telonics model 105, Telonics Inc, Mesa, AZ, USA). We located cats by triangulation using two bearings taken at less than 10 minutes apart to minimize errors caused by animal movements. Only bearings between 60º and 120º were accepted. Fixes were calculated by LOCATE with 95% error ellipses using length maximum likelihood estimators. We evaluated the location error (~64m) during trials when the cats were in known locations inside the farms. The animals were located on average 2-3 times per day at any time in the 24h. On average we tracked cats for 10 ± 0.7 (±SD) months, obtaining an average of 176 ± 14.8 fixes per animal.

4.2.3.2 Home range

We estimated the home range utilization distribution of the radio-marked animals using a kernel estimator (*kernelUD* function, *adehabitat* package in R software). The utilization distribution is the bivariate function giving the probability density that an animal is found at a given point according to its geographical coordinates. Using this model, the home range can be defined as the minimum area in which an animal has some specified probability of being located. Individual home ranges were estimated for the 95% utilization distributions.

4.2.3.3 Habitat selection

We investigated the habitat use of cats using five covariates which expand in habitat categories (Table 4.1). We compared between the habitat used by the tracked cats and the habitat available within their home ranges. First we used a compositional analysis to obtain a rank order of preferences, testing the overall significance of the selection with a Wilks lambda and then building a ranking matrix. Additionally we used the eigenanalysis of selection ratios and the graphical approach developed by Calenge and Dufour (2006) to describe habitat selection. This method undertakes an additive linear partitioning aiming at maximizing the difference between habitat use and availability in the first factorial axes. The habitat types with a selection ratio between 0 and 1 are used below their availability while those above 1 are positively selected. The analyses were computed using the adehabitat package in the R software v.9.1.

4.2.3.4 Daily movements

We analysed the environmental and human-related factors affecting the length of the movements of the radiomarked cats using the displacements built with one location per day (we selected the two consecutive locations as close as possible to 24 hours). We used generalised linear mixed models using the length of the daily displacement as response variable and a group of independent variables related to sampling features (sex, season) and environmental and human-related factors (Tables 4.1 and 4.2). Each displacement was divided by location error (64 m) in order to standardize the length size and avoid overdispersion. In this way the analysis will show mostly the determinants of longer displacements. The variables quantifying the percentage of land use classes along the displacements were built using a 5 m buffer around each displacement vector (Table 4.1). We included several variables describing the probability of encountering other carnivores during the displacement. With this purpose we performed a total of 54 transects of 1 km in which we surveyed signs of carnivore presence within the minimum convex polygon defined by all the locations of the marked cats. Transects were located randomly in areas in which we had entrance granted by landowners, along dirt roads or foot-paths facilitating the surveys. We built a kernel utilization distribution for each species using all the signs of presence detected and an additional one for all the species combined. We used the number of kernel probability isolines (in 5% increments) crossed by cat displacements as a proxy of potential competition between wild carnivores and domestic cats (Table 4.1). Again, we removed one independent variable when it showed a strong correlation with other one, retaining the one with the higher correlation with the dependent variable. We used a code identifying each individual as a random factor in all models, obtaining a total of 22 a priori models according to the potential factors that could affect the displacements (Table 4.2). Models were run using Lme4 package in R software v.2.9.1.

Table 4.2**.** Summary of models that analyze domestic cat distribution (0/1) and abundance (N) in rural farms related to independent descriptors, in order to test different hypotheses of domestic cats occurrence. A total of 55 GLMM models were run: n=17, cats P/A; n= 16, cats number and n= 22 in respect to movements. The best models for each hypothesis are represented by an alternative statistical model, and Akaike Information Criterion (AIC) provides an objective tool to rank the models. The best models present lowest AIC value (Burnham and Anderson, 2002).

Models	***Model code***	***Deviance***	***AIC***	***AIC weights***
Presence of domestic cats in rural household farms				
Intercept only	A0	157.4	159.4	-
People +Road_l+River_l	A8	109.4	117.4	0.278
People+Road_l	A17	111.7	117.7	0.234
People +Road_l+River_l+Elev_range	A7	108.2	118.2	0.183
People+Road_l+MDH	A16	111.4	119.4	0.101
People +Road_l+River_l+Elev_range+MDH	A6	107.7	119.7	0.088
Abundance of domestic cats in rural household farms				
Intercept only	B0	34.9	150.6	-
cats_feed+People+ Slope	B8	20.2	141.9	0.252
cats_feed+People	B16	22.7	142.3	0.200
cats_feed+People +MDH	B15	21.3	143.0	0.146
cats_feed+People +Slope +HOUSE	B7	19.5	143.1	0.135
cats_feed+People +Slope +MDH +HOUSE	B6	18.6	144.2	0.078
cats_feed+People +MDH +Road_l	B14	20.6	144.2	0.077
Daily movements				
Intercept only	C0	1973	1977	-
VV+Elev_range+Roads_c+Riv_c+ Natveg _c	C14	484.5	498.5	0.188
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+AGF	C13	482.8	498.8	0.162
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+season	C6	478.8	498.8	0.162
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+AGF+season	C5	477.4	499.0	0.146
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+AGF+season+House	C4	476.0	500.0	0.098
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+AGF+House	C12	481.8	499.8	0.098
VV+Elev_range+Roads_c+Riv_c+ Natveg _c+AGF+ House+AGF_c	C11	481.0	501.0	0.053

4.3. RESULTS

4.3.1 *Domestic cats distribution*

In spite of our initial expectations and efforts we were unable to detect any cat in the two trapping sites selected in the natural area away from farms (Figure 4.1). At the northern trapping site, with an effort of 1464 trap-nights we live-captured seven common genets *Genetta genetta*, seven red foxes *Vulpes vulpe*s, three Egyptian mongooses *Herpestes ichneumon*, three badgers *Meles meles* and two stone martens

Martes foina. At the same site, we obtained a total of 498 photos with a total effort of 612 trap-nights. Considering only one capture per day and camera we photo-captured 15 wildboars *Sus scrofa*, 13 red foxes, eight badgers, eight genets, seven mongooses and four stone martens. Similarly, at the Southern site, with an effort of 1117 trap-nights, we live captured 12 red foxes, five mongooses, three badgers, two genets, and two stone martens. Photo-trapping provided a total of photos with a total effort of 814 trap-nights, including 22 red deer *Cervus elaphus*, eight wildboars, nine foxes, eight genets, seven mongooses, five badgers, and two stone martens. On the contrary, at the ten farms where we carried out a total trapping effort of 297 trap nights we captured 30 different cats: 12 males (of which eight were adults) and 18 females (12 adults).

4.3.1.1 Cats presence and abundance at farms

In total we identified 128 farms within our study area of which 86 (67.2%) had no resident people. Many of them were abandoned or even in ruins. There were no cats in the abandoned houses. The average distance to the nearest house was 1.1 ± 5.51 km. The 42 farms in use (32.8%) give a density of 0.09 farms km^{-2}. Cats were present in 39 of them (92.5%), with a total of 130 individuals (3.3 ± 1.85 cats per farm) and a density of 0.26 cats km^{-2} 274 (this density excludes the area of the village of Barrancos and a buffer of 3 km around). The sex ratio of 88 individuals (29 males, 59 females) was 1M:2F but for the remaining 41 individuals sex was unknown. The average nearest distance between farms with cats was 2.7 ± 12.7 km. Farm owners or residents considered all cats to be free ranging i.e., they were no kept as pets. In none of the farms the cats received veterinary support. Food provisioning was never provided on a regular basis, with 33 farms feeding cats only sporadically with human refuse (84.6 % of the occupied houses). Except for one cat out of the 130, farm owners defined them as very wary (cannot be captured by hand, fleeing when approached). The best model describing the presence of domestic cats in farms included the presence of people and the length of roads and rivers around the farm (explained 30.5% of the deviance); the next best model included only the first two variables (models A8 and A17, Table 4.2). The most important predictor of cat presence was the occupation of farms by people, accounting for 90.6% of the deviance explained by the best model (Table 4.3). The other two predictors are also associated to the farms that are more intensively used by people, either because they are better communicated (road length) or because the area is more suitable for small-scale traditional agriculture (river length). These results go against our initial expectation that presence of cats in natural sites far from urban, suburban and rural areas would rely more heavily on environmental than on human-related variables. In the analysis of the variables that influence the number of domestic cats all models with the highest support included food supplementation by people and the presence of people (Table 4.2). The most supported model (B8, Table 4.2) also included the mean slope around the farm, which had a negative effect (Table 4.3). Together the two human related variables explain 83.2% of model deviance, with partial contributions of 45.1% and 38.2%, respectively for *cats_feed* and *people*. As in the analysis of cat presence, human factors seem to have the greatest influence in the number of cats per household farm, while environmental factors are probably linked to farm location.

Table 4.3**.** Variables included in best models in respect to: P/A cats~descriptors ; Number of Cats~descriptors , 24h locations segments~descriptors and their Standardized Estimates, Standard errors (SE), Z test values and significance *P* (>Z). Variable codes as in Table 1.

Best models/variables	*Standardized Estimate*	*S.E.*	*Z*	*P*
Presence of domestic cats in rural household farms				
Intercept	-1.1459	0.2597	-4.413	<0.0001
People	1.3179	0.2292	5.750	<0.0001
Road_l	0.4038	0.2350	1.719	0.0857
River_l	0.3658	0.2452	1.492	0.1358
Abundance of domestic cats in rural household farms				
intercept	1.1561	0.0947	12.203	0.5355
Cats_feed	0.2740	0.1255	2.182	0.0291
People	0.2504	0.1052	2.379	0.0174
Slope	-0.1452	0.0948	-1.531	0.1258
Daily movements				
intercept	1.6339	0.1319	12.382	<0.0001
VV (Vulpes Vulpes)	-0.5805	0.0428	13.539	<0.0001
Elev_range	0.2748	0.0258	10.763	<0.0001
Roads_c	0.1442	0.0160	8.978	<0.0001
Riv_c	0.1437	0.0180	7.974	<0.0001
Natveg_*c*	0.0417	0.0221	1.884	0.0596

4.3.2 *Space use*

4.3.2.1 Home range

The area covered by all the radiolocations of the marked cats was 10,416 ha (calculated as the minimum convex polygon). All individual home ranges included the farm where each cat was captured (Figure 4.1). The average of the maximum distance between the capture site (farm) and the furthest radio location was 2.9±1.8 km, ranging between 1.2 and 6.3 km. Male home range sizes were larger than those of females, with 430 ha (range 71 - 1476) and 87 ha (41 – 113), respectively. There was a substantial inter-sexual home range overlap (Figure 4.1). Home ranges were centred in farm buildings, but in some occasions males moved away to another farm or to the village. In fact, the furthest distances away from the farm belong to males during the mating season (autumn-winter), on average 3.8 ± 2.2 km (with a maximum of 6.4 km) *vs* 1.6 ± 0.7 km out of the mating season; for females the average furthest distance was 1.2 for both seasons (± 0.4 and ± 0.3, respectively). The maximum distances that males travelled are associated to the distance to the nearest farm with cats ($r2 = 0.67$) only during the mating season ($r^2 = 0.0$ outside the season). Males used farms as stepping stones in their mating displacements; the maximum inter-farm distance moved was 2.2 km while the male that never made any excursion to other farm was 3.4 km away from the nearest occupied farm. None of the females moved between farms.

4.3.2.2 Habitat selection

The radio-tracked cats did not use the habitat within their home ranges at random ($\lambda = 0.0122$, $P = 0.0080$). The compositional analysis showed that there was a clear preference order headed by human settlements (*House*), followed by areas at less than 200 m from roads and with a smaller slope (Table 4.4). Steep areas, far from roads and covered with natural vegetation were the less preferred (Table 4.4). The eigenanalysis of selection ratios confirmed those clear preferences. The results for the first two axes explain 93.3 % of the information (74.4 % for the first axis and 18.1 % for the second, Figure 4.2 in Supporting Information). *House* was the land-use type more used by cats; in fact seven of the eight individuals made it their first choice as shown by the highest selection ratios (Table 4.4). The selection ratios for the remaining habitats show that human settlements play an important role because cats spent most of their time in the areas around the houses, i.e, close to roads and with low slope (Table 4.4).

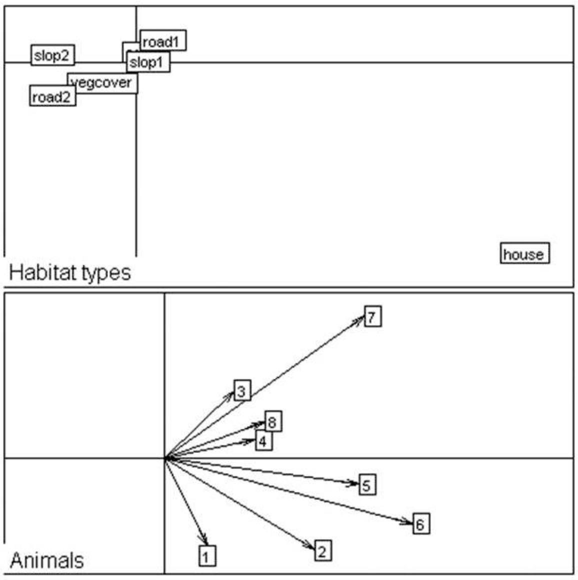

Figure 4.2**.** Eigenanalysis of selection ratios of habitat selection by the 8 domestic cats' relocations on seven habitat types within their home ranges. Top: Habitat type loadings on the first two factorial axes. The cross shows the position of a hypothetical habitat type unused by all individuals. Bottom: Individuals scores on the first factorial plane. The numbers corresponds to the animals: 1- F060, 2 – F178, 3 – F290, 4 - F240, 5 – F310, 6 – F230, 7 – F360, 8 – F200

Table 4.4**.** Ranking matrices for domestic cats comparing proportional radio locations for each individual in each habitat type with the proportion of each habitat type available within the cats home ranges**.** A triplet sign represents a positive or negative significant deviation from random at *P* = 0.05, for 500 randomisation tests. The habitat type used less than its availability is characterized by a selection ratio ranging from 0 to 1. The habitat type used more than its availability is characterized by a selection ratio ranging from 1 to infinity (Calenge and Dufour 2006). Average is for the value of each individual.

	Compositional analysis								Habitat Selection ratios	
	Habitat type (availability)							Rank		
Habitat type (use)	House	Road_d <200	Slope_r <13.5	AGF	NatVeg	Road_d >200	Slope_r >13.5		average	SE
House		+++	+++	+++	+++	+++	+++	1	3.19	0.56
Road_d<200	---		+	+	+++	+++	+++	2	1.14	0.07
Slope_r<13.5	---	-		+	+++	+++	+++	3	1.07	0.02
AGF	---	-	-		+	+++	+++	4	1.02	0.03
NatVeg	---	---	---	-		+++	+++	5	0.82	0.09
Road_d>200	---	---	---	---	---		+	6	0.57	0.13
Slope_r>13.5	---	---	---	---	---	-		7	0.40	0.11

4.3.2.3 Daily movements

We obtained a total of 339 daily displacements with a mean length of 605 ± 743 m, and an average time span of 20 ± 8 hours. The results of the linear mixed model showed that sex did not affect the daily displacements and that season only appeared in 3 of the 7 models with *w*AIC>0.05 (Table 4.2). Environmental variables seem to be very relevant in explaining the length of the daily displacements. In fact, the most supported model includes the average number of red fox 5% kernel isolines crossed, the elevation range, the number of roads and rivers crossed and the number of patches of natural vegetation crossed. The most important variable in all models was the proxy for red fox encounter probability, having a strong negative effect on daily displacement (Table 4.3). The positive effects of elevation range and number of roads and rivers crossed probably represents the differences in elevation when the animals moved far away from farms, since the households where we marked the cats are located at elevated places, and the further they moved away, the more probable it was that they crossed a road or a river.

4.4 DISCUSSION

Initially we expected to find cats living in a range of densities following the gradient of human occupation of the landscape. We also expected that cats living in natural areas far away from human settlements and living independently of people, i.e. relying on natural resources, should be more affected by environmental variables. However, we were unable to detect cats living freely far away from people. Our trapping effort was large enough to assume that in our natural area there were no cats living independently of people. The presence and number of cats was dependent on the presence of people and the resources they provide. In fact, the area around buildings was the preferred land use type for cats, as confirmed by the highest value of selection ratios. Many of the farms were abandoned along the past century, when human density in natural areas was higher. At the maximum of farm occupation cat density was probably much higher than nowadays (three times higher assuming the same distribution of cats per farm). Nowadays, the reduced pressure of domestic cats in Mediterranean natural areas can be relevant for the conservation of wildcats and Iberian lynx. Cats do not live far away from people in our area. However, it is generally assumed that feral cats can live independently of people in well preserved natural areas, as demonstrated by studies in some islands and in Australia (eg. Rensburg and Bester 1988, Paltridge 2002, Phillips *et al.* 2007). The evidence for other areas is very poor. In Scotland, Daniels *et al*. (2001) found that their putative wildcats were in contact with farm cats; in a natural area of Hungary the marked feral cats were close to farms, and their home ranges were at less than 2 km from one city and a village (Biró *et al.* 2004); and in northern France, domestic cats centred their home ranges in a village or around farms (Germain *et al.* 2008). Studies on feral cats are commonly located in urban and suburban areas (eg. Barrat 1997, Say and Pontier 2004) and even in inhabited small islands feral cats tend to rely on people (Yamane *et al.* 1996). It is therefore clear that high human density supports higher cat densities in natural or semi-natural areas, linking the expansion success of cats to different levels of human occupation. It remains to be explained how feral cats can live in islands on their own. We all have seen domestic cats roaming in natural areas far away from any human settlement. Cat home ranges are centred on farms, but males can make long displacements in search of females during the mating season (see also Barratt 1997, Germain *et al.* 2008). In fact, female distribution and density is the primary factor determining male range size (Liberg *et al*. 2000), as demonstrated by the relation between the maximum distance travelled in a season and the distance to the nearest farm with females. The furthest excursion by a male was 6 km away, but in this case the cat was using several farms as stepping stones. There seems to be a 3 km distance threshold between farms above which males cannot connect them. Germain, Benhamou and Poulle (2008) detected one male mating excursion between farms separated by 2.5 km. In summary, in natural areas cats can live strictly depending on only wild resources, as in some deserted islands, but the general pattern is that they do not, and they have the capacity to move long distances away from households, but they restrict their movements to the vicinity of human settlements. Like in islands, cats living in farms do not compete with other carnivores, but unlike the confined environment of islands, in many mainland areas they have to share space with other predators when moving away from houses. Our interpretation is that the differences in presence, abundance and movements of cats in natural areas of islands and mainland are also mediated by the presence and abundance of competing predators. Our results on the daily movements of cats show that they strongly avoided entering the areas with higher red fox density. In a study in New South Wales, after fox removal cats showed a significant resource shift, suggesting a strong interspecific competition mediated by both exploitation and interference (Molsher 1999). Foxes prey on cats and their kittens and cat remains have also been observed in fox diet samples in Europe and Australia (Fuchs 1972, Martin *et al.* 1996, Risbey *et al.* 1999).During our study all kittens from one female in Noudar Castle were predated by an Egyptian mongoose. In summary, feral or free ranging cats are more likely to be rare or absent in regions with well preserved wild predator populations. However, in areas with no other predator, such as many islands, or weak predator communities, such as humanized areas, feral cats may become the dominant predator and often exist at much higher densities than native predators. Our study provides a clear linkage between the distribution, numbers and movements of cats and several human and environmental factors that can be managed to reduce the pressure of domestic cats into natural areas. The presence of people is the first most important variable to be managed. The existence of small settlements or even isolated houses or farms represents a bridge allowing the intrusion of cats into the surrounding areas. The key here are those occupied by people and located in well preserved natural areas where we can find other species of conservation concern. The distance between houses is another key element that should be controlled since cats use them as stepping stones when moving. Even when residents do not own pet cats and do not directly provide food, there is a clear effect on cat presence. If we cannot manage the presence of people living in the field, in order to maintain low cat numbers, food provisioning should be banned while the access of cats to human refuse must be controlled. In the worst case scenario in which people is living in a network of well connected settlements and provisioning cats with food, males should be neuter to reduce the distances they move away from houses and to reduce the probability of hybridization, while veterinary support should be provided to reduce the prevalence of diseases in the population of domestic cats. In addition to these measures, an effective strategy for controlling hybridization and the transmission of diseases to other species involves maintaining the community of native predators, including red foxes. Finally, because private landowners are the ultimate controllers of their land, providing them with information is essential to increase the awareness of people before the implementation of any measure.

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Chapter 5

DIFFERENT CATS, DIFFERENT PLACES, DIFFERENT DIETS?

Paper III

DIFFERENT CATS, DIFFERENT PLACES, DIFFERENT DIETS?

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Diferent cats, different places, different diets?

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Abstract

The knowledge of domestic cat *Felis catus* feeding ecology in natural and semi-natural areas is fundamental to understand the mechanisms that promote or limit the survival and expansion of this species in nature conservation places. Historical differences in human association with domestic cats and the wildcat *Felis silvestris* possibly reflect distinct foraging behaviours. A total of 407 scats were collected from nine latrine sites located in southeast Portugal. A random sample of field-collected scats of each latrine site was genetically analysed to ascertain their origin as genus *Felis* individuals. To further obtain an overview of domestic cat diet along its distribution range we analysed 57 studies, published since the forties, which report information on the species food regime in different places of the world. Human refuse was the most frequent item (76.05%) in scats collected from latrines located near the houses and rabbits (71.43%) were more frequent in scats found far from houses. Multivariate analysis confirmed the separation of two groups of scats based on prey items differentiation, near and far from houses. In a global evaluation of domestic cats' diet, mammals revealed as the most important food item, and similarities were found between urban and natural areas, as opposed to findings in insular populations. Diet of the domestic cat expresses its dependence on people, even in natural areas, where prey diversity and availability is higher. Clear separation of scats collected in latrines near houses and those found far from human settlements and located in natural areas, typically associates with domestic and wildcats, respectively. To decrease domestic cats abundance in rural-natural areas of Iberian Peninsula, thus contribution to wildcat conservation, is crucial to limit food sources provided, directly or indirectly, by man.

Keywords: domestic feral cats, wildcats, people and cats distribution, food regimes, conservation

5.1. INTRODUCTION

The domestic cat *Felis catus* may be the most widespread predator in the world. Cats with dependable food sources are not, as other carnivores, vulnerable to changes in prey populations (Fitzgerald 1988). Moreover, unlike many native predators, domestic cats are not strictly territorial. As a result, cats can exist at much higher densities and may out-compete native predators for food (Bradshaw *et al.* 1996). Studies on the feeding habits of free-roaming domestic cats, conducted over the last decades in Europe, North America, Australia, Africa, and many islands, show that they prey on local wildlife, especially in "islands" habitats such as suburban and urban parks, and other areas surrounded by human development. In addition, it is in these habitats where the cats have more success as an opportunistic carnivore, preying on a vast range species and eating a wide variety of resources, revealing its versatility and unusual ability to utilize a broad spectrum of prey types and sizes (Pearre and Maass 1998).

The largest number of studies regards places where the species represents a serious conservation problem, such as in islands, urban environments and Australia (Barrat 1997, Arnaud *et al* 1993, Dowding and Murphy 2001). Since mid-nineties ~ 70 studies were carried out on the diet of domestic cat, but only 6 relate to Europe mainland natural/rural areas, inside European wildcat *Felis silvestris* distribution range. Moreover, assumptions on domestic cat vs European wildcat competition by food resources are rarely discussed (Daniels *et al.* 2001, Biró *et al.* 2005) and only two studies compare species diet (Corbett 1979, Biró *et al.* 2005). However, to establish an effective wildcat conservation strategy, knowing that its relations with domestic cat may pose a serious conservation problem, we have to concentrate in species interactions, including the hypothesis of a possible trophic niche overlap as emphasided already by. Corbett (1979) and Biró (2005).

Regarding food requirements, wildcats consume a large diversity of prey but small mammals are the stapple prey in most areas of its distribution range (Condé *et al.* 1972, Sládek, 1973, Hewson 1983, Sarmento 1996, Moleón and Gil-Sánchez 2003, Carvalho and Gomes, 2004). However, these are replaced by wild rabbits *Oryctolagus cuniculus* in most of the Mediterranean environments, such as the central and southern regions of the Iberian Peninsula (Malo *et al.* 2004, Gil-Sanchez *et al.* 1999, Lozano *et al* 2006).

For domestic-cats to establish feral populations in natural areas, it is necessary that they are able to feed exclusively on natural prey, like wildcats. In rural areas, however, humans provide domestic cats maintenance resources that other predators do not receive (Coleman and Temple, 1993). As a result, they may exist in higher densities and exert a greater predatory effect than natural predators. Also, cats are opportunistic predators Coman and Brunner, 1972), both in terms of time and space (Barratt, 1997), meaning they will depredate whatever prey item they encounter. However, most studies link the success of cats' predation on wildlife to places where they have a surplus of food provided directly or indirectly by people, or to areas where they not co-evolved with prey species, like in islands. Besides that, the presence (or absence) of other carnivore species must be taken into consideration when analysing the effects of domestic cats in wildlife, wildcats included. The disappearance of larger carnivores from a region can lead to what is known as "mesopredator release" (Fitzgerald 1988), in which the cats are free to roam freely and fill the ecological niche left by the first preying on smaller wild vertebrates.

To understand man's role on the survival of domestic cats in low humanised natural areas we used the information on scat contents from nine latrine-sites and analysed it relatively to distance from human settlements. Three hypotheses were upfront defined:

1) In natural areas domestic cats feed on wild prey and are not dependent on resources made available by humans;
2) Domestic cats do not roam and feed far from farm houses;
3) Latrines found in the middle of scrubland-woodland habitat patches, far from farm houses, are wildcat-originated;

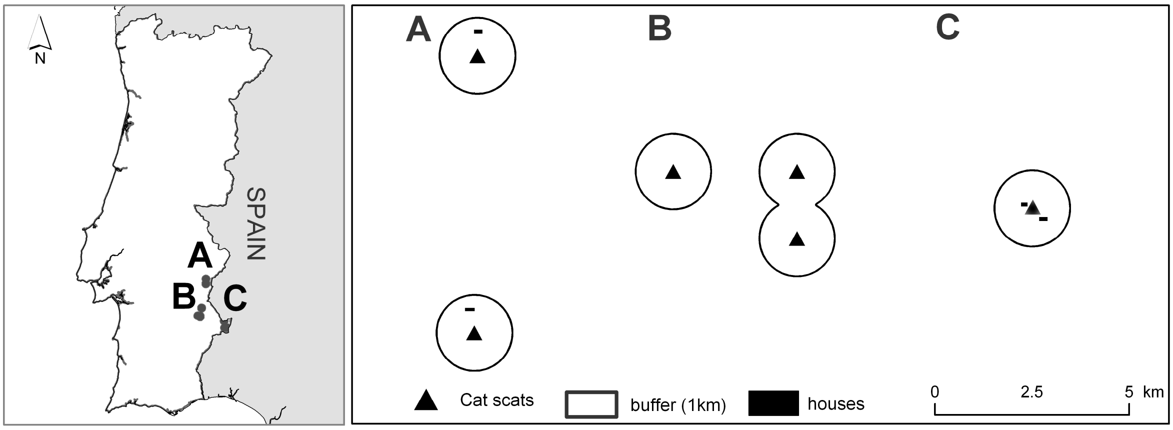
To test these, we investigated if the worldwide food regime of domestic cats reveal any pattern that can be comparable to the scat results found at the fine scale (study area), e.g. is domestic cat regime prey-based as like rodents and rabbits in the wildcat diet. In addition, in areas where it is associated with man, as in urban areas, the basis of their diet is the resources provided by man. Moreover, in species so close is to be expected that in natural environments, with low human presence, occurs a feeding niche overlap. Despite the very tenuous morphological differences between the two species, that can lead to trophic niche overlap, the historical domestic cat - human association determines different eating behaviours. In terms of wildcat conservation, to know the food regime of domestic cats in natural areas is a key issue.

5.2 METHODS

5.2.1Study Area

The study was carried out in Guadiana river basin, that includes Moura-Barrancos Natura 2000 site (43,309 ha) and part of a Bird Special Protection Area, encompassing the agroforestry areas around the village of Barrancos in the Southeast Portuguese-Spanish border (between 38º13’N - 37º57’N and 7º24’O - 6º59’O, Fig. 5.1), and is inhabited by species of carnivores with high conservation value. Moura-Barrancos Natura 2000 site belongs to two municipalities: Barrancos, with a single village occupied by about 1,800 people (resulting in a municipal density of 10.7 inhabitants/km²) and Moura, that encompasses five small villages close to the study area (overall municipal density is 17.1 inhabitants/km²). Human settlements are represented by traditional farm houses scattered throughout the landscape, which offers a very suitable habitat for wildcats and contacts with domestic cats and other carnivore species might occur. The region is characterized by a highly fragmented and complex landscape structure, dominated by holm oak *Quercus ilex* and scrublands-woodlands, where three main rural activities are pursued simultaneously in a single space (livestock husbandry, agriculture and hunting). Interspersed with the major forestry type, there are agricultural fields (cereal, vegetables and olives) and forest plantations (eucalyptus and pines). A large range of temperatures, with mild winters and hot summers, characterizes the climate of this region. Precipitation levels are between 400-600mm per year, with average temperatures <18ºC in the coldest months and >22ºC in the warmest months (Chícharo *et al.* 2001). Water is concentrated in rivers, streams and creeks, which have an intermittent regime.

Figure 5.1**.** Study area. The buffer of 1 km, in each latrine, represents the maximum distance travelled by domestic cats in the study area (Ferreira *et al.* submitted - Paper II of this thesis).



5.2.2 *Cats diet in the study area*

The diet of cats was investigated through the analysis of scats, routinely collected from latrines sites. A total of 407 scats originated from nine latrine sites, six monitored during 2002 (N=173 scats) and three in 2007 (N=234). A random sample of field-collected scats of each latrine site was genetically analysed to ascertain that they were from individuals of the genus *Felis*, using a recently developed protocol with species-specific mitochondrial DNA markers for Iberian carnivores (Fernandes *et al* 2008). Distance between each latrine and the nearest human settlements was assessed using a 1km buffer around the latrine centre.. Three main groups were defined: i) the latrine was located in the middle of houses, ii) the latrine buffer included houses inside, and iii) the latrine buffer did not included any house. Then, each scat was analysed as a single sample. For the analysis, scats were immersed in water and all remains examined to separate bone fragments, teeth, hair, feathers, insect pieces, or other prey remains. The prey items categories considered in the analysis were rabbits, rodents, other small mammals, ungulates, birds, reptiles, amphibians, insects, other invertebrates and human refuse. Rodents and insectivores were identified to species level from their teeth (Santero and Alvarez, 1985) and hair (Teerink, 1991). As reported in most carnivore studies, results were expressed as the frequency of occurrence (FO) of the different prey items (Reynolds and Aebischer, 1991). To investigate if resources consumption was, directly or indirectly, associated with human presence, in opposition to the wild-prey based diet of wild carnivores such as wildcats, a linear discriminant analysis was performed using the three categories of latrine sites above described and a total of 18 food resources categories: rabbitsD (rabbits in dry season), aposylD (wood mouse in dry season), musD (*Mus sp.* in dry season), passeD (passeriformes in dry season), alerufD (red-legged-partridge in dry season), repteilsD (reptiles in dry season), insectsD (insects in dry season), crayfishD (crayfish in dry season), human_refuseD (human refuse in dry season), rabbitsW (rabbits in wet season), aposylW (wood mouse in wet season), musW (*Mus sp.* in wet season), passeW (passeriformes in wet season), alerufW (red-legged-partridge in wet season), repteilsW (reptiles in wet season), insectsW (insects in wet season), crayfishW (crayfish in wet season) and human_refuseW (human refuse in wet season). All items resulting in small samples sizes (n < 20) were excluded from statistical analysis. Hierarchical cluster analysis was also used in order to generate groups of scats based on the complete dataset (N=407). For pairs of correlated variables the one less significant to the dependent variable was excluded from further analysis. To test the null hypothesis of no significant difference in the mean of the dependent variable for the different groups (cluster plots), formed by categories of the explanatory variables (prey items), a multivariate analysis of variance – MANOVA, was performed. Significant differences resulting from multivariate analysis were examined with univariate *F* tests at the variable level to allow interpretation of the respective effect. Statistical analysis were performed with MASS package of R software.

5.2.3 Domestic cat diet in the world

For the overview of domestic cat diet along the distribution range we analysed fifty seven studies published since the forties that report information about the species food regime around the world (Table 5.1). To homogenize the sample and allow results comparison from different geographical areas we used some exclusion criteria from the sample: studies with small samples sizes (n < 30) and data refering to a single season. Few other had also to be excluded, either because data was obtained by inquiries to cats' owners (Woods *et al.* 2003, Baker *et al.* 2005) or FO values could not be estimated (Barrat 1997, Giles and Clout 2003). Prey types were rearranged to homogenize the data for comparative purposes, and FO was calculated when necessary. Seven prey items were considered: Rabbits, Rodents, Other Mammals, Birds, Reptiles, Invertebrates and Human Refuse. Thirty one studies (54.3%) refer to insular habitats, sixteen (28.2%) to natural/rural areas and ten (17.5%) to urban areas. Of the studies referring to natural/rural areas, only four respect to areas out of Australia. The frequency of occurrence was the commonest measure made available by authors and was considered valid for comparative purposes (Reynolds and Aebischer, 1991). The prey items reported in the literature were collected and tabulated separately for each study. In some studies the food obtained by scavenging, or household is referred but data on the frequency of consumption is not available (Rodríguez-Moreno *et al.* 2007, Campos *et al.* 2007). Data compiled per study were: (i) type of food consumed (species and/or categories); (ii) frequency of occurrence [FO = (number of scats or gut samples with a particular item x 100)/(total number of scats or gut samples)]; (iii) number of carnivore species (> 2kg) that occurs in each study area. A linear discriminant analysis was performed using the data set of the 57 worldwide studies, classified as either to three types of areas: Islands, Urban or Natural area. To test the null hypothesis of no significant difference in the mean of the dependent variable for the different groups (cluster plots), formed by categories of the explanatory variables (prey items), a multivariate analysis of variance – MANOVA, was performed. Again, the significant differences resulting from multivariate analysis were examined with univariate *F* tests at the variable level to allow interpretation of the respective effect.

Table 5.1**.** Sources and types of data used for prey items, in different studies from Islands, Urban and Natural areas by chronological order. The number of carnivores (>2kg) respect to the potential species occurrence in each study area.

Study no.	Source	Location	Data source	Time period	Rabbits	Rodents	mammals	Birds	Reptiles	invertebrates	Human refuse	Nº carnivores (>2kg)
Islands												
1	Heidemann and Vauk 1970	Germany Isla de L'Helgoland	61 stom.	<1year		68					34	0
2	Jones 1977	Macquarie Island 54º30'S, 158º57E	756 scats	>1year	81.9	4.4 2.6	81.9	15.9				0
3	Gib et al 1978	New Zealand	279 scats	>1year	100	1.25	100	9.64	5	89.5		1
4	Vand Aarde 1984	Marion Island 46°52'S, 37°51'E	116 stom.	>1year			16.4	97.4				0
5 a	Van Rensburg 1985	Marion Island 46°52'S, 37°51'E	143 stom.	>1year		41.3	41.3	83.9				0
5 b	Van Rensburg 1985	Marion Island 46°52'S, 37°51'E	116 stom.	>1year		16.4	16.4	97.4				0
6	Kirkpatrick and Rauzon 1986	Jarvis Islands 0º23'S, 160º01'W	73 stom.	>1year			8.21	95.8	1.3	26		0
7	Santana et al 1986	Canarian Islands Gran canaria	133 scats	>1year	81.2	8.8 3.8	93.2	12	36.8	47.4	3.7	0
8	Konecny 1987	Galapagos Islands	200 scats	1year		18	18	23	19	30.5		0
9	Nogales et al. 1988	Canarian Islands El Hierro	248 scats	>1year	61.3	49.2 6.8	88.3	13.3	44.3	45.5	0.4	0
10	Furet 1989	L'ile Amsterdam 37º50'S, 77º35'E	241 scats	1 year	85.8		91	6.4		3.2		0
11	Nogales et al. 1990	Canarian Islands Tenerife High Mountain	221 scats	>1year	53.8	14.6 7.9	76.3	1.1	78.5	32.8	7.6	0
12	Fitzgerald and Veitch 1991	New Zealand Raoul Island 29º15'S, 177º52'W	57 stom	<1year	86		88	35		40		0
13	Nogales et al. 1992	Canarian Islands Alegranza	110 scats	>1year	83.6	54.5	100	5.5	4.5	6.4	16.4	0
14	Arnaud et al 1993	Revillagigedo Archipelago, Socorro island 18º20'N, 110º45'W	46 scats	<1year		71.7	76	19.5	52.1	82.6		0
15	Medina and Nogales 1993	Canarian Islands Tenerife	200 scats	>1year	47	51 11	86	2.5	57	3	0.5	0

Cont.

16	Tidemann et al 1994	Australia Christmas Island 10°25'S,10504WE	93 scats	>1year		45 27	63	28	31	62	20	2
17	Nogales and Medina 1996	Canarian Islands Gomera	135 scats	>1year	17.7	46.6 57	93.3	14.8	27.4	18.5	2.9	0
18	Keita 2002	Mexico Navidad Island	scats					90				1
19	Pontier et al 2002	Sub-Antartic Kerguelen	149 scats	>1year	72.6	11.6	72.6	14.9				0
20	Watanabe et al 2003	Japan Iriomote Island 24º20’N, 123º49E	31 scats	>1year		9.7	9.7	88.6				1
21 a	Martínez-Gómez and Jacobsen 2004	Revillagigedo Archipelago, Socorro island 18º20’N, 110º45’W	37 scats	>1year				73	19	84		0
21 b	Martínez-Gómez and Jacobsen 2004	Revillagigedo Archipelago, Socorro island 18º20’N, 110º45’W	46 stom	>1year				15	33	43		0
22	Harper 2005	New Zealand Stewart Island 47º00’S, 167º50’E	219 scats	>1year			100	26.9	1	1		0
23	Medina et. al. 2006	Canarian Islands La Palma	500 scats	>1year	63.4	24.6 15.6	92.2	9.8	37.6	18	7.4	0
24	Bonnaud et al 2007	Port-Cros Island 43º00’N, 6º21’E	1219 scats	1 year	4.10	79.25 38.80	94.09	13.86	9.98	11.46	6.06	0
25 a	Hess et al 2007	Mauna Kea	143 Stom	>1year			50	69		59		0
25 b	Hess et al 2007	Hawai Volcanoes NP	42 Stom	>1year			67	28		43		0
26 a	Phillips et al 2007	California San Clemente Island 32º55’N, 118º30’W	71 Scats	1 year		25.6		2.1	14.6	54.2		1
26 b	Phillips et al 2007	California San Clemente Island 32º55’N, 118º30’W	315 Scats	1 year		30.1		2.1	13.6	44.6		1
26 c	Phillips et al 2007	California San Clemente Island 32º55’N, 118º30’W	216 Scats	1 year		29.2		2	11.2	50.1	0.2	1
27	Rodríguez-Moreno et al 2007	México Isla Coronados 26º07’0N, 111º17’0W	100 scats	<1year	?	70	?	?	?	?	?	0

Cont.												
28 a	Matias and Catry 2008	Falkland Islands 51º42'S, 61º17'W	220 scats	<1year	32.7	45.9 37.3	45.9	21.8		3.6		0
28 b	Matias and Catry 2008	Falkland Islands 51º42'S, 61º17'W	153 scats	<1year	59.5	25.5 23.5	59.5	20.9		2		0
29	Medina et al. 2008	Canarian Islands Fuerteventura	209 scats	>1year	40.6	58 8.2	89.4	11.5	15	29.5	5.8	0
30	Peck et al 2008	Mozambique Channel 17º03'S, 42º43'E	104 scats	>1year		66 38		29	2	16	6	0
31	Faulquier et al 2009	SW Indian Ocean Reunion Islnad 21ºS, 55ªN	217 scats	>1year		22.2 21.6	>22.2	36.9		1.80		0
Urban												
32	McMurray and Sperry 1941	North America Oklahoma	107 scats	>1year			75.3	11.4	6.4	100	34.4	2
33	Borkenhagen 1978	Germany Kiel	309 prey	1 year	14	48	?	22				1
34	Borkenhagen 1979	Germany Kiel	187 stom.	>1year	17.5	65.7	65.7	16.1	2	41	93	1
35	Achterberg and Metzger 1979,1980	E. Germay	113 stom	>1year	0	0	0	0	0	0	66	1
36	Barrat 1997	Australia Camberra 35°178S, 149°138E	1961 prey	1 year	10	1095	1273	529	131			2
37	Giles and Clout 2003	New Zealand Auckland 36º43'S, 174º45'E	1684 prey	1 year	2	486	527	226	127	787		1
38	Woods et. al. 2003	Great Britain	14370 prey	<1year	1243	6369	9852	3391	144	171		?
39	Baker et al. 2005	England NW Bristol	358 prey	1year		239	269	86				1
40	Meckstroth et al 2005	South SanFrancisco Bay	68 stom.	>1year		63	63	14		10	32	4
41	Campos et al 2007	SE Brasil 22º42'S, 47º38'W	98 scats	<1year	2.25	7.5	20.51	12.8	1.7	63.2	observed But not quantified	1 (dog)
Natural/Rural												
42	Coman and Brummer 1972	Australia Vitoria	128 scats	1 year			88	5.2				2
43 a	Jones and Coman 1981	SE Australia Kinchega NP	65 stom	>1year	48	19		45	28	69		2
43 b	Jones and Coman 1981	SE Australia Victorian eastern Highlands	117 stom	>1year	39	26		29	3	16	2	2

Cont.

43 c	Jones and Coman 1981	SE Australia Victorian Mallee	131 stom	>1year	68	33		18	13	42	5	2
44	Triggs et al 1984	Australia Croajingalong NP 37º25’S, 149º45’E	48 scats	>1year	19		56	27	23	17		2
45	Liberg 1984	Scandinavian Peninsula 55º42’N, 13º25’E	238 scats	>1year	16-60	36-84		5-82				?
46	Catling 1988	Australia New South Wales 33º45’S, 145º30’E	112 stom	>1year	54	8.8 4.4	80.5	21.2	30.1	42.5	2	2
47	Léger and Stahl 1989	France Lorraine	94 scats	<1year	97.8		98.9	6.3				3
48	Langham 1990	New Zealand Hawk’s Bay	361 scats	>1year	3	50	76	24		2		0
49	Martin et al 1996	Western Australia (30-35ºS)	50 scats	>1year	16	50.6	50.6	37	16	81.4	2	2
50	Paltridge et al 1997	Central Australia	390 stom	>1year			70	14	17.6	26.5		2
51	Weber and Dailly 1998	Suisse Jura Mountains 47º09’N, 6º56’E	148 scats	1 year		7.5 7.0	18.8	1.1			72	5
52 a	Risbey et al 1999	W Australia Heirisson Prong 26º10’S, 113º23’E	109 stom	>1year	66.1	16.5 8.3		19.3	>4.3	>7.3	2.8	2
52 b	Risbey et al 1999	W Australia Heirisson Prong 26º10’S, 113º23’E	62 stom	>1year	12	77.4 25.4		9.7	>1.6	>17.7	27.4	2
53	Molsher 1999	Australia New South Wales	499 scats	>1year	81.6		>81.6	4.2	3.4	41.5		2
54	Read and Bowen 2001	South Australia Roxby Downs	391 stom	>1year	56.6	9.2 0.9	11.7	12.8	33.5	34.5	11.4	2
55 a	Paltridge 2002	Australia Tanami Desert 19º12’S, 132º40’E	76 scats	1 year		38.2	59.2	60.5	72.4	35.5		2
55 b	Paltridge 2002	Australia Kintore 22º51’S, 129º57’E	68 scats	1 year		32.9	77.1	64.3	62.9	38.6		2
56	Hutchings 2003	Australia Southern Vitoria	159 scats	< 1 year			36.4	11.3		23.8	81.7	2
57	Biró et al 2005	NE Hungary	263 stom.	1year	1.3	37.7 13.8	75.8	9.7	0.5	2.2	4.1	5

5.3 RESULTS

5.3.1Cats diet in the study area

The results of scat contents from latrines sites near and far from houses are summarised in table 5.2. Scats collected far from natural areas contained in average 1.44 different food items, while those near houses had 1.63. Human refuse was the most frequent item (76.05%) in scats collected at latrines close to houses but was absent in scats collected in latrines away from houses. Inversely, rabbits (71.43%) were the most consumed resource in scats found far from houses, showing little relevance (3.36%) in scats collected in latrines near human settlements. Rodents were the main vertebrate (58.8%) found in scats near the houses, with *Mus* sp (probably the house mouse – *Mus domesticus*) dominating (37.81%). This result contrasts with rodents' frequency of occurrence (17.14%), in particular that of *Mus* sp. (4.0%), detected in scats collected in natural areas away from houses. The wood mouse *Apodemus sylvaticus*, on the contrary, was most consumed (9.71%) in areas away from houses (3.28% in scats near houses). These differences in the consumption of house and wood mice relate to the preferred habitats of each species, with the house mouse being associated to humanized environments and the wood mouse to bushes and forested areas (Blanco 1998). A fact to be emphasised was the occurrence of wild carnivores remains (two of common genets *Geneta geneta* and one of stone marten *Martes foina*) in scats collected at latrines placed far from human settlements. Birds, like insects, occurred in similar frequency in the scats collected at the latrine groups, near and far from houses. Reptiles were clearly more frequent (13.14% vs. 2.94%) in scats far from houses, and amphibians and crayfish, were only found in the scats collected far from households.

Table 5.2**.** Diet composition of *Felis* sp. from latrines located near and far from houses; N, number of scats were the item was present; FO, percentage relative frequency of occurrence.

Prey items	Scats from latrine located in the middle of houses		Scats from latrine far from houses	
	N	F.O. (%) (n=238)	N	F.O. (%) (n=175)
Mammals	153	64.28	158	90.28
Rabbits	8	3.36	125	71.43
Rodents	140	58.8	30	17.14
Mus sp.	90	37.81	7	4.0
Black rat *Rattus rattus.*	6	2.51	5	2.86
Microtus sp.	4	1.68		
Wood mouse *Apodemus sylvaticus*	38	3.28	17	9.71
Water vole *Arvicola sapidus*	2	0.84	1	0.57
Other small mammals	5	2.1	3	1.71
Mole *Talpa* sp.			2	1.14
Greater white-toothed shrew *Crocidura russula*	5	2.1	1	0.57
Ungulates			17	9.71
Goat *Capra hircus*			3	1.71
Sheep *Ovies aries*			14	8.0
Wild board *Sus scrofa*			2	1.14
Carnivores			3	1.71
Stone marten *Martes foina*			1	0.57
Common genet *Geneta geneta*			2	1.14
Birds	46	19.32	42	24.0
Accipitriformes	2	0.84		
Anseriformes	1	0.42	7	4.0
Apodiformes	2	0.84		
Columbiformes	11	4.62	4	2.29
Galliformes			28	16.0
Red pardridge *Alectoris rufa*	26	10.92	28	16.0
Passeriformes	26	10.92	22	12.57
Aves n.i.	3	1.26		
Reptiles	7	2.94	23	13.14
Lizards	3	1.26	8	4.57
Snakes			7	4.0
Reptiles n.i.	4	1.68	9	5.14
Amphibians			5	2.86
Insects	68	28.57	54	30.85
American Crayfish *Procambarius Clarkii*			26	14.85
Human refuse	181	76.05		

Figure 5.2. resulting from the linear discriminant analysis for the three groups of latrines, in spite of some overlap show a clear separation between the groups of latrines located near and far from human settlements, but those with houses inside the 1km buffer show an intermediate position along the gradient overlapping with both the previous groups.

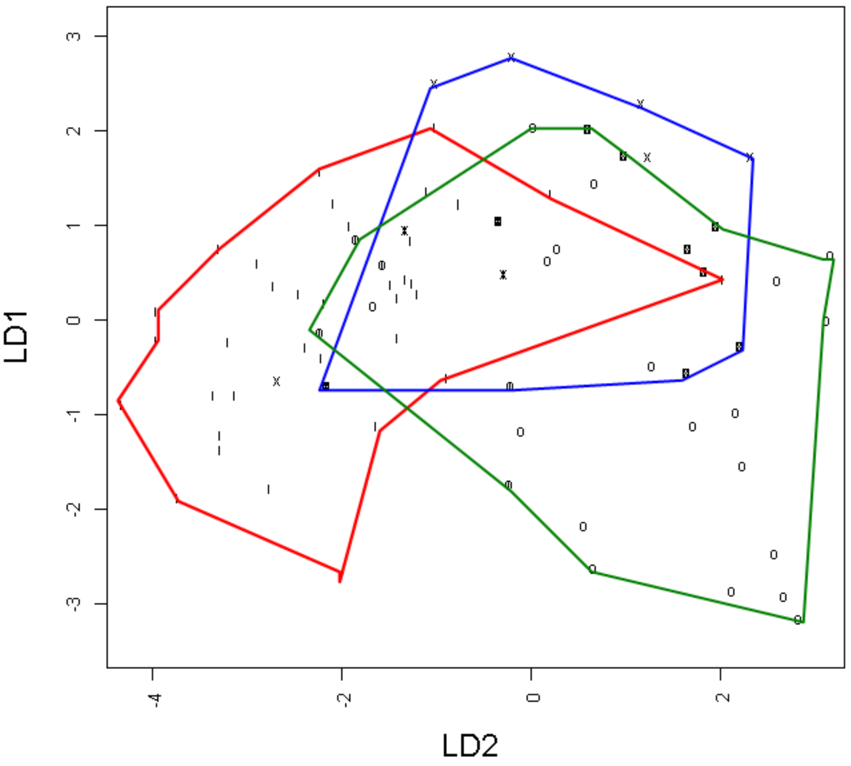


Figure 5.2**.** Scatterplot of the first Linear Discriminant (LD1) function versus the second (LD2). Observations are represented by their group: **I**. represents latrines sites located near houses; **X**. latrines with houses inside the 1km buffer and **O**. latrines without houses inside 1km buffer. The color lines connect the extremes of each group: red line for group of latrines located near houses; blue for the latrines with houses inside the 1km buffer and green for latrines without houses inside 1km buffer.

The prior classification probabilities of each group were 57.6% for the latrine groups located near the houses, 30.0% for those without houses inside the 1 km buffer and 12.4% when there was a house inside de 1km buffer. The first linear discriminant function explains 95.7% of all variability, with the greatest contributions from the positive partial coefficients of reptilesW (2.31), rabbitsW (2.00), rabbitsD (1.99) and negative of crayfishD (-1.87), crayfishW (-1.87), human_refuseD (-1.12) and human_refuseW (-1.06) (Figure 5.3, Table 5.3a).

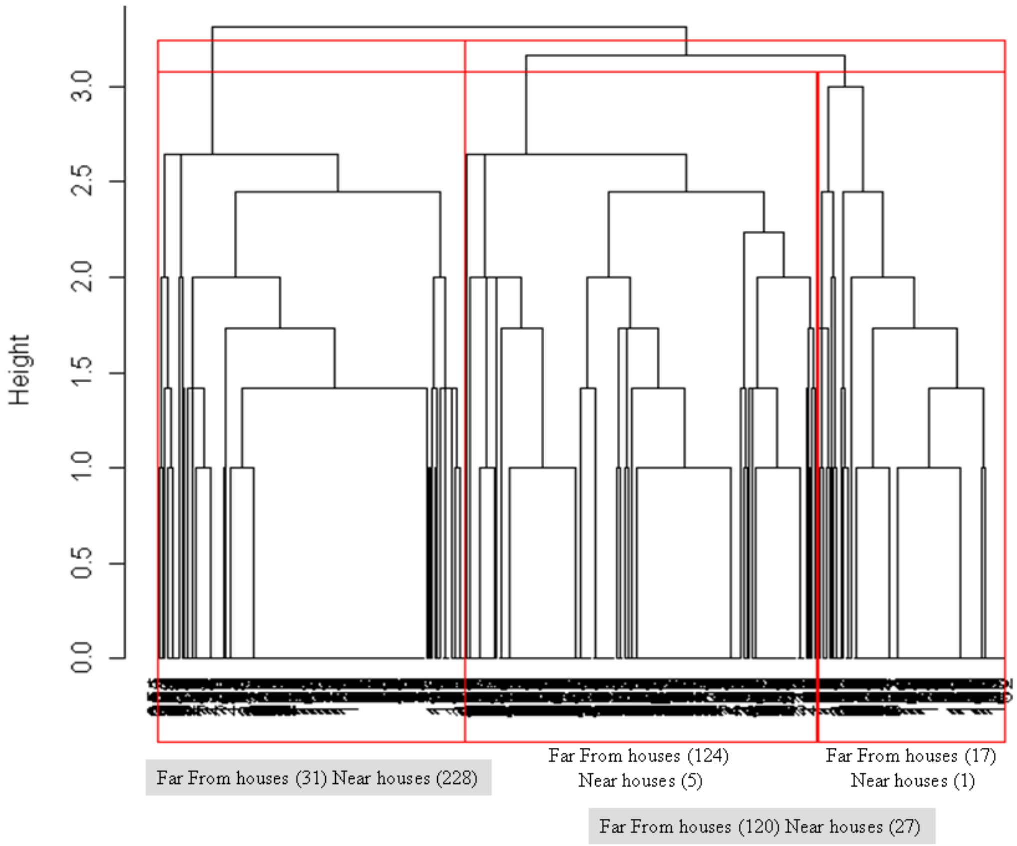


Figure 5.3. Cluster dendogram based on items in each scat, calculated with Hierarchical Cluster Analysis

The hierarchical cluster analysis, at the highest break point, generates two groups, corresponding to 259 and 147 scats respectively. The larger is dominated by scats collected near the houses (88%); in fact, 97.4% of scats collected in the vicinity of households are included in this group. Inversely, the small group is mostly composed by scats originated from natural places far from houses (82%), and 96.5% of that scat sample is here included. At a second level the small plot again subdivided in two other (N=129 and N=18) composed mainly (96.12% and 94.4%) by scats collected in latrines from natural places far from houses. The differences of two plots were compared through MANOVA showing significant main effects between the two first-level groups (Pillai-Bartlett Trace=0.906, $F_{1,404}$=208.05, P < 0.001). RabbitsD ($F_{1,404}$=206.56), aposylD ($F_{1,404}$=11.12), musD ($F_{1,404}$=19.22), Human_refuseD ($F_{1,404}$=49.01), RepteilsD ($F_{1,404}$=18.81), crayfishD ($F_{1,404}$=114.35), rabbitsW ($F_{1,404}$=198.73), crayfisW ($F_{1,404}$=26.39), alerufW ($F_{1,404}$=35.96), insectsW ($F_{1,404}$=9.82) and Human_refuseW ($F_{1,404}$=17.02) were the resources significantly associated to the main effects, with *P* values < 0.001. The same applies to the second-level groups (Pillai-Bartlett Trace=0.906, $F_{1,404}$=207.44, P < 0.001), as well for the independent variables.

Being the rabbit known as the main prey for wildcat in Mediterranean Iberian Peninsula, and appearing as a significant item in the results of previous analyses, we investigated if there was a relation between this species occurrence (presence/absence) and the number of items per scat. No significant relationship was found (r^2 = -0.0047, $F_{1,404}$=0.79, *P*=0.373), contrarily to what occurred with human refuse occurrence (r^2 = 0.142, $F_{1,404}$=66.12, *P*<0.001).

Table 5.3**.** Results from Linear Discriminants Analysis (LD) using the items composition of each scat *(a)* and world domestic cat diet studies *(b)*. Variables Coefficients of (LD) for the two first LD. W. Wet season; D. Dry season

Variables	*Linear Discriminant 1*	**Linear Discriminant 2**
(a)		
rabbitsW	2.006	-0.298
rabbitsD	1.995	-1.605
aposylD	0.065	-0.566
aposylW	-0.670	0.994
musD	-0.975	-0.096
musW	0.655	0.980
passeriformesD	0.952	0.969
passeriformesW	0.914	-3.220
alerufW	1.007	-3.673
alerufD	0.520	-0.419
repteilsD	0.558	0.277
repteilsW	2.31	-3.677
insectsW	0.162	-0.237
insectsD	0.304	1.549
crayfishD	-1.876	-1.176
crayfishW	-1.871	-1.449
Human_refuseD	-1.129	-0.671
Human_refuseW	-1.068	-0.813
(b)		
Rabbits	0.002	0.007
Rodents	0.001	0.021
Mammals	-0.001	0.010
Birds	-0.012	0.004
Reptiles	-0.012	-0.048
Invertebrates	0.001	0.009
Human_refuse	0.048	-0.012

5.3.2 Domestic cat diet in the world

In a global evaluation of domestic cats' diet in the world, mammals appeared as the most consumed resource although dominating species varied with habitat. Rabbits occur more frequently (number of areas that was the item with the biggest FO) in islands (35.4%) and natural areas (40%), being replaced by rodents (60%) in urban places. The second item that appears more times with the biggest FO, in islands, were birds (22.3%). In Natural areas were rodents, human refuse and insects (11.4% each) and invertebrates (30.4%) in urban places. Nevertheless, birds are the most frequent item (number of areas where the item occurred) in world cats diet in islands (100%) and natural areas (94.1%), and human refuse (100%) in urban places, followed by rodents in Islands (74.2%) and birds in urban places (90%), substitute by insects in natural areas (76.4%). The consumption of rabbits is more frequent in islands (48.4%) and natural areas (64.7%), alike human refuse in urban places (100%) and in natural areas (53.3%). The studies revealed that cats consumed in average 4.8 ± 1.8 (±SD) resource types (of a maximum of seven categories considered) in islands, 4.6 ± 1.7 items in urban places and 5.1 ± 1.4 in natural areas. A significant relationship was found between the number of prey items and rabbits consumption in islands (r^2 = 0.406, $F_{1,29}$=21.54, P<0.001) and natural areas (r^2 = 0.330, $F_{1,15}$=8.89, P<0.01). The same was found for human refuse in islands (r^2 = 0.360, $F_{1,29}$=17.92, P<0.001), but not in urban places (r^2 = -0.122, $F_{1,8}$=0.02, P=0.89) and natural areas (r^2 = 0.161, $F_{1,15}$=4.08, P=0.07). Using all the studies as a unique dataset, a significant relationship was obtained between the number of prey items and the consumption of human refuse (r^2 = 0.201, $F_{1,56}$=15.39, P<0.001) and rabbits (r^2 = 0.373, $F_{1,56}$=34.98, P<0.001).

Figure 5.4, that illustrates the linear discriminant analysis for the three groups of studies, shows a greater similarity between domestic cat diet in urban and natural areas, relatively to the islands. The prior probability of each group is 59.0% for islands, 29.5% for natural areas and 11.4% for urban places. The first linear discriminant function explains 71.4% of all variability, with the greatest contributions from the partial coefficients of human refuse (0.0481) and birds (-0.0129), while reptiles (-0.0487) and rodent (0.0219) consumption contributes most for the second discrimant function that explains 28.6% of variability (Table 5.3b).

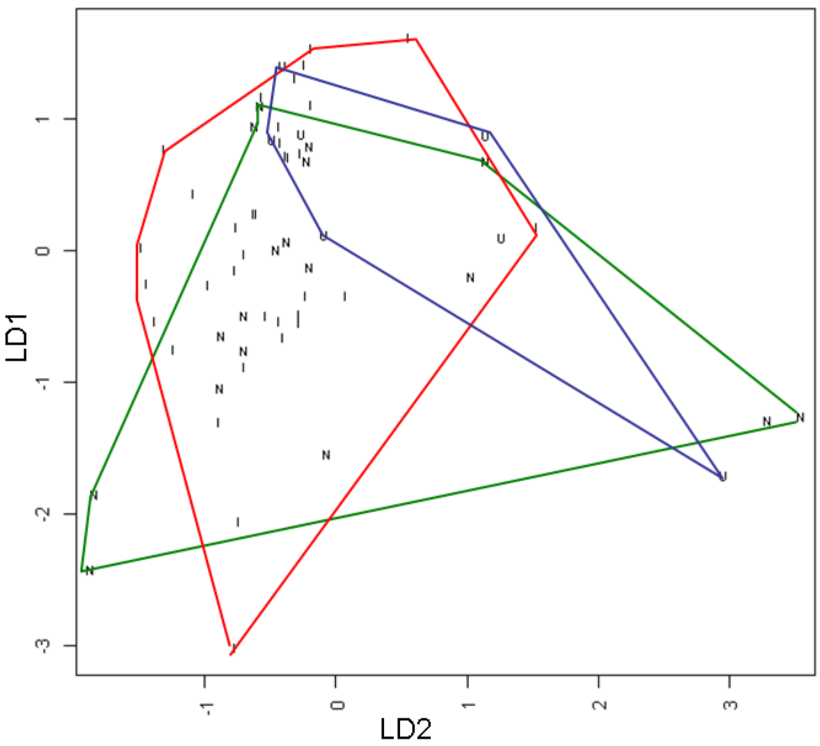


Figure 5.4. Scatterplot of the first Linear Discriminant (LD1) function versus the second (LD2). Observations are represented by their group: I. the studies in islands; U. in urban places and N. in natural areas.

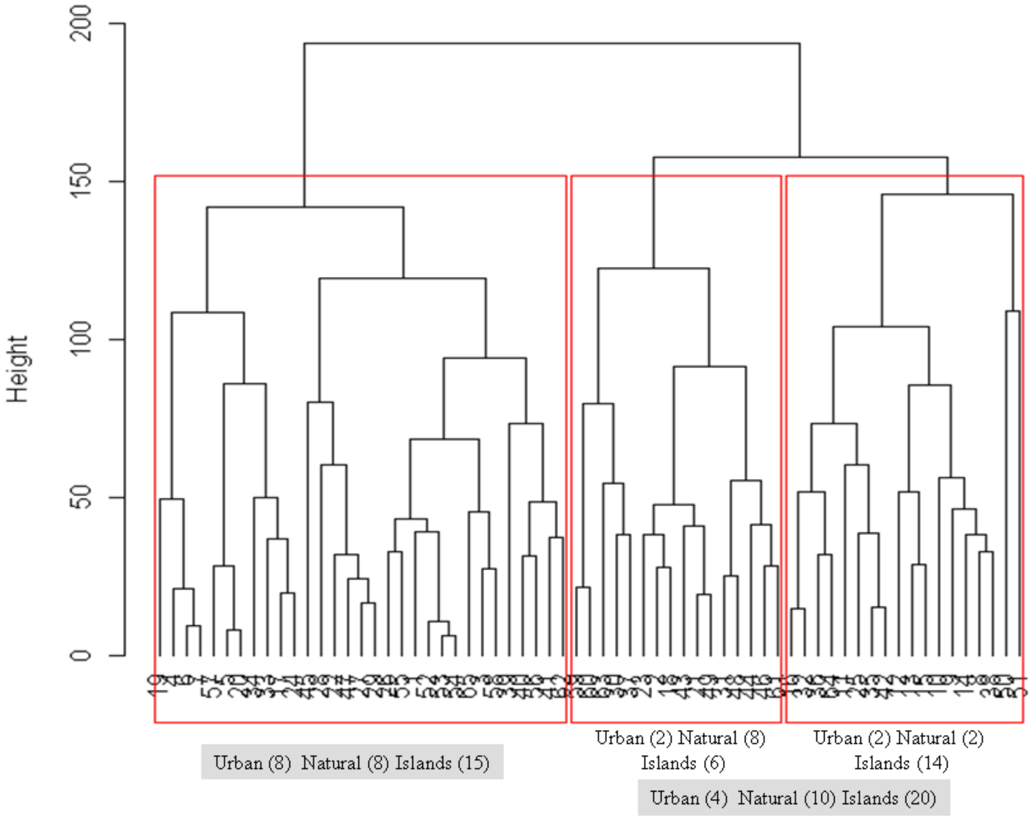


Figure 5.5. Cluster Dendogram based on frequency of ccurrence (FO) of different items in each study, calculated with Hierarchical Cluster Analysis

The hierarchical cluster analysis first separated two groups (A: 52.3% and B: 47.7% of all studies), with greater representation of studies made in natural (25.8%) and urban (22.5%) areas in group A (decreasing in group B to 17.6 % and 11.7%, respectively), while those relating to islands were mostly included (70.5%) in group B (Figure 5.5). At the second hierarchical level, three groups are evident (group A and two new resulting from the sub-division of plot B (B_1: 53% and B_2: 47%, respectively). Studies in islands represent 77.7% of the dataset of B_1, and natural areas 50% of those in B_2. Urban places had a smaller and similar representation in both groups (11.1% in B_1 and 12.5% in B_2). The MANOVA show significant main effects between groups A and B (Pillai-Bartlett Trace=0.840, $F_{1,59}$=39.83, $P < 0.001$) with a significant contribution of mammals ($F_{1,59}$=270.09, $P < 0.001$), rabbits ($F_{1,59}$=8.38, $P < 0.01$) and reptiles ($F_{1,59}$=6.03, $P < 0.05$). Significant effects were also found between the three groups formed at the second hierarchical level (Pillai-Bartlett Trace=0.871, $F_{1,59}$=51.03, $P < 0.001$), having as associated explanatory variables the mammals ($F_{1,59}$=199.96, $P < 0.001$), rabbits ($F_{1,59}$=37.29, $P < 0.001$), birds ($F_{1,59}$=5.15, $P < 0.05$) and reptiles ($F_{1,59}$=6.38, $P < 0.05$).

5.4 DISCUSSION

The results lead to the exclusion of hypothesis 1, has it appears to be a clear differentiation between prey items from latrine groups, according to its distance from houses. This is reinforced by the pattern of trophic regime of domestic cat in the world where there are similarities between urban and natural areas, as opposed to the islands. That is, the diet of the domestic cat expresses its dependence to people, even in natural areas, where the diversity and prey availability is higher. So, we can say that the results best fit hypotheses 2 and 3. In fact, feeding data resulting from scats collected away from homes are in accordance with the trophic regime described for the wildcat (Lozano *et al.* 2006) and that resulting from scats found near houses are close to those describing domestic cat diet in worldwide studies. Nevertheless, a group of latrines that was not located near the human settlements, but included houses in the 1km buffer, did not show a relation with any of the two other groups, probably because they didn't had a strong influence of the most significant items, rabbits and human refuse. The importance of human refuse for the group of latrines located near the houses, is reinforces by the fact that a study in the same area showed an association between domestic cat distribution and human presence, and their abundance with the food resources provided by humans (Ferreira *et al.* submitted - Paper II of this Thesis). A success strategy to reduce feral cats in natural areas is to limit their access to human refuses, once this will have effect on their distribution and density (Ferreira *et al.* submitted - Paper II of this Thesis).

The results of the fine scale study (study area level) revealed that *Felis* sp. scats collected from latrines sites at different spatial influence of human settlements, revealed two important food items, rabbits and human refuse, with the presence of the first associated to scats collected in natural areas and the later from latrines near houses. Also, differences were found in the specific composition of rodents consumed by cats using latrines sites near and far from human settlements. The gender *Mus* sp., most probably the house mouse, was the species with highest occurrence in scats collected at latrine sites near houses, while the wood mouse was most found in those located in undisturbed natural areas. Biró (2005) analysed the wildcat-feral domestic cat food regime in Hungary and found that no human-related prey items occurred in the diet of the wildcat but were preyed by feral cats. The results from the worldwide overview on cats diet are in accordance with thouse found by Liberg (1984), Fitzgerald (1988) and Biró *et al.* (2005), in which feral domestic cats are described as generalist and opportunist species. Wildcats, on the other hand, are considered selective predators that have a facultative feeding strategy, specializing on rabbits when present or on rodents when abundant and rabbits lacking, and shifting to alternative prey, such as invertebrates or reptiles, when rabbits are absent and rodents not very abundant (Lozano *et al.* 2006).

Worthwhile mention was the occurrence of two carnivore species in cat scats found far from human settlements, probably evidencing intraguild-predation events as already reported (e.g. Palomares and Caro 1999). No study on the diet of domestic cats refers the predation on midsize carnivores, already verified in wildcat diet studies – domestic cat (Tryjanowski *et al.* 2002, Biró *et al.* 2005), common genet and stone marten (Moleón and Gil-Sánchez 2003). These are predation evidences, although scavenging should also be an option similarly to what have might happen relatively to the ungulate remains found in 9.71% of scats originating from the same group of latrines. The differences between wildcat and feral domestic cat diets are reflected in the analysis of prey items found in this study, separating most of the scats from latrines near houses from those far from human settlements and located in natural areas, typically associated with domestic and wildcats, respectively. In continental landmasses, as the case of Europe, where prey species co-evolved with a great diversity of predators, like the wildcats, the domestic cats accompanies the man distribution that offers a plenty of food resources that they do not have to share with other predators (Kirkpatrick and Rauzon 1986). In the wild, co-existing carnivores have to compete for prey and because of that intra-guild predation may occur. The differences in domestic cat and wildcat diet reflect their relation with humans, showing the domestic cat less dependent of the prey density.

Inversely the wildcat depends on an optimal hunting strategy for they main preys (Liberg 1984). The overview of the world domestic cat diet confirmed mammals as the more frequent main prey, represented by rabbits in the islands and natural areas and rodents in urban places. Nevertheless, birds are the most frequent (number of areas where the item occurred) item in world cats diet in islands and natural areas, substitute by human refuse in urban places. Another interesting data is that the number of different items consumed by domestic cats increased with the human presence, reinforcing the nature of a generalist and opportunistic species. This positive relation, found in islands, is consequence of the increase prey diversity due to the presence of exotic species, linked to human presence, like house mice and rabbits in many islands (Nogales and Medina 1986). However, this result may be biased by the larger representativity of studies in islands. Identical results, were obtained in the fine scale analysis (latrine groups) where human refuse was significantly related to the number of prey consumed, possibly because human settlements promote the presence of opportunistic prey, like house mice. Unlike wildcats, domestic cats mainly eat young rabbits and the hunting techniques appear not to be adapted to exploiting adult rabbits (Liberg 1984, Catling 1988). Our worldwide review confirmed that the consumption of rabbits is associated with an increase in the diversity of items consumed. The same applies to the wildcat diet, with trophic diversity increasing with the inclusion of alternative prey such as rabbits (Lozano *et al.* 2006). The urban and natural areas seem to describe better the food regime of domestic cat in continental land mass, with a diet pattern that is consequence of the relationships between domestic cat and humans. The food regime of domestic cats in islands, on the other hand, must be analysed in the context of meso-predator release (Fitzgerald 1988, Arnaud *et al.* 1993), due to the absence of competitors and top predators that lead to the possibility of exploiting the whole diversity of available resources, that in many islands is lower. The number of carnivore species with more than 2kg, which may compete and/or predate domestic cats, and potentially occur in the geographic areas of each study, represent in islands an average of 0.22 ± 0.4 carnivore species, 1.7 ± 1.0 in urban places and 2.3 ± 1.1 in natural areas. This knowledge is relevant in the context of extensive ecological studies. Variation in feeding behaviour among domestic cat populations over a broad scale of environmental conditions, is quite important to understand the relation between domestic cats and food resources in continental natural areas, as well as potential competitive effects with the wildcat. Nevertheless, the small sample of studies in continental natural areas, with the exception of Australia, limits the analysis on the feeding ecology of the species due to the lack of robust results. This information is vital to know more about the mechanisms that limit the capacity of expansion and colonization of natural areas by domestic cats. In these areas, prey developed anti-predatory strategies and are preyed by several carnivore species with which domestic cats have to compete. Furthermore, human absence implies that human refuse and comensal prey species, like house mice, are not available for domestic cats, thereby limiting their expansion in these areas.

Implications on wildcat conservation

This study supports the idea that, in continental natural areas of Iberian Peninsula, the domestic cat depends on human refuse and comensal prey, reinforcing the results obtained in the study on domestic cats spatial ecology in the study area (Ferreira *et al.* Submitted - Paper II of this Thesis). On the other hand, rabbits formed the main component of the diet of wildcats in Mediterranean Iberian Peninsula (Gil-Sánchez *et al.* 1999, Lozano *et al.* 2006) and species distribution depends greatly on rabbit's abundance (Ferreira *et al.* 2003, Monterroso *et al.* 2009). Unlike, wildcat, the feral domestic cats only occasionally consumed lagomorphs (Borkenhagen 1978 and 1979, Fitzgerald 1988), eating mostly juveniles and sick individuals, and only on exceptional occasions rabbits were the main prey item (Liberg, 1984). Nevertheless, if the food resources associated with human presence disappear or became limit, the domestic-feral cats may start foraging in wildcat habitats and compete for shared resources (Biró *et al.* 2005). Additionally, this will promote direct encounters with wildcat and other carnivore species, and increase the risk of hybridization and disease transmission (Pierpaoli *et al.* 2003, Biró *et al.* 2004, Germain *et al.* 2008). To decrease domestic cats abundance in natural areas of Iberian Peninsula is therefore crucial for wildcat conservation.

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PART IV *– DOMESTIC CATS AS DISEASE RESERVOIRS TO WILDLIFE:*

THREATS TO WILDCATS IN NATURAL-RURAL AREAS

Chapter 6

VIRUS PREVALENCE IN CAT POPULATIONS.

IMPLICATIONS FOR WILDLIFE CONSERVATION, WILDCATS IN PARTICULAR

Paper IV

VIRUS PREVALENCE IN CAT POPULATIONS: IMPLICATIONS FOR WILDLIFE CONSERVATION, WILDCATS IN PARTICULAR.

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Virus Prevalence in Cat Populations: Implications for Wildlife Conservation, Wildcats in particular

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Abstract

The domestic cat *Felis catus* is the natural host of several viruses that infect feline populations worldwide and, sometimes, other wild carnivores. The most important viruses carried by domestic and wild cats, and that of concern in this study, are feline calicivirus (FCV), feline herpes virus (FHV), feline panleukopenia (FPV), feline coronovirus (FCoV), feline leukaemia virus (FeLV) and feline immunodeficiency virus (FIV). To obtain a global overview of feline-important virus prevalence in domestic (*Felis catus*) and wild cats (Irimote cat *Felis iriomotensis*, sand cat *Felis margarita*, and European wildcat *Felis silvestris*) we analyzed the data of twenty five studies published in five continents (Europe - n=11, Asia - n=6, Australia – n=1, and America - n=7), referring to a total of 36 areas. Hypotheses tested are: 1) Species density and social structure affects prevalence: high species densities promote high prevalence for the milder diseases, and prevalence rates increases in social groups; 2) Virus occurrence is related with other virus prevalence. To understand the influence of environment (island, natural, rural and urban), cat species and global viral prevalence in the occurrence of the six focal virus under analysis we use generalised linear models and the presence/absence of each virus type per cat sample. The environment and species were present in the FIV, FCoV and FPV best models, while other virus prevalence was significant for FeLV, FCV and FHV. The best model for FIV corroborates the hypothesis 1), with a “positive” contribution of urban and “negative” of natural areas, as the more important descriptors for virus occurrence. Further, FIV prevalence appears correlated with species sociability, being higher in rural and urban areas. The hypothesis 2), that the occurrence of a certain type virus is relate with other virus prevalence, was confirmed in the models for all six viruses, with special relevance for FeLV contributions. The most virulent virus (FIV and FeLV) need host direct contacts for propagation and once established, their prevalence affects other virus occurrence. And for some virus, like FeLV, the distribution of cats nucleus in natural areas is a determinant factor for virus propagation. In natural areas the cats densities and distribution are associated to human presence, and the availability of resources provided, directly or indirectly, by man.

Key Words: Wildlife diseases; domestic cat *Felis catus*; wildcat *Felis silvestris*; feline viruses; feline leukaemia virus (FeLV); feline immunodeficiency virus (FIV); species density and sociability

6.1 INTRODUCTION

The domestic cat *Felis catus* is the natural host of several viruses that infect feline populations worldwide and sometimes even other wild carnivores (Driciru *et al.* 2006, Millán *et al.* 2009b). The most important viruses carried by cats are feline calicivirus (FCV), feline herpes virus (FHV), feline panleukopenia (FPV), feline coronovirus (FCoV), feline leukaemia virus (FeLV) and feline immunodeficiency virus (FIV) (Daniels *et al.* 1999, Leutenegger et al. 1999, Fromont *et al.* 2000, Millán *et al.* 2009a). The high variability in virus prevalence is influence to cat social organization and mating system, which can be explained by the mode of transmission of these viruses (Courchamp *et al.* 1998, Fromont *et al.* 2003). The most common ways of FeLV transmission are bites, nasal secretions, mutual grooming, shared food and water. The adult cats are more resistant to FeLV than kittens, which are infected by the positive females during gestation or shed virus in milk (Green 1990, Arjona *et al.* 2000). FeLV related immunosuppression causes increased susceptibility to bacteria and other viral infections, and his persistence in the environment does not exceed a few hours (Green 1990, Murphy *et al.* 1999, Quimm *et al.* 2002). Like FeLV, FIV has a worldwide distribution and is related to cat density. The primary mode of FIV transmission, that is also not viable in environment, is through bite wounds, and casual non aggressive contact among cats rarely results in the spread of the virus. In fact, the infection is characterized by risk factors linked to aggressive behaviour: old mature male adults having dispersed are more likely to be infected (Fouchet *et al.* 2009). The maternal transmission occurs primarily when the female is exposed to FIV and becomes infected during gestation or lactation. Spread of FIV through sexual contact is an uncommon event. The prevalence of FIV affects, in general, between one and three percent of the population (Green 1990). Another virus that needs contact between individuals to spread is FHV since cannot exist outside of the host; the way of transmission is through respiratory and oral secretions (Green 1990, Murphy *et al.* 1999, Packer *et al.* 1999, Quimm *et al.* 2002). Mortality rates are higher in kittens or if individuals are immunocompromised for another reason (e.g. cats with FeLV or FIV, stress, illness) (Packer *et al.* 1999). Neonatal kittens are exposed to FHV during birth if their mother is infected with the virus (Quimm *et al.* 2002). Other group of viruses (FPV, FCV, FCoV) does not need contact between individuals and mode of transmission, besides oral, nasal and ocular secretions, can be through faeces for FCV and FCoV, and also urine for FPV (Green 1990, Murphy *et al.* 1999, Packer *et al.* 1999, Quimm *et al.* 2002). In addition, fleas may transmit FPV from infected to susceptible cats during the acute stage of the disease (Green 1990). Nevertheless, they present different environmental persistence: FCV can survive for as long as one week, FCoV from hours to weeks and FPV until a year (Green 1990, Packer *et al.* 1999). FCV is very common in kittens and multicat households and affects all cat breeds. FCoV is a very contagious virus and usually infect cats under 3 years of age, however almost never crosses the placenta to the unborn kitten (Green 1990). Most kittens usually become infected between 5-7 weeks of age, when the protective antibodies that they receive from their mother's milk are no longer active (Green 1990). FPV infection can be a fatal primary disease, affecting cats of all ages, and it is primarily a disease of kittens (Green 1990, Murphy *et al.* 1999, Steinel *et al.* 2001). The characteristics of the disease may vary considerably from population to population and from outbreak to outbreak. In susceptible populations, the disease may affect nearly 100 percent of individuals, resulting in a mortality rate that may vary between 25 to 75 percent (Packer *et al.* 1999).

Cats are found in a wide variety of ecological conditions and have developed highly variable population structures, ranging from solitary living individuals in low-dense populations to social groups in high-density populations (Liberg and Sandell 1988). Infectious agents play a relevant role in ecosystems, and are an important element in the dynamics of host populations (Altizer *et al.* 2003). Nevertheless, host-pathogen relationship has being disturbed mainly by environmental changes caused by human activity (Daszak 2000, Deem *et al.* 2001). This is frequently associated with the pathogen introduction into wild populations by man, or with a change in the host's susceptibility to infections (Grenfell and Dobson 1995). Incidence itself depends on the relation between population size, density, and rate of contact for efficient disease transmission. Characteristics like density and spatial structure of domestic cats populations depend on the abundance and distribution of resources linked to human presence (Kerby and McDonald 1988). In fact, there are notable differences in the organization of cat populations in terms of dispersal pattern, mating system and individual behaviour, according to resources distribution. At very low density (less than 10 cats km^{-2}) as in low humanized natural-rural areas, individual home ranges are larger and intra-specific encounters among adult cats are uncommon (Kerby and Mcdonald 1988). However, these environments favour the contact between domestic cat and other carnivore species and two types of interactions may occur: intraguild predation, particular in encounters with red foxes *Vulpes vulpes,* Iberian lynxes *Lynx pardinus* or other large carnivores, or agonistic behaviours and hybridization with wildcats (e.g. Europena wildcat *Felis silvestris*).

The occurrence and prevalence of viral pathogens varies because of several factors like, habitat structure, human presence, domestic cat and carnivore species population size and distribution. For example in Scotland, were the contacts between the domestic cats and the wildcats were frequent, the later were commonly infected with the major viruses of the domestic cats, except for FIV (Daniels *et al.* 1999). Low prevalence of diseases was found in Slovenian wildcats, suggesting a low level of contact between both populations (Račnik *et al.* 2008), but domestic cat populations change their density, sociability and size of family groups in function of availability of resources (Liberg and Sandell 1988).

Our interest focused on six (FeLV, FIV, FHV, FCV, FPV and FCoV) most common virus affecting domestic cat and wildcat populations (Daniels *et al.* 1999, Leutenegger *et al.* 1999, Fromont *et al.* 2000, Millan *et al.* 2009a) in order to test the a priori hypotheses:

1. Species density and structure affects prevalence;
    i. High species densities promote high prevalence for the milder diseases;
    ii. The prevalence rates increase in social groups.
2. The occurrence of a virus is related with other virus prevalence

6.2 METHODS

To obtain a global overview of feline-important virus prevalence in domestic (*Felis catus*) and wild cats (Irimote cat *Felis irimotensis*, sand cat *Felis margarita*, and

European wildcat *Felis silvestris*) we analyzed the data of twenty five studies published studies address in five continents: Europe (n=11), Asia (n=6), Australia (1) and America (n=7), including a total of 36 areas (Table 6.1).

Table 6.1**.** Sources, continent, environment, number of study sites, cat species analyzed and virus type. The virus analysed from worldwide studies were Feline Immunodeficiency Virus (FIV), Feline Leukaemia (FeLV), Feline Herpesvirus (FHV), Feline Panleukopenia Virus (FPV), Feline Calicivirus (FCV) and Feline Corona Virus (FeCoV). Species: Fc-*Felis catus*; Fs-*Felis silvestris*; Fi-*Felis iriomotensis*; Fm-*Felis margarita.*

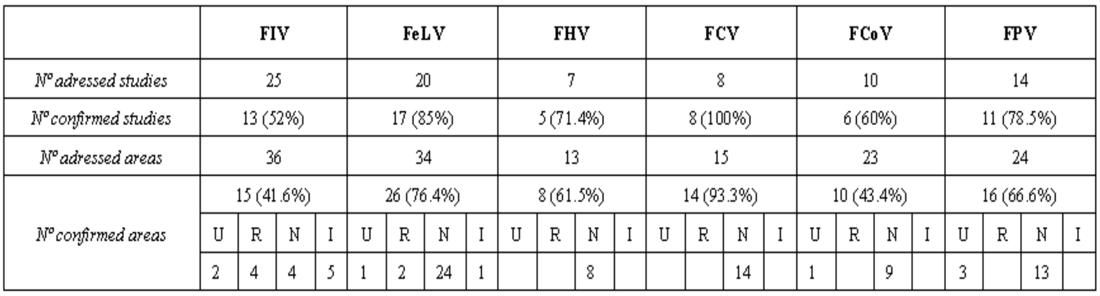
Autors	Continent	Envir.	Nº study sites	Species	Virus
1. Artois and Remond 1994	Europe	Natural	1	Fs	FIV, FeLV, FCV, FHV, FPV
2. Clifford *et al*. 2006	North America	Island	4	Fc	FPV
3. Courchamp *et al*.,1998	Europe	Rural	1	Fc	FIV
4. D'Amore *et al*. 1997	North America	Urban	1	Fc	FIV
5. Daniels *et al*. 1999	Europe	Natural	1	Fs	FIV, FeLV, FCV, FHV, FPV
6. Danner *et al*. 2007	North America	Island	1	Fc	FIV, FeLV
7. Fiorello *et al*. 2004	South America	Natural	1	Fc	FIV, FeLV, FCV, FHV, FCoV, FPV
8. Fromont *et al*. 2000	Europe	Natural	1	Fs	FIV, FeLV
9. Fushuku *et al*. 2001	Asia	Natural	1	Fi	FIV, FeLV, FCoV, FPV
10. Leutenegger *et al*. 1999	Europe	Natural	3	Fs	FIV, FeLV, FCV, FHV, FCoV, FPV
11. Little *et al*. 2009	North America	Urban	1	Fc	FIV, FeLV, FPV
12. López *et al*. 2009	Europe	Natural	2	Fc	FeLV
13. Luria *et al*. 2004	North America	Urban	1	Fc	FIV, FeLV, FCoV
14. Mainka *et al*. 1994	Asia	Natural	1	Fc	FPV
15. MC Orist *et al*. 1991	Europe	Natural	1	Fs	FIV, FeLV
16. Millán *et al*. 2009a	Europe	Natural	1	Fs	FIV, FeLV, FCV, FHV, FCoV, FPV
17. Miyazawa *et al*. 1998	Asia	Urban	1	Fc	FIV, FeLV
18. Mochizuki *et al*. 1990	Asia	Natural	1	Fi	FIV, FeLV, FCV, FHV, FPV
19. Nakamura *et al*. 2000	Asia	Urban	1	Fc	FIV, FeLV
20. Norris *et al*. 2007	Australia	Urban	2	Fc	FIV
21. Ostrowski *et al*. 2003	Asia	Natural	1	Fs, Fc, Fm	FIV, FeLV, FCV, FHV, FPV
22. Pointier *et al.* 1998	Europe	Rural	1	Fc	FIV, FeLV
23. Račnik *et al*. 2008	Europe	Natural	3	Fs	FIV, FeLV
24. Santos *et al*. 2009	Europe	Natural	1	Fs	FPV
25. Suzán *et al*. 2005	North America	Urban	3	Fc	FPV

The studies that used clinical data from house cats were not selected in our analysis because they were not representative of urban-feral populations. Fourteen studies (56%) refered to natural areas, seven (23%) to urban, two (8%) to rural areas, and two (8%) to islands The studies were performed in areas that exemplify different cats densities, ranging from natural habitats, with lower densities, to urban areas characterized by high-density populations (Liberg and Sandell 1988). To understand the influence of environment, cat species and other virus prevalence in the six focal virus occurrence, we used generalised linear models with a binomial error distribution and a logit link function in R software. Presence/absence of each virus per cat sample was related with cat species, environment (island, natural, rural and urban) and the other virus prevalence in the sampled population, using direct logistic regression analyses in which all predictors entered the equations simultaneously (Tabachnick and Fidell 1996). Before fitting these models, we calculated a correlation matrix among all the predictor variables using Spearman rank coefficients (Sokal and Rohlf 1995); candidate models containing highly correlated predictors (R >0.7) were modified or eliminated from the dataset. Candidate models were compared according to the Akaike Information Criterion (AIC) that provides an objective tool to rank these models and thus quantify the evidence for each hypothesis (Burnham and Anderson 2002). Knowing that species sociability increases contacts between individuals, we correlate the social behaviour of species (domestic cat, Irimote cat, sand cat and wildcat) with virus occurrence and prevalence. Despite some cats cohabiting in colonies, domestic cats do not have a social survival strategy (Bradshaw *et al.* 1996). Nevertheless, we used the term sociability in the perspective of the existence of groups of individuals that cohabite, and regularly share resources. Therefore, we consider domestic cat as a social species and the other as no social species.

6.3 RESULTS

The worldwide average prevalence rates in cat populations in natural areas was 21.9% for FIV, 29.9% for FeLV, 39.7% for FCV, 7.7% for FHV, 2.3% for FCoV and 17.5% for FPV. From the twenty five worldwide studies addressed to analysed virus prevalences in urban, rural, natural areas and islands, FCV and FeLV presents the mayor number of positives, mostly from natural areas. In contrast, FIV with lower confirmations for FIV (Table 6.2).

Table 6.2. Number of addressed worldwide studies, of the total dataset (n=25), performed in Urban (U), Rural (R), Natural (N) and Islands (I), that analysed prevalence of six virus types: Feline Immunodeficiency Virus (FIV), Feline Leukaemia (FeLV), Feline Herpesvirus (FHV), Feline Panleukopenia Virus (FPV), Feline Calicivirus (FCV) and Feline Corona Virus (FeCoV).



	FIV				**FeLV**				**FHV**				**FCV**				**FCoV**				**FPV**			
N° adressed studies	25				20				7				8				10				14			
N° confirmed studies	13 (52%)				17 (85%)				5 (71.4%)				8 (100%)				6 (60%)				11 (78.5%)			
N° adressed areas	36				34				13				15				23				24			
N° confirmed areas	15 (41.6%)				26 (76.4%)				8 (61.5%)				14 (93.3%)				10 (43.4%)				16 (66.6%)			
	U	R	N	I	U	R	N	I	U	R	N	I	U	R	N	I	U	R	N	I	U	R	N	I
	2	4	4	5	1	2	24	1			8				14		1		9		3		13	

The FCV, FeLV and FIV seem to have higher prevalence rates then the other virus, inversely to FCoV that showed the lowest value. However, this analysis may be biased by the size of the samples (Table 6.3). In the worldwide studies of cat populations FCV presents the higher values of virus prevalence in domestic cats from natural areas and second more high, after FeLV, in wildcats.

Table 6.3. Worldwide virus (FIV, FeLV, FHV, FCV, FCoV and FPV) prevalence rates and respective sample size (average, standard deviation) in cats (domestic and wildcats) populations in four environments: rural, natural, urban and islands.

		Rural	**Natural**	**Urban**	**Islands**
FIV	nº. of areas size	n=9	n=20	n=7	**n=4**
	Prevalence (averg.±SD)	11.8±4.2	21.9±2.6	12.3±86.6	**19.7±22.9**
	Sample size (averg.±SD)	96.2±133.1	26.8±14.9	398±557.9	**26.5±24.9**
FeLV	nº. of areas size	n=2	n=24	n=4	**n=4**
	Prevalence (averg.±SD)	11.9±5.7	29.9±32.7	1.5±1.7	**7.1±11.2**
	Sample size (averg.±SD)	245.5±177.5	26.0±15.85	557±705.5	**24.7±26.2**
FHV	nº. of areas size	-	N=13	-	-
	Prevalence (averg.±SD)		7.7±8.8		
	Sample size (averg.±SD)		24.4±15.7		
FCV	nº. of areas size	-	N=15	-	-
	Prevalence (averg.±SD)		39.7±29.1		
	Sample size (averg.±SD)		24.1±17.7		
FPV	nº. of areas size	-	N=21	n=3	-
	Prevalence (averg.±SD)		17.5±31.1	67±57.1	
	Sample size (averg.±SD)		22.1±16.2	30±146.7	
FCoV	**nº. of areas size**	-	**N=23**	**n=1**	-
	Prevalence (averg.±SD)		**2.39±3.46**	**18.3**	
	Sample size (averg.±SD)		**27.1±16.5**	**553**	

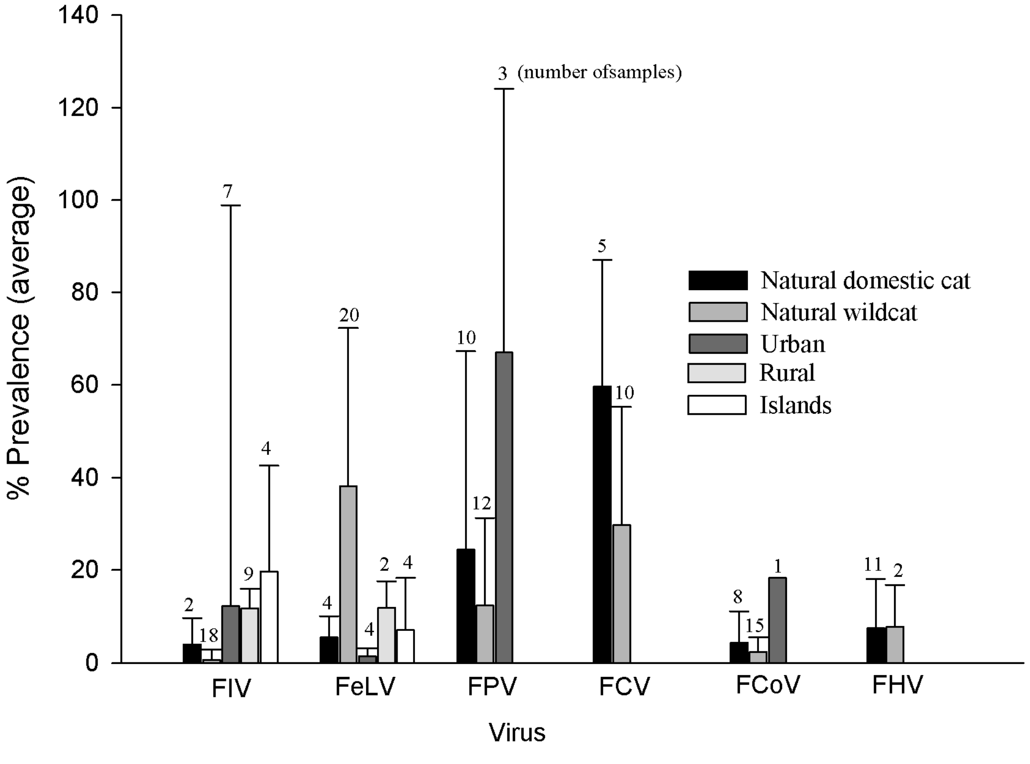
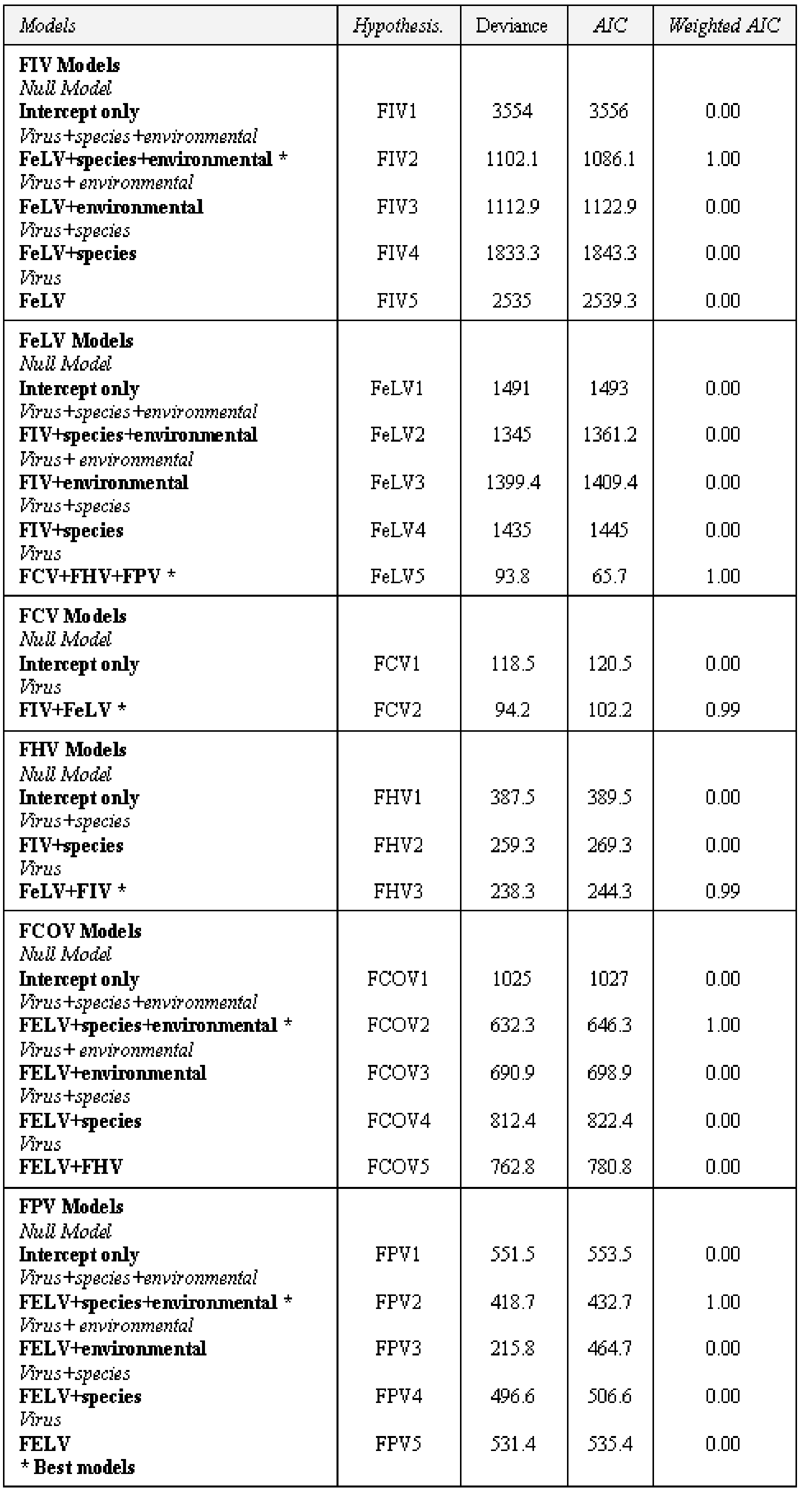


Figure 6.1. Worldwide prevalence rates (average, Standard Deviation) in cats populations for the FIV, FeLV, FPV, FCV, FCoV and FHV virus in four environments: Natural, Rural, Urban areas and Islands. The numbers indicate the number of analyzed samples.

Table 6.4**.** Summary of models with potential factors that affects virus occurrence in cats population of worldwide studies, based on host species, environmental types and other virus prevalence. Each hypothesis is represented by an alternative statistical model, and Akaike Information Criterion (AIC) provides an objective tool to rank the models for each virus. A total of 20 models were run. The best models present lowest AIC value (Burnham and Anderson, 2002).



Models	*Hypothesis.*	Deviance	*AIC*	*Weighted AIC*
FIV Models				
Null Model **Intercept only**	FIV1	3554	3556	0.00
Virus+species+environmental **FeLV+species+environmental ***	FIV2	1102.1	1086.1	1.00
Virus+ environmental **FeLV+environmental**	FIV3	1112.9	1122.9	0.00
Virus+species **FeLV+species**	FIV4	1833.3	1843.3	0.00
Virus **FeLV**	FIV5	2535	2539.3	0.00
FeLV Models				
Null Model **Intercept only**	FeLV1	1491	1493	0.00
Virus+species+environmental **FIV+species+environmental**	FeLV2	1345	1361.2	0.00
Virus+ environmental **FIV+environmental**	FeLV3	1399.4	1409.4	0.00
Virus+species **FIV+species**	FeLV4	1435	1445	0.00
Virus **FCV+FHV+FPV ***	FeLV5	93.8	65.7	1.00
FCV Models				
Null Model **Intercept only**	FCV1	118.5	120.5	0.00
Virus **FIV+FeLV ***	FCV2	94.2	102.2	0.99
FHV Models				
Null Model **Intercept only**	FHV1	387.5	389.5	0.00
Virus+species **FIV+species**	FHV2	259.3	269.3	0.00
Virus **FeLV+FIV ***	FHV3	238.3	244.3	0.99
FCOV Models				
Null Model **Intercept only**	FCOV1	1025	1027	0.00
Virus+species+environmental **FELV+species+environmental ***	FCOV2	632.3	646.3	1.00
Virus+ environmental **FELV+environmental**	FCOV3	690.9	698.9	0.00
Virus+species **FELV+species**	FCOV4	812.4	822.4	0.00
Virus **FELV+FHV**	FCOV5	762.8	780.8	0.00
FPV Models				
Null Model **Intercept only**	FPV1	551.5	553.5	0.00
Virus+species+environmental **FELV+species+environmental ***	FPV2	418.7	432.7	1.00
Virus+ environmental **FELV+environmental**	FPV3	215.8	464.7	0.00
Virus+species **FELV+species**	FPV4	496.6	506.6	0.00
Virus **FELV**	FPV5	531.4	535.4	0.00
*** Best models**				

FPV was more prevalent in domestic cats from urban areas, the same as FIV in islands (Figure 6.1). Modeling results (Table 6.4) for the occurrence of each virus revealed that FeLV prevalence was present in all best models for the other five viruses, being the variable most important in four (Table 6.5).

Table 6.5**.** Variables included in best models in respect to six virus (FIV, FeLV, FCV, FHV, FCoV and FPV) occurrence, Standardized Estimates, Standard errors (SE), Z test values and significance *P* (>Z).

	variables	**Estimate**	**S.E.**	**Z value**	**Pr(>|z|)**
FIV	**(intercept)**	-0.157	0.158	-0.998	0.318
	Environ_natural	-2.481	0.240	-10.340	<.0001
	Environ_rural	19.710	521.646	0.038	0.969
	Environ_urban	3.515	0.210	16.682	<.0001
	FeLV_prev.	-0.191	0.105	-1.810	0.070
FeLV	**(intercept)**	4.487	1.032	4.386	<.0001
	FCV_prev.	0.652	0.716	0.910	0.363
	FHV_prev.	-3.596	0.899	-3.997	<.0001
	FPV_prev.	2.118	0.785	2.697	0.007
FCV	**(intercept)**	9.240	506.913	0.018	0.985
	FIV_prev.	9.305	813.340	0.011	0.990
	FeLV_prev.	1.475	0.603	2.445	0.014
FHV	**(intercept)**	-0.940	0.206	-4.560	<.0001
	FIV_prev.	3.220	171.886	0.019	0.985
	FeLV_prev.	0.060	0.008	7.056	<.0001
FCoV	**(intercept)**	0.483	0.232	2.081	0.0374
	Species_Fi	-21.350	4300.0	-0.005	0.996
	Species_Fm	-21.510	4739.0	-0.005	0.996
	Species_Fs	-0.589	0.275	-2.142	0.032
	Environ_natural	0.303	0.321	0.944	0.345
	Environ_urban	20.020	754.0	0.027	0.978
	FeLV_prev.	0.001	0.0003	5.163	<.0001
FPV	**(intercept)**	0.585	0.204	2,870	0.004
	Species_Fi	-1.814	0.437	-4.148	<.0001
	Species_Fm	16.771	1743.248	0.010	0.992
	Species_Fs	-1.558	0.365	-4.258	<.0001
	Environ_natural	1.646	0.356	4.621	<.0001
	Environ_urban	18.612	711.678	0.026	0.979
	FeLV_prev.	1.002	0.178	5.618	<.0001

The environment and species was also retained in best models for FIV, FCoV and FPV, but the first was only significant for FIV while species was for FPV. Other virus prevalence are the unique variables in the best models for FeLV, FCV and FHV, with FeLV and FIV viruses representing the only descriptors in models selected for FCV and FHV. In the FeLV best model, the contributions of FHV and FPV were highly significant, $p_{\text{value} < 0.001}$ and $p_{\text{value} = 0.007}$ respectively, with a negative influence of FHV prevalence for FeLV occurrence. Natural environments, negatively influenced FIV occurrence, while in urban areas show a positive contribution. The occurrences of FCV, FHV and FCoV were significantly associated with FeLV prevalence. Also, for the FPV presence is still influent, together with the host species and the environment where the host population is located (Table 6.5). A significant positive correlation was found between species sociability and FIV (Spearman's rank correlation test: $r_s = 0.703$, $P < 0.0001$, n = 40) and FHV ($r_s = 0.556$, $P < 0.03$, n=15) prevalences, and negative with FeLV ($r_s = -0.508$, $P < 0.0023$, n=34.

6.4 DISCUSSION

In our hypothesis, high species densities promote high prevalence for milder diseases, which increases with the existence of social groups. Our results support this hypothesis once, the best model for FIV includes the "positive" contribution of urban and the "negative" of natural areas, as the more important descriptors for the virus occurrence. Moreover, the FIV prevalence appears correlated with species sociability, reflecting the worldwide data where the virus prevalence is higher in rural and urban areas (*see* Figure

1). Courchamp *et al.* (1998) refers that FIV is practically solely transmitted by bitting and therefore social behaviour of species can favour virus transmission in rural areas where cats show a well-marked polygynous mating system. However if cats nucleus are small and spaced, encounters between individuals may be a very rare event, especially if the habitat environmental is not favourable (less humanized) for domestic cat movements. Our second hypothesis, that virus occurrence is influenced by the prevalence of other virus, seems to be confirmed in the models for all six viruses, with special relevance for FeLV. The, negative correlation found between FeLV and species sociability, could be the expression of virus impact in populations with polygynous mating systems, once the fertility of viremic females is strongly reduced, resulting in high rates of abortion, and the few live kittens are viremic at birth and die early (Hoover *et al.* 1983). In natural or rural populations, when farms are connected to villages or when several surrounding populations lead to high numbers of feral cats roaming between populations, FeLV could be continuously present in the area (Fromont *et al.* 2003). Therefore, the impact of FeLV in domestic cats population growth increases and disease may act on distant populations through dispersal (Frommont *et al.* 2003), like wildcat populations in natural areas. In a detailed study that assessed FeLV risk, Fromont *et al.* (1998) hypothesized, that small population size may be responsible for too few contacts among cats to maintain persistent infection. The negative contribution of FHV prevalence to FeLV occurrence reinforces the idea of virus interactions. Therefore, we expect an increase of virus prevalence in high-density populations where the contacts between individuals are more frequent, specially in species with well-marked social behaviours.

Moreover, each viral agent has its mode of propagation, which is dependent on individual interactions in the host populations. In wildcat populations, the virus prevalence depends largely on stress conditions of their populations, if we exclude contact with domestic cats. These in turn, exhibit different population structures according to the type of occurrence areas: urban, rural and natural areas. Accordingly, it is expected that viruses respond to this change in host population structure. The domestic cat serves as a vehicle for dispersion of viral agents between their colonies and the wildcat populations. Therefore, free-ranging cats hosting viral agents in natural areas have more opportunity to interact with other carnivores and therefore increase the risk of diseases transmission (Millán *et al.* 2009).

Implications on wildcat conservation

The occurrence and prevalence of viral agents are very dependent on the spatial and social structure of the host population (Fromont *et al.* 2003) and for some virus, like FeLV, the distribution of cats nucleus in natural areas is a determinant factor for virus propagation. In natural areas cats distribution and densities are associated to human presence, and resources availability provided, directly or indirectly, by man (Ferreira *et al.* submitted - Paper II of this Thesis). In addition, the human activities like agro-forestry, agriculture activities and road densities favours domestic cat expansion, increasing the intra-specific and inter-specific contacts, and for the fragmentation of wildcat populations. This is quite relevant because the fragmentation of species populations, associate with human persecution, conduct to the existence of stress factors, that affects the virus prevalence (Pontier *et al.* 2009).

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PART V – *DISCUSSION.*

LESSONS FOR WILDCAT CONSERVATION

CHAPTER 7

General Discussion

7. General discussion

7.1 INTRODUCTION

The idea behind the thesis relates to the factors that, by force of human presence and activities, may affect wildcat populations in Iberian Peninsula. In general, the factors that critically affect the survival of carnivores are the scarcity of food resources, habitat destruction and degradation, human persecution and infectious diseases. In the case of the wildcat we can add a fourth element which is the introgression with domestic cat (Pierpaoli *et al.* 2003, Oliveira *et al.* 2008), that may endanger the genetic integrity of their populations. Hybridization, transmission of viral diseases and competition due to trophic niche overlap, have all been associated with the domestic cat (Courchamps *et al.* 1995, Fromont *et al.* 2003, Pontier *et al.* 2009), which is in turn heavily dependent of human populations. In this perspective, humans are a key-issue in wildcat conservation strategies, justifying the investment in the knowledge on the interactions between wildcats, domestic cats and, consequently, humans. My research shed light on wildcat ecological requirements and constrains imposed by human-related activities. Moreover, with this approach it is possible to learn important lessons about the mutual interactions among wildcats and domestic-free ranging-feral cats, and the effects of human land uses, that can be generalised to other similar situations.

7.2 OVERVIEW OF MAIN FINDINGS

7.2.1Large scale requirements of wildcat distribution in Iberian Peninsula

To evaluate the more important requirements in the wildcat Iberian distribution we used the advantages of correlative and mechanistic models to detect which are the large-scale determinants that express the local individual preferences (Paper I). Wildcat natural history and behaviour, obtained from ecological research at fine scales, suggest the importance of small mammals as prey, as well as a negative influence of human disturbance (Paper I). Apparently, habitat, coded as type of vegetation cover, is not influencing the distribution of the wildcat, thus reinforcing Lozano *et al.* (2003) opinion that the species is more habitat generalist than at first suspected, and is not behaving as a strictly forestall species (Stahl and Artois 1994). Moreover, at a large scale the wildcat does not show different requirements along its distribution range, with human disturbance and the number of species of small mammals as main descriptors for the wildcat distribution between temperate forest and Mediterranean vegetation (paper I). The relationship between prey availability and vegetation structure, namely the importance of pastures – scrubland mosaics for the wild rabbit in Mediterranean areas of Iberian Peninsula (Lozano *et al.* 2003), is a good example to show how the wildcat presence is indirectly related to vegetation type, because of the link between main prey and vegetation. In Mediterranean areas, dominated by sclerophylous vegetation, wildcats use rabbits as main prey (Malo *et al.* 2004, Ferreira 2003, Monterroso *et al.* 2009), while in Atlantic regions, mainly covered by mixed and broad-leaved forests, small mammals are the staple food (Lozano *et al.* 2006). In spite of the importance of small mammals for the wildcat in Atlantic areas, we found that this group of prey represent the most relevant predictor for species occurrence also in Mediterranean areas, opposed to the idea of specialization on rabbits. Probably, wildcats just take advantage of local wild rabbit's abundance, and its importance as a complementary food source is reinforced by the lower number of species of small mammals in Mediterranean areas. Represented by the relation of human occupation with elevation range, human disturbance is another important variable explaining the pattern of wildcat occurrence (Paper I). The negative relation between wildcat occurrence and human presence suggests a strong impact of human activities most probably through habitat destruction, direct killing and increasing contacts with domestic cats. Nevertheless, the impact of human presence is hard to quantify, given the multiple factors that act on the species, especially direct killing, which is not reported due to its illegality. This is particularly relevant in natural-rural areas where the number and distribution of human settlements and households can differ in terms of human density, representing different disturbance scenarios for wildcat populations (Papers I and II).

7.2.2 Humans and domestic cats relationships in rural-natural areas

High human density supports higher cat densities, linking the expansion of cats in nature to different levels of human occupation. The pattern of farm occupation by people is the main factor determining the distribution and abundance of domestic cats in natural or semi-natural areas (Paper II). Space use by domestic cats in our study area showed that females centred their home ranges on farms and males made long travels to find available females in the mating season (Paper II, see also Barratt 1997, Germain *et. al.* 2008). In fact, the distribution and density of females are the primary factors determining male range size (Liberg and Sandell 1988), and the maximum distances travelled in a season are associated to the distance to the nearest farm with females (Paper II). On the other hand, the daily movements of domestic cats was only constrained by red fox density that may translate into a high risk of predation (Paper II). Predation of cat offspring was observed during this study in Noudar Castle where the pups of the tracked female *F310* were killed by an Egyptian mongoose (pers. obsv.). In fact, feral or free ranging cats are more likely to be rare or absent in regions with well-preserved wild predator populations (Macdonald and Thom 2001). Domestic cats may move between farms but they have to share space with other carnivores, increasing the probability of interaction. Then it is more advantageous for farm cats to stay near secure shelters (farms) and avoid these interactions, especially with species that are more competitive or with predators. Dependence on people is also visible in the diet of the domestic cat, even in the vicinity of natural areas, where the diversity of potential prey is higher (Paper III). Domestic cats temporarily linked to humans may consume alternative prey (Fitzgerald 1988) around human settlements during the periods of natural food shortage, but they depend on human presence for their populations to increase. In continental landmasses, as the case of Europe, where prey species co-evolved with a great diversity of predators, like wildcats, the domestic cat benefits from staying in the proximity of people because they offer plenty food resources that they do not have to share with other predators. The differences found in the diets of domestic and wildcats illustrates well this relation between wild prey, predators, and man.

7.2.3 Spatial structure of domestic cat populations in natural-rural areas and relation with virus prevalence

The spatial occupation of farmhouses and human changes in the landscape are responsible for the distribution and displacements of domestic cats in natural-rural areas, and this potentially leads to the spreading of diseases to wildlifes (especially FIV and FelV) and hybridization with the wildcat (Courchamp *et al.* 1995, Fromont *et al.* 1997, Daniels *et al.* 1999, Leutenegge *et al.* 1999). The occurrence and prevalence of viral agents are very dependent on the spatial and social structure of the host population (Fromont *et al.* 2003) and the existence of stress factors (Pontier *et al.* 2009). Moreover, each viral agent has its mode of propagation, which is dependent on interactions between individuals. In wildcat populations, if we exclude contact with domestic cats, disease prevalence depends largely on stress conditions of the population.. Domestic cats in turn, exhibit different population structures according to the type of environment where they occur, being this either urban, rural or natural areas (Paper IV). Accordingly, it is expected that viruses go hand in hand with changes in the population structure of the host. The domestic cat serves as a vehicle for dispersion of viral agents between their colonies and the wildcat populations. Therefore, free-ranging cats in natural areas are likely to transmit diseases due to the opportunities to interact with other carnivores (Millán *et al.* 2009). The structure that characterizes polygamous colonies of cats in natural and rural areas is the one that most closely approximates that of the wildcat populations. Therefore, the impact of virus on domestic cats populations increases, including the transmission of the disease to distant populations through dispersal (Frommont *et al.* 2003), including wildcat populations in natural areas. Apparently, FeLV occurrence have large influence on the prevalence of other viruses (Paper IV) and is probably the most dangerous virus for wild feline populations in Europe. In natural areas with rural-farms connected to villages, either by the proximity or by their density, the number of cats roaming between the various colonies increases, contributing to a continued persistence of FeLV in the area. When the villages are far from rural-farms, the contacts between domestic cats, which determine FeLV persistence, will depend on their dispersal hability and the distance between active farms (Fromon *et al.* 2003) (Paper II). High dispersal rates will promote the contacts between domestic cats-domestic cats and domestic cats-wildcats, and as a result the probability of transmission and prevalence of FeLV and other viruses will increase (Paper IV).

7.3 IMPLICATIONS FOR WILDCAT CONSERVATION

7.3.1Habitat management and prey restocking / recovery

For a long time the conservation of wildcat focused on two main threat factors: loss of forested habitats and hybridisation with the domestic cat. In large part, this was due to the fact that most of the knowledge on the species originated from outside the Iberian Peninsula (Nowell and Jackson 1996). Only more recently, it was shown that the association between wildcat and Mediterranean vegetation, was not merely a consequence of its direct role as shelter, but resulted also from the indirect effect of providing an abundant food resource – the wild rabbit (Moreno and Villafuert 1995, Lozano *et al.* 2003, Fernández *et al.* 2006). Over decades, in rural areas people conducted small shrub removals for cattle grazing or to facilitate access to new exploitation areas, shaping a highly diverse landscape. These landscape mosaics promote prey diversity and availability, especially in terms of rabbits and rodents, the staple food of wildcats worldwide (Lozano *et al.* 2003, Fernández *et al.* 2003, Fernández 2005, Klar *et al.* 2008). The traditional farming system was highly diverse, combining the production of several types of grazing species (sheep, goats, Iberian pigs and cattle). However, changes in the agricultural policies that started in the 60's, have led to a larger investment in cattle production with the consequent decrease in the numbers of small ruminants (Joffre *et al.* 1988). A good example of this changing process can be seen in vast areas of the 'montado'system (or 'dehesa' in Spain), the landscape matrix of most southern Iberia, where the intensification of cattle production leaded to extensive clear-cutting of understorey, and consequent decrease in prey availability. This in turn decreased the abundance of prey and increased disturbance, due to intense cattle grazing. The opposite situation occurs when large amounts of private areas are devoted to big game hunting and shrubs are allowed to growth to provide better shelter opportunities to game species. In immediate terms, this management option may also have a positive effect in the wildcat in face of its high cover requirements (Stahl and Artois 1994). However, the absence of a mosaic structure in the landscape and the usually high densities of big game species, also decreases prey abundance, especially rabbits (Lozano *et al.* 2007), a already declining species due to other threats. In the last decades wild rabbit populations suffered a high decline (Malo *et al.* 2004), mainly as consequence of mixomatosis and hemorrahagic diseases (RHD), with direct consequences on the reproductive success of predators (Rodriguez and Delibes 1992). The recovery of rabbit populations is a hard task in conservation and species restocking is frequently carried out for hunting purposes, with thousands of individuals being introduced every year, often ending in failure (Calvete *et al.* 1997). Small mammals, the other key prey for wildcats, in many communities show preference for habitats with high vegetation cover (Kotler and

Brown 1988), a fact that is closely related with the perceived predation risk (Díaz 1992), and consequently are also affected by changes in the traditional farming system. However, a proper understanding on how human-induced changes in habitats and landscapes affect small mammal populations is still lacking, albeit being crucial to undertake the management and conservation of Mediterranean ecosystems. As shown, although needing cover the wildcat is not a specialist in a particular vegetation type (Paper I), but the composition, quantity and shape of vegetation cover, is important in determining prey availability. Human activities, namely agro-pastoral-forestry and hunting practices, have therefore a large influence in the habitat suitability for the species. In table 7.1, I summarise the main features that relate land management options with prey availability and disturbance for wildcats.

Table 7.1**.** Different scenarios of land management options and their implications for wildcat conservation in Mediterranean areas

Land-use management option	Without cattle grazing	Consequences for wildcat conservation	With cattle grazing	Consequences for wildcat conservation
Intensive agriculture Large monoculture area Short ecotone area	**Low-moderate prey availability** Small mammals availability depends on culture types (-+) Rabbit abundance (--)	**Unsuitable area** Shelter availability (--) Prey availability (--)	Small mammals availability depends on culture types and grazing intensity (--) Rabbit abundance (-)	**Unsuitable area** Disturbance
Traditional agriculture Mix of scrubland/cropland Riparian vegetation patches Long ecotone area	**High prey availability** Small mammals availability (++) Rabbit abundance (+)	**Highly suitable area** Shelter availability (++) Prey availability (++)	Small mammals and rabbits abundance depends on culture types and grazing intensity (-+)	**Highly suitable area** Disturbance
Small game management Mix of scrubland/cropland Long ecotone area	**High prey availability** Small mammals availability (+) Rabbit abundance (++) Small mammals-rabbit competition	**Suitable area** Shelter availability (+) Prey availability (++) Direct killing Sazonal disrurbance	Small mammals availability depends on culture types and grazing intensity (-) Rabbit abundance (+)	**Suitable area (-)** Disturbance Direct killing
Big game management Large scrubland area Short ecotone area	**Low prey availability** Small mammals availability (+) Rabbit abundance (-) Big game – rabbit competition	**Moderate suitable area (-)** Shelter availability (++) Prey availability (-+) Sazonal disrurbance		

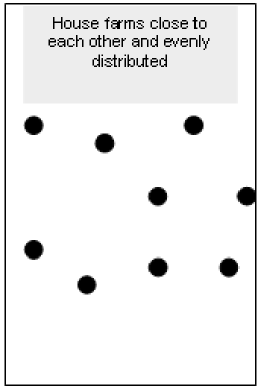
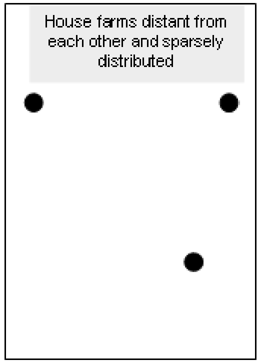
The immediate conservation needs for the wildcat in the Mediterranean region must therefore concentrate in promoting prey availability; which in turn is dependent of maintaining natural vegetation patches and low levels of agricultural intensification. To re-established sustainable land uses that incorporate the conservation of natural values it is necessary the maintenance of an equilibrium occupancy between the scrubland and agriculture patches. The multi-uses of landscape, instead of a large matrix with a unique use, will promote the diversity and abundance of prey. Important habitats that in many situations, usually forme small parts of the landscape and are often the focus of intensive human activity, are the riparian habitats. In fact, besides presenting numerous challenges for land managers, these habitat offer, in homogeneous landscapes, the ultimate conditions for species occurrence, increasing prey availability in the matrix.

7.3.2 Limiting domestic cats density and movements in rural farms

The most effective strategy for decreasing rates of hybridization involves, not only, habitat restoration that allows a healthy community of native carnivores to persist, but also eliminating or reducing the factors (farm resources) that promote domestic cats increase in numbers. Farm occupation by people is the main factor determining domestic cat distribution and abundance in natural Mediterranean areas (Paper II). Other anthropogenic structures, like roads and households, also favour domestic cat expansion to natural areas. Furthermore, because private landowners are the ultimate controllers of their land, they may be carrying out a wide variety of actions that could influence the distribution and abundance of cats. This information is therefore vital to better understand the mechanisms that limit the capacity of expansion and colonization of new areas by the domestic cats. In natural areas with no people, cats are strictly dependent of wild prey, while in urban habitats human refuse and opportunistic prey species like the house mice constitute the bulk of the cats diet (Paper III). A success strategy to reduce feral cats in rural-natural areas is therefore to limit the access by cats to human refuse. Moreover, in natural or rural areas the pattern of house farms distribution affects the distribution and numbers of domestic cats. In fact, until the early twenties human density in rural areas of the Mediterranean was much higher than today, with rural farms fully active, and typically including farm cats to control rodents. Cat densities in these areas were probably much higher at that time.

The distribution and abundance of domestic cat females are determined in first place by the resources provide by people (Devillard *et al.* 2003). However, for males, the main factor is the distribution of females (Liberg and Sandell 1988). With increased distances between operative farms, where cats still concentrate, males have to travel longer distances and spend more energy in mate guarding. Table 7.2, presents different scenarios depending on active farms location and landscape features, with different implications on domestic cat distribution and population dynamics, leading to different levels of threats to wildcat populations. In general, the spatial distribution of active farms, the quantity and quality of available resources and the characteristics of the landscape determines the impact on wildcat populations.

Table 7.2**.** Different scenarios of active farms distribution, landscape features and different levels of impact to wildcat populations.

House farms distribution	Human related food resources	**Landscape context**	**Domestic cats abundance and spatial behaviour**	**Implications for wildcat Risk of:** **(+++ high,++ moderate,+ low)**
House farms close to each other and evenly distributed	Abundant	High vegetation cover High diversity of native carnivores	High density of cats concentrated in farms with high number of females Even cats occupancy with high overlap of cats home ranges Males move short distances and females stay at houses Immature males are pushed to scrubland habitats, with risk of predation	Transmission (+++) (FIV↑FeLV↑) Hybridizadion (+++)
		Low vegetation cover Low diversity of native carnivores	High density of cats Cats move easily between farms Immature males do not need to use habitats with high risk of predation	Transmission (+) (FIV↑FeLV↓) Hybridizadion (++)
	Few	High vegetation cover High diversity of native carnivores	Low density of cats with unequal farms occupancy Females have to move between farms for food Adult males have to visit more farms for females, increasing the risk of predation	Transmission (++) (FIV↓FeLV↑) Hybridizadion (++)
		Low cover Low diversity of native carnivores	Low density of cats Females have to move between farms for food Adult males have to visit more farms for females	Transmission (+) (FIV↓FeLV↑) Hybridizadion (+)
House farms distant from each other and sparsely distributed	Abundant	High vegetation cover High diversity of native carnivores	Low density of cats concentrated in farms Males have to make long non-linear movements to avoid other carnivores while searching for females Immature males are pushed to scrubland habitats, with the risk of predation	Transmission (+) (FIV↑FeLV↑) Hybridizadion (++)
		Low vegetation cover Low diversity of native carnivores	Low density of cats Males move easily between farms using linear movements in their search for females	Transmission (+) (FIV↑FeLV↓) Hybridization (+)
	Few	High vegetation cover High diversity of native carnivores	Very low density of cats concentrated in farms Males have to make long non-linear movements to avoid other carnivores while searching for females	Transmission (+) (FIV↓FeLV↓) Hybridizadion (+)
		Low vegetation cover Low diversity of native carnivores	Very low density of cats Males move easily between farms using long linear movements while searching females	Transmission (-) (FIV↓FeLV↓) Hybridizadion (-)

To reduce free-ranging cat populations it is essential not to provide direct food for cats, prevent access to the barns, which provides them safe shelter, and an additional prey source-house mouse. The rodents inside the barn can be controlled by barn owls *Tyto alba*, simply by the existence of windows located in places inaccessible to cats. At the same time, it is important that natural habitats be protected because this limits the cats displacements, and increase the probability of predation on them.

7.3.3 Information gaps and research needs

A disagreement seems to exist in what concerns the conservation status of the wildcat in different areas of its southern European range, in spite of the fact that identified threat factors operate at large scale. In Europe, the IUCN classifies the species as Least Concern (IUCN 2006) while in Portugal the wildcat is considered Vulnerable (Cabral *et al.* 2005) and in Spain Near Threatened (Palomo 2007). Nevertheless, there is no data on the distribution of the species based on systematic surveys despite of the recommendations of the Council of Europe to Portugal and Spain (Council of Europe 1992). The Red Data Book of Vertebrates of Portugal refers to non-natural mortality (as consequence of road kills and illegal hunting), hybridization with domestic cat and habitat destruction as the main threats (Cabral *et al.* 2005). However, in the absence of robust data on small mammals and rabbit distribution and abundance it is impossible to develop a predictive model for wildcat distribution in Portugal which, in view of the apparent rareness (particularly in the south), elusive character, and similarity of signs of presence with the domestic counterpart, is a crucial tool to further develop a pro-active conservation strategy. Another important information gap is the role of human disturbance, still poorly known due to its high complexity, mainly in relation with data on wildcat direct persecution. Future, fine scale studies should focus on the aspects related to human disturbance and direct killing, mostly associated with small game hunting practices (predator control practices). These aspects must be reflected in a large scale predictor that, in addition with those relate to wildcat requirements (food and shelter), contribute to built an predictive model to map potential distribution of wildcat in Iberia Peninsula.

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