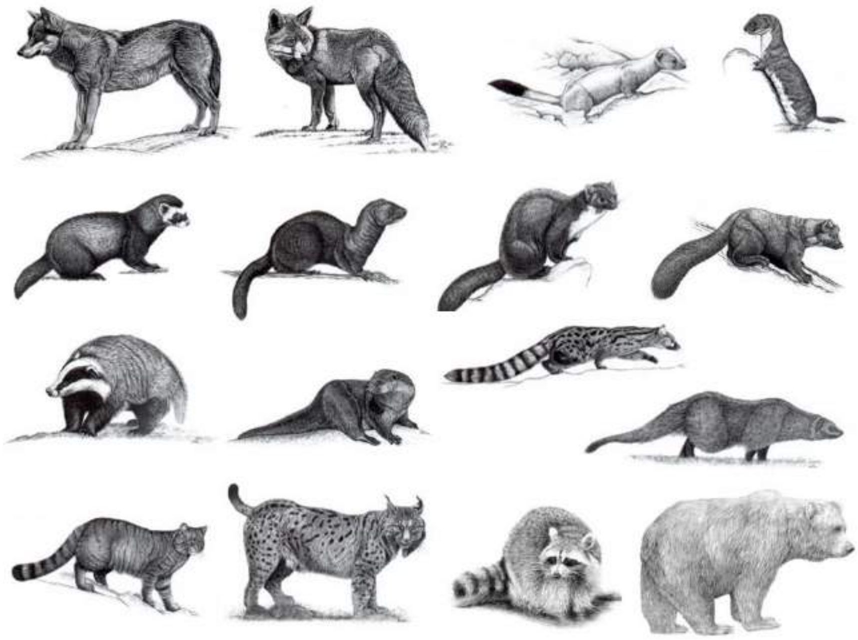

Portuguese mammalian carnivores: bibliometrics, species distribution models and a baseline for a future distribution atlas

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Summary

Information regarding the status and distribution of species is crucial for an effective management and conservation of biodiversity, from local to global scales. Despite being included in the Mediterranean biodiversity hotspot, Portugal lacks a detailed assessment of the distribution patterns of mammalian carnivores, which are important both ecologically and economically. Moreover, the available information is scattered, often unreliable and biased towards some species or regions.

The goals of this study were: i) to compile historical and current distribution data and evaluate the research trends on all species of mammalian carnivores in Portugal; ii) to determine the potential distribution of each species, using species distribution models based on the currently available records, and identify variables associated with their presence; and iii) to produce a detailed account of each carnivore species occurring since historical times in Portugal, as a baseline for a future distribution atlas.

On a first approach, a comprehensive review of 755 scientific studies was conducted to analyse several publication metrics (e.g. year of publication, publication type and research topic). 20,189 presence records of all mammalian terrestrial carnivores occurring in Portugal since historical times were also compiled, to evaluate their distribution patterns, including Extent of Occurrence, Area of Occupancy and range trends.

Carnivore research in Portugal began in the 18th century, with a boost in the mid-1990s, and has been biased towards regionally threatened species and mainly focused on the topics of General Ecology and Conservation. There are fifteen extant species in Portugal, with nine occurring across the country (>85% of the mainland area) and six showing a relatively limited range (<40%), while an additional species is currently extinct (*Ursus arctos*). During the last decades, the distribution ranges of seven species seem to have remained stable, two expanded, two contracted, and three showed unclear trends. The historical presence of the Eurasian Lynx (*Lynx lynx*) in the north of Portugal was hypothesised, based on historical records, and the confirmed presence of a new invasive carnivore in Portugal, the raccoon (*Procyon lotor*), is documented here for the first time.

On a second chapter, the compiled presence data were used to produce predictive ensemble models of the distribution of all extant carnivore species in Portugal (except for

the racoon, due to low sample size), and several criteria of variable selection were used to determine which predictor variables were most strongly related to species occurrences. As expected, the best-surveyed carnivore species produced the best performing models. For all species, at least one environmental variable was selected, and for nine species, also human-related variables emerged, mostly showing a negative relationship between species and human presence or activity. For several species known to occur throughout the country, a higher potential for occurrence was found in the north, suggesting better general conditions in this region. Furthermore, a possible connection was found between reduced consensus between model predictions and the latest range limits of expanding species.

Finally, all the information collected was gathered and presented in a detailed account for each carnivore species with a summary of the general distributional context, bibliometric analysis, presence records and distribution patterns. The species of some conservation concern, either by being threatened, nationally or internationally, or by currently undergoing an expansion process, are the ones for which there was generally more data and a better knowledge. Other common and widespread species with no pressing conservation concerns, along with Data Deficient and Extinct species, had the least available data. Concerning the records compiled, non-genetically validated presence signs constituted the majority of records, and most records were collected inside protected areas, stressing the need for collecting more reliable records (either by validating them genetically or using other methodologies) and for reducing survey bias .

This study demonstrates the relevance of non-systematic data to assess the historical and current status of mammalian terrestrial carnivores in Portugal, allowing the identification of knowledge gaps and research priorities. It is the first study on Species Distribution Modelling addressing all carnivore species in Portugal, by using a large number of occurrence data for modelling purposes. Furthermore, it allows a preliminary assessment of the factors associated with each carnivore species, particularly those for which there were no previous studies on ecological modelling. The results of this work will serve as a baseline to produce a future Atlas of Portuguese Carnivores. This information will contribute to updating assessments of species presence and distribution at the level of Iberian Peninsula, Europe and the Mediterranean biodiversity hotspot, with important

conservation and management implications.

Keywords: Bibliometric review, Carnivora, distribution trends, ensemble modelling, species check-list

Resumo

A informação relativa ao estatuto e distribuição das espécies é crucial para uma eficaz gestão e conservação da biodiversidade a todas escalas, desde locais até globais. Portugal, apesar de estar incluído no *hotspot* de biodiversidade da bacia do Mediterrâneo, carece de uma avaliação detalhada dos padrões de distribuição dos mamíferos carnívoros terrestres existentes neste território, importantes tanto a nível ecológico como económico. Além disso, a informação disponível encontra-se dispersa, é frequentemente pouco fiável e tendencialmente direcionada apenas para algumas espécies ou regiões. Tendo em conta estas questões, os objetivos do presente estudo foram: i) compilar dados de distribuição histórica e atual e avaliar as tendências da investigação sobre todas as espécies de mamíferos carnívoros terrestres em Portugal; ii) determinar a distribuição potencial de cada espécie, usando modelos de distribuição baseados nos registos atualmente disponíveis, e identificar variáveis associadas à presença de cada uma; e iii) produzir uma descrição detalhada da distribuição conhecida de cada uma destas espécies desde tempos históricos, como base para um futuro atlas de distribuição.

Numa primeira abordagem, foi realizada uma revisão exaustiva de 755 estudos científicos para analisar várias medidas bibliométricas (e.g. ano de publicação, tipo de publicação e tema de investigação). Também se compilaram 20.241 registos de presença dos carnívoros que ocorrem ou ocorreram em Portugal desde tempos históricos. Com estes dados, avaliaram-se os padrões de distribuição destas espécies, incluindo a extensão de ocorrência, área de ocupação e tendências na distribuição.

A investigação científica sobre carnívoros em Portugal começou no século XVIII, com um aumento significativo em meados da década de 1990. Tem sido geralmente direcionada para espécies ameaçadas a nível regional e tem-se focado principalmente em temas de Ecologia Geral e Conservação. Atualmente, existem quinze espécies a ocorrer em Portugal, estando nove delas presentes em quase todo o país (> 85% da área continental) e seis com uma distribuição relativamente limitada (<40%); uma outra espécie está atualmente extinta (*Ursus arctos*). Durante as últimas décadas, as áreas de distribuição de sete espécies parecem ter permanecido estáveis, duas expandiram, duas

contraíram e para três não existe uma tendência clara. Com base em registos históricos, é colocada a hipótese de o lince Euroasiático (*Lynx lynx*) ter existido em tempos históricos no norte de Portugal. É também documentada neste estudo pela primeira vez a presença confirmada de um novo carnívoro invasor em Portugal, o guaxinim (*Procyon lotor*).

Num segundo capítulo, os dados de presença compilados foram usados para produzir uma combinação de modelos preditivos da distribuição de cada espécie de carnívoros existentes em Portugal (exceto para o guaxinim devido à sua escassa presença atual), utilizando diferentes algoritmos. Vários critérios de seleção de variáveis foram usados para determinar quais as variáveis mais fortemente relacionadas com as ocorrências das espécies. Como esperado, as espécies melhor amostradas foram as que produziram os modelos com melhor desempenho. Para todas as espécies, pelo menos uma variável ambiental foi selecionada, e para nove espécies surgiram também variáveis relacionadas com o Homem, mostrando maioritariamente uma relação negativa entre a espécie e a presença ou atividade humana. Para várias espécies que ocorrem por todo o país, foi detetado um maior potencial para a sua presença no norte, o que sugere a existência de melhores condições gerais nessa região. Foi também encontrada uma possível ligação entre a falta de consenso entre as previsões de diferentes métodos de modelação e os limites mais recentes da distribuição de espécies atualmente em expansão.

Por fim, reuniu-se toda a informação recolhida e apresentou-se uma descrição detalhada de cada espécie com o resumo do seu contexto distributivo geral, análise bibliométrica, tipos de registos de presença e padrões de distribuição histórica e atual. As espécies com algum nível de preocupação em termos de conservação, quer por serem ameaçadas nacional ou internacionalmente ou por estarem a passar por um processo de expansão, são aquelas para as quais há geralmente mais dados e um melhor conhecimento. Para outras espécies comuns e de ocorrência generalizada, sem preocupações prementes em termos de conservação, bem como para espécies classificadas como Data Deficient e para espécies Extintas em Portugal, foram obtidos menos dados. Em relação aos registos compilados, a maioria foram indícios de presença não validados geneticamente, e a maior parte destes foi recolhida em áreas protegidas, salientando-se a necessidade de obter registos mais fiáveis (através de validação genética ou usando

outras metodologias) e de reduzir o viés da amostragem.

Este estudo demonstra a relevância dos dados não-sistemáticos para avaliar o estatuto histórico e atual das espécies, permitindo identificar lacunas no conhecimento e prioridades de investigação. Este é o primeiro estudo de modelação de distribuições que aborda todas as espécies de mamíferos carnívoros terrestres em Portugal, usando um grande número de dados ocorrência e de métodos de modelação. Os resultados permitem uma avaliação preliminar dos fatores associados a cada uma das espécies, particularmente aquelas para as quais não existiam estudos anteriores de modelação ecológica. Este trabalho servirá como base para produzir um futuro Atlas de Distribuição dos Carnívoros Portugueses. Esta informação irá também contribuir para atualizar os documentos de avaliação da presença e distribuição das espécies ao nível da Peninsula Ibérica, Europa e no *hotspot* de biodiversidade da bacia do Mediterrâneo e na Europa, com importantes implicações para a sua gestão e conservação.

Palavras-chave: Revisão bibliométrica, Carnivora, tendências de distribuição, modelação "ensemble", check-list de espécies

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List of Abbreviations

AOO	**A**rea **O**f **O**ccupancy
EOO	**E**xtent **O**f **O**ccurrence
IUCN	**I**nternational **U**nion for **C**onservation of **N**ature
PRLV	**P**ortuguese **R**ed **L**ist of **V**ertebrates
SDM	**S**pecies **D**istribution **M**odelling
UTM	**U**niversal **T**ransverse **M**ercator

Chapter 1

General Introduction

1.1 The relevance of carnivores

The mammalian order Carnivora is composed of 285 species (more than a quarter of which is Threatened or Extinct, 26.7%) divided by 128 genera and 16 families, being the most representative ones Canidae, Felidae, Mustelidae, Ursidae and Viverridae (IUCN, 2016). Carnivores represent about 5% of the global and 12% of the European mammalian fauna (Temple and Terry, 2007; Wilson and Mittermeier, 2009). This taxonomic group has an important ecological role (Miller et al., 2001), as the species that compose it often regulate or limit the numbers of their prey, thereby altering the structure and function of entire ecosystems (Treves and Karanth, 2003). They also provide both economic and ecosystem services that are frequently not taken into account (Ripple et al., 2014). Due to their iconic and charismatic nature, they are an attraction that leads to direct economic benefits through tourism or sport hunting (Ripple et al., 2014). Besides, as they exert a 'top-down' regulation, they influence the maintenance of ecosystem services on the trophic levels below (Miller et al., 2001). For example, by limiting the numbers of their herbivore prey and allowing plants to grow, carnivores contribute indirectly to an increase in carbon storage (which helps buffer climate change), and to the re-establishment of native plant diversity and riparian restoration (Ripple et al., 2014). They can also act as seed dispersers (Rosalino et al., 2010b), disease regulators, biodiversity enhancers and have positive effects on countless other cascading and ramifying ecological pathways (Ripple et al., 2014). However, carnivores have also been, for a long time, a source of attention and controversy to humans. The controversy regarding this group of mammals lies on the fact that, although they provide all these ecological services, they are also perceived as threats to human life, economic security or recreation, leading to human-carnivore conflicts (Treves and Karanth, 2003). This is a conservation dilemma which keeps increasing with the expansion and growth of human populations, farming frontiers and urbanisation on one side, and with humans who seek to preserve or restore wildlife populations on the other (Treves and Karanth, 2003). Adding to these factors, a third dimension should be considered, as some species of this group, mostly large carnivores, have deeply influenced human cultures since pre-historical times, leading to a rich cultural heritage and a close relationship with traditional human communities (Álvares and Domingues, 2010; Álvares et al., 2011; Feng et al., 2009; Herrmann et al., 2013). Taking all of this into account, it becomes clear that it is essential to collect as much knowledge as possible regarding carnivores, both at the ecological and sociological levels, in order to be able to preserve them and the important services they provide, while finding ways to reduce significantly the sources of conflict between them and the human society (Dickman et al., 2011; Redpath et al., 2013; Rigg et al., 2011; Treves and Karanth, 2003).

Despite their relevance, studying carnivore species is a true challenge. Many of their biological traits both make them prone to extinction and pose serious challenges for the collection of survey data, especially when populations are small and/or declining (Balme et al., 2009; Rosenblatt et al., 2014). Among the characteristics that constrain carnivore survey and study are their low densities, elusiveness, nocturnal habits, high mobility, relatively large home-ranges, occurrence across large and often remote areas, and signs of presence that, for many species, are ambiguous and not easy to identify (Balme et al., 2009; Bekoff et al., 1984; Boitani et al., 2012). All these factors make carnivores difficult to observe or capture, leading to reduced detection rates. To overcome this issue, substantial and often expensive survey efforts over large areas are required to obtain meaningful results with satisfactory precision (Boitani et al., 2012; Gompper et al., 2006). In humanised landscapes, such constraints are even more relevant due to intensive poaching, which often leads to the death of monitored animals as well as conflicts between local populations and some carnivore species, which hinders the efforts made by researchers and managers (Liberg et al., 2011; Treves and Karanth, 2003).

1.2 Carnivores in Portugal

Portugal harbours a very diverse natural heritage, thanks to its geographic location and geophysical conditions (Convention on Biological Diversity, 2016). It is officially home to 69 taxa of terrestrial mammals occurring throughout the mainland and the Azores and Madeira archipelagos (Convention on Biological Diversity, 2016). Regarding the mammalian order Carnivora, Portugal has a relatively high diversity (Fig. 1.1 and 1.2), with one recently extinct and fourteen extant species spanning five families: Ursidae (N=1, regionally extinct: Ursus arctos), Canidae (N=2: *Canis lupus*, *Vulpes vulpes*), Mustelidae (N=8: *Mustela erminea*, *Mustela nivalis*, *Mustela putorius*, *Neovison vison*, *Martes foina*, *Martes martes*, *Meles meles*, *Lutra lutra*), Viverridae (N=2: *Genetta genetta*, *Herpestes ichneumon*) and Felidae (N=2: *Felis silvestris*, *Lynx pardinus*) (Cabral et al., 2005; Loureiro et al., 2012; Mathias et al., 1998a; Santos-Reis and Mathias, 1996).

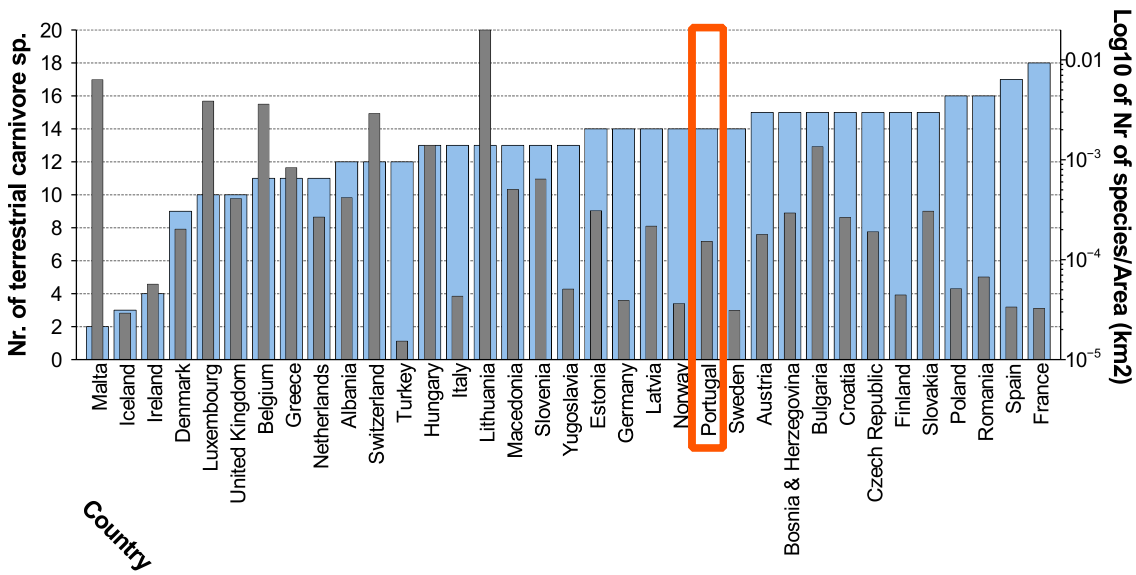


Fig. 1.1 – Number of terrestrial carnivore species (Native and Introduced) per European country (blue bars) and number of species per area (km^2)(grey bars). Source: IUCN (2016)

Portugal is currently home to two of the five large carnivores species that occur in Continental Europe (Temple and Terry, 2007): the grey wolf (*Canis lupus*) and the Iberian lynx (*Lynx pardinus*). Portugal harbours species from a variety of biogeographical origins (European, African and American). There is one carnivore species that is endemic to the Iberian Peninsula, the Iberian Lynx (Johnson et al., 2006; Werdelin, 1981; Wilson and Reeder, 2005), and there is evidence that some other species, such as the wolf (*Canis*

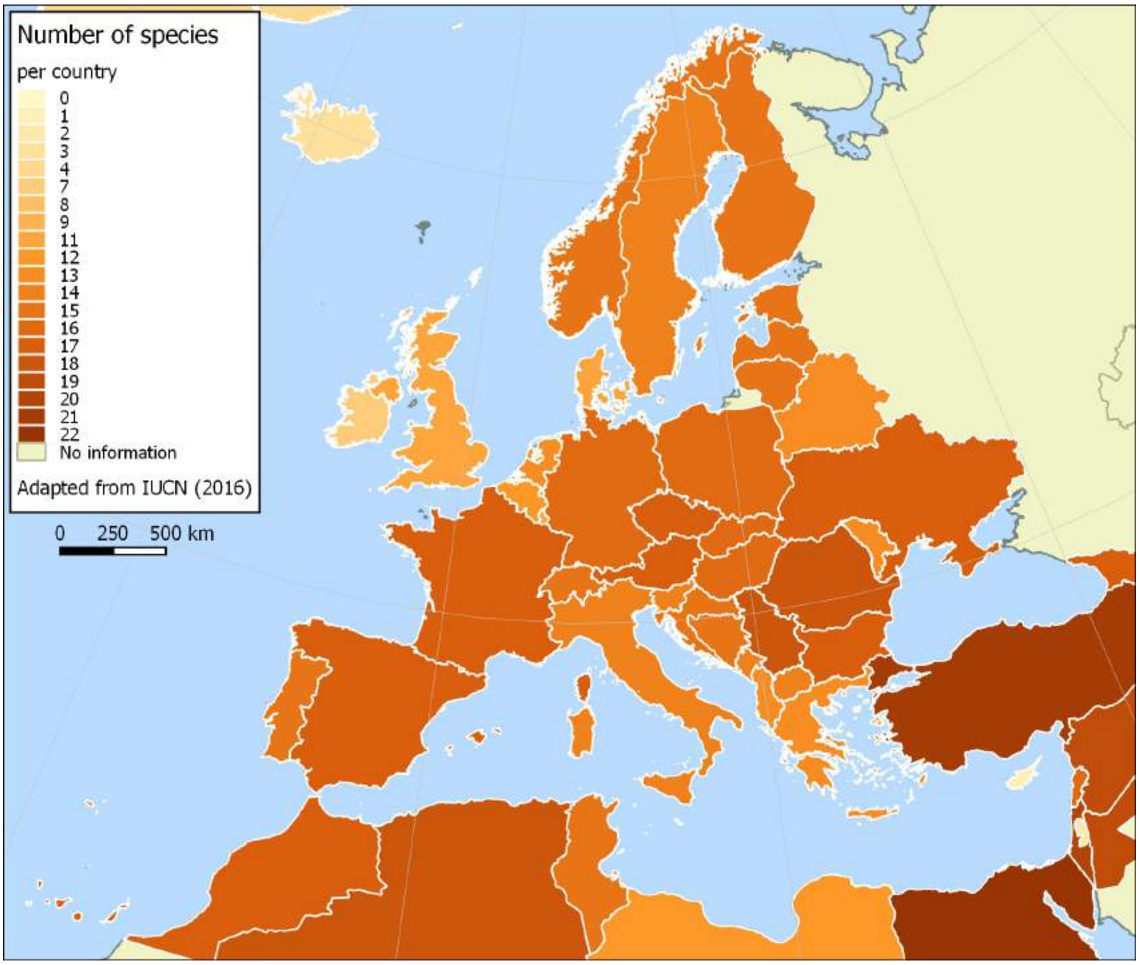


Fig. 1.2 – Distribution of carnivore species richness in Europe and the Mediterranean basin, in terms of number of terrestrial species of the Carnivora order per country. Source: IUCN (2016)

lupus signatus; Cabrera, 1907; Ramirez et al., 2006; Vilà, 1993; Vilà et al., 1999), the wildcat (*Felis silvestris silvestris*; Mattucci et al., 2016; Pierpaoli et al., 2003) and the Egyptian Mongoose (Barros et al., 2016; Gaubert et al., 2011), are actually sub-species or genetically differentiated populations of the Iberian Peninsula in relation to the remaining world distribution. This highlights the reproductive isolation or differentiation, possibly due to local adaptation (Gómez and Lunt, 2006).

The carnivore community in Portugal also includes the insular territories which, although not specifically addressed in this study, are worth mentioning. In the Portuguese Atlantic archipelagos of Azores and Madeira, only two wild/feral mammalian terrestrial carnivore species are known to occur: the least weasel (*Mustela nivalis*)and the domestic form of the western polecat, the ferret (*Mustela putorius furo*). These species are thought to have arrived to the islands at the time of the archipelagos' colonisation in the 15th century (Costa et al., 2014; Mathias et al., 1998b). The ferret was intentionally introduced, both in the archipelagos of Azores and Madeira, for hunting rabbits *(Oryctolagus cuniculus*), but it was able to establish feral populations from escaped individuals (Costa et al., 2014). Its presence has been reported in, at least, five islands of the Azores archipelago: Flores, Terceira, Pico, São Jorge and São Miguel (Mathias et al., 1998a) and in the archipelago of Madeira (Masseti, 2010; Mathias, 1999). Regarding the least weasel - whose presence is known in the islands of Terceira and São Miguel in the Azores archipelago and unconfirmed in the Faial island (Mathias et al., 1998b) - it has been hypothesized that this species, although not native, colonized these islands without direct human assistance (Mathias et al., 1998b). A particularity of this species that has not yet been confirmed by genetic or morphological comparative studies, is that the Azorean weasel has been considered, by various authors, to be a different species or subspecies from its continental form, due to the larger size, especially the increased tail length, and some fur peculiarities found in a few specimens (Abramov and Baryshnikov, 2000; Mathias et al., 1998b).

Over the last 40 years, research on mammals, including carnivores, has greatly increased in Portugal (Santos-Reis and Mathias, 1996). Field surveys have led to the "recent" detection of new species in mainland Portugal, such as the American Mink (*Neovison vison*; Vidal-Figueroa and Delibes, 1987), the stoat (*Mustela erminea*; Santos-Reis, 1985) and the pine marten (*Martes martes*; Santos-Reis and Mathias, 1996). Since most studies emerged from time-restricted funding opportunities (e.g. regional inventories, mitigation measures associated with infrastructure constructions, such as the Alqueva Dam) or researchers' species preferences (e.g. in the scope of PhD and MSc theses), the number of studies per species varies greatly among all extant carnivore species occurring in Portugal. All this is aggravated by the fact that detecting the presence of some carnivores is a challenging and quite recent effort for Portugal (Santos-Reis, 1985; Santos-Reis and Mathias, 1996). Consequently, there is still a lack of information regarding the population status and distribution of many carnivore species in Portugal.

Fig. 1.3 – Pictures from the 15 carnivore species known to occur in Portugal since historical times. (a) *Canis lupus signatus* (by Juan José González Vega); (b) *Vulpes vulpes* (by Maria Hale); (c) *Mustela erminea* (by Soumyajit Nandy); (d) *Mustela nivalis* (by Keven Law); (e) *Mustela putorius* (by Peter Trimming); (f) *Neovison vison* (by Anna Wójtowicz); (g) *Martes foina* (by Urs Zimmermann); (h) *Martes martes* (by Paul Gadd); (i) *Meles meles* (by Julia Kauer); (j) *Lutra lutra* (by Drew Avery); (k) *Genetta genetta* (by Guérin Nicolas); (l) *Herpestes ichneumon* (by José Luís Conceição); (m) *Felis silvestris* (by Lviatour); (n) *Lynx pardinus* (by Programa de Conservación Ex-situ del Lince Ibérico); (o) *Ursus arctos* (by Mike Needham). Source: Wikimedia

In the last decades, some research studies have dealt with carnivorous mammal ecology, but sparsely and at a regional or local scale. Therefore, for mammalian carnivores, only coarse-scale (50x50km scale; Mathias, 1999; Mitchell-Jones et al., 1999) or local (Loureiro et al., 2007) distribution maps are available. This translates into a lack of presence data portraying the complete and detailed historical and current distribution of mammalian carnivores in Portugal, hampering any research that depends on more comprehensive distribution records, such as range assessments, species distribution modelling, or general patterns of habitat selection.

1.3 Goals

This thesis is divided into three main chapters which explore several aspects related to the distribution of the order Carnivora known to occur in Portugal.

In Chapter 2, the goals were to compile historical and current distribution data and evaluate research trends of all species of the carnivore community in Portugal.

In Chapter 3, the goals were to determine the potential distribution of each species, based on Species Distribution Models, and to identify variables associated with the presence of each species.

In Chapter 4, the goal was to produce a detailed account and distribution map of each carnivore species occurring since historical times in Portugal.

With these approaches, I expect to contribute to a deeper knowledge about a carnivore guild occurring in humanized areas at a country level, which is a highly relevant research topic considering the growing humanization of the planet and the expansion of several species of carnivores, including large carnivores, in an increasingly crowded Europe. Additionally, this thesis will allow setting the basis for a National Distribution Atlas for carnivores, which will serve as a crucial tool for scientists, conservationists, managers and policy makers in the process of decision making and in planning conservation measures focused on carnivores (Mitchell-Jones et al., 1999).

Chapter 2

Research trends and geographical distribution of mammalian carnivores in Portugal: a review of non-systematic data and publication metrics

(Manuscript recently revised and re-submitted to *Mammal Review*)

2.1 Introduction

2.1.1 Challenges of collecting presence data on carnivores

Biodiversity is increasingly threatened by human-mediated habitat loss and climate change (Pimm, 2008; Wood et al., 2013), raising concerns about the rate of decline of an escalating number of species (Visconti et al., 2011). Currently, at least a quarter of the world's mammals is considered at-risk of extinction, so the success of specific conservation actions implemented to revert their decline will rely heavily on the quantity and quality of data available on the species' status and distribution (Whittaker et al., 2005). Such data are the baseline for a wide range of ecological, evolutionary and biogeographical studies (Austin, 2002; Baquero and Tellería, 2001; Ceballos et al., 2005; Elith et al., 2006), and hence updated information on species' past and current distributions is paramount to prioritize conservation investment in a changing world (Alagador et al., 2014).

Mammalian carnivores (Mammalia: Carnivora) are a charismatic group that illustrate well the relevance of collecting species distribution data. Carnivores are often species of major concern due to conservation needs and conflicts with humans (Miller et al., 2001; Treves and Karanth, 2003), being the target of many management and conservation plans, to which the assessment of range changes and population trends is a key pillar (Arnold et al., 2012; Chapron et al., 2014; Kauhala and Kowalczyk, 2011; Mitchell-Jones et al., 1999). In this context, the combined use of historical and current presence data provides an opportunity to investigate a wide array of ecological traits in carnivores, such as: range expansions and/or contractions (Clavero and Delibes, 2013; Palma et al., 1999); environmental factors that shape past and current presence (Barbosa et al., 2003; Areias-Guerreiro et al., 2016; Clavero and Delibes, 2013) and how populations and communities respond to past and future environmental changes (Huntley et al., 1991; Tingley and Beissinger, 2009; Varela et al., 2010).

Efficient regular surveys for carnivore species require diverse and complementary methodologies due to the elusiveness and ecological plasticity of this taxonomic group, and therefore may not be feasible due to logistical and/or funding limitations (Barea-Azcón et al., 2007; Vaughan and Ormerod, 2003). In this context, the use of non-systematic occurrence records scattered in the scientific literature or other available data sources can be useful to assess general distribution patterns. However, available data on carnivore status and distribution are often biased towards certain species, depending mostly on their biological traits, as well as on conservation and management interests (Brooke et al., 2014; Robertson and McKenzie, 2015). Moreover, when examining the information available for certain taxa, discrepancies emerge in relation to the reliability and the spatio-temporal coverage of research efforts (Brooke et al., 2014; Pérez-Irineo and Santos-Moreno, 2013). These constraints highlight the importance of performing extensive reviews on carnivore research trends and geographic distributions, in order to identify knowledge gaps and define research priorities for each species (Robertson and McKenzie, 2015).

2.1.2 Carnivores research and distribution patterns in humanised areas

The assessment of carnivore distribution patterns is particularly important in areas where human presence has a strong influence in the landscape, thereby shaping trends in species occurrence and promoting adaptation to disturbance (Blondel et al., 2010; Chapron et al., 2014; Clavero and Delibes, 2013; Kauhala and Kowalczyk, 2011). This is the case of the Mediterranean region, a biodiversity hotspot (Myers et al., 2000) where anthropic disturbances have been changing in frequency, scale and intensity over the past centuries (Blondel, 2006). Among the 38 carnivore species occurring in this region, two are endemic, almost a third (32%) is threatened and at least two species have already become regionally extinct (Temple and Cuttelod, 2009). In order to establish successful conservation and management plans for this region, accurate and up-to-date species distribution data at a regional scale, such as at country level, are essential (Cardillo et al., 2004; Chapron et al., 2014; Valenzuela-Galván et al., 2008).

Portugal, located within the Mediterranean biodiversity hotspot and at the south-western tip of Europe has one of the highest levels of mammalian carnivore richness in the continent (IUCN, 2016; Mitchell-Jones et al., 1999), mostly due to its biogeographical and ecological features, as it is encompassed by both the Mediterranean and Eurosiberian biogeographical regions (Costa et al., 1998). In fact, north-west Portugal is included in the Eurosiberian region while central and southern Portugal are included in the Mediterranean region (Baquero and Tellería, 2001). Previous status assessments of mammalian carnivores in Portugal dating from almost 20 years ago (Mitchell-Jones et al., 1999; Santos-Reis and Mathias, 1996) have considered 14 extant species, including two presumably introduced during historical times [the Egyptian mongoose (*Herpestes ichneumon*) and the common genet (*Genetta genetta*) (Gaubert et al., 2011)] and the recently introduced American mink (*Neovison vison*; Vidal-Figueroa and Delibes, 1987; Rodrigues et al., 2015). Moreover, detecting the occurrence of certain species of mesocarnivores in Portugal, such as the pine marten (*Martes martes*) and stoat (*Mustela erminea*) has been challenging, with the first confirmed records dating from late 20th century (Mathias, 1999; Santos-Reis, 1983). Besides, the lack of systematic distribution data for these species is the main reason why they are still classified as Data Deficient by the Portuguese Red Book of Vertebrates (Cabral et al., 2005). Indeed, data on the status and distribution of most Portuguese terrestrial mammals are outdated, scattered and scarce, and cartographic information detailing historical and recent distribution ranges is lacking for most species. This hampers the effective implementation of conservation and management strategies targeting mammalian carnivores in this region. Paradoxically, Portugal represents a high priority country to assess the status and distribution trends of carnivores at a regional level, given its high species richness (Mitchell-Jones et al., 1999), its position at a biogeographical crossroad, and the deep land use changes that have occurred in the country over the past decades (Pereira et al., 2009). The current lack of comprehensive distribution data for this country is precluding complete mammal diversity assessments in the Iberian Peninsula, Western Europe, and the Mediterranean biodiversity hotspot.

2.1.3 Goals

The goal of this thesis chapter was to review the existing body of scientific information on mammalian terrestrial carnivores in Portugal, in order to assess their research trends and distribution patterns. Specifically, the aim was to i) evaluate publication metrics related to carnivore research over time according to species traits, year of publication, type of publication and research topic; ii) obtain an updated species check-list for the country, based on non-systematic data of extinct and extant, native and non-native, species; and iii) compile as many existing carnivore presence records as possible, considering their accuracy and extent, and produce distribution maps based on the current knowledge.

This work provides the first attempt to perform a nation-wide assessment on carnivore distribution patterns in Portugal, at a relatively fine scale (10x10-km), by using non-systematic data.

2.2 Material and Methods

2.2.1 Literature review and publication metrics

We conducted an extensive review of the scientific literature available on carnivores in Portugal. Relevant studies were identified using several search engines, including Google Scholar (`http://scholar.google.com`), ISI Web of Knowledge / Web of Science (WoS, `www.wokinfo.com`), Scientific Electronic Library Online (SciELO, `www.scielo.org`) and online archives of Portuguese universities (which can be accessed to in `http://www.uc.pt/fcdef/documentosbiblioteca/Bibliotecadigital/Repositorio`). Both graduate and undergraduate theses were obtained from the University of Lisbon, University of Porto, New University of Lisbon, University of Évora, University of Aveiro,

University of Trás-os-Montes and Alto Douro, University of Minho and University of Algarve.
In each database, several combinations of keywords were used to identify relevant publications for all carnivore species known to occur in Portugal: the scientific and common name (both in Portuguese and English), 'carnivore', 'Portugal' and 'Iberian Peninsula'. Reference lists of retrieved publications were also used as bibliographic sources. Of all publications compiled, only those that included data on carnivore populations from Portugal were retained.

Publications were categorised by 'Species', 'Publication Year', 'Type of publication', and 'Research Topic'. The 'Type of publication' category comprised: SCI articles (peer-reviewed), Non-SCI articles, Theses and dissertations (PhD and others), Technical reports, Books (or book chapters), and Conference Proceedings. To avoid repetition, when the same study was published in different formats (e.g. SCI article as well as conference proceedings), only one of the formats was kept in the database, according to the following rank in decreasing order of importance: SCI article, Non-SCI article, Book (or book chapter), Conference Proceedings, Thesis or dissertation, Technical report. 'Research Topic' refers to the publication's main area of research and was defined as follows: 'Conservation' (studies related to human-wildlife conflicts; human perceptions and attitudes towards carnivores; illegal persecution; damages; habitat recovery; conservation action plans; impact of human activities), 'General Ecology' (trophic ecology; reproduction; habitat requirements and selection; home ranges; space use; activity; ecological modelling; scent-marking; behavioural responses; social ecology; abundance), 'Genetics' (phylogeography, population genetics, non-invasive genetics, hybridization, molecular markers), 'Health Status' (parasites, diseases, physiological parameters), 'Population Status' (past and present distribution patterns; population size; population trends and dynamics; population viability analysis; monitoring) and 'Others' (palaeontology; ethology; systematics; morphology; anatomy; methodological approaches; etc.). For simplicity, we specified that each publication could only fall within a single (main) Research Topic category.

The profile of research efforts on carnivores in Portugal was evaluated using three quantitative indicators: i) number of publications per year, considering SCI journals and all other publication types; ii) number of publications per species considering each 'Research topic'; iii) ratio between the number of publications focused on a single species vs. studies targeting multiple species.

2.2.2 Compilation of presence records

Presence data of all carnivore species were obtained from the aforementioned bibliographic references reviewed and complemented with records from several other sources: online databases, such as the Information System of Natural Patrimony (`www.icnf.pt/portal/naturaclas/patrinatur/sipnat`), the Global Biodiversity Information Facility (`www.gbif.org`) and Biodiversity4All (`www.biodiversity4all.org`) as well as unpublished data from individual expert researchers, universities, private companies and environmental associations in Portugal, through formal requests via e-mail. All records were mapped and compared within species, and implausible records due to potential species misidentification or inaccuracy in geographic locations were removed. The majority of the reviewed literature and collected records came from sources and databases written in Portuguese, and are therefore of limited accessibility to a wider audience. Hence, this study will also contribute to the dissemination of this information to a more international level.

All presence records were classified according to the date when the record was collected, as follows: 'Historical Data' included records prior to and including 1999; and 'Current Data' included records dated from 2000 to 2015. For each record we also collected, whenever possible, the following information: geographic location (current data were georeferenced on UTM 10x10-km grid cells, while historical data were, mostly, only available at the Municipality level) and type of record (direct observation, photographic record, acoustic detection, questionnaire, scat, footprint). For current data, we additionally classified each record as 'Confirmed' or 'Unconfirmed' according to the level of accuracy and reliability of species identification assigned to the presence record. 'Confirmed' records included all unequivocal records, such as direct observation/capture of live animals, dead animals, specimen photos, and genetically confirmed scats. Records with some degree of uncertainty, such as presence signs unconfirmed genetically, questionnaires and records of unidentified type, were classified as 'Unconfirmed'. This allowed us to classify each cell in the UTM 10x10-km grid of Portugal (N = 1004) for current data into one of three categories: ‘No records’, ‘Unconfirmed’ or ‘Confirmed’ presence of each species. Distribution maps were built for each species containing both historical and current data using the software QGIS 2.2.0 (QGIS Development Team, 2016).

2.2.3 Analysis of geographic range

For each species, we determined the Area of Occupancy (AOO) based on the current data, and the Extent of Occurrence (EOO), for both the historical and current data, as described by Gaston (1991) and following the guidelines for the IUCN Red List Categories and Criteria (IUCN Standards and Petitions Subcommittee, 2014). The AOO corresponds to the sum of the area of the UTM 10x10-km cells where the species has been recorded (whether confirmed or not). The EOO corresponds to the total area (within Portugal’s administrative borders) measured using the Minimum Convex Polygon based on all geographic units with species presence, considering UTM 10x10-km cells for current records and Municipalities for historical records. To make these estimates comparable with other regions or countries, we converted them into percentages of the total area of mainland Portugal (88,742 km^2).

We also measured the observed species richness across the country by summing up the species currently recorded per UTM cell. We further investigated whether either species richness or the number of records were biased towards protected areas. We first overlapped the total number of current presence records per UTM 10x10-km cell with the National Protected Areas network (Protected Areas managed by the Ministry of Environment, which include Sites under the Natura 2000 and RAMSAR networks). We classified a UTM cell as protected if more than 25% of its surface was inside a protected area (Estrada et al., 2008). We then used the non-parametric Mann-Whitney-Wilcoxon rank-sum test in R (R Core Team, 2016) to check for significant differences in species richness and in the total number of records among UTM cells falling inside and outside protected areas.

2.3 Results and Discussion

2.3.1 Research trends on carnivores in Portugal

A total of 755 publications was included in the final dataset and used for the bibliometric analysis. The first scientific publications on Portuguese carnivores dated as far back as 1789 and were concomitant with the foundation of the Academy of Sciences in Portugal (Almaça, 1991; Baptista, 1789). The first SCI (peer-reviewed) article was published in 1982, but only in the mid-1990s did the number of SCI publications start to show a noticeable increase, which became more pronounced in the mid-2000s (Fig. 2.1). This trend seems to be related to the creation of the first research groups within Portuguese universities in the 1990s that focused specifically on carnivore ecology (e.g. University of Lisbon) and is consistent with the worldwide overall pattern of increasing annual publication rate found for the order Carnivora (Brooke et al., 2014).

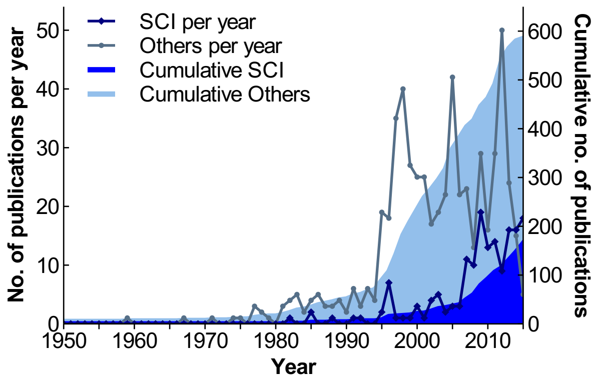
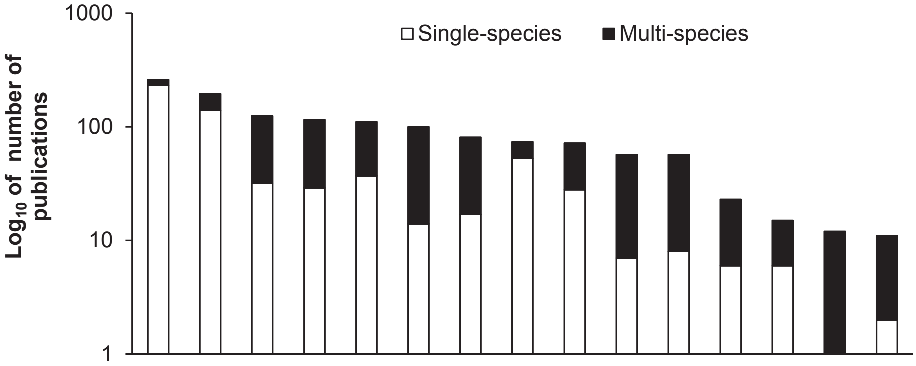


Fig. 2.1 – Annual total and cumulative number of publications (SCI and others) concerning mammalian carnivores in Portugal since the 1950s. Occasional publications dating from 1789, 1797, 1863, 1904 and 1910 were also found but are not included in the graph.

Most publications (82%) were about studies dedicated exclusively to one species and these were mainly focused on three carnivores [grey wolf *Canis lupus* (31%), Eurasian otter (19%) and Iberian lynx *Lynx pardinus* (8%)], all of which are of conservation concern at a national and/or international level (Fig. 2.2). This could be related to a general tendency for funding studies on iconic and/or threatened species, as suggested by previous reviews (Brooke et al., 2014; Robertson and McKenzie, 2015). Also, these results are consistent with the findings of Pérez-Irineo and Santos-Moreno (2013), which show that



Species		*Canis lupus*	*Lutra lutra*	*Vulpes vulpes*	*Genetta genetta*	*Meles meles*	*Martes foina*	*Herpestes ichneumon*	*Lynx pardinus*	*Felis silvestris*	*Mustela putorius*	*Mustela nivalis*	*Martes martes*	*Neovison vison*	*Mustela erminea*	*Ursus arctos*
IUCN Red List		LC	NT	LC	LC	LC	LC	LC	EN	LC	LC	LC	LC	LC	LC	LC
Portuguese Red List of Vertebrates		EN	LC	LC	LC	LC	LC	LC	CR	VU	DD	LC	DD	NA	DD	RE
International Protection Status	**Bern**	II	II	-	III	III	III	III	II	II	III	III	III	-	III	II
	CITES	II A	I A	D	-	-	-	-	I A	II A	-	-	--	-	--	II A
	EU Habitats & Species Directive	B-II* B-IV	B-II B-IV	-	B-V	-	-	B-V D	B-II* B-IV	B-IV	B-V	-	B-V	-	-	B-II* B-IV

Fig. 2.2 – Number of carnivore publications focusing on a single species vs multiple species in Portugal (N=755), and the Red List Categories of each species according to the International Union for Conservation of Nature (IUCN) Red List of Threatened Species and the Portuguese Red List of Vertebrates. LC, Least Concern; DD, Data Deficient; NT, Near Threatened; VU, Vulnerable; EN, Endangered; CR, Critically Endangered; RE, Regionally Extinct; NA, Not Applicable (recently introduced). Species with threatened conservation status are marked in grey. The International legal status is represented by the inclusion in the Annexes of the Bern Convention (II, Appendix II; III, Appendix III), CITES (I A, Appendix I Annex A; II A, Appendix II Annex A; D, Annex D) and EU Habitats & Species Directives (B-II, Annex B-II; B-II*, Annex B-II*; B-IV, Annex B-IV; B-V, Annex B-V; D, Annex D).

species large in size, habitat generalists, or charismatic such as the grey wolf, Eurasian otter, red fox (*Vulpes vulpes*) and European badger (*Meles meles*) have been the most studied carnivores in Europe in the last years. In contrast, mesocarnivores that usually occur in sympatry and are surveyed by similar methodological approaches tend to be the target of multi-species studies focusing at the community level. The species with smallest number of publications included those currently extinct in Portugal (e.g. brown bear *Ursus arctos*) or with restricted distributions, low densities and/or elusive behaviour (e.g. pine marten, stoat, and American mink), which is also consistent with previous findings (Brooke et al., 2014).

Regarding the type of publication, Conference Proceedings accounted for almost a third of the publications (32%), followed by SCI articles (22%), Theses (19%), non-SCI articles (13%), Technical reports (9%) and Books or Book Chapters (6%). Compared to other regions where mammal publication metrics were investigated (e.g.,Superina et al., 2014), Portugal has fewer scientifically peer-reviewed publications for the Order Carnivora. This might be due to the low stimulus given to researchers in Portugal to publish in SCI journals before 2000, probably associated with a disadvantage of Non-native English speakers to publish their work in English-dominated journals (Clavero, 2010). However, the amount of Conference proceedings suggests that important efforts were being made to divulge in-house scientific work.

The most common research topics investigated in carnivore studies were ‘General Ecology’ (32%), ‘Conservation’ (31%) and ‘Population status’ (18%), which is consistent with previous studies showing that at least one of these topics is among the top three research areas on other mammal species (Fig. 2.3; Ferreira et al., 2012; Prieto et al., 2012; Superina et al., 2014). In general, the patterns of research topics and carnivore species covered in publications from Portugal reflect the worldwide trends on carnivore research (Pérez-Irineo and Santos-Moreno, 2013).

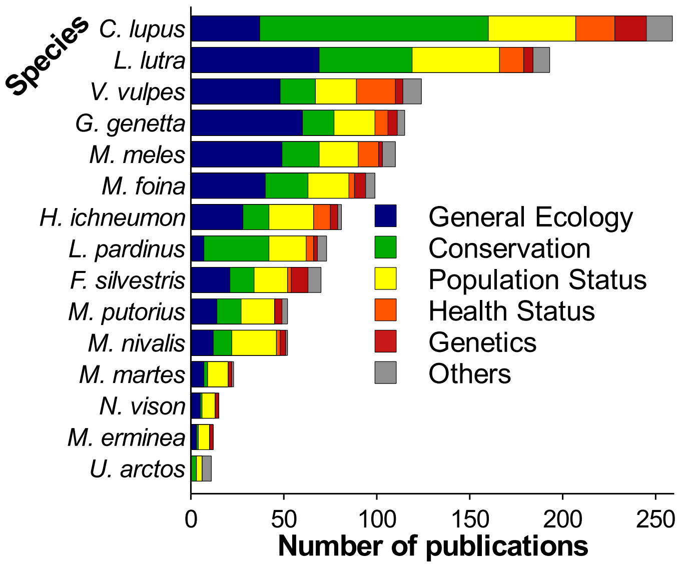


Fig. 2.3 – Number of publications per carnivore species in Portugal, grouped by research topic (N= 755).

2.3.2 Species Checklist

In this study we documented the presence of 16 species of carnivores known to currently occur, or to have historically occurred, in Portugal, confirming this as one of the European countries with highest species richness of mammalian terrestrial carnivores

(IUCN, 2016; Mitchell-Jones et al., 1999). According to the Portuguese Red Book of Vertebrates (Cabral et al., 2005), one carnivore species is classified as Regionally Extinct, three species are included in categories of threat (CR, EN and VU), three are classified as Data Deficient (DD), seven are classified as Least Concern (LC), and one (American mink) has the status of Not Applicable (NA), because it is a recent invasive species (Fig. 2.2). An additional exotic species, the racoon (*Procyon loctor*), was now recorded for the first time in Portugal at several locations, most likely related to different introduction events across the country.

The mammalian terrestrial carnivore community in Portugal is composed of species with different biogeographical origins: most species (N=10) are native in Portugal and widespread in the Palearctic (e.g. grey wolf, red fox, wildcat *Felis silvestris*) or Eurasia (e.g. Eurasian otter, European badger, stone marten *Martes foina*, pine marten, stoat, least weasel *Mustela nivalis*; western polecat; Mitchell-Jones et al., 1999). All these species are or were widespread across mainland Portugal, except the stoat and pine marten, which always occurred only marginally in northern Portugal due to their affinity to the Eurosiberian biogeographical region (Mitchell-Jones et al., 1999). One species, the Iberian Lynx, is endemic and restricted to the Iberian Peninsula, i.e., mainland Portugal and Spain (Palomo and Gisbert, 2002). The common genet and the Egyptian mongoose, two species with their origin and core distributions in Africa, were (supposedly) historically introduced in Europe and naturalised populations now occur in the Iberian Peninsula (Delibes, 1982; Gaubert et al., 2011; Riquelme-Cantal et al., 2008; but see Barros et al., 2016 with recent evidences of Egyptian mongoose occurrence in the late Pleistocene in Iberia).

The invading American mink and racoon, both native from North America, are spreading throughout the Iberian Peninsula (García et al., 2012; Rodrigues et al., 2015). For Portugal, the occurrence of the American mink was first documented during late 1980's (Vidal-Figueroa and Delibes, 1987), while the racoon was first sighted in 2008 but documented for the first time in this study. With the exception of these two recent invaders, for all the remaining carnivore species this study confirmed an established occurrence in Portugal since historical times. This includes the pine marten and stoat, whose occurrence in Portugal was only scientifically recognised in the 1990s (Santos-Reis and

Mathias, 1996). Regarding the brown bear, previous assessments consider the time of extinction in Portugal to be the mid-17th century (Cabral et al., 2005; Mathias et al., 1998a; Santos-Reis and Mathias, 1996). However, the present study compiled evidence of brown bear occurrence in Portugal until the late 19th century, most probably as a result of occasional incursions of dispersing individuals from relict breeding populations in NW Spain, which still occurred near the Portuguese border (Álvares and Domingues, 2010).

At the onset of the 21st century, the Iberian lynx was considered on the verge of extinction and had no confirmed presence records in Portugal (Sarmento et al., 2009). However, this species has recently been increasing its presence in Portugal, as a result of natural dispersal movements from captive-bred individuals released under reintroduction programmes, both in Spain and Portugal (Muñoz et al., 2007; Unknown, 2008a; Vargas et al., 2008). The present study has compiled several historical records of lynx, in north-western Portugal up to the 18th century, which are within the Eurosiberian biogeographical region and may suggest the former presence of another species in Portugal: the Eurasian lynx (*Lynx lynx*). In fact, recent genetic and historical evidences suggest that the Eurasian lynx occurred in the Atlantic-Alpine climate area of the northern Iberian Peninsula (within the Eurosiberian biogeographical region) from the Pleistocene until the early-19th century (Clavero and Delibes, 2013; Rodríguez-Varela et al., 2016) as opposed to the Iberian Lynx, which occurred further south, within the Mediterranean biogeographical region.

2.3.3 Distribution patterns and trends of the Portuguese carnivore guild

We compiled a total of 20,189 presence records, 5,217 of which were historical records (since the 12th century up to the 20th century) and 14,972 were current records (from 2000 to 2015). Of the current records, almost 75% came from previously unpublished data, 11% were obtained from online databases (not all of which are publicly available), and 14% came from the published literature.

The red fox and Eurasian otter were the species with the highest number of current presence records, likely due to the conspicuousness of their presence signs, their widespread distribution (Palomo and Gisbert, 2002) and high abundance (Pita et al., 2009; Quaglietta et al., 2015). There was a high number of historical records for the

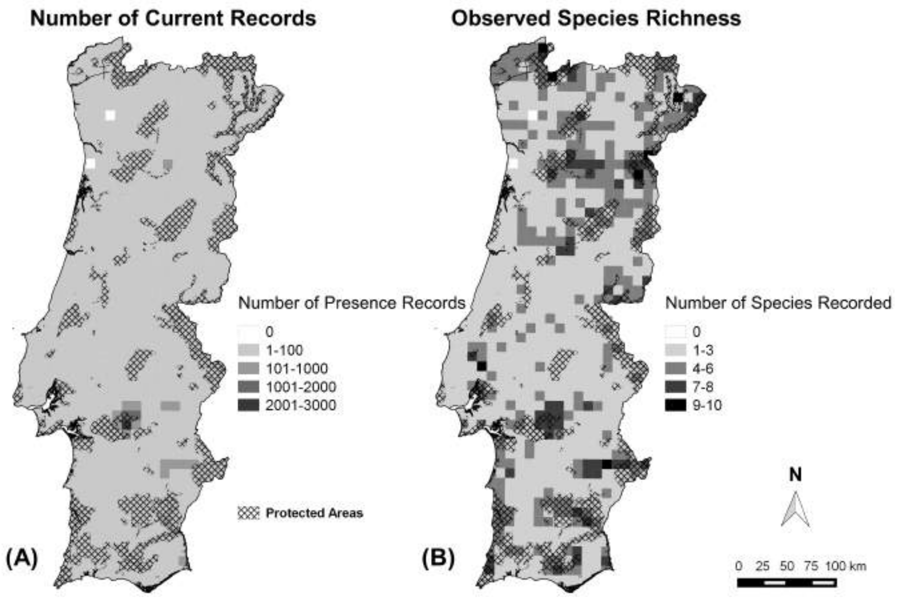


Fig. 2.4 – Number of presence records (A) and Observed Species Richness (B) since 2000 in UTM 10x10-km cells in mainland Portugal, and location of the mainland National Protected Areas Network.

Eurasian otter and the grey wolf, due to the existence of previous systematic and detailed assessments of their past distributions in Portugal (Petrucci-Fonseca, 1990; Trindade et al., 1998).

Most of the total species' historical records were from the 1980s and the 1990s (68%), with eight species having their first records in the country during these periods. Only three species presented historical data that covered a much wider temporal period. These were the grey wolf (records evenly distributed since the beginning of the 20th century), the Iberian Lynx (records available since the 18th century, although most dated from the 1980s and 1990s), and brown bear (regular records from the 12th to the 19th century). For current records, only 18% (N=2707) were classified as 'Confirmed'. The geographic distribution of the current data (Fig. 2.4A) is fairly homogeneous across mainland Portugal, except for a site in central-south Portugal where a disproportionally large amount of presence records is available due to a particularly important mammal sampling effort made over the last years (in and around the Monfurado Natura 2000 site).

Regarding the current distribution range of Portuguese carnivores (Fig. 2.5), more than half of the species (N=9) is widespread in Portugal, with current EOOs covering over 85% of the country territory, whereas six species have restricted ranges, occupying less than 40% of Portugal's mainland. When comparing historical and current distributions,

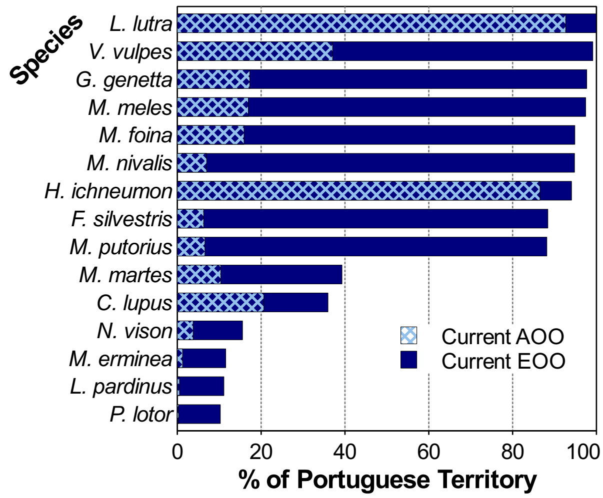


Fig. 2.5 – Comparison of current Area of Occupancy (AOO) and Extent of Occurrence (EOO) for each species, given as percentages of the mainland Portuguese territory (see Methods section for further details)

and despite the shortcomings of this comparison (i.e. different geographic units and sampling efforts), it is possible to infer that, for most species, their current range largely coincides with their historical distribution (Fig. 2.6 and 2.7).

Some carnivores that are fairly common and widely distributed at the European level (e.g., red fox, otter, badger, stone marten, weasel and polecat; Cabral et al., 2005; IUCN, 2016) are also so across Portugal, both in historical and current times. Two species of African origin, the common genet and Egyptian mongoose, are also widespread and seem to be well adapted to the Portuguese landscapes and climate (Cabral et al., 2005; Cavallini and Palomares, 2008; Gaubert et al., 2015b; IUCN, 2015). However, while the genet seems to have maintained its range, the Egyptian mongoose has been undergoing an extensive, rapid expansion towards the north of the country, and is currently absent only in the northwestern portion, included in the Eurosiberian biogeographic region (Barros et al., 2015). Nevertheless, all carnivore species, with the exception of the otter and the Egyptian mongoose, present a small AOO in Portugal. The small difference between the AOO and current EOO for the otter and mongoose is most probably due to the fact that these are the only widespread species whose distributions have been recently thoroughly assessed in Portugal (Barros et al., 2015; Trindade et al., 1998). For the remaining species, the discrepancy between small AOO and relatively large current EOO may be either due to insufficient survey coverage for generally common and widespread species (e.g. red fox, stone marten, weasel, badger and common genet), or because the

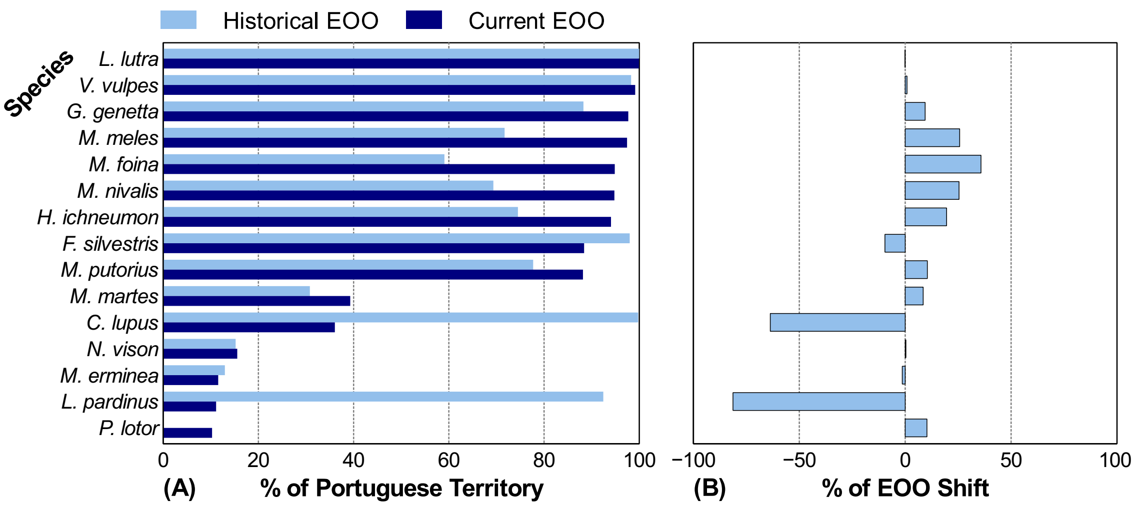


Fig. 2.6 – Comparison of historical and current Extent of Occurrence (EOO) for each species, as percentages of the mainland Portuguese territory (A), and the percentage of change in EOO from historical to current times. Negative values suggest range regression and positive values suggest range expansion (B).

species actually occurs in fragmented and localized populations and/or is less common (e.g. polecat and wildcat; Cabral et al., 2005; Fernandes, 2007)

For the six species that currently have a more restricted distribution, the observed pattern seems to be the result of different factors. For wolf and Iberian lynx, it is the result of a massive range contraction caused largely by anthropogenic factors in the beginning of the 20th century (Cabral et al., 2005). For stoat and pine marten, which seem to be restricted to northern Portugal since historical times, this is probably due to biogeographical constraints, since this area is at the edge of the Eurosiberian region (Brito and Álvares, 2004). Finally, the American mink and the racoon are recent invaders that have so far colonised a small area in mainland Portugal (Rodrigues et al., 2015). The American mink range is expanding southwards from the northern Portuguese border, and currently occupying most of the hydrographic basins of north-west Portugal and some areas in the north-east.

Three species – stoat, pine marten and wildcat - show unclear trends in distribution range. This ambiguity may be related to uncertainties regarding presence data and species identification (e.g., presence signs of pine marten and wildcat may be easily confounded with those of stone marten and domestic/feral cat *Felis catus*, respectively), or to the fact that their southern range limit is not yet clear (e.g. stoat and pine marten).

More than half of the presence records (56%) fell in UTM cells included in protected areas (35% of the analysed UTM cells). Both the number of records (Fig. 2.4A) and observed species richness (Fig. 2.4B) were significantly higher in the cells falling within protected areas ($W_{records}$=84698, and $W_{richness}$=89130, respectively; $p<0.001$). This might have two, not mutually exclusive, explanations: protected areas are a refuge where species are actually more abundant and diverse (e.g., due to lower anthropogenic influence, namely in the form of lower hunting pressure), so it is more probable to record their presence in these areas; and/or the collection of records for research purposes is biased towards protected areas (e.g., because research efforts and/or funding are prioritized there). The latter might represent a more reasonable explanation, given that geographical survey bias has been shown to have a widespread effect on biodiversity data (Barbosa et al., 2013a; Fontaneto et al., 2012). Additionally, even if protected areas actually encompass a more diverse landscape they may not be sufficient to act as refuges for carnivores, since some species have home ranges that are larger than the areas selected for protection (e.g. grey wolf, Iberian lynx; e.g. Soulé et al., 1999). Besides, carnivore distributions are generally more conditioned by prey abundance than by the noteworthy habitats that are at the origin of most protected areas.

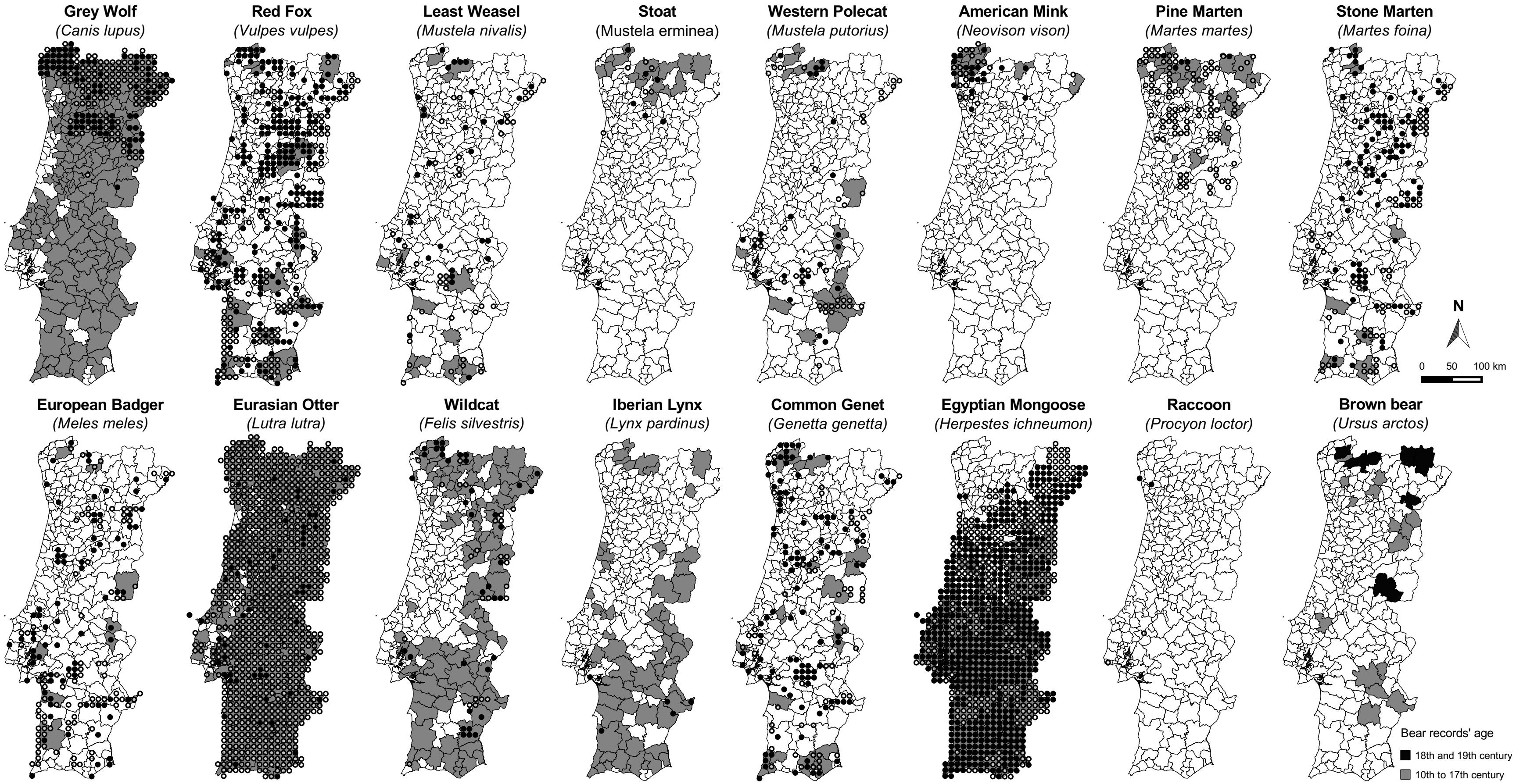


Fig. 2.7 – Historical (pre-1999) and current (post-2000) presence records of the 16 carnivores species occurring in mainland Portugal. Historical records are represented at the municipality level (Grey areas– Presence recorded; White areas – Presence not recorded); Current records are represented at the level of UTM 10x10-km cells (Black circles – Confirmed; White circles– Unconfirmed). See Methods section for further details.

2.3.4 Insights from non-systematic data: management and methodological implications

This study, based on the compilation of non-systematic data, provides the first thorough assessment of the distribution patterns of all 16 carnivores occurring in Portugal since historical times, which include 11 native species, two naturalised species, two recently introduced exotic species and one extinct species. The most recent invasive carnivore in Portugal, the racoon, is becoming an important conservation problem in Europe, including the neighbouring country, Spain, because it affects many native species through predation and/or competition (García et al., 2012; Kauhala and Kowalczyk, 2011). Yet the distant location of these first records collected in Portugal in relation to the known Spanish populations (García et al., 2012) suggests intentional releases or individuals escaped from captivity, rather than a naturally expanding population. Thus, a targeted management program in Portugal is essential to accurately assess this species' current distribution, identify the origin of these individuals and ensure their control or eradication.

The distribution ranges suggested by non-systematic data may reflect the actual ranges for some species (e.g. grey wolf, stoat, Iberian lynx, racoon), but for others it is evident that there are areas of the country that have been under-represented in monitoring and scientific studies. Consequently, these species (e.g. least weasel, western polecat, stone marten, European badger, common genet, wildcat) should be the focus of more research in the future, to allow a better grasp of mammalian terrestrial carnivore distribution at a national level and the design of specific conservation strategies.

With this work, it became clear that there are many data, but these are scattered and frequently unavailable to the general scientific community (and wider public), due to lack of compilation and centralization of the information. Online databases were an important source of species occurrence data for this study, as they do some of the work of centralizing information and making it publicly available. The downside of using online public databases is the uncertainty associated with records collected from heterogeneous sources, using different methodologies and by observers with varying levels of expertise. These data thus need to be critically analysed and cleaned to remove unreasonable and/or imprecise records, as we did in this study. Data obtained from the scientific literature are therefore great complementary sources, because they normally describe how the records were collected, providing more thorough information then other sources. However, depending on the age of the publications and/or on the availability of the authors to provide the raw data, underlying data like georeferenced presence records and associated information might not be easily obtainable from the literature. As conducted during this work, it might be necessary to retrieve the geographic location of data from maps and tables with as much precision as they allow.

Several of the Portuguese carnivores have more than half of their AOO classified as 'Unconfirmed' presence (see Table 2.1), since most records came from questionnaires or from presence signs without genetic validation. Although some species, such as the European badger, common genet and Eurasian otter, produce presence signs (such as footprints, scats or latrines) that are easily recognizable and fairly unequivocal (Blanco, 1998), in this study we have used a conservative approach for standardization purposes and have classified these records as 'Unconfirmed'. Regarding the pine marten, most current records are based on questionnaires (Matos and Santos-Reis, 2006) and, since this species is easily confused with a more common species, the stone marten, the actual occurrence area may be much more restricted than the one reflected by all collected records. Thus, we believe there is an urgent need to improve the accuracy of presence records for most species, which could be achieved by a standardization of the methods used to collect them (e.g., by using camera-traps or genetic confirmation of scats).

Table 2.1 – Common and scientific names of the 16 carnivore species recorded in mainland Portugal since historical times, total number of historical (pre-1999) and current (post-2000) records compiled for each species and values of the current Area of Occupancy (AOO) and the historical and current Extent of Occurrence (EOO) for each carnivore species in mainland Portugal. Current AOO and EOO for each species were based on the total number of UTM 10x10-km cells where the species was recorded. Historical EOO for each species was based on the total number of municipalities where the species was recorded. All measures are presented as percentage of cover in relation to the total area of mainland Portugal. Species are listed by phylogenetic order.

		Historical Data			Current Data						
					Number of records	AOO				EOO	
English Common Name	**Scientific Name**	**Number of records**	**All Records (km2)**	**EOO/Total country (%)**		**All Records (km2)**	**AOO/Total country (%)**	**Confirmed Records (km2)**	**Confirmed AOO/ Total AOO (%)**	**All Records (km2)**	**EOO/Total country (%)**
Grey wolf	***Canis lupus***	1687	88527	100	567	18327	21	7973	44	32000	36
Red fox	***Vulpes vulpes***	89	87212	98	3377	32886	37	21471	65	87976	99
Stoat	***Mustela erminea***	46	11498	13	16	1122	1	596	53	10260	12
Least weasel	***Mustela nivalis***	56	61541	69	281	6210	7	2789	45	84097	95
Western polecat	***Mustela putorius***	81	68960	78	177	5848	7	2493	43	78247	88
American mink	***Neovison vison***	49	13508	15	84	3355	4	1655	49	13808	16
Stone marten	***Martes foina***	44	52419	59	1515	14127	16	8764	62	84172	95
Pine marten	***Martes martes***	71	27339	31	105	9215	10	404	4	34870	39
European badger	***Meles meles***	96	63640	72	1992	15035	17	7336	49	86465	97
Eurasian otter	***Lutra lutra***	1400	88727	100	3061	82231	93	5070	6	88677	100
Common genet	***Genetta genetta***	58	78335	88	1330	15343	17	10144	66	86696	98
Egyptian mongoose	***Herpestes ichneumon***	675	66118	75	2340	76800	87	51680	67	83470	94
Wildcat	***Felis silvestris***	490	86963	98	113	5586	6	3389	61	78461	88
Iberian lynx	***Lynx pardinus***	326	82030	92	5	471	1	471	100	9868	11
Raccoon	***Procyon lotor***	0	0	0	4	288	0	122	42	9116	10
Brown bear	***Ursus arctos***	49	64382	73	0	-	-	-	-	-	-

Chapter 3

Modelling distributions and assessing large-scale correlates of carnivore occurrence in Portugal

(Manuscript in preparation to be submitted to a scientific journal)

3.1 Introduction

3.1.1 Influence of humans on carnivore occurrence

The wide distribution ranges that are characteristic of most carnivore species (Mitchell-Jones et al., 1999; Noss et al., 1996), combined with the growing expansion of human populations throughout the globe, makes an overlap between these two almost inevitable. For this reason, it is especially important to study how carnivores respond to human-related variables, particularly in humanised areas (Gastón et al., 2016; Grilo et al., 2016).

Human-related factors have been exerting a strong influence on carnivore occurrence by being a limiting factor for some species and a positive factor for others. Large carnivores, for example, have experienced massive population declines due to habitat destruction, predominantly associated with urban and agricultural expansion (Chapron et al., 2014), and have been actively persecuted in most regions of the world because their requirements often conflict with those of local people, leading to human intolerance (Ripple et al., 2014; Woodroffe, 2000). On the other hand, mesocarnivores often have high plasticity, both in terms of diet and habitat requirements, which allows them to adapt and even thrive in agricultural and other human-dominated landscapes, where often there is an absence of top predators and increased food availability (Rosalino et al., 2010a; Verdade et al., 2011). Furthermore, it seems that current diversity patterns of carnivores are being determined not only by their distribution trends, but also by the constant land use changes (Carroll et al., 2001; Smith et al., 2010). Although there has been a general increase in carnivore populations over the last years, even for some large carnivores (Chapron et al., 2014; Trouwborst, 2010; Verdade et al., 2011), the maintenance of this positive trend depends on changes in land use, which are currently characterised by decreasing agricultural and increasing urbanised uses (Fischer et al., 2014; Rey Benayas, 2007; Rey Benayas et al., 2008). Taking this into account, it is very important to identify the human factors that influence the occurrence of carnivores.

3.1.2 Species Distribution Modelling: potential and constraints

Species Distribution Modelling (SDM) is a tool that combines observations of species occurrence with predictor variables, in order to estimate the actual or potential geographic distribution of a species. SDM helps to characterise the suitable conditions for the species and identify how suitable environments are distributed in space (Elith and Leathwick, 2009; Pearson, 2010). SDM is currently a popular and particularly useful tool in several fields of biology, such as biodiversity conservation – e.g. allowing the identification of areas that may be suitable for the reintroduction of species (Osborne and Seddon, 2012; Pearce and Lindenmayer, 1998); Survey planning – e.g. guiding field surveys toward regions where it is more probable to find new populations of a known species, or even accelerate the discovery of previously unknown species (Engler et al., 2004; Raxworthy et al., 2003); Invasive species – e.g. identifying sites where a species is most likely to become invasive (Peterson, 1973); Climate change – e.g. assessing the potential impacts of climate change on species distribution ranges (Gutiérrez-Rodríguez et al., 2016; Thomas et al., 2004; Thuiller, 2004); Ecological requirements – e.g. examining habitat selection and niche evolution (Monterroso et al., 2009; Reino et al., 2016); among other applications – e.g. identification of potential areas for disease outbreaks, informing taxonomy, etc. (Herkt et al., 2008; Pearson, 2010; Peterson et al., 2004; Porfirio et al., 2014; Raxworthy et al., 2007).

SDM allows building relevant knowledge about a species, not only by helping to predict its potential distribution, but also by identifying which factors are most related to its occurrence (Blach-Overgaard et al., 2010; Rosalino et al., 2010a). This information, especially regarding human-related factors in humanised areas, is of major importance to understand how species react to various forms of human presence (Hebblewhite and Merrill, 2008; Stefanescu et al., 2004) and to improve wildlife management and conservation (Bath, 1995; Charoo et al., 2011).

Several issues, challenges and limitations along the process of SDM, if left to chance, may lead to deceitful results. It is critical to understand and take into account data quality issues (since "a model is only as good as the data it contains", Pearson, 2010), the modelling process and model reliability (Herkt et al., 2008). Regarding data quality, it is necessary, for example, to be aware of the sampling bias that may arise from under-sampling (both in sample size and environmental range coverage) and spatial auto-correlation, which might lead to a predicted distribution different from the one which we could obtain with a more complete sampling (Herkt et al., 2008). During the modelling process, the limitations nowadays are no longer on the computation capacity and the mathematics, but rather on our knowledge about ecosystems and ecological processes (Guisan and Thuiller, 2005) and on the comprehension of how the SDM works and what are the assumptions behind each modelling algorithm (Pearson, 2010). Many of the prevailing challenges facing SDM research involve the inclusion of ecologically relevant parameters and an improved assessment of errors and uncertainties to yield more robust predictions (Guisan and Thuiller, 2005).

To avoid the issue of having to choose a modelling technique from a range of alternatives and the uncertainty related to inter-model variations (including contradicting projections by alternative models), an alternative solution is to apply several models and do ensemble forecasting (Araújo and New, 2007). One of the advantages of this option is that combined forecasts tend to yield lower mean error than any of the constituent individual forecasts, increasing the confidence on the results obtained (Araújo and New, 2007; Bates and Granger, 1969).

3.1.3 Previous studies on distribution modelling and variables related to carnivore distribution in Portugal

In Portugal, there have been studies using SDM for at least seven species of mammalian carnivores (wolf , polecat, pine marten, otter, genet, wildcat and Iberian lynx; Álvares and Brito, 2006; Barbosa, 2001; Barbosa et al., 2003; Barbosa et al., 2012; Eggermann et al., 2011; Galantinho and Mira, 2009; Matos and Santos-Reis, 2006; Mestre et al., 2007; Monterroso, 2004; Monterroso et al., 2009; Palma et al., 1999). For the only two species of carnivores in Portugal which have information at a national level from systematic surveys – wolf (Pimenta et al., 2005) and otter (Trindade et al., 1998) –, records both from Portugal and Spain (where a national distribution atlas is available for mammals; Palomo et al., 2007) were put together in order to do distribution models for the Iberian Peninsula (Barbosa, 2001; Barbosa et al., 2003; Barbosa et al., 2012), with rather successful results assessed so far (Barbosa et al., 2010; Areias-Guerreiro et al., 2016). Most of the remaining SDM studies on carnivores in Portugal have been done at a relatively local scale. A prediction of wolf presence was made for an area of 1000 km^2 included in the Alvão/Marão Natura 2000 site, in Vila Real district, central northern Portugal, using field survey data from 2005 to 2007 (Eggermann et al., 2011). An evaluation of the distribution of the polecat and identification of its major environmental descriptors were made for an area of 64000 ha in Alentejo (southern Portugal), near the Spanish border, using field survey data from 2003 and 2004 (Mestre et al., 2007). Habitat requirements and suitable habitat areas were determined for the pine marten in a 1974 km^2 area encompassing two protected areas, Peneda-Gerês National Park (Portuguese) and Baixa Limia-Serra do Xurés Natural Park (Spanish), along the north border of Portugal with Spain, using records from the 1940s to 2000 (Álvares and Brito, 2006). Also for the pine marten, a prediction of the probability of occurrence was done for the North and Centre of Portugal using mostly questionnaires collected in 2002 and 2003 (Matos and Santos-Reis, 2006). The relationship between occurrence patterns of the genet and ecological, human and livestock descriptors was studied in a 23878 ha area at the Monfurado Natura 2000 Site in southern Portugal, using field survey data from 2003 and 2004 (Galantinho and Mira, 2009). The home-range size and environmental factors related to wildcat spatial ecology were determined for the Guadiana Valley Natural Park, a protected area of 69700 ha located in Southern Portugal, using field survey data from 2004 and 2005 (Monterroso, 2004; Monterroso et al., 2009). Iberian lynx habitat relationships and distribution patterns were quantified from sighting data in 1990-1995 for an area of about 1500 km^2 in a rugged coastal and mountain region of western Algarve (south-west Portugal) (Palma et al., 1999). An estimation of the contribution of landscape composition and configuration to spatial variation was done for species richness and abundances of mammalian carnivores (including the fox, badger, otter, genet and Egyptian mongoose) in the coastal plateau of south-western Portugal (Pita et al., 2009). Several topics have been focused on in studies using SDM for carnivores in Portugal, such as questions of scale and its effect on the results of modelling (Barbosa, 2001; Barbosa et al., 2003; Barbosa et al., 2010; Barbosa et al., 2012), responses of carnivores to landscape patterns (Pita et al., 2009), the influence of several types of features (ecological, human-related, etc.) on the occurrence of carnivore species (Álvares and Brito, 2006; Eggermann et al., 2011; Galantinho and Mira, 2009; Monterroso et al., 2009), the prediction of carnivore distribution ranges (Barbosa, 2001; Barbosa et al., 2012; Mestre et al., 2007), and the use of SDM results to improve conservation planning - e.g. habitat management, prey restocking/recovery (Ferreira, 2010; Monterroso et al., 2009; Nunes et al., 2015), among others.

Previous research studies using SDM for carnivores in Portugal have focused on 3 main types of factors that affect species occurrence: environmental, prey-related and human-related. Although species relate differently to these factors, there were several specific variables that appeared more frequently related to carnivore species distribution for each type of factor. Regarding environmental factors, topography (unevenness, elevation range and altitude), vegetation cover and humidity of the habitat were amongst the variables which most influenced carnivore species distributions (Álvares and Brito, 2006; Barbosa, 2001; Barbosa et al., 2003; Barbosa et al., 2012; Ferreira, 2010; Galantinho and Mira, 2009; Grilo et al., 2002; Mestre et al., 2007; Monterroso et al., 2009; Palma et al., 1999; Pita et al., 2009). Regarding prey-related factors, the availability of prey, namely livestock, European rabbit and other small mammals and invertebrates, has been identified as a major factor related to the occurrence of some Portuguese carnivores (Eggermann et al., 2011; Ferreira, 2010; Galantinho and Mira, 2009; Grilo et al., 2002;

Monterroso et al., 2009; Palma et al., 1999). Concerning human-related factors, variables related to human activity such as distance to motorways and proportion of game-estate areas (as a proxy for hunting pressure), and related to human density, such as proximity to settlements and road density, have been also found to be strong correlates to carnivore species presence, mainly due to the disturbance that they represent (Barbosa et al., 2003; Barbosa et al., 2012; Galantinho and Mira, 2009; Grilo et al., 2002; Eggermann et al., 2011; Monterroso et al., 2009; Palma et al., 1999).

Taking into account the research that has so far been done in Portugal, there is still a need for SDM studies focusing on each carnivore species as well as the carnivore community at a national scale. However, until now, the scarcity and lack of compilation of presence records in Portugal have made it very hard or impossible to do SDM on a national scale for most of these species.

3.1.4 Goals

The goals of this chapter of the were: i) to determine the potential distribution of the carnivores occurring in Portugal, by producing predictive distribution models, based on a model ensemble approach, using the presence records compiled in chapter 2; ii) to identify environmental and human-related variables associated with the occurrence of the carnivore species in Portugal.

This is the first SDM study addressing all carnivore species in Portugal, by using a large number of non-systematic presence data for modelling purposes. Furthermore, it allows a preliminary assessment of the variables associated with each carnivore species, particularly those for which there were no previous studies on ecological modelling.

3.2 Materials and Methods

3.2.1 Collection of presence data

Considering the presence records of carnivores compiled in chapter 2 of this thesis (see section 2.2 for details on the compilation procedures), a dataset was selected specifically for modelling the distribution of the extant carnivore species. This Modelling dataset also included new presence records that were obtained after the end of the work for chapter 2, which went through the same quality control as the remaining data. The dataset included presence records dated from 1995 until 5 July 2016 with an identifiable geographic location at the level of UTM 10x10-km grid cells. The final Modelling dataset was composed of 16951 records of 14 extant carnivore species occurring in Portugal. The number of records used for each species is represented on Table 3.1. Both the bear and the racoon were excluded from modelling, since the first is currently extinct in Portugal and the second has too few presence records due to its recent invasion.

Table 3.1 – Number of records per species used in the Modelling dataset, and number of UTM 10x10-km cells with Reliable records (R cells), Unreliable records (U cells), and No records (Empty cells).

Species	Nr. of records	R cells	U cells	Empty cells
Canis lupus	875	92	143	769
Vulpes vulpes	3495	243	129	632
Mustela erminea	27	11	11	982
Mustela nivalis	295	12	15	977
Mustela putorius	229	36	47	921
Neovison vison	106	19	23	962
Martes foina	1540	98	56	850
Martes martes	118	6	94	904
Meles meles	2070	160	8	836
Lutra lutra	4117	880	24	100
Genetta genetta	1377	138	43	823
Herpestes ichneumon	2378	572	284	148
Felis silvestris	319	59	105	840
Lynx pardinus	6	5	0	998

In the Modelling dataset, records were reclassified as 'Reliable' (records with a high level of confidence due to its type or origin) or 'Unreliable' (records with low level of confidence). Records classified as 'Reliable' included all records considered as 'Confirmed' in chapter 2. Signs of presence that were not genetically confirmed but that are easily recognisable and unequivocally attributable to a particular species (such as scats, latrines and footprints of badger and otter, and latrines of genet) were also considered 'Reliable'. All other unconfirmed records from chapter 2 were classified as 'Unreliable'.

For modelling, data on carnivore occurrence were converted into presence/absence data in UTM 10x10-km cells. Cells with at least one Reliable record were given the value of 1 (Presence), cells with only Unreliable records were given the value of NA (not available, to be excluded from the model), and cells with no records were given the value of 0 (Absence).

Auto-correlation was dealt with by thinning occurrence records to a maximum of one presence per UTM cell. At the analysed resolution scale of 10x10 km, additional auto-correlation is a natural consequence of contagious biotic processes such as migration (Barbosa et al., 2003).

3.2.2 Predictor variables

QGIS 2.14 (QGIS Development Team, 2016) was used for spatial data processing and R software version 3.2.4 (R Core Team, 2016) was used for data management and analysis.

A total of 28 variables of two main types, 19 environmental and 9 human-related, were included in the analysis (Table 3.2). The variables were chosen considering their availability at this scale and their potential predictive power, and are considered to be surrogates for more local causal factors affecting species distributions (Areias-Guerreiro et al., 2016; Barbosa et al., 2003; Post and Forchhammer, 2002).

The environmental variables were representative of different natural factors, namely topography, water availability, environmental energy, environmental disturbance, climatic stability and productivity (Table 3.2). Some of these variables serve as indicators of a more coastal or more inland distribution (e.g. HJul, HRan), while others serve as indicators of the Mediterranean vs. Eurosiberian biogeographical regions (e.g. DPre, Inso, SRad, TJul; for abbreviations see Table 3.2). The human-related variables were indicative of human density and human activity (Table 3.2).

Table 3.2 – Factors and their related variables used for modelling, with respective codes and sources

Factor	**Variable**	**Code**	**Source**
Topography	Mean altitude (m)	Alti	U.S. Geological Survey (1996)
	Mean slope (degrees) (calculated from Alti)	Slop	Barbosa et al. (2003) and Barbosa et al. (2009b)
	Altitude range	DAlt	Font (1983) and Font (2000)
Water Availability	Mean annual precipitation (mm)	Prec	Font (1983) and Font (2000)
	Mean relative air humidity in January at 07:00h (%)	HJan	Font (1983) and Font (2000)
	Mean relative air humidity in July at 07:00h (%)	HJul	Font (1983) and Font (2000)
	Mean annual number of days with precipitation ≥ 00.1mm	DPre	Font (1983) and Font (2000)
Environmental Energy	Mean annual insolation (h/year)	Inso	Font (1983) and Font (2000)
	Mean annual solar radiation (kwh/m^2/day)	SRad	Font (1983) and Font (2000)
	Mean temperature in January (°C)	TJan	Font (1983) and Font (2000)
	Mean temperature in July (°C)	Tjul	Font (1983) and Font (2000)
	Mean annual temperature (°C)	Temp	Font (1983) and Font (2000)
	Mean annual number of frost days (minimum temperature ≤ 0 °C)	DFro	Font (1983) and Font (2000)
	Mean annual potential evapotranspiration (mm)	PET	Font (1983) and Font (2000)
Environmental Disturbance	Maximum precipitation in 24h (mm)	MP24	Font (1983) and Font (2000)
	Relative maximum precipitation (=MP24/Prec)	RMP	Barbosa et al. (2003) and Barbosa et al. (2009b)
Climatic Stability	Annual relative air humidity range (%) (=|HJan-HJul|)	HRan	Barbosa et al. (2003) and Barbosa et al. (2009b)
Productivity	Mean distance to fresh water sources (km)	DHidro	Sistema Integrado de Informacion del Agua (www.magrama.gob.es/es/agua) and Portuguese climatic atlas (www.apambiente.pt)
	Mean annual actual evapotranspiration (mm) (=minimum [PET, Prec])	AET	Barbosa et al. (2003) and Barbosa et al. (2009b)
Human Density	Distance to the nearest town with more than 100,000 inhabitants (km)	U100	I.G.N. (1999)
	Distance to the nearest town with more than 500,000 inhabitants (km)	U500	I.G.N. (1999)
	Distance to nearest road (km)	Droad	OpenStreetMap (www.openstreetmap.org)
	Intensity of Night Lights (Calibrated Radiance)	NLight	NOAA National Centers for Environmental Information (www.ngdc.noaa.gov)
Human Activity	Distance to the nearest motorway (km)	DMo	I.G.N. (1999)
	Livestock (normalized head count)	Liv	Portuguese National Statistics Institute (www.ine.pt)
	Number of farms Farms	Farm	Portuguese National Statistics Institute (www.ine.pt)
	Area of permanent meadows and grassland (ha)	SMG	Portuguese National Statistics Institute (www.ine.pt)
	Agricultural area (ha)	AgrA	Portuguese National Statistics Institute (www.ine.pt)

Data on the number of inhabitants of urban centres taken from Enciclopédia Universal (www.universal.pt) for Portugal and from the Instituto Nacional de Estadística (www.ine.es) for Spain, both in 1999.

Most of the variables (Alti, Slop, DAlt, Prec, HJan, HJul, DPre, Inso, SRad, TJan, Tjul, Temp, DFro, PET, MP24, RMP, HRan, AET, DMo, U100, U500; Table 3.2) were previously digitized and interpolated on a 1x1-km resolution (Barbosa et al., 2003). Regarding the variables digitized and interpolated in this thesis, data on livestock (counts of poultry, cattle, goats, rabbits, equines and sheep, which were obtained as normalized head count, *Liv*), number of farms, area of permanent meadows, and grassland and agricultural area, were obtained in alphanumeric form either at the municipality level (Liv) or at the county level (i.e. "freguesia"; Farms, SMG and AgrA). Each of these four variables was attributed to the centroid of their spatial unit and interpolated using the Inverse Distance Weighting method (Liszka, 1984) in QGIS with a Distance Coefficient of 1, on a resolution of 1x1-km.

To produce the variable Distance to nearest road (DRoad), shapefiles containing the entire road network for the Iberian Peninsula were obtained (OpenStreetMap, `www.openstreetmap.org`). For the Distance to nearest fresh-water source, shapefiles were used of the rivers, large rivers' water bodies and dams (i.e. "albufeiras") in the Iberian Peninsula (Sistema Integrado de Informacion del Agua, `www.magrama.gob.es/es/agua` and Portuguese climatic atlas, `www.apambiente.pt`). For both variables, the shapefiles were rasterized on a resolution of 100x100-m, in order to represent accurately the locations of the roads and of all fresh water sources. Mean distance was calculated using the 'Proximity (Raster Distance)' tool of QGIS with the pixels as a distance unit. For both variables, although the final maps were just for Portugal, the roads and water sources in Spain were also considered, to achieve accuracy near the border. The variable Night Lights (calibrated radiance of lights visible from satellites at night) was obtained in raster format, at approximately 1x1-km resolution.

The values of all variables were then averaged over each UTM 10x10-km cell, using the 'Zonal Statistics' tool of QGIS.

3.2.3 Model building

Generalized Linear Models (GLM) were used to guide the selection of the most relevant variables for each species, as this algorithm has widely proven to produce robust models (Areias-Guerreiro et al., 2016; Barbosa et al., 2010; Elith, 2000; Wintle et al., 2005). Type I errors (which tend to increase with multiple tests) were handled by controlling the False Discovery Rate (FDR) (Benjamini and Hochberg, 1995; García, 2003). Only variables under a FDR value lower than 0.05 were accepted. Pearson correlation coefficients (Upton and Cook, 2008) were used to test for collinearity between pairs of predictor variables, in order to exclude highly correlated variables (correlation threshold = 0.8). A forward-backward stepwise procedure based on Akaike's Information Criterion (AIC) was then performed to select the final set of variables to be included in the models of each species. All remaining non-significant variables were removed (Reino et al., 2016; Gutiérrez-Rodríguez et al., 2016). This procedure is implemented in the 'multGLM' function of the 'fuzzySim' R package (Barbosa, 2016).

To account for uncertainty due to disagreements between the predictions of different modelling algorithms (Araújo and New, 2007; Bertelsmeier and Courchamp, 2014), the predictor variables selected for each species were used in a multi-ensemble model forecasting approach, using the "sdm" package in R (Naimi and Araújo, 2016). This package includes thirteen state-of-the-art modelling methods:

- Boosted Regression Trees (BRT; Friedman, 2001)
- Classification and Regression Trees (CART; Breiman et al., 1984)
- Flexible Discriminant Analysis (FDA; Hastie et al., 1994)
- Generalized Additive Models (GAM; Hastie and Tibshirani, 1990)
- Generalized Linear Models (GLM; McCullagh and Nelder, 1989)
- Lasso and Elastic-Net Regularized Generalized Linear Models (GLMNET; Friedman et al., 2010)
- Multivariate Adaptive Regression Splines (MARS; Friedman, 1991)
- Maximum Entropy (Maxent; Phillips et al., 2006)
- Maxlike (Royle et al., 2012)
- Mixture Discriminant Analysis (MDA; Hastie et al., 1994)
- Random Forests (RF; Breiman, 2001)
- Recursive Partitioning and Regression Trees (RPART; Breiman et al., 1984)
- Support Vector Machines (SVM; Vapnik, 1995)

For each species, the average of the ensemble model predictions, weighted by the

Area Under the receiver operating characteristic Curve (AUC) of each successfully run model, and the variance among the predictions given by the different modelling algorithms, were obtained and mapped. The weighted average of the predictions represents the potential area of distribution of each species, measured by the suitability of the conditions throughout the country (Marmion et al., 2009). Models with an AUC below 0.6, which according to Swets (1988) have failed prediction, were excluded from the weighted average. The AUC measure was chosen for model average weighting because it did not require the arbitrary choice of a threshold value (Bertelsmeier and Courchamp, 2014). The variance among predictions is a measure of the consensus between modelling algorithms. UTM cells with a smaller variance, which means less uncertainty, were considered the most robust in the forecast, and vice versa (Buisson et al., 2010).

Model performance was evaluated for the ensemble weighted average using R package "modEva" (Barbosa et al., 2014). Eight measures were calculated: AUC, Correct Classification Rates (CCR), Sensitivity, Specificity, Cohen's kappa, True Skill Statistic (TSS), and Pearson's and Tjur's (pseudo) R^2 statistics (Areias-Guerreiro et al., 2016; Reino et al., 2016). For all threshold-dependent measures (CCR, Sensitivity, Specificity, Cohen's kappa and TSS), species prevalence (i.e., proportion of presences) was used as a threshold to separate predicted presence from predicted absence, as it has proved to work well for this purpose (Liu et al., 2005).

3.3 Results and Discussion

3.3.1 Carnivore Species Distribution Models and selected variables

The final set of variables selected for each carnivore species is represented on Table 3.3.

Table 3.3 – Variables selected for modelling the distribution of each carnivore species in Portugal. "+" represents a positive relationship with the species and "-" a negative one. (See Table 3.2 for Code Variable interpretation)

Species	Selected Variables
Canis lupus	+Alti, -SRad, +HJul, +Farm, -NLight, -Liv, -DAlt, +DRoad
Vulpes vulpes	+Alti, +Liv, -HJul
Mustela erminea	+Alti, -Inso
Mustela nivalis	+Alti, -RMP
Mustela putorius	-SRad, +MP24
Neovison vison	-SRad, -U500, +Farm
Martes foina	-HJul, +Slop, +DMo, -RMP
Martes martes	+Prec, +Farm
Meles meles	+SAgr, +SRad
Lutra lutra	+HRan, +DRoad, +Slop, -RMP
Genetta genetta	+DPre
Herpestes ichneumon	+SRad, +U500, -Farm, -PET, +Temp, +DRoad, +MP24
Felis silvestris	-SRad, +SMG, +Alti, -AET, +DAlt, +U500
Lynx pardinus	+Inso

3.3.1.1 Wolf

For the wolf model, half the selected variables were human-related (Appendix B: Table B.1a), suggesting that this species' distribution is strongly influenced by human activities, more than any of the other species modelled. Wolf occurrences show a positive relationship with increasing altitude, humidity in July, number of farms and distance to roads, and a negative relationship with annual solar radiation, intensity of nights lights, livestock density and altitude range of the terrain.

The positive relationship with altitude is most likely the result of a selection of higher altitudes, which have been major refuges for wolves due to decreased anthropic pressures in these areas (Carreira and Petrucci-Fonseca, 2000; Glenz et al., 2001; Grilo et al., 2002; Massolo and Meriggi, 1998). The positive relationship with number of farms but negative relationship with livestock density might be justified by the difference in production intensity: in farms, a more extensive and traditional livestock production is probably used (Eggermann et al., 2011; Torres et al., 2015), which would mean easier prey to hunt. On the other hand, high values of livestock density reflect confined animals and a more intensive production regime of livestock. This would mean more intense human activity, a more difficult access to the animals (the potential preys) and enhanced man-wolf competition (Grilo et al., 2002; Massolo and Meriggi, 1998). The positive relationship of the wolf with distance to roads (or the equivalent) has been also found by several authors (e. g. Thiel, 1985; Mech et al., 1988; Mladenoff et al., 1995). This avoidance of roads is probably related, not only to the risk of road casualties, but also to a way of avoiding close contact with human presence and the various threats it represents (Cayuela, 2004; Jedrzejewski et al., 2005; Kaartinen et al., 2005; Mech et al., 1988; Mladenoff et al., 1995; Musiani and Paquet, 2004; Thiel, 1985). The negative relationship with night lights, a proxy for human density and larger urban areas, represents the preference of the wolf for areas away from large human settlements, where disturbance tends to be lower. The positive relationship with humidity in July might be related to a preference for areas with less dry summers, which mean more water and, consequently, more food availability, especially in areas at higher altitude, generally farther away from large water sources such as main rivers. The negative relationship with annual solar radiation, which follows a north-south gradient, shows a northern affinity, which would be expected taking into account that all records of the species are currently restricted to the North of Portugal. The negative relationship with altitude range could be explained by the possibility of easier movement in a less rugged terrain.

The potential for occurrence of the wolf (Fig. 3.1A and 3.1B) seems to be higher in, and rather restricted to, the North of Portugal, including the mountainous areas of the Peneda-Gerês, Alvão and Montesinho, as well as the area south of Douro river. These areas correspond to the known main areas of wolf presence in the last decades (Álvares, 2004b). Interestingly, there is an especially low consensus between models for the area of Serra da Estrela, in central-eastern Portugal (Fig. 3.1C), probably because these mountains gather several conditions favourable to wolf presence but, due to the extreme range contraction during the last decades, this species does not occur there currently.

When comparing the set of unreliable cells (i.e. cells with existing but unconfirmed presence records) with the potential areas of wolf presence, a great overlap can be found, except for the species' range limits, where conditions are probably less favourable for wolf occurrence.

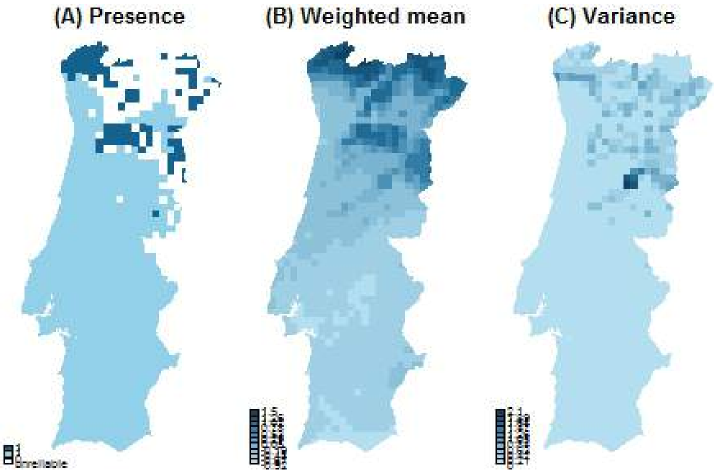


Fig. 3.1 – Presence data (A) and potential distribution of the wolf according to the averaged ensemble model (B) and variance among model predictions (C).

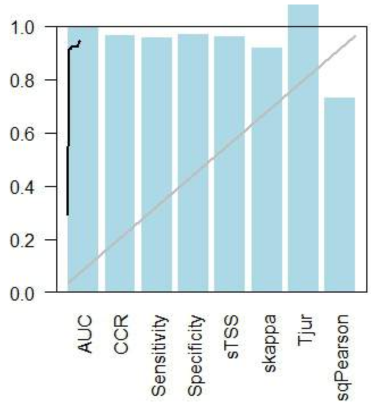


Fig. 3.2 – ROC curve and measures of evaluation of the wolf ensemble model performance.

3.3.1.2 Fox

In the fox model, mostly environmental variables were found to be related to this species' distribution. The variables selected were altitude, with a positive relationship, and livestock density and relative air humidity in July, which were both negatively related to the species (Appendix B: Table B.1b).

As was found for the wolf, the positive relationship with altitude, and also the negative relationship with livestock density, might be a way for foxes to avoid higher levels of human presence which, although not having strong known conflicts, might still represent disturbance for the species. The negative relationship with air humidity in July might be a proxy for continentality and/or avoidance of more coastal areas with more human presence and habitat of less quality. The combination of positive relationship with altitude and increased presence towards the east is supported by a study that found that the consumption of invertebrates decreased and fruit/seed consumption increased from west to east, and consumption of lagomorphs decreased and of small mammals increased with altitude (Díaz-Ruiz et al., 2013). These findings suggest that the red fox in Portugal may use more areas, at a national-scale, where its diet is composed more by fruit/seed and small mammals, although at more local scales it has a preference for lagomorphs which are more nutrient-rich (Díaz-Ruiz et al., 2013; Rosalino et al., 2010a).

The potential distribution of the fox presented in Figure 3.3B suggests that this species is generally more likely to occur in the North, especially in Serra da Estrela, south of

Douro river and the mountainous area of Peneda-Gerês. This contradicts the idea that the species has a ubiquitous distribution throughout the country (Santos-Reis and Mathias, 1996). It further suggests that, although the current EOO (see section 2.3.3) may be correct, conditions for fox occurrence might be more favourable in the northern half of the country, where there is also a higher proportion of cells with reliable records of species presence.

The consensus between models is lower around the area of Monfurado, Alentejo (Figure 3.3C). Possibly, this is because this area does not harbour, according to many algorithms, the best conditions for this species to occur, although numerous reliable records exist there due to particularly intense survey efforts (e.g Ascensão and Mira, 2006; Carvalho, 2004; Carvalho et al., 2012) .

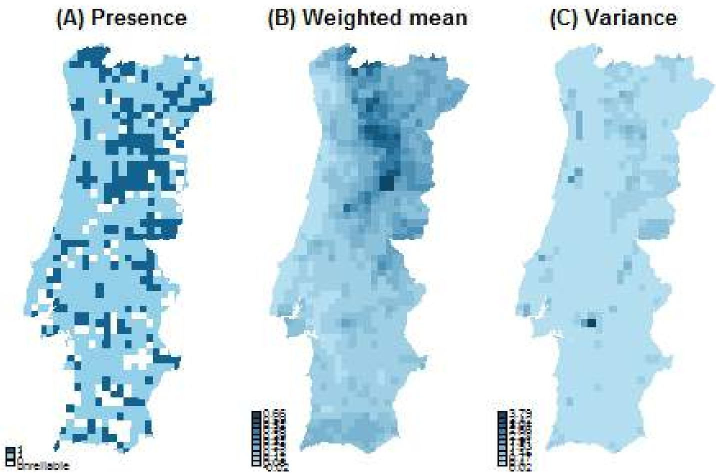


Fig. 3.3 – Presence data (A) and potential distribution of the fox according to the averaged ensemble model (B) and variance among model predictions (C).

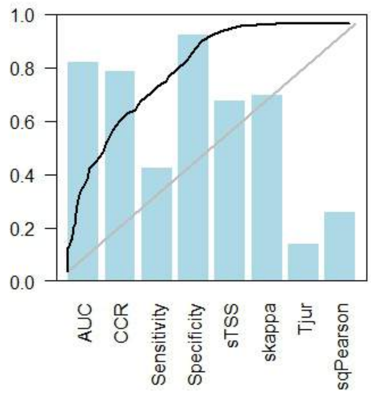


Fig. 3.4 – ROC curve and measures of evaluation of the fox ensemble model performance.

3.3.1.3 Stoat

For the stoat model, only environmental variables were selected. A positive relationship was found with altitude and a negative relationship was found with annual insolation (Appendix B: Table B.1c).

The positive relationship with altitude might, as for other species, be related to lower levels of human presence. It could also be related with the adaptations that this species has to alpine and snowy areas, which make the stoat prepared for living at high altitudes all year long, where it uses alpine meadows, rich in small mammals to hunt (Cabral et al., 2005; King, 1983; Blanco, 1998). The negative relationship with annual insolation is probably related to a higher affinity of this species with higher latitudes in Portugal and/or a more Eurosiberian environment, since the north-west of the Iberian Peninsula corresponds to the known southern limit of the stoat's distribution in Europe (Cabral et al., 2005; Palomo et al., 2007).

The potential for occurrence of the stoat seems to be higher in the mountainous areas of Peneda-Gerês and Montesinho, as well as Serra da Estrela (Fig. 3.5B). Interestingly no historical or current presence records are known in this last area (Fig. 3.5A). This prediction means that stoats are either extinct in that area which might have favourable conditions, or they are still present but not recorded, until the central mountainous system, an area larger than the one depicted by the current EOO (see section 2.3.3). The general area with high occurrence potential also includes most cells classified with unreliable presence, which indicates that these records probably represent true presences of the species.

The consensus between models across the territory was generally high, although smaller along the northern border between Portugal and Spain and in the area of Serra da Estrela, where this would be expected, given that there are currently no presence records in or near this area (Fig. 3.5C).

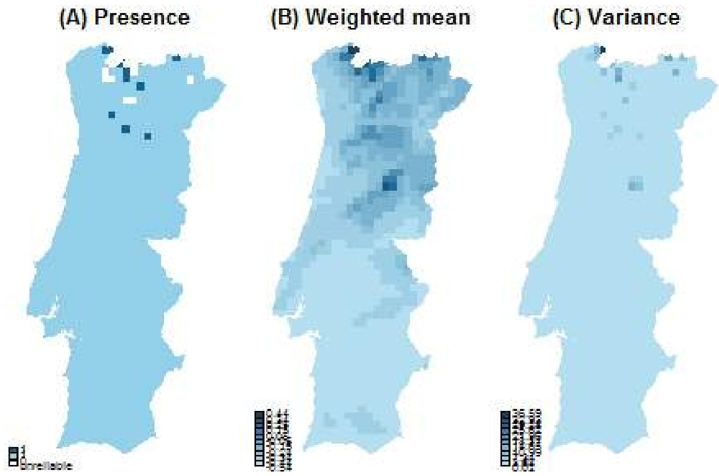


Fig. 3.5 – Presence data (A) and potential distribution of the stoat according to the averaged ensemble model (B) and variance among model predictions (C).

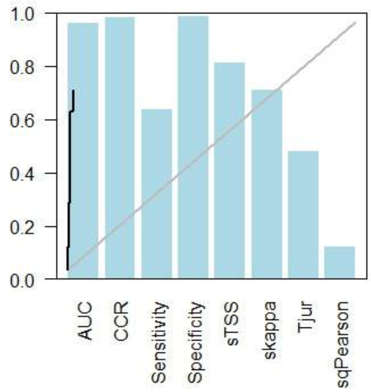


Fig. 3.6 – ROC curve and measures of evaluation of the stoat ensemble model performance.

3.3.1.4 Weasel

For the weasel, the variables selected were both environmental. A positive relationship was found with altitude and a negative relationship was found with relative maximum precipitation (Appendix B: Table B.1d). The positive relationship with altitude is possibly related to an avoidance of lower altitude areas, which commonly have higher levels of human presence. The negative relationship with relative maximum precipitation suggests an avoidance of areas which tend to be more severely affected by the natural disturbance of inundations.

The potential distribution of the weasel suggests that this species is more often present in the northern half of the country, especially in the areas of Alvão and Peneda-Gerês, but also in a part of Serra da Estrela (Fig. 3.7B). Considering only the areas of the country with the highest predicted potential for occurrence, the weasel' current EOO (see section 2.3.3) would seem to be over-estimated. Another possibility, taking into account that reliable records are available from the south of the country (Fig. 3.7A), is that environmental conditions are better for weasel occurrence in certain areas of the North of Portugal, but the species is able to occur bellow optimal conditions, thus increasing the size of its distribution range.

In terms of consensus between model predictions, the weasel had similar results to the stoat, although with a low consensus in the area of Serra da Estrela, where only one reliable record was obtained (Fig. 3.7C).

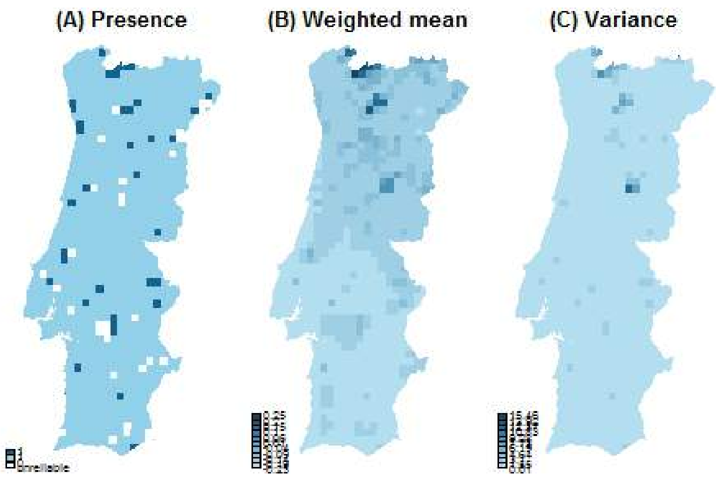


Fig. 3.7 – Presence data (A) and potential distribution of the weasel according to the averaged ensemble model (B) and variance among model predictions (C).

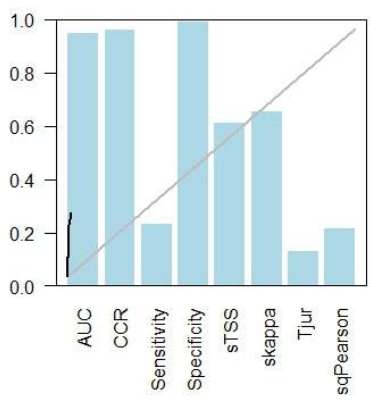


Fig. 3.8 – ROC curve and measures of evaluation of the weasel ensemble model performance.

3.3.1.5 Polecat

For the polecat, only environmental variables were selected. A positive relationship was found with maximum precipitation in 24h, and a negative relationship was found with annual solar radiation (Appendix B: Table B.1e). The former could mean this species may dwell in areas with higher probability of climatic disturbances. Since these areas might be avoided by humans and other species, it could mean less competition for the polecat. The negative relationship with solar radiation is probably related to a more Eurosibierian affinity of the species or, at least, a preference for higher latitudes within the study area.

The area with the highest potential for polecat occurrence seems to be the north-western corner of Portugal, especially in the south of the mountainous area of Peneda-Gerês (Fig. 3.9B), which also coincides with where there is the least consensus between models (Fig. 3.9C). Predictions also point to relatively favourable conditions in the areas of Serra da Estrela and the basins of the river Sado and Baixo river Tejo. Considering the regions of higher potential for polecat, it would seem that this species distribution is fragmented in Portugal, as stated by Cabral et al. (2005) and suggested by Santos-Reis (2008). When looking at the cells with unreliable records, according to ensemble model, they seem to be probably false records of the species but, given the low overall accuracy (CCR) and specificity of the model, these records should not be excluded as true ones.

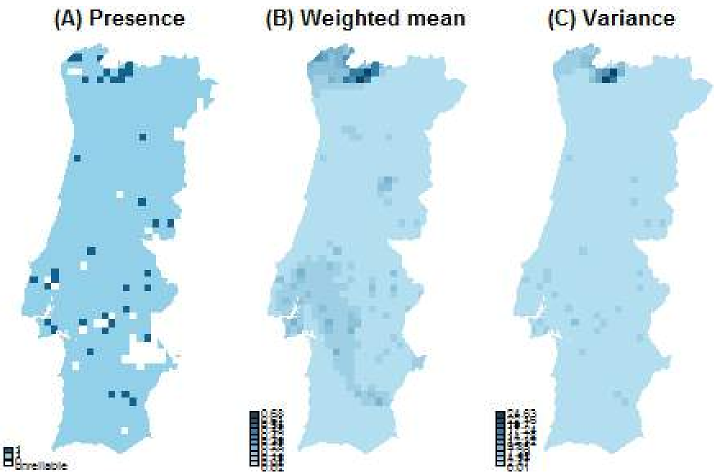


Fig. 3.9 – Presence data (A) and potential distribution of the polecat according to the averaged ensemble model (B) and variance among model predictions (C).

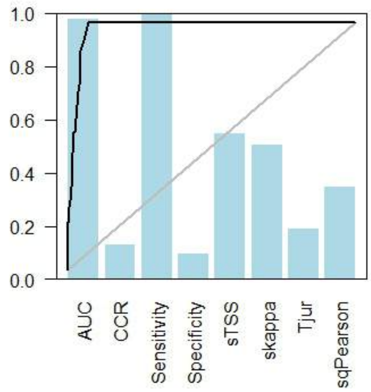


Fig. 3.10 – ROC curve and measures of evaluation of the polecat ensemble model performance.

In 2003, a survey in the centre and north of Portugal, based on written questionnaires to municipalities and hunting associations, was promoted by the IUCN to clarify the distribution of the polecat in this country. The results were published by Matos and Santos-Reis (2003) and indicated a generalised distribution of the polecat but also a declining trend (Costa et al., 2014). However, it was not possible to have access to this report nor the results published in it, so these were not taken into account for modelling, therefore inspiring some caution when considering the results obtained for this species.

3.3.1.6 American Mink

For the American mink, occurrence was found to be related to one environmental and two human-related factors. A positive relationship was found with the number of farms and negative relationships were found with annual solar radiation and with distance to the nearest major city (Appendix B: Table B.1f). The positive relationship with the number of farms might not, as for other species, mean higher prey availability, as this species' key food resource is crayfish (Rodrigues et al., 2015). Taken into consideration together with the negative relationship with annual solar radiation, farms might serve as a proxy for agricultural environments and a more Eurosiberian affinity of this species, since the number of farms tends to increase northwards (Fig. A.2). The negative relationship with increasing distance to large urban centres suggests a more commensal behaviour of this mustelid, which is able to forage and breed near human settlements (Mech, 2003).

The potential distribution of the American Mink is circumscribed to the river basins of the north-western corner of Portugal (Minho, Lima, Cávado, and Ave rivers), practically the only area where there are presence records of this species in Portugal (Fig. 3.11A and 3.11B). These results are as expected, taking into consideration the latest survey regarding the American mink' distribution in Portugal (Rodrigues et al., 2015), where a clear range expansion southwards from the north-western border with Spain to most of the region's hydrographic basins is found.

Comparing the areas with highest potential for mink occurrence with the current EOO (see section 2.3.3), the potential distribution area is smaller, probably because the two most outlying presence records (in the Tua and Douro rivers) are not given the same importance by the modelling algorithms as in the prediction of the EOO, since they probably do not fit the conditions found to be favourable for mink presence.

Lower consensus was found in the southern (river Cávado) and northern (river Minho) limits of this species' distribution (Fig. 3.11C). It is possible that this is the result of the quick expansion of the American mink, which not all modelling algorithms are able to predict.

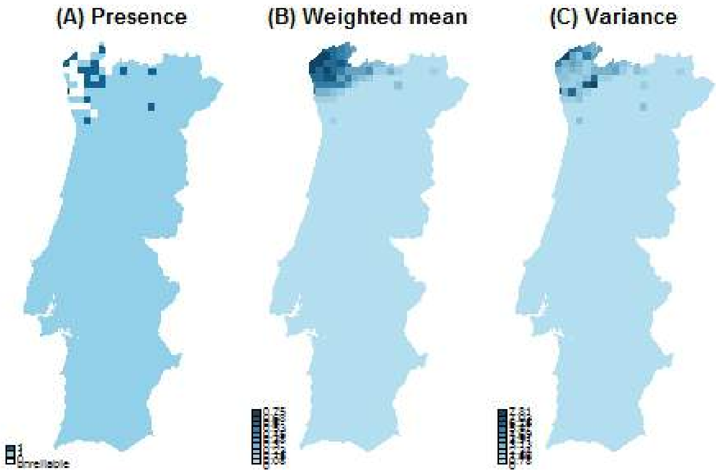


Fig. 3.11 – Presence data (A) and potential distribution of the American mink according to the averaged ensemble model (B) and variance among model predictions (C).

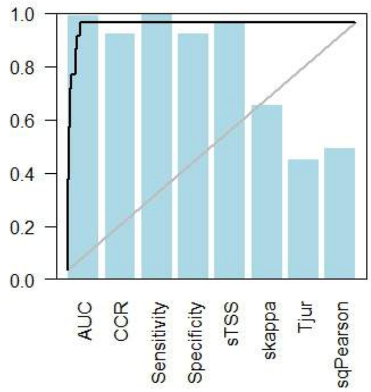


Fig. 3.12 – ROC curve and measures of evaluation of the American mink ensemble model performance.

3.3.1.7 Stone Marten

For the stone marten, one human-related and three environmental variables were selected. Positive relationships were found with slope and with distance to nearest motorway, and negative relationships were found with relative air humidity in July and with relative maximum precipitation (Appendix B: Table B.2a). The positive relationship with slope is possibly related with this species' use of open rocky hillsides, including for placement of dens in rock crevices (Santos-Reis, 1983). The positive relationship with distance to the nearest motorway suggests that the stone marten tends to avoid roads with more traffic and more difficult to cross. Santos and Santos-Reis (2009) also found that foraging and resting activities of this species were positively influenced by distance to roads, reflecting a preference for less disturbed areas. The negative relationship with air humidity in July possibly means more continentality or avoidance of the more coastal areas, which harbour more degraded habitats due to intense human presence (McAtee and Drawe, 1981). The negative relationship with relative maximum precipitation suggests avoidance of areas which tend to be more severely affected by the natural disturbance of floods.

The potential distribution of the stone marten, suggests that the areas of high potential for this species' occurrence are spread through most of the country's area, except the coastline (Fig. 3.13B). The reduced presence in the coast might be due to human activity (e.g. urbanisation, pollution, motor and pedestrian traffic), which has been becoming more and more concentrated in the coastal areas, where habitats have consequently become degraded (Unknown, 2008b; McAtee and Drawe, 1981).

There were not many cells classified as unreliable, but most of them coincided with areas of generally higher occurrence potential, suggesting they might be true presences of the species. Moreover, areas suitable for stone marten presence seem to be spread throughout the entire country, suggesting the current EOO (see section 2.3.3) might correspond to the true distribution range of the species in Portugal.

The areas of least consensus are the mountainous areas of Peneda-Gerês, Serra da Estrela and Monfurado (Fig. 3.13C)), where disagreements between models were highest.

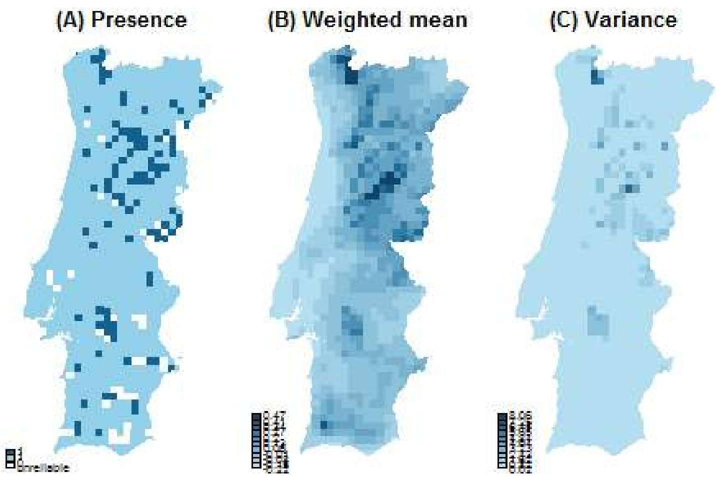


Fig. 3.13 – Presence data (A) and potential distribution of the stone marten according to the averaged ensemble model (B) and variance among model predictions (C).

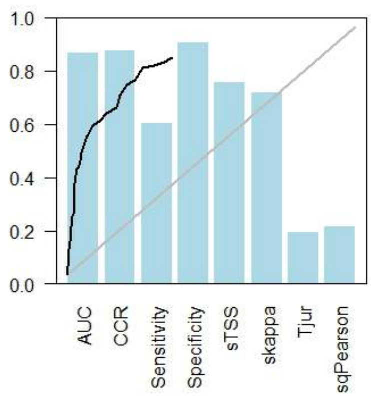


Fig. 3.14 – ROC curve and measures of evaluation of the stone marten ensemble model performance.

3.3.1.8 Pine Marten

For the pine marten, both an environmental and a human-related variable were selected. These were annual precipitation and number of farms, which were positively related to this species' occurrence (Appendix B: Table B.2b). The positive relationship with precipitation is supported by previous results of Álvares and Brito (2006), which relate pine marten presence with high rainfall levels, which is coincident with a more Eurosiberian biogeography. The positive relationship with the number of farms also suggests a tendency to more agricultural and northern areas and might also represent a higher availability of prey, such as rodents associated with the extensive, more traditional production systems probably used in these farms. However, previous studies found pine martens presence to be highly related to absence of agricultural fields (Álvares and Brito, 2006). This difference in results might be justified by the different spatial scale used in both studies, possibly indicating that, on a more local scale, this species does avoid agricultural areas, but on a larger scale this is not the case. At a national scale, there is actually a higher number of farms in the areas where pine marten actually occurs, and those farms are located in a matrix of semi-natural agricultural areas with mixed forest, where other more important conditions, such as the amount of autochtonous forest, are found for the species occurrence (Álvares and Brito, 2006; Cabral et al., 2005).

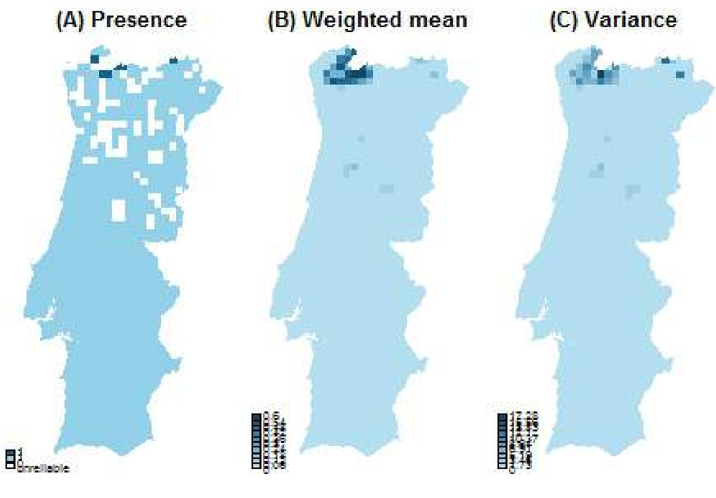


Fig. 3.15 – Presence data (A) and potential distribution of the pine marten according to the averaged ensemble model (B) and variance among model predictions (C).

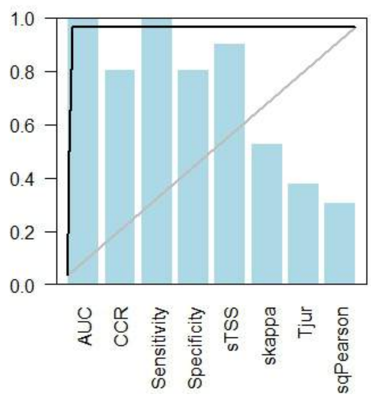


Fig. 3.16 – ROC curve and measures of evaluation of the pine marten ensemble model performance.

The ensemble model for the pine marten shows a higher potential for occurrence in the North-West, at the mountainous area of Peneda-Gerês, and some specific locations in the North-East, in the area of Serra de Montesinho (Fig. 3.15B). These areas are also where models show less consensus (Fig. 3.15C). The low consensus is to be expected, taking into account the very small number of records and their marginality relative to the species worldwide distribution.

Comparing the cells with unreliable records with the areas of high occurrence potential, it seems that most of these records do not actually correspond to true presences of the pine marten, probably due to misidentifications with stone marten. This would mean that the current EOO (see section 2.3.3) clearly over-predicted the distribution range of this species, which might actually occur in a much smaller area near the northernmost border of Portugal.

3.3.1.9 Badger

For the badger, a positive relationship was found with both a human-related and an environmental variable: utilised agricultural area and annual solar radiation, respectively (Appendix B: Table B.2c). The positive relationship with agricultural areas could be because this variable serves as a proxy for the availability of food for the badger, such as invertebrates and fruits, associated with this type of habitats (Barea-Azcón et al., 2010; Loureiro, 2008). The positive relationship with solar radiation points to a more southern and Mediterranean affinity. However, this species has previously been said to occur throughout the country (Santos-Reis, 1983; Santos-Reis and Mathias, 1996). These results might be a consequence of the difference in the amount of studies (and, consequently, of presence records) of this species in the SW, where most of the studies have focused, especially Serra de Grândola (e.g. Marques, 2003; Rosalino et al., 2005; Santos and Beier, 2008) compared to virtually no studies in the North of Portugal and only a few at a national level (Rosalino et al., 2016; Santos-Reis et al., 2005). Survey bias should thus be considered when interpreting our potential distribution map.

The badger shows small areas of relatively high potential for occurrence distributed through the entire country, but the highest potential for occurrence is concentrated in the coastal area of the South of Portugal, in and around South-west Alentejo and Vicentine Coast Natural Park (Fig. 3.17B). The species seems to be less likely to occur in the coastline of the North of the country, which is a more humanised area. These results seem to support that the current EOO (see section 2.3.3) should cover most of the country, as it does, but the badger might find more suitable conditions in small patches mostly located in the south-western region of Portugal.

There is just one UTM cell in the south area of Peneda-Gerês which has very low consensus between models, possibly because it has a reliable presence record that does not fit well in most models produced for the ensemble (Fig. 3.17C).

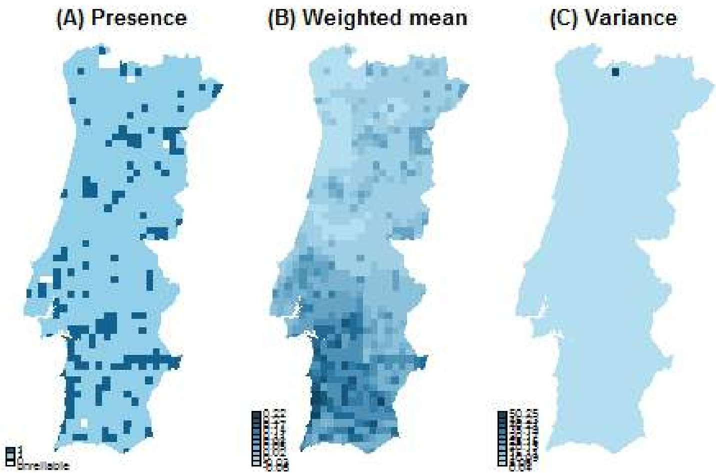


Fig. 3.17 – Presence data (A) and potential distribution of the badger according to the averaged ensemble model (B) and variance among model predictions (C).

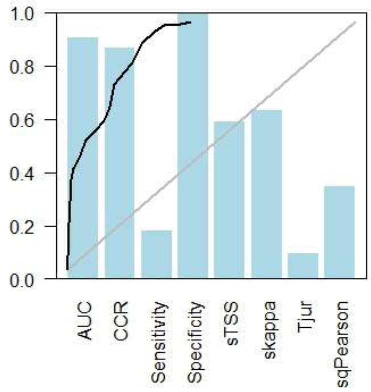


Fig. 3.18 – ROC curve and measures of evaluation of the badger ensemble model performance.

3.3.1.10 Otter

For the otter, mostly environmental variables were found to be related to this species' occurrence. Positive relationships were found with the annual relative air humidity range, with distance to roads and with slope, and a negative relationship was found with relative maximum precipitation (Appendix B: Table B.2d). The positive relationship with air humidity range can be a sign of avoidance of coastal areas, where habitats can be more degraded by human presence (Unknown, 2008b; McAtee and Drawe, 1981). The positive relationship with distance to roads is relatively coincident with previous studies in the Iberian Peninsula, which found a negative relationship with the density of motorways (Barbosa, 2001). This avoidance probably is, as for other species, due not only to road casualties suffered by the species but also to indirect effects such as air and water pollution, noise and habitat destruction and fragmentation (Spellerberg, 1998). The positive relationship with slope is generally a sign of more natural vegetation, which can be used as shelter, and less intense human presence. The negative relationship with relative maximum precipitation suggests avoidance of areas which tend to be more severely affected by the natural disturbance of floods.

The ensemble model for the otter shows that this species is highly likely to occur in almost the entire country, and it is probably more absent in Estremadura, coastal Central Portugal, and in some other coastal areas, such as the Douro river mouth and the SW tip of Algarve (Fig. 3.19B). These results are in agreement with the distribution presented for this species in the last nation-wide survey (Trindade et al., 1998). Concerning the current EOO (see section 2.3.3) which includes the entire country, it would probably be more accurate if the Estremadura region was excluded from it, where conditions do not seem very suitable for this species' presence.

Consensus between models is lower along the central and northern coastal lines, where otter presence has been reduced in the last years. This might be a sign of range contraction along that area, possibly due to degradation of the habitat with high human presence (Fig. 3.19C).

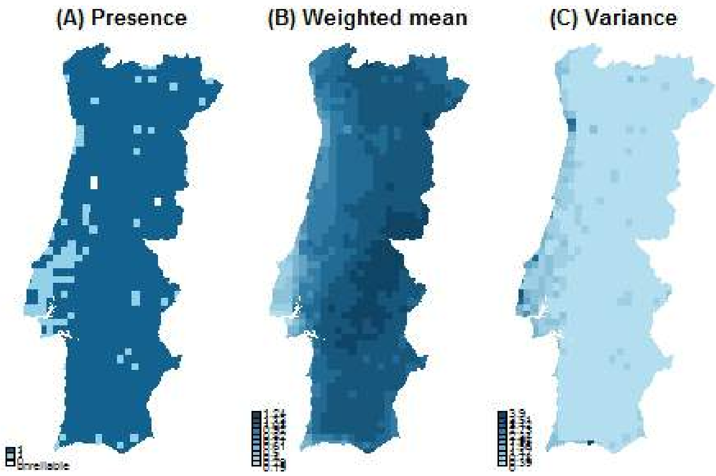


Fig. 3.19 – Presence data (A) and potential distribution of the otter according to the averaged ensemble model (B) and variance among model predictions (C).

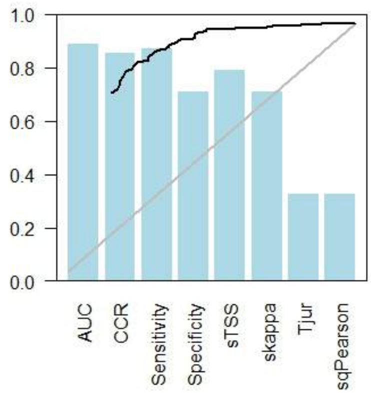


Fig. 3.20 – ROC curve and measures of evaluation of the otter ensemble model performance.

3.3.1.11 Genet

Only one environmental variable was found to be related to genet distribution. Given the high number of reliable presences distributed throughout the country (Fig. 3.21A), it is possible that only one variable was selected due to a high level of environmental ubiquity of the genet in Portugal.

This species distribution was found to be positively related to the mean annual number of days with precipitation, which may be related to a northern affinity (Appendix B: Table

B.2e). This could be explained either by a bias in the location of the records obtained for this species, or by the higher forest density and connectivity that exists in NW Portugal, which would be favourable to this arboreal species (Calzada, 2007; FOREST EUROPE et al., 2011).

The ensemble model for the genet shows that this species has areas of likely potential distribution spread throughout the country (Fig. 3.21B), which means that the current EOO (see section 2.3.3) probably reflects accurately the true distribution range of this species. However, contrary to what would be expected taking into account the African origin of the genet, the area with the highest potential for occurrence is located in the NW corner of Portugal, with Eurosiberian influence. This may result from a sampling bias or rather, considering the results for several other carnivore species in Portugal, it suggests that this NW area could harbour more favourable habitat conditions for carnivores than any other area in Portugal. However, although the ensemble model suggests a higher potential of occurrence of the genet in that NW area of Portugal, consensus between models is not very high, which might mean that the species might actually not be more often present here than anywhere else in the country.

Consensus between models was very low in several small areas along inland Portugal, possibly because, many algorithms would not assume the genet to be present in these areas (Fig. 3.21C).

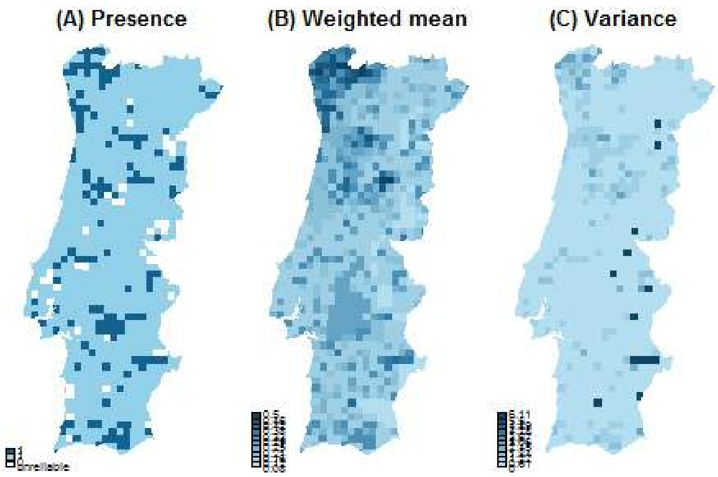


Fig. 3.21 – Presence data (A) and potential distribution of the common genet according to the averaged ensemble model (B) and variance among model predictions (C).

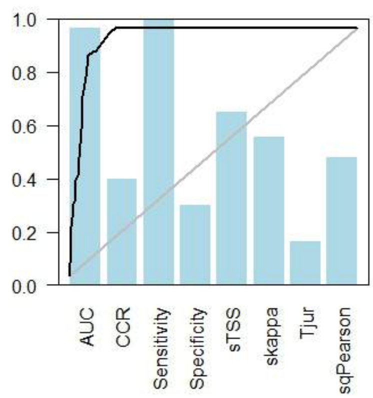


Fig. 3.22 – ROC curve and measures of evaluation of the common genet ensemble model performance.

3.3.1.12 Egyptian Mongoose

For the Egyptian mongoose, almost as many human-related variables were selected as environmental variables. This suggests this species can be highly influenced by human presence or activity. Positive relationships were found with annual solar radiation, distance to the nearest major city, annual mean temperature, distance to nearest road, and maximum precipitation in 24 hours. Negative relationships were found with the number of farms and with mean annual potential evapotranspiration (Appendix B: Table B.2f).

The positive relationship with maximum precipitation in 24h could mean that this species may dwell in areas with higher probability of climatic disturbances. Since these areas might be avoided by humans and other species, it could mean less competition for the mongoose. The positive relationship with solar radiation probably represents a more Mediterranean and southern affinity of this species, for which latitude was described to be markedly correlated with Mongoose abundance (Borralho et al., 1996). The positive relationship with distance to major cities and distance to roads, and the negative relationship with the number of farms, suggest that this species tends to occur in areas with lower levels of human activity, possibly to avoid the usual negative impacts on wildlife of these factors. In fact, Borralho et al. (1996) found that the recent increase in the number of abandoned farms and the human exodus from many low-production agricultural areas (Le Houérou, 1993; Meeus, 1993) was probably benefiting the mongoose and some other vertebrate species adapted to Mediterranean shrub habitats (Magalhães and Palma, 1985). Furthermore, they suggested that the high human interference in some overpopulated areas near big cities could be the reason for the mongoose to avoid these areas (Borralho et al., 1996). As expected, taking into account the African origin of this species, the Egyptian Mongoose prefers areas with higher annual temperatures and has a negative relationship with mean annual potential evapotranspiration, a variable associated with both productivity and water availability. These results are concordant with those from Borralho et al. (1996), who found a positive relationship between mongoose abundance and average annual temperature, and negative relationship with annual rainfall. This was to be expected, since most of the global distribution of this carnivore is in the warmer habitats of Africa (Corbet, 1984).

The potential distribution of the Egyptian mongoose suggests, as expected taking into account the reliable presence records (Fig. 3.23A), that this species has favourable conditions to occur practically in the entire country. The exception is the North-Western corner of Portugal, an area belonging to the Eurosiberian biogeographical region (Fig. 3.23B). These results make for a distribution area coincident with the current EOO (see section 2.3.3), which is thus corroborated.

The consensus between models was lower in and around the basin of the Douro river, which coincides with the Egyptian mongoose's currently known expansion limit (Fig. 3.23C), suggesting a connection between the two – i.e., as was observed with the American mink (see section 3.3.1.6), model predictions tend to disagree on the range edges of expanding species, which are not at equilibrium with the environment.

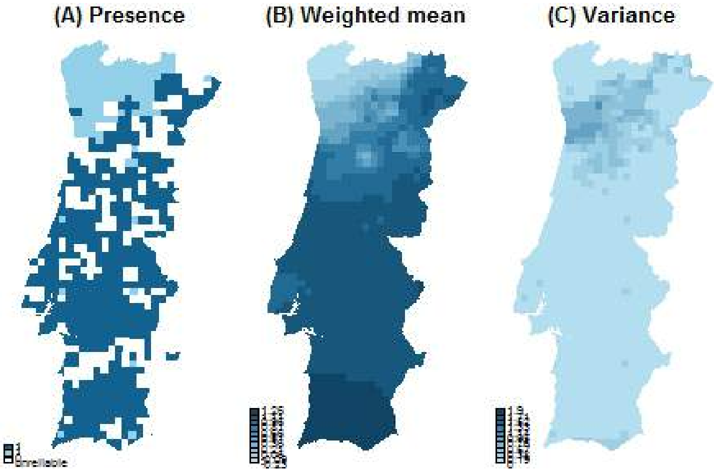


Fig. 3.23 – Presence data (A) and potential distribution of the Egyptian mongoose according to the averaged ensemble model (B) and variance among model predictions (C).

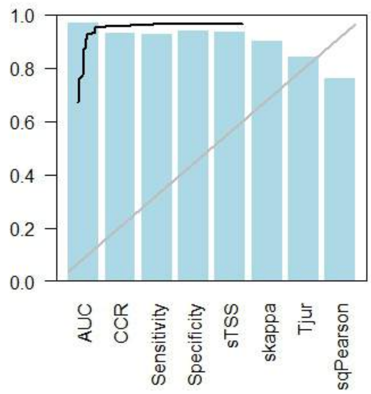


Fig. 3.24 – ROC curve and measures of evaluation of the Egyptian mongoose ensemble model performance.

3.3.1.13 Wildcat

For the wildcat, positive relationships were found with areas of permanent meadows and grassland, altitude, altitude range and distance to the nearest major city. Negative relationships were found with annual solar radiation and with annual actual evapotranspiration (Appendix B: Table B.2g). The positive relationship with meadows and grassland is probably related to the higher presence of prey such as small mammals and rabbits, which are associated with this type of land use (Ferreira, 2010; Monterroso et al., 2009; Palma et al., 1999; Sarmento and Cruz, 1998), making these the main hunting grounds for the wildcat

(Fernandes, 1991). The positive relationship with altitude and altitude range is probably due lower levels of human presence in these regions. Furthermore, larger altitude ranges are also associated with higher levels of environmental diversity, which can be a proxy for a higher diversity of shelter, prey, etc. (Ferreira, 2010; Monterroso et al., 2009). The positive relationship with distance to major cities can mean that this species tends to avoid highly populated areas, which is concordant with the anthropophobic character of this species (Fernandes, 1991). This is further supported by the findings of Monterroso et al. (2009) which stated human disturbance as one of the most important correlates of wildcat occurrence, with a negative influence on this species (Monterroso et al., 2009). The negative relationship with solar radiation points to this species' preference for more northern areas, especially north-west and south-east of the Douro river (Appendix A: Fig. A.1). The negative relationship with actual evapotranspiration can mean this species tends to occur in areas with lower levels of natural water availability and lower general productivity, possibly to avoid areas where other competitor species might be more present due to more favourable conditions.

The prediction of the ensemble model reflects much of the known distribution of this species in Portugal (Fig. 3.25A and 3.25B). It shows a generalized potential distribution of the wildcat, with a more concentrated presence in the North-Western corner of Portugal, especially in the mountainous area of Peneda-Gerês, and in the interior region along the border with Spain (Fig. 3.25B). Two areas, besides Peneda-Gerês, where the ensemble model suggests the wildcat is more likely to be present are the Serra da Estrela mountain range and the Guadiana Valley Natural Park, where the southern regional distribution of the wildcat might be restricted to (Santos-Reis et al., 2003). The ensemble model further predicts an absence from the central and northern coastal strip, an area that appears included in the current EOO (see section 2.3.3), which should therefore be revised. This predicted potential distribution coincides highly with the one predicted by Pinto and Fernandes (2001).

Regarding the consensus between models, this was generally lower in the same areas where a higher potential for occurrence was found for the wildcat. However, a high consensus was found for the western half of Portugal and in Algarve, suggesting the species is, very likely, absent from these areas (Fig. 3.25C).

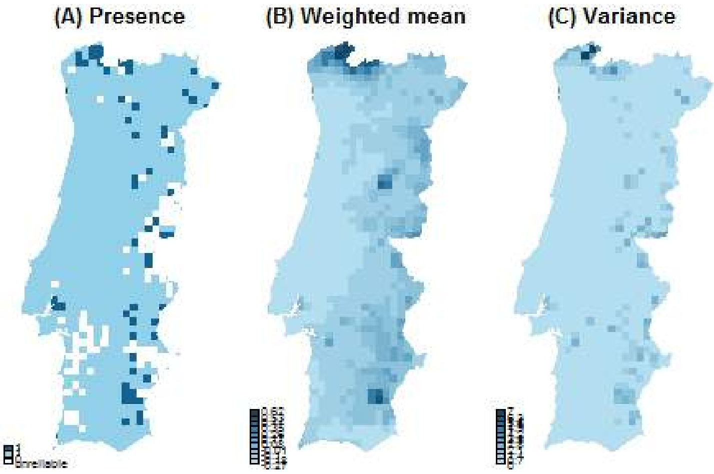


Fig. 3.25 – Presence data (A) and potential distribution of the wildcat according to the averaged ensemble model (B) and variance among model predictions (C).

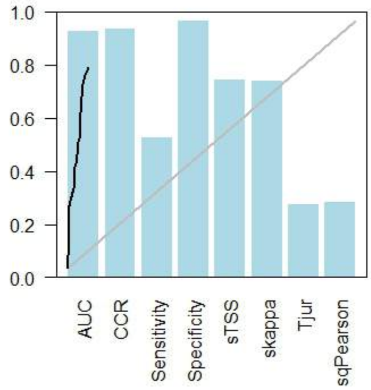


Fig. 3.26 – ROC curve and measures of evaluation of the wildcat ensemble model performance.

3.3.1.14 Iberian Lynx

For the Iberian lynx, the only selected variable was an environmental one, annual insolation, with a positive relationship with the species. This positive relation is probably due to the lynx' association with a more Mediterranean environment (Appendix B: Table B.2h). In this case, differently from the genet, it is probable that the selection of only one variable was to avoid over-fitting, due to the very reduced number of cells with reliable records (N=5, and no unreliable cells).

The Iberian lynx was predicted to occur mostly south of the river Tagus and especially in the basin of the Guadiana river (Fig. 3.27B). This corresponds to the reintroduction area of this endangered species in Portugal (Iberlince LIFE Project, 2015). These results naturally reflect the available occurrence records, but also reinforce the potential success of the reintroduction project, given the apparently favourable conditions in the area that attract animals reintroduced in Spain, which constitute most of the occurrence data. The current EOO of the lynx in Portugal (see section 2.3.3) corresponds to an area predicted with high occurrence potential according to the ensemble model. However, in the future, this may need to be updated if reintroduction attempts and the recovery of the species in this area are successful.

The consensus among model predictions seems to be smaller in most of the exact places where presence records were obtained, but the high consensus in most of the remaining areas seems to suggest that most models widely agree on the potential distribution of this species, based on those records (Fig. 3.27A and 3.27C).

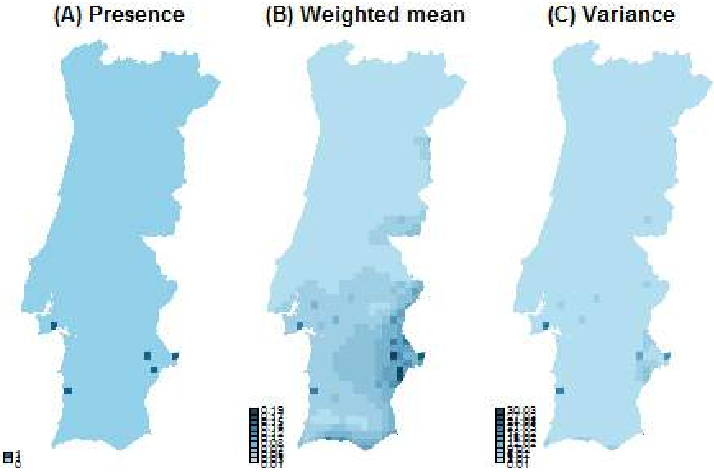


Fig. 3.27 – Presence data (A) and potential distribution of the Iberian lynx according to the averaged ensemble model (B) and variance among model predictions (C).

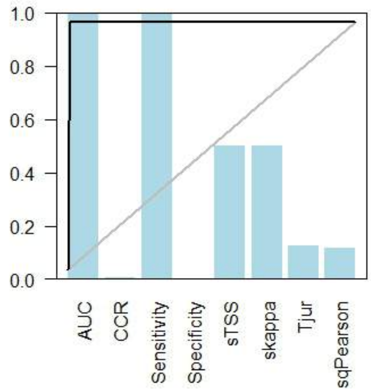


Fig. 3.28 – ROC curve and measures of evaluation of the Iberian lynx ensemble model performance.

3.3.2 Correlates of carnivore occurrence

During the preparation of the set of predictor variables, to be used for modelling, a constraint was found that prevented from obtaining several variables thought to be adequate and related to carnivore species distribution at a national level. This constraint was the lack of available information at a national level. For example, a useful variable could have been the distance to nearest small village, but information specifically regarding villages was only found for some small areas of the country, which prevented from transforming it into a national-scale variable. Another matter regarding the set of predictor variables is the chosen and used variables themselves. It would have been interesting to use some other variables not included in this study, such as land uses, forest and shrub cover, distribution of wild prey and others. However, the goal was to use a set of variables which could be comparable with other already existing studies at the national or Iberian level (Barbosa et al., 2003; Barbosa et al., 2009a; Real et al., 2008; Real et al., 2009), and adding many more variables would make the set too big and increase type I error in statistical analyses.

With this study, it was found that species' distributions are mostly related to environmental factors, but more than half the species (N=9) are related at some level to human-related factors. The wolf is the best example in Portugal of a carnivore whose distribution is highly related to human factors. This is probably because the wolf is one of the largest carnivore species to currently occur in Portugal (Kaczensky et al., 2013), and it is the one for which there is a higher level of human-carnivore conflicts due mainly to livestock depredations (due to lack of wild prey and because domestic prey are easier to capture; Álvares, 2003; Álvares, 2013; Díaz Álvarez, 2013; Torres et al., 2015; Vos, 2000).

The variables that were most frequently found to have a relationship with carnivore species in Portugal were related to three main factors, namely Topography, Environmental Energy and Human Activity (Fig. 3.29). The prevailing positive relationship with topographic factors, mainly altitude, could be, as was previously suggested, related to lower levels of human presence and better-conserved habitats, and might be a way for wild species to avoid human disturbance (Massolo and Meriggi, 1998). Also, considering that most of the species for which this variable was selected (wolf, fox, stoat, weasel) have a Palearctic distribution, this might be a way for the species to find habitat conditions that in higher latitudes would be at lower altitudes (based on the concept of "Life zones" by Merriam, 1894). Regarding the environmental energy factor, the most selected variables were mean annual insolation and solar radiation, which are indicators of southern vs. northern distribution patterns and Mediterranean vs. Eurosiberian biogeographical afffinities. These variables were mostly found to be negatively related to species occurrence (for the wolf, stoat, polecat, American Mink and wildcat), showing a tendency for many of the species to occur in the more northern areas of Portugal, while being positively related to the few species with a more southern affinity (badger, Egyptian mongoose and Iberian lynx). In what concerns human-related factors, variables of this type have been positively selected a large number of times, particularly those related to the Human Activity factor. This is because half of the times when a human activity variable was positively selected, it was concerning distance to motorways and roads, and the only two times when a human density variable was positively selected, it was regarding distance to urban centres. This tells us, as expected, that Portuguese carnivore species tend to avoid human presence when it mostly just causes disturbance, as is mostly the case of roads and major urban centres (Barbosa et al., 2003; Eggermann et al., 2011; Galantinho and Mira, 2009; Palma et al., 1999). The remaining times when human activity variables were selected were regarding agricultural and grazing areas and mostly extensive production systems, which can provide carnivores with a variety of food sources, from domestic prey to small mammals and fruit (Hipólito, 2014; Rosalino and Santos-Reis, 2002; Verdade et al., 2011).

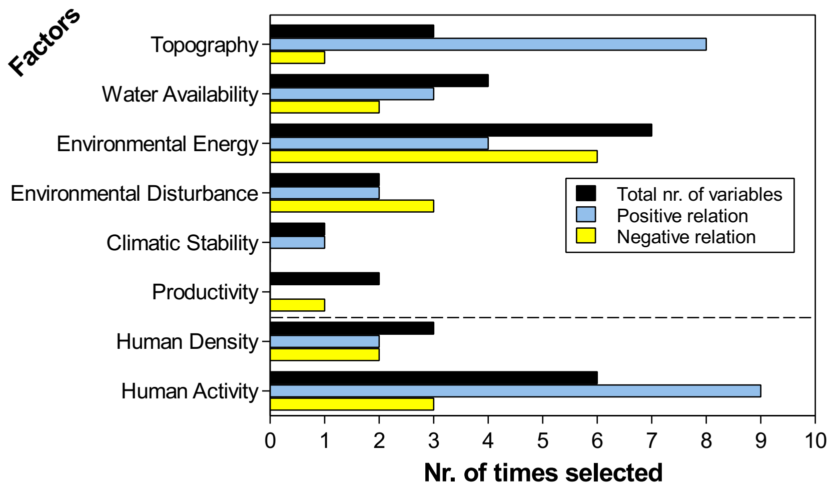


Fig. 3.29 – Number of times a variable of each factor was positively and negatively selected.

Another interesting finding was that some species which had presence records scattered all over the country, such as the fox, weasel, polecat and genet, show a higher potential for occurrence in the North of the country than other areas, suggesting either survey bias (Barbosa et al., 2013b) or an actual higher suitability for their occurrence (Basille et al., 2008; Jedrzejewski et al., 2005; Zimmermann, 2004).

3.3.3 Model performance

Model performance was generally higher for well-sampled species with well-defined occurrence patterns, and lower for under-sampled species or those with scattered occurrence records.

As expected, due to being the most well-sampled species, the ones with the best results in terms of accuracy/quality of the produced model were the wolf (Fig. 3.2), the American Mink (Fig. 3.12) and the Egyptian mongoose (Fig. 3.24), which had all threshold dependent measures above 0.8. The otter also yielded good results, but not as good as the other three species, possibly due to its widespread occurrence and/or the existence of several cells with absence of records located within the main distribution area (Fig. 3.20).

The Iberian lynx and the polecat, the species with the lowest number of reliable presence records and the other also with a relatively low number of those, respectively, yielded the worst results on model performance (Fig. 3.10 and 3.28). They had at least two measures, particularly CCR and Specificity, bellow 0.2, which means that overall accuracy of the ensemble model was very low and a very low proportion of absences were correctly predicted.

Most species that were under-sampled or had few known occurrence records scattered throughout the country, such as the weasel, badger, genet and wildcat (Fig. 3.8, 3.18, 3.22 and 3.26), had generally good results for most performance measures, but suffered from poor sensitivity (weasel and badger) or poor CCR and Specificity (genet), which means their models had limitations predicting correctly the presences and/or absences.

For several species (e.g. wolf, American Mink, stone marten, otter and Egyptian mongoose) the areas with potential for occurrence probably reflect the actual distribution areas of the species in Portugal. This is because they are very coincident with the existing presence records, including cells classified as reliable and unreliable (Fig. 3.1, 3.11, 3.13, 3.19 and 3.23) and they all had relatively good results in terms of model Sensitivity and Specificity (>0.5; Fig. 3.2, 3.12, 3.14, 3.20 and 3.24).

From the consensus results of the American mink and the Egyptian Mongoose, it was interesting to find that both species, the only ones which are known to have been increasingly expanding their range in Portugal in the last decades, had lower model consensus in the range limit of their expansion front (Fig. 3.11 and 3.23). This might indicate that there is a relationship between model consensus and species expansion edges, which might be useful in the future to identify such situations.

Chapter 4

An overview on carnivore species in Portugal: a detailed account for a distribution Atlas

4.1 Introduction

The first check-list of known mammals for continental Portugal, including eleven carnivore species, was presented in 1863 by Bocage (1863). Later on, new and updated mammal checklists were published including three more extant carnivore species and one extinct species (Cabral et al., 2005; Mathias et al., 1998a; Santos-Reis and Mathias, 1996). Recently, in 2012, a book was published focusing exclusively on the Carnivora community in Portugal, which describes comprehensively the species of terrestrial carnivores of the Portuguese fauna and their natural history (Loureiro et al., 2012). But with the increasing production of new scientific knowledge on carnivores over the years, only two publications focusing the entire set of carnivore species at the national level include distribution maps, although both presented at a coarse scale, i.e. 50x50-km cells (Mathias, 1999; Mitchell-Jones et al., 1999), while for several other taxonomic groups there are already detailed distribution atlas published (Equipa Atlas, 2008; Loureiro, 2008; Maravalhas, 2003; Rainho et al., 2013).

Therefore, it becomes urgent to produce an Atlas of Mammal Carnivores of Continental Portugal, with updated and spatially detailed data on the distribution and status of the species, in which the bias and unevenness of the information should be accounted for. Taking this into consideration, the goals of this chapter are to produce a detailed account of each carnivore species occurring since historical times in Portugal, and to assess their past and current distributions based on non-systematic presence records and accounting for data reliability.

The species accounts presented in this chapter are based on data collected and analysed in chapters 2 and 3 of this thesis and intend to provide the most updated knowledge on the current and historical distribution of carnivores in Portugal, regarding previous reviews, such as the Portuguese Red Book of Vertebrates (Cabral et al., 2005). This information is intended to provide the basis for a national distribution Atlas, in order to make carnivore distribution data available to researchers, managers, decision-makers and the general public, and to support well-informed planning and management applied to carnivore species.

4.2 Materials and Methods

The presence data presented in this chapter is the same and divided into the same time periods as the ones presented in section 2.2.2. A Universal Transverse Mercator (UTM) grid was used to represent presence records, in accordance with other European species mapping projects (Creemers et al., 2014; Hagemeijer and Blair, 1997; Mitchell-Jones et al., 1999; San-Miguel-Ayanz et al., 2016). We used, in particular, the 10x10-km cells in Lisboa Hayford Gauss IGeoE UTM datum, clipped by the borders of the country, which divides Portugal into 1004 cells.

Based on available literature and in the data obtained in previous chapters, for each species account we presented information organised in four themes:

- General context
    - Scientific, Portuguese and English common names
    - Origin (native, introduced), Category in the IUCN Red List (IUCN, 2016) and in the Portuguese Red List of Vertebrates (PRLV; Cabral et al., 2005)
    - Geographic range of the species at the Gobal (IUCN, 2014), European (Mitchell-Jones et al., 1999) and Spanish (Palomo et al., 2007) level
    - Historical (<1999) presence records and Extent of Occurrence (EOO) in Portugal
    - Current (>2000) presence records, Area of Occupancy (AOO) and Extent of Occurrence (EOO) in Portugal

- Bibliometric analysis
  - Number of publications and percentage of single-species studies and those shared with other species
  - Main research topics
- Presence records
  - Number of historical and current records and number of UTM cells with current records
  - Percentage of confirmed and unconfirmed records
  - Percentage of UTM cells with confirmed and unconfirmed records
  - Percentage of records of each type (live observations, dead animals, photos, presence signs, telemetry, vocalisations)
- Distribution patterns
  - Historical and current EOO
  - Current AOO
  - Distribution trend (before vs. after 2000)
  - Variables related to species occurrence according to SDM

The European distribution maps were obtained from the EMMA database, which is maintained by the Societas Europaea Mammalogica (Mitchell-Jones et al., 1999). In these maps, black circles correspond to records pre-1970 and grey circles represent records post-1970 (until 1999), on UTM 50x50-km cells.

The Spanish distribution maps were obtained from the Spanish Atlas and Red Book of Terrestrial Mammals (Palomo et al., 2007), where presence records are represented in UTM 10x10-km cells. Blue dots represent cells with confirmed presence, while white dots represent cells where the species appears cited in the previous edition of the atlas and, after being specifically monitored, was considered absent from that cell. Pink dots appear for the specific cases of the Iberian lynx and the wolf, and they represent unstable populations that might disappear in the near future (Palomo et al., 2007). For the racoon, the only species for which there was no account in the last Spanish Distribution Atlas, the distribution map in Spain was obtained from García et al. (2012), a review with presence data collected between 2001 and 2011.

Regarding historical (until 1999, at the municipality level) and current presence records (since 2000, on UTM 10x10-km cells) of all carnivore species in Portugal, data were based on the maps presented in chapter 2 (Fig. 2.7).

For the bibliometric analysis, data are as in chapter 2 (Fig. 2.2 and 2.3). The total number of publications and the percentage that are dedicated only to that carnivore species (single-species studies) or shared with other carnivore species (shared studies) are presented. Also, the main research topics are presented, as the top three most studied research areas for each species.

In the distribution patterns section, the following information is presented: i) the historical and current EOO in Portugal, expressed as a percentage of the total area of the country; ii) the current AOO, also expressed as a percentage of the total area of the country; and iii) the distribution trend of the species, obtained by comparing the historical and current EOOs. This information is in accordance with chapter 2 (Table 2.1). Finally, for each species, the final variables selected for modelling each species are listed.

Two carnivore species are presented with different accounts: the bear, for which there are only historical records, and the racoon, for which there are only current records. For the bear, its past distribution in Portugal is represented in two figures, the first one with records between the 10th and 17th century (until the previously known date for extinction; Santos-Reis and Mathias, 1996; Cabral et al., 2005), and the second one with new records between the 18th and 19th century.

4.3 Results and Discussion

4.3.1 Species accounts

Bellow are presented the species accounts for the 16 carnivore species occurring in mainland Portugal since historical times. Maps of species distribution in the world, Europe and Spain (Iberian Peninsula) are reproduced to provide geographic context. Abbreviations of the human and environmental correlates of species distributions are as in Table 3.2.

Canis lupus

Portuguese name: **Lobo**

English Name: **Grey Wolf**

Origin: Native
IUCN Category: LC
PRLV Category: EN

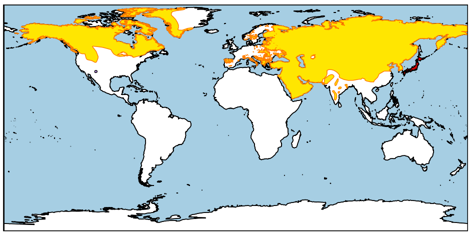


Fig. 4.1 – Grey wolf global distribution range (from IUCN, 2014)

Fig. 4.2 – Grey wolf distribution in Europe (from Mitchell-Jones et al., 1999)

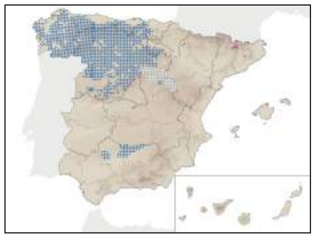


Fig. 4.3 – Grey wolf distribution in Spain (from Palomo et al., 2007)

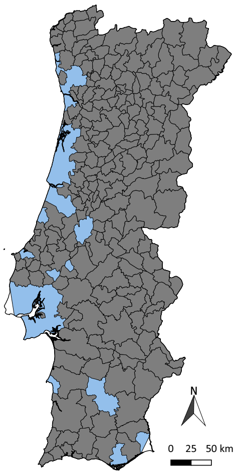


Fig. 4.4 – Historical records (grey) and EOO (blue) of the grey wolf in Portugal

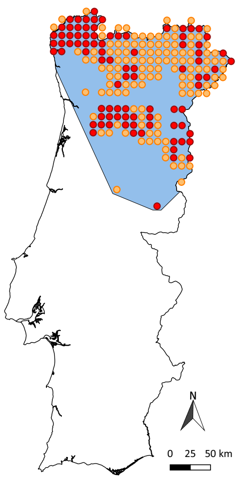


Fig. 4.5 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the grey wolf in Portugal

Bibliometric analysis

Nr. of publications: 261 (89% single-species studies; 11% shared studies)

Main research topics: Conservation, Population Status and General Ecology

Presence records

Nr. of historical records: 1687 (Fig. 4.4)

Nr. of current records: 567 (209 cells; Fig. 4.5)

Confirmed records: 42% of records (8.8% of cells)

- Live observations: 16%
- Dead animals: 5%
- Photos: 5%
- Presence signs (genetic): 8%
- Telemetry: 4%
- Vocalizations: 5%

Unconfirmed records: 58% of records (12.1% of cells)

- Presence signs (non-genetic): 13%
- Others: 45%

Distribution patterns

Historical EOO (range cover in Portugal): 100% (Fig. 4.4)

Current EOO (range cover in Portugal): 36% (Fig. 4.5)

Current AOO (nr. of cells w/ records): 21%

Distribution trend (before vs. after 2000): Contraction

Selected correlates: Alti, SRad, HJul, Farm, NLight, Liv, Dalt, Droad (Table 3.2)

Wolf

The wolf is widespread in the northern hemisphere (Mech and Boitani, 2010; Fig. 4.1), but currently has a relatively restricted and scattered distribution in Europe (Mitchell-Jones et al., 1999; Fig. 4.2), including Spain (Palomo et al., 2007; Fig. 4.3), due to local extinctions (Boitani, 1995). This charismatic species is the largest wild canid that currently exists in the world and is one of the two remaining large carnivore species with a permanent occurrence in Portugal (Loureiro et al., 2012). In this country, this species occurred almost in the entire continental territory, but in the beginning of the last century, it underwent a massive range contraction. The species is now restricted to the northern half of Portugal, with populations located north of the Douro river and in the mountains just south of this river (Álvares, 2004a; Cabral et al., 2005; Petrucci-Fonseca, 1990).

The wolf is classified by the IUCN as Least Concern (Mech and Boitani, 2010). In Portugal, it is classified since 1990 as Endangered (Cabral et al., 2005), being the only mammal species strictly protected by a specific national law (Lei n^{o} 90/88, Decreto-Lei n^{o} 139/9). Wolf populations in Portugal are threatened due to conflicts with humans (e.g damages to livestock) and, for the specific case of the south of the Douro river population, due to isolation and reduced genetic variability (Alexandre et al., 2000; Godinho et al., 2012).

The wolf was the carnivore species with most scientific studies in Portugal, with the majority (89%) of them exclusively dedicated to this species and focusing on Conservation. This is probably due to the charismatic nature of this species and the known extensive range contraction suffered over the last decades (Petrucci-Fonseca, 1990).

Regarding presence records, the wolf was the species with the largest amount of historical records and one of the few species for which there were more historical than current records. The complete historical account in the 20th century (Fig. 4.4) was mostly compiled (80%) from a systematic and detailed assessment of wolf past distribution in Portugal (Petrucci-Fonseca, 1990).

The wolf is one of the few carnivore species in Portugal for which there was a recent national survey with systematic sampling conducted in 2002/2003 (Pimenta et al., 2005). This publication provided 19% of the current occurrence records, while the remaining came from online databases, such as SIPNAT (33%), other articles (8%) and unpublished data from several researchers and institutions (45%). For this species, records of all types were obtained, particularly, from telemetry and vocalisations, which were not available in a usable form for any other species. Most of the current records (58%) were unconfirmed and unreliable (Fig. 4.5), suggesting the need for further sampling to collect more confirmed records (e.g. scats genetically validated), particularly in the NE region of Portugal.

The distribution range (EOO) presented for the wolf (Fig. 4.5) probably reflects the actual range of the species as well as the potential area for its occurrence in Portugal.

The wolf was the species for which more human-related variables were found to be related to its occurrence, confirming the effect that human presence and activity have on the species.

Vulpes vulpes

Portuguese name: **Raposa**

English Name: **Red Fox**

Origin: Native

IUCN Category: LC

PRLV Category: LC

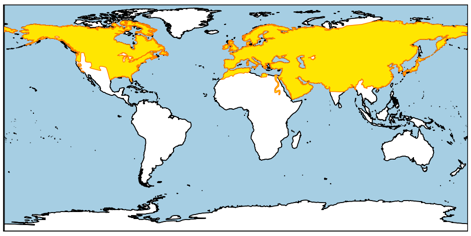


Fig. 4.6 – Red fox global distribution range (from IUCN, 2014)

Fig. 4.7 – Red fox distribution in Europe (from Mitchell-Jones et al., 1999)

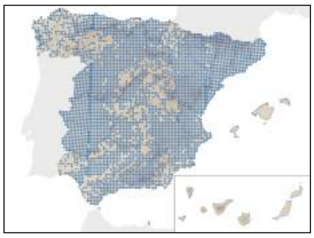


Fig. 4.8 – Red fox distribution in Spain (from Palomo et al., 2007)

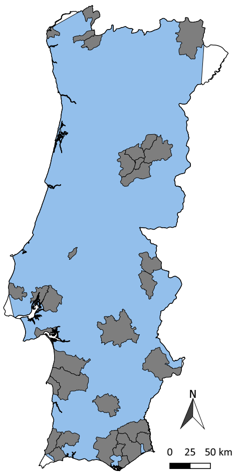


Fig. 4.9 – Historical records (grey) and EOO (blue) of the red fox in Portugal

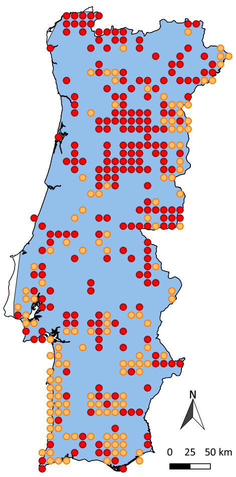


Fig. 4.10 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the red fox in Portugal

Bibliometric analysis

Nr. of publications: 125 (26% single-species studies; 74% shared studies)

Main research topics: General Ecology, Population Status and Health Status

Presence records

Nr. of historical records: 89 (Fig. 4.9)

Nr. of current records: 3363 (359 cells; Fig. 4.10)

Confirmed records: 23% of records (22.6% of cells)

- Live observations: 14%
- Dead animals: 7%
- Photos: 2%
- Presence signs (genetic): 0%

Unconfirmed records: 77% of records (13.1% of cells)

- Presence signs (non-genetic): 71%
- Others: 6%

Distribution patterns

Historical EOO (range cover in Portugal): 98% (Fig. 4.9)

Current EOO (range cover in Portugal): 100% (Fig. 4.10)

Current AOO (nr. of cells w/ records): 93%

Distribution trend (before vs. after 2000): Stable

Selected correlates: Alti, Liv, HJul (Table 3.2)

Fox

The fox is one of the largest mesocarnivores occurring in Portugal and is the carnivore with the widest distribution worldwide, being widespread in Europe and in Spain (Macdonald et al., 2008; Mitchell-Jones et al., 1999; Palomo et al., 2007; Fig. 4.6, 4.7 and 4.8). It is classified as Least Concern both by the IUCN and in Portugal (Cabral et al., 2005; Macdonald et al., 2008), where it is a game species with hunting regulated by law (Lei nº 202/2004, Decreto-Lei nº 173/99). However, this (legal and illegal) hunting activity directed at the fox has been considered one main threats to the populations of this species in Portugal (Loureiro et al., 2012).

There is a fair amount of Portuguese studies on foxes, but they are mostly composed of community studies focusing also on several other species of mesocarnivores (74%). The most frequently covered topics of research are focused on General Ecology.

Considering its distribution range, few historical records (N=89) were found for this canid, which were mostly scattered throughout the country (Fig. 4.9). Taking into account the wide current distribution of this species in Portugal based in a large number of presence records (Fig. 4.10), the depiction of the historical distribution based on the collected records is apparently very deficient, due to a lack of sampling in past periods.

Although this species never had a specifically directed systematic sampling effort across the country, it is frequently detected, which makes it one of the species with the highest number of current records, mostly unconfirmed (77%). The North of Portugal presents the highest number of cells with confirmed presence records, as well the highest potential for occurrence based on SDM. These results suggest that these northern regions harbour better habitat conditions and higher abundance (Araújo and Williams, 2000; Barbosa et al., 2005; Real et al., 2009). However, this pattern can also reflect a lack of sampling in Central and Southern Portugal.

As for many of the other species, current presence records of foxes mostly comprise non-genetically validated presence signs (71%). Although this species is easily recognisable, when observed directly, its presence signs, such as scats, are easily misidentified, being confused with those from other mesocarnivores, and should be, whenever possible, confirmed by genetic validation (Monterroso et al., 2013b).

Mustela erminea

Portuguese name: **Arminho**

English Name: **Stoat**

Origin: Native

IUCN Category: LC

PRLV Category: DD

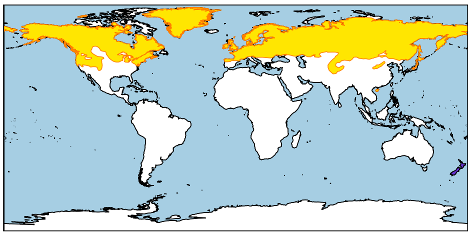


Fig. 4.11 – Stoat global distribution range (from IUCN, 2014)

Fig. 4.12 – Stoat distribution in Europe (from Mitchell-Jones et al., 1999)

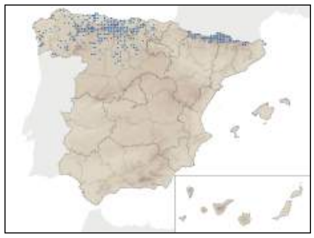


Fig. 4.13 – Stoat distribution in Spain (from Palomo et al., 2007)

Fig. 4.14 – Historical records (grey) and EOO (blue) of the stoat in Portugal

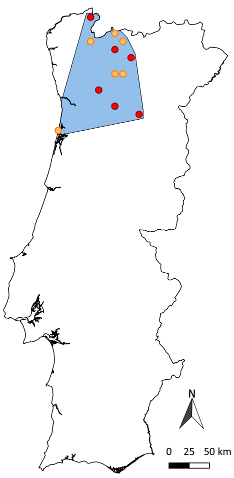


Fig. 4.15 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the stoat in Portugal

Bibliometric analysis

Nr. of publications: 12 (8% single-species studies; 82% shared studies)

Main research topics: Population Status, General Ecology and Genetics

Presence records

Nr. of historical records: 46 (Fig. 4.14)

Nr. of current records: 16 (12 cells; Fig. 4.15)

Confirmed records: 44% of records (0.6% of cells)

- Live observations: 13%
- Dead animals: 31%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 56% of records (0.6% of cells)

- Presence signs (non-genetic): 0%
- Others: 56%

Distribution patterns

Historical EOO (range cover in Portugal): 16% (Fig. 4.14)

Current EOO (range cover in Portugal): 12% (Fig. 4.15)

Current AOO (nr. of cells w/ records): 1%

Distribution trend (before vs. after 2000): Uncertain

Selected correlates: Alti, Inso (Table 3.2)

Stoat

The stoat, one of the smallest mustelids in Portugal, is widespread in the northern hemisphere, with a circumboreal range (Reid et al., 2016; Santos-Reis, 1985; Fig. 4.11). Its distribution, both in Europe and in Spain, is restricted to the most northern regions, due to its affinity with the Eurosiberian biogeographical region (Mitchell-Jones et al., 1999; Palomo et al., 2007; Fig. 4.12 and 4.13). As a result, the stoat seems to have always occurred only marginally in northern Portugal, apparently limited by climatic constraints and human pressure (Santos-Reis, 1985).

This species is classified as Least Concern by the IUCN (Reid et al., 2016) but, in Portugal, it is classified as Data Deficient due to the lack of knowledge on most of its ecological traits (Cabral et al., 2005). In fact, this is one of the carnivore species with fewest compiled publications, most of which (82%) are studies shared with other species.

The occurrence of stoat in Portugal was first confirmed in the late 20th century, north of the Douro river, with the detection in 1983 of two road-killed specimens in Chaves and Varges (Vila Real) and two sightings, one in Ponte de Travassos (Bragança) in 1983 and the other in Baçal (Bragança) in 1984 (Santos-Reis, 1985). Our work allowed the compilation of a larger amount of historical and current presence records (N=46 and N=16, respectively), providing a significant contribution to the knowledge on this species in Portugal.

Historical records show a practically continuous distribution of this species along most of the mountain ranges in northern Portugal, but only north of the Douro river (Fig. 4.14). However, two recent confirmed records of sightings in Lamego, in March 2003, and in Sernancelhe, in November 2003, were obtained in and near Serra de Montemuro, located south of Douro River, suggesting that the limits of the stoat's distribution in Portugal are further south than the range assumed for this species in previous publications (Santos-Reis, 1983; Santos-Reis, 1985; Fig. 4.15). Also, the historical presence of stoat was detected in coastal areas (e.g. Lima river estuary in the mid 20th century) where no confirmed presence has been detected in recent times, suggesting a local extinction of these lowland populations due to increasing urbanisation. Among the compiled current records, more than half are unconfirmed and unreliable (56%), with confirmed presence records possibly representing the actual area where the species occurs presently. However, the potential distribution area based on SDM suggests that this species might have favourable conditions, for occurrence further south, including the mountainous area of Serra da Estrela.

Taking all this into consideration, it becomes evident that there is a need for a systematic sampling targeting this elusive species in order to determine its range limits and trends.

Mustela nivalis

Portuguese name: **Doninha**

English Name: **Least Weasel**

Origin: Native

IUCN Category: LC

PRLV Category: LC

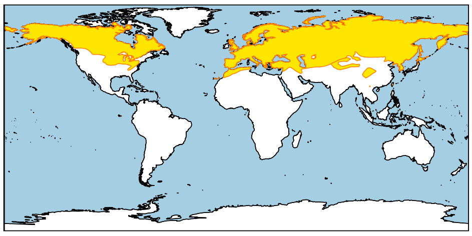


Fig. 4.16 – Least weasel global distribution range (from IUCN, 2014)

Fig. 4.17 – Least weasel distribution in Europe (from Mitchell-Jones et al., 1999)

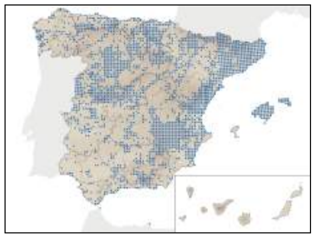


Fig. 4.18 – Least weasel distribution in Spain (from Palomo et al., 2007)

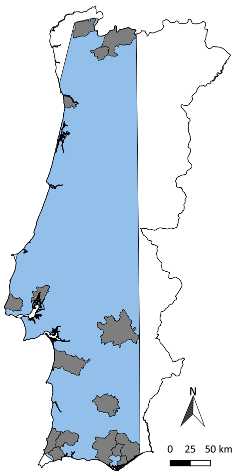


Fig. 4.19 – Historical records (grey) and EOO (blue) of the least weasel in Portugal

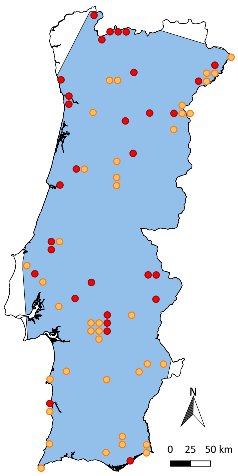


Fig. 4.20 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the least weasel in Portugal

Bibliometric analysis

Nr. of publications: 57 (12% single-species studies; 88% shared studies)

Main research topics: Population Status, General Ecology and Conservation

Presence records

Nr. of historical records: 56 (Fig. 4.19)

Nr. of current records: 281 (69 cells; Fig. 4.20)

Confirmed records: 15% of records (3.0% of cells)

- Live observations: 8%
- Dead animals: 7%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 85% of records (3.9% of cells)

- Presence signs (non-genetic): 78%
- Others: 7%

Distribution patterns

Historical EOO (range cover in Portugal): 69% (Fig. 4.19)

Current EOO (range cover in Portugal): 95% (Fig. 4.20)

Current AOO (nr. of cells w/ records): 7%

Distribution trend (before vs. after 2000): Stable

Selected correlates: Alti, RMP (Table 3.2)

Weasel

The weasel, the smallest carnivore mammal in the world, has a circumboreal Holarctic distribution and is found almost throughout Europe (Brown et al., 2004; Mitchell-Jones et al., 1999; Tikhonov et al., 2008b; Fig. 4.16 and 4.17). It also occurs throughout Spain, but with a known distribution rather scattered (Palomo et al., 2007; Fig. 4.18). This species is classified both by the IUCN and in Portugal as Least Concern (Cabral et al., 2005; Tikhonov et al., 2008b). Even so, there are not many Portuguese studies addressing this species, and the ones that exist are mostly focused at the community level (88%).

The number and distribution of historical and current records is limited but scattered throughout mainland Portugal (Fig. 4.19 and 4.20), suggesting lack of adequate surveys targeting this small carnivore. In fact, the weasel is a difficult species to detect and might currently occur in low densities, hampering the collection of presence records. Furthermore, although there is a higher number of current records (N=281) than historical ones (N=56), this number can be deceiving because 85% of them are unconfirmed (mostly scats with no genetic validation) and 72% came from an intensively surveyed small region in central Alentejo, around the Monfurado site. As a result, the obtained AOO is very small in comparison with the current EOO. These results, especially in comparison with other mustelids, contradict the previously set idea that the weasel is the least elusive carnivore and the most widespread and abundant mustelid in Portugal (Santos-Reis, 1983; Santos-Reis and Mathias, 1996). This apparent contradiction could be because its abundance tends to vary in correlation with the abundance of its preys (e.g. rodents), and so it might suffer periods of population collapse followed by others of increasing density (Sheffield and King, 1994). Taking this into consideration, and according to Palomo et al. (2007), this species might currently be going trough a phase of population decline.

Regarding the distribution trend of the weasel, and although there are areas clearly under-sampled both in past and current times, the range of this species seems to be stable overall.

Taking this into consideration, there is a need for a larger sampling effort for this species, covering the whole country and directed to obtaining more reliable records.

Mustela putorius

Portuguese name: **Toirão**

English Name: **Western Polecat**

Origin: Native

IUCN Category: LC

PRLV Category: DD

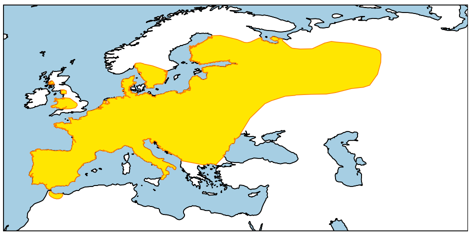


Fig. 4.21 – Western polecat global distribution range (from IUCN, 2014)

Fig. 4.22 – Western polecat distribution in Europe (from Mitchell-Jones et al., 1999)

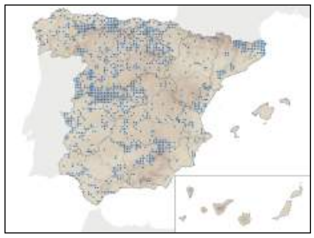


Fig. 4.23 – Western polecat distribution in Spain (from Palomo et al., 2007)

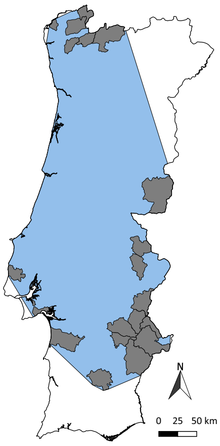


Fig. 4.24 – Historical records (grey) and EOO (blue) of the western polecat in Portugal

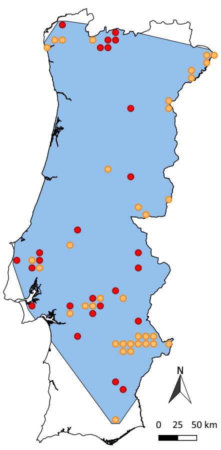


Fig. 4.25 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the western polecat in Portugal

Bibliometric analysis

Nr. of publications: 57 (14% single-species studies; 86% shared studies)

Main research topics: Population Status, General Ecology and Conservation

Presence records

Nr. of historical records: 81 (Fig. 4.24)

Nr. of current records: 177 (61 cells; Fig. 4.25)

Confirmed records: 23% of records (2.5% of cells)

- Live observations: 7%
- Dead animals: 16%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 77% of records (3.6% of cells)

- Presence signs (non-genetic): 72%
- Others: 5%

Distribution patterns

Historical EOO (range cover in Portugal): 78% (Fig. 4.24)

Current EOO (range cover in Portugal): 88% (Fig. 4.25)

Current AOO (nr. of cells w/ records): 7%

Distribution trend (before vs. after 2000): Stable

Selected correlates: SRad, MP24 (Table 3.2)

Polecat

The polecat is widespread in the western Palaearctic (Fernandes et al., 2008; Fig. 4.21), widely distributed in Europe (Mitchell-Jones et al., 1999; Fig. 4.22) and has a reduced and scattered range in Spain (Palomo et al., 2007; Fig. 4.23). Although it is considered Least Concern by the IUCN (Fernandes et al., 2008), in Portugal this species is classified as Data Deficient (Cabral et al., 2005), mostly due to lack of knowledge, considering that it is a difficult species to observe, being elusive, solitary and nocturnal (Santos-Reis, 1983). In fact, the polecat is under-represented in monitoring and scientific studies in Portugal, with most of the publications (86%) being community-level studies.

This species has few and scattered historical and current presence records in Portugal (Fig. 4.24 and 4.25), with most recent records coming from the area in and around Monfurado (27%) and Moura-Barrancos sites (35%), in central Alentejo. Even so, both historical and current records are widespread across the country and show a remarkable overlap in spatial extent, although this species may occur outside the areas detected in this study, such as NE (Bragança) and south (Algarve). Nevertheless, this species seems to have a scattered range, occurring only in certain areas with suitable conditions, as suggested by the large observed difference between current AOO e EOO. Also, supported by the results of SDM, there is the possibility that the species has two sub-populations in Portugal, corresponding to the two subspecies considered to occur in the Iberian Peninsula: *Mustela putorius putorius* and *M. p. aureolus*, with the first corresponding to the population restricted to the north, and the second to the centre and south Iberia (Palomo et al., 2007).

In order to improve the knowledge about this species, there is a need for a larger sampling effort all over the country, particularly in Central and Northern Portugal, as well as in Algarve.

Neovison vison

Portuguese name: **Visão-Americano**

English Name: **American Mink**

Origin: American

IUCN Category: LC

PRLV Category: NA

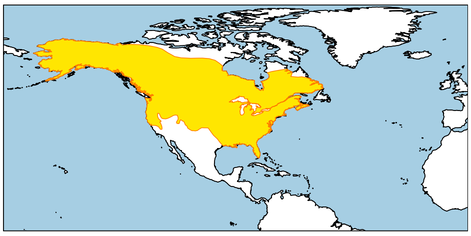


Fig. 4.26 – American mink global distribution range (from IUCN, 2014)

Fig. 4.27 – American mink distribution in Europe (from Mitchell-Jones et al., 1999)

Fig. 4.28 – American mink distribution in Spain (from Palomo et al., 2007)

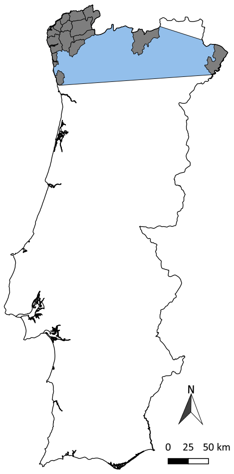


Fig. 4.29 – Historical records (grey) and EOO (blue) of the American mink in Portugal

Bibliometric analysis

Nr. of publications: 15 (40% single-species studies; 60% shared studies)

Main research topics: Population Status, General Ecology and Conservation

Presence records

Nr. of historical records: 49 (Fig. 4.29)

Nr. of current records: 84 (39 cells; Fig. 4.30)

Confirmed records: 36% of records (1.9% of cells)

- Live observations: 20%
- Dead animals: 2%
- Photos: 1%
- Presence signs (genetic): 12%

Unconfirmed records: 64% of records (2.0% of cells)

- Presence signs (non-genetic): 50%
- Others: 14%

Distribution patterns

Historical EOO (range cover in Portugal): 15% (Fig. 4.29)

Current EOO (range cover in Portugal): 16% (Fig. 4.30)

Current AOO (nr. of cells w/ records): 4%

Distribution trend (before vs. after 2000): Expansion

Selected correlates: SRad, U500, Farm (Table 3.2)

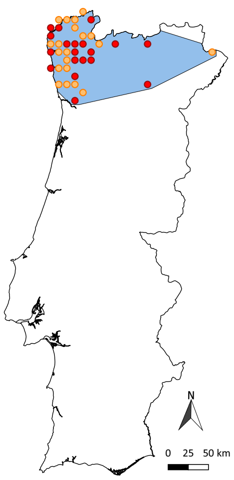


Fig. 4.30 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the American mink in Portugal

American Mink

The American mink, as the name reflects, is native to North America (Reid and Helgen, 2008; Fig. 4.26). In the last century, it was brought to Europe for fur farming (Dunstone, 1983), and it has been introduced in several regions of this continent, especially in northern Europe and in scattered areas in the southern peninsulas (Bonesi and Palazón, 2007; Mitchell-Jones et al., 1999; Fig. 4.27). In the Iberian Peninsula, this species was first detected in the late 1950s (Albizua, 2006; Bravo and Bueno, 1992) and since then it has been expanding from several areas, where individuals have been released, mostly in the north of Spain and Portugal (Palomo et al., 2007; Rodrigues et al., 2015; Fig. 4.28). This species is classified as Least Concern by the IUCN (Reid and Helgen, 2008), but in Portugal, being an invasive species recently introduced, it has the Not applicable (NA) category (Cabral et al., 2005).

The occurrence of the American mink in Portugal was first documented in the late 1980s, in Minho river, suspected of being due to accidental escapes of several individuals from the fur farms near that area (Santos-Reis and Mathias, 1996; Vidal-Figueroa and Delibes, 1987). As expected from such a recent occurrence, this is one of the Portuguese carnivore species with the smallest number of publications. Even so, it is already addressed in the Portuguese legislation that regulates introduced non-indigenous species (Decreto-Lei nº 565/99). A recent study assessed the distribution and expansion of American Mink in NW Portugal and found that, in 2010/2011, the southernmost records of this semi-aquatic mustelid are located in the rivers Sousa and Tua, which are northern tributaries of the Douro river (Harrington et al., 2012; Rodrigues et al., 2015).

Comparing historical and current distribution maps (Fig. 4.29 and 4.30) it is evident that the historical distribution of the American mink in Portugal, assessed in 1987, and the current one, obtained from Rodrigues et al. (2015), largely overlap. The outer western limit of the current extent of occurrence helps to confirm that the American mink entered the Portuguese borders during the 1980s by the NW corner of Portugal, throughout the Minho river. After an expansion southwards over the years, this species currently occupies all of the hydrographic basins of NW Portugal. Besides this main area, some isolated occurrences have also been detected in NE Portugal (rivers Tua, Tâmega and international portion of the Douro), an area isolated from the NW core distribution range by extensive mountain ridges. This suggests multiple invasion events, probably originated from expanding Spanish populations along the Douro river basin (Rodrigues et al., 2015). Taking this into consideration, this species should be the target of effective population control programmes, in order to prevent its negative impacts on native species, both trough predation of native fauna (e.g. bivalves, fish, amphibians and birds; Ahola et al., 2006; Clode and Macdonald, 2002; Fischer et al., 2009; Melero et al., 2012) or competition with similar native carnivores (such as the polecat and the otter; Bonesi et al., 2004; Melero et al., 2012; Sidorovich and MacDonalds, 2001).

Considering SDM results (Fig. 3.11), the American mink's potential distribution area was very coincident with the main known area of occupancy of this species (Rodrigues et al., 2015). Interestingly, its occurrence was found to be positively related with the presence of farms and with proximity to major cities. These results reflect the commensal character of this small carnivore and the deep influence of human presence and activities, by being the source of new individuals for this species' populations, easy prey (fowl and fish farms) for this opportunistic species, and shelter (e.g. human-created embankments; Birnbaum, 2013; García et al., 2010).

Martes foina

Portuguese name: **Fuinha**

English Name: **Stone Marten**

Origin: Native

IUCN Category: LC

PRLV Category: LC

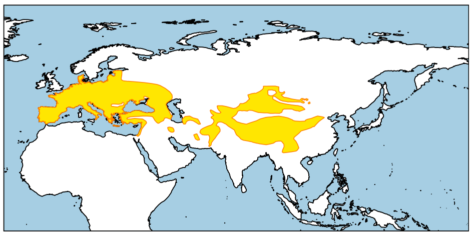


Fig. 4.31 – Stone marten global distribution range (from IUCN, 2014)

Fig. 4.32 – Stone marten distribution in Europe (from Mitchell-Jones et al., 1999)

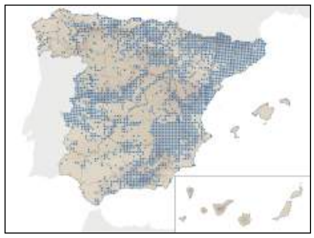


Fig. 4.33 – Stone marten distribution in Spain (from Palomo et al., 2007)

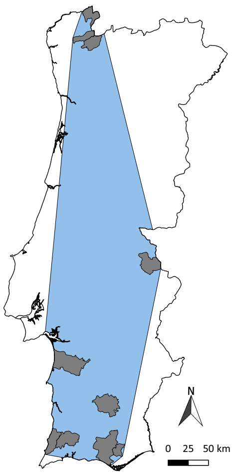


Fig. 4.34 – Historical records (grey) and EOO (blue) of the stone marten in Portugal

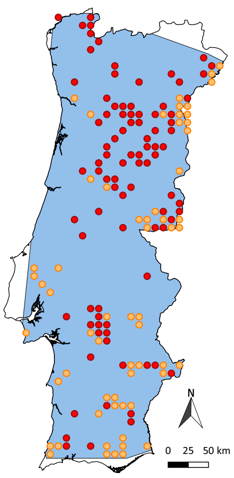


Fig. 4.35 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the stone marten in Portugal

Bibliometric analysis

Nr. of publications: 100 (14% single-species studies; 86% shared studies)

Main research topics: General Ecology, Conservation and Population Status

Presence records

Nr. of historical records: 44 (Fig. 4.34)

Nr. of current records: 1515 (151 cells; Fig. 4.35)

Confirmed records: 19% of records (9.0% of cells)

- Live observations: 12%
- Dead animals: 6%
- Photos: 1%
- Presence signs (genetic): 0%

Unconfirmed records: 81% of records (6.1% of cells)

- Presence signs (non-genetic): 78%
- Others: 3%

Distribution patterns

Historical EOO (range cover in Portugal): 59% (Fig. 4.34)

Current EOO (range cover in Portugal): 95% (Fig. 4.35)

Current AOO (nr. of cells w/ records): 16%

Distribution trend (before vs. after 2000): Stable

Selected correlates: HJul, Slop, DHi, RMP (Table 3.2)

Stone Marten

The stone marten occurs throughout much of the Palearctic (Europe and central Asia; Mitchell-Jones et al., 1999; Tikhonov et al., 2008a; Fig. 4.31 and 4.32) and has a widespread distribution in Spain, particularly on the eastern side of this country (Palomo et al., 2007; Fig. 4.33). This species is classified as Least Concern both by the IUCN (Tikhonov et al., 2008a) and in Portugal (Cabral et al., 2005) and, similarly to most meso-carnivores analysed in this study, the majority of publications in Portugal (86%) are shared with the remaining carnivore community.

For the stone marten, there is a small number of historical records, which most probably reflects a lack of historical sampling, but the depiction of historical distribution based on the collected records shows an occurrence throughout mainland Portugal (Fig. 4.34). Despite the large amount of current occurrence records, they do not translate into a high coverage of the country because most of them (76%) were obtained in the area of Monfurado, central Alentejo (Fig. 4.35). There is a large difference between current AOO and EOO, but this is also likely due to deficient sampling coverage. Although the percentage of cells with confirmed records is higher than that for unconfirmed ones, given that most of thesse (78%) are unconfirmed presence signs, an increase in the effort to genetically validate presence signs (such as scats) should be assured (Monterroso et al., 2013b).

This species should have a larger sampling effort, particularly in the south of the Tagus river and North of the Douro river in order to confirm actual presence areas.

Martes martes

Portuguese name: **Marta**

English Name: **Pine Marten**

Origin: Native

IUCN Category: LC

PRLV Category: DD

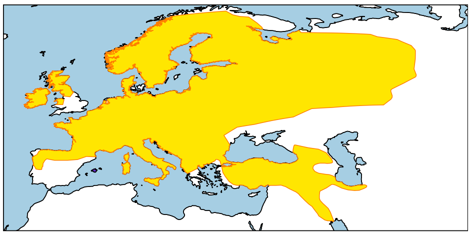


Fig. 4.36 – Pine marten global distribution range (from IUCN, 2014)

Fig. 4.37 – Pine marten distribution in Europe (from Mitchell-Jones et al., 1999)

Fig. 4.38 – Pine marten distribution in Spain (from Palomo et al., 2007)

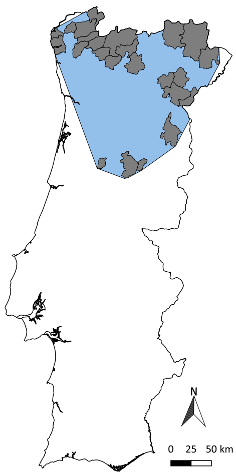


Fig. 4.39 – Historical records (grey) and EOO (blue) of the pine marten in Portugal

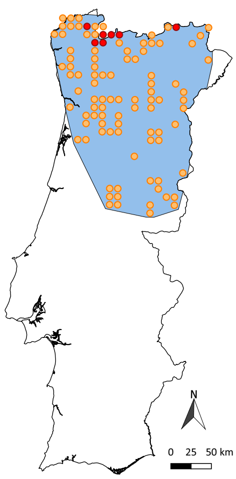


Fig. 4.40 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the pine marten in Portugal

Bibliometric analysis

Nr. of publications: 23 (26% single-species studies; 74% shared studies)

Main research topics: Population Status, General Ecology and Conservation

Presence records

Nr. of historical records: 71 (Fig. 4.39)

Nr. of current records: 105 (99 cells; Fig. 4.40)

Confirmed records: 7% of records (0.7% of cells)

- Live observations: 0%
- Dead animals: 2%
- Photos: 5%
- Presence signs (genetic): 0%

Unconfirmed records: 93% of records (9.2% of cells)

- Presence signs (non-genetic): 0%
- Others: 93%

Distribution patterns

Historical EOO (range cover in Portugal): 31% (Fig. 4.39)

Current EOO (range cover in Portugal): 39% (Fig. 4.40)

Current AOO (nr. of cells w/ records): 10%

Distribution trend (before vs. after 2000): Uncertain

Selected correlates: Prec, Farm (Table 3.2)

Pine Marten

The pine marten is a mesocarnivore species with a wide distribution in the west and central Palaearctic (Kranz et al., 2008; Fig. 4.36), and occurs across most of Northern and Central Europe (Mitchell-Jones et al., 1999; Fig. 4.37). However, in Spain, as in Portugal, this species has always occurred only marginally in northern regions, due to its affinity with the Eurosiberian biogeographical region (Palomo et al., 2007; Fig. 4.38). This species is classified as Least Concern by the IUCN (Kranz et al., 2008) and as Data Deficient in Portugal (Cabral et al., 2005).

The occurrence of the pine marten in Portugal was only confirmed in the 1990s (Santos-Reis and Mathias, 1996), although it was most probably present since historical times, with Bocage already hypothesising its presence in Portugal in the mid 19th century (Bocage, 1863). Although it has been mainly focused on in community-level studies, there is one study that assessed the distribution of the pine marten at a national level (Matos and Santos-Reis, 2006). However, that study was mostly based on unconfirmed and unreliable records obtained from questionnaires, many of which probably refer to the more common stone marten, with whom the pine marten is easily confused (Matos and Santos-Reis, 2006; Proulx et al., 2005; Santos-Reis, 1983). The compiled historical records, suggest that the pine marten has always occurred in the entire north of Portugal (including the area south of the Douro river), with the Serra da Estrela mountain range as a southern limit, as suggested by Santos-Reis (1983). However, it is possible that actually the pine marten has a much more restricted range in Portugal, limited to the northern fringe of the country (Peneda-Gerês and Montesinho mountains), taking into account the confirmed current records and the climatic and habitat suitability of this region predicted by ecological modelling (Brito and Álvares, 2004; Fig. 4.39 and 4.40). The apparent restriction of this species to the climatic conditions of the Eurosiberian biogeographical region and to mature native forests dominated by oaks (Brito and Álvares, 2004), which in Portugal are mostly limited to the northern border of the country, puts into question the reliability of most previous records obtained for the pine marten throughout central and northern Portugal. Consequently, the current occurrence area of pine marten in Portugal may be highly restricted and fragmented, as is reflected by current confirmed records

(N=7), and Portuguese populations are probably isolated from the remaining distribution range of this species in Spain (Palomo et al., 2007). Besides, population size and connectivity are probably low, due to limited potential habitat suitability, since in the main core area of occurrence in NW Portugal, Brito and Álvares (2004) estimated a total population size of 25 to 294 individuals distributed along 12 potential partially isolated areas. If these estimates are accurate, this species could become one of the most endangered carnivores in Portugal.

In order to have a clear idea of the actual range of the pine marten in Portugal and evaluate its conservation status, it becomes urgent to conduct a specific, systematic and reliable survey, particularly covering the areas where unconfirmed records were obtained.

Meles meles

Portuguese name: **Texugo**

English Name: **European Badger**

Origin: Native

IUCN Category: LC

PRLV Category: LC

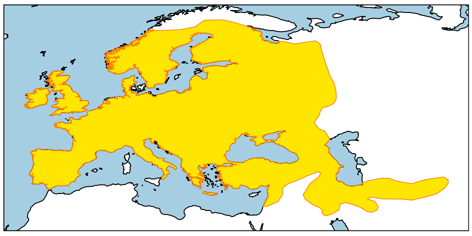


Fig. 4.41 – European badger global distribution range (from IUCN, 2014)

Fig. 4.42 – European badger distribution in Europe (from Mitchell-Jones et al., 1999)

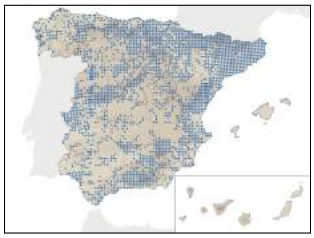


Fig. 4.43 – European badger distribution in Spain (from Palomo et al., 2007)

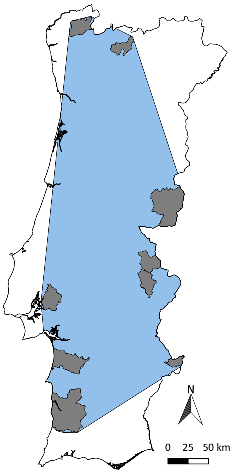


Fig. 4.44 – Historical records (grey) and EOO (blue) of the european badger in Portugal

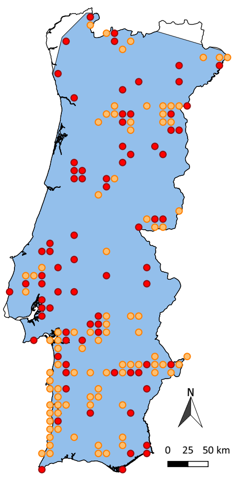


Fig. 4.45 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the european badger in Portugal

Bibliometric analysis

Nr. of publications: 111 (33% single-species studies; 67% shared studies)

Main research topics: General Ecology, Population Status and Conservation

Presence records

Nr. of historical records: 200 (Fig. 4.44)

Nr. of current records: 1992 (166 cells; Fig. 4.45)

Confirmed records: 7% of records (7.8% of cells)

- Live observations: 3%
- Dead animals: 4%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 93% of records (8.8% of cells)

- Presence signs (non-genetic): 92%
- Others: 1%

Distribution patterns

Historical EOO (range cover in Portugal): 72% (Fig. 4.44)

Current EOO (range cover in Portugal): 97% (Fig. 4.45)

Current AOO (nr. of cells w/ records): 17%

Distribution trend (before vs. after 2000): Stable

Selected correlates: SAgr, SRad (Table 3.2)

Badger

The European badger, the largest mustelid known to occur in Portugal, is widespread throughout Europe and West Asia (Kranz et al., 2016; Mitchell-Jones et al., 1999; Santos-Reis, 1983; Fig. 4.41 and4.42), with a more reduced and fragmented distribution in Spain (Palomo et al., 2007; Fig. 4.43). This species is classified both by the IUCN and in Portugal (Cabral et al., 2005; Kranz et al., 2016) as Least Concern and it has been the focus of a fair amount of publications in Portugal, one-third of which werededicated exclusively to this carnivore species.

Following the trend of other common and widespread mesocarnivores in Portugal, the badger also had a limited historical sampling, although with a distribution throughout most of the mainland (Fig. 4.44). The large amount of current records (also mostly from the area inside and around the Monfurado site, 74%) are also distributed throughout the country, although the AOO (actual number of cells with records) is relatively small, suggesting a patchy distribution determined by specific habitat conditions (Rosalino et al., 2004; Santos and Beier, 2008; Fig. 4.45). A recent study by Rosalino et al. (2016), based on toponymy, supports this idea that the badger has been widespread in Portugal since historical times and until the present. However, considering the results from SDM (Fig. 3.17, it would seem the most favourable conditions are in the SW of Portugal, where cells with records are more abundant and landscape features that are positively related to the badger, such as the high proportion of oak woodlands and pastures, can be found (Rosalino et al., 2008).

Also, similarly to the findings for other mesocarnivores, the majority of current records are unconfirmed and are mostly presence signs not validated by genetic analysis. However, for the badger in particular, most presence signs (such as footprints, scats or latrines) can be considered reliable, since they are easily recognisable and fairly unequivocal regarding other species (Blanco, 1998).

Based on these findings, future research is needed to survey badgers at a national level, particularly north of the Tagus river and in the SE corner of Portugal.

Lutra lutra

Portuguese name: **Lontra**

English Name: **Eurasian Otter**

Origin: Native

IUCN Category: NT

PRLV Category: LC

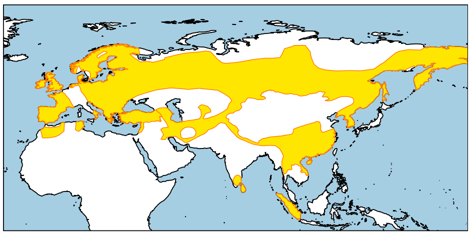


Fig. 4.46 – Eurasian otter global distribution range (from IUCN, 2014)

Fig. 4.47 – Eurasian otter distribution in Europe (from Mitchell-Jones et al., 1999)

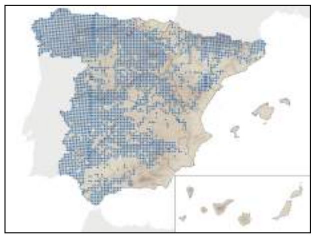


Fig. 4.48 – Eurasian otter distribution in Spain (from Palomo et al., 2007)

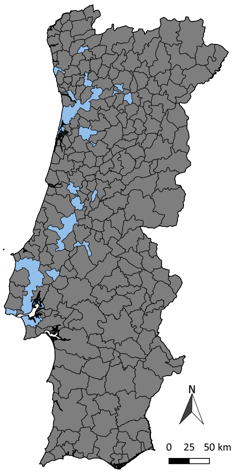


Fig. 4.49 – Historical records (grey) and EOO (blue) of the eurasian otter in Portugal

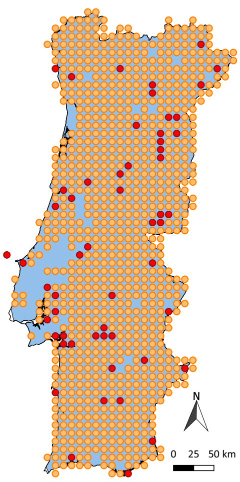


Fig. 4.50 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the eurasian otter in Portugal

Bibliometric analysis

Nr. of publications: 196 (71% single-species studies; 29% shared studies)

Main research topics: General Ecology, Conservation and Population Status

Presence records

Nr. of historical records: 1400 (Fig. 4.49)

Nr. of current records: 3061 (916 cells; Fig. 4.50)

Confirmed records: 2% of records (5.5% of cells)

- Live observations: 1%
- Dead animals: 1%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 98% of records (85.8% of cells)

- Presence signs (non-genetic): 67%
- Others: 31%

Distribution patterns

Historical EOO (range cover in Portugal): 100% (Fig. 4.49)

Current EOO (range cover in Portugal): 100% (Fig. 4.50)

Current AOO (nr. of cells w/ records): 93%

Distribution trend (before vs. after 2000): Stable

Selected correlates: HRan, DRoad, Slop, RMP (Table 3.2)

Otter

The Eurasian Otter has one of the widest distributions of all Palaearctic mammals, with a range spanning Europe, Asia and north Africa (Roos et al., 2015; Fig. 4.46). Its current distribution in Europe is marked by a large area in the Central region, where the species has become extinct or reduced to small, isolated subpopulations, which divide this species' range into two main areas (Mitchell-Jones et al., 1999; Fig. 4.47). In Spain, the distribution of the otter has a longitudinal gradient with increasing presence from East to West (Palomo et al., 2007; Fig. 4.48).

This semi-aquatic species is globally classified as Near Threatened (Roos et al., 2015) due to an ongoing population decline. However, in Portugal, this is not the case, since the otter is classified as Least Concern and the Portuguese otter population is considered one of the most viable in Europe (Cabral et al., 2005; Trindade et al., 1998). Furthermore, the otter has been one of the most studied carnivore species in Portugal (with only the wolf surpassing it), with most publications (71%) being exclusively dedicated to this species. Included in these previous studies is a systematic assessment of the otter distribution in Portugal, published in the late 1990s (Trindade et al., 1998) which lead to the very complete account of historical distribution presented here (Fig. 4.49).

Regarding the current distribution, and although no systematic survey has recently been done for the entire country, we were able to compile a large amount of records, and thus present a very complete depiction of the otter range based on online data sources (e.g. SIPNAT), mostly dated from 2008. However, there is no certainty that these records, taking into account their completeness, are not the same as the ones published in the survey of the 1990s, since limited information was available on their origin. Nevertheless, assuming the date of their collection is correct, these data allowed to obtain a current range which is largely coincident with the historical distribution, and led to this species being one of the Portuguese carnivores with the highest number of current presence records and the largest current AOO (Fig. 4.50). Desthpite the large proportion of unconfirmed records among current presence data, these are fairly reliable since otter scats and footprints are easily recognisable and practically unequivocal (Blanco, 1998).

This species has been occurring nearly in all hydrographic basins and along most of the coastline of mainland Portugal (Beja, 1989; Pedroso et al., 2014; Fig. 4.49 and 4.50). However, Trindade et al. (1998) and Bernardo (2008), identify several critical areas where this species' range might be decreasing dramatically, such as the Estremadura region (in coastal Central Portugal, where this species is mostly absent); the coastal area south of Porto (between the Douro river and Ria de Aveiro, in the Vouga river Estuary), and on the southern coast of Algarve (near Ria Formosa). Taking this into consideration, future systematic surveys should be conducted in order to evaluate distribution trends at both national and local levels (Areias-Guerreiro et al., 2016).

Genetta genetta

Portuguese name: **Geneta**

English Name: **Common Genet**

Origin: African

IUCN Category: LC

PRLV Category: LC

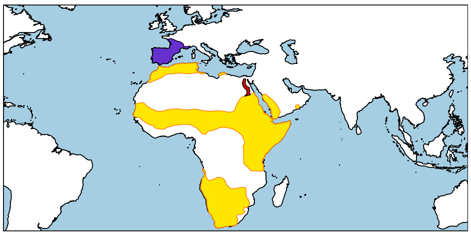


Fig. 4.51 – Common genet global distribution range (from IUCN, 2014)

Fig. 4.52 – Common genet distribution in Europe (from Mitchell-Jones et al., 1999)

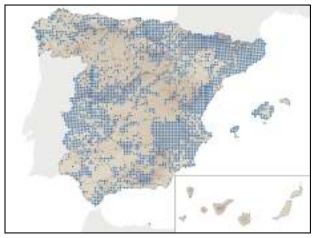


Fig. 4.53 – Common genet distribution in Spain (from Palomo et al., 2007)

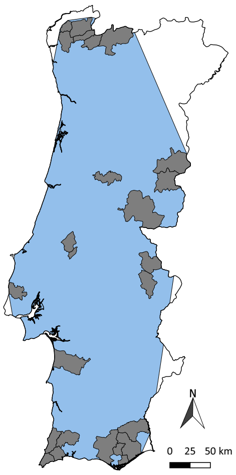


Fig. 4.54 – Historical records (grey) and EOO (blue) of the common genet in Portugal

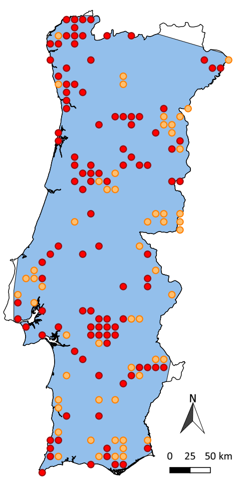


Fig. 4.55 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the common genet in Portugal

Bibliometric analysis

Nr. of publications: 116 (25% single-species studies; 75% shared studies)

Main research topics: General Ecology, Population Status and Conservation

Presence records

Nr. of historical records: 58 (Fig. 4.54)

Nr. of current records: 1330 (164 cells; Fig. 4.55)

Confirmed records: 20% of records (10.8% of cells)

- Live observations: 9%
- Dead animals: 9%
- Photos: 2%
- Presence signs (genetic): 0%

Unconfirmed records: 80% of records (5.6% of cells)

- Presence signs (non-genetic): 77%
- Others: 3%

Distribution patterns

Historical EOO (range cover in Portugal): 88% (Fig. 4.54)

Current EOO (range cover in Portugal): 98% (Fig. 4.55)

Current AOO (nr. of cells w/ records): 17%

Distribution trend (before vs. after 2000): Stable

Selected correlates: DPre (Table 3.2)

Genet

The common genet is a widespread species, with its origin and core distribution in Africa (Gaubert et al., 2015a; Fig. 4.51). It is considered to have been introduced in Europe in historical times, and currently naturalised populations occur, with an apparently fragmented distribution, from the SW corner of France to Gibraltar, the southernmost area in the Iberian Peninsula (Gaubert et al., 2011; Mitchell-Jones et al., 1999; Palomo et al., 2007; Fig. 4.52 and 4.53). This species is classified as Least Concern both by the IUCN and in Portugal (Cabral et al., 2005; Gaubert et al., 2015a). As most mesocarnivores in Portugal, it is mostly addressed in community-level studies (75%), with publications generally more focused on General Ecology of this species.

For the genet, there are few historical records in comparison with the large number of current records. However, available records translate into a low number of geographical units with documented presence and, consequently, into a low current AOO, although with a wide EOO in both time periods (Fig. 4.55). These results suggest a widespread but patchy distribution in Portugal. Previous studies state that this species is more abundant in southern Portugal, especially south of the Tagus river (Santos-Reis and Mathias, 1996), but the compiled current and historical records do not support this assumption, as they are evenly distributed throughout the country (Fig. 4.55 and 4.54), and the results of SDM also point to a possibly more concentrated presence in NW Portugal.

Most of the recent data regarding this species (77%) comprise unconfirmed records, mostly presence signs not confirmed genetically, but which can be easily recognisable and fairly unequivocal (Blanco, 1998). Also, most records were collected in or near the Monfurado site (71%), where this species has been intensively studied (Carvalho and Gomes, 2004; Carvalho, 2012). Many areas of Portugal where presence records are not available have still not been assessed for the detection of this species and are most likely within its distribution range. In fact, previous studies suggest that the genet is widespread and well adapted to the Portuguese landscapes and climate (Cabral et al., 2005; Cavallini and Palomares, 2008; Gaubert et al., 2015b; IUCN, 2015). Future research should systematically assess the presence of genets and clarify the coverage and density of its occurrence in Portugal.

Herpestes ichnenumon

Portuguese name: **Sacarrabos**

English Name: **Egyptian Mongoose**

Origin: African
IUCN Category: LC
PRLV Category: LC

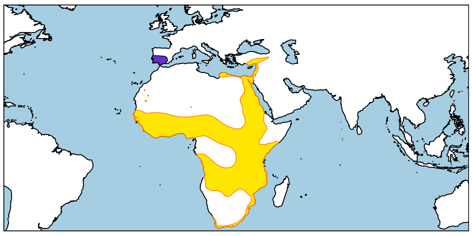


Fig. 4.56 – Egyptian mongoose global distribution range (from IUCN, 2014)

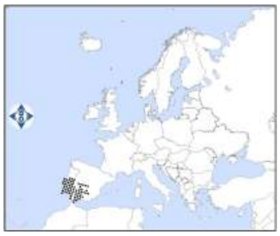


Fig. 4.57 – Egyptian mongoose distribution in Europe (from Mitchell-Jones et al., 1999)

Fig. 4.58 – Egyptian mongoose distribution in Spain (from Palomo et al., 2007)

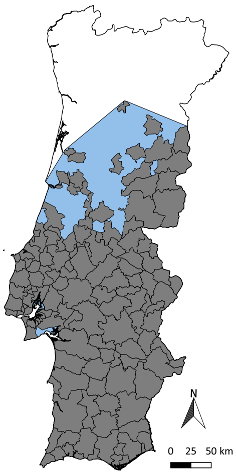


Fig. 4.59 – Historical records (grey) and EOO (blue) of the Egyptian mongoose in Portugal

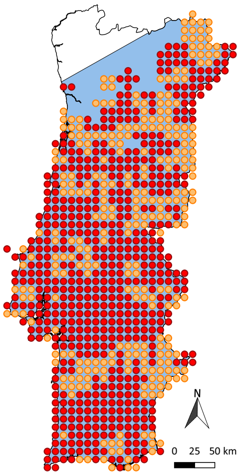


Fig. 4.60 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the Egyptian mongoose in Portugal

Bibliometric analysis

Nr. of publications: 81 (21% single-species studies; 79% shared studies)

Main research topics: General Ecology, Population Status and Conservation

Presence records

Nr. of historical records: 675 (Fig. 4.59)

Nr. of current records: 2340 (866 cells; Fig. 4.60)

Confirmed records: 30% of records (57.4% of cells)

- Live observations: 10%
- Dead animals: 19%
- Photos: 1%
- Presence signs (genetic): 0%

Unconfirmed records: 70% of records (28.9% of cells)

- Presence signs (non-genetic): 53%
- Others: 17%

Distribution patterns

Historical EOO (range cover in Portugal): 75% (Fig. 4.59)

Current EOO (range cover in Portugal): 94% (Fig. 4.60)

Current AOO (nr. of cells w/ records): 87%

Distribution trend (before vs. after 2000): Expansion

Selected correlates: SRad, U500, Farm, PET, Temp, DRoad, MP24 (Table 3.2)

Egyptian Mongoose

The Egyptian mongoose, like the genet, has its origin and core distribution in Africa, mainly in the sub-Saharan region (Cavallini and Palomares, 2008; Fig. 4.56). Outside of Africa, this species occurs only in south Turkey and in the southern Iberian Peninsula (Gaubert et al., 2015b; Mitchell-Jones et al., 1999; Fig. 4.56, 4.57). In Spain, according to Palomo et al. (2007), this species occurs only in the SW of the mainland, close to the border with Portugal (Fig. 4.58). The Egyptian mongoose was previously thought to be introduced in Europe, in historical times, now having naturalised populations in this continent (Mitchell-Jones et al., 1999). However, recent publications based on genetic data, concerning the origin of the mongoose in the Iberian Peninsula, suggest that this species already occurred in the area during the Pleistocene, having dispersed from north Africa through existing land bridges across the Strait of Gibraltar and naturally colonised Europe (Barros et al., 2016; Gaubert et al., 2011). This would make the mongoose a native species in Portugal and Europe, and might be the reason why it is currently widespread and well-adapted to the Portuguese landscapes and climate (Cabral et al., 2005; Cavallini and Palomares, 2008; Gaubert et al., 2015b; IUCN, 2015).

The Egyptian mongoose is classified as Least Concern, both globally (Cavallini and Palomares, 2008) and in Portugal (Cabral et al., 2005). It is also a game species for which hunting is regulated by the Portuguese hunting laws (Lei nº 173/99; Decreto-Lei nº 202/2004).

This species has been the focus of some research in Portugal, mostly (79%) in community-level studies. However, several systematic studies at the national level were exclusively dedicated to assessing this species distribution, both in the past and the current century (Barros and Fonseca, 2011; Borralho et al., 1996). In both studies, information on species occurrence was gathered via questionnaires, field observations, game hunting data and analysis of bibliographic sources. Most of the historical (98%) and many current occurrence records (38%) came mostly from those two assessments and probably represent well the areas where this species occurred at the end of the last century (Fig. 4.59) and more recently (Fig. 4.60).

The Egyptian mongoose underwent an extensive and rapid expansion towards the north, from occupying only the south of the Tagus river, in the 20th century, to occurring practically across the country in the present day, except for the NW region, which is included in the Eurosiberian biogeographical region (Barros and Fonseca, 2011). Based on the compiled records from these previous studies, this species went throughout a dramatic expansion, occupying now more 19% of the country than it did in the previous century. However, even with this widespread and expanding distribution, based on the results of SDM, its occurrence is negatively influenced by high human density and activity. This suggests that, although this species has a strong ability to adapt to different habitats, it tends to prefer areas with lower human disturbance (Borralho et al., 1996).

Felis silvestris

Portuguese name: **Gato-Bravo**

English Name: **Wildcat**

Origin: Native

IUCN Category: LC

PRLV Category: VU

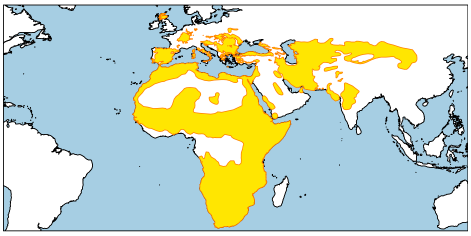


Fig. 4.61 – Wildcat global distribution range (from IUCN, 2014)

Fig. 4.62 – Wildcat distribution in Europe (from Mitchell-Jones et al., 1999)

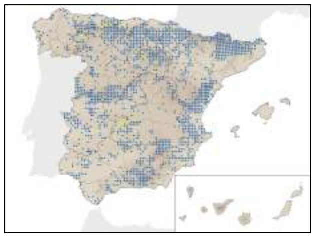


Fig. 4.63 – Wildcat distribution in Spain (from Palomo et al., 2007)

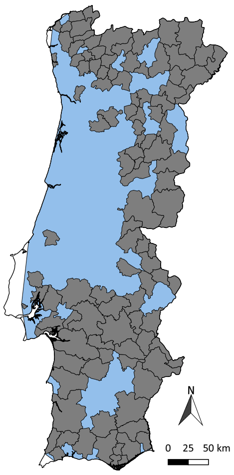


Fig. 4.64 – Historical records (grey) and EOO (blue) of the wildcat in Portugal

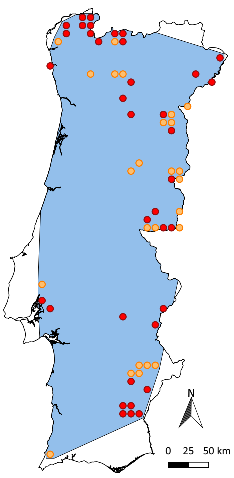


Fig. 4.65 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the wildcat in Portugal

Bibliometric analysis

Nr. of publications: 72 (39% single-species studies; 61% shared studies)

Main research topics: General Ecology, Population Status and Conservation

Presence records

Nr. of historical records: 490 (Fig. 4.64)

Nr. of current records: 113 (62 cells; Fig. 4.65)

Confirmed records: 54% of records (3.7% of cells)

- Live observations: 23%
- Dead animals: 11%
- Photos: 20%
- Presence signs (genetic): 0%

Unconfirmed records: 46% of records (2.5% of cells)

- Presence signs (non-genetic): 35
- Others: 11

Distribution patterns

Historical EOO (range cover in Portugal): 98% (Fig. 4.64)

Current EOO (range cover in Portugal): 88% (Fig. 4.65)

Current AOO (nr. of cells w/ records): 6%

Distribution trend (before vs. after 2000): Uncertain

Selected correlates: SRad, SMG, Alti, AET, DAlt, U500 (Table 3.2)

Wildcat

The wildcat has a broad distribution at the global level, occurring throughout most of Africa and southern Eurasia (Yamaguchi et al., 2015; Fig. 4.61). In Europe, its distribution is very fragmented and mostly restricted to the more southern countries (Mitchell-Jones et al., 1999; Fig. 4.62). In Spain, the wildcat distribution follows the same highly fragmented pattern, with occurrence detected only in the main mountainous regions across the country (Palomo et al., 2007; Fig. 4.63).

This species is globally classified as Least Concern (Yamaguchi et al., 2015), but in Portugal it is considered Vulnerable due to a strong populations reduction over the last three decades (Cabral et al., 2005).

Several studies have focused on the distribution of this species at the end of the last century and the beginning of the current century (Fernandes, 1991; Fernandes, 2007; Pinto and Fernandes, 2001), from which we obtained most of our historical records (94%). Consequently, the wildcat presents more historical records than current ones, which are well distributed, suggesting an adequate assessment of the actual historical range of this species in Portugal (Fig. 4.64). On the contrary, current records, while largely overlapping with the historical distribution range, are relatively scarce and resulted in a very small AOO assessed for this species (Fig. 4.65). These patterns can be the result either of a dramatic reduction of wildcat occurrence or of inadequate sampling effort. However, sampling wildcats is a challenging task: this species may be easily confounded with a domestic/feral cat (*Felis catus*), even when observed at close distance (O'Connor, 2007); hybrids between both species are common and difficult to distinguish from parental forms phenotypically (Oliveira et al., 2008; Ramos, 2014); and most of its signs of presence can be largely confused with those of other mesocarnivores, so genetic validation is crucial (Monterroso et al., 2013b).

Although the frequency of detection of this felid (mostly reported records without confirmation) has been decreasing in the last years, we believe that the collected data for the current century might reflect the main areas where this species actually persists in Portugal, which is supported by the potential area of occurrence resultant from SDM (Fig.

3.25). In order to confirm this, it is essential to conduct a specific and systematic sampling at a national level (but mostly focused in the areas with historical presence), which should be genetically validated to identify pure wildcats and hybrids.

Lynx pardinus

Portuguese name: **Lince Ibérico**

English Name: **Iberian Lynx**

Origin: Native

IUCN Category: EN

PRLV Category: CR

Fig. 4.66 – Iberian lynx global distribution range (from IUCN, 2014)

Fig. 4.67 – Iberian lynx distribution in Europe (from Mitchell-Jones et al., 1999)

Fig. 4.68 – Iberian lynx distribution in Spain (from Palomo et al., 2007)

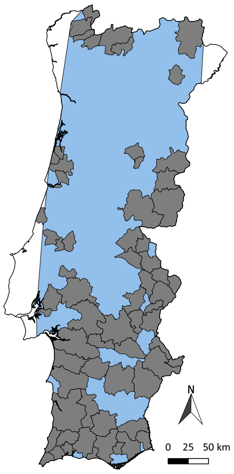


Fig. 4.69 – Historical records (grey) and EOO (blue) of the Iberian lynx in Portugal

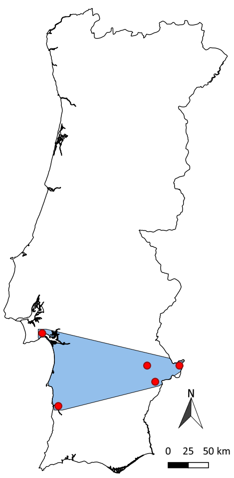


Fig. 4.70 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the Iberian lynx in Portugal

Bibliometric analysis

Nr. of publications: 74 (72% single-species studies; 28% shared studies)

Main research topics: Conservation, Population Status and General Ecology

Presence records

Nr. of historical records: 329 (Fig. 4.69)

Nr. of current records: 10 (5 cells; Fig. 4.70)

Confirmed records: 100% of records (0.5% of cells)

- Live observations: 70%
- Dead animals: 10%
- Photos: 10%
- Presence signs (genetic): 10%

Unconfirmed records: 0% of records (0.0% of cells)

Distribution patterns

Historical EOO (range cover in Portugal): 92% (Fig. 4.69)

Current EOO (range cover in Portugal): 11% (Fig. 4.70)

Current AOO (nr. of cells w/ records): 1%

Distribution trend (before vs. after 2000): Contraction

Selected correlates: Inso (Table 3.2)

Iberian Lynx

The Iberian lynx is the other large carnivore (besides the wolf) to currently inhabit Portugal. This endemic species occurs exclusively in the Iberian Peninsula (Mitchell-Jones et al., 1999; Palomo et al., 2007; Rodríguez and Calzada, 2015; Fig. 4.66, 4.67 and 4.68)), being currently mostly restricted to two separate regions of SW Spain: eastern Sierra Morena and the coastal plains west of the lower Guadalquivir (Rodríguez and Calzada, 2015).

Due to the apparent success of recent reintroduction programmes, the Iberian lynx is now classified globally as Endangered (Rodríguez and Calzada, 2015). However, in Portugal, this species is still considered as Critically Endangered, since it had a drastic population decline in the last three decades due several causes including: reduced habitat quality and habitat fragmentation, low densities of their main prey (*Oryctolagus Cuniculus*), illegal hunting, and several pathologies (Cabral et al., 2005). For the Iberian lynx, most of the studies are exclusively dedicated to this species and mostly focused on Conservation issues, as a result of its conservation status.

The historical distribution of the lynx (from 17th to 20th century) suggests a wide past distribution in Portugal. However, this distribution was apparently fragmented and separated by a large stretch of absence of records along the Douro river. As was stated in chapter 2, most records found north of the Douro river might have been of Eurasian lynx (*Lynx lynx*), as suggested for northern Spain. This is supported by the results of a genetic study (Rodríguez-Varela et al., 2016) and a historical assessment based on bibliographic sources (Clavero and Delibes, 2013). These studies suggest that populations of both species of lynx (Iberian and Eurasian) might have been present at the same time in the Iberian Peninsula, possibly from the Pleistocene/Holocene until just a few centuries ago. Each species would have been restricted to the areas with more suitable conditions, with Eurasian lynx occurring mainly occupying the Atlantic-climate area of northern Iberia and Iberian Lynx in the southern and more Mediterranean part of the peninsula. One of the possible causes for the disappearance of the Eurasian lynx from the Iberian Peninsula might have been their extermination from the northern areas before the 19th century, possibly due to conflicts with humans (due to livestock depredation, similarly to the wolf;

Clavero and Delibes, 2013).

Current records of lynx occurrence are all confirmed and are mostly the result of tracking individuals released in Spain that dispersed to the Portuguese side of the Iberian Peninsula, to areas in the Guadiana river basin (Moura-Barrancos and Alqueva; ICNF, 2015b) and south-western coastal areas (Odemira; ICNF, 2015a). Some of these current records might also refer to the last surviving animals from relict populations in Portugal (e.g Moura-Barrancos and the coast of Alentejo). There is knowledge of several other dispersing Iberian lynxes in the last few years, namely in the NE of the country, but for which it was not possible to obtain georeferenced records.

There were no records of any natural breeding populations in the last decades in Portugal. However, as a result of the reintroduction programme that started releasing animals into the wild in Portugal in 2014, two females (reintroduced in 2014 and 2015) had the first litters of Iberian lynx born in the wild in Portugal during the spring of 2016 (ICNF, 2016a; ICNF, 2016b).

It would be important to assure that there is regular monitoring of the lynx populations (as done so far by the ICNF), in order to compile all occurrence records and evaluate the distribution area and trends of the Iberian lynx.

Ursus arctos

Portuguese name: **Urso-pardo**

English Name: **Brown Bear**

Origin: Native

IUCN Category: LC

PRLV Category: RE

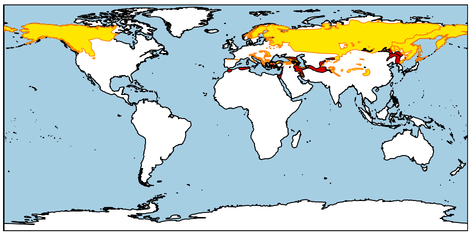


Fig. 4.71 – Brown bear global distribution range (from IUCN, 2014)

Fig. 4.72 – Brown bear distribution in Europe (from Mitchell-Jones et al., 1999)

Fig. 4.73 – Brown bear distribution in Spain (from Palomo et al., 2007)

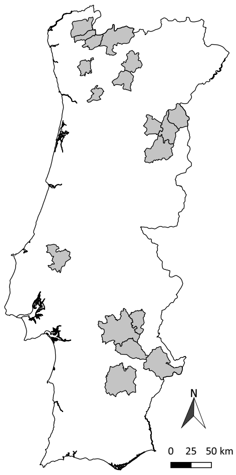


Fig. 4.74 – Records of the brown bear in Portugal from the 10^{th} to the 17^{th}

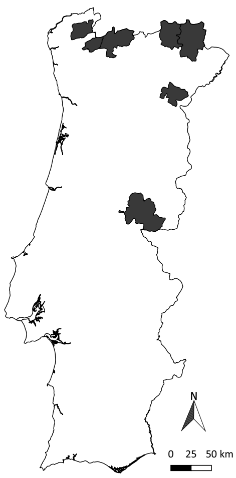


Fig. 4.75 – Records of the brown bear in Portugal from the 18^{th} and 19^{th}

Bibliometric analysis

Nr. of publications: 11 (18% single-species studies; 82% shared studies)

Main research topics: Population Status and Conservation

Presence records

Nr. of historical records: 69

Nr. of current records: 0

Distribution patterns

Historical EOO (range cover in Portugal): 73%

Bear

The brown bear is the most widely distributed ursid in the world, ranging across most of the northern hemisphere but with fragmented populations and significant extinctions in the most southern regions (McLellan et al., 2008; Fig.4.71). In Europe, the brown bear occurs mainly in Eastern and Northern countries. Currently it is reduced to several small and isolated populations, including two relict and geographically separated populations that persist in the north of Spain, located in the Pyrenees and the Cantabrian mountains (Mitchell-Jones et al., 1999; Palomo et al., 2007; Fig. 4.72 and 4.73). This species is globally classified as Least Concern (McLellan et al., 2008). but in Portugal it has become Regionally Extinct (Cabral et al., 2005). Although it has been extinct for a long time, this species has been the focus of several publications, mostly concerning research topics such as population status and conservation.

The compiled historical records of brown bear in Portugal led to the production of two distribution maps representing different time periods: i) until the 17th century (Fig. 4.74 and ii) after the 18th century (Fig, 4.75). The first map and time period represent bear occurrence records until the previously thought to be the date of extinction, suggested by Baeta Neves (1967) in a study focused on the historical occurrence of brown bear in Portugal. In that study, the date of extinction was determined by the record of a shot specimen in the Gerês mountain range (NW Portugal) in 1650. This date was then adopted by posterior reviews on the status of Portuguese mammals (Cabral et al., 2005; Mathias et al., 1998a; Santos-Reis and Mathias, 1996). The records represent the distribution of the bear during the Middle ages, when this species apparently was present throughout the country but already in fragmented areas, such as the mountains of NW Portugal, Beira Interior and the Guadiana river basin. The second map and time period represent brown bear presence records from the 18th until late 19th century (Fig, 4.75), obtained by Álvares and Domingues (2010) and compiled in this study. These were found in northern Portugal and the Tagus river basin, long after the date of extinction mentioned in previous assessments.

The two non-overlapping maps allow observing the regular presence of the brown bear throughout the last centuries in several areas of Portugal near the Spanish border, such as Peneda-Gerês, Montesinho, upper river Douro basin and upper Tagus river basin. Occurrences were also found in the Guadiana river basin (South Portugal), but only until the 15th century. The most northern areas probably were the last strongholds for the brown bear in Portugal, particularly Peneda-Gerês, with regular sightings during the 19th century. The last known record was on the Spanish side – less than 5 km from the Portuguese border but not included in this study - and dated as recent as 1946 (Álvares and Domingues, 2010). The presence of the bear in Portugal during the late 19th and the early 20th centuries may have been mostly related to sporadic incursions of dispersing individuals originated from nearby Spanish breeding populations (e.g. Serra do Faro and Serra da Queixa, Ourense; La Cabrera, León), which were then located less than 40 km from the Portuguese border (Álvares and Domingues, 2010). However, there is some evidence of breeding females with cubs until the early 20th century in the Spanish slopes of Gerês and Larouco mountains, which suggest the persistence of a residual, but still reproducing population in NW Portugal until recent times (Álvares and Domingues, 2010).

Currently, there are no presence records of brown bear in Portugal. However, due to the recent recovery of the Spanish population in the Cantabrian mountains (Gonzalez et al., 2016; Naves et al., 2003), the occurrence of this large carnivore has been increasingly detected in areas located less than 25 km from the NE Portuguese border (Montesinho), which suggests that in a near future bears can once again inhabit Portuguese landscapes (Loureiro et al., 2012).

Procyon lotor

Portuguese name: **Guaxinim**

English Name: **Racoon**

Origin: American

IUCN Category: LC

PRLV Category: –

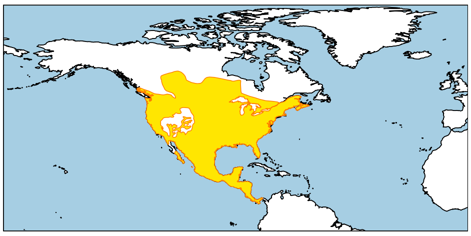


Fig. 4.76 – Racoon global distribution range (from IUCN, 2014)

Fig. 4.77 – Racoon distribution in Europe (from Mitchell-Jones et al., 1999)

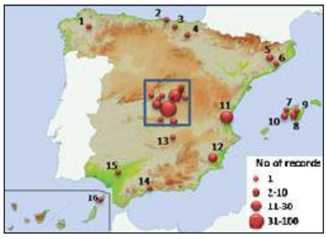


Fig. 4.78 – Racoon distribution in Spain (from Palomo et al., 2007)

Bibliometric analysis

Nr. of publications: 0

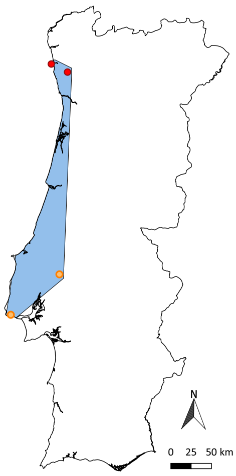


Fig. 4.79 – Current records (red dots - confirmed; orange dots - unconfirmed) and EOO (blue) of the racoon in Portugal

Presence records

Nr. of historical records: 0

Nr. of current records: 4 (4 cells; Fig. 4.79)

Confirmed records: 50% of records (0.2% of cells)

- Live observations: 50%
- Dead animals: 0%
- Photos: 0%
- Presence signs (genetic): 0%

Unconfirmed records: 50% of records (0.2% of cells)

- Presence signs (non-genetic): 0%
- Others: 50%

Distribution patterns

Current EOO (range cover in Portugal): 10% (Fig. 4.79)

Current AOO (nr. of cells w/ records): 0%

Racoon

The racoon is originally from North and Central America (Timm et al., 2016; Fig. 4.76. Like the American mink, it has been introduced in Europe, originally in several countries of Central Europe (Mitchell-Jones et al., 1999; Fig. 4.77), and is currently already present in other European regions. This is the case of the Iberian Peninsula (García et al., 2012; Rodrigues et al., 2015), with several established populations in different areas throughout Spain (Fig. 4.78), and as now documented for the first time in this study, with several presence records in Portugal (Fig. 4.79).

The racoon is internationally considered as Least Concern (Timm et al., 2016). However, considering that this species is a very recent invader, no legal category has yet been attributed in Portugal. Furthermore, there are no previous publications focusing on this species in Portugal, and no historical records are known.

Regarding the current records that were collected in the scope of this work, the first sighting dates from 2008 and was found in Vila Nova de Famalicão, and three more have since been obtained, in 2012, 2013 and 2014. As in Spain (García et al., 2012), most records were obtained near important urban areas in northern and central Portugal, suggesting that these individuals might be the result of escapes from captivity due to illegal importation, rather than the result of dispersing animals from neighbouring Spanish populations. Also, all Portuguese records involve single and quite tamed animals, with no evidence of breeding obtained so far. In order to monitor and control racoon occurrence in Portugal, future studies should be conducted, especially taking into consideration the negative effects that this species can have on several native species through predation and/or competition (García et al., 2012; Kauhala, 1996).

4.3.2 Future perspectives

Currently, presence records of several carnivore species are being collected in environmental impact assessments and other general surveys produced across all of Portugal. However, these relevant data are scattered in technical reports, often not accessible to the general public or even to researchers. For example, most information on the occurrence of bat species for a recent Portuguese Distribution Atlas was produced in Environmental Impact Evaluation and Monitoring studies (Rainho et al., 2013). Also, presence records of carnivore species are often available among researchers, naturalists, wildlife photographers or as a side catch (i. e. secondary data) in scientific publications focused on other subjects. The valuable information from these sources should be compiled and centralised, for improving the knowledge on carnivore species and for their effective conservation. Collecting data from all these types of sources can become the baseline for a future carnivore distribution atlas, as the present study demonstrates. However, it is important to be aware that these data are often with no detailed date and collected throughout a variety of methods which, sometimes, are not even mentioned or described, leading to uncertainty regarding the quality of the data. Having this in mind, it is necessary to carefully evaluate the credibility of these presence records, and to give them appropriate credit according to their level of accuracy in species identification. The described scenario regarding current distribution data can be extended to the evaluation of species' historical distributions. Regarding historical records, special attention should be given to studies under other scientific areas, such as history, archaeology and other social sciences, which are often not connected with ecology and, consequently, are frequently disregarded as sources of ecological information (but see Álvares and Domingues, 2010; Clavero and Delibes, 2013). These historical records are mostly related to carnivore species that have or had some conflict or close relationship with humans (such as large carnivores), representing a unique opportunity to assess historical distributions.

Concerning the knowledge gathered regarding the extant carnivores species in Portugal, several patterns were found. For many species, records were collected inside protected areas. This leads to a concentration of records in those areas and a deficiency in the rest of the territory, which in turn leads to uncertainty regarding if the species is actually absent in other areas or if it is just suffering from lack of systematic sampling throughout the study area. Also, it would be desirable to increase the research effort on those species lacking a systematic assessment, and to try to do so without restricting the efforts to areas where it is easier to survey, or more likely to observe the species. This also means trying to obtain true (or at least surveyed) absences.

For common and widespread species with no pressing conservation concerns (e.g fox, weasel, stone marten, badger and genet), survey coverage is usually scarce and insufficient to make inferences with a high level of accuracy. For species of high conservation concern, such as the wolf and the Iberian lynx, survey efforts are considerably larger, allowing a more precise assessment of their status and distribution, although not many records were obtained for the lynx due to its scarcity in Portugal over the last decades. The American mink, the otter and the Egyptian mongoose were also species for which there was a good knowledge in terms of distribution data and trends - the American mink and the Egyptian mongoose due to their noticeable expansions and invasive potential, and the otter probably due to its charismatic nature. For the three Data Deficient carnivore species (stoat, polecat and pine marten), the records compiled in this study were not enough to clarify their distribution and status, but they served as a tool to understand the gaps that need to be filled. Regarding the racoon, no specific survey has yet been carried out, with only four scattered records currently known, so the knowledge of this species in Portugal is incipient.

Concerning the overall reliability of the records compiled in this study, non validated presence signs constituted the majority of records for most carnivore species. The exceptions were the wolf, stoat, pine marten and racoon, for which the majority of unconfirmed records was from inquiries or of unknown type, and the wildcat and Iberian lynx, for which more confirmed records were obtained than unconfirmed ones. This type of records can be very useful for species which produce scats and/or footprints that are easily detectable and identifiable (such as the badger, otter and genet). However, for most species, presence signs without genetic validation are unreliable concerning the identification of the species. In this study, very few presence signs genetically validated and associated with a geographic location (N=64) were obtained considering all species and only four species benefited from this type of records: wolf, American mink, otter and Iberian lynx. This lack of validation can be due to several reasons: i) the signs of presence such as scats and fur did not actually undergo any kind of genetic identification; ii) the source of the records did not provide any information about genetic validation being done, so the records were assumed as unconfirmed; iii) bibliographic sources with genetically validated presence signs did not provide the geographic location of the sampling sites. However, with the increasing development of genetic markers and tools, the process of non-invasive genetic validation may become cheaper and/or faster (Hall, 2007; Shendure et al., 2004), which would open the possibility of testing many of the presence signs that currently are left without genetic validation. Molecular validation, together with a better communication of the records origin, would allow an increase in the production of reliable records, which is essential for the production of good quality knowledge.

Concerning the confirmed records, live observations and dead animals were the majority (N=2392; 88%). For all species, except the extinct brown bear and the recent invader racoon, there were at least some records of dead animals, mostly road-kills. This type of data is very important, as it enables to observe the specimen with enough time to confirm the species identification with confidence. In what concerns photos, remote photography, such as camera-trapping, has become a key tool in wildlife research over the last years, for several groups of vertebrates (Cutler and Swann, 1999). However, among the data compiled in this study, the total number of photographic records (N=195) and the proportion of this type of records for most carnivore species was very low, even when including photographic records from other types of sources (e.g. wildlife photographers). This can be justified by the difficulty to observe most carnivores, due to their elusive and/or nocturnal behaviour, and possibly due to money constraints or methodological decisions that lead to this not being a main source of records.

The results of this work set a baseline to produce a distribution Atlas of Portuguese Carnivores which might eventually contribute to an Atlas of Portuguese Mammals in the future. This information will help update assessments of species presence and distribution at the level of Iberian Peninsula, Europe and the Mediterranean biodiversity hotspot, with important conservation and management implications.

Chapter 5

General Discussion

5.1 Insights on Portuguese carnivores

In this study, the distribution of 15 extant carnivore species in Portugal was analysed, including the 14 species accounted for in previous check-lists (Cabral et al., 2005; Mathias et al., 1998a; Santos-Reis and Mathias, 1996), and one new species, the racoon, for which this is the first account in Portugal. These numbers move Portugal to a higher position in terms of species richness and diversity at the European level.

The historical presence in Portugal of the brown bear was also analysed and the date for its extinction updated, after obtaining reliable records from the 18th and 19th century (Álvares and Domingues, 2010). Moreover, recent movements of vagrant individuals from this species near the Portuguese-Spanish border (Gonzalez et al., 2016; Naves et al., 2003) suggest the possibility of recolonization of Portugal by dispersing animals in the near future. Also regarding species that occurred in Portugal in historical times, it was hypothesised that another carnivore species, the Eurasian lynx, might have been present in Portugal up to the 19th century in the NW mountains of the country, at the same time as the Iberian lynx in the south (Clavero and Delibes, 2013).

Finally, through modelling of distribution data, it was found that the occurrence of carnivores in Portugal is related not only to climatic factors but also largely to human-related ones, as would be expected in such a humanised country. The carnivore community in Portugal presents important diversity between species in what concerns research efforts, biogeographical origin, distribution patterns, population trends, and variables related to their occurrence. Therefore, the particularities of each species should be taken into account when planning future research, conservation and management.

5.2 Implications for Portugal

Portuguese Authorities should develop efforts to monitor and manage exotic species (racoon and American mink), to monitor Data Deficient species (stoat, polecat and pine marten), and to maintain or recover adequate habitats for the native species, especially the Iberian lynx and the wolf, which are the most threatened ones (Cabral et al., 2005). This should be done having in mind the factors that most seem to affect carnivore species, focusing especially on the human-related factors that are manageable, such as road (and motorway) density, areas used for agriculture and livestock production, and areas of high human presence or activity.

It would also be important to do a similar study for the archipelagos of Azores and Madeira, where updated and spatially detailed distribution maps on carnivore species should be produced and the drivers of their occurrence identified.

Some measures that could be taken to further help mitigate the issues of lack of presence data and lack of centralization and divulgation of that information include: i) Implementing projects, workshops and other well-organized initiatives to promote the production of citizen-based science, in order to collect presence records which would increase the amount of surveyed areas while guaranteeing an approach generating reliable records; ii) Creating a single online platform to gather all species occurrence records obtained in Environmental Impact Evaluation and Monitoring studies, as well as other sources; iii) Creating a dynamic database, with connection to the previously suggested platform, where presence records from several origins (and ideally also absence in surveyed areas) would be gathered, classified in terms of reliability (according to type and origin of the information), and mapped; iv) Assuring knowledge transfer and scientific advisement from researchers to decision-makers and the general public, in order to increase awareness for carnivores, identify research needs and achieve efficient and active procedures for carnivore conservation and management.

5.3 Implications beyond Portugal

The lack of comprehensive distribution data for Portugal was precluding the completion of mammal diversity assessments in the Iberian Peninsula, Western Europe, and the Mediterranean biodiversity hotspot. This study allows reducing that gap, contributing to increase the knowledge of global patterns of biodiversity. Thus, this assessment of carnivore mammal research trends and distributions in Portugal represents a model study that can be used to plan future similar investigations in countries with high biodiversity, but deficient available data and/or peripheral geographies, where scientific investment has been traditionally low. It would also be important to produce similar studies (with similar methodological approaches) including the entire carnivore community, allowing comparisons among areas and species. Moreover, the Portuguese carnivore community encompasses all families that are found in the Palearctic, from restricted to widespread ranges, which makes it a good model to study research trends and investigate the relative attention given to each carnivore species. The latter ultimately influences the body of knowledge available and the conservation status given to each species, which in turn determines the amount of conservation investment made at national and international level. Thus, the volume, resolution and geographical extent of the data gathered in this study provide valuable information for the future assessment, conservation and management of mammalian terrestrial carnivores in Portugal, but also globally.

In this study, non-systematic data was found to have great potential. In fact, when non-systematic presence records are compiled, they become a source of valuable information to allow the preliminary analysis of species distributions; identify knowledge gaps and they are considerably cheaper and normally easier to obtain than systematic data, which generally demands strong human and resource efforts.

Concerning the results from Species Distribution Modelling, human-related variables, such as road density, agricultural activity, livestock production and urbanization, were found to have important associations with species presence. The positive relationship with altitude found for many carnivore species is also probably an indirect result of the response of species to the intensity of human presence felt at lower altitudes. These factors are especially important taking into account the increasing humanisation of the planet, where humanised scenarios, such as Portugal, are increasingly expected (Cohen, 2003). Climatic variables are also important to keep in mind in view of the global climate change predictions (Walther et al., 2002) and the possible consequent species range shifts in the limits of the adequate or favourable environmental conditions, such as for stoat and pine marten (Schmitz et al., 2003; Thuiller, 2004).

5.4 Conclusions and Future Work

This study revealed Portugal as a good example of a highly humanized landscape, with a marginal position in continental Europe and in the Mediterranean biodiversity hotspot, which only recently has suffered a boost in scientific production. Therefore, this study may represent well the research trends of marginal countries. Moreover, Portugal was confirmed as having a remarkably high diversity of carnivore species from different biogeographic origins, but it lacks detailed information on distribution limits and abundance for most of them, which hinder adequate regional or global biodiversity assessments.

Our study revealed some important knowledge gaps, especially concerning carnivore species classified as Data Deficient and recent invasive species. Few species have been deeply studied, and studies on the most neglected species or focusing on poorly known research issues, such as disease and genetics, are urgent to allow managers to efficiently define species status, as well as management and conservation measures.

The present compilation of non-systematic species distribution data can be valuable as a baseline for a mammal distribution Atlas in Portugal. Moreover, it may prompt further initiatives (e.g. citizen-science based) to gather species occurrence data and allow the prioritisation of areas and species for future assessments. This approach based on non-systematic data also provides an opportunity to expand our knowledge regarding carnivore ecology and distribution at a regional scale, namely through the development of better species distribution models in order to assess potential areas of occurrence and related factors (biogeographic, environmental, topographic and anthropogenic).

In general, future studies targeting a more precise evaluation of carnivore distribution patterns should also focus on: i) obtaining more reliable records (e.g. through camera-trapping or genetic validation of presence signs; Monterroso et al., 2013b; Monterroso et al., 2013a), ii) sampling/surveying regions where there are less records (e.g NE Portugal, Algarve, Tejo river basin); and iii) assuring a wider compilation of historical records, considering both geographical range and time periods.

Based on this and previous studies, for each species, the following measures and studies should be done to serve as a basis for management and conservation:

- **Wolf**:
  - Prospect the areas in and around Serra da Estrela, where no confirmed current presence records have been obtained but the habitat conditions might be appropriate for this species presence, according to the model.
  - Develop more efforts to actually implement the measures predicted in the legislation, particularly the measures directed to mitigate human-wolf conflicts.
- **Fox**:
  - Increase survey effort in the centre and south of Portugal, to evaluate if the species truly has a lower presence in these areas.
- **Stoat**:
  - Survey the areas where historical records were obtained but where there are no current records, in order to try to understand if the species is still present in these areas or if it is going through a contraction and to know if it became extinct in order to assess distribution trends of the species in Portugal.
  - Also survey the area of Serra da Estrela where there are no confirmed presence records but, according to the respective model, there might be good habitat conditions for this species to occur.
  - Taking into account the reduced distribution range of this species in Portugal, try to preserve as best as possible the preferential habitats of the species, including meadows and riparian areas.
- **Weasel**:
  - Conduct a national survey, using methodologies that provide reliable records, to have an updated and more complete view of the current distribution and

abundance of the species. This will help understand if the species is still truly of Least Concern or if it's conservation status needs to be updated, due to a reduction in population size or range.

- **Polecat**:
  - Conduct a national survey, using methodologies that provide reliable records, to have an updated and more complete view of the current distribution and abundance and/or population size of the species. This can give enough information to know the actual conservation status of the species in Portugal.
  - A study on the impact of hybridization between the polecat and it's domestic form, the ferret (Lynch, 1995), should be conducted in Portugal in order to know if prevention measures, such as control of ferret populations and ferret releases, need to be taken.
- **American Mink**:
  - For this invasive species, regular surveys should be done along the outer limits of its distribution to monitor further expansions.
  - Develop a plan for eradication and control of the American Mink to prevent further expansion due to its strong negative impacts on native wildlife, and evaluate if high otter densities can be acting as a delaying factor (Rodrigues et al., 2015).
- **Stone Marten**:
  - A larger sampling effort should be conducted, particularly in the south of Tagus river and North of the Douro river, in order to confirm the actual presence areas.
- **Pine Marten**:
  - Conduct surveys using methodologies that provide reliable records focusing on the entire area where unconfirmed records were previously obtained mainly via inquiries, in order to assess more precisely the southern distribution limit of the Pine Marten in Portugal. Due to the tendency to confuse this species with the Stone Marten, this survey should be done using the more reliable sources of information and methodologies available such as camera-trapping or genetic validation of presence signs.

- Taking into account the restricted habitats where this species seems to occur in Portugal (e.g. mature native forests), measures should be taken to improve this species habitat quality, for example, through the renewal of autochtonous forests and a better management of existing ones.

- **Badger**:
  - A national survey is also needed to better understand the distribution of the badger and try to confirm if the south is truly a preferential area for this species occurrence and if there are discontinuities in its distribution at country-level.
- **Otter**:
  - Future surveys should focus on the areas where the otter range seems to be decreasing, such as the Estremadura region, the coastal area south of Porto and the southern coast of Algarve, in order to evaluate if this trend for range contraction is continuing and if conservation measures need to be taken.
- **Genet**:
  - Future surveys should systematically assess the presence of genets throughout the country and clarify the coverage and density of its occurrence in Portugal.
- **Egyptian Mongoose**:
  - The impacts of the expansion and population growth of this carnivore on other species should be analysed, since it might pose a threat, endangering the balance of the ecosystem by driving away other predators by competition or depleting prey populations, such as the wild rabbit, which are essential for the survival of many carnivores. If these effects are found to be an existing problem, control measures might need to be taken to control populations at high densities.
- **Wildcat**:
  - A national survey should be conducted, focusing particularly on the areas where historical records were obtained in order to confirm if the species range has actually regressed, being now mainly in the Northern and Eastern areas of the country. This survey should be done using, in particular, genetic tools, due to the tendency to misidentify this species using other methodologies.

  - Regarding the impact of hybridization with domestic cats, several measures could be taken: i) create awareness campaigns to inform the general public about the wildcat and the problem of feral cats for the conservation of this species; ii) control feral cats' populations with campaigns to sterilize and/or exterminate these animals.
- **Iberian Lynx**:
  - Keep implementing the measures proposed in the international and Portuguese Actions Plans for the conservation of the Iberian Lynx, which include: actions to recover the habitat and the main prey species (wild European rabbit); the reinforcement of legal protection; reintroduction and monitoring of the species; environmental education campaigns.
- **Bear**:
  - Create awareness of the historical and potential future presence of the brown bear in Portugal, through environmental awareness campaigns directed particularly at the populations that live in areas where the probability for bear occurrence will be higher, such in the North-eastern corner of the country.
- **Raccoon**:
  - This invasive species should also be urgently focused in monitoring studies, to understand the extent and trend of this species' occurrence in Portugal (e.g. sporadic vs. reproductive). Specifically, this survey should start in the areas where the species has been firstly reported.
  - Having in consideration the distance from the Spanish populations, which suggests that individuals found in Portugal are the result of released or escaped animals, special attention should be given to the potential sources of these animals such as pet-shops of exotic species and airports, where illegally imported animals might be introduced in Portugal.

Regarding management and conservation measures that should be taken for all carnivore species in Portugal, these include:

- Making use of the current trend for rural exodus and rewilding, combined with the reintroduction of large herbivores in the areas where this is occurring to: maintain a mosaic landscape (decreasing habitat fragmentation and increasing habitat diversification), provide wild prey for large carnivores (e.g. wolf and bear) and to maintain large, open and low vegetation areas which are beneficial for several mesocarnivores for shelter and feeding purposes, while reducing human presence.

- Recovering other important wild prey populations, such as the wild European rabbit, that are crucial for the survival of several carnivore species, such as the Iberian Lynx, polecat, wildcat, and others.
- Monitoring more frequently the practice of illegal hunting, especially for species that tend to be of more conservation interest (e.g. wolf, stoat, wildcat).
- Applying more measures to reduce road impact along the extensive road network that exists in Portugal, such as fencing and the construction of crossing structures adequate to minimize fragmentation for the local fauna.
- Develop awareness campaigns among the general public, including decision makers, people who co-exist with carnivores regularly and children. These campaigns, along with a continuous effort for collaboration, should be particularly directed to the main stakeholders concerning carnivore occurrence and human-carnivore conflict, including hunters and farmers.

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Appendix A

Predictor Variables

Table A.1 – Pairs of variables with high correlations (correlation coefficient above 0.8) according to the Pearson correlation analysis of the variables are presented on Table A.1

Variable 1	Variable 2	Correlation coefficient
DFro	Alti	0.831382
TJan	Alti	-0.85275
Temp	DFro	-0.81474
TJan	DFro	-0.83191
Inso	DPre	-0.82617
Prec	DPre	0.819769
HRan	HJul	-0.96586
PET	Inso	0.80954
SMG	Inso	0.812937
SAgr	Inso	0.837817
Tjul	PET	0.837539
TJan	Temp	0.840064
SAgr	SMG	0.979429

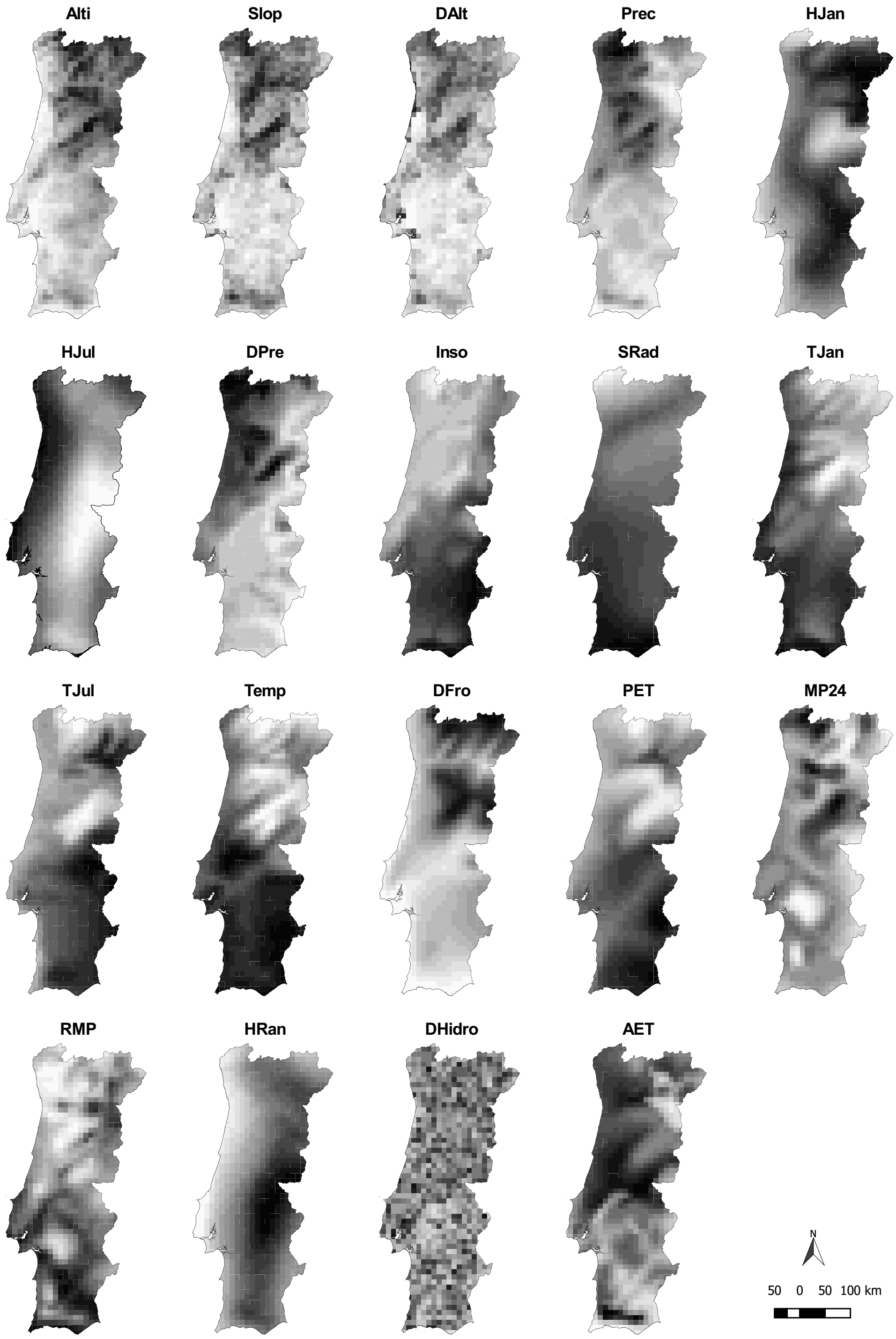

Fig. A.1 – Graphic representation of each of the environmental variables recorded to be used for modelling the species distribution. Alti, Mean altitude; Slop, Mean slope; DAlt, Altitude range; Prec, Mean annual precipitation; HJan, Mean relative air humidity in January at 07:00h; HJul, Mean relative air humidity in July at 07:00h; DPre, Mean annual number of days with precipitation ≥ 00.1mm; Inso, Mean annual insolation; SRad, Mean annual solar radiation; TJan, Mean temperature in January; Tjul, Mean temperature in July; Temp, Mean annual temperature; DFro, Mean annual number of frost days (minimum temperature ≤ 0 °C); PET, Mean annual potential evapotranspiration; MP24, Maximum precipitation in 24 h; RMP, Relative maximum precipitation; HRan, Annual relative air humidity range; DHidro, Mean distance to fresh water sources; AET, Mean annual actual evapotranspiration

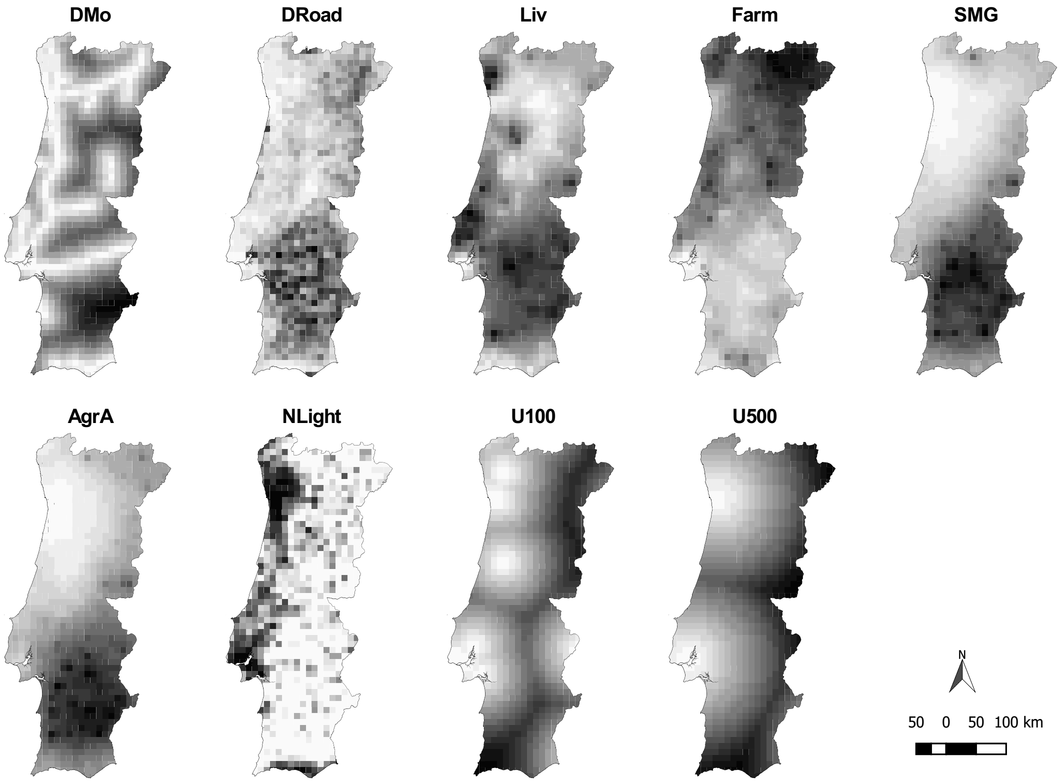

Fig. A.2 – Graphic representation of each of the human-related variables recorded to be used for modelling the species distribution. DMo, Distance to the nearest motorway; DRoad, Mean distance to roads; Liv, Livestock; Farm, Farms; SMG, Surface of permanent meadows and grassland; AgrA, Agricultural area; NLight, Intensity of Night Lights (Calibrated Radiance); U100, Distance to the nearest town with more than 100,000 inhabitants; U500, Distance to the nearest town with more than 500,000 inhabitants

Appendix B

Variables selected for each species

Table B.1 – Variables selected for each species, respective coefficients and degrees of freedom (df) the measure AIC.

(a) *Canis lupus*

Variable	Coefficient	df	AIC
Alti	0.011	860	136.3
SRad	-0.117		
HJul	0.362		
Farm	0.007		
NLight	-0.013		
Liv	-0.002		
DAlt	-0.003		
DRoad	0.369		
Intercept	21.462		

(b) *Vulpes vulpes*

Variable	Coefficient	df	AIC
Alti	0.001	874	982.9
Liv	0.000		
HJul	-0.028		
Intercept	2.313		

(c) *Mustela erminea*

Variable	Coefficient	df	AIC
Alti	0.004	992	80.96
Inso	-0.007		
Intercept	9.700		

(d) Mustela nivalis

Variable	Coefficient	df	AIC
Alti	0.002	966	315.9
RMP	-7.452		
Intercept	-2.481		

(e) *Mustela putorius*

Variable	Coefficient	df	AIC
SRad	-0.013	956	299
MP24	0.008		
Intercept	1.557		

(f) Neovison vison

Variable	Coefficient	df	AIC
SRad	-0.073	980	89.98
U500	-0.068		
Farm	0.009		
Intercept	21.993		

Table B.2 – Variables selected for each species, respective coefficients and degrees of freedom (df) the measure AIC.

(a) *Martes foina*

Variable	Coefficient	df	AIC
HJul	-0.057	947	586.5
Slop	0.231		
DMo	0.018		
RMP	-5.321		
Intercept	1.424		

(b) Martes martes

Variable	Coefficient	df	AIC
Prec	0.005	909	39.03
Farm	0.013		
Intercept	-30.187		

(c) *Meles meles*

Variable	Coefficient	df	AIC
SAgr	0.000	995	856.3
SRad	0.012		
Intercept	-8.027		

(d) Lutra lutra

Variable	Coefficient	df	AIC
HRan	0.087	979	514.7
DRoad	0.327		
Slop	0.216		
RMP	-7.505		
Intercept	0.720		

(e) *Genetta genetta*

Variable	Coefficient	df	AIC
DPre	0.017	960	779.2
Intercept	-3.440		

(f) Herpestes ichneumon

Variable	Coefficient	df	AIC
SRad	0.109	719	290.4
U500	0.038		
Farm	-0.004		
PET	-0.015		
Temp	0.488		
DRoad	0.247		
MP24	0.013		
Intercept	-44.871		

(g) *Felis silvestris*

Variable	Coefficient	df	AIC
SRad	-0.029	898	379.3
SMG	0.000		
Alti	0.001		
AET	-0.005		
DAlt	0.002		
U500	0.010		
Intercept	9.499		

(h) Lynx pardinus

Variable	Coefficient	df	AIC
Inso	0.009	1003	56.47
Intercept	-31.372		

Appendix C

Models produced for each species

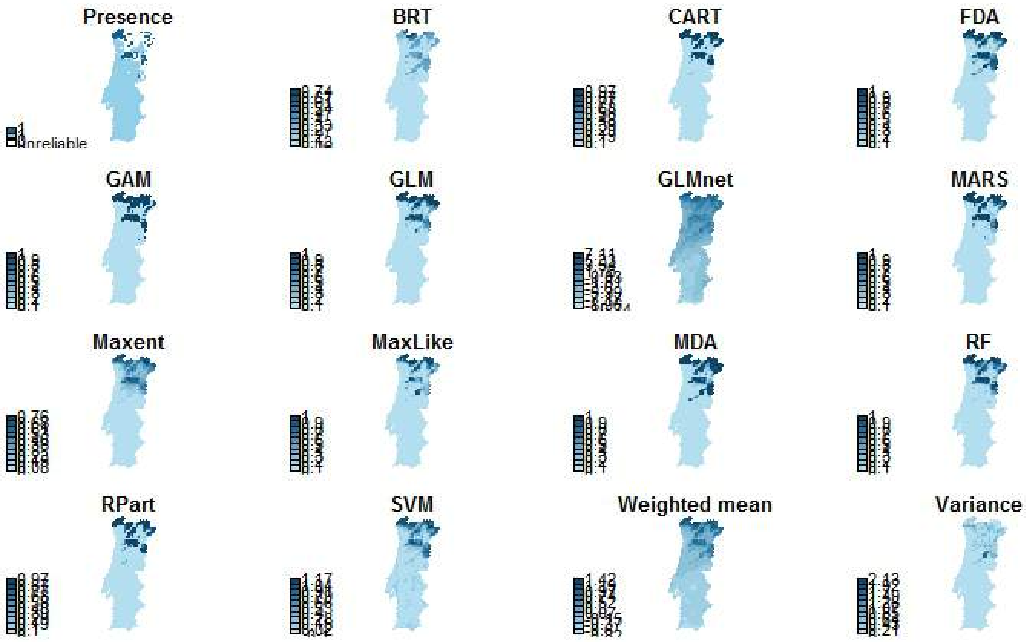

Fig. C.1 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the grey wolf

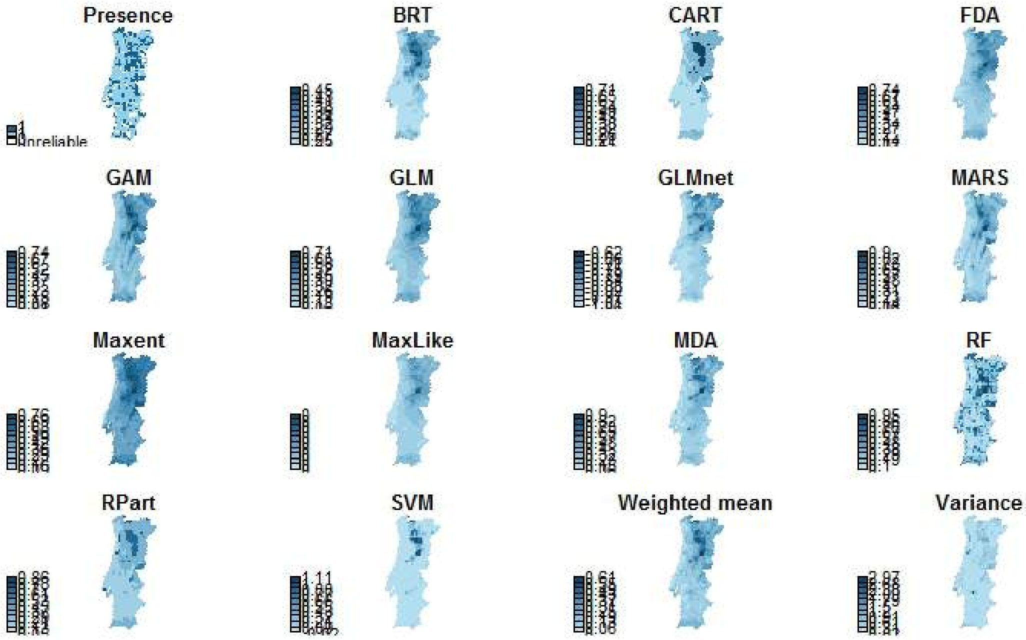

Fig. C.2 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the red fox

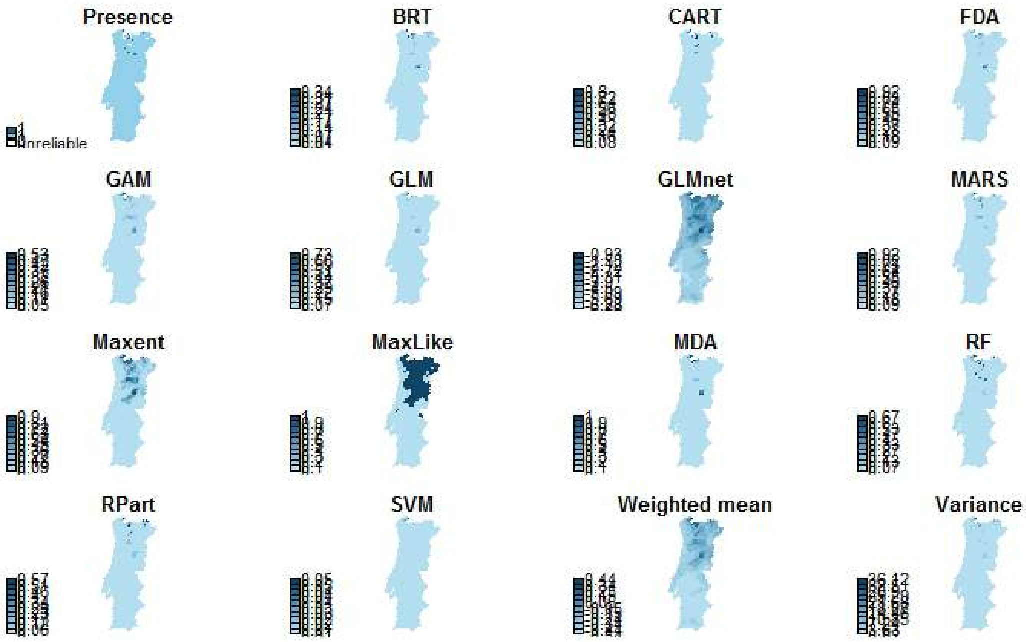

Fig. C.3 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the stoat

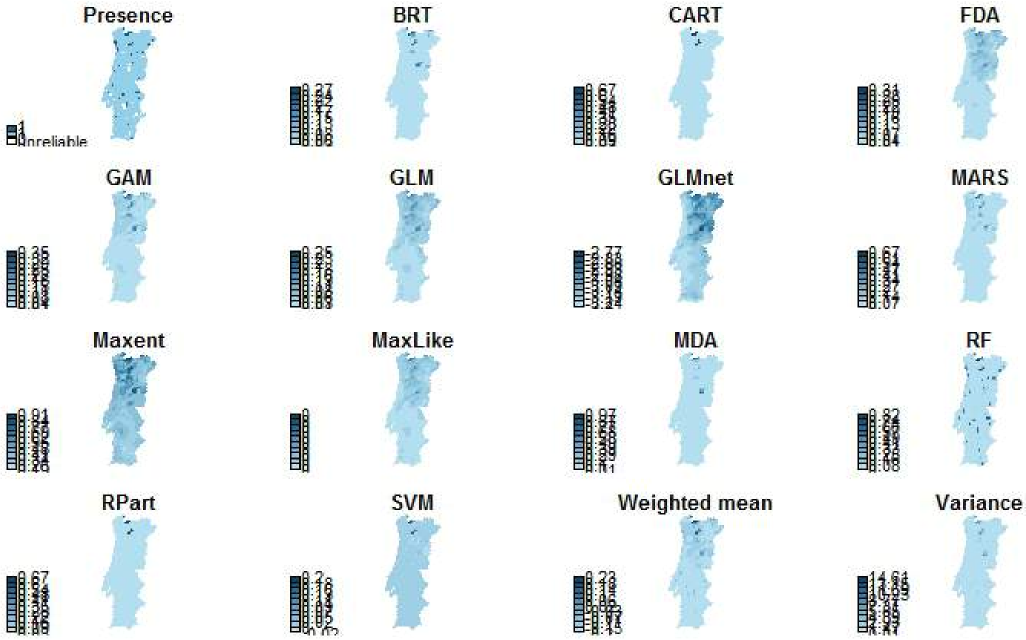

Fig. C.4 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the least weasel

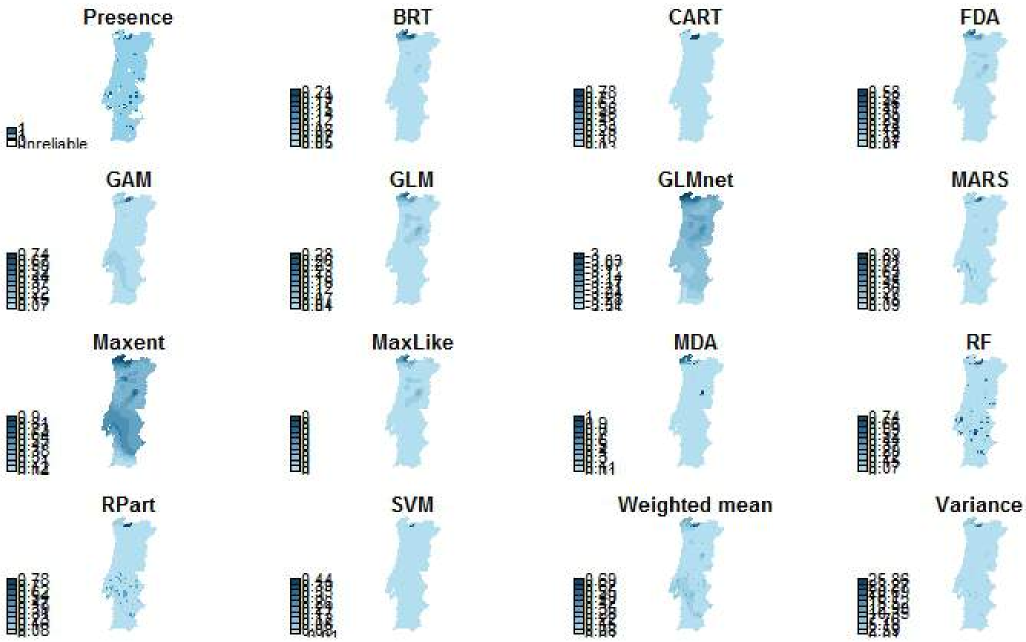

Fig. C.5 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the polecat

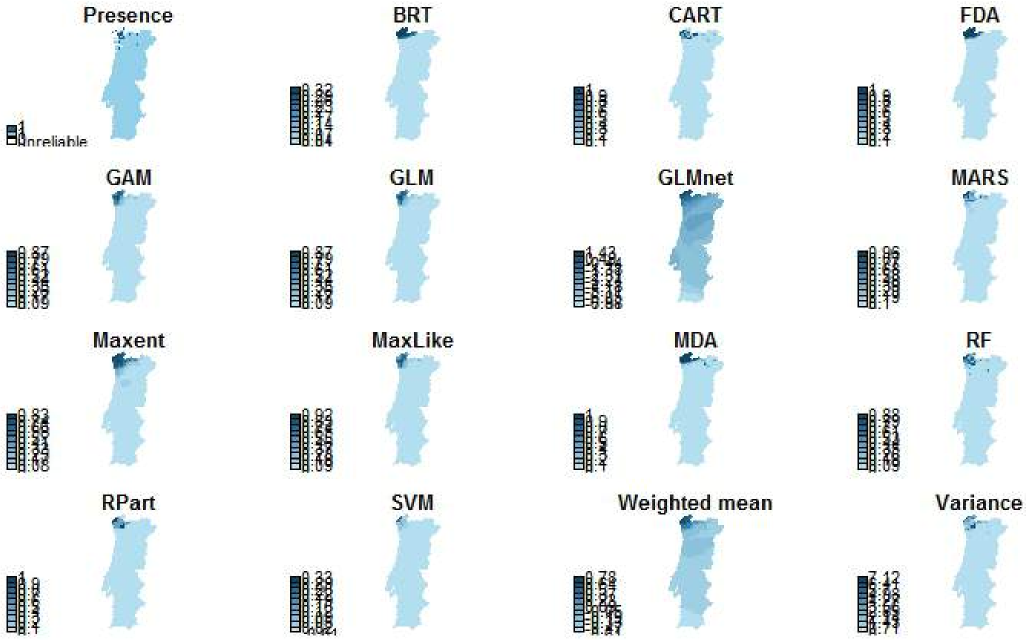

Fig. C.6 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the American mink

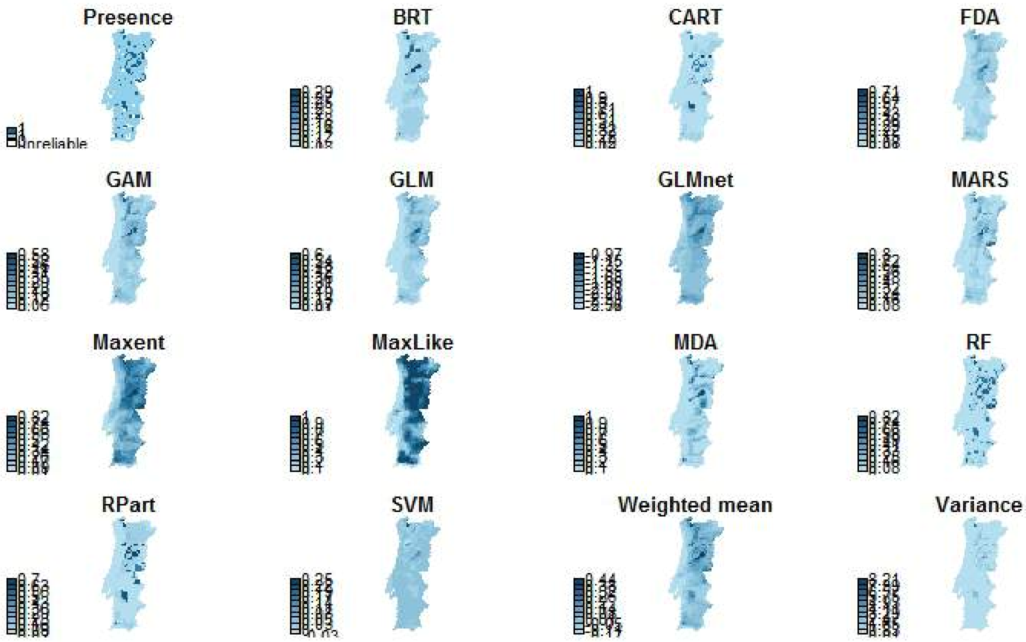

Fig. C.7 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the stone marten

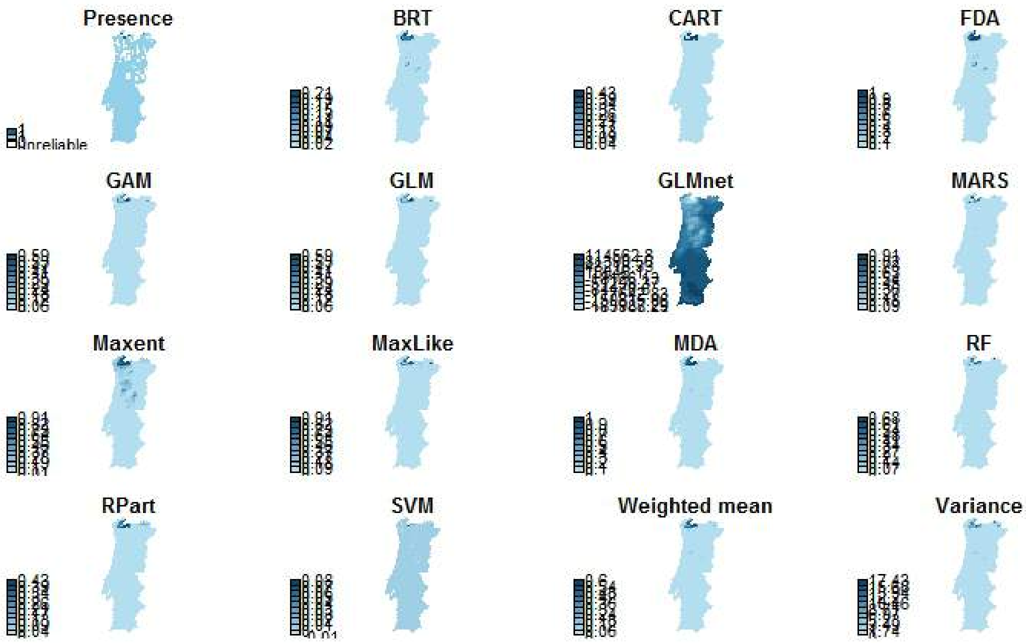

Fig. C.8 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the pine marten

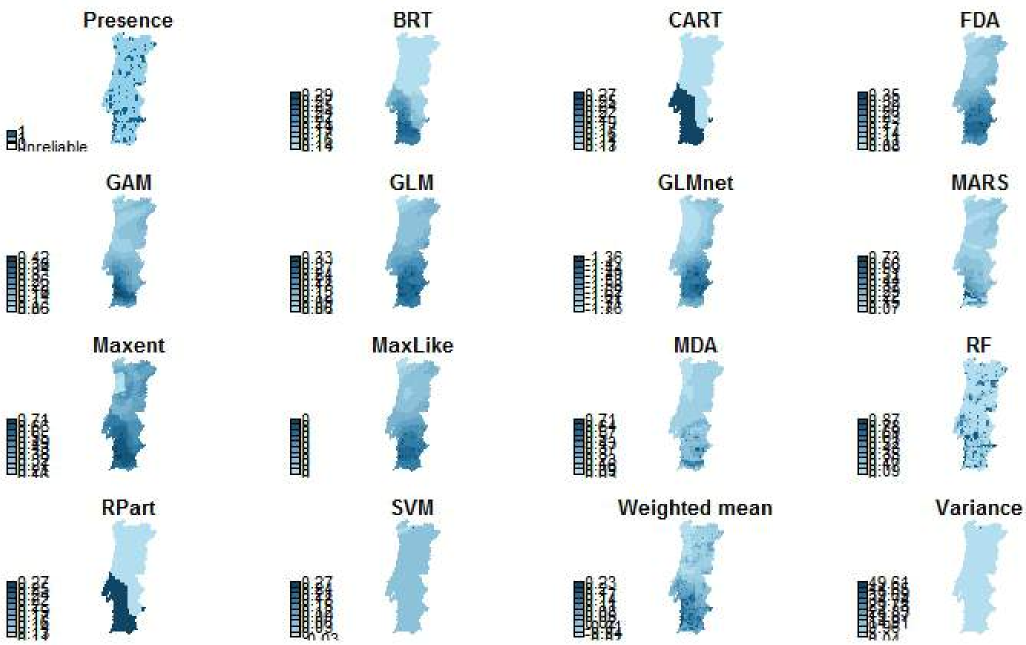

Fig. C.9 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the European badger

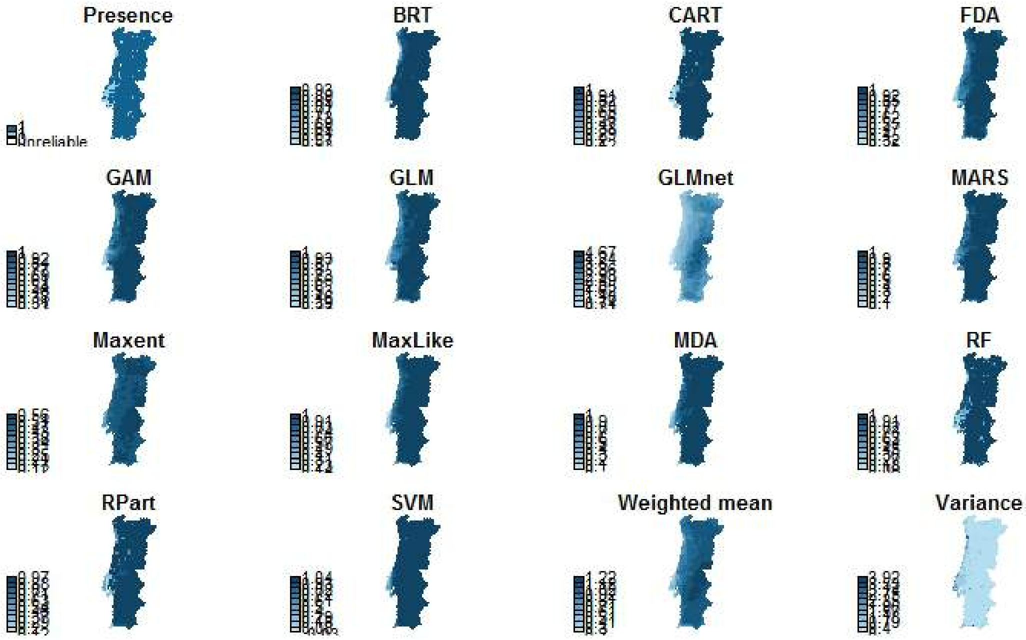

Fig. C.10 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the Eurasian otter

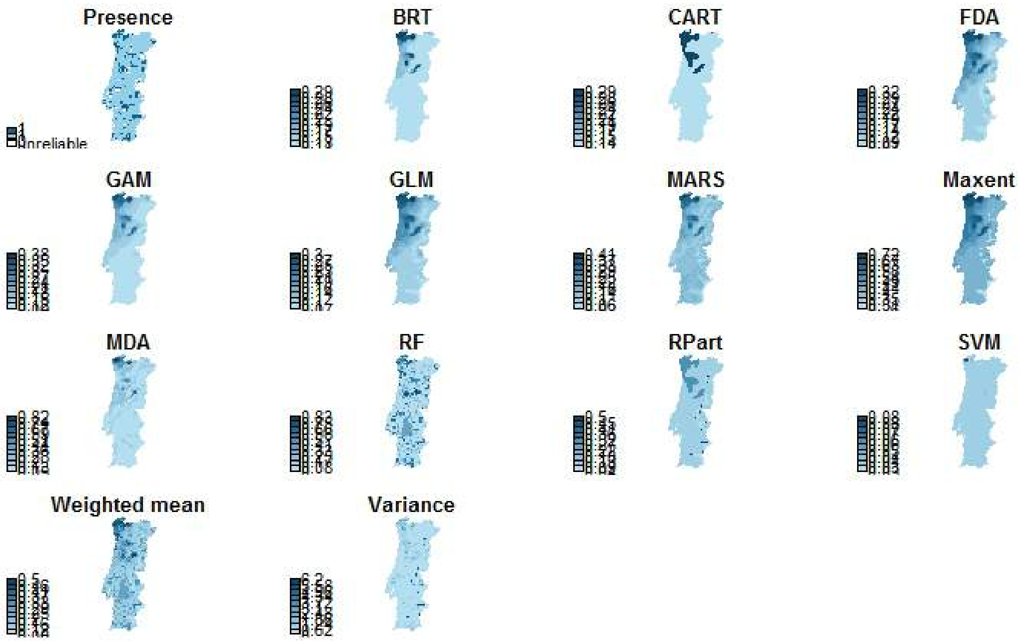

Fig. C.11 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the common genet

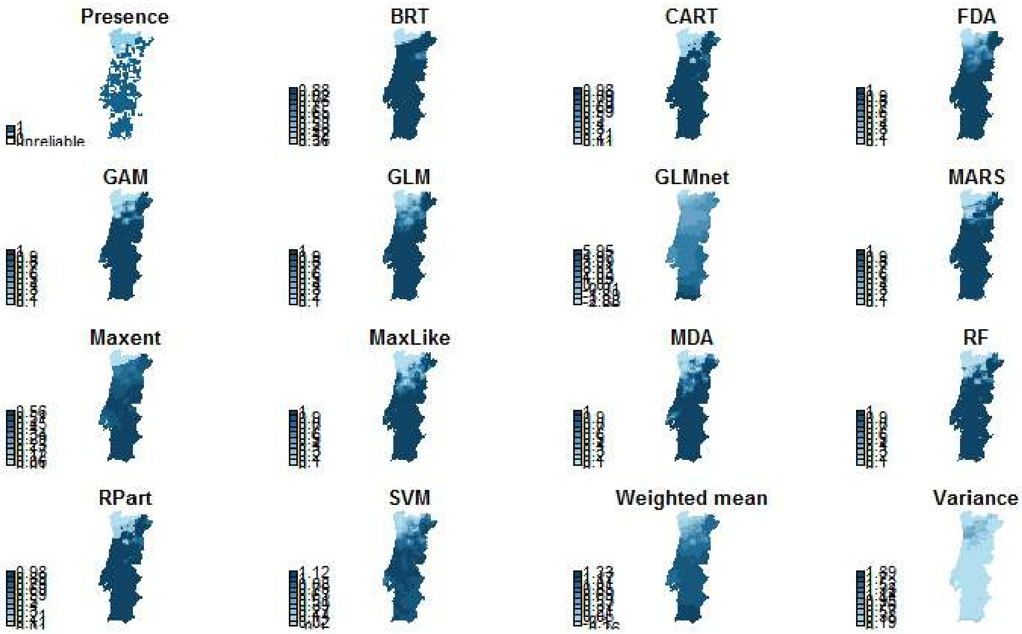

Fig. C.12 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the Egyptian mongoose

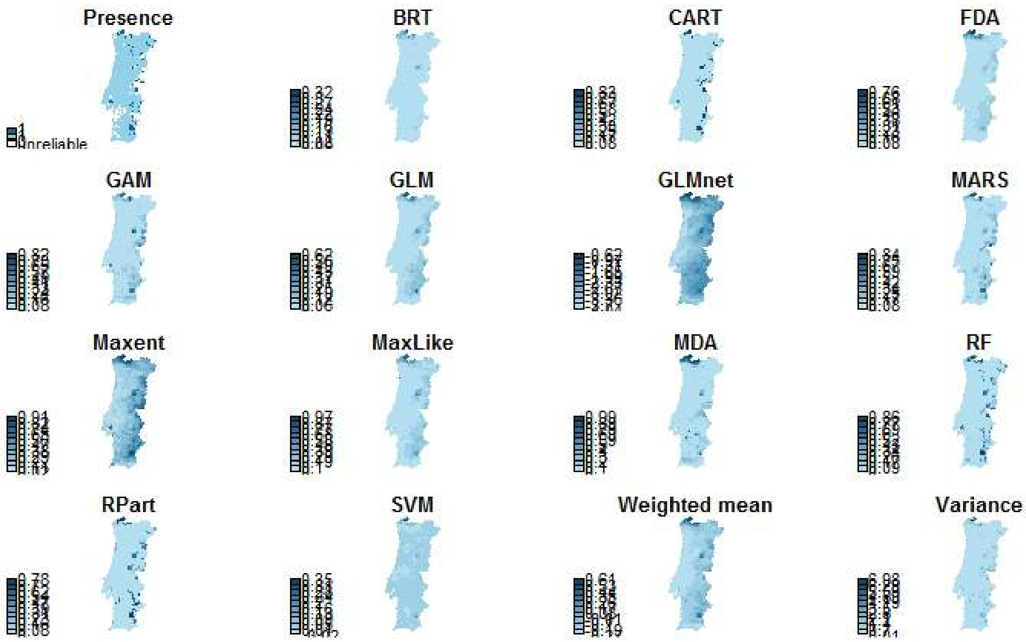

Fig. C.13 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the wildcat

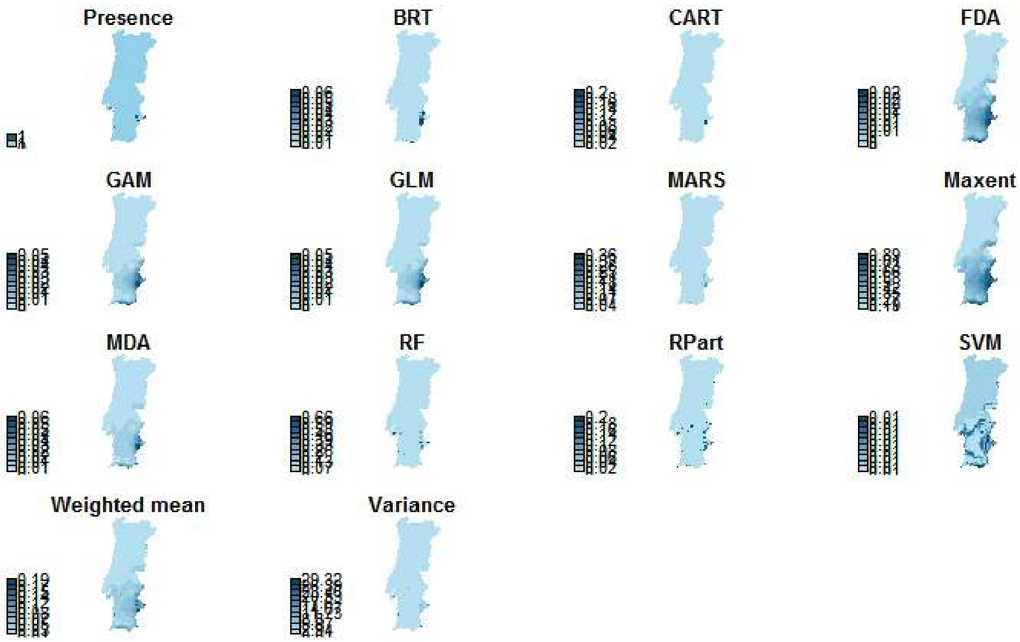

Fig. C.14 – Distribution of the presences, absences and unreliable cells, maps produced from each modelling algorithm and ensemble model (weighted average and variance) for the Iberian lynx