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Mammals in the Collection of the National Museum of Natural History and Science (University of Lisbon, Portugal): A Contribution to Research and Conservation

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Abstract: Museum collections serve as valuable repositories of biodiversity, offering a substantial amount of data and specimens for scientific research. This study describes the intrinsic value of the mammal collection at the National Museum of Natural History and Science of the University of Lisbon (Portugal) (MUHNAC), and its nationwide representativeness, with the final aim of revealing its potential to support research and conservation initiatives. The collection includes 6158 specimens, from 131 species, across 10 orders, the great majority collected within Portugal, although a small dataset mostly from other parts of Europe and Africa is also available. The most represented orders are Rodentia, Eulipotyphla, and Carnivora, in contrast to Chiroptera, Cetacea, and Artiodactyla. Approximately 40% of the species within these groups are of conservation concern according to both national and international conventions, with nearly 20% at risk of extinction based on IUCN criteria. Additionally, the representativity of species in MUHNAC reflects the museum's coverage of species records across the country, with smaller, non-threatened species being more prominently represented and larger, at-risk species being comparatively underrepresented. The influence of conservation, economic, legal, and ethical factors on the species spatial coverage is discussed, providing insights into the variability observed in museum collections.

Keywords: scientific collections; natural history museums; biodiversity intrinsic value; conservation

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1. Introduction

In recent decades, biodiversity has declined at an alarming rate, primarily due to human activities, leading to habitat destruction and accelerated climate change [1]. Currently, over 42,000 species out of the 150,300 assessed on the International Union for Conservation of Nature (IUCN) Red List face the threat of extinction. These figures reveal alarming trends for vertebrate species, with 41% of amphibians, 13% of birds, and 27% of mammals classified as threatened (IUCN Red List of Threatened Species, https://www.iucnredlist.org/) (accessed 1 October 2024).

Natural history museum collections are key resources for supporting biodiversity and nature conservation-related research [2,3]. A total of around 3000 million biological specimens of both living and extinct species are estimated to be housed nowadays in museums, providing a wealth of information about the Earth's biodiversity [4,5]. These repositories provide access to extensive natural history data, including detailed records of species distributions, morphological and phenological variations, and ecological interactions [3,4]. This amount of detailed information offers opportunities to explore a wide range of research questions, across both spatial and temporal dimensions, enabling a comprehensive understanding of the past and the prediction of future scenarios. Furthermore, in addition to traditional studies, the use of modern molecular techniques on preserved specimens can reveal temporal genetic variations, aiding in the understanding of biodiversity loss and providing a foundation for conservation initiatives [6,7].

In addition to the significant contributions that natural history collections can make to interdisciplinary studies in fields such as biogeography, evolution, and parasitology, it is widely recognized that museums hold great potential for collaborating on new and emerging research challenges, namely related to climate change or pandemic outbreaks [8–12].

In this paper, our aim is to uncover the intrinsic biological value for research and conservation of the mammal collection housed at the Portuguese National Museum of Natural History and Science (MUHNAC). The museum traces its origins back to 1768, with collections contributed by the Royal Museum of Natural History and the Botanical Garden of Ajuda, and became part of the University of Lisbon in 1911. At that time, the Museum held specimens collected since the 18th century, from several geographic locations, across different countries [13,14]. However, a devastating fire in 1978 destroyed most of the existing collection, which had been steadily growing over the years, and today, the collection primarily includes recently acquired specimens' representatives of species occurring in Portugal, although covering a vast amount of information reflecting the natural value of the Portuguese mammal fauna [15].

Like other countries in the Mediterranean basin, Portugal represents an outstanding hotspot of biological diversity, characterized by a rich fauna and flora associated with a wide variety of ecosystems, habitats, and landscapes [16,17]. This richness also extends to the Portuguese archipelagos of Madeira and Azores (e.g., [18]). By highlighting and promoting the importance of the MUHNAC mammal collection for research and conservation planning, we are also considering the country's commitments under various international and regional frameworks, such as the 2030 Agenda for Sustainable Development, the Strategic Plan of the Convention on Biological Diversity, and the European Union Strategy for Biodiversity. In line with these commitments, the museum is included in the European consortium DiSSCo (Distributed System of Scientific Collections), through the research infrastructure PRISC—Portuguese Research Infrastructure for Scientific Collections—aiming to aggregate, harmonize, and make available biodiversity data by providing open and universal access to scientific collections.

In this context, in addition to contributing to the understanding and conservation of the country's natural heritage, this study also aims to assess the nationwide representativeness of the collection, identify gaps, and suggest potential strategies to enhance its value. Thus, we seek to raise awareness among researchers, academics, research institutions, and the general public about the critical importance of sustained support for our National Museum, as a key infrastructure for mammalogy research, thereby ensuring the long-term preservation of biological diversity.

2. Materials and Methods

2.1. The Mammal Collection

The mammal collection of the National Museum of Natural History and Science (MUHNAC) consists of skins, skeletons and skulls, mounted specimens, and animals preserved in fluid. Some specimens are also represented by post-cranial material. The collection data are fully computerized and can be made available upon request (www.museus.ulisboa.pt (accessed 1 October 2024)).

All specimens in the collection are labeled. Each specimen is identified by a catalogue number, sex, locality, and date of collection. For most specimens, information on the collector's name is also available (see Figure 1).

Figure 1. Illustrations of selected species showcasing different types of preserved material in the collection (skins, skulls, mounted specimens for exhibitions). (**A**)— Skins of the Iberian wolf, *Canis lupus*; (**B**)—a mounted red squirrel, *Sciurus vulgaris*; (**C**)—skulls of a large marine mammal, the Common dolphin, *Delphinus delphis*; and (**D**)—skins and skulls of a small rodent, the Mediterranean pine vole, *Microtus duodecimcostatus*.

The collection spans over a century, from 1924 to 2024; however, most specimens were collected in the past 50 years, especially in the decades following the devastating 1978 fire. Approximately 80% of the collection dates from 1978 to 2008, reflecting the museum's substantial efforts to rebuild and expand the collection after its near-total loss. Only around 10% of the collection comprises older holdings. Recent specimens have been acquired from various sources, including donations from other museums and conservation organizations, though the majority were contributed by mammalian researchers and academics through their research activities. It is worth noting that the collection includes several dozen specimens of domestic and domesticated mammals. While not described in detail in this paper, these specimens are also available for request and study.

The taxonomic classification of the collection follows the nomenclature used by Wilson and Mittermeier's *Handbook of the Mammals of the World* [19] (see also [20]). Additionally, the species list has been updated to include information from recent taxonomic revisions focused on selected species [21,22] (and references therein).

The species common names align with those in the IUCN Mammal Red List of Threatened Species, with contributions from [22,23]. The taxa are presented in alphabetical order, organized by the hierarchy of orders. Within each order, families are listed from the most to the least represented.

2.2. The Intrinsic Natural Value of the Collection

For assessing the intrinsic value of the collection and its representativeness in the country's mammalian fauna, the following criteria and sub-criteria were defined:

2.2.1. International Criteria

(i) Species inclusion in the IUCN Threatened Categories in the IUCN Mammal Red List (Critically Endangered, CR; Endangered, EN; Vulnerable, VU; Near Threatened, NT; and Data-Deficient, DD) (IUCN 2022), designated to identify those at greatest risk of extinction;
(ii) Species inclusion in the B Annexes of the Habitats Directive (B-II species of community interest whose conservation requires the designation of special areas of conservation; B-IV species of community interest in need of strict protection; B-V species whose taking in the wild and exploitation may be subject to management measures) (Council Directive 92/43/EEC);
(iii) Species inclusion in Annexes II and III of the Bern Convention (II strictly protected species; III protected species) (Council Decision 82/72/EEC);
(iv) Species inclusion in Annexes I and II of the Washington Convention (CITES—Convention on International Trade in in Endangered Species of Wild Fauna and Flora) (A-I species most endangered, trade subjected to strict regulation; A-II species not necessarily threatened, trade subjected to strict regulation) (Council Regulation EC 338/97);
(v) Species endemic of the Iberian Peninsula.

2.2.2. National Criteria

(i) Species inclusion in the IUCN Threatened Categories in the Portuguese Mammal Red Books (island species [24]; mainland species [22]);
(ii) New species documented in the country over the past 20 years [22];
(iii) Species with restricted distribution in the country (terrestrial species—less than 5% of the country territory: UTM 10x10km squares occupied/total UTM 10 × 10 km squares in the country (1000) [22]; marine mammals, island mammals [22,24];
(iv) Species population trend: Increasing (I) Stable (S), Declining (D), Unknown (NK) [22,24].

2.2.3. Representativity of the Collection

This approach involved only terrestrial mammals in mainland Portugal. Marine mammals, island mammals, and a few terrestrial species were not considered due to either (i) reduced datasets or (ii) unknown or imprecise range limits in the country.

A first step involved fully georeferencing the analyzed terrestrial species localities (i.e., collecting sites), using the free online geocoding service from Geoapify (https://www.geoapify.com/tools/geocoding-online/ (accessed on 1 October 2024) to determine location coordinates. Subsequently, the collected data underwent processing to evaluate the national representativeness of the collection.

2.2.4. Species Presence in the Country

The distribution of each species in the country was assessed by the number of UTM squares (10 × 10 km) with species presence, against the total UTM squares that can potentially be occupied, i.e., a percent of a total of 1000 UTM in the entire country, following the most up-to-date source of the species occurrence in Portugal [22]. This approach also allowed us to identify the species with restricted distribution in the country, as mentioned earlier.

To assess how well museum samples cover the known distribution area of each species, we created a buffer around each museum geographic data point (i.e., locality coordinates) and calculated the percentage of UTM squares where the species is present and whose centroid intersects with the buffer. This analysis was conducted using a buffer size of 7.5 km, corresponding to approximately half of the diagonal of a 10 × 10 km UTM square, so that calculated buffers always touch at least one centroid of a UTM square. We then calculated the weighted average, by species distribution area, for each taxonomic order, national threat category, and body size. For the body size definition, we followed the criteria adopted by IUCN Species Specialists Groups: small mammals (less than 2 kg), medium-sized mammals (2 to 30 kg), and large-sized mammals (over 30 kg).

2.2.5. Species Representativity in the Collection

To assess whether a species was over or underrepresented in the museum collection, we compared the number of museum records to the species occurrence, measured by the number of squares where the species is present in the country, as mentioned above.

First, we summed the distribution area of all mammal species in the country (even if not included in the collection), and then calculated for each species in the collection the percentage of squares occupied relative to the total summed area. We repeated this calculation considering the total number of records instead of the total distribution. Next, we determined, for each species, how much the percentage of contribution to the museum collection deviated from the percentage of contribution to the overall distribution area. The deviation formula is thus:

$$D = \frac{Sr_j}{\sum_{i=1}^{s} Sr_i} \Big/ \frac{Sa_j}{\sum_{i=1}^{s} Sa_i}$$

where Sr_j is the number of records of species j and Sa_j is the number of UTM squares where the species occurs.

If D equals 1 for a species, it indicates that the proportion of records in the collection for that species equals the proportion of its distribution area relative to the total distribution area of all species. If D is greater than 1, it means the proportion of records is higher than the proportion of its distribution area, while if D is less than 1, the proportion of records is lower.

When a species' records represented a higher percentage of the museum collection than its distribution area, it was considered overrepresented in the collection, and vice-versa.

We also performed a second version of this analysis grouping the species by taxonomic order instead of considering the total individual collection records.

3. Results

3.1. The Mammal Collection

The museum houses a total of 131 species from 10 orders and 29 families, represented by 6163 specimens. Of these, only a small portion (less than 10%) has been collected from countries other than Portugal, highlighting the value of the collection as a repository of the country's biodiversity. The most represented orders in the collection, considering record numbers, are Rodentia, Carnivora, and Eulipotyphla, which together comprise more than

80% of the total specimens, while the remaining orders are relatively less represented (Table 1 and Supplementary Material S1).

Table 1. Number of specimens per taxonomic group from Portugal, other European countries, and non-European countries in the MUHNAC collection with the corresponding number of species (in brackets).

Order	Number Specimens (Number Species)			
	Portugal	**Europe**	**Elsewhere**	**TOTAL**
Eulipotyphla	769 (9)	87 (12)	14 (6)	870 (19)
Chiroptera	220 (21)	6 (2)	1 (1)	227 (21)
Lagomorpha	54 (2)	-	-	54 (2)
Rodentia	3689 (15)	256 (23)	59 (18)	4004 (39)
Cetacea	80 (14)	1 (1)	5 (4)	86 (16)
Carnivora	883 (15)	5 (4)	8 (8)	896 (22)
Artiodactyla	15 (4)	-	8 (5)	23 (9)
Monotremata	-	-	1 (1)	1 (1)
Didelphimorphia	-	-	1 (1)	1 (1)
Macroscelidea	-	-	1 (1)	1 (1)
Total specimens per location	5710 (80)	355 (42)	98 (45)	6163 (131)

Regarding national coverage, the collection includes a total of 5710 specimens from all seven recognized orders in the country—Eulipotyphla, Chiroptera, Lagomorpha, Rodentia, Cetacea, Carnivora, and Artiodactyla—encompassing 25 out of 28 families and 70% of the currently documented species (80 out of 113 species) [22,24]. Eulipotyphlan, rodent, and lagomorph species are fully represented, but in contrast, cetaceans are the least represented group, with only about half of the known species included (14 out of 31 species) (Figures 2 and 3; Supplementary Material S1). Most of the missing species are recent or occasional occurrences, known from only a single or a few locations (e.g., [22]).

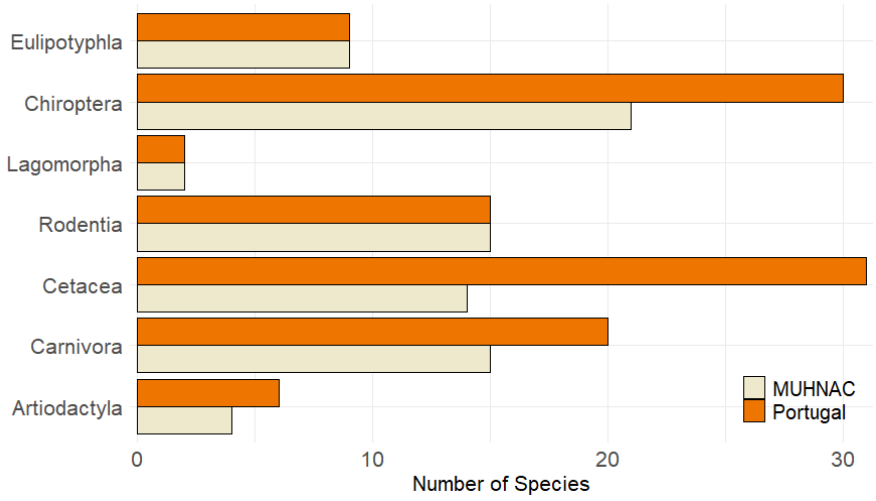

Figure 2. Number of species from Portugal occurring in the MUHNAC mammal collection.

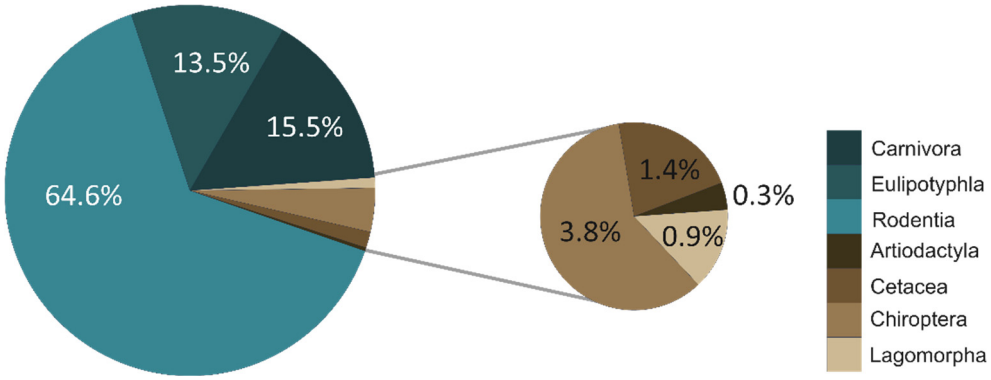

Figure 3. Percentage of specimens collected in Portugal within the museum's collection, organized by taxonomic order.

Small mammals, including eulipotyphlans and rodents, make up the largest samples in the museum collection, with a substantial number of specimens across multiple species. In contrast, lagomorphs and artiodactyls hold fewer specimens, which aligns with them being the orders with the lowest number of species (Figure 3, Table 2). Additionally, although bats and cetaceans are represented in the collection by approximately 70% and 50% of the species documented in the country, respectively, they have relatively few recorded specimens.

Table 2. Value of mammal species in the MUHNAC collection following international criteria (only species classified into at least one of the five sub-criteria analyzed are listed). CR—Critically Endangered, EN—Endangered, VU—Vulnerable, NT—Near Threatened, DD—Data-Deficient; other abbreviations as referred to in the main text.

SPECIES	IUCN Red List	Habitat Directive	Bern Convention	CITES Convention	Iberian Endemism
EULIPOTYPHLA					
Erinaceus europaeus			III		
Crocidura fingui	DD		III		
Crocidura russula			III		
Crocidura suaveolens			III		
Galemys pyrenaicus	EN	B-II, B-IV	II		
Neomys anomalus *			III		x
Sorex minutus			III		
Sorex granaries			III		x
Suncus etruscus			III		
Talpa occidentalis					x
CHIROPTERA					
Eptesicus serotinus		B-IV	II		
Miniopterus schreibersi	VU	B-II, B-IV	II		
Myotis bechsteini	VU	B-II, B-IV	II		
Myotis blythii		B-II, B-IV	II		
Myotis daubentonii		B-IV	II		
Myotis escalerai	NT	B-IV	II		

Table 2. *Cont.*

SPECIES	IUCN Red List	Habitat Directive	Bern Convention	CITES Convention	Iberian Endemism
Myotis myotis		B-II, B-IV	II		
Nyctalus azoreum	VU	B-IV	II		#
Nyctalus noctula		B-IV	II		
Plecotus auritus		B-IV	II		
Plecotus austriacus	NT	B-IV	II		
Pipistrellus maderensis	EN	B-IV	II		x
Pipisrellus pipistrellus		B-IV	III		
Rhinolophus euryale	NT	B-II, B-IV	II		
Rhinolophus ferrumequinum		B-II, B-IV	II		
Rhinolophus hipposideros		B-II, B-IV	II		
Rhinolophus mehelyi	VU	B-II, B-IV	II		
Tadarida teniotis		B-IV	II		
LAGOMORPHA					
Lepus granatensis			III		
RODENTIA					
Arvicola sapidus	VU				
Chionomys nivalis			III		
Eliomys melanurus		B-IV	IV		
Eliomys quercinus	NT		III		
Glis glis			III		
Microtus cabrerae	NT	B-II, B-IV	II		x
Microtus rozianus *					x
Microtus tatricus		B-II, B-IV	III		
Sciurus vulgaris			III		
CETACEA					
Balaenoptera acutorostrata		B-IV	III	A-I	
Delphinus delphis		B-IV	II		
Globicephala melas		B-IV	II	A-II	
Globicephala macrorhynchus		B-IV	II	A-II	
Grampus griseus		B-IV	II	A-II	
Kogia breviceps		B-IV	II	A-II	
Mesoplodon bidens		B-IV	II	A-II	
Mesoplodon densirostris		B-IV	III	A-II	
Mesoplodon europaeus		B-IV	III	A-II	

Table 2. *Cont.*

SPECIES	IUCN Red List	Habitat Directive	Bern Convention	CITES Convention	Iberian Endemism
Peponocephala electra		B-IV	III		
Phocoena Phocoena		B-II, B-IV	II	A-II	
Pseudorca crassidens	NT	B-IV	II	A-II	
Sousa teuszii	CR	B-IV	III	A-I	
Stenella coeruleoalba		B-IV	II	A-II	
Tursiops truncates		B-II, B-IV	II	A-II	
Ziphius cavirostris		B-IV	II	A-II	
CARNIVORA					
Arctocephalus pusillus		B-V		A-II	
Canis lupus		B-II, B-IV	II	A-II	
Cystophora cristata		B-V	III		
Felis silvestris		B-IV	II	A-II	
Genetta genetta		B-V	III		
Herpestes ichneumon		B-V	III		
Leptailurus serval				A-II	
Lutra lutra	NT	B-II, B-IV	II	A-I	
Lynx pardinus	EN	B-II, B-IV	II	A-I	x
Martes foina			III		
Martes martes		B-V	III		
Meles meles			III		
Monachus monachus	CR	B-II, B-IV		A-I	
Mustela erminea			III		
Mustela nivalis			III		
Mustela putorius		B-V	III		
Phoca vitulina		B-II, B-IV	III		
Pusa hispida		B-V	III		
Ursus maritimus	VU	B-II		A-II	
Zalophus californianus		B-V			
ARTIODACTYLA					
Capreolus capreolus			III		
Dama dama			III		
MONOTREMATA					
Ornithorhynchus anatinus	NT				

* Recently documented species, not yet globally evaluated (e.g., [22]). # Endemic species in Portugal (resident in the Azores archipelago).

The worldwide coverage includes representatives from 24 countries (excluding Portugal), 12 in Europe, 1 in Asia, 8 in Africa, 2 in North America, and 1 in Australia, corresponding to 9 orders, 23 families, 87 species, and 453 specimens (Figure 4, Supplementary Material S1). Out of these species, 48 species are not represented in Portugal.

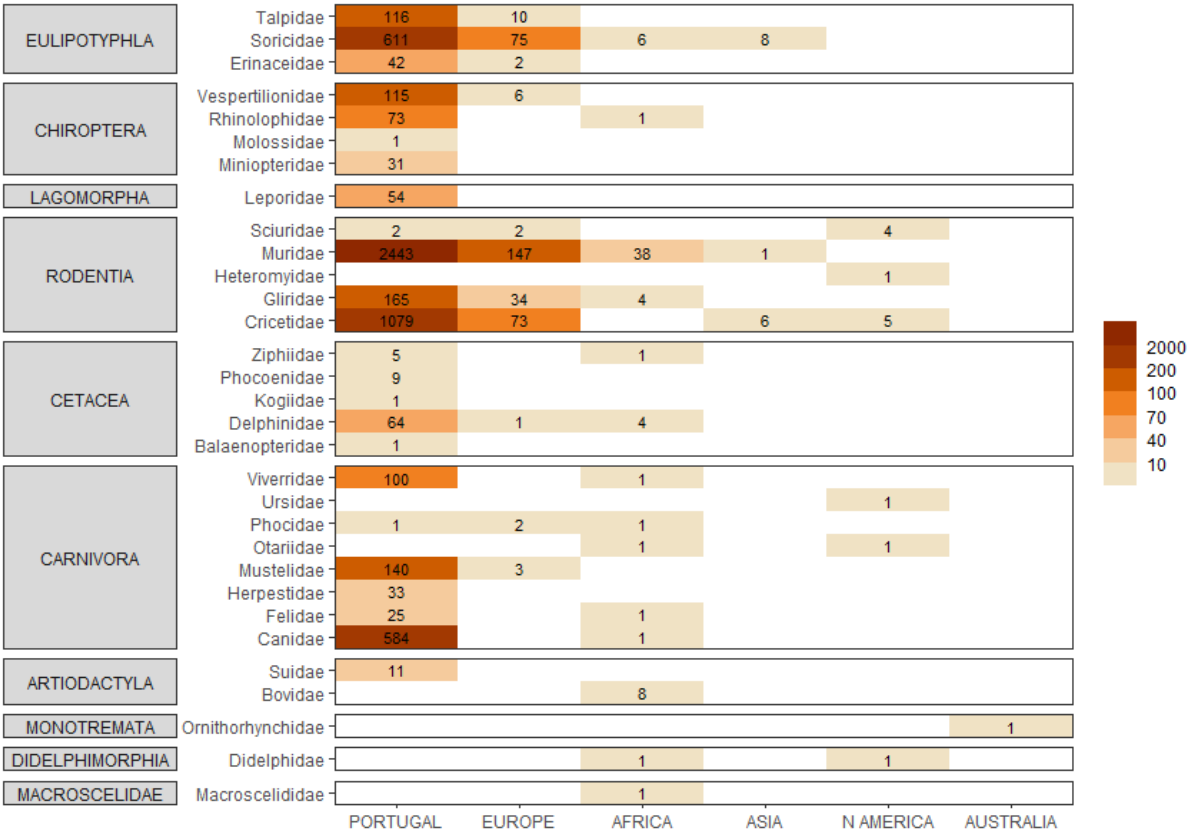

Figure 4. Worldwide coverage of the museum's collection, including an overview of the taxonomic groups represented and the corresponding specimen's abundance.

The European collection is the most extensively represented, particularly by eulipotyphlans and rodents, comprising a total of 21 species ranging from central to eastern Europe, some of which are also found in Portugal. Examples are the lesser white-toothed shrew (*Crocidura suaveolens*), the Nathusius's pipistrelle (*Pipistrellus nathusii*), the European snow vole (*Chionomys nivalis*), and the Common vole (*Microtus arvalis*), occurring in Portugal but only represented in the collection by specimens originating from other European countries.

The African collection spans over seven orders, but most of the 13 species represented having just a single specimen. This trend is similar for the Asian, North American, and Australian samples.

3.2. The Intrinsic Natural Value of the Collection

3.2.1. Research and Conservation Criteria

Approximately 60% of the species in the collection (79 out of 131 species) stand out for meeting at least one of the selected international criteria, highlighting their intrinsic natural value, with about 15% of these species facing the risk of extinction (10 species; CR, EN, or VU) (Table 2). According to the global IUCN evaluation, two species in the collection are currently Critically Endangered (CR), the Atlantic humpback dolphin (*Sousa teuszii*) and the Monk seal (*Monachus monachus*); three species are Endangered (EN), the Pyrenean desman (*Galemys pyrenaicus*), the Madeira pipistrelle (*Pipistrellus maderensis*), and the Iberian lynx (*Lynx pardinus*); and five are Vulnerable (VU), four bats (the Mehely's horseshoe bat,

Rhinolophus mehelyi; the Azorean bat, *Nyctalus azoreum*; the Bechstein's bat, *Myotis bechsteini*; and the Schreibers' bat, *Miniopterus schreibersi*) and one rodent (the Southern water vole, *Arvicola sapidus*).

Most eupotyphlan species, along with bats and marine mammals (cetaceans and carnivores), are of conservation concern according to international regulations and conventions. The majority of Eulipotyphla species are listed as protected under the Bern Convention, while both Chiroptera and Cetacea species are classified as strictly protected. Additionally, Chiroptera and Cetacea species are also included in the Habitat Directive, requiring either the designation of special areas of conservation for their protection or the provision of strict protection. The international legislation on the trade in endangered species (CITES Convention) lists numerous Carnivora and Cetacea species under strict trade regulation, regardless of whether they are currently threatened or not. Among these, the Common minke whale (*Balaenoptera acutorostrata*), the Atlantic humpback dolphin (*Sousa teuzii*), the Iberian lynx (*Lynx pardinus*), the Otter (*Lutra lutra*), and the Monk seal (*Monachus monachus*) are among the species whose survival could be compromised without a strict control across international borders.

Furthermore, six species are unique to the Iberian Peninsula, reflecting significant scientific value: the Iberian shrew (*Sorex granarius*), both the recently documented Iberian water shrew (*Neomys anomalus*) and the Portuguese field vole (*Microtus rozianus*), the Iberian mole (*Talpa occidentalis*), the Critically Endangered Iberian lynx (*Lynx pardinus*), and the Madeira pipistrelle (*Pipistrellus maderensis*). In addition, it is relevant to highlight the presence of the Azorean bat (*Nyctalus azoreum*), a species endemic to Portugal and found exclusively in the Azores archipelago.

It is relevant to note that six species in the collection are included in the EDGE list (the world's most Evolutionary Distinct and Globally Endangered species), the Pyrenean desman (*Galemys pyrenaicus*), the Madeira pipistrelle (*Pipistrellus maderensis*), the Iberian rabbit (*Oryctolagus cuniculus*), the Hooded seal (*Crystophora cristata*), the Iberian lynx (*Lynx pardinus*), and the Monk seal (*Monachus monachus*) (https://www.edgeofexistence.org/) (accessed on 1 October 2024)

Regarding the national criteria and species in Portugal classified as threatened under the IUCN categories [22,24], the collection holds nearly 90% of the threatened species in the country (41 out of 51 species), including as well 90% of the most at-risk species (CR, EN, and VU) (27 out of 30 species). Most of the species in Portugal classified as Critically Endangered (CR) are represented in the collection (six out of six), highlighting its scientific value and potential for research and conservation efforts: three bat species, the Lesser mouse-eared bat (*Myotis blythii*), the Azorean bat (*Myotis azoreum*), and the Madeira pipistrelle (*Pipistrellus maderensis*); one cetacean, the Harbor porpoise (*Phocoena Phocoena*); and one seal, the Monk seal (*Monachus monachus*). It is also notable that all the Endangered (EN) species in the country (a total of 10 species) are fully represented in the museum collection, belonging in the orders Eulipotyphla, Chiroptera, and Carnivora (Table 3, Supplementary Material S2, Figure 5). Species categorized as Vulnerable (VU) are also well represented (12 out of 14), with particular emphasis on rodents and lagomorphs. In addition, most threatened species represented in the collection are often simultaneously rare, with their populational trend assumed to be decreasing or unknown (Table 3) [22,24].

By combining both international and national criteria, it is shown that approximately 40% of the species in the collection (53 species) are protected under both international and national conventions and regulations, including species categorized as threatened according to IUCN criteria. The datasets for bats, shrews, and carnivores encompass most of the species categorized as threatened, either globally or in Portugal. Additionally,

approximately 50% (25 species) are considered rare or endemic due to their restricted geographic range, either within the country or in the Iberian Peninsula (see also [22,24]).

Table 3. Value of mammal species in the MUHNAC collection following national criteria (only species classified into at least one of the four sub-criteria analyzed are listed); abbreviations are as in Table 3 or as referred to in the main text.

SPECIES	Red Book	Recent Occurrence	Rarity	Population Trend
EULIPOTYPHLA				
Crocidura suaveolens	EN		x	D
Galemys pyrenaicus	EN		x	D
Neomys anomalus	VU	x	x	D
Sorex granarius	VU		x	D
Sorex minutus	EN		x	D
Suncus etruscus			x	I
CHIROPTERA				
Miniopterus schreibersi	NT			S
Myotis bechsteini	DD		x	NK
Myotis blythii	CR		x	D
Myotis emarginatus	EN		x	NK
Myotis escalerai	VU	x		NK
Myotis myotis	VU			S
Nyctalus azoreum	CR		x	NK
Plecotus auritus	DD		x	NK
Plecotus austriacus	NT			NK
Pipistrellus maderensis	CR		x	NK
Rhinolophus euryale	EN		x	NK
Rhinolophus mehelyi	EN		x	NK
LAGOMORPHA				
Lepus granatensis	VU			D
Oryctolagus cuniculus	VU			D
RODENTIA				
Arvicola sapidus	VU			D
Chionomys nivalis	DD	x		NK
Eliomys quercinus	NT	x		D
Microtus arvalis	DD			NK
Microtus cabrerae	VU			D
Microtus rozianus	VU	x		D
CETACEA				
Balaenoptera acurostrata	VU			S
Delphinus delphis	NT			NK
Globicephala melas	DD			NK
Grampus griseus	VU			NK
Kogia breviceps	DD		x	NK
Mesoplodon bidens	DD	x	x	NK

Table 3. *Cont.*

SPECIES	Red Book	Recent Occurrence	Rarity	Population Trend
Mesoplodon densirostris	DD		x	NK
Mesoplodon europaeus	NA		x	NK
Phocoena phocoena	CR		x	D
Pseudorca crassidens	NA		x	NK
Ziphius cavirostris	DD		x	NK
CARNIVORA				
Canis lupus	EN			S
Felis silvestris	EN		x	D
Lynx pardinus	EN		x	NK
Martes martes	VU		x	D
Monachus monachus	CR		x	S
Mustela erminea	DD		x	D
Mustela putorius	EN			D

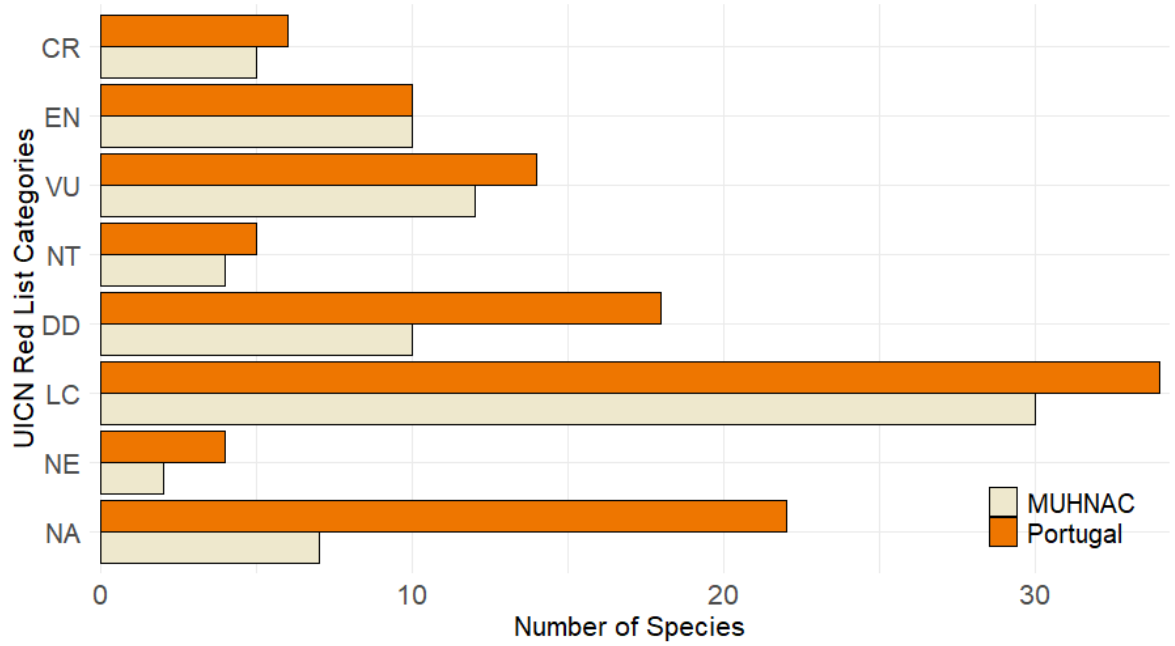

Figure 5. Number of species per threatened category in the MUHNAC collection, including Least Concern species (LC), recently documented species in the country (NE, not evaluated), and vagrant or non-indigenous species (NA—not applicable); other abbreviations are as in Tables 2 and 3.

3.2.2. Representativeness of the Collection

Spatial Representativeness in the Country

The representativeness of the museum collection was evaluated based on the number of species records, and the geographic distribution of these records across the country. Table 4 provides the results for each species, against their percentage of presence, and includes species body size (small, medium, or large) and the classification in the Portuguese Red Data Book [22].

Table 4. Presence of terrestrial species in Portugal and in the MUHNAC collection, including their representativeness; Sb—small mammals, Mb-medium-sized mammals, Lb—large-sized mammals; D—Deviation of the museum species from the species distribution area, for the overall country species and for the overall species in each taxonomic group; other abbreviations are as in Figure 5 or as referred to in the main text.

	Species Profile				Species Representativity		
SPECIES	**% Presence in Portugal ***	**Body Size**	**Red Book**	**Number Records**	**% Presencein MUHNAC**	**D for Overall Country sps.**	**D for Group sps.**
EULIPOTYPHLA							
Erinaceus europaeus	21.40	Sb	LC	39	9.35	0.47	0.18
Crocidura russula	20.00	Sb	LC	558	22.50	7.13	2.78
Galemys pyrenaicus	**2.90**	Sb	EN	9	6.90	0.79	0.31
Neomys anomalus	**2.20**	Sb	VU	11	9.09	1.28	0.50
Sorex granarius	**2.60**	Sb	VU	30	11.54	2.95	1.15
Sorex minutus	**0.20**	Sb	EN	3	50.00	3.83	1.49
Suncus etruscus	**4.00**	Sb	LC	4	2.50	0.26	0.10
Talpa occidentalis	22.20	Sb	LC	105	12.16	1.21	0.47
CHIROPTERA							
Eptesicus serotinus	7.10	Sb	LC	10	2.82	0.36	2.22
Miniopterus schreibersi	11.40	Sb	NT	27	7.02	0.61	3.74
Myotis bechsteinii	**2.80**	Sb	DD	-	-	-	-
Myotis blythii	**2.90**	Sb	CR	11	6.90	1.23	7.61
Myotis daubentoni	14.40	Sb	LC	11	4.17	0.20	1.20
Myotis emarginatus	**4.40**	Sb	EN	1	-	0.06	0.36
Myotis escalerai	10.40	Sb	VU	2	0.96	0.05	0.30
Myotis myotis	10.00	Sb	VU	15	4.00	0.38	2.37
Nyctalus leisleri	22.20	Sb	LC	2	1.80	0.02	0.14
Pipistrellus kuhlii	30.30	Sb	LC	1	0.66	0.03	0.16
Pipistrellus pipistrellus	33.40	Sb	LC	27	5.69	0.21	1.28
Plecotus auritus	**5.00**	Sb	DD	1	-	0.05	0.32
Plecotus austriacus	7.90	Sb	NT	8	-	0.26	1.60
Rhinolophus euryale	**4.90**	Sb	EN	10	4.08	0.52	3.22
Rhinolophus ferrumequinum	18.80	Sb	LC	17	3.72	0.23	1.43
Rinolophus hipposideros	19.00	Sb	LC	18	1.58	0.24	1.49
Rynolophus mehelyi	**3.70**	Sb	EN	18	-	1.24	7.67
Tadarida teniotis	24.00	Sb	LC	1	-	0.01	0.07
LAGOMORPHA							
Lepus granatensis	30.00	Mb	VU	31	4.67	0.26	1.81
Oryctolagus cuniculus	49.60	Sb	VU	14	1.81	0.07	0.51
RODENTIA							
Apodemus sylvaticus	25.2	Sb	LC	592	19.84	6.00	1.25
Arvicola amphibius	-	Sb	NE	2	-	-	-
Arvicola sapidus	12.30	Sb	VU	32	6.50	0.66	0.14
Eliomys quercinus	**5.70**	Sb	NT	163	5.26	7.31	1.52
Microtus cabrerae	14.10	Sb	VU	10	2.13	0.18	0.04
Microtus duodecimcostatus	7.30	Sb	LC	450	19.18	15.75	3.28
Microtus lusitanicus	13.80	Sb	LC	484	15.94	8.96	1.87
Microtus rozianus	**5.50**	Sb	VU	18	3.64	0.84	0.17
Mus musculus	11.20	Sb	LC	239	11.61	5.45	1.14
Mus spretus	19.60	Sb	LC	775	21.43	10.10	2.10

Table 4. *Cont.*

SPECIES	Species Profile			Species Representativity			
	% Presence in Portugal *	Body Size	Red Book	Number Records	% Presencein MUHNAC	D for Overall Country sps.	D for Group sps.
Rattus norvegicus	6.40	Sb	NA	38	7.81	1.52	0.32
Rattus rattus	9.90	Sb	NA	142	13.13	3.67	0.76
Sciurus vulgaris	25.60	Sb	LC	1	0.78	0.01	0.00
CARNIVORA							
Canis lupus	20.40	Lb	EN	68	30.39	0.85	1.60
Felis silvestris	**5.20**	Mb	EN	18	3.85	0.88	1.66
Genetta genetta	53.80	Mb	LC	84	7.62	0.40	0.75
Herpestes ichneumon	44.70	Mb	LC	32	6.26	0.18	0.34
Lutra lutra	45.50	Mb	LC	11	2.64	0.06	0.12
Lynx pardinus	**1.90**	Mb	EN	7	-	0.94	1.76
Martes foina	47.00	Sb	LC	31	3.83	0.17	0.32
Martes martes	**1.20**	Sb	VU	1	8.33	0.21	0.40
Meles meles	54.90	Mb	LC	20	2.91	0.09	0.17
Mustela erminea	**0.30**	Sb	DD	5	-	4.26	7.98
Mustela nivalis	12.80	Sb	LC	43	9.38	0.86	1.61
Mustela putorius	10.00	Sb	EN	21	9.00	0.54	1.01
Vulpes vulpes	78.40	Mb	LC	451	17.60	1.47	2.75
ARTIODACTYLA							
Capreolus capreolus	59.6	Mb	LC	1	0.50	0.00	0.26
Cervus elaphus	48.4	Lb	LC	2	0.62	0.01	0.63
Dama dama	12.8	Lb	NA	1	1.56	0.02	1.19
Sus scrofa	100	Lb	LC	11	0.80	0.03	1.68

* Rare species in the country are highlighted in bold.

The percentage of species distribution in the country represented in the museum collection varies approximately between 2 and 30%. Exceptions to this pattern are the Chiroptera and the Artiodactyla, which have a comparatively lower representation in the collection than other taxonomic groups. The highest number of collection sites is recorded for Eulipotyphla, Rodentia, and Carnivora, reflecting the greater representation of these taxonomic groups in the collection, as previously noted (see Figure 2). The higher number of rodent specimens in the collection, compared to the other two groups, underscores the greater representation of certain rodent species from a relatively limited number of collecting sites (e.g., *Mus spretus*, *Apodemus sylvaticus*, *Microtus duodecimcostatus*, and *M. lusitanicus*) (see also Supplementary Material S1). The number of collecting sites, or UTM grids with recorded species presence, is notably low for bats and artiodactyls, indicating a limited number of records and overall representation for these groups. In contrast, for all other groups, the museum generally holds more records of small-sized and non-threatened species, with fewer records for larger species categorized as at-risk. However, there are some exceptions, where the museum's representation of rare species may exceed the average values referred to above. An example is the Pygmy shrew (*Sorex minutus*), the smallest-sized species in the country categorized as Endangered, which, despite the limited number of records, has a collection coverage of 50% its geographic range in the wild. This is largely due to the restricted distribution of *S. minutus* in Portugal, which corresponds the southern edge of its European range. In contrast, the squirrel (*Sciurus vulgaris*), a small rodent evaluated as of Least Concern, is scarcely represented in the museum, covering less than 1% of its distribution in the country. Although this species has a wide range in

Portugal, it inhabits very specific environments. A similar pattern can be reproduced in many bat species, which occupy limited areas within their habitats, often associated with their roosting sites (e.g., [22]). It is also worth noting that some museum records do not align with the current national distribution of species. For older records, this could indicate that the species no longer occupies that area, while more recent records may suggest an expansion of the species' range. For example, the Eurasian water vole (*Arvicola amphibius*) is represented in the collection by specimens collected from the northeastern most part of the country, although it has not been observed in the wild since 1988 [25]. However, there is no confirmation of the species' regional extinction.

Most terrestrial species in Portugal are small-bodied, with only a reduced set including medium- and large-sized mammals. The average species representativeness, grouped by body size, reflects this disparity in each group, as indicated in Table 5. It is important to note that the percentage of collecting sites for small-sized mammals is significantly influenced by several rodent species with a higher-than-expected spatial representativity, while for large mammals, the expected value is largely influenced by the relatively high number of records for the Iberian wolf (*Canis lupus*) compared to other large-sized species in the country (Supplementary Material S1). The results also confirm the limited representativeness of Chiroptera, Lagomorpha, and particularly Artiodactyla.

Table 5. Percentage of the spatial representativity of the country presences in the museum collection considering taxonomic group, body size, and threatened category; abbreviations are as in Table 4.

Taxonomic group		
	% presence in the museum	**% representativeness**
Eulipotyphla	13.30%	223.88
Chiroptera	1.92%	21.10
Lagomorpha	2.89%	16.38
Rodentia	11.24%	503.77
Carnivora	8.94%	77.99
Artiodactyla	0.70%	1.05
Body size		
	% presence in the museum	**% representativeness**
Small	5.88	166.98
Medium	6.79	47.69
Large	3.96	15.17
Threatened category		
	% presence in the museum	**% representativeness**
CR	6.90	123.35
EN	14.18	107.36
VU	3.24	62.55
NT	4.23	204.27
LC	5.91	187.22

Regarding species categorization according to IUCN criteria, Near Threatened (NT) and Least Concern (LC) species combined are represented in the collection at two to three times the expected rate, given their coverage in Portugal. In particular, Least Concern (LC)

species are considerably represented in a limited number of collection sites; however, their overall representativeness is negatively impacted by the limited sampling of LC bat species.

Interestingly, the spatial distribution of Critically Endangered (CR) and Endangered (EN) species aligns well with their robust representation in the collection, as previously noted.

3.2.3. Representativeness in the Collection

Two approaches were followed to assess the representativeness of the different species in the collection. In the first approach, the representativeness was calculated based on the average percentage of presence of all documented mammal species across the country, i.e., including those not represented in the collection (Supplementary Material S3), while in the second approach, the representativeness was determined against the average percentage of presence for all the species within the same taxonomic group, again regardless of their inclusion in the collection. Table 4 shows that, as expected, in general species with a higher number of records also tend to have a greater relative representativeness, reaching values up to more than ten times the expected level ($D \geq 1$) considering the area covered in the country. In contrast, species with fewer records fall below the expected representativeness ($D \leq 1$) (see Supplementary Material S4). However, when comparing the number of records to their percentage of presence in the country, it is interesting to note that several species with restricted distributions, despite their limited presence in the collection, still surpass the expected level of representativeness, as outlined above. This trend applies to most bat species and a few threatened species with limited museum records.

4. Discussion

4.1. The Mammal Collection and Its Intrinsic Value

Natural history collections offer valuable insights into biodiversity across different time periods and geographic locations, thereby enhancing our scientific knowledge of life on Earth. The mammal collection at the Portuguese National Museum of Natural History and Science (MUHNAC), though relatively recent, provides a relevant database to support a wide range of studies and science initiatives. The present study analyzed the mammal collection records to assess their intrinsic natural value and to determine how well they represent the occurrence of different species throughout the country.

The concept that species have intrinsic value was first discussed by [26], who argued that this value stems from their long evolutionary heritage and potential. Subsequent studies have supported this idea, asserting that every species is worthy of protection as an end, as stated in the Earth Charter International [27], although there have been differing views on whether an entity should be valued for its inherent qualities rather than for its utility (e.g., [28]). Despite the ongoing debate on the intrinsic value of species, balanced between ecocentric and anthropocentric perspectives, the recognition of intrinsic natural value represents a crucial aspect in biodiversity conservation, entailing the need of protecting our natural world, as recently emphasized by [29,30]. This appreciation also aligns with a recent report by the Interagency Working Group on Scientific Collections [5] stating that scientific collections represent a public good by holding objects of relevant scientific value regardless of the reason for which they were originally collected and preserved.

From this perspective, we describe the significant contributions of the MUHNAC mammal collection to both research and conservation. A key question in the present study was also whether the species dataset in the museum is representative of the species range across Portugal, a significant factor for various scientific approaches. The MUHNAC collection houses a total of 6163 specimens from 131 species, including skulls, skins, and alcohol-preserved and mounted specimens. Less than 10% of the specimens represent

species from 24 countries, outside of Portugal, ranging from Europe to Australia, although most these species are represented by single or very few specimens. The European dataset is the most well-represented, featuring several species with extensive geographic ranges, including Portugal, and consists of specimens originating from donations and exchanges with other museums and research institutions.

Regarding the repository dataset, although temporally biased, due to the high representation of samples collected in the two to three decades following the destruction of the original collection in 1978, the collection provides a substantial coverage of the mammalian diversity in Portugal, making a valuable resource not only for biodiversity planning, including traditional taxonomic and systematic studies, but also for more advanced research initiatives (e.g., [8,10–12,31]). However, the collection is highly opportunistic, with some species overrepresented and comprising numerous specimens, while others have very few records, a trend also observed in other museums (e.g., [32]). This reflects not only the research interest of the collectors and the relative abundance of species in the wild, but also the size of the specimens in relation to the requirements for their preservation and storage, as well as economic, legal, and ethical restrictions. Using these factors as a basis for justification can help explain why the collection is not uniform across different taxonomic groups.

Approximately 40% of the species in the collection are protected under both international and national conventions and regulations, including species categorized as threatened according to IUCN criteria. Additionally, 50% of these species are considered rare or endemic due to their restricted geographic range, either within the country or in the Iberian Peninsula. Examples include the critically endangered Lesser mouse-eared bat (*Myotis blythii*), the Azorean bat (*Myotis azoreum*), the Madeira pipistrelle (*Pipistrellus maderensis*), the harbor Porpoise (*Phocoena phocoena*), and the Monk seal (*Monachus monachus*). Moreover, species such as the Iberian shrew (*Sorex granarius*), the Pygmy shrew (*Sorex minutus*), the Garden dormouse (*Eliomys quercinus*), and the Wildcat (*Felis sylvestris*) are rare in the country, and their populations are estimated to be currently declining.

As expected, rarer species, with limited distribution ranges and heightened conservation concern, as those referred above, are represented in the collection by fewer specimens, while more abundant, widespread, non-threatened species are represented by larger samples. However, given the documented ongoing environmental changes, particularly climate changes [1], that confirm threatening factors for mammals worldwide [33,34], even reduced sets of samples are likely to prove valuable for comparative spatiotemporal assessments.

4.2. The Mammal Collection and Its Representativeness

Historically, researchers and museum collectors primarily focused on large species, such as carnivores, primates, and herbivores, not only because of their scientific interest but also due to the public's fascination with these animals (e.g., [13,35]). Many of these species were legally hunted in several countries [36], and those with abundant populations were extensively sampled during early natural history expeditions. This trend is strongly reflected in the MUHNAC's historical collection [13,15]. Today, however, the collection is shaped by the influence of several constraints, primarily resulting from stricter regulations on animal capture and handling, which in turn limit scientific research. As a result, species prioritized in research, often dependent of more funding support, are mostly those relevant to zoonotic disease studies, agriculture planning due to their impact as crop pests, or those serving as bioindicators of environmental quality, such as rodents and eupotyphlans.

Accordingly, the MUHNAC's recent collection has a higher prevalence of non-volant small mammals, not only because they are generally widespread, abundant, and of lesser conservation concern [37], but also due to the health and ecological significance of several

species. Examples include the Lusitanian pine vole (*Microtus lusitanicus*), a common orchard pest in fruit-growing areas [38]; the House mouse (*Mus musculus*), a frequent pest in urban areas and closely associated with human-related activities, and a relevant host of many zoonotic parasites (e.g., [39–41]); and the Algerian mouse (*Mus spretus*) and the Greater white-toothed shrew (*Crocidura russula*), both used as bioindicators for environmental pollution [42,43]. All these species are represented by extensive datasets that fully cover their geographic range within the country and may represent a valuable resource for information processing as pointed out by [2] when describing the contributions of biological collections to science and society.

In contrast, bats make up only a small portion of the overall mammal collection. All bat species are legally protected and listed in the annexes of both the Habitat Directive and the Bern Convention. Accordingly, 50% of the bat species in the country are of conservation concern requiring specific conservation measures, including strict regulations for their capture. These factors, combined with fragmented distributions and often inaccessible shelters, are likely to contribute to the limited bat sampling in the MUHNAC's collection, with some species represented by only a single or very few specimens. Nevertheless, despite this reduced dataset, some species are more represented in the collection than expected based on the average percentage of presence of all bat species in the country. Examples include the Schreiber's bat (*Miniopterus schreibersii*), the Bechstein's bat (*Myotis bechsteinii*), the Grey long-eared bat (*Plecotus austriacus*), and the Lesser horseshoe bat (*Rhinolophus hipposideros*).

For other mammal groups, ethical and legal restrictions are also the primary factors regulating scientific studies. This applies to carnivores and marine mammals, in general.

The most well-represented medium-sized terrestrial carnivore in the collection is the Fox (*Vulpes vulpes*), while the largest is the Iberian wolf (*Canis lupus*), with a representativity almost three and two times higher than expected, respectively. The Fox, a common game species, is abundant both in Portugal and across its geographic range, which likely accounts for its high numbers in the collection. Conversely, despite the higher-than-expected representation of the Endangered Iberian wolf (*Canis lupus*) in the collection, its natural range is restricted to northern Portugal. Although this species was historically hunted, hunting has been banned since 1988 (Law No. 90/88, August 13), which explains why nearly 90% of the specimens in the collection date prior to this ban. Recent specimens were likely obtained from roadkill incidents or poisoning, reflecting the ongoing conflict between wolves and humans, stemming from the belief that wolves prey on livestock and domestic animals [44], although this is not explicitly indicated in their collection labels.

Road killing poses a major threat for many other species, with small-sized and medium-sized mammals having a significant risk of mortality [45]. In Portugal, roads pose a relevant accidental threat to several of these species, with medium-sized carnivores being the most affected, including the Egyptian mongoose (*Herpestes ichneumon*), the Common genet (*Genetta genetta*), the Badger (*Meles meles*), and the Otter (*Lutra lutra*). But there are also fatalities reported for small-sized carnivores, such as the Stone marten (*Martes foina*), the Weasel (*Mustela nivalis*), and the Western polecat (*Mustela putorius*), and even for small rodents, including the Wood mouse (*Apodemus sylvaticus*) and the Cabrera's vole (*Microtus cabrerae*) [46–48]. Many roadkill specimens are added to the museum collection through donations from researchers, academics, and members of the public, who recognize the scientific and educational value these animals may provide for research and education.

Marine mammals, including carnivores and cetaceans, are significantly underrepresented in the collection, although precise values have not been determined in this paper. In Portugal, as in other countries, the protection of these species is governed by strict laws that regulate or prohibit activities such as deliberate capture, transport, killing, whale

watching, and commercial fishing, making a challenge to expand their representation in the collection. However, each year, the stranding of various species is recorded, including the Sowerby's beaked whale (*Mesoplodon bidens*), and the Short-finned pilot whale (*Globicephala macrorhynchus*), as well as other species not currently represented in the museum collection [49]. Although these events may offer a potential source of new specimens to expand the collection, the difficulty of collecting and processing animals due to their large size may be a constraint.

All artiodactyl species in the collection are game species, primarily hunted in designed hunting areas, often for touristic reasons. The most abundant species, both in the country and the collection, is the Wild boar (*Sus scrofa*), exceeding in 1.5 the representation in the collection of the remaining artiodactyl species, the Roe deer (*Capreolus capreolus*), the Fallow deer (*Dama dama*), and the Red deer (*Cervus elaphus*), which are underrepresented. This scarcity may be attributed to their large size, which complicates preservation and storage. However, it is primarily due to limited donations over the years, largely driven by the economic value of trophies, particularly in selective hunting, and the high demand for game meat, which is prized in gourmet restaurants.

By identifying data gaps for many species, we aim to draw the attention of researchers and potential donors to support efforts to enhance the museum's collection by completing the missing data. Recognizing the challenges posed by current ethical standards concerning the capture, care, and study of wild species, we propose that establishing exchange partnerships with larger museums that maintain extensive collections could be a key step toward reducing data gaps. Another approach to gathering information, particularly for rare species, those of conservation concern, or large-sized species, could involve maintaining a comprehensive collection of sound recordings or a photo archive, which can play a valuable role in various research approaches. This should always include detailed descriptions of the collection sites and their geographic coordinates.

In summary, the description of the mammal collection at MUHNAC (i) highlights its remarkable potential not only for biodiversity planning and conservation studies, but also for a wide range of other scientific initiatives, with the full georeferencing of terrestrial species in the country adding significant value for spatiotemporal assessments; (ii) the museum records provide a good coverage of the mammal diversity in Portugal; (iii) although there are gaps in specimen numbers and geographic representation, these gaps primarily involve threatened and range-restricted species, still offering valuable opportunities for targeted studies; (iv) the collection reflects not only the scientific interests of the collectors but also the economic, ethical, and legal restrictions documented for the diverse taxonomic groups; and (v) the inclusion of several dozen species representatives from countries ranging from Europe to Australia adds intrinsic value to the collection.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d17010001/s1. Table S1: List of the species in the mammal collection at the National Museum of Natural History and Science (MUHNAC), including location and number of specimens; Table S2: Number of species of Portugal per taxonomic order and threatened category in the MUHNAC collection; Table S3: Species from Portugal not represented in the MUHNAC collection; S4: Occurrence maps of the most represented species in the museum's collection for each taxonomic order in Portugal.

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