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Conservation status of the world's carnivorous mammals (order Carnivora)

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Abstract

The conservation of carnivores (order Carnivora) can lead to the conservation of other species as well as entire ecosystems since they play an important ecosystemic role. However, their predatory behaviour has caused many of these species to experience marked population declines worldwide and they may therefore face greater anthropogenic threats than other animal groups. To examine the conservation status, population trends, distribution patterns, habitats and threats of all extant species belonging to this order ($N = 290$), we collected data from the International Union for the Conservation of Nature's Red List. In addition, we calculated the Red List Index (RLI) to measure the change in extinction risk of species over time. Carnivores are more threatened than mammals in general (26.9% of endangered species vs. 22.7%) and have a significantly higher proportion of species with declining populations (48.3% vs. 31.9%). Eupleridae, Ursidae and Felidae families have the worst conservation status. Between the 1990s and 2000s, most families suffered a considerable decline in their RLI value, the most notable being Felidae. The greatest numbers of threatened carnivore species are found in forest, shrubland and grassland habitats. East and South Asia hold great numbers of carnivore species as well as the highest proportion of threatened and declining species. Hunting and trapping of terrestrial animals, along with habitat loss (caused by deforestation and agricultural expansion), pose the main threats to the Carnivora order. Our findings indicate that, within mammals, the conservation of carnivores should be a priority, and conservation measures directed at this group should be undertaken or increased as a matter of urgency.

Keywords Extinction risk · IUCN red list · Threatened species · Distribution maps · Caniformia · Feliformia

Introduction

Carnivores (order Carnivora) are one of the most diverse groups of mammals and have managed to populate all continents and a wide variety of habitats (from deserts to tropical forests, savannas or even rivers and oceans; Eizirik et al. 2010; Wilson et al. 2009). Consequently, this order has a great diversity of forms and functions, evolved as adaptations to the habitat and lifestyle of each species (MacDonald and Norris 2001; Nowak 2005). Furthermore, the order Carnivora reveals one of the most extreme cases of the size range among all mammals (Hunter and Barrett 2019), from approximately 50 g of a weasel (*Mustela nivalis*) to nearly 4000 kg for a male elephant seal (*Mirounga leonina*). Despite all these differences, all carnivores share several features typical of this order such as highly developed senses of vision, smell and hearing, claws and relatively dense fur (Van Valkenburgh and Wayne 2010). Even though many carnivores are adapted to a predominantly meat diet, this order comprises species with broad diets that include invertebrates and vertebrates as well as fruit and green plants (Wilson et al. 2009; Pineda-Munoz and Alroy 2014). According to Burgin et al. (2018) there are 305 extant carnivore species, classified into 16 families. Many phylogenetic studies support the division of the order Carnivora into two main evolutionary lineages: Feliformia (which includes seven families: Felidae, Viverridae, Eupleridae, Nandiniidae, Prionodontidae, Herpestidae and Hyaenidae) and Caniformia (including

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nine families: Canidae, Ursidae, Otariidae, Odobenidae, Phocidae, Mustelidae, Mephitidae, Procyonidae and Ailuridae; Rose and Archibald 2005; Eizirik et al. 2010).

The relationship between humans and carnivores has always been complex (Lozano et al. 2019). On the one hand, we admire them for their strength, beauty and frequent predatory behaviour, and on the other hand, we fear them because they conflict with our activities, as they may prey on livestock or even pose a risk to human life (Bruskotter et al. 2017). For this reason, carnivores, especially those of large body size, have been persecuted throughout history, causing a dramatic decline in their populations over the last 200 years (Linnell et al. 2001; Ripple et al. 2014). Thus, many carnivore species are in danger of extinction or will soon become so (Gittleman et al. 2001; Ripple et al. 2014). However, this decline has occurred unevenly across the world: while some populations have been completely extirpated, others have managed to survive or are slowly recovering, such as some populations in America (Ripple et al. 2014), Africa (Winterbach et al. 2013) or even densely populated areas of Europe (Chapron et al. 2014). These examples illustrate how human populations can coexist with carnivores at least under certain conditions (Linnell et al. 2001). However, some authors point to a direct relationship between carnivore extinction risk and human density (Woodroffe 2000) or carnivore body size (Brown 1986).

Carnivores, especially large species, often require large individual home ranges (Gese 2001). They are consequently particularly vulnerable to local extinction when their habitat is reduced or fragmented (Crooks 2002). Protecting areas large enough to sustain these animals is the main challenge for their conservation (López-Bao et al. 2017). This can be quite problematic in a world where most natural landscapes are urbanised or dominated by human presence (Trajçe et al. 2019). Carnivore conservation is therefore constrained by the fact that humans have modified and occupied most of their habitats, but also by the establishment of protective legislation and the achievement of public opinion favourable to their presence (Linnell et al. 2001; Tisdell et al. 2005; Chapron et al. 2014; Bruskotter et al. 2017).

Carnivores have been identified as a priority for biodiversity conservation strategies, because, since they occupy high positions in food chains, their protection may imply the conservation of other elements of biodiversity (Gittleman et al. 2001; Ray 2005). For example, large carnivores like brown bears (*Ursus arctos*) or lions (*Panthera leo*) are key predators that regulate their prey populations and, through trophic cascades, have profound effects on the entire community structure (Nowak 2005; Ripple et al. 2014). Carnivores can therefore serve as tools for reserve planning and design, as well as being good indicators of the overall health of an ecosystem (Soulé and Terborgh 1999). This means that protection of areas large enough to maintain stable carnivore populations can lead to effective conservation of the biodiversity present in those areas, the so-called "umbrella effect" (Roberge and Angelstam 2004; Sergio et al. 2008). Beyond their usefulness as a tool for biodiversity conservation and ecosystem functioning, the predatory and scavenging role of carnivores provides ecosystem services of great value to human well-being, for example, the regulation of zoonotic diseases, waste disposal, increased agricultural output through competition reduction and consumption of problematic crop-destroying species, and diverse cultural values (O'Bryan et al. 2018; Willcox 2020).

Despite their attractiveness and importance for the proper functioning of ecosystems, a current global synthesis of the conservation status, threats and distribution of the world's carnivorous mammals is lacking. The aim of this study is to fill this gap by analysing the assessments made by the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species for all families and species belonging to the order Carnivora. For each family, we examine the proportion of threatened and declining carnivore species and analyse the trends in their extinction risk according to the Red List Index (RLI). Distribution patterns of threatened species, preferred habitats and the most important threats affecting this group and their families are also examined from a conservation perspective.

Materials and methods

Conservation status

We collected data from the Red List of Threatened Species database for all 290 extant carnivore species (IUCN 2021). Then, we divided them according to the 16 taxonomic families in this order: Mustelidae (63 species), Felidae (38), Canidae (36), Herpestidae (35), Viverridae (33), Phocidae (18), Otariidae (15), Procyonidae (14), Mephitidae (12), Eupleridae (9), Ursidae (8), Hyaenidae (4), Prionodontidae (2), Ailuridae (1), Nandiniidae (1) and Odobenidae (1).

To assess the conservation status of species, the IUCN Red List uses an alphanumeric hierarchical system of criteria and sub-criteria (IUCN Standards and Petitions Committee 2019). In this way, species are classified into different categories according to their risk of extinction: Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR), Extinct in The Wild (EW) and Extinct (EX). However, certain species are classified as Data Deficient (DD), due to the lack of adequate information to assess their extinction risk. In this study, VU, EN and CR species were grouped as "Threatened Species". We calculated the number and percentage of threatened species belonging to each family, the whole order Carnivora and the class Mammalia and compared them by Chi-square tests when the number of species in a group was greater than 10. The Red List also provides information about the population trend of species and classifies them according to whether the population is increasing, stable, decreasing or unknown. Thus, we calculated the number and percentage of species whose populations follow one of these four trends for the group, each family and for all mammals.

Following Butchart et al. (2007), we used the "Red List Index calculator" assessment tool hosted at www.iucnredlist.org/resources/ to calculate the Red List Index (RLI) for each family and for all carnivores and compare them with the RLI for all mammals. For a particular taxonomic group, the RLI considers the proportion of species in each conservation category and the changes in category that occur for each individual species over time (either improvement or deterioration), to calculate a value ranging from 0 (which equates to all species in the group being Extinct) to 1 (which equates to all species in the group being Least Concern). The RLI can be used to track the evolution of the extinction risk of a given taxon over time and is commonly used as an indicator of the rate of biodiversity loss (Butchart et al. 2007). We calculated the RLI grouped by decade (1980s, 1990s, 2000s, and 2010s) and for the most recent assessment (IUCN 2021) which we later refer to as the 2020s decade. Following a conservative approach, if for a given species and decade there were multiple assessments of conservation status, the category representing the highest risk of extinction was chosen for the analyses. The information related to the RLI of all mammals was obtained from Hoffmann et al. (2011) and the latest update from the IUCN Red List (IUCN 2021).

Habitat

The IUCN Red List documents the habitat preference of each species by establishing three levels of hierarchy. The first level consists of 18 habitat types, further subdivided into more specific ones (second and third level) considering biogeography, latitude and depth in the case of marine ecosystems (Table 1). For example, at the first level the habitat type "Forest" is divided into several more specific forest types (second level), such as "Boreal Forest" or "Temperate Forest" among others. In this study, only first level habitats considered "Suitable" for each species have been included, as they indicate that the species occur regularly or frequently in these habitats (IUCN 2021). A given species can occur in several types of habitats (Nowak 2005; Hunter and Barrett 2019). The number of species in each IUCN Red List Category was calculated for each of the 15 habitat types where carnivores occur (Table 1). Finally, the proportion of threatened species present in each habitat was compared by Chi-square test.

Distribution patterns

Red List assessment also records the species' geographic distributions, indicating the countries and continental regions where each species occurs. We followed the division into 13 continental regions established by the IUCN to classify the terrestrial geographical distribution of all carnivores (Table 2). To estimate the richness and number of threatened and declining species per country and ecoregion, we used ArcGIS (ESRI 2020) to quantify overlap of the species' geographic ranges (IUCN 2021) with terrestrial

Table 1 Number of carnivore species in each IUCN Red List Category (CR—Critically Endangered; EN—Endangered; VU—Vulnerable; NT—Near Threatened; LC—Least Concern; DD—Data Deficient), and percentage of threatened species for each habitat category

Habitat category	IUCN Red List category							
	CR	EN	VU	NT	LC	DD	Total	% threatened
Forest	3	18	37	25	120	4	207	28
Savanna	0	1	7	12	53	1	74	11
Shrubland	1	16	20	16	110	1	164	22
Grassland	0	8	18	15	86	2	129	20
Wetlands (inland)[a]	3	9	6	11	32	0	61	30
Rocky areas	0	2	4	2	20	0	28	21
Desert	0	1	5	4	29	0	39	15
Marine neritic[a]	0	11	5	5	24	0	45	35
Marine oceanic[a]	0	8	4	1	22	0	35	34
Marine intertidal[a]	0	9	6	7	21	0	43	35
Marine Coastal/supratidal[a]	0	10	7	6	25	0	48	35
Artificial/terrestrial	3	3	12	12	82	1	113	16
Artificial/aquatic and marine[a]	0	3	2	5	4	0	14	36
Introduced vegetation	0	0	0	0	5	0	5	0
Other	0	1	3	0	9	0	13	31

[a]Aquatic habitats

Table 2 Number of carnivore species in each IUCN Red List Category (CR—Critically Endangered; EN—Endangered; VU—Vulnerable; NT—Near Threatened; LC—Least Concern; DD—Data Deficient) and percentage of threatened species for each land region

Land region	IUCN Red List Category							
	CR	EN	VU	NT	LC	DD	Total	% threatened
North America	1	3	5	4	42	0	55	16
Mesoamerica	1	4	4	4	34	0	47	19
South America	0	8	5	11	36	0	60	22
Caribbean Islands	0	0	1	0	5	0	6	17
Europe	1	2	5	1	26	0	35	23
North Africa	0	2	4	2	25	0	33	18
Sub-Saharan Africa	0	6	15	8	63	3	95	22
West and Central Asia	1	4	8	3	39	0	55	24
North Asia	1	5	8	4	34	0	52	27
East Asia	0	6	14	6	45	1	72	28
South and Southeast Asia	0	10	17	9	47	2	85	32
Oceania	0	3	0	0	15	0	18	17
Antarctic	0	0	0	0	7	0	7	0

ecoregion designations (Olson et al. 2001). We excluded range polygons with presence classified as 'possibly extinct,' 'extinct,' and 'uncertain,' with origin classified as 'introduced,' 'vagrant,' or 'uncertain,' and those ecoregions classified as 'rock and ice' and 'lake.'

Threats

Threats affecting wildlife are also documented in the Red List according to three levels of hierarchy. They include both human activities and natural elements or processes that have affected, are affecting or may affect the conservation status of a species. The first of these hierarchy levels groups 12 general types of threats, which are broken down into more specific ones (Table 3). For example, a first level threat type called "Biological resource use" is composed of several more specific threat types for level 2, such as "Hunting and trapping terrestrial animals" and others. In this study, only first level threats have been considered, except for "Biological resource use", which has also been analysed up to the second level, as it is the most frequently listed threat. We compare the number and proportion of species affected by each of the different threat categories by Chi-square tests.

Table 3 Number and percentage of carnivore species (total and threatened) affected by each of the 12 main threat categories. Second level categories of "Biological resource use" are also shown

Threat category	Species affected		Threatened species affected	
	n	%	*n*	%
Residential and commercial development	86	29.6	37	47.4
Agriculture and aquaculture	138	47.6	58	74.3
Energy production and mining	43	14.8	25	32.0
Transportation and service corridors	84	28.9	40	51.3
Biological resource use	246	84.8	75	96.1
Hunting and trapping terrestrial animals	204	70.3	63	80.7
Gathering terrestrial plants	19	6.5	10	12.8
Logging and wood harvesting	92	31.7	41	53.8
Fishing and harvesting aquatic resources	50	17.2	19	24.3
Human intrusions and disturbance	38	13.1	19	24.3
Natural system modifications	61	21.0	25	32.0
Invasive and other problematic species, genes and diseases	99	34.1	37	47.4
Pollution	58	20.0	24	30.7
Geological events	3	1.0	3	3.8
Climate change and severe weather	60	20.7	27	34.6
Other options	7	2.4	3	3.8

Results

Conservation status

Of the 290 carnivore species analysed, 78 (26.9%) are considered threatened, most of these being Vulnerable (43), and a further 30 (10.3%) are classified as Near Threatened. Currently, only six carnivore species are classified as Data Deficient, half of which are mustelids (Fig. 1). Of the total 5881 extant mammals, excluding two Extinct in the Wild (the white oryx *Oryx dammah* and Father David's deer *Elaphurus davidianus*), 1333 (22.7%) are threatened. Thus, the proportion of threatened species is higher in the order Carnivora than in the class Mammalia, although not significantly ($\chi^2 = 2.6$, $df = 1$, $p = 0.09$).

The percentage of threatened species differs significantly among carnivore families ($\chi^2 = 22.8$, $df = 8$, $p = 0.004$). Excluding single-species families, Eupleridae has the

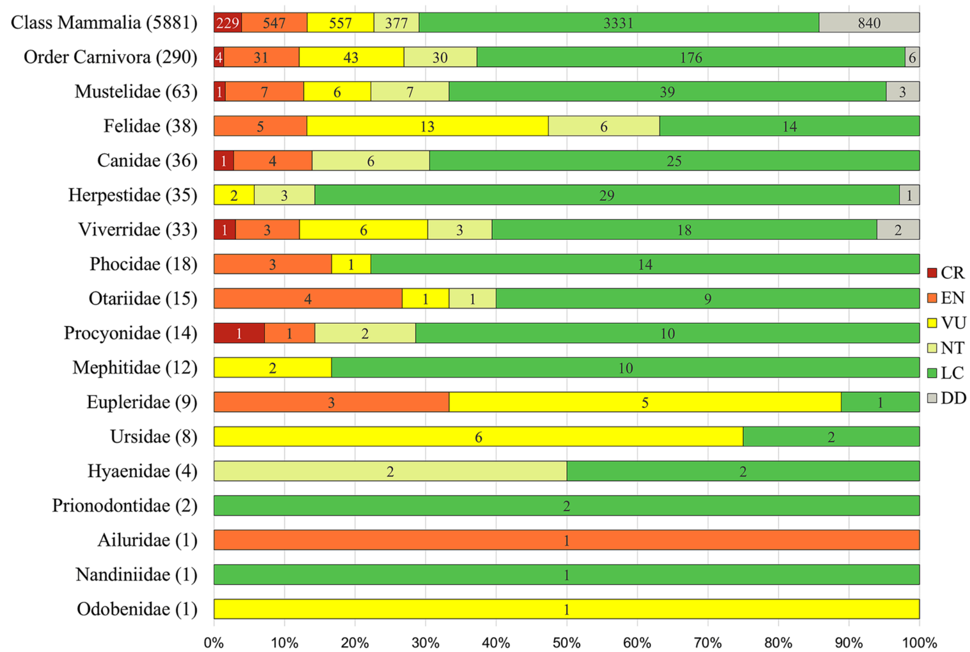

Fig. 1 Percentage and number (within bars) of extant carnivore species within IUCN Red List Categories (Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD)), for the order, each family and all mammals

highest proportion of threatened species (88.9%), followed by Ursidae (75%) and Felidae (47.3%; Fig. 1). In contrast, Hyaenidae, Prionodontidae and Nandiniidae do not have any threatened species, while Herpestidae, Canidae, and Procyonidae only have 5.7%, 13.9% and 14.3% of threatened species, respectively (Fig. 1).

1879 (31.9%) mammals are in decline, whilst 24.1% maintain their population trends stable and only 84 (1.4%) species show an increasing population trend (Fig. 2). In contrast, 140 (48.3%) carnivore species have decreasing trends, 70 (24.1%) have stable populations and a small minority of 21 (7.2%) species have an increasing population trend (Fig. 2). The proportion of species with declining populations differs significantly between the order Carnivora and the class Mammalia ($\chi^2 = 32.7$, $df = 1$, $p < 0.001$). Ailuridae (100%), Prionodontidae (100%), Eupleridae (100%), Procyonidae (78.6%) and Felidae (76.3%) showed the highest proportions of declining species among all carnivore

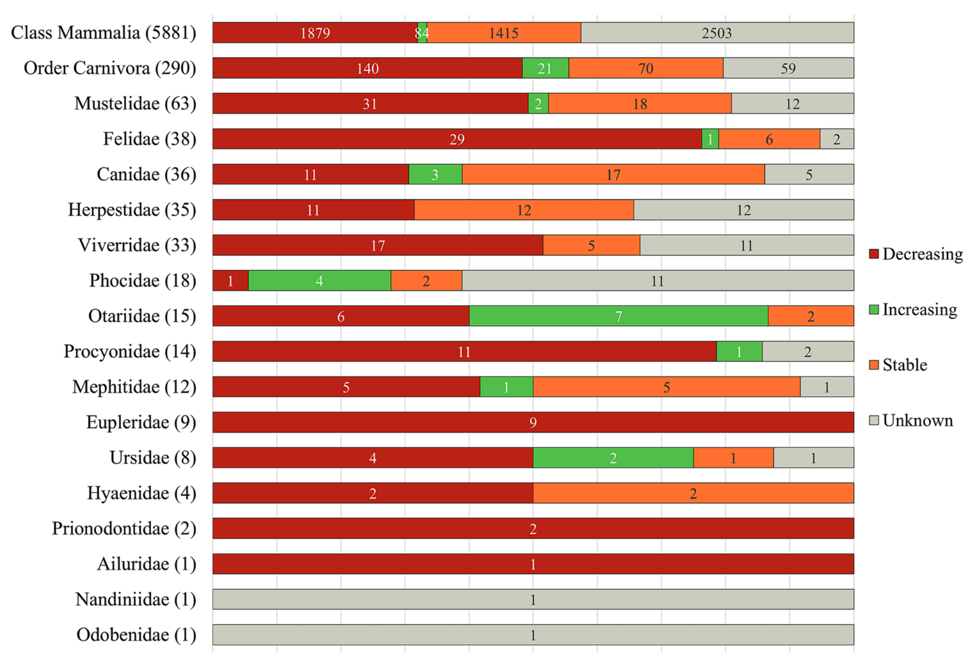

Fig. 2 Percentage and number (within bars) of extant carnivore species with the direction of population trends according to the IUCN Red List, for the order, each family and all mammals

families ($\chi^2 = 39.3$, $df = 8$, $p < 0.001$, Fig. 2). In contrast, Phocidae, Canidae, Herpestidae and Otariidae were the families with the lowest proportion of declining species, with 5.5%, 30.5%, 31.4% and 40.0% respectively (Fig. 2).

RLI values for carnivores were consistently lower than for mammals in general; for example, during the 2000s the RLI was 0.82 for carnivores and 0.86 for mammals (Fig. 3). Eupleridae, Ursidae, Felidae and Otariidae are the families whose RLI values are clearly lower than those of the other carnivore families (Fig. 3). Furthermore, Eupleridae showed the minimum RLI value (0.49 in the 2000s). Between the 1990s and 2000s, most families suffered a decline in their RLI values, the most notable being that of Felidae (decrease from 0.80 to 0.68; Fig. 3). On the other hand, Herpestidae, Mephitidae and Hyaenidae show the highest RLI values among all families, even reaching the value of 1 (Hyaenidae during the 1990s; Fig. 3). In addition, there is a small increase in the RLI values for Canidae, Ursidae, Felidae and Otariidae, among others, between the 2000s and 2010s, while other families remained stable (Herpestidae, Hyaenidae, Procyonidae and Viverridae) and others even worsened, such as Mephitidae and Mustelidae (Fig. 3).

Habitat

Forest is the habitat used by the most carnivore species (207), followed by shrubland (164) and grassland (129), while "Introduced vegetation" and "Other" (5 and 13 species respectively) were the least frequent habitats for carnivores (Table 1). Moreover, the proportions of threatened species differed significantly between the 15 habitat types ($\chi^2 = 31.2$, $df = 14$, $p = 0.005$). Of all species using forests, 58 (28%) are globally threatened and about a third of the species using aquatic habitats are also threatened, although the latter are used by fewer species (Table 1). Approximately, one-fifth of carnivore species living in shrublands, grasslands and rocky areas are threatened. In particular, shrublands have more threatened species (37) than the other two (26 and 6 respectively; Table 1). On the other hand, the habitats with the lowest proportion of threatened species were savannas (11%) and deserts (15%; Table 1).

Distribution patterns

South–Southeast Asia and East Asia, together with sub-Saharan Africa, have the highest number of carnivore species (85, 72 and 95 species respectively; Table 2). In addition, South–Southeast Asia and East Asia are the regions with the highest proportion of threatened and declining species, followed closely by North Asia (Table 2, Fig. 4). On the other hand, North America and Mesoamerica, despite having a large number of carnivores (55 and 47 species respectively), showed a proportion of threatened species below 20% (Table 2). Oceania, Caribbean Islands and Antarctica are the regions with the lowest number of carnivore species, and the lowest proportion of threatened carnivores (Table 2). Comparing the 13 continental regions, the proportions of threatened species were not significantly different ($\chi^2 = 9.9$, $df = 12$, $p = 0.62$). By country, India (59) and China (57), followed by the USA (49), Myanmar (48) and Russia (47), are the richest countries in the number of carnivore species. Moreover, India (18, 36), Myanmar (17, 33) and China (17, 32) hold the highest amount of threatened and declining species. Worryingly, eight (88.9%) of Madagascar's terrestrial carnivore species are threatened and all nine are declining (Fig. 4). The five most carnivore species-rich ecoregions are found along the Himalayas, with 43 or more species each, followed by the East Sudanian Savanna of central and east Africa with 42 species (Fig. 5). The highest numbers of threatened carnivore species are found in the Thailand semi-evergreen rain forests and the Myanmar coast mangroves (16 and 15 species, respectively, Fig. 5). The Thailand semi-evergreen rain forests and the Eastern Himalayan broadleaf forests have the highest number of declining carnivores (30 species each; Fig. 5).

Threats

The proportions of species affected by each of the 12 main threat categories were significantly different ($\chi^2 = 837.16$, $df = 11$, $p < 0.001$). The most frequently cited threat for carnivores was "Biological resource use", affecting 84.8% of species (246 out of 290; Table 3). Within this type of threat, species are affected by several sub-categories, such as "Hunting and trapping terrestrial animals" which affects 204 species (70.3%), and "Logging and wood harvesting" or "Fishing and harvesting aquatic resources", which threatens 92 and 50 species, respectively (Table 3). "Agriculture and aquaculture" is the second most frequent threat to carnivores, affecting 138 species (47.6%). "Invasive and other problematic species, genes and diseases" poses a threat to the third highest number of carnivore species (99, 34.1%; Table 3). Likewise, "Residential and commercial development" and "Transportation and service corridors" are important threats because they each affect about a third of carnivores. Threatened carnivore species follow similar patterns (Table 3) and the proportions of threatened species also differ significantly among the 12 main threat categories ($\chi^2 = 254.64$, $df = 11$, $p < 0.001$).

Discussion

Conservation status

Our results indicate that carnivores are proportionally more threatened and declining than all mammals in

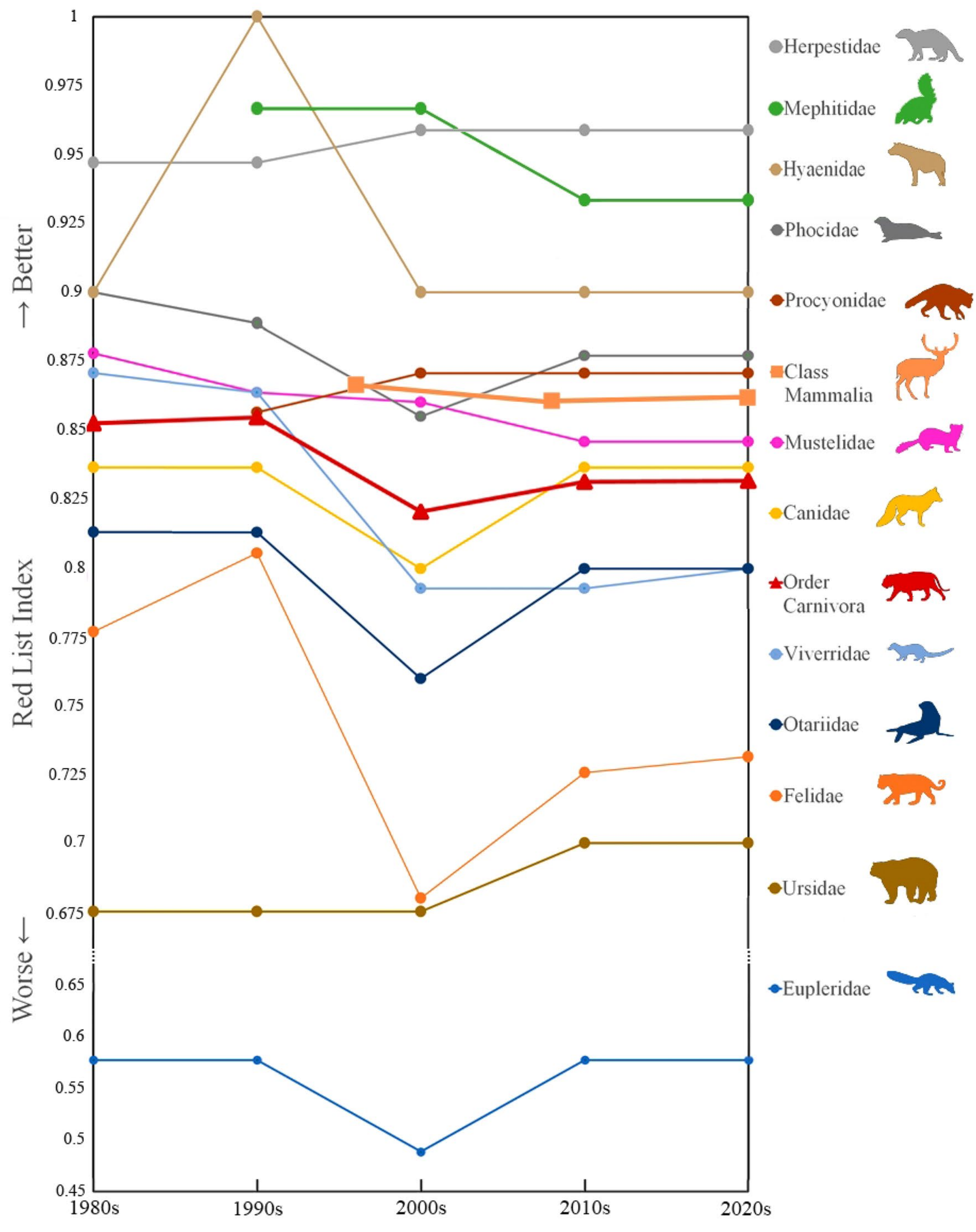

Fig. 3 Red List Indices for 1980–2020 for the order Carnivora, its families and all mammals. Note that the *y*-axis changes scale and only families with four or more species are shown. The rest of the species remain stable in their category (*Prionodon pardicolor* LC; *Prionodon linsang*LC; *Nandinia binotata* LC) except *Ailurus fulgens* (which changes from EN to VU in 2008 and back to EN in 2015) and *Odobenus rosmarus* (which changes from LC to DD in 2008 and to VU in 2016). Information related to all mammals (years 1996 and 2008) was obtained from Hoffmann et al. (2011) and updated from the IUCN Red List for 2020 (IUCN 2021)

general (26.9% vs. 22.7% of threatened species and 48.3% vs. 31.9% of declining species, respectively). Information on the risk of extinction and on the population trends of species are two key factors in the conservation of global biodiversity (Ceballos et al. 2017; Brooks et al. 2006). The global loss of carnivores is alarming for several reasons.

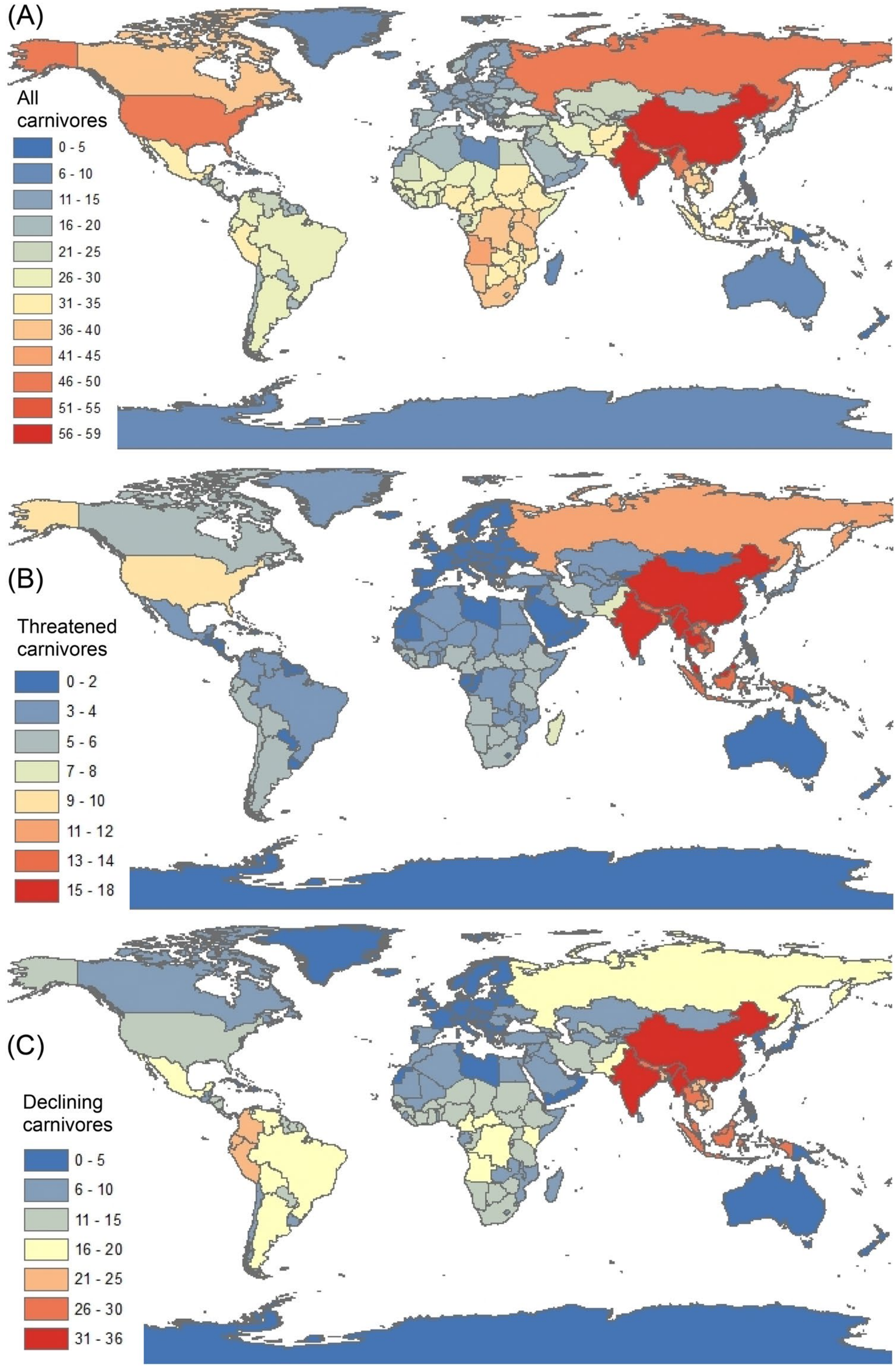

Fig. 4 Maps showing the number of **A** total, **B** threatened or **C** declining extant carnivore species per country according to the UICN Red List. Note that the colour scale ranges from red, indicating many species, to blue, indicating few species

On the one hand, carnivores often play a key role within ecosystems, as they control the numbers and behaviour of other species, so their disappearance or decline can have cascading effects that alter the integrity of the ecosystem (Noss et al. 1996; Ripple et al. 2014). On the other hand, the decline of carnivores may impact human well-being through the loss of the ecosystem services they provide, such as carcass and waste disposal, zoonotic disease regulation, herbivore control and increased crop production, among others (O'Bryan et al. 2018). Finally, the loss of charismatic and flagship carnivores may, in some cases, encourage disinterest in biodiversity conservation where they disappear (Jepson and Barua 2015).

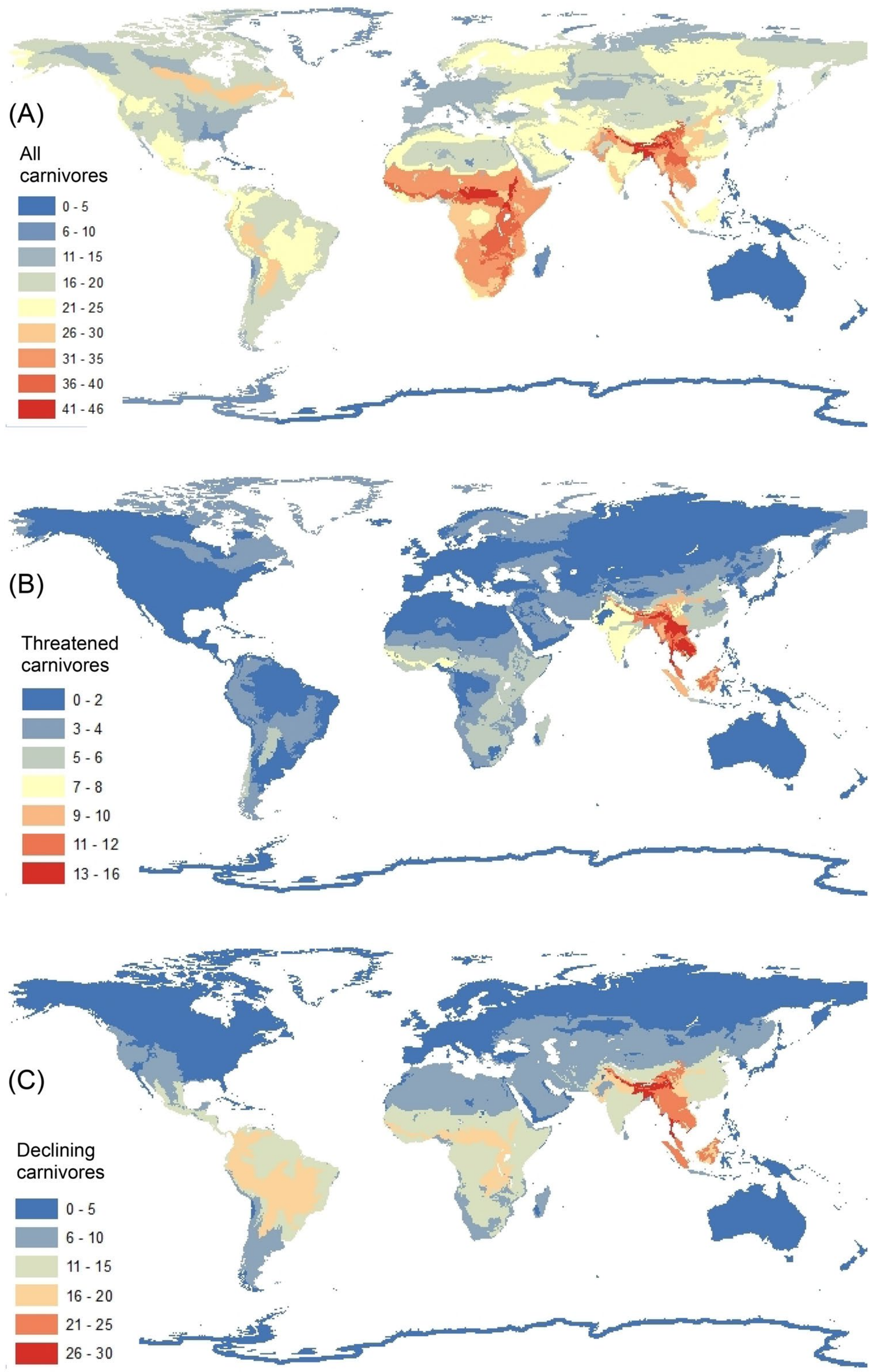

Fig. 5 Maps showing the number of **A** total, **B** threatened or **C** declining extant carnivore species per ecoregion according to the UICN Red List. Note that the colour scale ranges from red, indicating many species, to blue, indicating few species

RLI values for carnivores are also worse compared to all mammals. In the last update of the Red List Index, carnivores are more threatened (i.e. have lower index values) than mammals in general (0.83 vs 0.86). Overall, RLI values for carnivore families worsened until the 2000s (from the 1990s to the 2000s, 57 carnivores were classified in a higher threat category and 27 in a lower category) and then seem to stabilise and improve slightly in more recent years (from the 2000s to the 2010s, 26 carnivores were classified in a higher threat category and 30 in a lower category), indicating that generally, over the last two decades, the loss of carnivore diversity has not accelerated. However, this should not lead us to lower vigilance, and we should aim to improve these values; therefore, more effective and interdisciplinary conservation actions are still urgently needed to prevent carnivore decline and restore carnivore populations (Carter et al. 2014).

Within the order Carnivora, there are four families that stand out for their poor state of conservation, below the average for the rest of the carnivores. Eupleridae is the most threatened carnivore family, with eight of its nine species listed as Endangered or Vulnerable, all of them are in decline, and with the worst RLI values. This group is endemic to Madagascar, a region recognised as a clear priority for biodiversity conservation, due to its large number of endemics and the wide range of threats facing its fauna and flora, such as habitat destruction and fragmentation and poaching (Vieilledent et al. 2018; Willcox 2020; Broekman et al. 2022).

The bear family (Ursidae), with six of the eight species threatened, and half of the species in population decline, has the second worst conservation status among carnivores. Historically, bears have always had conflicts with human populations (Lozano et al. 2019; Trajçe et al. 2019). Recently, however, their important role in regulating their prey populations has been recognised and they are often the focus of many conservation efforts (Ripple et al. 2014). Fortunately, numerous conservation programmes have succeeded in slowing the rate of decline of local bear populations (Penteriani and Melletti 2020), as in the case of the giant panda (*Ailuropoda melanoleuca*), a flagship species that has been the focus of one of the most intensive efforts to recover an endangered species (Swaisgood et al. 2016).

Felidae is the second largest family within Carnivora and the third most threatened, with 18 of the 38 species listed as Endangered or Vulnerable and 76.3% of the species in decline. Among all carnivores, Felidae has suffered the greatest decline in RLI between the 1990s and 2000s (0.80 vs. 0.68; Fig. 3). Despite the fact that this negative trend has been reversed in the last two decades, the RLI values of the 1990 decade have not been recovered. This is a charming group for the public and has received a lot of research effort, so it is particularly well studied, especially their large species (Ripple et al. 2014). This is probably because big cats are more charismatic and easy-to-study species than other smaller species (Tisdell et al. 2005), although there are also advances in research on small and understudied cats (Brodie 2009). Conservation efforts towards this group have included the protection of their habitats, the recovery of their prey populations, and even the reintroduction of captive-bred specimens, as in the case of the Iberian lynx (*Lynx pardinus*), where it has been shown that the positive opinion of society is fundamental to the success of these programmes (Delibes-Mateos et al. 2022).

Finally, one-third of Otariidae species are threatened (5 out of 15), and 40.0% show a global population decline. This family, along with Phocidae and Odobenidae (known as the Pinnipedia suborder), have been toughly persecuted throughout history, mainly for their meat and fat, but also for their potential role as competitors to fishermen. Currently, entanglement and accidental mortality in fishing nets, pollution and climate change pose the main threats to this group (Kovacs et al. 2012; Würsig et al. 2018).

At the other extreme, the high RLI values (> 0.95) and the low percentage of threatened species within the Herpestidae family (only 2 out of 35) may be due to a combination of different factors such as the wide distribution range of most species, their small–medium body size, their discreet and elusive behaviour, and, although scientific information is scarce, their low conflict with humans (Nowak 2005). However, 31.4% of herpestid species show an overall decline in their populations.

Hyaenidae also have high RLI values (> 0.9), which means that suitable habitats for some of their species are widely distributed, contributing to their good conservation status compared to other carnivores. Even in some cases, human presence attracts carnivores rather than generating conflict, as is the case in some human-dominated landscapes in Ethiopia, where the abundance of spotted hyenas (*Crocuta crocuta*) is up to 15 times higher than in more natural areas (Yirga et al. 2015). However, low population size, together with the lack of food and shelter owing to competition with other carnivores and human activities, may be factors contributing to the decline of other hyena species and populations (Derouiche et al. 2020).

Habitat

Our review indicates that forest is the habitat used by most carnivore species (71.4%), following the same pattern as approximately 80% of terrestrial species (Lindenmayer and Franklin 2003). In addition, carnivores inhabiting forests have the highest proportion of globally threatened species (28%), second only to that of those carnivores occurring in aquatic habitats, although the latter are used by far fewer species (Table 1). Threat to a high proportion of forest carnivores can be explained by the continuing massive destruction of their habitats: around 4.2 million km^2 of forest have been cleared worldwide since 1990 (FAO and UNEP 2020). Forest protection is therefore essential for the conservation of carnivores and global biodiversity (Brooks et al. 2006).

Shrubland and grasslands are also used by large numbers of carnivores, many of which are threatened. In the past decades, many areas of shrubland and grassland areas have disappeared to make way for the development of cropland, pastures and urbanised areas (Goldewijk et al. 2011; Fuller and DeStefano 2003). Efficient management of scrub and grasslands habitats, where vegetation cover remains heterogeneous, can be an effective way to protect carnivores in these environments, as showed in some areas of the USA and Europe (Fuller and DeStefano 2003; Lozano et al. 2003).

Carnivore species that occur in aquatic habitats have the highest percentages of globally threatened species (around 35%; Table 1). Like aquatic mammals, aquatic or semi-aquatic carnivores have become critically endangered or even extinct over the recent decades (Veron et al. 2007). Due to their special habitat requirements and, in some cases, to their social breeding behaviour, these species are usually affected by a greater number of types of threats than terrestrial species (Schipper et al. 2008). Furthermore, knowledge about some marine carnivores (mainly Otariidae and Phocidae) is comparatively much lower than that of their terrestrial counterparts, which makes the design and implementation of conservation plans very difficult (Kovacs et al. 2012; Würsig et al. 2018).

Distribution patterns

The global distribution patterns of carnivores are quite similar to those of the class Mammalia, with tropical regions containing the majority of carnivore species (Schipper et al. 2008; Wilson et al. 2009). Sub-Saharan Africa, South and Southeast Asia, and East Asia stand out as the regions with the highest species richness and therefore of great importance for carnivore conservation. In fact, South and Southeast Asia are home to 85 carnivore species and have the highest proportion of threatened species, and nine of the ten countries with the highest number of threatened carnivores belong to South or East Asia, most notably India, China and Myanmar (Fig. 4). It is well known that these regions have seen a marked increase in agricultural expansion (mainly palm oil and rice crops), deforestation and hunting, which are highly detrimental threats to wildlife and in particular carnivores (Wikramanayake et al. 2008). The need for immediate actions to protect the biodiversity of these regions has already been stressed in several studies (Brooks et al. 2006; Duckworth et al. 2012; McClure et al. 2018).

Excluding Madagascar, which contains the highest concentration of globally threatened carnivores in the world, and which faces an alarming biodiversity crisis (Willcox 2020), the proportion of threatened carnivores in African countries is moderate (Figs. 4, 5). African large carnivores are probably the most iconic and charismatic mammals and provide enormous economic benefits associated with tourism (Winterbach et al. 2013). However, much of this tourism consists of trophy hunting, which can seriously interfere with the stability of carnivore populations (Packer et al. 2009). A strong proliferation of small (mostly fenced) ecotourism and game reserves has emerged across Africa (Winterbach et al. 2013). In addition to the fact that managing these small reserves can be complicated, some studies indicate that a small number of large areas may be more effective for carnivore conservation than many small ones (Ripple et al. 2014). The Kruger National Park is an example of proper management, where priority is given to the conservation of the whole ecosystem and its natural fluctuations. Without the presence of carnivores, these fluctuations (especially in prey density) are more drastic (Ray, 2005). In addition, the presence of apex predators such as lions (*Panthera leo*) is associated with slightly richer mesocarnivore communities, even though their local abundance appears to be lower in their presence (Curveira-Santos et al. 2021).

In the last century, North America came close to completely exterminate some carnivores, even in sparsely populated areas (Woodroffe 2000; Wilcove et al. 1998). However, many carnivores have experienced recent population growth following the implementation of pro-conservation legislation (Linnell et al. 2001). Whereas increasing human populations may seem counter to carnivore conservation, certain elements of anthropogenic modernisation, for instance, the mechanisation of agricultural practices or the concentration of human populations in cities, may facilitate conservation actions by reducing the conflicts that carnivores may pose to livestock or human welfare (Expósito-Granados et al. 2019; Bruskotter et al. 2017). Like in Africa, the economic benefits associated with large carnivore tourism have greatly promoted the development of large carnivore conservation plans in North America. However, several carnivore species, such as the mountain lion (*Puma concolor*), continue to suffer population declines and range contractions on this continent due to habitat loss and prey reduction caused by human activities (Laliberte and Ripple 2004; Ripple et al. 2014).

Human–carnivore conflict is a very old concept, especially in Europe, where considerable efforts have been made for centuries to eradicate large carnivores (Bruskotter et al. 2017). However, some large carnivores in Europe have recently experienced a slight recovery and even population growth despite high human populations (Chapron et al. 2014; Llaneza et al. 2011) and the scarcity of unfragmented or undisturbed landscapes (Trajçe et al. 2019). The expansion of areas with less human presence due to rural exodus may have largely contributed to the reintegration of large carnivores in Europe (Wolf and Ripple 2016). This recovery suggests that they are capable of thriving in human-modified landscapes, and that coexistence with humans in developed, densely populated countries is feasible, at least where effective conservation policies are in place (Linnell et al. 2001). In Europe, a huge effort is being made to conserve large carnivores as an ecological functional group, with the main objective of reconciling carnivore recovery with the maintenance of human well-being in shared landscapes (Boitani et al. 2015; Carter and Linnell 2016; Delibes-Mateos et al. 2022). Nonetheless, the conservation of carnivores remains somewhat constrained by the fact that the European landscape has been modified over millennia and by the degree of tolerance local human populations have towards the presence of these species (Kleiven et al. 2004).

In Australia, since European colonisation, invasive carnivores including foxes (*Vulpes vulpes*) or feral cats (*Felis silvestris catus*) have led to the decline and extinction of a wide range of native species (Glen and Dickman 2005; Johnson et al. 2006). Recent conservation plans are beginning to focus on the recovery of a key native carnivore, the dingo (*Canis lupus dingo*), to conserve other animal and plant species, as well as to control and minimise the impact of invasive species (Johnson et al. 2006; Letnic et al. 2011).

Threats

"Hunting and trapping", within "Biological resource use" category, is the main threat to carnivores (Table 3) and a major driver of biodiversity loss worldwide (Benítez-López et al. 2017). Direct persecution often leads to a decline in carnivore abundance and, when focused on trophy hunting, can have catastrophic effects on population health and stability (Packer et al. 2009). The use of illegal, and sometimes permitted, non-selective trapping methods can have serious impacts on target and non-target populations and threaten carnivore conservation (Ripple et al. 2014; Virgós et al. 2016). In addition, prey depletion because of poaching can be equally important for carnivore maintenance; however, more research is needed in this regard (Wolf and Ripple 2016; Wright et al 2022). As a result, some large carnivores have adapted to prey on a wide variety of species, even hunting smaller prey when larger prey become scarce due to human hunting (Wolf and Ripple 2016).

"Logging and wood harvesting" and "Agriculture and aquaculture" are also common threats to carnivores. Throughout history, humans have modified most natural landscapes, often through deforestation for agricultural and livestock expansion (Goldewijk et al. 2011). These changes often lead to the extinction of local carnivore populations or force them into a matrix of humanised environments (Trajçe et al. 2019; Wikramanayake et al. 2008). Whereas most carnivores are particularly vulnerable to local extinction in fragmented landscapes (Crooks 2002), some of them have been reported to use the humanised matrix as ecological corridors or supplementary habitats (Ferreira et al. 2018). Many studies have also highlighted logging and habitat destruction and alteration as major threat to carnivores and other wildlife globally (Wikramanayake et al. 2008; Barnosky et al. 2012; Tilman et al. 2017).

Emerging infectious diseases are one of the most pressing issues facing biodiversity conservation (Ceballos et al. 2017) and are also relevant for carnivore conservation (Murray et al. 1999). The impact of these diseases can become fatal (McCarthy et al. 2007), such as that caused by the canine distemper virus, which is transmitted by domestic animals (Murray et al. 1999). Due to their superior position in ecological food chains, contaminants, including heavy metals, can severely affect terrestrial and marine carnivores (Schipper et al. 2008; Würsig et al. 2018). Nevertheless, cause–effect relationships are not fully studied outside theoretical frameworks (Rodríguez-Estival and Mateo 2019). It is therefore essential to establish effective, long-term monitoring programmes to measure the extent of diseases and contaminants and their impact on carnivore populations.

Conclusions

The order Carnivora has an unfavourable global conservation status, and, within mammals, the conservation of carnivores should be a priority. Despite the fact that general knowledge of carnivores is quite good and we know a lot about certain species, there is still a lack of information about many carnivores, and basic information is still needed on the ecological requirements of many species and on their population sizes and trends. The global assessment provided by the IUCN Red List needs to be reviewed and updated at regional and local levels and, in general, current conservation actions for this group should be substantially improved and focused on the most threatened species, habitats and regions (Ceballos et al. 2017; Brooks et al. 2006). There is a particularly urgent need to enhance the protection and management of carnivore habitats, especially forest, shrubland and grassland, and to step up efforts to prevent mortality caused by direct persecution. In addition, long-term monitoring of their populations would help to guide more effective and faster-response conservation plans. Even though the perspectives for carnivore populations globally are quite adverse, particularly in South and Southeast Asia, there is still reason for optimism. It has been shown that strategic and targeted conservation actions, such as the restoration and management of prey species and the conservation translocations to restore species to parts of their former range, can significantly improve the conservation status of carnivores (Chapron et al. 2014; Hoffmann et al. 2010; Wright et al. 2022). Moreover, as keystone species, carnivore conservation has the potential to benefit biodiversity, as well as ecosystem functioning (Sergio et al. 2008; Ray 2005). National authorities, with the support of other stakeholders, including international cooperation, should accelerate their efforts to safeguard these ecologically and culturally important species within their territories.

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