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Research

Carnivores' contributions to people in Europe

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ABSTRACT. Human-carnivore relations in Europe have varied throughout history. Because of recent conservation efforts and passive rewilding, carnivore populations are recovering, which translates into more interactions with humans. Thus, unraveling these interactions as well as the multiple contributions carnivores provide to people is crucial to their conservation. We examined the literature conducted in Europe since 2000 and used the nature's contributions to people (NCP) framework to identify factors that have shaped human-carnivore relations. To do so, we examined the state of scientific knowledge and relationships among types of NCP from carnivores, countries, and carnivore species; and between NCP, actors, and management actions. Results indicated that research has been oriented toward large carnivore species and their detrimental contributions to people. Further, the effectiveness of carnivore management strategies has only been evaluated and monitored in a limited set of all the research. To balance any negative views on carnivores, we suggest that the recognition of the duality of carnivores, as providers of both beneficial and detrimental contributions, should be included in EU conservation policies.

Key Words: *conservation conflict; ecosystem service; human-carnivore interactions; human-nature framing; human-wildlife conflicts; nature's contributions to people; nature's values; social-ecological systems*

INTRODUCTION

According to the latest report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), approximately 20% of the planet's species have gone extinct and almost half of terrestrial mammals (47%) are at risk of extinction (Díaz et al. 2018a, b, IPBES 2019). This increasing rate of extinction also includes carnivores (Chapron et al. 2014, Ripple et al. 2014, Hindrikson et al. 2017). However, recent research reports that, in Europe, carnivore populations are recovering in large parts of the territory, even outside of protected areas. This has been in part due to more protective legislation across Europe (Chapron et al. 2014, Terraube et al. 2020). Despite this progress, carnivore conservation has become intertwined with broader emotional, political, and socioeconomic issues that further complicate this endeavor. As a consequence, the recovery of carnivores in Europe yet brings the challenge of implementing new strategies that engage with the complexity of social-ecological interactions and that give insights for people and carnivores coexistence (Frank et al. 2019, Wilkinson et al. 2020).

The IPBES framework introduced the concept of nature's contributions to people (NCP), defined as all contributions, beneficial or detrimental, which individuals, communities, societies, nations, or humanity as a whole derive from nature (Díaz et al. 2018a). The NCP framework specifically recognizes the diverse and culturally mediated ways that people interact with nature (Díaz et al. 2018a, Hill et al. 2021). The NCP framework explicitly recognizes the dual role of nature as provider of beneficial and/or detrimental contributions to people's quality of life (Díaz et al. 2018a, b). By beneficial contributions, we refer to the direct and indirect benefits that humans obtain from biodiversity that support human well-being (Díaz et al. 2018a, b). Examples of beneficial contributions include disease regulation (Tanner et al. 2019), biological control (Britton et al. 2017), removal of animal carcasses (Moleón et al. 2014), seed dispersal (Cancio et al. 2017), and non-material contributions, such as, for example, recreational and aesthetic experiences or learning and inspiration opportunities (Aguilera-Alcalá et al. 2020, Tattoni et al. 2023). Conversely, detrimental contributions refer to ecosystem-generated functions, processes, and attributes that result in perceived or actual negative impacts on human well-being (Shackleton et al. 2016). Some of the most widely documented detrimental contributions (Lozano et al. 2019) are livestock predation (Petridou et al. 2019), competition for game species (Lozano et al. 2013), damage to fisheries (Grant and Harrington 2015), and attacks on humans or fear of being attacked (Bisi et al. 2007). For this study, we state that to understand the full spectrum of human-carnivore relations, carnivores must be perceived simultaneously as providers of both beneficial and detrimental contributions to people depending of the context (Carter et al. 2014, Lozano et al. 2019).

Taking into account the complexity of human-carnivore relations, this article uses the IPBES lens to analyze the role of carnivores in Europe as providers of both beneficial and detrimental NCP. To do so, we conducted a systematic review of the scientific literature on human-carnivore relations in Europe published between 2000 and 2019. First, we characterized scientific knowledge on the human-carnivore relations in Europe according to the spatial and temporal distribution of the research, species of carnivores and biomes, social actors, and whether the research consider their perceptions, values, and knowledge. Second, we explored the diversity of beneficial and detrimental NCP provided by carnivores in Europe. Third, we explored the management measures suggested according to the studied beneficial and detrimental NCP. Finally, we discussed emerging trends of European research on human-carnivore relations and implications for future research.

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METHODS

Systematic review

The systematic review examined scientific articles written in English addressing any type of human-carnivore relation, with an emphasis on detrimental NCP (i.e., damages, disservices or conflicts) or beneficial NCP (i.e., benefits or ecosystem services) provided by carnivores in Europe. For this purpose, we used the Scopus database and followed the guidelines of Pullin and Stewart (2006). This review used the search string used by Lozano et al. (2019), which included four main elements: (1) beneficial NCP, (2) detrimental NCP, (3) human-carnivore relations, and (4) carnivore taxa. The terms searched in the title, abstract, or keywords were as follows.

1. Regarding human-carnivore relations:

a. Ecosystem services: "ecosystem service*" OR "ecosystem good*" OR "environmental service*" OR

b. Conflicts and damages: "conflict*" OR "damage*" OR "impair*" OR "harm*" OR

c. Human-carnivore relations: "human-wildlife" OR "human-carnivore*" OR

"human-felid*" OR "human-canid*" AND

2. Regarding taxonomy of carnivores:

a. Order: "carnivore*" AND "mammal" OR

b. Genera: "Ailurus" OR "Atelocynus" OR "Canis" OR "Cerdocyon" OR "Chrysocyon" OR "Cuon" OR "Dusicyon" OR "Lycalopex" OR "Lycaon" OR "Nyctereutes" OR "Otocyon" OR "Speothos" OR "Urocyon" OR "Vulpes" OR "Cryptoprocta" OR "Eupleres" OR "Fossa" OR "Galidia" OR "Galidictis" OR "Mungotictis" OR "Salanoia" OR "Acinonyx" OR "Caracal" OR "Catopuma" OR "Felis" OR "Leopardus" OR "Leptailurus" OR "Lynx" OR "Neofelis" OR "Panthera" OR "Pardofelis" OR "Prionailurus" OR "Profelis" OR "Puma" OR "Uncia" OR "Atilax" OR "Bdeogale" OR "Crossarchus" OR "Cynictis" OR "Dologale" OR "Galerella" OR "Helogale" OR "Herpestes" OR "Ichneumia" OR "Liberiictis" OR "Mungos" OR "Paracynictis" OR "Rhynchogale" OR "Suricata" OR "Crocuta" OR "Hyaena" OR "Proteles" OR "Conepatus" OR "Mephitis" OR "Mydaus" OR "Spilogale" OR "Aonyx" OR "Arctonyx" OR "Eira" OR "Enhydra" OR "Galictis" OR "Gulo" OR "Hydrictis" OR "Ictonyx" OR "Lontra" OR "Lutra" OR "Lutrogale" OR "Lyncodon" OR martes OR "Meles" OR "Mellivora" OR "Melogale" OR "Mustela" OR "Neovison" OR "Poecilogale" OR "Pteronura" OR "Taxidea" OR "Vormela" OR "Nandinia" OR "Bassaricyon" OR "Bassariscus" OR "Nasua" OR "Nasuella" OR "Potos" OR "Procyon" OR "Ailuropoda" OR "Helarctos" OR "Melursus" OR "Tremarctos" OR "Ursus" OR "Arctictis" OR "Arctogalidia" OR "Chorogale" OR "Civettictis" OR "Cynogale" OR "Diplogale" OR "Genetta" OR "Hemigalus" OR "Macrogalidia" OR "Paguma" OR "Paradoxurus" OR "Poiana" OR "Prionodon" OR "Viverra" OR "Viverricula"

The search considered all articles published between 2000 and 2019 and carried out in any European countries. In this sense, this study expands the systematic review conducted by Lozano et al. (2019) by considering the research published in European countries in 2017–2019 aiming at understanding new research on human-carnivore relations using an NCP lens. The obtained articles were then refined through a two-step process. First, the abstract, title, and keywords of the articles were read to check whether they were related to the goals of this review (we excluded non-empirical articles, reviews, and articles not conducted in Europe or not related to human-carnivore relations). In a second step, full texts of the articles included after the previous step were read. At this stage, we excluded articles mentioning only superficially aspects related to carnivores' beneficial or detrimental NCP or focused on strictly ecological research. This process yielded a set of 177 articles for in-depth analysis. See Figure 1 for detailed methods of the review process.

All variables were coded according to: (1) biome type (based on the Millennium Ecosystem Assessment, MA 2005); (2) carnivore family; (3) carnivore species; (4) beneficial NCP (i.e., whether the article mentioned, studied or considered the benefits provided by carnivores; based on Díaz et al. 2018b); (5) detrimental NCP (i.e., whether in the research carnivores were the source of damage

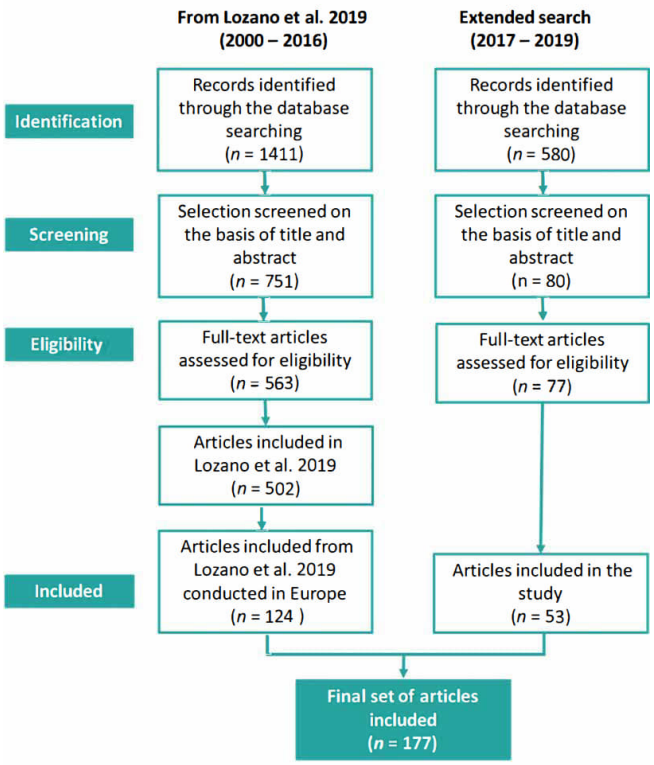


Fig. 1. Flow diagram of the selection process of the articles used in the systematic review of the human-carnivore relations in Europe. The search process expands the systematic review conducted by Lozano et al. (2019) by considering the research published in European countries in 2017–2019 aiming at understanding new research on human-carnivore relations using a nature's contributions to people lens.

Table 1. Variables and their definitions used in the systematic review on human-carnivore relations in Europe. Modified from Lozano et al. (2019).

Variable	Description	Type of variable	References
Publication characteristics			
Year	Year of the publication	Quantitative	
Journal	Journal where the paper is published	Nominal	
Study area	Research site(s)	Nominal	
Country	Country where the research was conducted	Nominal	
Biological components			
Biome	Type of biome based on Millennium Ecosystem Assessment (MA 2005), which includes 12 dummy variables: (1) boreal forest, (2) temperate forest, (3) tropical forest, (4) temperate grassland, (5) tropical grassland, (6) mediterranean system, (7) arid system, (8) freshwater system, (9) coastal system, (10) island, (11) mountain, and (12) polar	Dummy: 0 (no) / 1 (yes)	MA 2005
Species of carnivore	Species of carnivores that are the object of research	Nominal	
Number of species	Number of species studied in the research	Quantitative	
Family	Taxonomic family of the species that is object of research. It includes 12 dummy variables: (1) Ailuridae, (2) Canidae, (3) Eupleridae, (4) Felidae, (5) Herpestidae, (6) Hyanidae, (7) Mephitidae, (8) Mustelidae, (9) Nandiniidae, (10), Procyonidae, (11) Uryesdae, (12) Viverridae	Dummy: 0 (no) / 1 (yes)	
Native or alien species	Whether the carnivore species are native or alien in the case study	Nominal	
Reintroduced	Whether the carnivore species have been reintroduced in the case study	Dummy: 0 (no) / 1 (yes)	
Beneficial nature's contributions to people (NCP)			
Providers	Whether carnivore species are considered as providers of beneficial NCP, ecosystem services, or benefits to people's quality of life in the paper	Dummy: 0 (no) / 1 (yes)	
Material	Whether the paper studied or identified material NCP from carnivores, i.e., benefits derived from material resources such as fur or skin	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2018
Regulating	Whether the paper studied or identified regulating NCP from carnivores, i.e., benefits derived from regulating processes	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2018
Non-material	Whether the paper studied or identified non-material NCP from carnivores, such as being the basis of recreational, cultural, or spiritual experiences	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2018
Number of beneficial NCP	Number of beneficial NCP provided by carnivores that are studied or identified in the research	Quantitative	
Detrimental nature's contributions to people (NCP)			
Detrimental NCP	Whether carnivore species are considered as source of detrimental contribution or conflict in the research	Dummy: 0 (no) / 1 (yes)	
Threats to biodiversity (detrimental regulating)	Whether the paper studied or identified the damage of biodiversity (non-game species) generated by carnivores, such as predation on endangered species	Dummy: 0 (no) / 1 (yes)	Lozano et al. 2019
Damage to human food (detrimental material)	Whether the paper studied or identified the damages caused by carnivores on crops, livestock, poultry, fisheries, and beehives	Dummy: 0 (no) / 1 (yes)	Peterson et al. 2010, Lozano et al. 2019
Damage to game species (detrimental material/non-material)	Whether the paper studied or identified damage caused by carnivores to game species	Dummy: 0 (no) / 1 (yes)	
Damage to human property (detrimental material)	Whether the paper studied or identified the damages caused by carnivores on human properties, including buildings and vehicles	Dummy: 0 (no) / 1 (yes)	Peterson et al. 2010, Lozano et al. 2019
Damage to human safety (detrimental non-material)	Whether the paper studied or identified direct attacks of carnivores to humans or transmission of diseases to humans	Dummy: 0 (no) / 1 (yes)	Peterson et al. 2010, Lozano et al. 2019
Human-human conflict (detrimental non-material)	Whether the paper studied or identified conflicts derived from human disagreements over carnivore management decisions	Dummy: 0 (no) / 1 (yes)	Peterson et al. 2010, Lozano et al. 2019
Number of detrimental NCP	Number of different conflicts generated by carnivores that are studied or identified in the research	Quantitative	
Human-nature connection			
Emotional	Whether the paper studied or identified emotional connection to carnivores, which are based on extended immersion in nature that may inspire and enliven one's spirit or can invoke strong affective responses	Dummy: 0 (no) / 1 (yes)	Ives et al. 2017
Experiential	Whether the paper studied or identified experiential connection to carnivores, which are based on outdoor sports and recreation, facilitated eco-adventure and field trips	Dummy: 0 (no) / 1 (yes)	Ives et al. 2017
Cognitive	Whether the paper studied or identified cognitive connection to carnivores, which are based on cognitive concepts, intellect, and information as obtained through education or media to satisfy the mind's curiosity and increase knowledge	Dummy: 0 (no) / 1 (yes)	Ives et al. 2017
Perceptions, values and traditional ecological knowledge (TEK)			
Perceptions	Whether the paper studied the way humans observe, understand, interpret, and evaluate carnivore species or experiences with carnivores	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2015, Lozano et al. 2019
Values	Whether the paper identified or elicited the values of carnivores, including intrinsic, relational, and instrumental values, as well as direct use value, indirect use value, bequest and existence values	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2015, Lozano et al. 2019
TEK	Whether the paper identified or elicited TEK related to cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment.	Dummy: 0 (no) / 1 (yes)	Díaz et al. 2015
Social actors	What social actors were considered in the paper	Nominal	
Type of social actor	Eleven dummy variables were considered as type of social actor: (1) rural residents, (2) commercial farmers (i.e., broad-scale producers of crop and animal products primarily for commercial sale) (Kansky et al. 2014), (3) subsistence farmers (i.e., small-scale crop and animal producers who primarily produce for subsistence or possibly for sale) (Kansky et al. 2014), (4) indigenous communities, (5) hunters, (6) urban residents, (7) general public, (8) tourists, (9) environmental NGOs, (10) environmental managers, and (11) other decision makers	Dummy: 0 (no) / 1 (yes)	Kansky et al. 2014, Lozano et al. 2019
Number of actors	Number of social actors considered in the paper	Quantitative	
Management actions	What management actions were considered in the paper	Nominal	
Type of management actions	Thirteen dummy variables were considered as type of management actions (Inskip and Zimmermann 2009): (1) use of deterrents and barriers, (2) livestock husbandry, (3) livestock guarding, (4) zoning, (5) aversive conditioning, (6) translocation, (7) attack verification, (8) lethal control, (9) regulate local hunting, (10) education, (11) financial incentives, (12) comanagement, and (13) restoration of habitat and/or prey populations (Kruuk 2002)	Dummy: 0 (no) / 1 (yes)	Inskip and Zimmermann 2009, Lozano et al. 2019
Number of management actions	Number of management actions considered in the paper	Quantitative	

or conflict; based on Peterson et al. 2010, Lozano et al. 2019); (6) human-nature connections (based on Ives et al. 2017); (7) perceptions, values, and traditional ecological knowledge (based on Díaz et al. 2015, Lozano et al. 2019); (8) type of social actor involved (Kansky et al. 2014, Lozano et al. 2019); and (9) type of management actions recommended or evaluated in order to promote coexistence (Kruuk 2002, Inskip and Zimmermann 2009, Lozano et al. 2019). Table 1 presents the list of variables used for coding.

Following the generalizing perspective of the NCP approach, we classified beneficial NCP into material, non-material, and regulating NCP (Díaz et al. 2018a, Table 2). We coded the beneficial NCP as material when the paper referred to substances, objects, or other elements from carnivores that sustain people's physical existence and material assets, such as fur or meat (Díaz et al. 2015, Dean et al. 2021). We coded the beneficial NCP as non-material when the paper referred to the beneficial effects of carnivores on subjective and psychological aspects of people's quality of life, such as recreational experiences (e.g., hunting, eco-tourism opportunities; Arbieu et al. 2018, Dean et al. 2021, Giergiczny et al. 2022). We coded beneficial regulating NCP when the paper referred to those functional and structural aspects of carnivores that modify environmental conditions or the generation of other NCP, such as scavenging, regulation of diseases, and dispersion of seeds (Moleón et al. 2014, Dean et al. 2021). We mirrored the generalizing perspective of material, non-material, and regulating NCP to classify detrimental NCP. We then distinguished between detrimental material NCP (e.g., livestock depredation), detrimental non-material NCP (e.g., damage to human safety, creation of fear) and detrimental regulating NCP (e.g., damage to biodiversity that is important for humans; Lozano et al. 2019). Although we used "ecosystem services" and "conflicts" associated to carnivores as searching terms, these were classified as beneficial and detrimental NCP for further analysis. In addition, and following the NCP framework, we acknowledged that one contribution can simultaneously belong to different NCP categories (Díaz et al. 2018, Topp et al. 2022). For example, carnivore attacks on game species can have negative implications on the material dimension (e.g., reduction in the number of hunted animals) and on the non-material dimension (e.g., impact on the recreational experience of hunting; Methorst et al. 2020). Table 3 shows the complete list of beneficial and detrimental NCP classifications used for coding human-carnivore relations.

Based on Ives et al. (2017, 2018), we classified human-nature connections derived from carnivores into experiential (e.g., recreational tourism), emotional (e.g., fear of being attacked by a carnivore), and cognitive (e.g., knowledge and beliefs). This classification has been proved useful to analyze human-carnivore relations (Lozano et al. 2019) and to explain coexistence scenarios (Expósito-Granados et al. 2019). To code values, we used the IPBES classification that considers intrinsic, relational, and instrumental values (Díaz et al. 2015, Pascual et al. 2017). Intrinsic values refer to those values inherent to nature, independent of any human judgment (Díaz et al. 2015). Relational values are the values that emerged from desirable relationships, including those among people mediated by nature and between people and nature (Chan et al. 2016). Finally, instrumental values refer to the direct and indirect contributions of nature's benefits to the achievement of people's good quality of life (Díaz et al. 2015). Often, instrumental values are expressed within the framework of "Total Economic Value," which classifies values according to use and non-use values (Krutilla 1967). In this paper, we also coded a non-use value category for existence value, which refers to the utility derived from knowing that a species or a population exists (Krutilla 1967).

Analysis of collected variables

First, we carried out a descriptive analysis to classify the state of the art regarding research on human-carnivore relations in Europe. We studied the NCP in a temporal and geographical analysis in order to show the evolution of studies addressing NCP provided by carnivores, as well as to find evidence of research regarding NCP in the European context. The spatially explicit results were obtained by using QGIS 3.10.5.

Table 2. Nature's contributions to people (NCP) classification, according to Díaz et al. (2018a). NCP types: material, non-material, and regulating. One NCP can be included in more than one NCP type. "•" and "••" are used to indicate the NCP straddle across the three NCP groups (material, non-material, and regulating), belonging mostly to the one indicated with ••, while belonging to some extent to the one indicated with •.

NCP	Material	Non-material	Regulating
Habitat creation and maintenance			••[1]
Pollination and dispersal of seeds and other propagules			••
Regulation of air quality			••
Regulation of ocean acidification			••
Regulation of freshwater quantity, location, and timing			••
Regulation of freshwater and coastal water quality			••
Formation, protection, and decontamination of soils and sediments			••
Regulation of hazards and extreme events			••
Regulation of detrimental organisms and biological processes			••
Energy	••	•[2]	
Food and feed	••	•	
Materials, companionship, and labor	••	•	
Medicinal, biochemical, and genetic resources	••	•	
Learning and inspiration	•	••	
Physical and psychological experiences	•	••	
Supporting identities	•	••	
Maintenance of options	••	••	••

[1] This type of NCP belongs entirely to this category.
[2] This type of NCP belongs partially to this category.

RESULTS

Temporal and geographical distribution of human-carnivore research in Europe

The number of articles studying human-carnivore relations in Europe has exponentially increased since the year 2000, with a peak of 23 and 24 articles in 2015 and 2019, respectively (Appendix 1). Overall, research mentioned more detrimental NCP than beneficial NCP. However, a slight increase of research on beneficial NCP was observed from 2013 onward. The largest proportion of studies were carried out in Sweden, Norway, and Spain (40.1% of the total number of articles with a quantity of between 21 and 30 publications), followed by Italy, Finland, France, Poland, and the United Kingdom, which covered 35.6% of the studies (Fig. 2).

Biological components: families and species of carnivores and biomes

Wolves and bears inhabiting mountain and temperate forest biomes were by far the most frequently mentioned carnivore species, whereas meso-carnivore species in the Mediterranean and freshwater biomes received relatively less attention. Most research focused on the Canidae family, followed by Ursidae, Mustelidae, and Felidae (Fig. 3a). Regarding the biomes covered, most of the research was conducted in mountain areas, followed closely by temperate forests, agroecosystems, boreal forests, Mediterranean ecosystems, and freshwater ecosystems (Fig. 3b).

Table 3. Beneficial and detrimental nature's contributions to people (NCP) classification suggested to analyze human-carnivore relations according to according to Díaz et al. (2018) and Lozano et al. (2019). Beneficial and detrimental NCP types: material, non-material, and regulating. One NCP can be included in more than one NCP type. "•" and "••" are used to indicate the NCP straddle across the three NCP groups (material, non-material, and regulating), belonging mostly to the one indicated with ••, while belonging to some extent to the one indicated with •.

Human-carnivore relation NCP	Material	Non-material	Regulating
Beneficial NCP			
Food	••[1]		
Materials	••		
Medicinal resources	••		
Habitat creation and maintenance			••
Dispersal of seeds			••
Formation, protection, and decontamination of soils: nutrient cycling			••
Regulation of organisms detrimental to humans			••
Regulation of organisms: biological control			••
Regulation of organisms: disease regulation			••
Regulation of organisms: scavenging			••
Learning and inspiration		••	
Physical extractive experiences: hunting		••	
Physical non-extractive experiences		••	
Maintenance of options		••	
Supporting identities		••	
Detrimental NCP			
Animal damage biodiversity			
Animal damage biodiversity			••
Animal damage to human food			
Animal damage crops	••		
Animal damage livestock	••		
Animal damage poultry / domestic animals	••		
Animal damage domestic animals (diseases)	••		
Animal damage beehives	••		
Animal damage: fisheries	••		
Animal damage: game species			
Animal damage: game	••	••	
Animal damage to human property			
Animal damage: property losses	••		
Animal damage: transportation	••		
Animal damage: human safety			
Animal damage: human (attacks)		••	
Animal damage: human (health)		••	
Human-human conflict		••	
Fear		••	

[1] This type of NCP belongs entirely to this category.

The gray wolf was the most studied species, followed by brown bears and the Eurasian lynx (Fig. 4a). Other species representing more than 5% of total articles were red foxes, European badgers, Eurasian otters, and beech martens. Although the wolverine is a poorly studied species, studies cover 100% of its distribution range, followed by brown bears, gray wolves, and Eurasian lynxes. Among the most studied species, we found meso-carnivores were studied in fewer countries than larger mammals, considering their distribution range (Fig. 4a).

Fig. 2. Geographical distribution of reviewed articles published on nature's contributions to people (NCP) provided by carnivores. Pie charts indicate the proportion of papers that focused on each NCP type.

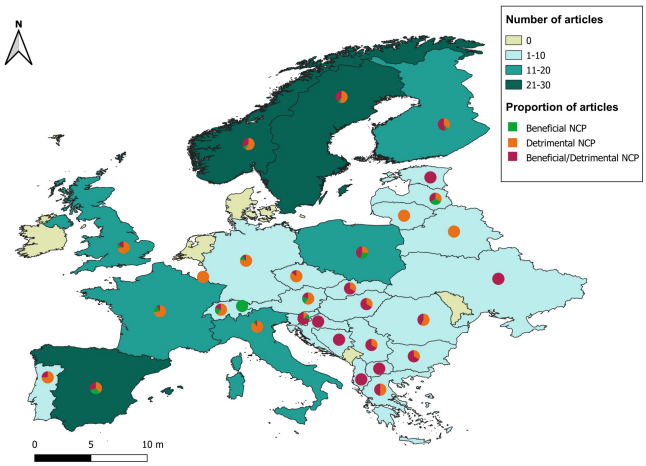
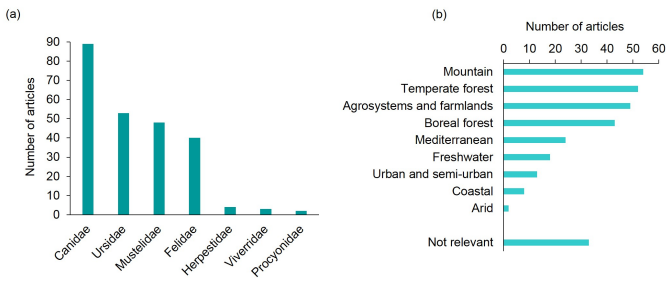


Fig. 3. Number of reviewed articles according to (a) taxonomic families and (b) biomes.

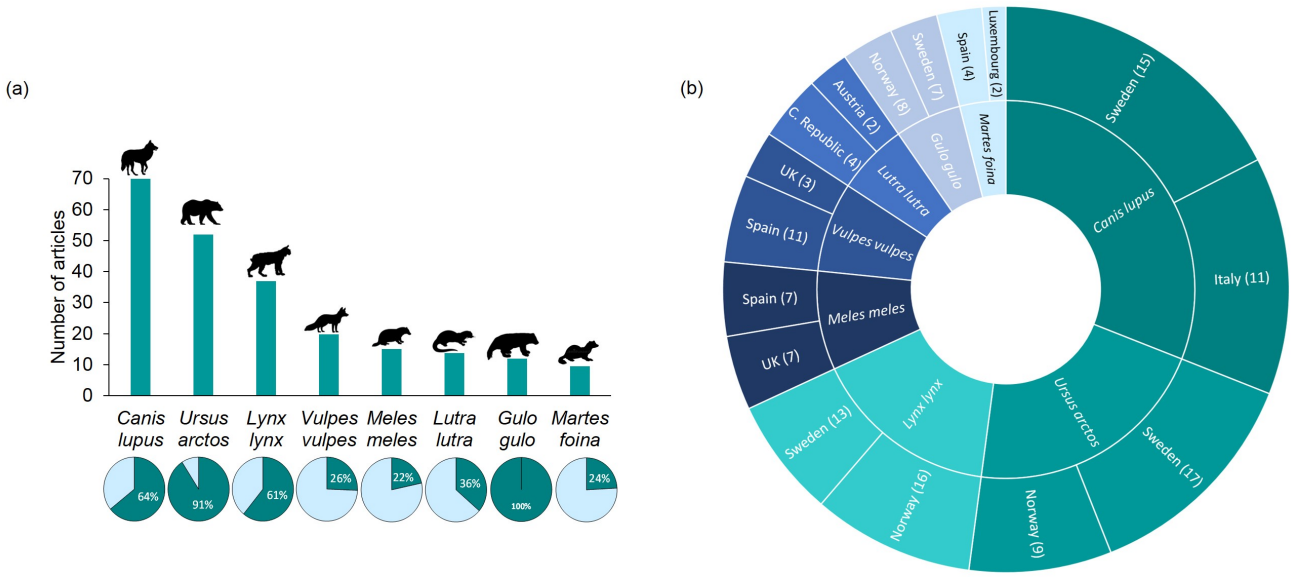


Among the four most studied large carnivores, we found that articles researching the gray wolf were mainly located in Sweden and Italy, whereas the brown bear was more studied in Sweden and Norway, the Eurasian lynx in Norway and Sweden, and the wolverine in Norway and Sweden (Fig. 4b). In addition, only seven articles mentioned reintroduced species (especially lynxes).

Beneficial and detrimental NCP provided by carnivores

We found a positive trend toward the mention of detrimental NCP by carnivores, with a high frequency of articles focused on damages to livestock. Our assessment found that 60.5% of them focused on detrimental NCP, whereas 29.4% identified both beneficial and detrimental NCP. Only a small proportion of articles studied exclusively beneficial NCP provided by carnivores (10.2%). Of the articles that mentioned beneficial NCP (70 articles), 58.6% referred to non-material NCP (e.g., physical extractive experiences, such as hunting); 54.3% mentioned regulating NCP, mainly the role in regulating detrimental organisms to humans (e.g., removal of carcasses); and only 4.3% mentioned beneficial NCP referred to material contributions (e.g., fur and food) (Fig.5a, b). Regarding research mentioning detrimental NCP (159 articles), 94.3% referred

Fig. 4. Number of reviewed articles according to (a) species with > 5% representation (pie charts show the proportion of countries where studies were conducted [in dark blue], over the number of countries where each species is present according to IUCN [in light blue]), and (b) list of countries with the highest number of articles per species.



to detrimental material NCP, such as damage to livestock, and 34.6% mentioned detrimental non-material NCP, such as damage to human safety (i.e., human-human conflicts; fear; attacks on humans, such as in Sweden where encounters between Scandinavian brown bears and humans result in human injuries, and fatalities usually coincide with den entry in October and November and frequently occur near a den; Sahlén et al. 2015). Twenty-seven per cent of articles referred to damages to hunting, which is here considered both material and non-material detrimental NCP because carnivores may negatively affect the amount of materials (e.g., fur, skin; material NCP) or the recreational experience (non-material NCP) (Fig. 5c, d).

Human-nature connections, perceptions, values, and traditional ecological knowledge

All of these items were rarely mentioned in human-carnivore research. Results indicated that only 18.6% of articles were focused on human-nature connections, mostly on emotional connections (15.3%), followed by cognitive (7.9%) and experiential connections (4.5%). Furthermore, perceptions toward carnivores were found in 22.6% of the articles. Only 11.3% focused on values of carnivores, of which 6.8% referred to intrinsic values, 5.6% to instrumental values, and 3.4% to relational values. In addition, we found that 4.5% of articles referred to the notion of existence value, i.e., the utility derived from knowing that a species or a population exists. Moreover, the analyses of TEK in human-carnivore connection was considered in only 6.8% of all studies.

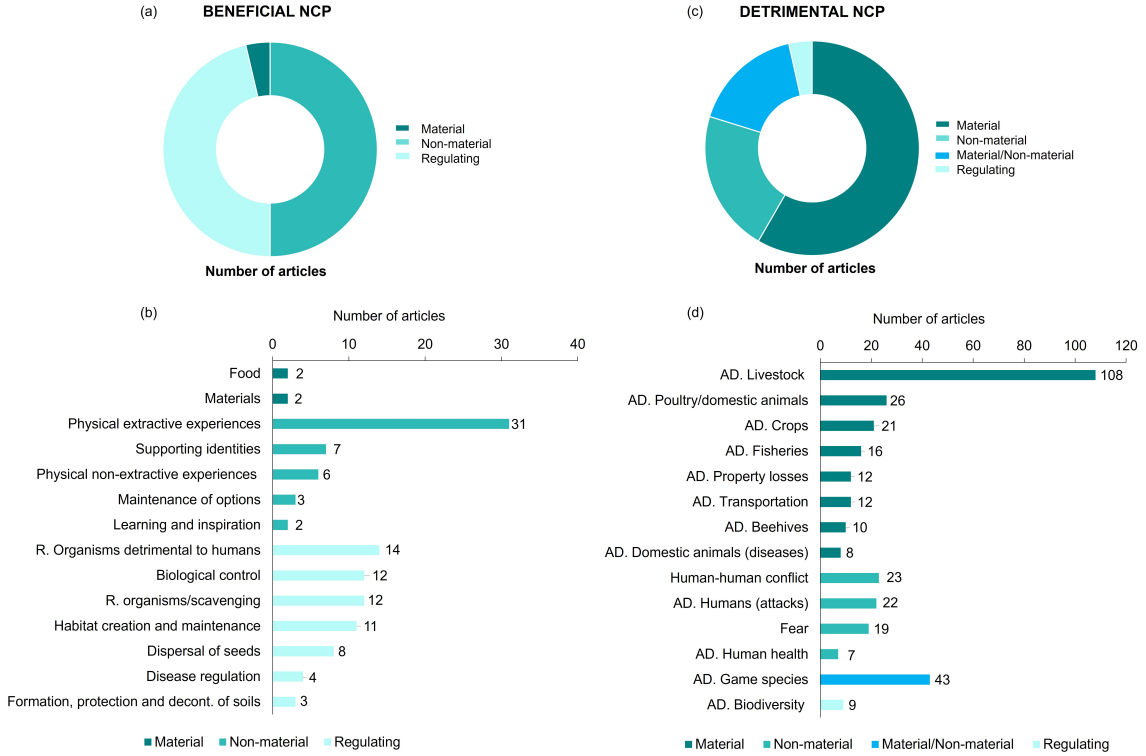
Social actors involved in human-carnivore relations

Local actors were often mentioned in the literature, with notable attention given to commercial farmers and hunters, whereas indigenous communities received only minimal mention. Of the total number of articles, 89.8% considered aspects related to how social actors are involved in human-carnivore relations. Most of the studies referred to local actors (75.7%), mainly commercial farmers, hunters, and rural residents; subsistence farmers and urban residents were mentioned in 19.8% and 12.4% of the articles, respectively. Only 3.4% of articles conducted research related to indigenous communities (i.e., indigenous Sami people in Scandinavian countries). Furthermore, actors from academia and managers were found to be representative in current research, as they were mentioned in 48.6% of the studies, especially environmental managers and people involved in decision making (governments). A total of 22.6% referred to the general public and 3.4% of the articles to tourists (Fig. 6a).

Human management of carnivores

Carnivore management was a recurrent topic in human-carnivore research. Although numerous studies recommended social measures, only a limited number of them evaluated their effectiveness. Over eighty percent of studies provided recommendations to alleviate the impact of detrimental NCP and to foster human-carnivore coexistence. Social measures were the most frequently mentioned, especially those related with financial incentives (e.g., compensation after livestock attacks) and educational processes and public awareness raising (e.g., harmful effect of the use of poison on biodiversity and public health). Based on its mention in 40.1% of the articles, we concluded that the role of non-lethal management actions was highly relevant. They included (1) deterrents used to protect animals or crops (e.g., electric fences, specialized corrals, or noise); (2) the implementation of livestock husbandry techniques (e.g., increased supervision, synchronization of births, grazing times); and (3) livestock guarding (e.g., use of guard dogs). Lethal management measures were considered in 28.2% of the articles, including lethal control and regulation of local hunting (Fig. 6b). Although management measures were suggested in a large proportion of the articles, only 32.5% evaluated their effectiveness.

Fig. 5. Number of reviewed articles in terms of (a-b) beneficial nature's contributions to people (NCP) types, and (c-d) detrimental NCP types. "R" refers to regulation (b) and "AD" refers to animal damage (d).

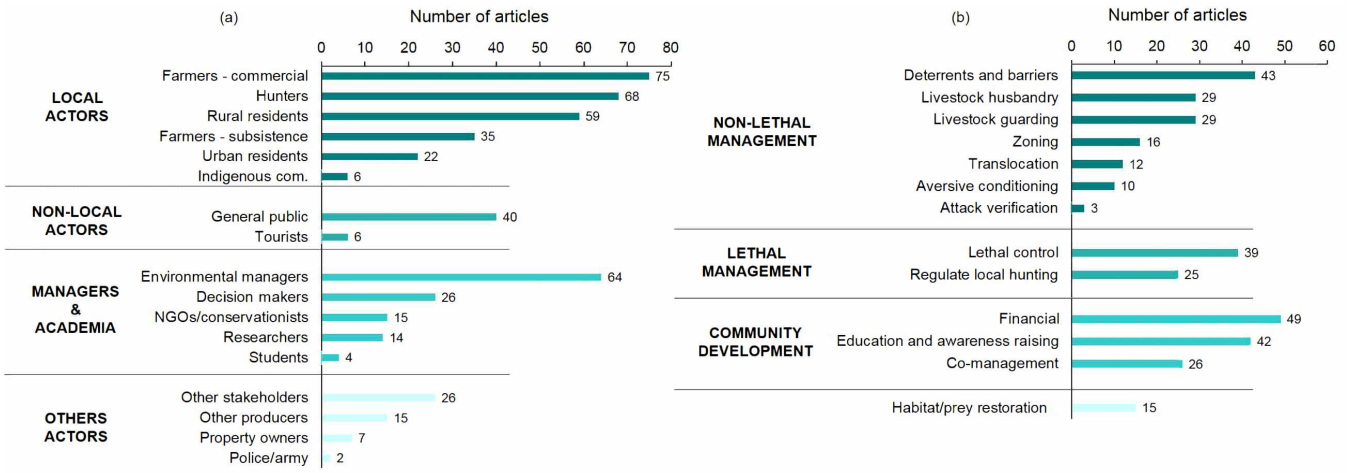


DISCUSSION

This research shows that the number of English-language articles evidencing the diversity of beneficial and detrimental NCP from carnivores to people in Europe has continuously increased in recent decades, with clear patterns. First, we found that only a small proportion of all research in Europe makes visible the beneficial NCP of carnivores to people. Second, most of the scientific attention has been focused on investigating NCP provided by large carnivores, thus neglecting the role of meso-carnivores in providing NCP. Third, the effectiveness of carnivore management strategies was evaluated and monitored in only a limited set of all the research conducted. Finally, findings suggest the need of considering the duality of carnivores as providers of both beneficial and/or detrimental NCP. We therefore argue that to foster human-carnivore coexistence in Europe, more scientific attention is required to understand how specific actors in a given context perceive both beneficial and/or detrimental NCP from carnivores. This understanding is essential for designing inclusive, adaptive, and socially acceptable conservation strategies that effectively address conflicts and raise awareness of the multiple benefits provided by carnivores.

The first trend found was on the disproportion between articles reporting beneficial and detrimental NCP from carnivores. Despite the relevance of carnivores in positively contributing to people's quality of life, our results indicated that current research has focused mainly on the analysis of detrimental NCP. Specifically, detrimental material NCP were the most studied (Fig. 5c), which supports findings of Lozano et al. (2019) that showed how global research of carnivores is mostly focused on conflicts with humans. Yet our results showed a slight increase in the mentioning of beneficial NCP from carnivores from 2013 onward, which might be influenced by the publication of the IPBES framework in 2013 (Pascual-Rico et al. 2021). The most frequently mentioned detrimental NCP was damage to livestock and game species, whereas the most frequently mentioned beneficial NCP were psychological and physical experiences (i.e., wildlife watching or hunting; Fig. 5d). Another beneficial NCP often mentioned in the literature was the regulation of detrimental organisms to humans, such as the removal of animal carcasses or the control of wild ungulates that may cause damage in commercial forests (Inger et al. 2016, Bojarska et al. 2017, Lozano et al. 2019). Moreover, this study shows that a certain NCP, such as hunting, can be classified as both a beneficial and detrimental NCP. This result aligns with Díaz et al. (2018a) who argued that NCP can be perceived as both detrimental and beneficial because they are often perceived by people in starkly different and conflicting ways. This is particularly important in the context of human-carnivore relations, because focusing research efforts only on detrimental NCP may be perpetuating a negative opinion about carnivores, thus affecting the success of tolerance and coexistence strategies (Expósito-Granados et al. 2019, Frank et al. 2019, Lozano et al. 2019).

Fig. 6. Number of reviewed articles that mentioned (a) types of social actors and (b) management actions recommended.



The second trend observed was associated with the scarce research on the NCP provided by meso-carnivores compared with those focused on large carnivore species (e.g., wolves and brown bears). Meso-carnivores, such as the red fox *(Vulpes vulpes)*, the Eurasian badger *(Meles meles)*, and the beech marten (*Martes foina*), have been documented to play an important role in maintaining ecosystem stability (Requena-Mullor et al. 2014, Cancio et al. 2017) and providing non-material NCP, such as learning and inspiration opportunities (Aguilera-Alcalá et al. 2020). Moreover, whereas large carnivore species mainly occur in low human-impacted environments, more and more medium-sized carnivore species colonize urban environments, increasing the chances to interact with humans (Červinka et al. 2013, Requena-Mullor et al. 2016, 2017). The impact of rapid human population growth and urban expansion is expected to increase human–meso-carnivore interfaces in cities and surrounding areas, leading to more opportunities for beneficial and detrimental NCP (Soulsbury and White 2015). Here, we argue that the growing presence of meso-carnivores in humanized environments may offer a unique opportunity to reduce the aforementioned negative trend toward detrimental NCP, and to emphasize and make visible the multiple and diverse beneficial NCP.

The third trend indicates that most scientific papers recommended management measures, but only a few addressed their effectiveness. This lack of evaluation of the effectiveness of management measures within a specific context of human-carnivore relations can result in perpetuating measures that trigger existing conflicts. For example, our findings show that although the success of financial compensation has been broadly used in fostering tolerance toward carnivores in the face of livestock depredation (as can be seen in the "EU Platform on Coexistence between People and Large Carnivores"), its effectiveness may vary depending on the local context and the trust that local populations have in the authorities responsible for carrying out compensation programs (López-Bao et al. 2017). Thus, a pending challenge has to do with the evaluation of effectiveness and the search for a wider consensus on which specific actions and measures can be implemented to foster coexistence with carnivores and beneficial NCP.

Finally, in the context of the documented recovery of carnivore populations in Europe, we argue that to transition toward human-carnivore coexistence, we must consider carnivores and involved actors (such as farmers, hunters, and decision-makers) as part of socio-ecological systems. The application of a social-ecological lens to study human-carnivore relations needs to consider the perceptions of carnivores by key social actors, the reasons underpinning key actors' attitudes and behaviors toward carnivores, as well as social relations between actors. For example, applying a social-ecological lens to understand the interactions between hunters and larger carnivores might lead to uncovering some of the reasons behind existing conflicts: (1) human hunters fear their competition with large carnivores both for prey and for regulating herbivore populations (Massei et al. 2015), (2) the identity of hunters is at stake with the decreasing number of young hunters in Europe (Fernández-Gil et al. 2016), and (3) power relations between social actors (i.e., hunters vs. conservation and animal rights groups) regarding the legalization of large carnivore hunting might lead to perceptions of injustices and subsequent intolerance of large carnivores (Richardson 2022). Therefore, it is crucial to operationalize frameworks of social-ecological systems that consider people, carnivores, and their interactions.

CONCLUSION

This research evidences how the NCP framework is useful for making visible the beneficial and detrimental contributions of carnivores on the quality of life of multiple social actors. This paper shows that the consideration of NCP as beneficial and detrimental allows for a more nuanced understanding of human-carnivore relations in Europe, an understanding that will not be complete if new research does not include the diversity of carnivores, including meso-carnivores and the diversity of social actors (beyond farmers and hunters). By exploring diverse perspectives held by multiple actors toward carnivores, conservation strategies could be developed in a way that are culturally sensitive and socially acceptable. Therefore, we suggest the need for comprehensive studies that delve into the diversity of human-carnivore relations in different social-ecological contexts.

Author Contributions:

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by all authors. The first draft of the manuscript was written by Sofía Palacios-Pacheco and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data Availability:

Data/code sharing is not applicable to this article because no data/code were analyzed in this study.

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Appendix 1. Temporal distribution of reviewed articles published on NCP provided by carnivores in Europe. Bars indicate the total number of papers per year that focused on each NCP type.