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Species bias and spillover effects in scientific research on Carnivora in China

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ABSTRACT

Scientific research provides essential information for conservation of threatened species. Data deficiency due to insufficient research impedes the design of conservation plans, and research bias may mistakenly direct limited resources to low biodiversity regions or less threatened species. Here, we conducted a systematic review of published papers, grants, and graduate student training on carnivorans in China to identify species bias and research gaps. Furthermore, we collected intrinsic and extrinsic features of carnivorans, and identified features that impact research intensity using generalized linear models. We found that the amount of research on carnivorans increased markedly after 2000, but species bias existed. Bears and big cats received the greatest research attention, while most small- and medium-sized carnivorans received little attention, thus showing the 80–20 phenomenon. Species with a higher level of endemism and protection under Chinese law received more consideration. As an animal conservation icon in China, the giant panda (*Ailuropoda melanoleuca*) attracted more than 50% of overall carnivoran research resources. However, the giant panda also showed spillover effects, i.e., post-doctoral graduates who studied the giant panda shifted their research focus to other species after graduation, which may help improve research on other species. Thus, to improve and strengthen Carnivora research and conservation, we suggest investing greater effort in species of less concern, training of more graduate students, and reinforcing academic exchange. If such actions are not taken, many carnivoran species will continue being data deficient and threatened.

Keywords: *Ailuropoda melanoleuca*; Carnivora; Conservation; Research bias; 80–20 phenomenon

INTRODUCTION

Scientific research provides biological and ecological information on species and helps identify the main threats to their survival (Wilson et al., 2016). Furthermore, research attracts public attention and influences policy-making processes (Hu et al., 2019), which are crucial for conserving threatened species in the context of the sixth mass extinction (Barnosky et al., 2011). The Aichi Biodiversity Target 19 seeks to improve knowledge, science, and technology related to biodiversity (CBD, 2010). However, existing research bias prevents us from achieving this goal (Wilson et al., 2016). While some large charismatic species receive considerable research attention, many others are overlooked (Brito, 2008; Tensen, 2018). Vertebrates receive more attention than invertebrates, and mammals and birds receive more attention than other vertebrates (Clark & May, 2002). Furthermore, even in mammalian research, bias and gaps still exist (Fan & Ma, 2018), causing negative impacts on threatened species

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conservation. For example, data deficiency due to insufficient research impedes conservation planning, which may result in missing the best window in which to save a threatened species (Christie et al., 2021). Moreover, research bias may mistakenly direct limited resources to low biodiversity regions or less threatened species (Brito, 2008).

Carnivora is an order of Mammalia and includes over 280 species globally (Wilson & Mittermeier, 2009). Many carnivorans (e.g., cats and pinnipeds) are obligate carnivores and depend solely on animal flesh for their nutrient requirements, while others are facultative carnivores, e.g., large Indian civet (*Viverra zibetha*) and masked civet (*Paguma larvata*), which also consume non-animal food. The giant panda (*Ailuropoda melanoleuca*) is an exception in Carnivora as it is almost exclusively herbivorous (Nie et al., 2015). Carnivorans have important ecological functions. They can affect the structure of ecosystems, dynamics of disease, wildfire, carbon sequestration, species invasion, and biogeochemical cycles through predation and trophic cascade (Estes et al., 1998, 2011). Some facultative carnivorans, such as the masked civet, can also disperse seeds (Miller et al., 2001).

China has a rich biodiversity and contains 63 carnivoran species from nine families (Jiang et al., 2017). Of these carnivorans, 16 are listed as Endangered (EN) or Vulnerable (VU) on the IUCN Red List of Threatened Species (IUCN Red List), and six are listed as Near Threatened (NT). Habitat destruction and unsustainable exploitation are the main threats to carnivorans in China (Cardillo et al., 2004; Lau et al., 2010). Intuitively, research intensity varies across species. For example, flagship species such as giant pandas and tigers (*Panthera tigris*) receive considerable research attention (Hu et al., 2019; Tensen, 2018), while others, including otters and viverrids, are largely overlooked (Papeş & Gaubert, 2007; Zhang et al., 2018). However, the general patterns, species biases, and gaps in carnivoran research in China have not been studied.

In this paper, we conducted a systematic review of scientific research on carnivorans in China. We used papers, grants, and graduate student training related to carnivoran species as indices of research intensity (Fan & Ma, 2018), and described the general patterns and trends of research. We then identified species biases and research gaps by calculating a research score (RS) for each species and tested whether data followed the 80-20 rule (also called the Pareto principle, which states that 80% of consequences result from 20% of causes) (Newman, 2005). We used a generalized linear model (GLM) to identify potential variables that may cause species bias. Considering that the giant panda receives substantial research attention, we also tested potential spillover effects, i.e., whether researchers who studied the giant panda during their doctoral program shifted their research focus to other species or fields following graduation. Our results should help to guide future carnivoran research in China.

MATERIALS AND METHODS

Data collection

We obtained the carnivoran species list of China from the second edition of the Checklist of China's Mammal Species (Jiang et al., 2017). For papers in Chinese, we used the Chinese and scientific names of each species as search terms in "Topic" in the Chaoxing database (https://www.chaoxing.com/). We limited the search to journals indexed by the Chinese Science Citation Database (CSCD). For English papers, we searched the Web of Science Core Collection (WOSCC, http://www.webofknowledge.com) using common and scientific names of species as search terms in "Topic", while restricting Countries/Regions to "China", "Hong Kong", "Macao", and "Taiwan". Because we focused on research capacity in China, we excluded certain papers after examining their title and abstract: i.e., (1) papers involving foreign scientists only, with no Chinese researcher; (2) studies conducted outside China; (3) papers unrelated to carnivorans (e.g., some papers on tiger shrimp were returned when "tiger" was used as a search term); and (4) papers that focused on pathogeny instead of disease of the animal (e.g., researchers took samples from captive martens to study rabies virus without mentioning marten treatment). We collected the published year, focal species, and whether international cooperation was involved for each paper.

We used the Chinese and scientific names of each species to search for grants awarded by the National Natural Science Foundation of China (NSFC) from two online databases (http://fund.zsci.com.cn/ and http://fund.sciencenet.cn/). Although governmental agencies such as the National Forestry and Grassland Administration and the Ministry of Science and Technology of China also fund scientific research on carnivorans, the NSFC is the largest funding source and the only open source that we can access. We collected the year, amount, and focal species of each grant.

We used the Chinese and scientific names of each species to search for Doctoral and Master's theses within several databases, including CNKI (http://kns.cnki.net/kns/brief/result.aspx?dbprefix=CDMD), Airitilibrary (http://www.airitilibrary.cn), Chaoxing (http://www.chaoxing.com/), and Wanfang (http://www.wanfangdata.com.cn/). By reviewing the titles and abstracts, we excluded theses that were obviously unrelated to Carnivora research (such as architectural design of captive facilities for giant pandas), theses focused on pathogeny instead of disease of the animal, and theses focused on taxa higher than Carnivora (e.g., Mammalia), communities, or biodiversity. We collected the year, training organization, and focal species of each thesis.

We also used order, family, and genus names in the above searches to include studies focused on taxa higher than species. Papers, grants, and theses from 1958 to March 2020 were included in the following analyses.

General patterns and trends of research

We divided the study period into three-year intervals, and calculated the average annual number of papers, proportion of international cooperation (number of papers with Chinese and foreign authors/total number of papers), number and amount of grants, number of graduates, and number of training organizations for each interval. We then assigned papers, grants, and theses into different research fields, including: (1) ecology and conservation (EC); (2) genetics (GE); (3) veterinary science (VS); (4) physiology (PH); (5) captive management (CM); (6) microbiome (MI); (7) behavior (BE); (8) anatomy and morphology (AM); (9) quarantine (QU); and (10) computer technology (CT, such as techniques for species identification based on animal images). We summed the numbers of papers, grants, and theses for each field, and identified the top three fields.

Species bias

To quantify research intensity for each species, we calculated a synthesized RS using the equation:

$$RS = \left[\frac{P_i}{P_t} + \frac{\frac{F_n}{F_{nt}} + \frac{F_m}{F_{mt}}}{2} + \frac{S_i}{S_t} \right] / 3 \quad (1)$$

where P_i is the number of papers of a species, P_t is the number of papers of all carnivorans, F_n is the number of grants for a species, F_{nt} is the number of grants for all carnivorans, F_m is the amount of grants for a species, F_{mt} is the amount of grants for all carnivorans, S_i is the number of theses of a species, and S_t is the number of theses of all carnivorans.

The RS values ranged from 0 to 1, with a higher RS indicating higher research intensity. We used a one-sample Wilcoxon signed rank test to assess whether the RS of the giant panda was significantly greater than the RS values of other species using R v4.0.2 (R Core Team, 2019). We checked whether the distribution of RS followed a continuous power-law distribution (Newman, 2005), indicative of the 80-20 phenomenon, using the poweRlaw package v0.70.6 (Gillespie, 2015). We also tested if any families were well represented in research by comparing the actual and estimated RS values, calculated as the ratio of number of species in a family/number of all species in Carnivora, assuming each species should receive equal research attention (Christie et al., 2021). If the actual RS was larger than the expected RS, we concluded that a family received greater than average research attention. We downloaded 1 000 phylogenetic trees from VertLife.org (http://vertlife.org/phylosubsets/) (Upham et al., 2019), and generated a maximum clade credibility tree using TreeAnnotator v1.6.1 for visualization. We used the ggtree package v2.4.1 (Yu et al., 2017) to annotate the RS of species and bias among families on the tree.

Potential variables causing species bias

According to previous studies, we considered five variables that may affect research intensity of different species, including: (1) body mass; (2) endemism (i.e., proportion of distribution area within China, using QGIS v3.6.2); (3) category on the IUCN Red List; (4) protection level in China; and (5) evolutionary uniqueness (details in Table 1). As the giant panda received far more research attention than other species, we ran GLMs (family=gamma) including and excluding the giant panda to determine whether its inclusion in the dataset affected the results. We tested collinearity between the five variables before running GLMs. No variable was excluded in the following analyses because all Pearson correlation coefficients were <0.7. Category on the IUCN Red List and protection level in China were not considered simultaneously in a same model because they both represent extinction risk, either globally or regionally. Due to missing data in the variables, the Bengal fox (*Vulpes bengalensis*), large-spotted civet (*Viverra megaspila*), crab-eating mongoose (*Herpestes urva*), spotted seal (*Phoca largha*), and Asian small-clawed otter (*Aonyx cinerea*) were excluded from the GLMs. We selected models based on the second-order Akaike information criterion (AICc) for small sample sizes, and considered models with ΔAICc≤2 as the "best-fit" models (Burnham et al., 2011). We calculated the AICc weight (Wagenmakers & Farrell, 2004) for each model. As no model was superior than others (AICc weight >0.9), we averaged models with a cumulative AICc weight >0.9 (Symonds & Moussalli, 2011).

Influence of the giant panda : spillover effects

We defined spillover effects as the phenomenon in which doctoral students who studied the giant panda as their focal species shifted their research focus to other species after graduation, which may enhance the research and conservation of other species. We identified "panda PhDs" and recorded their published papers and NSFC grants obtained after they graduated. We used the names of PhD graduates to search for NSFC grants and used their names and affiliations to search for papers in the CSCD and WOSCC databases. We checked the title and abstract of each paper and counted the number of post-doctoral graduates who continued to study the giant panda as a research focus (i.e., >50% of papers after graduation were still focused on the giant panda).

RESULTS

General patterns and trends of carnivoran research in China

We found 1 327 Chinese papers and 1 310 English papers

Table 1 Potential variables resulting in species bias in carnivoran research in China

Factor	Hypothesis	Data source	References
Body mass (kg)	Larger animals tend to receive more research attention.	Animal Diversity Web (https://animaldiversity.org/)	Ford et al., 2017
Endemism	Endemic species would be a local priority and attract more regional research attention.	IUCN, 2020	Arponen, 2012
Category on IUCN Red List	Species with higher extinction risk would receive more research attention.	IUCN, 2020	Mace et al., 2008
Protection level in China	Species that are regionally threatened attract more regional research attention.	National Forestry and Grassland Administration	Arponen, 2012
Evolutionary uniqueness	Species with higher evolutionary uniqueness would attract more research attention because extinction of these species will cause more genetic diversity loss.	Gumbs et al., 2018; EDGE of Existence Programme (https://www.edgeofexistence.org/)	Mace et al., 2003

related to carnivorans in China. The number of papers increased greatly after 2001 (Figure 1A). The total number of papers in 2019 was 169, which was four times that in 2000. The number of Chinese papers per year increased before 2008, after which they remained stable. After 2003, the number of English-language papers increased greatly, surpassing the number of Chinese-language papers for the first time in 2013, and accounting for more than twice as many each year since (Figure 1A). Chinese researchers have actively engaged in international cooperation (Figure 1B), with ~42% of English-language papers (550 out of 1 310) involving international collaboration. In contrast, only 4.4% (58 out of 1 327) of Chinese-language papers involved international cooperation (Figure 1B). We found the top three research fields for the papers were EC, EG, and VS (Figure 1C).

The NSFC was established in 1986 and funded three carnivoran projects in that year. Grant number and amount increased markedly from 2000 (three grants, 0.5 million yuan) to 2019 (14 grants, 6.1 million yuan) (Figure 1D, E), with a plateau in 2011 and slight decrease thereafter (Figure 1D, E). In total, the NSFC has funded 139 projects totaling 60.4 million yuan, supporting 95 researchers from 41 organizations. Among them, 133 projects studied a single or two sympatric species, four projects studied a single genus or family, and two projects studied the entire order of Carnivora. The top three fields for grants were EC, GE, and VS (Figure 1F).

China started to recruit Master's and PhD students in 1979. Up to 2019, academic institutions (universities and research institutes) had trained 169 PhD graduates and 650 Master's graduates who studied carnivorans for their theses. We could not obtain the graduation year for 48 graduates (5.9% of the total number), so they were excluded in the following analyses. The numbers increased from seven graduates and two academic institutions in 2000 to 40 graduates and 16 institutions in 2019 (Figure 1G, H). By 2019, the number of institutions with Master's program totaled 93, whereas the

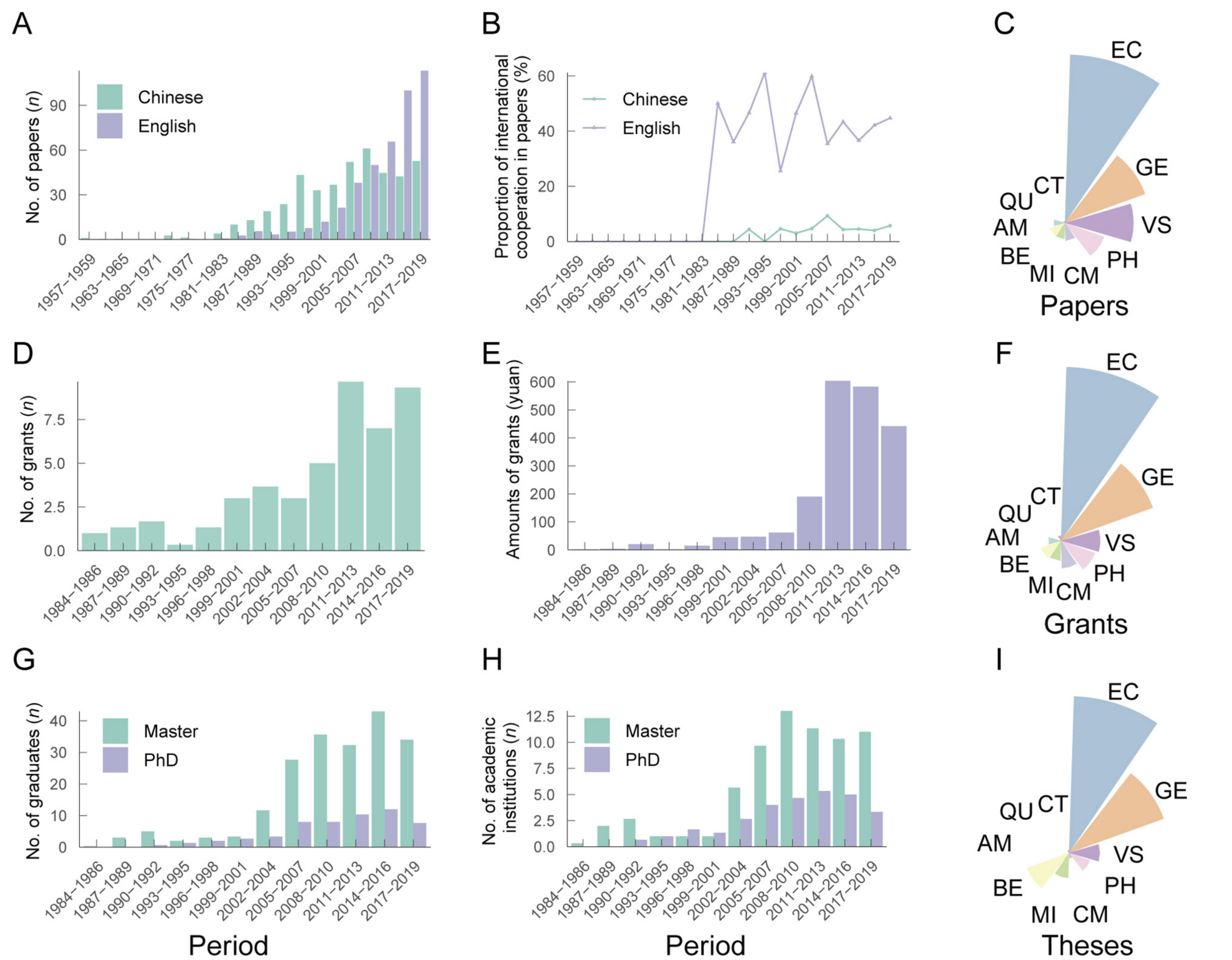

Figure 1 General patterns and trends of carnivoran research in China up to 2019

A: Number of Chinese and English papers; B: Proportion of international cooperation in Chinese and English papers; C: Research fields of papers; D: Number of grants; E: Amount of grants; F: Research fields of grants; G: Number of Master's and PhD graduates; H: Number of academic institutions that have graduates on carnivorans research; I: Research fields of graduate theses. Panels in left and middle columns show average annual figures. EC: Ecology and conservation; GE: Genetics; VS: Veterinary science; PH: Physiology; CM: Captive management; MI: Microbiome; BE: Behavior; AM: Anatomy and morphology, QU: Quarantine; CT: Computer technology.

number of institutions with PhD program totaled 45. However, both the number of graduates and institutions reached a plateau in recent years (Figure 1G, H). The top three research fields for theses were EC, GE, and VS (Figure 1I).

Species bias and influential variables

Our results showed that the giant panda received far more research attention (RS=0.512) than any other carnivoran in China (V=0, *P*<0.001, Figure 2). Furthermore, the RSs of carnivorans followed continuous power-law distribution (*P*=0.51, H_0: data generated from a power law distribution), thus showing the 80-20 phenomenon. The top 10 researched species were giant panda, tiger, red panda (*Ailurus fulgens*), raccoon dog (*Nyctereutes procyonoides*), gray wolf (*Canis lupus*), Asiatic black bear (*Ursus thibetanus*), leopard (*P. pardus*), sable (*Martes zibellina*), Siberian weasel (*Mustela sibirica*), and snow leopard. Bias was also evident at the family level. The Ursidae and Ailuridae families received more research attention than the average, whereas the Mustelidae and Viverridae families were the least studied (Figure 2).

The GLMs including and excluding the giant panda produced similar results, suggesting that this species did not influence the general pattern of species bias (Table 2). GLMs indicated that endemism and protection level in China had positive effects on RS values (Table 3), whereas evolutionary uniqueness had a negative effect, and body mass and IUCN Red List category had no effect. Although listed as protected animals in China, the sun bear (*Helarctos malayanus*), wolverine (*Gulo gulo*), binturong (*Arctictis binturong*), and clouded leopard (*Neofelis nebulosa*) received little research attention. Furthermore, although a large proportion (>80%) of the distribution range of the Tibetan fox (*Vulpes ferrilata*), northern hog badger (*Arctonyx collaris*), crab-eating mongoose, and Chinese mountain cat (*Felis bieti*) is within China, these species were poorly studied. Most small- and medium-sized carnivorans (body mass <15 kg), which usually function as mesopredators, were not well-studied either (Figure 2; Supplementary Table S1).

Influence of the giant panda

In our dataset, 89 PhD graduates studied the giant panda for their thesis. Sixty-three continued doing research and publishing scientific papers after graduation, with a total of 1 165 papers in the CSCD and WOSCC databases. Twenty of the 63 graduates continued to focus on giant panda research (accounting for >50% of their papers) after graduation, whereas 43 graduates shifted their research focus to other taxa (including but not limited to birds, amphibians, reptiles, and other mammals) and/or other fields (including but not limited to GIS, immunology, and economy), indicating spillover effects from the giant panda to other species. We also found 49.2% of PhD graduates (31 out of 63) were employed by the institutions where they received their doctorates, indicating a certain extent of academic inbreeding.

DISCUSSION

Based on the number of published papers, grants, and graduates, we found that carnivoran research in China has increased greatly over the past two decades, which is likely due to increasing investment in science and education (Marginson, 2018). However, carnivorans other than the giant panda received less research attention than many primate species in China (Fan & Ma, 2018). Although all indices showed a significant increase, the number of grants and graduates reached a plateau after rapid development in the last decade. Conservation-related research capacity in China, as measured by the number of conservation scientists, has lagged the UK and USA (Fan et al., 2020), indicating a lack of conservation scientists considering China's high but

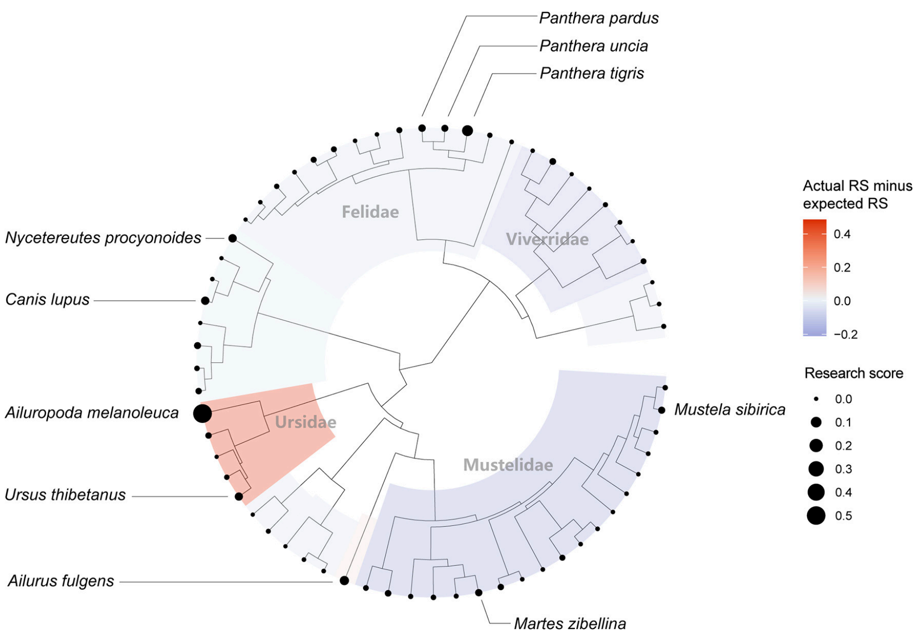

Figure 2 Research bias among species and families on a phylogenetic tree

Black circles on end of lines show research score (RS) of species. Shadows on clades show actual RS minus expected RS for each family.

Table 2 Top five GLMs ranked by second-order Akaike information criterion (AICc) predicting research scores (RSs) of carnivorans in China

Group	Variable	*K*	Loglik	AICc	ΔAICc	ω_i
Including panda	Endemism, Chinese protection level, Evolutionary uniqueness	4	–126.274	263.701	0.000	0.713
	Endemism, Chinese protection level	3	–128.392	265.540	1.838	0.284
	Endemism, Body mass, Chinese protection level	4	–132.683	276.520	12.818	0.001
	Endemism, Body mass, IUCN category	4	–133.073	277.299	13.598	0.001
	Endemism, IUCN category, Evolutionary uniqueness	4	–134.204	279.562	15.860	0.000
Excluding panda	Endemism, Chinese protection level, Evolutionary uniqueness	4	–120.481	252.139	0.000	0.707
	Endemism, Chinese protection level	3	–122.581	253.931	1.792	0.289
	Endemism, Body mass, IUCN category	4	–126.980	265.136	12.996	0.001
	Endemism, Body mass, Chinese protection level, Evolutionary uniqueness	5	–125.934	265.548	13.409	0.001
	Endemism, Body mass, Chinese protection level	4	–127.533	266.243	14.104	0.001

K: Number of parameters; Loglik: Log-likelihood; ΔAICc: Difference in AICc values between each model and best model; ω_i: AICc weight.

Table 3 Model-averaged coefficients (+*SE*) and relative importance based on AICc weight (ω_i) for each variable that affected research scores (RSs) of carnivorans in China

Group	Variable	Coefficient	*SE*	Relative variable importance based on ω_i
Including panda	(Intercept)	0.190	0.172	
	Endemism	33.466	13.567	1.000
	Evolutionary uniqueness	–0.011	0.009	0.715
	Chinese protection level	6.735	4.615	1.000
Excluding panda	(Intercept)	0.190	0.176	
	Endemism	32.766	13.762	1.000
	Evolutionary uniqueness	–0.011	0.010	0.710
	Chinese protection level	6.702	4.687	1.000

threatened biodiversity. To achieve the grand vision of an “Ecological Civilization” (Xiao & Zhao, 2017), China needs to implement more science-based conservation projects, for which conservation scientist training is needed. Reinforcing funding and graduate student training, especially doctoral students, is needed to increase the number of conservation scientists in China.

Species bias was evident in carnivoran research. The giant panda and big cats received most research attention. The giant panda is a well-known symbol of conservation (Hammerschlag & Gallagher, 2017), and has thus received much more research attention than any other carnivoran in China. Big cats are top predators and charismatic species favored by Chinese culture. Benefiting from intensive research and conservation activities, the giant panda and snow leopard have been downgraded from EN to VU on the IUCN Red List. In contrast, many species and taxa remain poorly studied and small felids, viverrines, and mustelids in China have been largely overlooked. For example, the Eurasian otter (*Lutra lutra*), Asian small-clawed otter, and smooth-coated otter (*Lutrogale perspicillata*) are all found in China and have experienced large population declines and range contractions since the 1960s (Zhang et al., 2018). Even though otters are top predators that play important ecological roles in freshwater ecosystems and are considered as indicator species of ecosystem health (Kruuk, 2006), they have been the focus of very few studies, which likely impedes their conservation (Brito, 2008; Hu et al., 2019; Zhang et al., 2018). Many small felids, viverrines, and mustelids are mesopredators. Many large carnivorans have been extirpated across China (Lau et al., 2010; Li et al., 2020). This may lead to mesopredator release through trophic downgrading (Estes et al., 2011) and introduce ecological, economic, and social issues (Prugh et al., 2009). Studies on mesopredator release have not been reported in China but warrant research attention.

We found that endemism and protection level in China were positively correlated with the RS of carnivorans. Interestingly, we found that the IUCN Red List category did not affect RSs. These results imply that Chinese researchers have paid more attention to endemic or high extinction risk species in China. Some globally threatened species with small distribution ranges in China, such as the sun bear, dhole (*Cuon alpinus*), and clouded leopard, received little research attention despite being listed as nationally protected animals in China. Certain other species with a large proportion of their distribution range in China, such as the Tibetan fox, northern hog badger, crab-eating mongoose, and Chinese mountain cat, were also neglected by researchers. For example, the Chinese mountain cat in Qinghai and northern Sichuan is one of the most poorly known living felids and is currently categorized as VU on the IUCN Red List (He et al., 2004). We found only three Chinese papers and one English paper with a focus on the Chinese mountain cat. Obviously, such species require more research to elucidate their distribution, population dynamics, threats, and ecological requirements to support conservation. Such knowledge gaps make it difficult to develop science-based conservation plans.

The giant panda attracted more than half of carnivoran research resources in China, which could negatively impact other species. Of potential benefit, however, giant panda research provides a high-profile and successful model for conservation (Swaisgood et al., 2018). Chinese scientists have developed and applied diverse techniques and methods in giant panda research and have published many papers in leading journals (Hu et al., 2017; Nie et al., 2015, 2019). Research and conservation of other species can benefit from these new techniques and approaches. We also found spillover effects, in which many PhD graduates who received giant panda research training shifted their research focus to other species following graduation. Such species can benefit from the knowledge and techniques of these post-doctoral graduates. However, we noted moderate academic inbreeding in giant panda research institutions, which may lead to a decrease in academic output and openness to other scientific communities (Horta et al., 2010).

In summary, the amount of research on carnivorans in China increased substantially after 2000. The numbers of papers, grants, and graduates all increased, but we found obvious species biases. The giant panda and big cats received considerably more research attention than average, while many mesopredators, including small felids, viverrines, and mustelids, were mostly neglected. Species with high endemism and protection in China received more research attention. The giant panda had spillover effects to other species. To improve research capacity and promote conservation of carnivorans in China, we strongly suggest that the NSFC and other funding sources invest more resources on less studied species, such as mesopredators. We also suggest that PhD students should be encouraged to pursue an interest in ecology and conservation of carnivorans and that post-doctoral scientists trained in giant panda research shift to study overlooked species. Research capacity can also benefit from international academic exchange (Fan et al., 2020). Without sufficient scientific information, we may miss the best window in which to save threatened species (Christie et al., 2021) or mistakenly direct limited resources to low biodiversity regions or less threatened species (Brito, 2008).

SUPPLEMENTARY DATA

Supplementary data to this article can be found online.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

P.F.F. conceived and designed the study. Z.N.W. prepared the data. Z.N.W., L.Y., and L.Z. analyzed the data. Z.N.W., L.Z., and P.F.F. wrote the paper. All authors read and approved the final version of the manuscript.

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