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Divergent Importance and Geographic Patterns in Threats to Birds and Mammals in China

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ABSTRACT

Aim: Wildlife populations are continuing to decrease worldwide. Understanding the ranking and distribution of drivers of species declines is crucial to enable targeted actions to counteract major threats. However, few studies have assessed the relative importance and geographic distribution of threats to biodiversity in China, even for high-profile groups such as birds and mammals. Therefore, this study aims to rank and map the distribution of threat to birds and mammals in China, which could provide novel insight into biodiversity conservation in China.

Location: China.

Methods: A database of different threats for 147 threatened bird species and 176 threatened terrestrial mammal species was obtained from China's Red List of Biodiversity published in 2021. We collated information on the distribution and threat categories for birds and mammals in China, aiming to classify, rank and map threats. We used Bray–Curtis dissimilarity index to examine the correlations of threats occurring simultaneously, and compared the distribution of habitat of threatened birds and mammals. In addition, we conducted threat ranking analyses of threatened birds and mammals between different orders and traits (body mass and clutch/litter sizes).

Results: The results showed that the most common threats to birds were habitat loss, hunting, human disturbance, agriculture, pollution and logging, while the most common threats to mammals were hunting, agriculture, logging, habitat loss, human disturbance and livestock farming or ranching. These threats showed different geographic patterns, and some threats frequently

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co-occur as threat syndromes. Forests were the primary habitat for most threatened species, and orders formed by larger species with small clutch or litter sizes were more likely to be threatened.
Main Conclusions: We highlight the most common threats and key areas for conservation. Furthermore, focusing on clusters of co-occurring threats may be the most effective way to aid recovery of threatened species, and targeted actions are needed to counter ongoing population declines in many groups. These actions should not be limited to the protection of regions where species are at risk of multiple significant threats, but should also include the maintenance and restoration of native forests and strategic planning of afforestation through planted forests.

1 | Introduction

Halting global biodiversity loss is a key priority and requires urgent action (Chan et al. 2022; Raven and Wackernagel 2020). Yet despite a 'decade of biodiversity conservation' and increasing funds and attention for biodiversity, none of the UN's Aichi targets were successfully completed (Heywood 2017; Yang et al. 2020). The recent Living Planet Report 2022 has shown that the relative abundance of monitored wildlife populations declined by an average of 69% between 1970 and 2018 (Almond et al. 2022). In addition, more than one million species are estimated to be at risk of extinction (Ceballos, Ehrlich, and Dirzo 2017; Munstermann et al. 2022). Various analyses suggest that the state of biodiversity will be more worrying if it continues along its current trajectory (Anonymous 2021; Irwin et al. 2022; Yuan, Zhang, and Zhang 2024). Therefore, in order to develop and implement effective policies to reduce biodiversity loss, it is necessary to understand which species are at risk, what the main threats are and how they vary across space and time (Glaubrecht 2023). The Convention on Biodiversity recently launched 23 targets within the Kunming–Montreal Global Biodiversity Framework (Naeem, Lu, and Jackson 2022). Without a doubt, effective action depends on the combined will of all nations, which will be the most important biodiversity policy process of our times (Diaz et al. 2020; Hughes et al. 2022). Concerted action at subnational levels and across sectors is also crucial to achieving the planned goals (Anonymous 2021; Hughes et al. 2022; Lu et al. 2020).

Recent studies on biodiversity loss and its impact on ecosystem services have revealed the relative importance of species threats at the global and regional levels (Mahmoud et al. 2020; Shuai et al. 2021; Whytock et al. 2021). Large global data sets across spatial and temporal scales indicate that habitat destruction, overexploitation, biological invasions, climate change and pollution are the five main global threats (Bellard, Marino, and Courchamp 2022). Policymakers are frequently tasked with prioritising funding for species based on extirpation risk or threats ranking (Chichorro, Juslen, and Cardoso 2019). To aid with prioritisation, protectors often use ranking systems, such as those developed by IUCN and NatureServe, or rank main threats according to the number of species they affect (Droghini et al. 2022; Wraith and Pickering 2019). Since species traits are also linked to conservation status, they are often used to quantify the extinction risk (Nowakowski et al. 2017; Wolff et al. 2023). For example, some studies used phylogenetic generalised linear models to evaluate the relationships between habitat fragmentation and two widely used traits (body mass and range size) to explain extinction risk (Crooks et al. 2017). For many taxa, species with smaller geographical ranges are more likely to reduce or face a greater risk of extinction than species with larger geographical ranges (Cuervo and Moller 2020). Unfortunately, the resources currently available are insufficient to protect all threatened species. Thus, to make the most efficient use of available resources, the ranking of threats can be used to identify the most effective conservation actions (Chamberlain et al. 2016).

Habitat loss has received the most attention, as it poses a direct threat to the survival of species, drives population decline, alters resource availability and changes ecosystem function (Wu et al. 2019). Therefore, documenting the distribution of habitats is vital for efforts to conserve threatened species (Stevens and Conway 2021). Furthermore, diversity and endemism patterns, relative extinction risks and drivers vary across habitat types and the guilds that depend on them (Sfair et al. 2022). For example, forest species can be threatened by logging, while more generalist species can be threatened by overexploitation even if they may be more robust to habitat losses (Brummitt et al. 2015). Various threats tend to co-occur so many species are subject to multiple, interacting threats (Wraith and Pickering 2019). At present, the geographic distribution of species threats is poorly understood, despite being key to enabling targeted conservation efforts (Gaisberger et al. 2022; Tan, Herrel, and Roedder 2023). Combining threats with species distributions can enable efficient conservation management, or limit activities that may threaten species populations in these areas and mitigate the impact of threats on biodiversity (Chamberlain et al. 2016).

China has a vast territory, and its complex biogeography is linked to high biodiversity. As a global mega-biodiversity country, China is home to at least 8201 vertebrate species (Sun, Huang, and Zhou 2022). Simultaneously, China's diverse fauna is also threatened. According to the latest assessment, 21.4% of vertebrates in China were assessed as threatened (Jiang et al. 2016). With a high human population in addition to high biodiversity, understanding the threats to biodiversity and how they vary across space and taxa is crucial (Wang et al. 2020). China has established multiple nature reserves to preserve biodiversity, natural landscapes and ecosystem function (Xu et al. 2019; Zhang et al. 2020). By the end of 2017, China had established 2833 nature reserves covering 15.3% of the country's area (Zhang et al. 2020). However, the current protected areas and the limited space for the establishment of parks are not enough to cover China's biodiversity, and the protection of wildlife is not effective. There is still a knowledge gap about the distribution of threatened vertebrates and how to protect them. In addition, the topography, landcover and development, economic and climatic conditions differ between different provinces in China (Lu et al. 2020). To better conserve biodiversity and enable targeted and efficient action, province-specific priorities should be identified. To date, there is no comparative assessment of the existence or status of Chinese birds and mammals. Little analysis has been conducted at the provincial level, making targeting efficient conservation and management actions challenging.

To fill this gap, we collected information on the provincial distribution and threat categories for birds and mammals in China from two recently published books. Our objectives were to rank threats, analyse the spatial distribution of these threats and assess the threatened species diversity in each habitat. Currently, the Kunming–Montreal Global Biodiversity Framework calls for an expansion of the current protected areas (PAs) to cover at least 30% of global land and water areas by 2030 (i.e., the 30 × 30 target). We hope that with the gradual implementation of this goal and the further development of China's protected area network, China can optimise how such areas are determined to best safeguard threatened species. Therefore, this study aims to determine: (1) What is the relative importance of each threat factor to birds and mammals in China? (2) What are the geographic patterns of major threats? (3) Do threats co-occur as threat syndromes? (4) Which major habitat type has the most threatened species? (5) Does the rank of the threats to threatened birds and mammals differ between orders or relate to species' functional traits? The results of this analysis will demonstrate patterns of diversity and threat to allow targeted action. This will provide new insights for China to develop National Biodiversity Strategies and Action Plans that are consistent with the goals and targets of the new global biodiversity framework.

2 | Methods

2.1 | Study Area

Considering that the survey of biological resources and the management of biodiversity in China are mostly based on administrative units, we used the number of species in each province as the study unit. In addition, due to China's significant differences in geographical location, physical geography, history of human activities and biodiversity composition, we grouped the 34 province-level administrative units (including the municipalities directly under the central government) in China into seven regions, that is, Northeast China (Heilongjiang, Jilin and Liaoning), North China (Beijing, Tianjin, Inner Mongolia, Hebei and Shanxi), Northwest China (Shaanxi, Ningxia, Gansu, Qinghai and Xinjiang), Central China (Henan, Hubei and Hunan), East China (Shandong, Jiangsu, Anhui, Shanghai, Zhejiang, Jiangxi, Fujian and Taiwan), Southern China (Guangxi, Guangdong, Hainan, Hong Kong and Macao) and Southwest China (Sichuan, Chongqing, Guizhou, Yunnan and Tibet). We merged the municipalities with their most relevant provinces, that is, Beijing and Tianjin were merged with Hebei Province, Shanghai was merged with Jiangsu Province, Chongqing was merged with Sichuan Province, Hong Kong and Macao were merged with Guangdong Province, eventually including 28 province-level units (Figure S1).

2.2 | Data Collection

To assess the geographical distribution patterns of threatened birds and mammals as well as their threats, we collected the distribution data of all threatened birds and mammals from two recently published books (Jiang et al. 2021; Zhang and Zheng 2021). A total of 1445 bird species of 497 genera, 109 families, 26 orders and 700 mammalian species of 248 genera, 56 families and 13 orders in China were assessed. China's Red List of Biodiversity assessed the conservation status of species across the country through a series of criteria such as taxonomic status, assessment information, geographic distribution, population, habitat(s) and ecosystem(s), threat(s), protection category and conservation action(s). Evaluation of species extinction risks has already been conducted exhaustively for birds and mammals in China. In total, birds and mammals above vulnerable level were collectively classed as threatened species. Because the vast majority of mammals in China are terrestrial mammals, and marine mammals only account for a very small proportion. Moreover, the distribution of marine mammals in waters is relatively complex, and it is difficult to have a unified measurement standard. Therefore, in order to facilitate the geographical mapping of provincial distribution, we removed 15 of the threatened marine mammals from analyses. Therefore, the final analyses included 147 threatened bird species and 176 threatened terrestrial mammal species. Recorded information included scientific name, conservation class, habitat, provincial distribution and threat categories.

2.3 | Data Details

2.3.1 | Threat Data

Threats are the proximate human activities or processes that impact the status of the taxon being assessed (e.g., unsustainable fishing or logging). Direct threats are synonymous with sources of stress and proximate pressures to taxa. The Red List of China's Biodiversity was compiled by a number of experts and scholars. The classification of these threats is based on the earlier red books and experts' inputs (Sung, Peiqi, and Yiyu 1998; Zheng, Wang, and Sung 1998). To reduce taxonomic biases, the participants have held seminars at the beginning of the assessment to decide the classification of threats. To be able to analyse and compare threats, we referred to the IUCN Red List threat categories and the Salafsky et al. (2008) categorisation for a more detailed threat classification of the threat information collected on threatened birds and mammals. Thus, we divided threats to birds and mammals into 27 categories respectively. Moreover, we provided a threat classification scheme with a list of direct threats (see Table 1).

Especially, 'habitat loss' combines all factors that can contribute to the loss of native vegetation in a habitat. Although other threats (grazing, logging, etc.) can also result in habitat loss, a key purpose of threat classification in this study was to identify the causes that affect the processes of threatened species, rather

TABLE 1 | Specific threat categories of threatened birds and mammals in China.

Threat category	Bird	Mammal
Hunting	▲	▲
Agriculture	▲	▲
Logging	▲	▲
Habitat loss	▲	▲
Human disturbance	▲	▲
Livestock farming or ranching	▲	▲
Fire	▲	▲
Road and dam construction	▲	▲
Food shortage	▲	▲
Pollution	▲	▲
Disease	▲	▲
Poisoning	▲	▲
Collection	▲	▲
Climate change	▲	▲
Tourism	▲	▲
Residential and commercial development	▲	▲
Human–animal conflict	/	▲
Hybridisation	/	▲
Inbreeding depression	/	▲
Low reproductive ability	▲	▲
Mining	▲	▲
Nature disaster	▲	▲
Predation by natural predators	▲	▲
Fencing	/	▲
Nature ecosystem modification	▲	▲
Limited water source	/	▲
Trade	▲	▲
Egg collection	▲	/
Overfishing	▲	/
Electric shock and crash	▲	/
Invasion	▲	/
Bamboo flowering	▲	/

than focusing only on the results of habitat fragmentation or loss. The purpose of this merge is to group threats into broad categories. It is important to note that the threats are not mutually exclusive, for example, 'habitat loss' is not mutually exclusive with 'human exploitation'. In addition, because of the difference in life history, there are different threats to birds, like 'egg collection' and 'electric shock' uniquely faced by birds. Species can be affected by one or multiple threats, and the association type was binary (i.e., presence was denoted as 1, and absence was denoted as 0).

2.3.2 | Habitat Data

In order to compare the habitats of threatened birds and mammals effectively, we used the IUCN Habitat Classification Scheme to classify species-specific habitat information into a unified ecosystem. For example, the *Grus leucogeranus* nests in tundra wetlands and winters in lakes. We classified it into wetland ecosystem. The main habitats of the *Chrotogale owstoni* were forests, secondary forests and bamboo forests. We classify them into forest ecosystem. The purpose of this merge is to group habitat information into broad categories. We classified habitats as: forest, shrubland, cropland, karst, grassland, wetland, desert, island, hilly, human settlement, tundra, alpine meadow and rocky Area. Based on this, the habitats of threatened birds were divided into 13 categories and the habitats of threatened mammals were divided into 12 categories.

2.3.3 | Trait and Order Data

To determine if the ranks of the threats to threatened birds and mammals vary in different orders and specific trait groups (body mass and clutch/litter size), we classified the orders and obtained the body mass and clutch/litter size data from two recent published datasets (Harfoot et al. 2021; Lees et al. 2022). We removed orders with fewer than five species in China from the dataset because these orders differed greatly in species number from the other orders, such as Piciformes (one species), Caprimulgiformes (one species) and Procellariiformes (one species) in birds, Pholidota (three species) and Proboscidea (one species) in mammals. Leporidae had two species and could be merged with Rodentia because they were phylogenetically close. Therefore, the final dataset included seven orders of mammals, and nine orders of birds (see Figure S2 for the final order classification for birds and mammals). We had body mass data of 144 threatened birds and 166 threatened mammals, clutch size data for 128 threatened birds and litter size data for 161 threatened mammals.

2.4 | Data Analysis

Firstly, we assessed the proportions of threatened birds and mammals in each province, which was performed in ArcGIS V10.7 using location data obtained from the National Basic Geographic Information System data (1:1,000,000). Secondly, we ranked the number of bird and mammal species of different threat categories at the national and seven regional scales (Appendix Table S1). Thirdly, to obtain a more detailed assessment of the spatial distribution of major threats, we matched the listed threats for each species to their corresponding distribution and calculated the number and proportion of threatened birds and threatened mammals by each of the six major threats in each province (see Appendix Tables S2 and S3). We then mapped the distribution of threatened species proportions in each province in ArcGIS V10.7 using location data (1:1,000,000) obtained from the National Basic

Geographic Information System. Fourthly, we performed a hierarchical clustering of threats to assess whether certain threats co-occurred among birds and mammals (Appendix Table S4). The clustering used the results of a Bray–Curtis similarity matrix. Fifth, the number of threatened birds and mammals were calculated for different habitats to assess which major habitat type has the most threatened species (Appendix Table S5). Finally, to determine the most common threats to birds or mammals within each orders and traits, the number of birds or mammals per order was calculated for each threat (Appendix Table S6). We sorted the data of body mass and clutch/litter size from small to large, and divided them into three fairly equal groups (high, medium and low body mass groups, as well as high, medium and low clutch/litter size groups). Then, we calculated the number of different threats to species by group (see Appendices Tables S7 and S8).

3 | Results

3.1 | Relative Importance of Threat Factors to Birds and Mammals in China

Ranking the number of birds and mammals species facing each threat, we found that habitat loss, hunting, human disturbance, agriculture, pollution and logging were the most common threats to birds (Figure 1A). Hunting, agriculture, logging, habitat loss, human disturbance and livestock farming or ranching were the most common threats to mammals (Figure 1B). In terms of seven regions, the ranking of the major threats to birds and mammals was roughly consistent with the national threat patterns, with some changes in the order of threats in different regions (Figure 1).

Hunting ranked first to mammals but second to birds (Figure 1). Habitat loss ranked first to birds but fourth to mammals, indicating that hunting posed a threat to a greater proportion of mammals than to birds, while habitat loss affected birds more than mammals (Figure 1). Moreover, agriculture and logging impacted proportionally more mammals (Figure 1). In addition, pollution, livestock farming or ranching appeared separately as the major threats to birds and mammals respectively (Figure 1). It is important to note that whilst we are mapping how many species are exposed to different threats, assessing the intensity or level of impact is challenging, and thus we have not included it here.

3.2 | Geographic Patterns in Major Threats

The six major threats to birds and mammals showed different distribution patterns (Figures 2 and 3). Specifically, proportion of birds threatened by habitat loss was high in Southwest China,

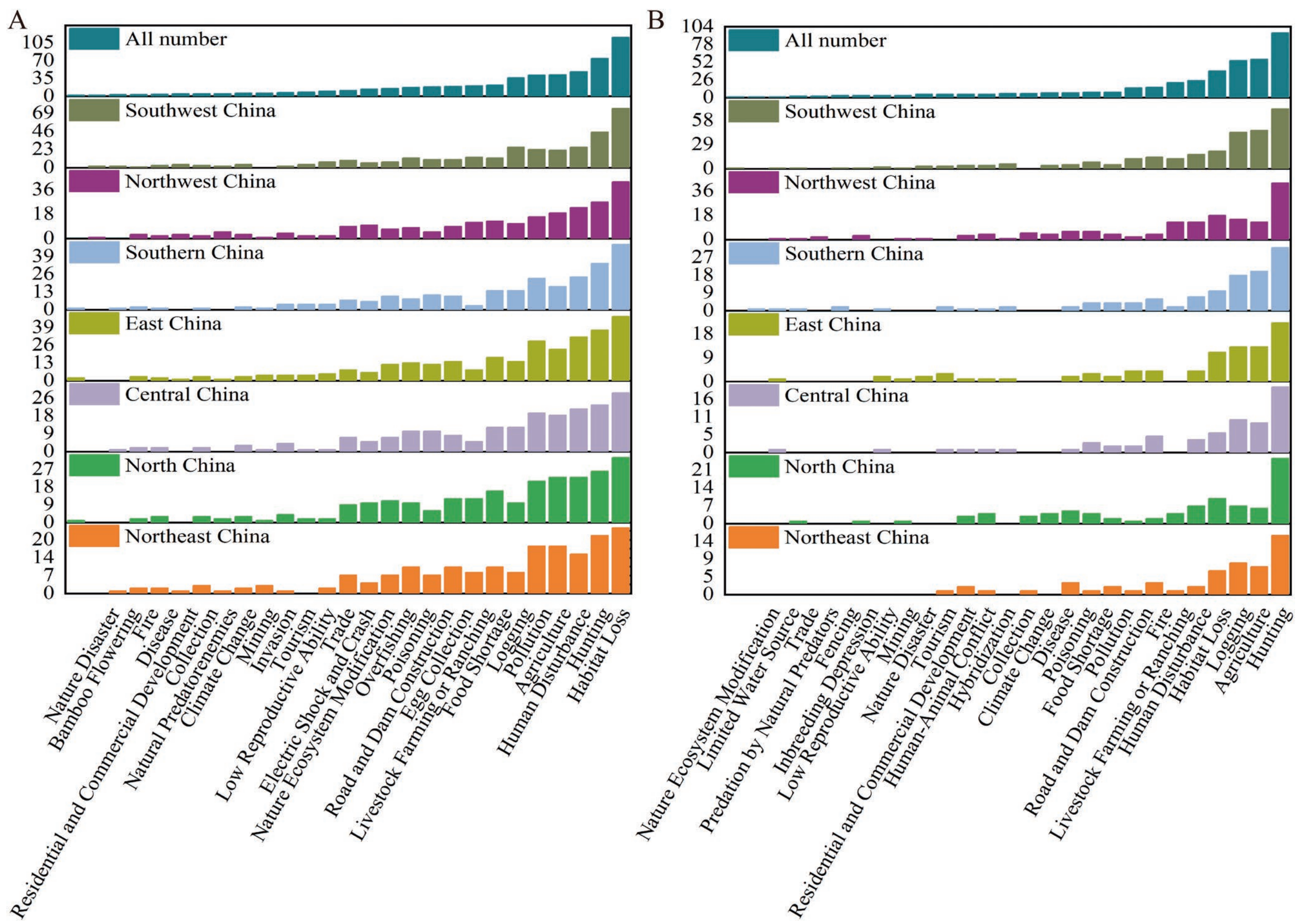

FIGURE 1 | Ranking of the threats to birds (A) and mammals (B) in China and seven regions. ‘All number’ on the top panels represents the national threat pattern. The following from top to bottom are seven regions ranked by the total number of threats.

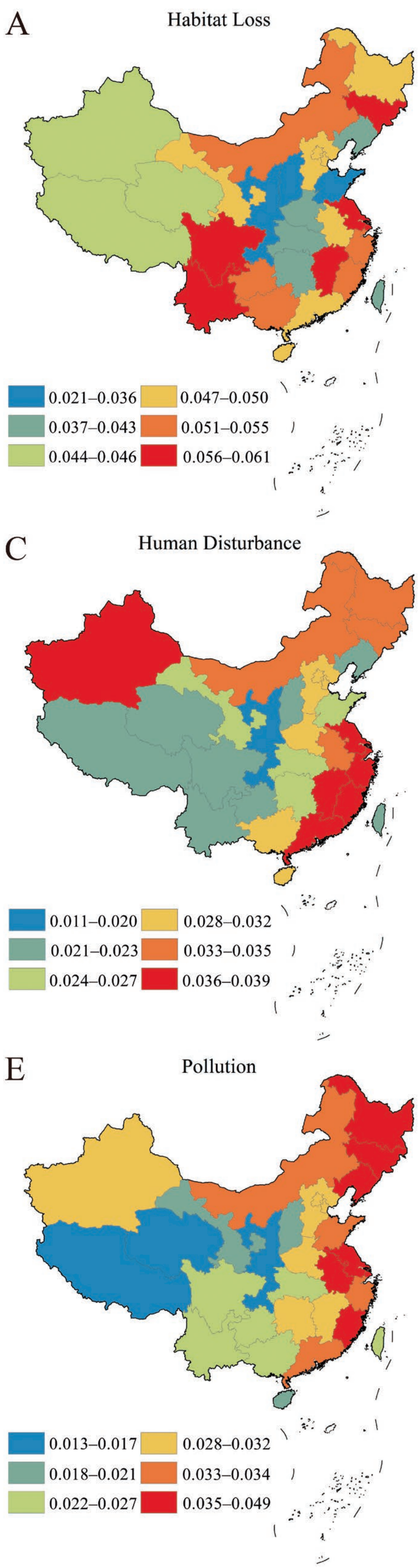

FIGURE 2 | The distribution of the six most common threats to threatened birds in China. The numbers in the figure are the ratio of the number of threatened birds in each province divided by the number of all birds in the province.

East China and Northeast China (Figure 2A). Proportion of birds threatened by hunting was high in East and Northeast China (Figure 2B). The proportion of birds threatened by human disturbance was higher in Southeast China and Xinjiang than in other threats (Figure 2C). Notably, the presence of agriculture was more dominant in North and Northeast

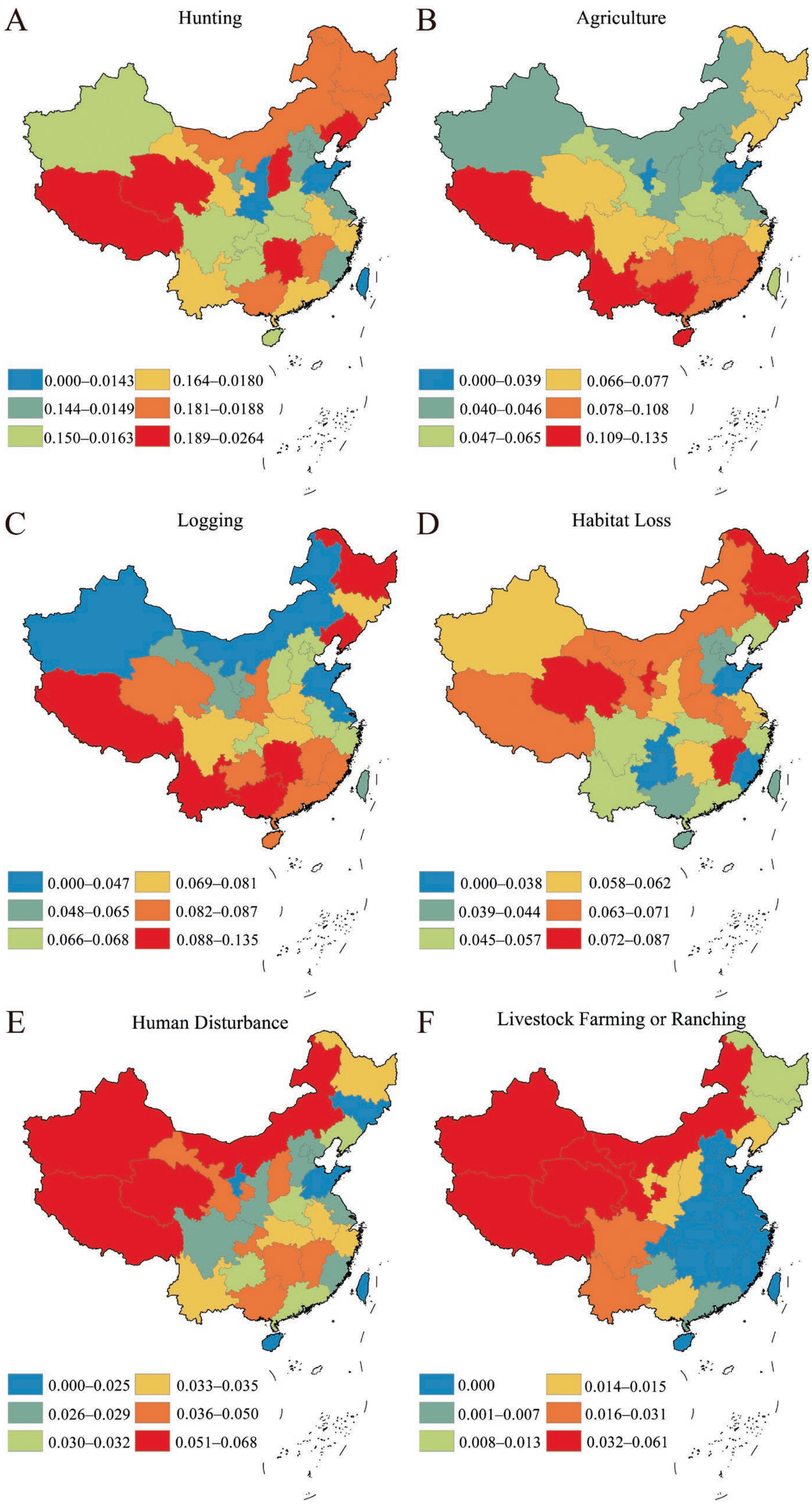

FIGURE 3 | The distribution of the six most common threats to threatened mammals in China. The numbers in the figure are the ratio of the number of threatened mammals in each province divided by the number of all mammals in the province.

China (Figure 2D). Pollution appeared to be more important in Northeast and Eastern China (Figure 2E). Logging was more common in Southwest and Southeast China (Figure 2F).

Compared to birds, proportion of mammals threatened by hunting was high in Tibet and North China (Figure 3A). Agriculture was very important in Southwest and Southern China (Figure 3B).

Logging had a greater impact in Southwest and Southern China, as well as Northeast China (Figure 3C). Habitat loss appeared to be more of a threat in North China, especially Northeast China (Figure 3D). Human disturbance and livestock farming or ranching were more common in Northwest China (Figure 3E,F).

Notably, agriculture mainly affected birds in Northeast China, but mainly impacted mammals in Southwest China (Figures 2D and 3B). Habitat loss had a greater impact on birds in Southwest China than on mammals in Southwest China (Figures 2A and 3D). The human disturbance impacted a higher proportion of bird species in Southeast China, while the impact on mammals was mainly in Northwest China (Figures 2C and 3E). Logging had impacted a smaller proportion of birds in Northeast China but had more impact on mammals in Northeast China (Figures 2F and 3C).

3.3 | Threats Co-Occur as Threat Syndromes

Excluding unknown threats, 145 bird species (98.6%) and 148 mammal species (84.1%) were under more than one threat (Figure 4). Some threats occur simultaneously as potential 'threat syndromes', indicating that both birds and mammals are not only affected by a single threat (Figure 4). For example, many birds threatened by pollution were often also threatened by human disturbance and agriculture while these three threats were correlated with road and dam construction and logging (Figure 4A). Birds threatened by egg collection were also threatened by poisoning, and both threats were related to overfishing and food shortages (Figure 4A). In contrast, the few species of birds threatened by invasions or natural disasters were rarely at risk from other threats (Figure 4A). For mammals, species threatened by agriculture and logging were also threatened by habitat loss and hunting (Figure 4B). Mammals threatened by fire were usually threatened by human disturbance, and both threats were related to road and dam construction and livestock farming or ranching (Figure 4B). By contrast, the mammals threatened by fencing were rarely at risk from other threats (Figure 4B).

3.4 | Assess Which Major Habitat Type Has the Most Threatened Species

Threatened birds were found in 13 habitats, and threatened mammals were found in 12 habitats. Most of the threatened birds (83 species) and mammals (140 species) were found in forests (Figure S2). In addition to forests, threatened birds were mainly found in wetlands (53 species), shrublands (33 species), grasslands (28 species),

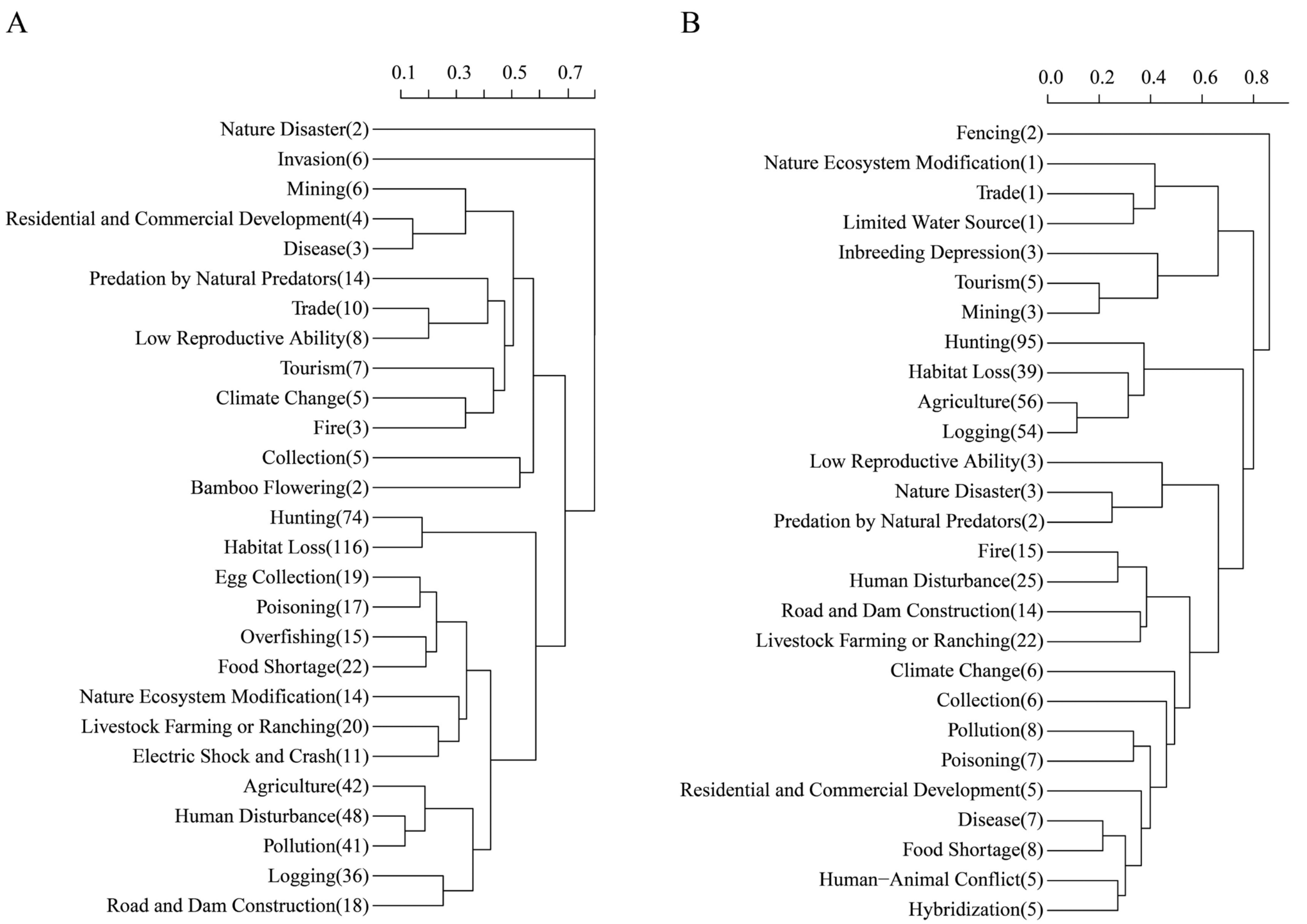

FIGURE 4 | Bray–Curtis similarity resemblance plot shows the levels of similarity among threats to the threatened birds (A) and threatened mammals (B) in China. The abscissa is Bray–Curtis distance, and the ordinate is the threat category. The Bray–Curtis distance ranges from 0 to 1, and the smaller the distance between different threats, the higher the possibility of co-occurrence. Hence, these threats with high co-occurrence can be treated as threat syndromes. In brackets are the total numbers of threatened species.

croplands (15 species) and rocky areas (10 species; Figure S2A). Some habitats such as tundra areas (two species) and karst areas (one species) had very few threatened birds (Figure S2A). In addition to forests, most threatened mammals were found in grasslands (46 species), shrublands (34 species), croplands (25 species), wetlands (16 species) and desert areas (13 species; Figure S2B). In contrast, rocky areas (one species) and coast (one species) had the lowest numbers of threatened mammals (Figure S2B).

3.5 | Ranking the Threats by Orders, Body Mass and Clutch or Litter Size

We also explored the relationships between threats and various traits (such as body mass). The results showed that the most common threat to birds of different orders, body mass and clutch size was habitat loss, and the most common threat to mammals of different orders, body mass and litter size was hunting (See Figures S3, S4 and S5). However, the second most common threat for mammals was different for body mass and litter size groups, with agriculture as the second most common for large and small mammals, but logging for medium body size. Similarly, for mammals with the largest litter size logging was the second most common, and agriculture for medium and small litter sizes. For bird species with large clutch sizes, human disturbance was the second most common, whereas for birds with small or medium clutches, hunting was the second greatest threat. For both clutch and body size, the overall ranking varied considerably for less common threats. Trade was the sixth most common threat, occurring only in small body mass group birds (Figure S4). In addition, trade was a threat for 60% of all threatened Bucerotiformes (Figure S3). Food shortage was more important for birds with large body mass, and species with small clutch sizes (Figures S4 and S5). Notably, hunting, agriculture and logging were disproportionately common threats for Carnivora, Artiodactyla and Primates (Figure S3).

Furthermore, some threats were only listed for single orders (Figure S3), for example, only Carnivora were potentially threatened by food shortages, and most mammals threatened by poisoning were carnivores (with some Rodentia and Leporidae). Inbreeding depression was only noted to be a risk to primates, mining only to Chiroptera and natural disasters to Artiodactyla, as well as the majority of mammals at risk from disease also being within Artiodactyla. Likewise, most mammals threatened by collection were Chiroptera, as well as some primates and a small number of Carnivora. For birds, threats were more heterogeneous across groups, but most species at risk of electric shock were Accipitriformes, and most species at risk of trade were Passeriformes as well as some Bucerotiformes. Gruiformes were most at risk of invasion, and Galliformes to predation and collection.

4 | Discussion

4.1 | Drivers of Species Declines

Understanding the patterns of threat and how they impact different taxa is a key question in management; yet, this type of analysis is limited to certain regions and taxa. The six most common threats to birds in China were habitat loss, hunting, human disturbance, agriculture, pollution and logging, while the six most common threats to mammals were hunting, agriculture, logging, habitat loss, human disturbance and livestock farming or ranching. Although these threats are not new and are similar to other studies concerning the top threats terrestrial vertebrates face globally (Chang et al. 2019; Maxwell et al. 2016; Mcclure et al. 2018), we found that the ranking was somewhat different, especially for birds and mammals in China. At the global scale, birds and mammals were mainly affected by overexploitation and habitat loss (Chang et al. 2019), while in China, birds were more commonly impacted by habitat loss and mammals were more commonly impacted by hunting (Figure 1).

Hunting and collection are now illegal in China, but may still occur, and were previously widespread and harmful (Leclerc, Courchamp, and Bellard 2018; Tilman et al. 2017). However, globally for birds, the difference in the impact of collection was only marginally higher than agriculture, but the severity of impact for impacted species is higher from agriculture (Thinley et al. 2020). Similarly in global analysis of island faunas, extinct birds were shown to have been most threatened by exploitation or invasion, followed by agriculture, whereas mammal extinctions were attributed to invasions. For extant threatened island birds and mammals, agriculture and exploitation are the major threats (Troyer and Gerber 2015). In global mammal analysis, loss and fragmentation is also generally stated to be a threat to the highest number of species (Ye et al. 2015). In addition, other analyses list many of the same threats we found, including agriculture, logging and overgrazing (Maxwell et al. 2016). Our analysis for China aligns well with these previous analyses, and highlights the primary direct threats to set conservation priorities for China (Warren-Thomas, Dolman, and Edwards 2015).

In temperate regions across the globe, species typically have larger ranges, and thus habitat loss is less likely to cause extinctions (Mcclure et al. 2018). However, in tropical regions, species often have smaller ranges, and therefore, may be more sensitive to habitat losses (Mcclure et al. 2018). The clearance and degradation of primary or secondary forests and the conversion to rubber monoculture affect a high proportion of species in many tropical regions (Li et al. 2015; Trull, Boehm, and Carr 2018; Wang et al. 2018). Furthermore, it is known that species already at risk from other threats may have an exaggerated risk from climate change (Li et al. 2020). Furthermore, species dependent upon certain habitats, such as wetlands may have slightly different threat rankings due to the accumulation of pesticides in water bodies (Li et al. 2022).

4.2 | Spatial Patterns of Threat

Threat is not uniformly distributed, and we identified geographic hotspots of threatened birds and mammals in China (Zhang et al. 2022a, 2022b; Zhou and Ke 2020), which are broadly comparable to the overall patterns shown in global analysis (Maxwell et al. 2016). These hotspots reflect both richness patterns and the different patterns of the various threats (Tang et al. 2015). For example, Southwest China is a hotspot for some major threats to birds and mammals, including habitat loss, agriculture and logging. Unsurprisingly, these threats are associated with the transformation of natural landscapes (Yamaura et al. 2017). Northeast and southeast China, especially coastal areas (with higher bird richness), are rich in wetlands and farmlands, which are often used as stopovers or breeding grounds for birds. For example, the East Asia-Australasian flyway (EAAF) is one of the largest migratory shorebird bird routes worldwide, with 50 million individuals stated to use it globally (Grainger et al. 2018). However, key wetland areas along the EAAF are often surrounded by agricultural development, land reclamation and river pollution, thus population declines of some species is sometimes over 70% since the 1960s (Tian, Xu, and Wang 2020). In China, we found that 67% of the threatened Charadriiformes species is more vulnerable to river pollution than other families. In contrast, although economically developed regions reduce the risk of agriculture and pollution, it increases the risk of human disturbance to the species. Severe urbanisation tends to decrease bird population densities by changing bird foraging behaviour, reproductive activities and migration, and reduces diversity of birds and mammals (Peng et al. 2017; Xie et al. 2022). Birds in Southeast China are at a higher risk from human disturbance, while the impact of human disturbance on mammals is mainly in Northwest China. Northwest China is the biggest livestock production area in China (Yin et al. 2016). Studies have shown that livestock are fed mainly by grazing on pastures, and that overgrazing leads to grassland degradation, thereby increasing the proportion of threatened mammals (Hughes 2017). Since the demand for beef and dairy products is increasing, the number of specialised farms is also increasing (Yin et al. 2016), thus livestock farming or ranching is a major threat for mammals.

4.3 | Threat Syndromes and Their Impacts

Threatened species often face multiple threat interactions (Figure 4). In terms of high-threat clusters, many birds threatened by pollution and human disturbance were also threatened by agriculture, which was associated with both road and dam construction and logging. For example, the rapid economic development in East China has affected birds through various interrelated threats (Jiang 2016; Mccarthy et al. 2012). Common threats to mammals, specifically agriculture, logging, habitat loss and hunting, often coexisted, likely because many of these stem from development in rural areas across the Asia region (Allek et al. 2018). Therefore, solutions to prevent biodiversity loss from these co-occurring threats need to be managed jointly, likely requiring coordinated collaboration with all stakeholders (Wraith and Pickering 2018). For example, strengthening laws to curb illegal hunting, popularising animal protection knowledge, sustainable agriculture and limiting logging would help counteract major threats responsible for biodiversity losses (Mccarthy et al. 2021). Especially in areas where threatened species are concentrated, integrated threat management also provides a more effective approach to reduce investment cost and improve the efficiency of multiple species protection (Mehta et al. 2020). In contrast, single-threat conservation strategies are more specific and more likely to need tailored actions for specific species (Greenberg et al. 2018).

4.4 | Distribution of Threats by Habitat

Similar to birds and mammals across the globe, most threatened birds and mammals in China occur in forests (Figure S2) (Cordier et al. 2021; Thompson, Nowakowski, and Donnelly 2016), highlighting the need for forest protection to conserve the greatest number of threatened species. Unsurprisingly, forest-dependent species are disproportionally threatened when forests are modified (Nowakowski et al. 2018; Pyron 2018). Following forest, the habitats with the second highest number of threatened species were wetlands for birds, and grasslands for mammals (Figure S1). Therefore, overarching conservation strategies must include all major biomes to ensure all species have at least some habitat protection (wetlands, grasslands and shrublands) (Luo et al. 2016). Furthermore, generalist species were able to utilise more habitats and therefore were less vulnerable to threats (Teng et al. 2020). Conversely, more specialist species occupied fewer habitats (such as karst or coastal specialist species) are less adaptable, and thus habitats which may require more specialist adaptations may form biodiversity hotspots of endemic species, thus they are vital for species conservation (Luo et al. 2016). Specialist threatened species are also especially likely to become extinct once these habitats are greatly disturbed or destroyed (Teng et al. 2020).

4.5 | Traits and Threats

There are complex relationships among orders, body mass, clutch/litter size and threats (Figures S3, S4 and S5). The Millennia-long spread of agricultural land and agricultural intensification, along with cultural filtering, has reduced the number of large-bodied species, such as Carnivora, Artiodactyla and Perissodactyla in much of their former ranges (Moreno-Rueda et al. 2017). Although we calculated the number of threats to rank how common they are, this does not represent the severity of impact of threats (Hennin et al. 2018). In addition, species with slow reproduction are more frequently threatened by direct threats. For example, within the Accipitriformes, larger species with fewer clutches are most affected by food shortages (Kearney et al. 2023), as under adverse conditions (e.g., food shortage), parenting costs are too high (Kearney et al. 2023). This may suggest that increased food competition controls for body mass and clutch/litter size, while this needs to be confirmed by more experiments (Greenville et al. 2021). The two orders with the most threatened mammals are the Carnivora and Artiodactyla, possibly due to the slow reproductive rates which hamper recovery following population crashes.

4.6 | Synthesis

Globally threats vary by taxa and region, and the same is true on the scale of China (Veach et al. 2017; Wraith, Norman, and Pickering 2020). With limited resources and high levels of species endangerment, developing diverse, targeted and integrated action plans is necessary for different species, ecosystems and regions. Some threats impact fewer species, but such threats may pose more intense risks, as the prevalence of these threats varies both spatially and taxonomically. In addition, species afflicted by multiple threats are likely to face greater extinction risk (Zhang et al. 2022a, 2022b), and this is likely true beyond the taxa studied here (Jiang and Luo 2012; Wang et al. 2021). These findings reinforce that actions to conserve bird and mammal biodiversity should prioritise addressing loss and degradation of habitat and overexploitation, (as these were universally shown to present high threats), comprehensively manage threats, and wherever possible strictly protect endangered species. Targeting threats which impact the greatest number of species, or managing regions where certain threats are particularly pertinent both have the potential to dramatically reduce the risk of species extinction.

Although the implementation of biodiversity conservation and environmental protection programs in China has improved the population and status of many species (such as forest management, combating desertification, curbing land degradation, etc.) (Ding et al. 2022; Lu et al. 2020), more work is needed to broaden species beyond Key Nationally Protected Species. To address common threats to species nationwide, a fully integrated approach will be needed. Furthermore, global targets, such as the Kunming–Montreal Global Biodiversity Framework can only be achieved through effective national level action. Therefore, effective implementation of the targets of the Kunming–Montreal Global Biodiversity Framework will be a major opportunity and challenge for China to improve conservation, curb biodiversity losses nationwide. In addition, it will provide a framework for identifying priorities, which could translate to other countries to help prioritise regions to meet current and future conservation targets.

Our study provides the following recommendations to governments, managers, scientists and stakeholders to address the extinction risks faced by the Chinese birds and mammals, irrespective of their commercial status or value: (1) Encourage conservation practitioners to prioritise the top threats to biodiversity in partnership with others. (2) Strengthen the legislative framework for managing birds and mammalian resources, and develop suitable protection plans for different species, ecosystems and regions. (3) Addressing one threat in isolation would have little effect on protection, so we propose to increase protection investment in areas with integrated threat management. (4) Develop comprehensive conservation plans to protect and rehabilitate all habitat types where threatened species are distributed. (5) Support and strengthen more research between threats and ecology. Understanding which traits are making species more vulnerable would lead to better targeting when investing the limited conservation resources. (6) Educate and promote awareness of birds and mammalian vulnerability to human disturbance, and promote public participation.

4.7 | Limitations

This study was based on two recently published books (Jiang et al. 2021; Zhang and Zheng 2021), including information on scientific name, conservation class, habitat, provincial distribution and threat categories. Despite this useful information, this dataset also has some limitations. For example, while most categories appear to be mutually exclusive, a few threat categories seem to be umbrella terms that include other threat categories (not mutually exclusive), for example, 'Habitat Loss', 'Human Disturbance' and 'Natural Ecosystem Modification'. This problem may bias the interpretation of results of this study. Thus, determining the detailed threat categories for species is still a high priority for future research. But at least some general conclusions could be summarised in this study, which may be helpful for species that have identified specific threats (e.g., logging, grazing and pollution).

Author Contributions

G.F. conceived the idea. Z.L. collected the data. G.F., Z.L. and X.G. analysed the data. G.F., X.G., Z.L., R.T.C., Z.J., A.H., K.M. and J.-C.S. wrote the paper.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All relevant data underlying the main results (i.e., Tables S1–S8) are provided as supplementary files.

Peer Review

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.