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HYAGO KESLLEY DE LUCENA SOARES

Interações entre pessoas e mamíferos silvestres no mundo: usos, conflitos e conservação

João Pessoa - PB
2024

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Tese de Doutorado apresentada ao Programa de Pós-graduação em Ciências Biológicas – PPGCB (Área de concentração: Zoologia) da Universidade Federal da Paraíba, como requisito às exigências, para obtenção do título de Doutor em Ciências Biológicas (Zoologia).

Orientador: Prof. Dr. Rômulo Romeu da Nóbrega Alves (UEPB)
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Neste trabalho, todos os capítulos seguem as normas dos jornais científicos aos quais eles foram submetidos. O nome de cada jornal consta na página título de cada capítulo.

Dedico esse trabalho aos meus familiares, a ciência brasileira e a todos aqueles que fazem dela sua labuta diária.

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RESUMO

Os mamíferos são utilizados para diversas finalidades por grupos humanos de todo o planeta. Entretanto a escolha e o uso das espécies não são aleatórios, sendo influenciados por características (biológicas/ecológicas) das espécies usadas e fatores culturais e socioeconômicos. Atualmente a exploração de mamíferos para suprir as necessidades humanas além das demandas cada vez maiores do comércio de animais selvagens (partes, produtos e animais vivos) representam uma importante ameaça para muitas espécies. Neste sentido, o presente estudo compreende uma análise sobre os fatores que determinam a escolha e utilização de mamíferos selvagens em escala global. Os objetivos principais desse estudo foram testar como as características das espécies, relações evolutivas e fatores socioeconômicos atuam na seleção das espécies para o comércio de animais selvagens, uso como animais de estimação (pets) e alimento (carne de caça), bem como das espécies envolvidas em conflitos com humanos. Outros objetivos foram identificar as regiões com maior riqueza de espécies consumidas e verificar se existe viés nos estudos investigando o consumo de mamíferos nas categorias citadas acima. Por meio de uma revisão sistemática, compilamos um compreensivo banco de dados e usamos métodos comparativos filogenéticos para testar se as características das espécies influenciam o consumo e conflitos de mamíferos com humanos. Além disso, testamos quais variáveis socioeconômicas e como elas influenciam o consumo desses animais. Uma expressiva riqueza de espécies é usada respectivamente no comércio de animais selvagens (n=458), como animais de estimação (n=704), alimento (1.486) e envolvidas em conflitos com humanos (713). Entre as espécies registradas, pelos menos 162, 300, 391 e 160 são consideradas ameaçadas pelo comércio, uso como pets, consumo de carne de caça e conflitos com humanos, respectivamente. As características das espécies determinam seu uso em todas as categorias investigadas. No geral, espécies com menor massa corporal e área de extensão geográfica são mais utilizadas como animais de estimação, como alimento (carne de caça) e em conflitos com humanos. Por outro lado, espécies com maiores massas corporais e extensão geográfica são mais comercializadas (tem mais partes corpóreas usadas e são comercializadas para mais usos). Os usos das espécies são agrupados na filogenia, nesse sentido espécies evolutivamente próximas estão envolvidas nas mesmas categorias investigadas. Os usos das espécies são globalmente disseminados, contudo os países em áreas tropicais apresentam maior riqueza de espécies usadas em cada uma das categorias investigadas. Com base nos nossos resultados, pelo menos 125, 65, 133 e 127 países estiveram envolvidos no consumo de mamíferos para comércio, pets e carne de caça, bem como em conflitos com humanos, respectivamente. Países subdesenvolvidos ou em desenvolvimento apresentam maior riqueza de espécies nas quatro categorias investigadas. No geral, nossos resultados ampliam substancialmente as informações sobre os fatores determinantes do consumo e conflitos de mamíferos selvagens por populações humanas e possibilitam uma melhor contextualização em escala global com vistas a elucidar políticas públicas que busquem atenuar os problemas relacionados ao consumo desses animais tanto para as populações das espécies exploradas, quanto para garantir o bem-estar das populações humanas.

Palavras Chaves: Características ecológicas, Filogenias, Comércio, Pet, Carne de caça, Conservação.

ABSTRACT

Mammals are used for various purposes by human groups worldwide. However, the selection and use of species are not random, as they are influenced by the biological and ecological characteristics of the species, as well as cultural and socioeconomic factors. Currently, the exploitation of mammals to meet human needs, along with the increasing demands of the wildlife trade (including parts, products, and live animals), poses a significant threat to many species. This study therefore, analyses the factors that determine the selection and use of wild mammals on a global scale. The main objectives were to test how species traits influence the selection of species for the wildlife trade, use as pets, and for food (bushmeat), as well as species involved in conflicts with humans. Additional objectives were to identify the regions with the greatest species richness and to assess whether there is bias in studies investigating mammal consumption in these categories. Through a systematic review, we compiled a comprehensive database and used phylogenetic comparative methods to test whether species traits influence mammal consumption and conflicts with humans. Furthermore, we tested which socioeconomic variables influence the consumption of these animals and how they do so. A significant number of species are used in the wildlife trade (n = 458), as pets (n = 704), as food (n = 1,486), and are involved in conflict with humans (n = 713). Among the recorded species, at least 162, 300, 391, and 160 are considered threatened by trade, use as pets, bushmeat consumption, and conflicts with humans, respectively. Species traits determine their use in all categories investigated. Generally, species with larger body mass and wider distribution are more frequently used as pets, as food (bushmeat), and in conflicts with humans. In addition, larger and more widely distributed species are more frequently commercialised (they have more body parts used and are commercialised for more purposes). Species´ uses are grouped phylogenetically, meaning that evolutionary closely related species are involved in the same categories investigated. Species´ uses are globally widespread; however, countries in tropical areas have greater species richness in each of the categories investigated. Based on our results, at least 127, 65, 133, and 125 countries were involved in the consumption of mammal for trade, pets, bushmeat, and in conflicts with humans, respectively. Low-and-middle income countries have greater species richness in all four categories that we have investigated. Overall, our results substantially expand knowledge of the determinants of consumption and conflicts involving wild mammals by human populations, and enable better contextualisation on a global scale to inform public policies aimed at mitigating problems related to the consumption of these animals, both for the populations of the exploited species and to ensure the well-being of human populations.

Key words: Ecological traits, Phylogeny, Wildlife trade, Pet, Bushmeat, Conservation.

SUMÁRIO

INTRODUÇÃO GERAL

Desde tempos remotos as populações humanas têm desenvolvido diferentes estratégias que possibilitaram o uso e manejo de animais silvestres em praticamente todo o planeta (ALVES, 2012; SPETH et al., 2013; THOMPSON et al., 2019). Inicialmente praticada com finalidades de subsistência, a caça é uma das atividades humanas mais antigas que se tem conhecimento e foi fundamental para o melhoramento de aquisição proteica, vestimenta, controle de predadores, cura de doenças, locomoção e transporte de cargas (SPETH et al., 2013). Atualmente a caça e o consumo de animais selvagens representam juntamente com o desmatamento os principais responsáveis pela redução populacional e extinção de muitas espécies (BENÍTEZ-LÓPEZ et al., 2017, 2019; LEE et al., 2020; RIPPLE et al., 2016; SYMES et al., 2018a; YOUNG et al., 2016).

Os mamíferos estão entre os principais animais caçados em todo o planeta (ALVES et al., 2020a; BENÍTEZ-LÓPEZ et al., 2019; RIPPLE et al., 2016), são utilizados para diversas finalidades (ALVES et al., 2020a; RIPPLE et al., 2016; SCHEFFERS et al., 2019) e são fundamentais para a subsistência de vários grupos humanos (CAWTHORN; HOFFMAN, 2015; FA; BROWN, 2009; FA; PERES; MEEUWIG, 2002) e funcionalidade dos ecossistemas de todo o planeta (BENÍTEZ-LÓPEZ et al., 2019; BOWYER et al., 2019; HARRISON, 2011; LACHER et al., 2019; REDFORD, 1992).

Embora o uso de mamíferos selvagens para suprir necessidades de subsistência (aquisição de proteína e renda) seja um dos principais fatores que impulsionam a sua caça (BENÍTEZ-LÓPEZ et al., 2017; BRASHARES et al., 2011; FA; PERES; MEEUWIG, 2002; RIPPLE et al., 2016), a utilização destes animais extrapola a finalidade alimentar e um único animal pode ser capturado ou abatido, sendo utilizado de diversas formas, com suas partes corpóreas e subprodutos utilizados pelas pessoas em todas as regiões do planeta (ALVES et al., 2016, 2020a; ALVES; ROSA, 2013; ANTUNES et al., 2016). Outro fator adicional, é que embora uma grande quantidade de espécies seja utilizada, algumas espécies apresentam uma grande variedade de usos (diferentes usos) e se destacam por serem mais versáteis (diferentes usos e partes corpóreas usadas), utilizadas com maiores frequências e/ou em maiores quantidades.

Estudos têm abordado as várias utilizações de mamíferos selvagens ao longo do planeta (ALVES et al., 2020a; HAUSMANN et al., 2023; PALAZY et al., 2012; SCHEFFERS et al., 2019) evidenciando que muitos fatores ambientais, ecológicos/biológicos das espécies e sociopolíticos estão envolvidos na seleção, coleta e utilização destes animais por populações humanas (BRASHARES et al., 2011; LIEW et al., 2021; RIBEIRO et al., 2022; SCHEFFERS et al., 2019). Estudos com caça (subsistência e caça de troféu) e comércio de animais selvagens (carne de caça e animais vivos), têm evidenciado que espécies com maiores tamanhos do corpo, são mais frequentemente coletadas e valorizadas tanto em áreas rurais como urbanas (BENÍTEZ-LÓPEZ et al., 2019; BRASHARES et al., 2011; CHAVES et al., 2018; FA; PERES; MEEUWIG, 2002; PALAZY et al., 2012; PARRY; BARLOW; PEREIRA, 2014). Esses estudos partem da premissa que espécies maiores podem fornecer um maior retorno energético (caça de subsistência e mercados de carne de caça) e cultural “status” (caça de troféus) fornecido ao caçador (KÜMPEL et al., 2010; PARRY; BARLOW; PERES, 2009), além de fornecer uma maior probabilidade de maximização de usos (partes maiores podem ser usadas para mais de uma finalidade). Entretanto, muitos outros fatores como raridade (ANGULO et al., 2009; ANGULO; COURCHAMP, 2009; GAULT; MEINARD; COURCHAMP, 2008; HAUSMANN et al., 2023), hábitos e comportamentos (FA; RYAN; BELL, 2005; PEREIRA et al., 2024), maior visibilidade no ambiente (espécies gregárias, diurnas, com maiores tamanhos populacionais) também influenciam a escolha e utilização das espécies (PEREIRA et al., 2024).

Por outro lado, muitas espécies incluindo aquelas utilizadas pelas pessoas, podem ser negativamente percebidas, uma vez que elas podem vir a causar prejuízos as pessoas devido aos danos causados à agricultura (HILL, 2018; STENSETH et al., 2003; TORRES; OLIVEIRA; ALVES, 2018) e bens humanos (casas, automóveis) (TORRES; OLIVEIRA; ALVES, 2018), predação de animais domesticados como gado e/ou animais domésticos (KANSKY; KNIGHT, 2014; NYHUS, 2016; TORRES; OLIVEIRA; ALVES, 2018; TREVES; KARANTH, 2003) além de ameaçar diretamente a vida das pessoas através da predação (PETERSON et al., 2010). Nesse sentido, uma espécie pode ser percebida de maneira positiva e negativa e podem resultar em conflitos com pessoas (NYHUS, 2016; TORRES; OLIVEIRA; ALVES, 2018).

Naturalmente, toda atividade humana é permeada de fatores culturais e sócio-políticos (CAWTHORN; HOFFMAN, 2015; LIEW et al., 2021; RIBEIRO et al., 2022), de maneira que uma mesma espécie pode ser percebida e usada de diferentes maneira por diferentes populações humanas (ALVES; ROSA, 2013; ROBINSON; BENNETT, 2000). Fatores socioeconômicos como renda, densidade populacional humana e o desenvolvimento humano de determinada região são influenciadores direto do consumo de espécies, como por exemplo carne de caça e comércio de pets (MILNER-GULLAND et al., 2003; RIBEIRO et al., 2022). No geral, esses estudos mostram que países subdesenvolvidos ou em desenvolvimento têm um maior consumo de recursos naturais e perda de biodiversidade devido à sobre exploração (LIEW et al., 2021; RIBEIRO et al., 2022; SYMES et al., 2018b).

Por exemplo, países com maiores taxas de pobreza (portanto baixo Produto Interno Bruto (PIB) e menor Índice de Desenvolvimento Humano (IDH)), estão diretamente correlacionados com o consumo de recursos naturais e perda de biodiversidade (LENZEN et al., 2012; MILNER-GULLAND et al., 2003; OTERO et al., 2020; SYMES et al., 2018b). Por outro lado, países desenvolvidos (aqueles com maiores PIB e IDH) tendem a consumir mais produtos da vida selvagem, uma vez que apresenta uma maior quantidade de dinheiro para gastar com bens supérfluos (como troféus e animais de estimação) (LIEW et al., 2021; RIBEIRO et al., 2022). Somado a isto, a concentração de pessoas em determinada região (densidade populacional humana (DPH)) tem sido associada com o consumo de recursos naturais e extirpação de espécies selvagens devido a coleta abusiva e insustentável (MILNER-GULLAND et al., 2003).

Dessa maneira, fica evidente que utilização e percepção das espécies pelas pessoas engloba um conjunto de fatores, biológicos, socioeconômicos, culturais, políticos e institucionais (ANDERSSON et al., 2021; LIEW et al., 2021; RIBEIRO et al., 2022; SYMES et al., 2018b) além de envolver uma variedade de participantes e espécies (SCHEFFERS et al., 2019; STREET et al., 2023). Portanto, identificar quais fatores biológicos e sociopolíticos e como eles influenciam o uso e relações dos seres humanos com mamíferos é fundamental para delinear e/ou aprimorar medidas que busquem atenuar os efeitos da sobre caça para suprir as necessidades humanas ou para controlar populações de espécies prejudiciais ao bem estar humano.

Diante do exposto, o presente trabalho tem como objetivos: (1) registrar as espécies que são frequentemente usadas para o comércio de animais selvagens, como animais de estimação (pets), alimento (carne de caça) e presente em conflitos com humanos; (2) testar quais fatores biológicos/ecológicos e socioeconômicos atuam na escolha e utilização destes animais por grupos humanos em todo o planeta; (3) identificar quais as regiões exercem maior consumo sobre as espécies; e (4) verificar se a pesquisa envolvendo o uso de mamíferos selvagens é enviesada pelas características biológicas e história evolutiva das espécies.

Com base nas informações acima foram testadas as seguintes hipóteses:

- Existem padrões convergentes de características biológicas/ecológicas das espécies que influenciam seus usos (categorias de usos) entre diferentes populações humanas;
- Espécies filogeneticamente próximas são usadas para as mesmas finalidades;

- Os indicadores socioeconômicos (IDH, PIB, DPH) influenciam o uso das espécies;
- O esforço de pesquisa em cada categoria de uso é influenciado por características das espécies, história evolutiva e fatores socioeconômicos;

Os resultados deste trabalho subsidiam quatro capítulos da tese. O primeiro deles, com título “Padrões mundiais do comércio de mamíferos silvestres é influenciado por ecologia das espécies, relação evolutiva e variáveis sociopolíticas: inferências com base no Boletim TRAFFIC”, engloba aspectos relacionados a características de história de vida e evolução das espécies e o comércio de partes corpóreas e tipos de comércio (quantidades de usos), além de aspectos sociopolíticos dos países relacionados aos números de importações e exportações. O segundo capítulo com título “Avaliação global de mamíferos silvestres usados como pets”, o terceiro capítulo “Da selva para a mesa: impulsionadores ecológicos e evolutivos do consumo de mamíferos selvagens como alimento/carne de caça” e quarto capítulos “Impulsionadores ecológicos e socioambientais de conflitos entre humanos e mamíferos silvestres no mundo” são semelhantes ao primeiro, mas direcionado ao uso de mamíferos como animais de estimação (pet), carne de caça e conflitos com humanos, além de verificar se existem vieses nas pesquisas direcionadas ao uso de mamíferos com pet, alimento e presentes em conflitos. Todos os capítulos abordam os fatores ecológico e socioambientais que permeiam a escolha e o consumo destes animais, além de chamar atenção para medidas de regulação (caso de comércio, pet e alimento) baseadas nas características de história de vida das espécies.

ESTADO DA ARTE

Histórico da caça de mamíferos

O histórico da evolução humana baseia-se no aumento do cérebro dos primeiros hominídeos (WALTER, 2009). Esta expansão cefálica possibilitou que estes seres desempenhassem atividades mais complexas, como o manuseio da pedra (BEN-DOR et al., 2011; HILL, 1982). Esta manipulação possibilitou que alguns hominídeos construíssem uma grande variedade de ferramentas de usos múltiplos (BEN-DOR et al., 2011; HILL, 1982; KORTLANDT, 1980).

No entanto, foi com o advento de objetos cortantes, que estes seres, que eram coletores oportunistas, tornaram-se caçadores, o que possibilitou a aquisição de uma grande variedade de fontes alimentícias (BEN-DOR et al., 2011; SPETH et al., 2013). Nesse sentido à caça de animais foi um componente vital para a evolução humana, pois forneceu um alimento rico em energia e proteínas (BEN-DOR et al., 2011). Estudos investigando a dieta de hominídeos mostraram que esses seres possuíam uma dieta bastante diversificada alimentando-se de aves, peixes, moluscos e mamíferos (BEN-DOR et al., 2011; SPETH et al., 2013; THOMPSON et al., 2019). A exploração de diferentes recursos alimentícios necessitava de uma maior capacidade de raciocínio, uma vez que há particularidades nas estratégias de captura para diferentes grupos animais.

Deste modo, a elaboração de estratégias de caça em grupo possibilitou que nossos ancestrais obtivessem maior sucesso na busca e abate de presas, e, consequentemente reduzisse o gasto energético para desempenhar a caçada (BEN-DOR et al., 2011; THOMPSON et al., 2019). O planejamento sazonal da caça, as estratégias para se defender de predadores, o abate de grandes herbívoros, divisão das presas em partes menores e a seleção consciente de uma espécie, apesar de serem bastante debatidas, são apontadas por diversos estudos como estratégias de subsistência modernas e complexas (THOMPSON et al., 2019).

Nesse sentido, os seres humanos têm estabelecido relações com os mamíferos desde tempos remotos (ALVES, 2012) de maneira que esses animais têm sido usados de diversas formas pelas sociedades primitivas e contemporâneas, tal como alimento, animais de estimação, atividades culturais além de usos medicinais, mágico-religiosos, transporte e comércio (ALVES, 2012), sendo um dos grupos dentre os vertebrados continentais que mais sofre pressão antrópica devido à sobre exploração (BENÍTEZ-LÓPEZ et al., 2017, 2019; MAXWELL et al., 2016).

Em todas as regiões do planeta milhares de povos tem vivido da caça há milhares de anos, porém o aumento da população humana, melhoria das tecnologias empregadas na caça e ausência de outras fontes de proteína tem causado drástico desequilíbrio para a biodiversidade (BENNETT; ROBINSON, 2000; BRASHARES; GAYNOR, 2017). Em muitas regiões, o difícil acesso aos centros urbanos, à disponibilidade de recursos silvestres e as dificuldades para criação de rebanhos domésticos, tal como a baixa renda de diversas populações humanas são fatores que contribuem para captura indiscriminada de muitas espécies. Atualmente a caça e os usos indiscriminados das espécies representam a principal ameaça para muitas populações selvagens em todo o planeta (SCHEFFERS et al., 2019).

Interações com mamíferos e por que? Alimento, animais de estimação, comércio e conflitos?

Existe um fervoroso debate a respeito dos fatores subjacentes às extinções do pleistoceno (BARNOSKY et al., 2004; FAITH et al., 2018; KOCH; BARNOSKY, 2006; SANDOM et al., 2014; WROE et al., 2004). Eventos climáticos e pressões humanas (principalmente caça), ou uma combinação de ambos, são considerados os principais fatores responsáveis pela extinção de grandes mamíferos (megafauna) no Quaternário em praticamente todo o planeta (FAITH et al., 2018; GRAYSON, 2001; KOCH; BARNOSKY, 2006; SANDOM et al., 2014). A extinção seletiva da megafauna coincide com a expansão e conquista dos ambientes terrestres pelos hominídeos e consequentemente pelos indivíduos da espécie *Homo sapiens* (GRAYSON, 2001; SANDOM et al., 2014).

A coleta e abate de mamíferos selvagens para consumo alimentar representa um dos primeiros usos de mamíferos por humanos (BEN-DOR et al., 2011; SPETH et al., 2013; THOMPSON et al., 2019). Atualmente, embora o uso desses animais ainda represente a única fonte de proteína para muitas populações humanas em diferentes locais (SARTI et al., 2015; VOLPATO et al., 2020), o consumo de carne de caça extrapola o âmbito rural, tradicional de subsistência e em muitos centros urbanos a carne de animais selvagens é considerada iguaria com alta valoração cultural e comercial (CHAUSSON et al., 2019; VOLPATO et al., 2020).

No mesmo sentido, o uso das espécies como animais de estimação remonta tempos primitivos (DRISCOLL; MACDONALD; O’BRIEN, 2009; MILLA et al., 2018). A domesticação do cão doméstico *Canis lupus familiaris* entre 23.000 - 15.000 anos atrás (AHMAD et al., 2020; DRISCOLL; MACDONALD; O’BRIEN, 2009), representa um marco no processo evolutivo humano, uma vez que a partir do cão, o homem pode gerenciar aquelas espécies que eram úteis para sua subsistência e segurança (AHMAD et al., 2020; MILLA et al., 2018). Muitas outras espécies foram domesticadas posteriormente, grande parte destas, para finalidades alimentares (AHMAD et al., 2020; MILLA et al., 2018).

Atualmente, uma grande variedade de animais selvagens é usada como animais de estimação (STREET et al., 2023). Aves e répteis são os grupos com maior riqueza de espécies usadas (MARSHALL; STRINE; HUGHES, 2020; SCHEFFERS et al., 2019), entretanto, mamíferos englobam uma considerável quantidade de espécies ameaçadas pelo uso como animais de estimação (SCHEFFERS et al., 2019; STREET et al., 2023), além de também estarem presentes em mercados da vida selvagens em escalas locais, regionais e globais (HARFOOT et al., 2018; SCHEFFERS et al., 2019), funcionando como um dos principais estimuladores do comércio ilegal de animais selvagens em todo o planeta (HARFOOT et al., 2018; SCHEFFERS et al., 2019; STREET et al., 2023).

Esse último, o comércio, engloba uma complexidade de fatores como por exemplo, diferentes tipos de comércio (medicina tradicional, partes e produtos, troféus, além de carne de caça e animais de estimação), grande diversidade de espécies e múltiplos atores sociais envolvidos desde a coleta até o consumidor final (ESMAIL et al., 2020; PHELPS; BIGGS; WEBB, 2016; SAS-ROLFES et al., 2019). Além disso, um único animal pode ser comercializado para mais de uma finalidade, o que resulta em demandas diferentes com base nos tipos de comércio envolvidos. Atualmente esta prática representa um dos principais causadores de redução populacional e extinção de espécies em todo o planeta (HUGHES et al., 2022; SAS-ROLFES et al., 2019).

Essas três finalidades de uso, (alimento, pet e comércio) embora distintas, são estimuladores direto da captura seletiva de vertebrados selvagens (MARSHALL; STRINE; HUGHES, 2020; SCHEFFERS et al., 2019; STREET et al., 2023; VOLPATO et al., 2020), além de também serem consideradas como as responsáveis pela pandemia mundial de Covid-19 (SARS-Cov-19) que durou até metade de 2021 (LAM et al., 2020; SHIVAPRAKASH et al., 2021).

Em relação aos conflitos entre humanos e mamíferos selvagens, essa problemática também tem início nos primórdios da evolução humana (FAURBY et al., 2020; KORTLANDT, 1980). Recentes evidências mostram que o aumento do cérebro dos hominídeos coincide com o desaparecimento de grandes predadores que competiam e ameaçavam diretamente a sobrevivência de nossos antepassados (FAURBY et al., 2020).

Diante da complexidade de fatores envolvidos nas interações, conflitos e consumo de mamíferos selvagens por populações humanas desde a pré-história, estudos têm buscado investigar padrões e tendências em escalas globais sobre os fatores que estimulam ou impulsionam o consumo de espécies selvagens (ALVES et al., 2020; SCHEFFERS et al., 2019; STREET et al., 2023). Os dados mostraram que a escolha e o consumo das espécies para algumas finalidades ou categorias de uso não são aleatórios, mas direcionados às características das espécies (ALVES et al., 2020b; SCHEFFERS et al., 2019; STREET et al., 2023). Espécies maiores tendem a serem mais exploradas e são mais prováveis de serem usadas para algumas finalidades como medicina tradicional, comércio (de pet e troféus) e alimento (ALVES et al., 2020a; BODMER; EISENBERG; REDFORD, 1997; HUGHES et al., 2022; PALAZY et al., 2012; BRAGA-PEREIRA ET AL., 2021; SCHEFFERS et al., 2019). Portanto, os padrões de uso dependem do compartilhamento de características semelhantes entre as espécies usadas em cada categoria de uso (ALVES et al., 2020a; SCHEFFERS et al., 2019; STREET et al., 2023).

CAPÍTULO 1

Worldwide patterns of wild mammal trade are driven by species ecology, evolutionary relatedness, and socio-political variables: inferences from the TRAFFIC bulletin

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Worldwide patterns of wild mammal trade are driven by species ecology, evolutionary relatedness, and socio-political variables: inferences from the TRAFFIC bulletin

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Abstract

Wildlife trade is one of the main drivers of species decline and extinction worldwide. Although many studies have investigated the magnitude and extent of the wildlife trade, little is known about the role that species traits play in the trade of species body parts and trade purposes. Here, we test how species traits, phylogenetic relationships, and socio-political variables determine the purpose of trade, number of body parts, species, and specimens traded. We compiled records of mammal trade from the TRAFFIC bulletin (n = 100 bulletins). We fitted Bayesian generalized linear models (GLMs) to test whether species traits influence the number of body parts, purpose of trade, and number of TRAFFIC bulletins per species. We fitted GLMs to test whether socio-political variables influence the number of trade records, species and specimens traded by country. Products of at least 16,279,031 specimens from 458 mammal species were traded, including 162 threatened species (65 vulnerable, 70 endangered, and 27 critically endangered) and two extinct species. Larger and "vulnerable" species are more likely to have more parts traded for more uses, and closely related species tend to be traded for similar purposes. In addition, 127 countries were associated with trade, with high-income countries (those with greater human development index) having a greater number of species traded. Our results highlight the importance of species traits and socio-political factors on mammal trades. We emphasize the need for multidisciplinary research to investigate the species loss due to trade based on species traits and socio-political factors.

Keywords: ecological traits, wildlife trade, phylogenetic relationship, threat status, CITES.

Introduction

Wildlife trade is a common practice around the globe (Andersson et al. 2021; Rosen and Smith 2010; Scheffers et al. 2019). Products and parts of wild vertebrates, in addition to whole specimens, supply demands from markets, such as pets, trophies, game meat, traditional medicine, and fur trade (Bush et al. 2014; Graham-Rowe 2011; Palazy et al. 2012). Mammals are among the most traded wild vertebrates on the planet (Bush et al. 2014; Harfoot et al. 2018; Scheffers et al. 2019), with estimates that at least 1 in 4 species is traded (Scheffers et al. 2019).

Although many studies have investigated wildlife trade and its effects on species (e.g., Hughes et al. 2022; Morton et al. 2021; Symes et al. 2018a), understanding the factors that determine the likelihood of a species be traded is complicated due to the diversity of species and products involved, the trade chain, cultural preferences, and the dynamics of trade itself (Challender et al. 2015; Phelps et al. 2016; Sas-rolfes et al. 2019). For example, wildlife trade may involve specific parts (e.g., bear bile; Feng et al. 2009), multiple parts of one individual/species (e.g., penis, bones, skins, claws, paws, and teeth; Saif et al. 2016), or even whole individuals, such as pangolins (Soewu and Ayodele 2009; Volpato et al. 2020). Furthermore, a single animal may be traded for various purposes e.g. traditional medicines and food (Alves et al. 2020; Soewu and Ayodele 2009; Volpato et al. 2020). This variety of factors (body parts traded and multiple trade purposes) can intensify the trade of versatile species and lead to their overexploitation to supply multiple wildlife markets. This may pose an extra threat to animal conservation (Hughes et al. 2022; Phelps et al. 2016; Sas-rolfes et al. 2019).

Previous studies suggest that the composition and volume of traded species are directly influenced by their intrinsic (e.g., body mass, evolutionary relationship) and extrinsic (i.e. threat status and CITES regulation) characteristics (Johnson et al. 2010; Palazy et al. 2012; Prescott et al. 2012; Su et al. 2015). These studies found that the choice of commercialized species is not random, but associated with species ecological traits (Palazy et al., 2012; Scheffers et al., 2019; Su et al., 2015). For example, larger, narrow-ranged, and threatened species are more likely to be commercialized than smaller, widespread, and non-threatened species (Palazy et al. 2012; Scheffers et al. 2019). In addition to the above traits, closely-related species are more likely to be traded than distantly-related ones (Scheffers et al. 2019; Tanalgo et al. 2023).

However, so far, most studies have focused on specific types of trade (e.g., trophies and pet trade; Johnson et al. 2010; Palazy et al. 2012; Su et al. 2015). Little is known about how species traits affect the species versatility (number of body parts and trade purposes). Furthermore, few studies have evaluated the influence of biases on trade reports (e.g. as in the recording of charismatic species) (Abellán et al. 2016; Margulies et al. 2019; Paudel et al. 2022). Therefore, identifying the drivers of species uses, inclusion in trade and biases related to the wildlife reports is critical for designing and/or improving interventions to mitigate the impacts of trade on target species populations and also prevent the loss of exploited species (Challender et al. 2015; Hughes et al. 2022; Paudel et a. 2022).

Socio-political aspects of countries and regions involved in trade can also play a key role in determining which species or parts are traded, as well as the volume of trade. Overall, high income countries (e.g., those with a higher *gross domestic product* - GDP and *human development index* – HDI) generally exert greater pressure on biodiversity (consumption of natural resources and commodities) than low to mid income countries (Andersson et al. 2021; Lenzen et al. 2012; Liew et al. 2021; Symes et al. 2018b). For example, countries with higher GDP tend to consume more wildlife products, because they have more money to spend on superfluous goods/items, such as trophies and pets (Andersson et al. 2021; Liew et al. 2021; Ribeiro et al. 2022). Therefore, to better understand the trade chain, both socio-political and biological traits need to be assessed together in an integrative framework.

Here, we compiled data on worldwide trade from the TRAFFIC bulletin to ask the following questions: 1) which species characteristics influence their trade in terms of body parts and trade purposes? 2) are trade and shared evolutionary history related? 3) how do socio-political factors influence mammal trade? We further explored taxonomic biases in wild mammal trade.

We hypothesize that: (1) larger, widespread, evolutionary distinct, and threatened species (vulnerable, endangered, or critically endangered) are more traded both in number of parts and trade purposes; (2) species with stronger trade restrictions (i.e. those included in the appendices of CITES I) have more parts used and are traded for multiple purposes; (3) closely related species are commercialized for the same purposes; and (4) high-income countries have higher number of records of trade and greater number of species and specimens traded.

Materials & Methods

Data collection

The TRAFFIC bulletin (www.traffic.org) is the only journal that exclusively publishes information on the trade (legal and illegal) of animals and plants. In addition, the TRAFFIC organization operates another major database on illegal wildlife trade: the Wildlife Trade Portal (https://www.wildlifetradeportal.org/dashboard). However, in this study, we focused only on the TRAFFIC bulletin to address our hypothesis about biases in the wildlife trade report. The records came from news, government agencies, non-governmental organizations, case reports, and investigations led by the bulletin staff. We manually compiled data records on wild mammal trade (wild trade) from all 100 bulletins published between 1975 and 2019. Bulletins with special issues on specific trade in pangolins, ivory, rhino horns, and other specific taxa were not included. The dataset was compiled between January and April 2020. Only records related to the wild trade that allowed the identification of traded mammals to the species level were compiled. The following data were recorded for each transaction: species and parts traded, purpose, quantities (number of individuals, parts, and products), and year.

Our dataset was built using aspects that have been demonstrated to be important in recent research on wildlife trade (e.g., Challender et al. 2022). We did not treat each trade record as an independent shipment, as a single incident of trade report may contain multiple traded items (e.g., species or body parts). It is noteworthy that not all records contained standardized and complete information on the quantities and/or parts of animals sold (see Rosen and Smith, 2010). For example, 77.2% and 36.4% (n = 4,022 and 1,895) of the records had no information on importer and exporter countries, respectively. In addition, only 17.4% (n = 905) of the records had information about both exporters and importers. About 6.5% (n = 340) of records include temporal data, for example 1969-1979 or 1998-2008.

Species traits and phylogenetic data

Species body mass was obtained from the PanTHERIA and Phylacine databases (Faurby et al. 2018; Jones et al. 2009). Extent-of-occurrence data for each species were taken from the IUCN Red List (IUCN, 2020) (Additional File 1). Evolutionary distinctiveness (ED) was calculated using the "fair proportion" approach (Redding et al. 2008) implemented in the R package picante (Kembel et al., 2010). This method divides the value of each branch length of a phylogeny by the number of species. This metric quantifies how isolated (distinct) a species is in a phylogeny. The higher the ED, the more distinct (few or no close living relatives) a given species is. To obtain a phylogeny for the species for which we had trait data, we pruned the fully-sampled tree of Upham et al. (2019), which includes 452 of the 458 species in our database (*Bubalus bubalis*, *Felis lybica*, *Leopardus pajeros*, *Otaria flavescens*, *Piliocolobus badius*, and *P. wladronae* were not present in the phylogeny). We used 1,000 dated trees from the posterior distribution, which were converted to a consensus tree using the R package phytools (Revell 2010). Species nomenclature followed The Mammal Diversity Database of the American Society of Mammalogists (Burgin et al. 2018).

CITES and IUCN data

Occurrence in the appendices of CITES was taken from CITES (CITES/UNEP-WCMC, 2020; http://checklist.cites.org). Species most threatened by trade are listed in Appendix I and are subject to stronger trade restrictions. In this case, they may only be traded for non-commercial purposes, such as scientific research or captive breeding programs. Species listed in appendices II and III have fewer restrictions and may be legally traded with export or import permits, if they comply with CITES requirements National Scientific Authorities and National Management Authorities. Threat status and population trend data for each species were taken from the IUCN Red List (IUCN, 2020) (Additional File 1).

Socio-political variables

Human Development Index (HDI) – HDI was obtained from the UN Human Development Reports (HDR, UNDP, retrieved on 20.06.2020). This index shows the average performance of key dimensions of human development for a country or region based on income, health, and education indicators (Additional File 2). We used the mean index between the year range in which TRAFFIC bulletins were published (1975 – 2019).

Gross Domestic Product (GDP *per capita*) – GDP *per capita* was obtained from the World Bank database (databank.worldbank.org). This index represents the country's economic output divided by its population. This variable was used as a proxy for economic development (Additional File 2). We used the mean GDP *per capita* between the year range in which TRAFFIC bulletins were published (1975 – 2019).

Human Population Density (HPD) – HPD was obtained from the Open Spatial Demographic Data and Research database (https://hub.worldpop.org). This index represents the number of people per square kilometre (at a resolution of 30 arc-seconds – approximately 1 km^2 at the Equator) and was used as a proxy for natural resource consumption (Additional File 2). We used the mean HPD between 2000 – 2020.

Data standardization

Traded body parts are recorded using different terms (e.g., skulls, skins, skins bags, bones powder) through the TRAFFIC bulletins. Therefore, to reduce redundancy of parts and/or trade purpose and make the data comparable between item types and products sold, we grouped similar body parts into 24 categories, as follows: 1) fluids (ambergris, bile, blood, bone marrow, semen, tears, urine, musk); 2) organs (bladder, brain, eyes, gallbladder, genitals, glands, heart, intestines, liver, stomach, tongue, and penis); 3) arms, 4) claws, 5) ears, 6) feet, 7) hands and paws, 8) hooves, 9) jaws, 10) legs, 11) nose, 12) tail, 13) teeth, 14) whiskers, 15) unspecified parts, 16) ivory, including whole and/or cut tusks and ivory products; 17) bones/skeletons; 18) skin/leather; 19) specimens/whole organisms; 20) scales, 21) heads/trophies; 22) horns; 23) meat, and 24) spines. Therefore, if a given trade report includes 2 ears, 2 L of blood, 10 mL of urine, 4 paws, and 1 horn, we computed it as four body parts, as blood and urine were grouped as fluids, but ears, paws, and horns were considered independent body parts.

Trade purposes were divided into 10 categories: (1) manufactured goods (ivory carvings; jewelry made with teeth or claws); (2) circus/zoo animals; (3) food (human and animal); (4) leather; (5) religious-magical purposes; (6) pets; (7) scientific research; (8) commercial – when no specific purpose was given; (9) traditional medicine; and (10) hunting trophies and stuffed (taxidermies) animals (Additional File 3). We separated manufactured goods from religious-magical purposes as the latter can include organs, meat, whole organisms as well as some manufactured items (e.g., bone powder). However, analyses based on trade databases are knowingly subject to reporting errors and therefore need to be interpreted with caution (Morton et al. 2022).

The number of specimens per species was obtained by converting body parts (when available) into whole organism equivalents (henceforth WOE) (Challender et al. 2015; Harfoot et al. 2018). This metric uses body parts of species as parameters to estimate the number of individuals. For example, records that involve heads are considered as a single individual. Only records that provided numbers of whole tusks were used for the conversion of ivory tusks into numbers of specimens. Products made of ivory and records that gave the weight of tusks were not used. The body mass of captured or sold pangolins (individuals or scales) was converted into WOE based on metrics available in the literature (Challender et al. 2015; Ullmann et al. 2019) (Additional File 4 – Table S1). Not all products could be converted into WOEs (e.g., bones, teeth, meat, manufactured goods - ivory, leather, bones, etc.), and therefore only transactions that provided species-level identification for WOE were used (n= 3,287 records).

In view of geopolitical changes during the period assessed, Czechoslovakia, East Germany, the Union of Soviet Socialist Republics (USSR), South Yemen, and Zaire were renamed to Czech Republic, Germany, Russia, Yemen, and the Democratic Republic of Congo, respectively. Mainland China, Tibet, and Taiwan were renamed to China. The American territories of Samoa, Guam, and Rota were renamed to the United States. The Faroe Islands and Greenland were renamed to Denmark and New Caledonia was renamed to France. These changes were made based on UN Human Development Reports databases.

Statistical analyses

We fitted two phylogenetic mixed-effects generalized linear models with a Poisson distribution using the R package brms (Bürkner, 2021) to test whether species traits (body mass, extent of occurrence, evolutionary distinctiveness, threat status, and presence in CITES appendices) affect the number of parts and uses. Threat status and presence in CITES appendices were treated as ordinal variables with five and four levels, respectively (LC < NT < VU < EN < CR; Absent < III < II < I). We excluded species categorized as data deficient (DD) from the analyses because DD is not a threat status per se and is therefore not suitable for answering our hypotheses (Guedes et al. 2023). However, it is worth noting that many species categorized as DD are actually predicted to be prone to extinction (Borgelt et al. 2022; Morais et al. 2013). We included the IUCN and CITES status variables together in the full model because threat category (IUCN status) is perceived as a proxy for rarity and presence in CITES appendices (especially when associated with trade restrictions) can have the opposite effect and may stimulate trade by increasing demand for threatened species (Rivalan et al. 2007). Prior to analysis, all numerical variables were $\log_{10}$ – transformed, centered and scaled (z-transformation) to allow direct comparisons of effect sizes. Models were run with the set of species for which all trait data were available (n = 447 – the extinct species *Rucervus schomburgki* and *Pteropus pilosus* were excluded from this analysis) (Additional File 1). For all models (body parts, uses, and number of bulletins), we used the *get priors* function in the brms package to obtain model-specific priors. We used the inverse of the phylogenetic distance matrix to account for phylogenetic relationships between species. We used 4 chains with 5,000 iterations in all models, sampling every iteration and discarding the first 1,000 as burn-in. Model diagnosis was performed using density and trace plots of fixed effects. We used Rhat (potential scale reduction values) equal or below 1 as indicating good convergence. Moreover, we computed the probability of direction (pd) to assess the effect of each species traits on the number of parts, uses, and bulletins. Values indicate the certainty of the direction of an effect, therefore pd – values were considered as being significant when the likelihood of an effect in a certain direction was over 97.5%.

We further tested the phylogenetic signal for trade purposes using Fritz's *D* (Fritz and Purvis, 2010) implemented in the R package caper (Orme et al., 2018). This is a measure of phylogenetic signal for binary traits and was applied here for each trade purpose individually (1 = traded for a given purpose; 0 = not traded). Fritz's *D* can be interpreted as follows: $D = 1$ corresponds to a random distribution of uses, $D = 0$ indicates that uses are clumped, $D > 1$ indicates phylogenetic overdispersion, and $D < 1$ indicates that purposes are more clustered than expected (strong phylogenetic signal) and suggests that humans tend to trade closely related species for the same purposes. For these analyses, the dataset containing all species sampled in the phylogeny (n = 452 species) was used (Additional File 3).

As a sensitivity analysis, we use the Fritz's *D* (Fritz and Purvis, 2010) to test whether the trade reports are biased toward a given clade of the phylogeny considering all species included in phylogeny. Additionally, we calculated the Net Relatedness Index (NRI) and Nearest Taxon Index (NTI) to test whether trade reports are biased toward a given depth of the phylogeny considering only the species recorded in the TRAFFIC bulletins. For the null model, we randomized the community data matrix by drawing species from the pool of species occurring in the phylogenetic distance matrix with equal probability. NRI quantifies phylogenetic clustering/overdispersion of a community (here, each TRAFFIC bulletin), giving more weight to relationships closer to the root of the phylogeny, while NTI captures patterns closer to the tips. Positive values indicate that a community contains closely-related species (phylogenetic clustering) more than expected by chance, while negative values indicate phylogenetic overdispersion. For these analyses, we used all species sampled in the phylogeny (n = 452) (Additional File 5). Analyses were performed in the R package picante (Kembel et al., 2010). Clades contributing disproportionately to the pattern were identified using the NODESIG function in R (R Core Team 2021) adapted from Abellan et al., (2016).

To assess whether socio-political variables (IHD, GDP *per capita*, and HPD) affect the number of species, bulletins, and WOE per country, we fitted three generalized linear models with Poisson error distribution. Prior to the analysis, GDP *per capita* and human population density were $\log_{10}$ – transformed, and then centered and scaled (z-transformation) to allow direct comparisons of effect sizes. Analyses were performed in the R package glmmTMB (Brooks et al., 2017). Residual diagnostics were conducted in the R package DHARMa (Hartig 2022). Residuals had normal distribution and homogeneity of variance. Models did not show overdispersion. Finally, we used Spearman correlation to test whether the number of species was correlated with the number of bulletins per country.

Results

Traded taxa and species traits

During the period-analyzed (1975-2019), at least 16,279,031 specimens (WOE) of wild mammals were traded, including manufactured goods (e.g., traditional medicines or carving/sculptures, jewellery) and body parts of at least 458 species from 79 families and 19 orders (Fig. 1). Of the species involved, 424 (92.6%) are terrestrial and 34 (7.4%) are marine. The population trends of 246 species (53.71%) are "decreasing", while 92 (20.1%) are "stable", 81 (17.7%) are "unknown", and 39 (8.51%) are "increasing" (Additional File 1).

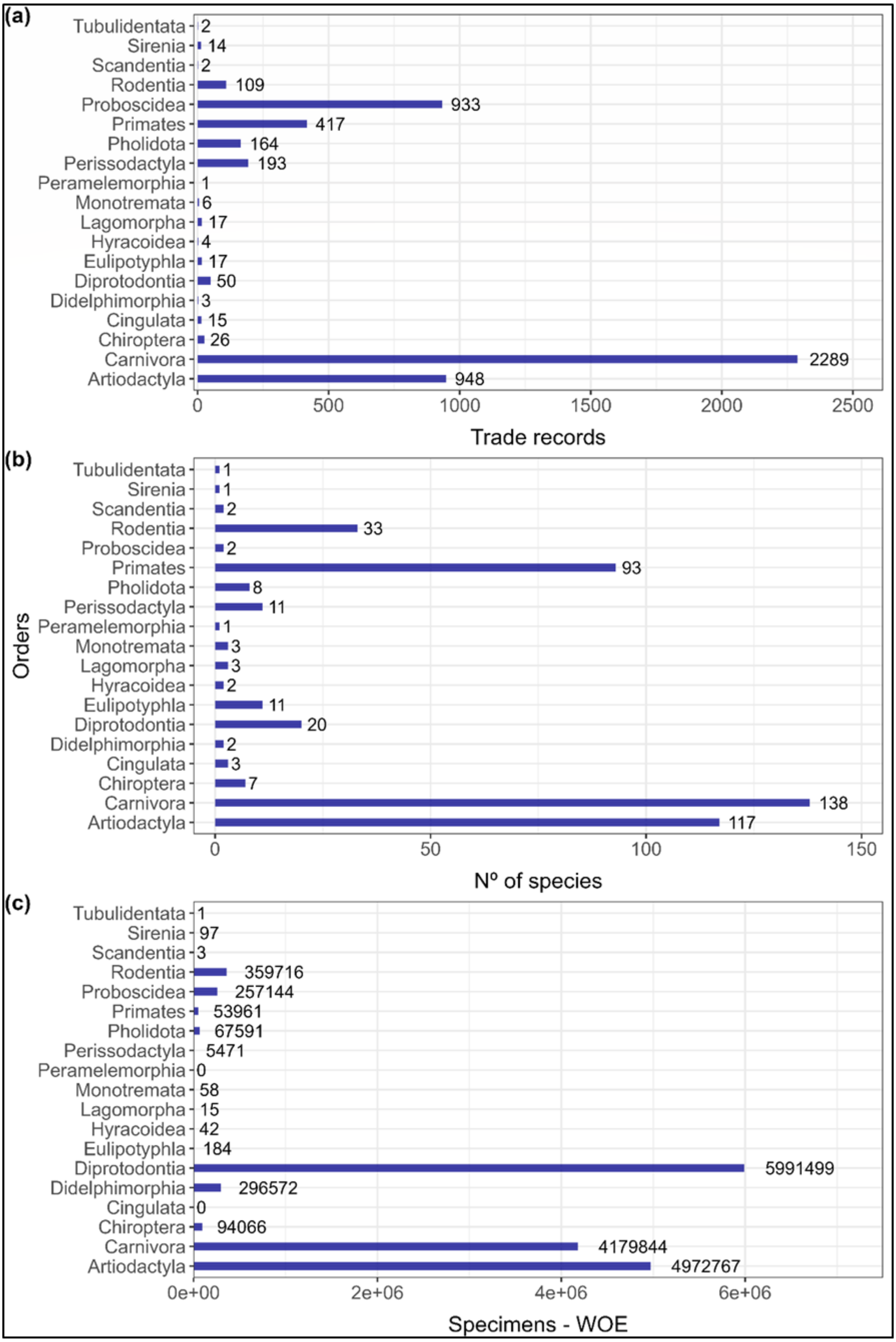

Figure 1: (a) Number of trade records, (b) species and (c) specimens of mammals traded per order. (Additional File 4 – Table S2 for values per family).

Species body mass and threat status positively influenced the number of parts and the uses for species traded (Table 1; Fig. 2a – 2b; Fig. 3a – 3b). In addition, species listed in the CITES appendix I have more parts traded (Table 1). We found no effect of evolutionary distinctiveness and geographical range on the number of body parts and uses. Closely related species were traded for the same purposes in all 10 categories (Table 2; Fig. 4). In addition, our results show that 26 threatened species (13 vulnerable, 12 endangered, and 1 critically endangered) have parts and/or products traded and were not included in any CITES appendices (Additional File 1).

Table 1: Results of the Bayesian GLMM models to test the effect of species traits on the number of parts and uses of mammal species. ^{c} = conditional, ^{m} = marginal.

	Incidence rate ratios	Standard Error	CI (95%)	*Rhat*	*P* direction
Model Parts – $R^2 = 0.141^m/0.397^c$					
Intercept	1.79	0.76	0.73 – 4.23	1.00	90.39%
Body mass (g)	1.31	0.08	1.16 – 1.49	1.00	**100%**
Geographical occurrence (km^2)	1.03	0.05	0.93 – 1.13	1.00	70.16%
Evolutionary distinctiveness	1.04	0.04	0.96 – 1.12	1.00	84.29%
CITES III	1.15	0.11	0.96 – 1.38	1.00	93.77%
CITES II	1.02	0.10	0.84 – 1.23	1.00	57.02%
CITES I	1.30	0.15	1.03 – 1.64	1.00	**98.53%**
IUCN - LC	0.91	0.13	0.69 – 1.19	1.00	74.70%
IUCN - NT	0.95	0.10	0.78 – 1.16	1.00	68.74%
IUCN - VU	1.12	0.12	0.91 – 1.38	1.00	**97.92%**
IUCN - EN	1.21	0.11	1.01 – 1.45	1.00	89.49%
Model Uses - $R^2 = 0.148^m/0.260^c$					
Intercept	1.76	0.45	1.01 – 2.98	1.00	97.60%
Body mass (g)	1.20	0.07	1.08 – 1.35	1.00	**99.96%**
Geographical occurrence (km^2)	1.02	0.05	0.93 – 1.13	1.00	67.71%
Evolutionary distinctiveness	1.02	0.04	0.95 – 1.11	1.00	74.11%
CITES III	1.12	0.10	0.93 – 1.33	1.00	88.83%
CITES II	1.06	0.11	0.87 – 1.29	1.00	70.82%
CITES I	1.04	0.13	0.81 – 1.32	1.00	61.72%
IUCN - LC	1.08	0.15	0.83 – 1.41	1.00	71.71%
IUCN - NT	0.94	0.10	0.77 – 1.15	1.00	71.87%
IUCN - VU	0.97	0.11	0.78 – 1.20	1.00	**99.81%**
IUCN - EN	1.31	0.12	1.09 – 1.58	1.00	59.83%
Model Bulletins - $R^2 = 0.032^m/0.891^c$					
Intercept	1.76	1.85	0.13 – 21.25	1.00	67.46%
Body mass (g)	1.38	0.16	1.10 – 1.72	1.00	**99.74%**
Geographical occurrence (km^2)	1.16	0.07	1.03 – 1.31	1.00	**99.46%**
Evolutionary distinctiveness	1.02	0.05	0.94 – 1.12	1.00	69.86%
CITES III	1.16	0.14	0.91 – 1.48	1.00	88.68%
CITES II	1.09	0.13	0.86 – 1.39	1.00	77.02%
CITES I	1.50	0.22	1.12 – 2.01	1.00	**99.74%**
IUCN - LC	0.85	0.15	0.60 – 1.19	1.00	**99.60%**
IUCN - NT	1.16	0.15	0.90 – 1.49	1.00	75.92%
IUCN - VU	0.91	0.11	0.71 – 1.17	1.00	88.24%
IUCN - EN	1.34	0.15	1.08 – 1.66	1.00	82.46%

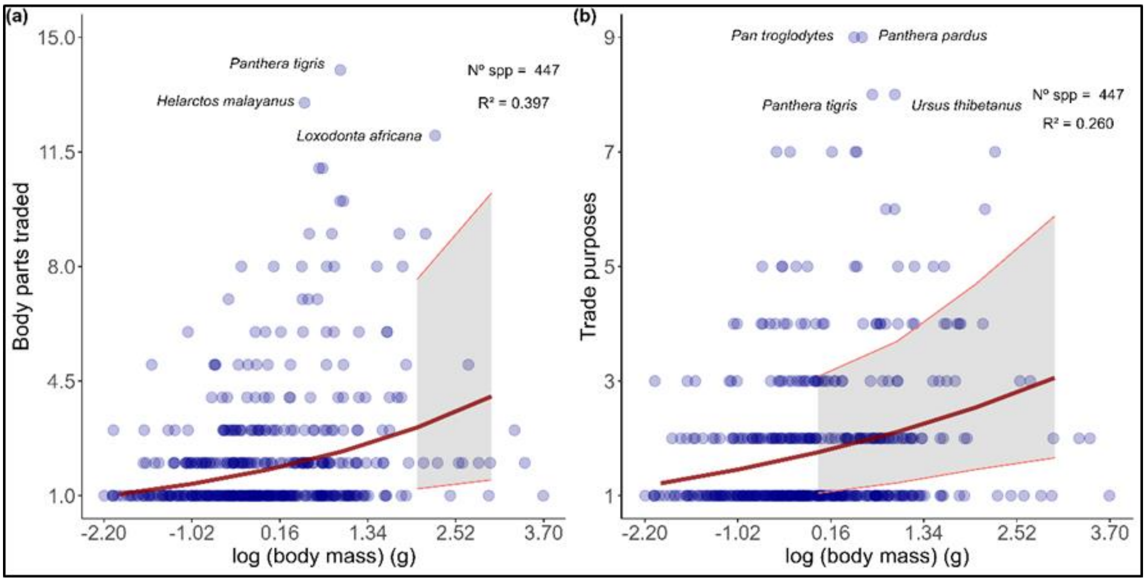

Figure 2: Plot showing the positive relationship between body mass on the number of body parts (a) and uses (b) of traded mammals as predicted by the Bayesian model.

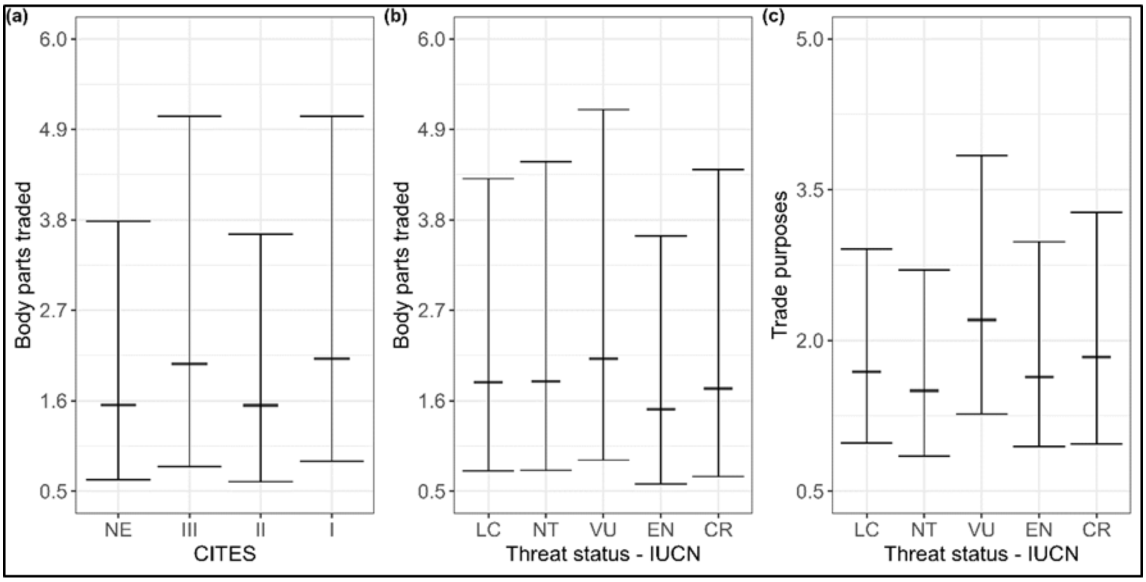

Figure 3: Plot showing the differences between the number of body parts and trade purposes of mammals for CITES appendices (body parts) and threat category (parts and uses) as predicted by the Bayesian model.

Table 2: Phylogenetic signal (Fritz's *D*) of the 10 trade purposes.

Trade purposes	**Number of species**	***D***	***P*-value (Brownian)**	***P*-value (Random)**
1 – Manufactured	64	0.5291368	**< 0.0001**	**< 0.0001**
2 – Circus/Zoo	30	0.9325216	**0.013**	**< 0.0001**
3 – Food	128	0.5596142	**< 0.0001**	**< 0.0001**
4 – Leather	27	0.6069808	**< 0.0001**	**0.002**
5 – Magic-Religious	35	0.6607803	**< 0.0001**	**< 0.0001**
6 – Pet	46	0.7728501	**< 0.0001**	**< 0.0001**
7 – Scientific research	11	0.7759848	**0.031**	**0.004**

8 – Commercial	357	0.7654602	**< 0.0001**	**< 0.0001**
9 – Traditional medicine	97	0.7812306	**< 0.0001**	**< 0.0001**
10 – Trophies	59	0.4237164	**< 0.0001**	**0.004**

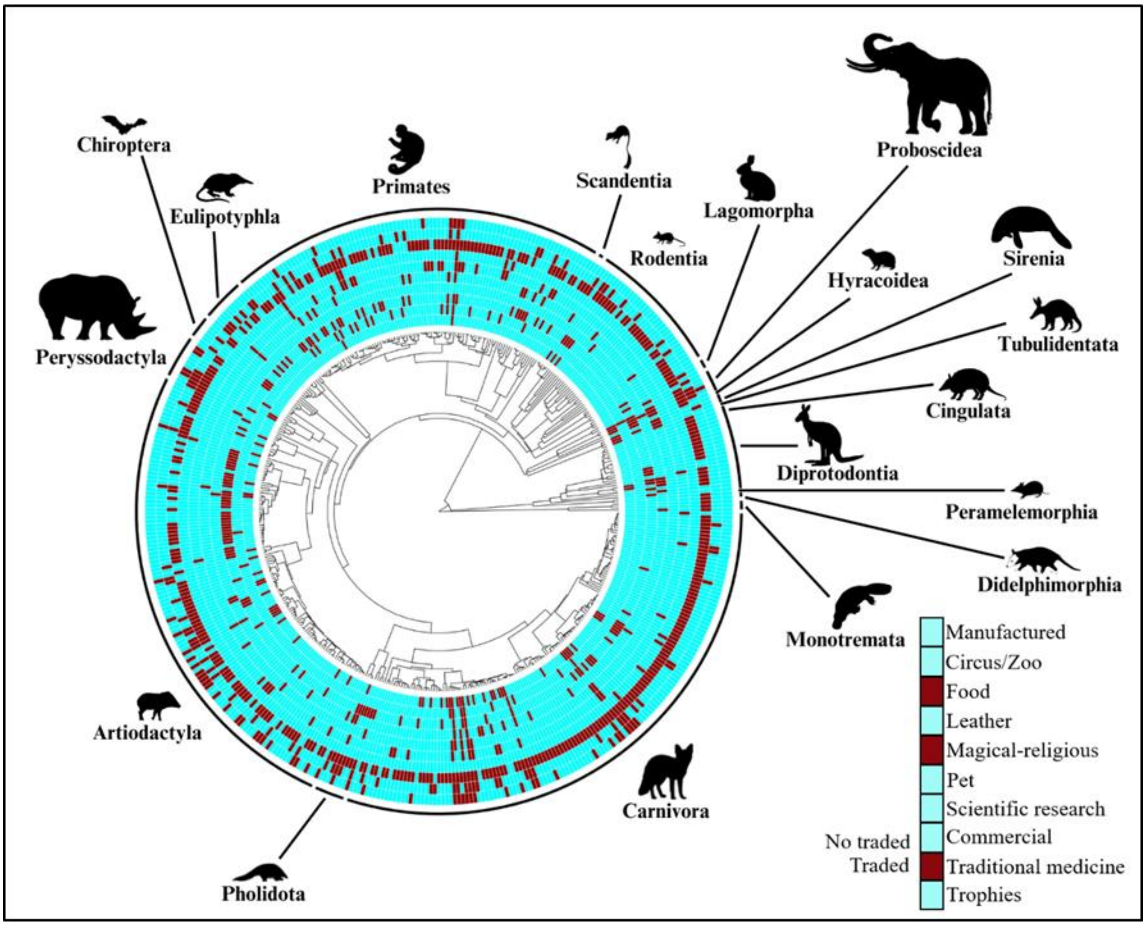

Figure 4: Phylogenetic tree of mammal species included in the analyses showing their use in each of the 11 trade purposes. Each species used for a particular trade purpose is indicated (in purple): each line represents a use category, from 1 (inner ring) to 11 (outer ring). Trade purposes follow the same sequence as in Table 2.

Species body mass, geographical range size, presence in the CITES appendix I, and species classified as “Least concern” positively influenced the number of entries in the TRAFFIC bulletin (Table 1; Fig. 5). This means that larger, widespread species, and species with trade regulations, and those not experiencing any strong threat were more represented in the TRAFFIC bulletins (Fig. 5). There is a phylogenetic signal for the species included in the bulletins (considering all species included in the phylogeny) ($D = 0.4555$; $P < 0.0001$). Furthermore, species included in the bulletins were phylogenetic clustered at both root and tip level ($NRI = 2.5915$, $NTI = 2.6234$; $P < 0.05$), indicating that trade is biased towards a few representative clades. Specifically, some clades have contributed disproportionately to the reports, especially Artiodactyla, Carnivora, Perissodactyla, Primates, and Proboscidea (Additional File 4; Fig. S1).

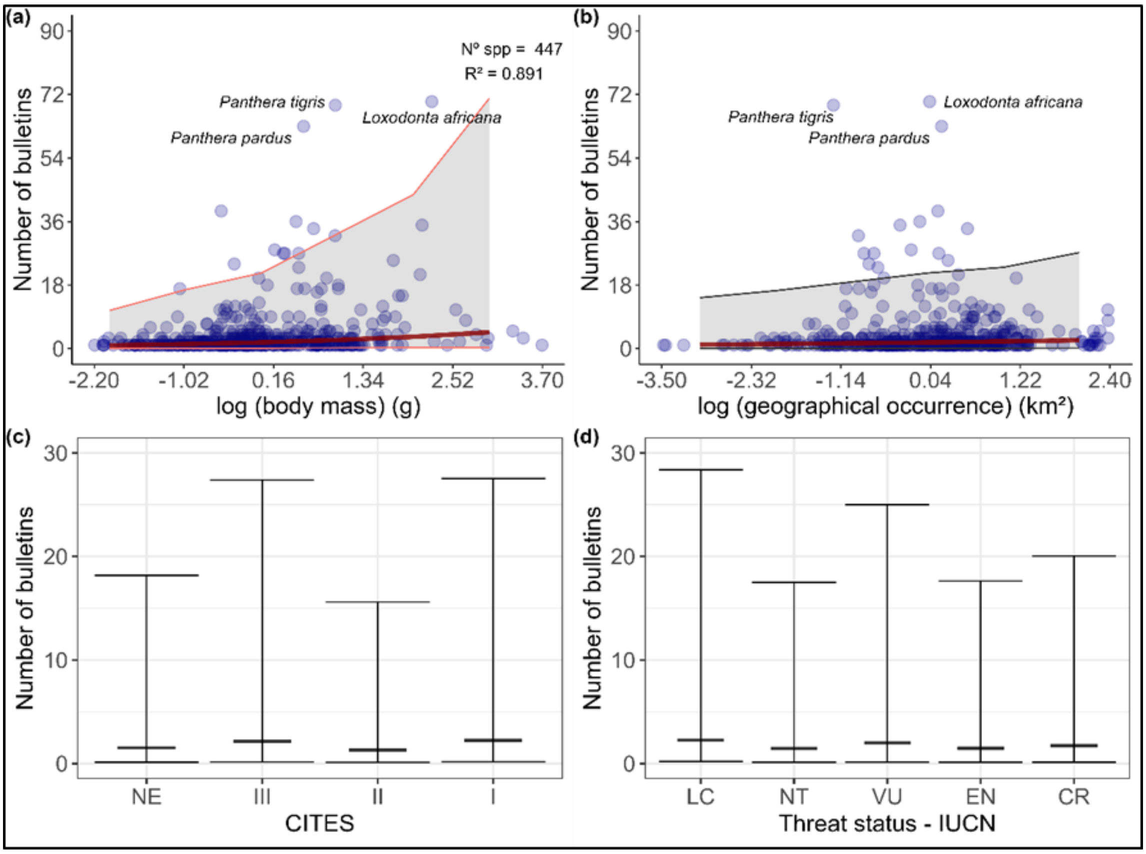

Figure 5: Plot showing the effect of species traits on the number of bulletins as predicted by the Bayesian model.

Socio-political variables

At least 127 countries are involved in wild mammal trade (Fig. 6), of which 125 are Parties to the CITES Convention (Additional File 2). In terms of socio-political variables, only HDI influenced the number of traded species per country (Table 3). In general, countries with higher HDI scores tended to trade more species (Fig. 7). The number of species was strongly correlated with the number of bulletins per country (rho = 0.82; $P < 0.0001$).

Table 3: Results of the generalised linear models to test the effect of socio-political indices on the number of trade records, species and specimens - WOE traded per country. ^{c} = conditional, ^{m} = marginal.

	Incidence Rate Ratios	Std. Error	CI (95%)	*P* value
Species – $R^2 = 0.0949^m/0.9443^c$				
(Intercept)	6.59	0.72	5.33 – 8.15	**<0.001**
GDP per capita	0.56	0.18	0.30 – 1.04	0.065
HDI	2.25	0.71	1.22 – 4.18	**0.010**
HPD	1.09	0.12	0.88 – 1.34	0.438
Bulletins – $R^2 = 0.0178^m/0.9398^c$				
(Intercept)	6.13	0.69	4.91 – 7.64	**<0.001**
GDP per capita	0.72	0.23	0.38 – 1.37	0.319
HDI	1.46	0.47	0.78 – 2.76	0.239
HPD	1.06	0.12	0.85 – 1.32	0.624
WOE – $R^2 = 0.1237^m/0.9999^c$				
(Intercept)	1571.14	506.16	835.58 – 2954.20	**<0.001**
GDP per capita	1.89	1.79	0.30 – 12.11	0.500
HDI	1.77	1.66	0.28 – 11.15	0.544

HPD	0.53	0.17	0.28 – 1.00	0.051

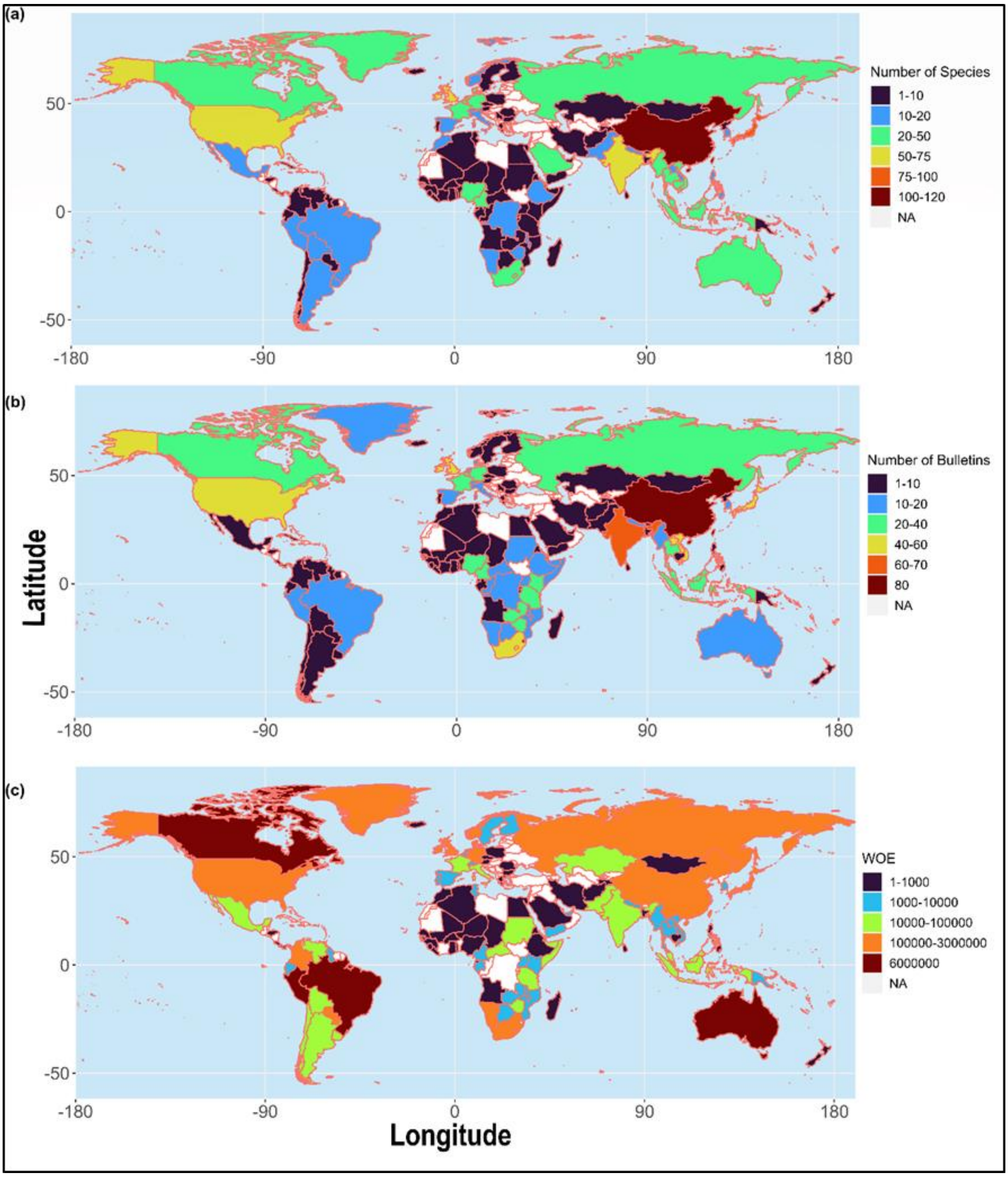

Figure 6: World map showing the main countries involved in wild mammal trade in terms of number of species, trade records, and specimens (WOE) traded.

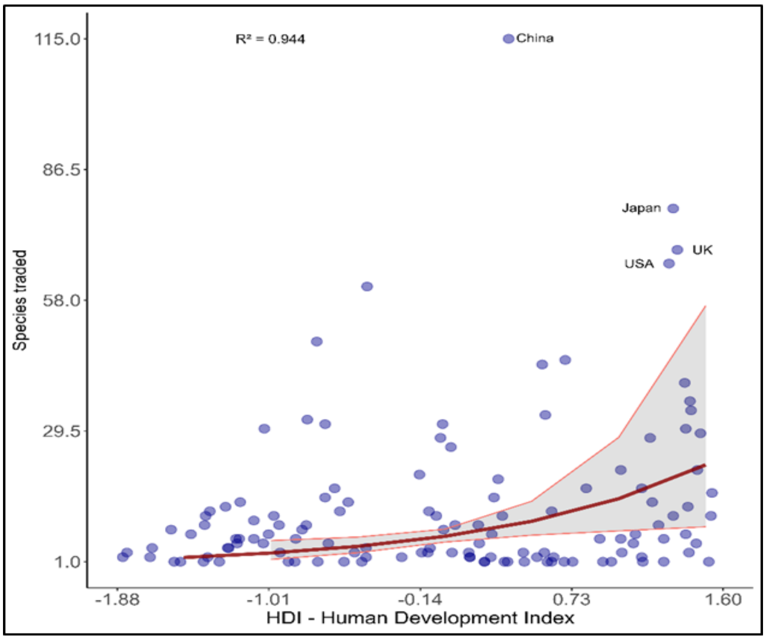

Figure 7: Plot showing the effect of HDI on the number of species traded *per* country, as predicted by the glmm.

Discussion

We found that at least 7.15% of mammal species (458 out of 6,399 known species; Burgin et al., 2018) have been traded in the last 40 years. Our results confirm partially our first hypothesis that larger species have more parts traded and are used for more purposes than smaller species. Prior studies that have examined the use (e.g., for food and traditional medicine) and trade of wild mammals also showed that body mass is a key trait for species selection and use (Alves et al., 2020; Hughes et al., 2022; Scheffers et al., 2019). Large-bodied species provide more products used in traditional medicine (Alves et al., 2020), are also more valued in the trophy trade (Johnson et al., 2010; Palazy et al., 2012), and as pets (Su et al., 2015). For example, the price and list of species traded as trophies are directly influenced by their size, which results in a higher demand and a higher market value for them (Johnson et al., 2010; Palazy et al., 2012). Thus, our results not only provide independent evidence to support those results, using a different dataset (although limited in the number of species), but also reveal the influence of body mass, threat status, and presence in CITES appendix on two aspects not previously investigated: the number of body parts and trade purposes.

We found that threatened species and those listed in CITES appendix I have more body parts and trade uses, supporting our second hypothesis. Threat status and presence in CITES is perceived as a proxy for rarity and may increase the demand for or the value/price of a given species (Chen 2016; Johnson et al. 2010; Palazy et al. 2012; Rivalan et al. 2007; Su et al. 2015). For example, threatened birds from the Taiwan pet market are more expensive than non-threatened species (Su et al., 2015). The threat status also influences the price of wild mammals traded as trophies in African countries (Johnson et al., 2010).

Interestingly, we found no effect of geographic range size and evolutionary distinctiveness on the number of traded body parts. Nevertheless, recent studies have shown that a great number of evolutionarily distinct species, which are also the most ancient species that play a crucial role in global ecosystems, are exploited for wildlife trade (Hughes et al. 2023; Scheffers et al. 2019). Similarly, species with narrow geographic ranges (Johnson et al., 2010) are traded more heavily in the trophy trade. However, these studies have used a different analytical approach to assess wildlife trade, such as presence/absence in trade (Scheffers et al., 2019; Hughes et al., 2023) and the price/value of trophies (Johnson et al., 2010).

Our results support the claim that taxa with greater number of parts and uses may have a higher incidence of trade and of threat by wildlife trade (Additional File 1). For example, *Panthera tigris*, *Helarctos malayanus*, *Loxodonta africana*, *Capricornis sumatraensis*, and *Ursus thibetanus* that had the largest numbers of body parts and *Pan troglodytes*, *P. tigris*, *P. pardus*, and *U. thibetanus* that had the highest number of uses are all considered "threatened" species by the IUCN. In addition, these species also had the greatest number of records. Furthermore, due to the greater cultural value (Volpato et al., 2020) and risks (law enforcement) associated with poaching and trade of threatened species, there may be a maximization of uses of these species (they may be used for various purposes, e.g. in traditional medicines and culinary products, wet markets), directly increasing the number of body parts traded per species. As some authors point out (Alves and Rosa, 2006; Alves et al., 2020), the diversity of uses of a species can be a factor that increases demand for products derived from it and increases commercial pressure on it.

Another important finding is that closely-related taxa were traded for similar purposes, which supports our third hypothesis. This result shows that the choice of a species for a particular use is not random, but directed toward taxa that share similar characteristics. Common ancestry also determined trade in other terrestrial vertebrates (Scheffers et al., 2019). This fact can be observed in the trade of certain groups, such as rhinos, felids, and pangolins. When populations of these species are depleted, trade is directed toward another phylogenetically closer species (Scheffers et al., 2019). For example, there has been an increasing demand for lion bones as a substitute for tiger bone in traditional medicines and the production of wine in Asian markets (Coals et al. 2020).

Our results show that larger and widespread taxa, species listed in CITES appendix I, and non-threatened ones are overrepresented in TRAFFIC bulletin records. In addition, species recorded in the bulletins are phylogenetically clustered at different phylogenetic scales. For example, Artiodactyla, Carnivora, Perissodactyla, Primates, and Proboscidea had species recorded in at least 20 TRAFFIC bulletins. This pattern points out to a taxonomic bias in our dataset. Therefore, our results only apply to these specific clades within mammals. Studies on wildlife trade may be affected by the uncertainty and bias related to the data used (Challender et al. 2022, Paudel et al., 2022). Although the scope of the TRAFFIC bulletin is on publishing information on wildlife trade, it might not capture the full variety of species, countries, and types of trade. Much of its published information came from non-governmental institutions, seizures by law enforcement, and newspaper reports, which may lead to inaccurate taxonomic identification, and bias on the parts or items traded as well as the reported countries (Berec et al. 2018; Smith et al. 2009). This same problem may be observed in other datasets used for wildlife trade investigations. For example, based on the United States Fish and Wildlife Service (USFWS) – Law Enforcement Management Information System (LEMIS), only 13% of wildlife specimens imported into the USA were identified to the species level (Smith et al. 2009). For the CITES database, considering only the trade of *Ursus americanus*, 96% of entries in the CITES database were not complete and 75% of entries did not include the quantities or type of items listed (Berec et al. 2018). Additionally, larger, charismatic, and threatened species are reported more often on seizure records and media (Paudel et al., 2022). This may justify for example, the high number of bulletins records that include Artiodactyla, Carnivora, Perissodactyla, Primates, and Proboscidea, which have many larger, threatened, and charismatic species, such as "big cats", rhinos, apes, and elephants. Some factors can influence this over-reporting. For example, larger and charismatic species are more easily recognised by customs officials, therefore they tend to be more reported in the media (Paudel et al. 2022). Alternatively, those species could be recorded more regularly because of their high demands

(Scheffers et al. 2019). Despite its limitations, TRAFFIC can be a valuable resource to identify trends in wildlife reports, since it includes records of species listed and non-listed in CITES, and can serve as a baseline to investigate underlying sources of biases and reporting preference on wildlife trade reports.

Trade in wild mammals is widespread worldwide. Our results show that there is a difference in the number of traded species and WOE per country. For example, countries with the largest number of traded species are in Asia (> 50 species), except for the USA and the UK, while the countries with the largest number of traded WOE are in Oceania (> 5,000,000 specimens) and South America (> 2,000,000 specimens). Conversely, the most frequently reported countries in TRAFFIC bulletins are India and China (both with n = 61 and n = 115 bulletins, respectively). These results show that analyses to understand the spatial patterns in the wild mammal trade need to consider the different nuances in wildlife trade. For example, Japan and China had the greater number of species (> 70 species), while Brazil, Peru, and Australia had the greater number of WOE (> 2,000,000 specimens). Many factors can contribute to these differences. For instance, trade chains can encompass countries that play different roles (Liew et al. 2021; Ribeiro et al. 2022; Wu et al. 2025); some may act as suppliers of wildlife products, while others may drive the flow of traded species, acting as consumers (Wu et al. 2025). China is considered the most important centre for wildlife consumption and trade in Asia (Jackson et al. 2023; Wu et al. 2025). At least 90 species of wild mammals are used in traditional Chinese medicine (Alves et al., 2020), and all pangolins, rhino, and felids species are traded in the numerous wildlife markets (fur/skins, trophies, restaurants, traditional medicine/culinary) in the country (Hughes 2021; Volpato et al. 2020; Zhu and Zhu 2020). The greater number of WOE traded by Australia is due to the high harvest rates of *Trichosurus vulpecula* (> 450,000 WOE) and *Pseudocheirus peregrinus* (> 5,000,000 WOE) for fur/skin and meat trading programmes as a measure for reducing crop and grazing damage (TRAFFIC bulletin Volume 12 Issue 3). In the past decades, Australia has been the main exporter of pelts and hides of Diprotodontia species (TRAFFIC bulletin Volume 12 Issue 3). Brazil and Peru were also among the main exporters of fur/skins in South America (Antunes et al. 2016; Redford 1992). At least 23.3 million (between 21.6 – 26.8 million) wild mammals have been hunted for the fur/skin trade in the Amazon basin over the past century (Antunes et al., 2016).

Our study further shows that more species of wild mammals were traded in countries with higher Human Development Index. These results partially support our fourth hypothesis, showing that high-income countries tend to consume more wildlife products than low-and middle-income countries. However, developed countries, such as Japan and China appear to be the main consumers of wildlife products and are among the largest economies in the world, confirming previous findings (Liew et al. 2021; Symes et al. 2018b). Overall, the demand for wildlife products are higher in high-income countries of the northern hemisphere, while low-middle income countries in the south hemisphere act as suppliers of wildlife products (Liew et al. 2021). Although most countries have laws and are signatory of international commitments, such as CITES, that restrict and regulate wildlife trade, the wide diversity of species and regional influence make problem solving difficult (Phelps et al., 2016; Sas-rolfes et al., 2019). This fact highlights the need for ongoing assessment and reformulation of measures to regulate and monitor trade in wild mammals, as well as measures to mitigate the impacts caused by trade and prevent over-exploitation of species.

In conclusion, our study highlights the importance and contribution of species traits (body mass, threat status, and presence in CITES-listing) and socio-political factors to the dynamics of wild mammal trade. Our results show that (1) larger and vulnerable species are more traded and versatile in terms of body parts and trade purposes, (2) closely related species tend to be traded for similar purposes, and (3) the mammal trade record is biased towards specific lineages. Although there are numerous studies on wildlife trade, the extent of the impact of trade on many species is unclear because most traded species (including threatened species) remain unprotected at local and international scales. Furthermore, current conservation and management measures for traded species are ineffective and fail to protect species. Given that a single species may be traded for more than one purpose, understanding the factors involved in wildlife trade is important for developing strategies to mitigate its impacts. For example, including or changing the status of species listed in CITES appendix, or providing financial assistance for the conservation of target species based on trade purposes or body parts traded. Moreover, a single body part can be used and traded for many purposes (e.g., rhino horn and pangolin scales are both used for traditional medicines and handcrafts). Thus, understanding species and their body parts uses are key to improve conservation practices of overexploited species, which can be a challenge for national and international law enforcement agencies worldwide.

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Data Accessibility Statement

All datasets are available in support information.

SUPPORTING INFORMATION

Additional File 1: Spreadsheet containing trade data (number of records, specimens, body parts and uses) and species attributes (body mass, geographic range, Evolutionary distinctiveness, threat status and CITES appendices).

Additional File 2: Spreadsheet containing number of trade records, species and specimens traded, and socio-political variables by country.

Additional File 3: Spreadsheet containing trade categories for mammal species.

Additional File 4: Supplementary information.

Table S1: Parameters used to estimate the number of specimens sold.

Table S2: Number of trade records, species, and specimens – WOE of mammals traded by taxonomic families.

Figure S1: Phylogenetic relationships of world mammals (from Upham et al., 2019), showing clades that contribute significantly to phylogenetic clustering for trade. The subset of traded mammals is in red. Clades with more descendent taxa in each subset than expected by chance are indicated with red asterisks.

Additional File 5: Spreadsheet containing mammal species in each TRAFFIC bulletin.

ADDITIONAL FILE 4

Supplementary tables and figures.

Table S1: Parameters used to estimate the number of specimens sold.

Part (S)	**Description**	**Considered taxa**	**Conversion factor for the equivalent of a whole organism**
Specimen	Complete specimens (alive or dead)	All	1
Specimens (Dead)	(Animal weight)	All	Biomass[a,b]
Carcasses	Dead animals	All	1
Eyes and Ears	-	All	2
Feet/Paws/Hooves	-	All	4
Penis			1
Heads			1
Horns	-	All	2
		Diceros bicornis	2
		Ceratotherium simun	2
		Dicerorhinus sumatrensis	2

		Rhinoceros sondaicus	1
		Rhinoceros javanicus	1
Tail		All	1
Hands		Primates	2
Gallbladder		Ursidae	1
Skin/Hide		All	1
Scales		*Manis pentadactyla*	0.573g[c,d]
		Manis crassicaudata	1 000g[c,d]
		Manis culionensis	0.360g[c,d]
		Manis javanica	0.360g[c,d]
		Smutsia gigantea	1 000g[c,d]
Nose		All	1
Tusks (ivory)		Elephantidae, Suidae, Dugongidae, Hippopotamidae, Odobenidae	2
		Monodontidae	1
Legs	-	All	2

Organs (heart, stomach, tongue, penis, intestines)	All	1

[a]Jones et al. (2009), [b]Faurby et al. (2018), [c]Challender et al. (2015) and [d]Ullmann et al. (2019).

Table S2: Number of trade records, species, and specimens – WOE of mammals traded per taxonomic families.

Family	Total_species	Total_records	Total_WOE
Ailuridae	1	6	8
Atelidae	2	3	12
Balaenidae	1	3	50
Balaenopteridae	6	57	NA
Bovidae	47	304	NA
Camelidae	1	9	555
Canidae	14	66	NA
Castoridae	2	3	NA
Caviidae	1	8	200230
Cebidae	15	40	1379
Cercopithecidae	46	162	NA
Cervidae	15	151	NA
Chlamyphoridae	3	15	NA
Cricetidae	1	6	30608
Dasyproctidae	1	1	3
Delphinidae	17	89	279786
Diatomydae	1	1	3
Didelphidae	2	3	296572
Dugongidae	1	14	97
Echimyidae	1	3	6282
Elephantidae	2	933	257144

Equidae	3	6	45
Erinaceidae	9	15	NA
Eschrichtiidae	1	1	NA
Felidae	30	1420	NA
Galagidae	4	13	NA
Giraffidae	1	5	NA
Herpestidae	8	14	NA
Hippopotamidae	1	30	17830
Hominidae	5	117	953
Hyaenidae	2	8	12
Hylobatidae	9	29	NA
Hystricidae	7	50	NA
Indriidae	1	1	NA
Iniidae	1	1	252
Kogiidae	1	1	1
Lemuridae	3	7	NA
Leporidae	3	17	NA
Lorisidae	7	44	NA
Macropodidae	14	26	NA
Manidae	8	164	67591
Monodontidae	2	102	12765
Moschidae	4	91	NA
Muridae	2	2	NA
Mustelidae	31	89	NA
Nandiniidae	1	1	NA
Nesomyidae	1	4	NA
Odobenidae	1	17	998
Ornithorhynchidae	1	2	6
Orycteropodidae	1	2	1
Otariidae	9	64	NA
Peramelidae	1	1	NA
Petauridae	1	4	1500
Phalangeridae	3	14	NA

Phascolarctidae	1	1	NA
Phocidae	16	199	1832895
Phocoenidae	3	15	155065
Physeteridae	1	19	4093
Prionodontidae	2	8	NA
Procaviidae	2	4	NA
Procyonidae	2	8	276008
Pseudocheiridae	1	5	5478200
Pteropodidae	7	26	NA
Rhinocerotidae	5	177	5399
Sciuridae	12	19	NA
Spalacidae	3	7	NA
Suidae	7	36	NA
Tachyglossidae	2	4	52
Talpidae	2	2	NA
Tapiridae	3	10	27
Tarsiidae	1	1	NA
Tayassuidae	3	16	4434330
Thryonomyidae	1	5	NA
Tragulidae	3	11	NA
Tupaiidae	2	2	NA
Ursidae	8	331	NA
Viverridae	13	58	NA
Ziphiidae	2	7	217

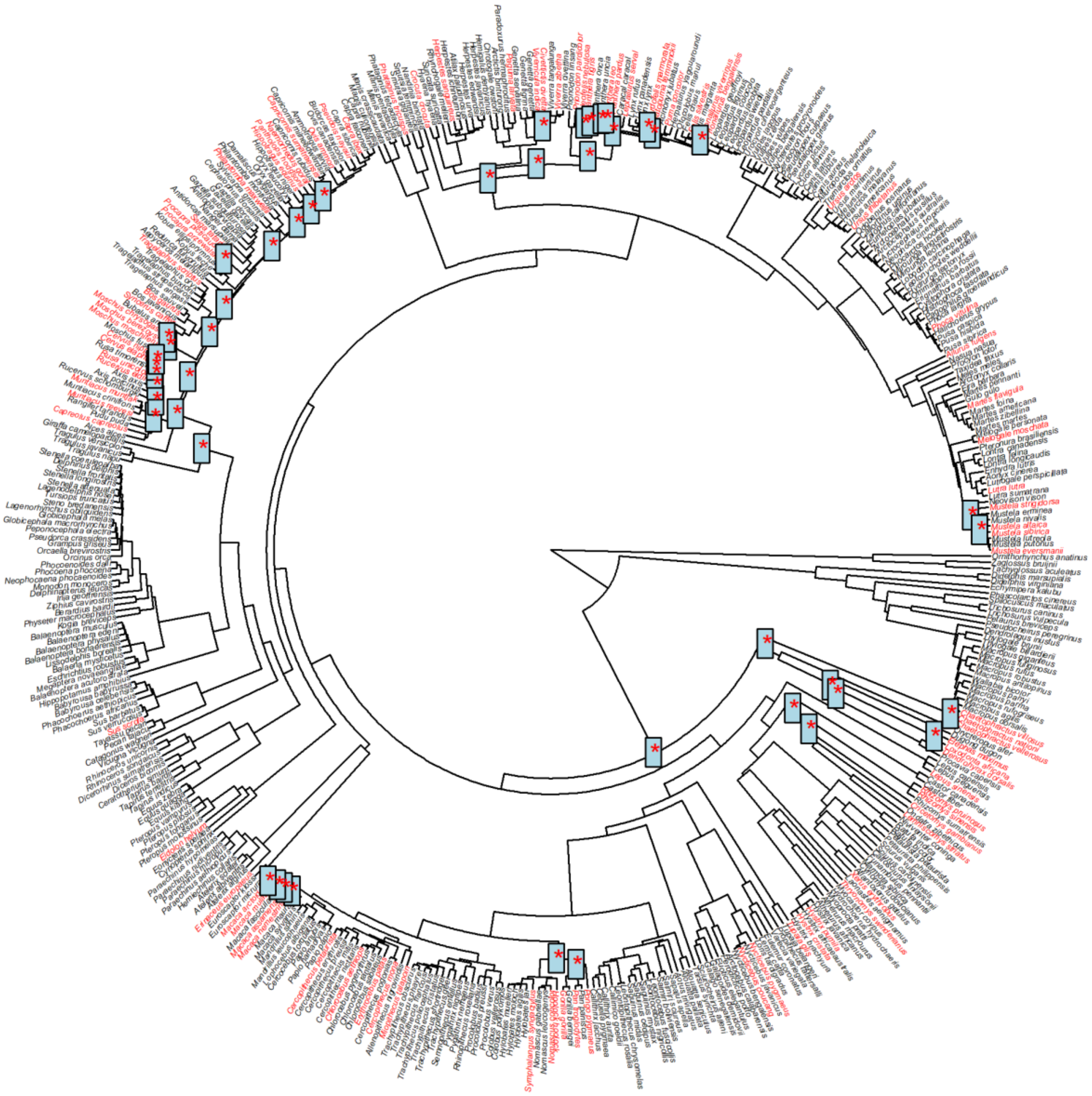

Figure S1: Phylogenetic relationships of world mammals (from Upham et al., 2019), showing clades that contribute significantly to phylogenetic clustering for trade. The subset of traded mammals is in red. Clades with more descendent taxa in each subset than expected by chance are indicated with red asterisks.

CAPÍTULO 2

A global assessment of wild mammals used as pets

Under review: **Scientific Reports**

A global assessment of wild mammals used as pets

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Abstract

The growing trend of keeping wild vertebrates as pets is an emerging conservation concern and a major driver of wildlife trade, biodiversity loss, and biological invasions worldwide. In this study, we recorded at least 704 mammal species being kept as pets, including 300 threatened taxa. We detected strong phylogenetic clustering, indicating that closely related species—particularly within the orders Primates, Carnivora, and Rodentia—are disproportionately represented among pet mammals. Species with larger body mass and broader geographic ranges were significantly more likely to be kept as pets, while other traits, such as evolutionary distinctiveness, low fecundity and threat status, showed positive associations in simpler models. At least 65 countries were represented in our dataset, which likely reflects research availability rather than the actual global extent of pet-keeping practices. This research supports efforts to inform policy, strengthen enforcement, and raise public awareness about the conservation risks associated with the ownership of wild pets.

Keywords: Ethnozoology, life-history traits, phylogenetic relationship, threatened species, pet ownership, pet trade

Introduction

The keeping of wild mammals as pets is an increasingly widespread phenomenon, driven by factors such as rising wealth, globalization, and the ease of access provided by online trade[1–3]. While this practice has deep historical roots, with humans having kept wild animals as pets since the early stages of domestication[4,5], its current global expansion raises critical concerns that extend far beyond individual pet ownership.

The demand for wild mammals as pets is no longer an isolated cultural practice but a phenomenon with complex ecological, economic, and socio-political dimensions. The growing demand for wild pets has significant implications for animal welfare[6] and the well-being of pet owners themselves[7]. Additionally, the wildlife trade associated with pet keeping is a major driver of biodiversity exploitation[3,8,9], with cascading effects such as the introduction of alien species[10–13] and the spread of zoonotic diseases[12,14]. Moreover, pet keeping can fuel illegal wildlife trafficking, further exacerbating conservation challenges[15–17].

Understanding which species are more likely to be kept as pets, and why, is essential for informing conservation actions and regulatory frameworks. Recent studies indicate that the composition of mammals, birds, reptiles, amphibians, and fishes traded as pets is not random but determined by specific traits (e.g. body mass, extent of geographic occurrence, fecundity, evolutionary relationships, and threat status) and common ancestry[3,16,18,19]. These factors are closely linked to market prices and demand[15–17,20], reflecting both people’s preferences[16,20] and intended purposes or uses within the pet trade (e.g. companion animals, ornaments, and ceremonial animals)[17].

For example, body size is one of the main traits influencing human preference for pets[21], with larger-bodied species being more desirable in the wildlife trade[3,16] and pet markets[15,17,19]. Similarly, narrow-range and threatened species are often recognised as proxies for rarity and desirability[16,17,22] increasing their presence in the wildlife trade[15–17]. High fecundity may also influence species selection for pet markets, as species that produce more offspring may be more profitable for breeders[19]. Overall, these traits increase both the likelihood of a species being traded as a pet and the prices it can fetch on the market[15–17].

Beyond species-level traits, socio-political and economic factors at the national level also shape the global landscape of pet keeping[17,23,24]. In general, high-income countries (e.g. those with higher GDP and HDI) tend to have greater economic output and consumer purchasing power, potentially increasing the demand for exotic pets[25,26].

In this context, we compiled a global database of wild mammals species kept as pets using information from the literature to: (1) determine how many, and which, wild mammal species are kept as pets worldwide; (2) assess which species' life-history traits may influence their use as pets; (3) examine whether evolutionary relationships influence the pool of species kept as pets; and (4) identify which socio-political factors may explain the diversity of species kept as pets across countries. We further explored taxonomic biases in studies addressing mammal species kept as pets, as well as country-level biases stemming from the absence of studies in certain regions.

Based on the information above, we hypothesise that: (1) due to the greater cultural valuation[16] and higher market prices[15,20] larger-bodied, narrow-range species, evolutionarily distinct mammal species, threatened species, and species with higher fecundity will have a higher likelihood of being used as pets; (2) due to the easier and lower maintenance costs and simpler dietary requirements of herbivorous and omnivorous species in captivity, we hypothesise that they are more likely to be kept as pets compared to carnivorous species; (3) as phylogenetically close species tend to share similar ecological traits, we expect that closely-related species will be more likely of being used as pets; and (4) higher income level, urbanisation, and human development are often associated with increased disposable income and rising consumer demand for non-essential goods, including wild animals kept as pets.

Based on that, we hypothesise that countries with higher GDP per capita, HDI, and population density will exhibit a greater number of species kept as pets.

3) Results

3.1) General Characterisation of the Analysed Studies

We retrieved 192 peer-reviewed articles reporting on wild mammals kept as pets (Appendix A; Figure S1), with an average of seven publications per year. The number of studies doubled between 2000 and 2020 (Appendix A; Figure S2). Most of the publications were focused on Asia (45%) and South America (26%).

3.2) Taxonomic and Phylogenetic Patterns of Mammals Kept as Pets

At least 704 mammal species from 22 orders are kept as pets worldwide (Table 1; Figure 1; Appendix B). The orders with the highest number of species kept as pets were Primates (n = 280, 39.8%), Carnivora (n = 131, 18.6%), and Rodentia (n = 107, 15.2%). Together with Certartiodactyla, Chiroptera, Diprotodontia, Perissodactyla, and Scandentia, these orders contain more pet species than expected by chance (Table 1). A total of 300 species (42%) recorded are considered threatened (129 Vulnerable, 112 Endangered, and 59 Critically Endangered); 70 are classified as Near Threatened (Appendix B), and 12 as Data Deficient.

The species most frequently reported as pets (> 15 publications) were *Callitrix jacchus* (20 publications), *Sciurus vulgaris* (18 publications), *Cebus paella* (17 publications), and *Nycticebus coucang* and *N. javanicus* (both with 15 publications).

Table 1: The distribution of all observed mammal species and the expected number of species used as pets per order (mean, based on 100,000 lists of the permutation test), assuming that mammal species were kept as pets by chance. The species totals are based on the taxonomy in Burgin et al. (2018).

Order	Species total	Species observed	Median (5 – 95% quantile expected species)	Range (min – max)
Afrosoricida	55	1	0	0 – 1
Carnivora	253	131	16	3 – 25
Artiodactyla	248	78	9	0 – 25
Chiroptera	1282	22	3	0 – 11
Cingulata	21	6	1	0 – 5
Dasyuromorphia	77	1	0	0 – 1
Dermoptera	2	1	1	0 – 1
Didelphimorphia	105	4	0	0 – 4
Diprotodontia	139	18	2	0 – 10
Eulipotyphla	484	5	0	0 – 5
Hyracoidea	5	2	0	0 – 2
Lagomorpha	90	5	0	0 – 5
Macroscelidea	19	0	0	0 – 0
Microbiotheria	1	0	0	0 – 0
Monotremata	5	2	0	0 – 2
Notoryctemorphia	2	0	0	0 – 0
Paucituberculata	7	0	0	0 – 0
Peramelemorphia	19	1	0	0 – 1
Perissodactyla	18	12	1	0 – 7
Pholidota	8	6	1	0 – 5
Pilosa	10	6	1	0 – 5
Primates	449	280	34	13 – 58
Proboscidea	2	2	1	1 – 2
Rodentia	2354	107	13	0 – 28
Scandentia	20	8	1	0 – 6

Tubulidentata	1	1	1	1 - 1

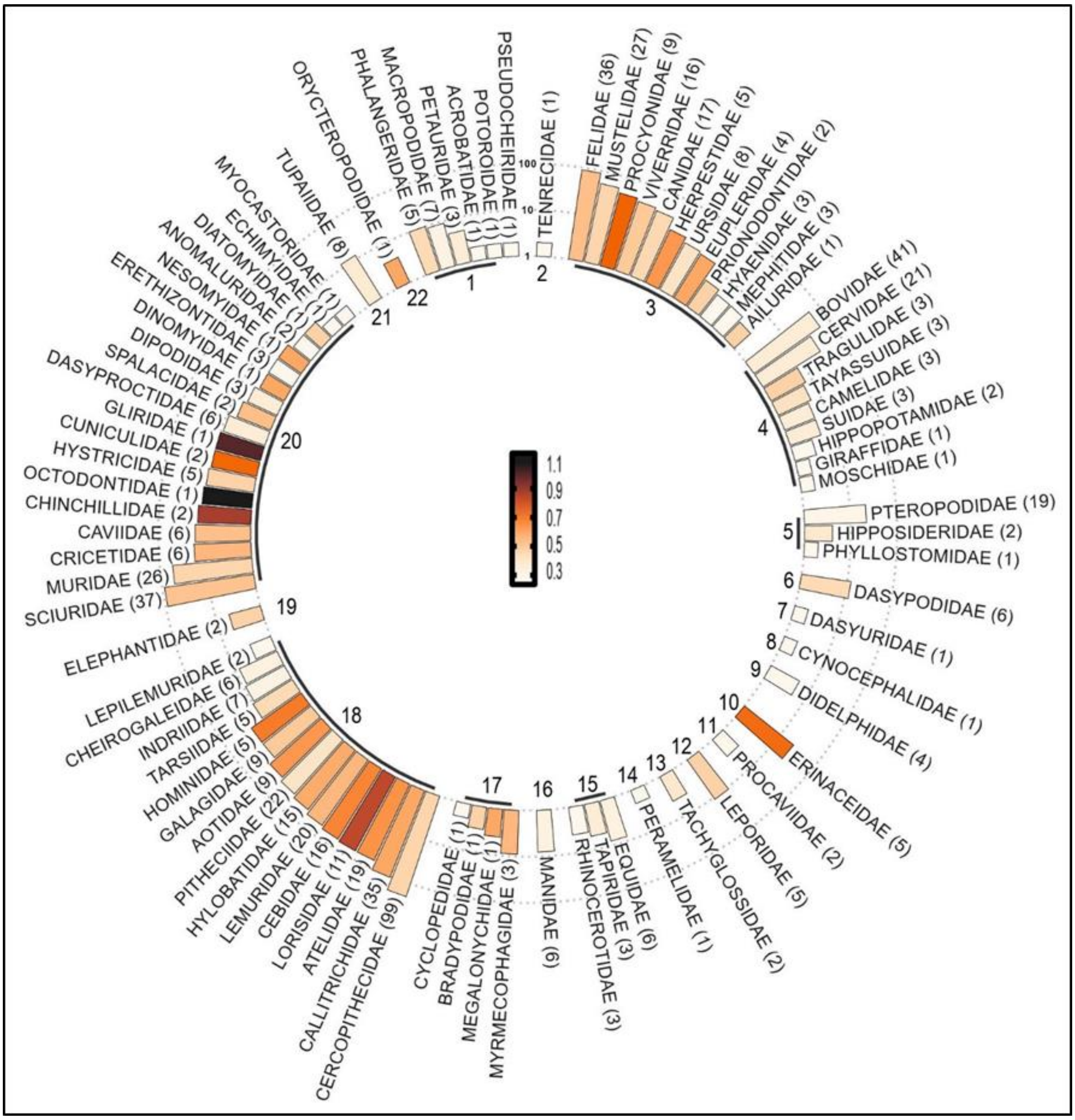

Figure 1: Number of studies on pet-keeping across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number in brackets represents species richness per family. Bar height reflects the total number of articles per family. Orders are numbered as follows: 1 – Diprotodontia, 2 - Afrosoricida, 3 – Carnivora, 4 – Artiodactyla, 5 – Chiroptera, 6 – Cingulata, 7 – Dasyuromorphia, 8 - Dermoptera, 9 – Didelphimorphia, 10 – Eulipotyphla, 11 - Hyracoidea, 12 – Lagomorpha, 13 – Monotremata, 14 – Peramelemorphia, 15 – Perissodactyla, 16 – Pholidota, 17 – Pilosa, 18 – Primates, 19 –

Proboscidea, 20 – Rodentia, 21 - Scandentia, 22 – Tubulidentata.

Analyses of phylogenetic signal revealed that pet species are not randomly distributed across the mammalian tree, but are phylogenetically clustered, particularly within the orders Primates, Carnivora, and Rodentia ($D = 0.3601$, $P < 0.0001$; Figure 2). Overall, species within these clades represent 73% ($n = 518$) of species recorded in our dataset as being kept as pets. This indicates that humans tend to select closely related species with shared traits for pet keeping. Certain mammal groups are disproportionately represented in the literature on species kept as pets compared to others (Figure 1; Appendix D), as shown by the NRI and NTI indices at both deeper and shallower phylogenetic levels ($NRI = 5.1650$, $NTI = 12.1868$; $P < 0.001$). For instance, species from the orders Primates, Carnivora, Rodentia, and Eulipotyphla were cited in at least 10 articles, whereas the orders Macroscelidea, Microbiotheria, Notoryctemorphia, and Paucituberculata were not cited in any. On average, each species was the focus of 2.2 studies (Appendix A).

At the same time, univariate phylogenetic logistic regressions showed that species with higher evolutionary distinctiveness (ED)—i.e., those more phylogenetically isolated—were also more likely to be used as pets. This suggests that both phylogenetic clustering and selection for evolutionary uniqueness operate simultaneously: while certain clades are overrepresented in the pet trade, within those clades, species with more evolutionarily distinctive lineages may be particularly valued, possibly due to their uniqueness or perceived rarity.

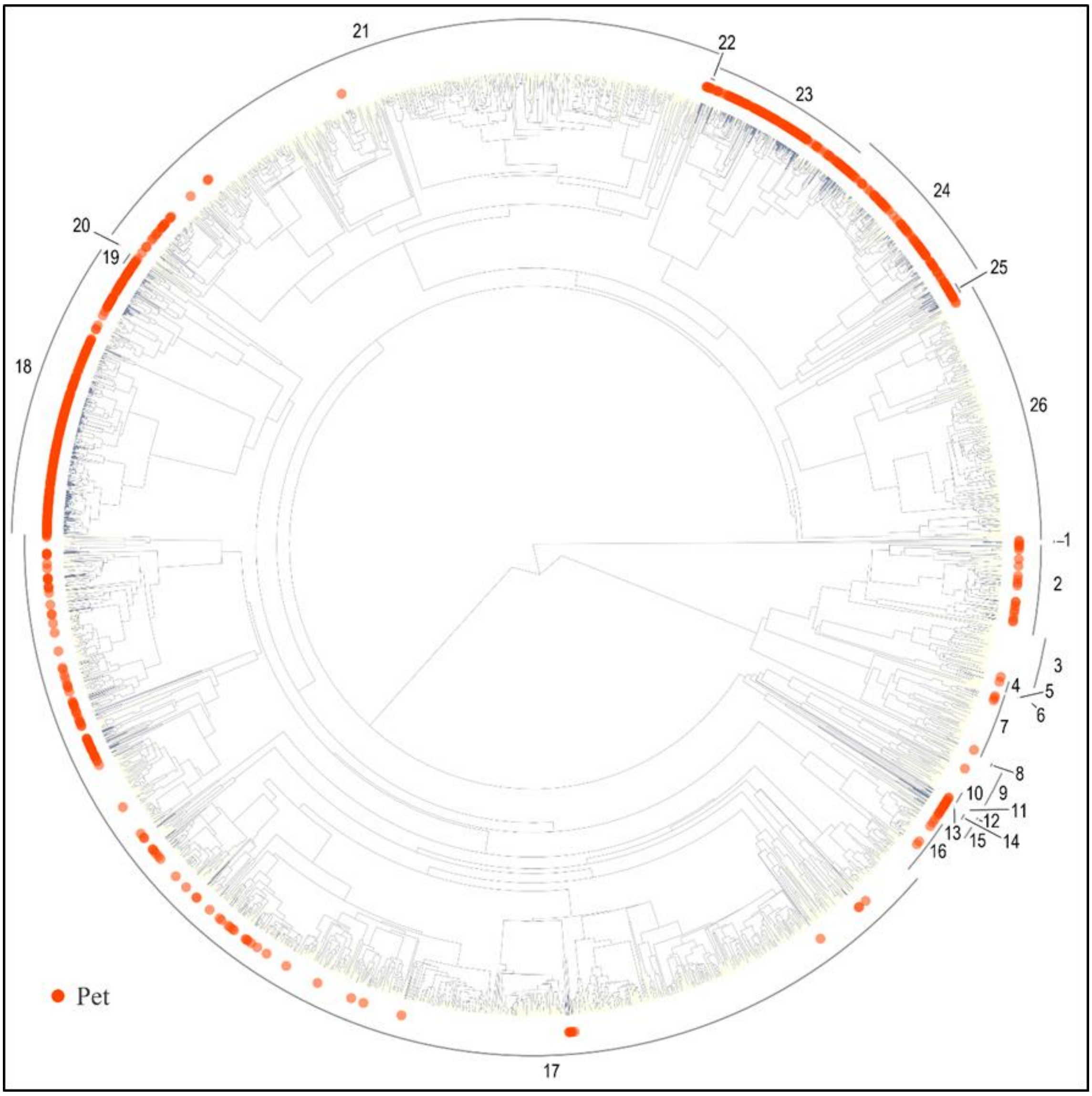

Figure 2: Phylogenetic tree of mammal species used as pets. Each specie used is indicated (in orange). The numbers represent the mammalian orders: 1 – Monotremata, 2 – Diprotodontia, 3 – Dasyuromorphia, 4 – Peramelemorphia, 5 – Notoryctemorphia, 6 – Microbioteria, 7 – Didelphimorphia, 8 - Paucituberculata, 9 – Afrosoricida, 10 – Macroscelidea, 11 – Tubulidentata, 12 – Hyracoidea, 13 – Proboscidea, 14 – Pilosa, 15 – Cingulata, 16 – Lagomorpha, 17 – Rodentia, 18 – Primates, 19 – Scandentia, 20 – Dermoptera, 21 – Chiroptera, 22 – Pholidota, 23 – Carnivora, 24 – Artiodactyla, 25 – Perissodactyla, 26 – Eulipotyphla.

3.3) Bioecological Traits of Species Most Likely to Be Kept as Pets

Bioecological traits that were significantly associated with the likelihood of being kept as pet in univariate models included larger body mass, broader geographic range, lower fecundity, and herbivorous or omnivorous diets (Table 2, Figure 3). Additionally, 42% of the recorded pet species were classified as threatened (18% Vulnerable, 16% Endangered, and 8% Critically Endangered). However, in the full model, species with larger body mass and broader geographic ranges were significantly more likely to be kept as pets (Table 3).

Table 2: Results of phylogenetic logistic regression models to test the effect of species traits on the likelihood of mammal species being used as pets.

	Estimate	StdErr	z-value	Lower CI	Upper CI	p-value
Intercept	-2.878399	0.139240	-20.672248	-3.107156	-2.6977	< **0.0001**
Body mass	1.308306	0.078708	16.622305	1.201212	1.4289	< **0.0001**
Intercept	-2.890824	0.180132	-16.048345	-3.145534	-2.6482	< **0.0001**
Geographical occurrence	0.78908	0.081555	8.815037	0.587062	0.8654	< **0.0001**
Intercept	-2.35067	0.18774	-12.52106	-2.61738	-2.1423	< **0.0001**
Evolutionary distinctiveness	0.40600	0.08568	4.73855	0.32957	0.4972	< **0.0001**
Intercept	-1.689759	0.149138	-11.330147	-1.927077	-1.4685	< **0.0001**
Litters per year	-0.727292	0.095495	-7.616034	-0.869622	-0.6030	< **0.0001**
Intercept	-1.747629	0.214671	-8.140971	-1.951425	-1.5187	< **0.0001**
Herbivore	-0.759492	0.136476	-5.565019	-0.917902	-0.6150	< **0.0001**
Omnivore	-0.353513	0.085993	-4.110970	-0.459429	-0.2613	< **0.0001**
Intercept	-2.688833	0.175808	-15.294150	-2.912315	-2.3921	< **0.0001**
Threatened	1.050764	0.239905	4.379916	0.924126	1.3439	< **0.0001**
Not threatened	0.289768	0.14709	1.967075	0.087684	0.5729	< **0.05**

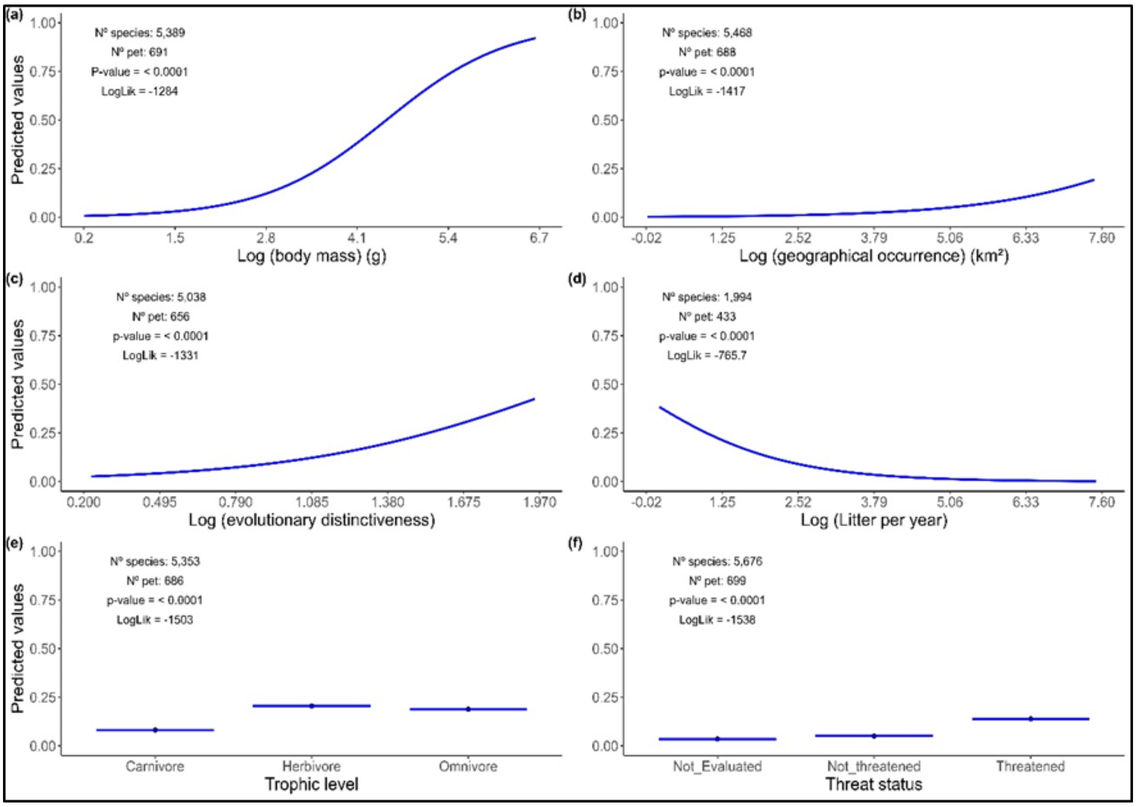

Figure 3: Plot showing the relationships among species traits and likelihood of being used as pets as predicted by the phylogenetic logistic regression models.

Table 3: Output of the full phylogenetic logistic regression model to test the effect of species traits on the likelihood of mammal species being used as pets.

	Estimate	StdErr	z-value	Lower CI	Upper CI	p-value
Intercept	-8.850051	176.526962	-0.050134	-9.296167	-8.5788	0.9600
Body mass	0.651895	0.098735	6.602492	0.500713	0.7551	**<0.0001**
Geographical occurrence	0.415744	0.069960	5.942608	0.326022	0.5281	**<0.0001**
Evolutionary distinctiveness	-0.599815	0.377718	-1.587998	-0.905999	-0.0147	0.1123
Litters per year	-0.086710	0.382709	-0.226568	-0.826306	0.2611	0.8208
Herbivore	-0.160720	0.184094	-0.873036	-0.488006	0.0482	0.3826

Omnivore	0.007491	0.129710	0.057752	-0.226967	0.1919	0.9539
Not threatened	8.642672	374.467820	0.023080	8.461585	8.7748	0.9816
Threatened	-4.739844	216.199096	-0.021923	-4.925991	-4.5328	0.9825

3.4) Influence of Socioeconomic Variables

We identified studies on wild mammals kept as pets across 65 countries (Figure 4; Appendix C). The countries with the highest number of mammal species kept as pets were Indonesia (97 spp), Lao PDR (53 spp), and Brazil (49 spp). Importantly, we detected a positive correlation (S=1518, rho=0.6525; *P* < 0.0001) (Appendix A; Figure S3) between species richness and the number of studies per country, suggesting potential bias in the results. Indonesia (32 studies) and Brazil (18 studies) accounted for 26% of all studies analysed. We found no significant effect of the socio-political variables (GDP per capita, HDI, HPD) on the number of species or studies by country (Table 4).

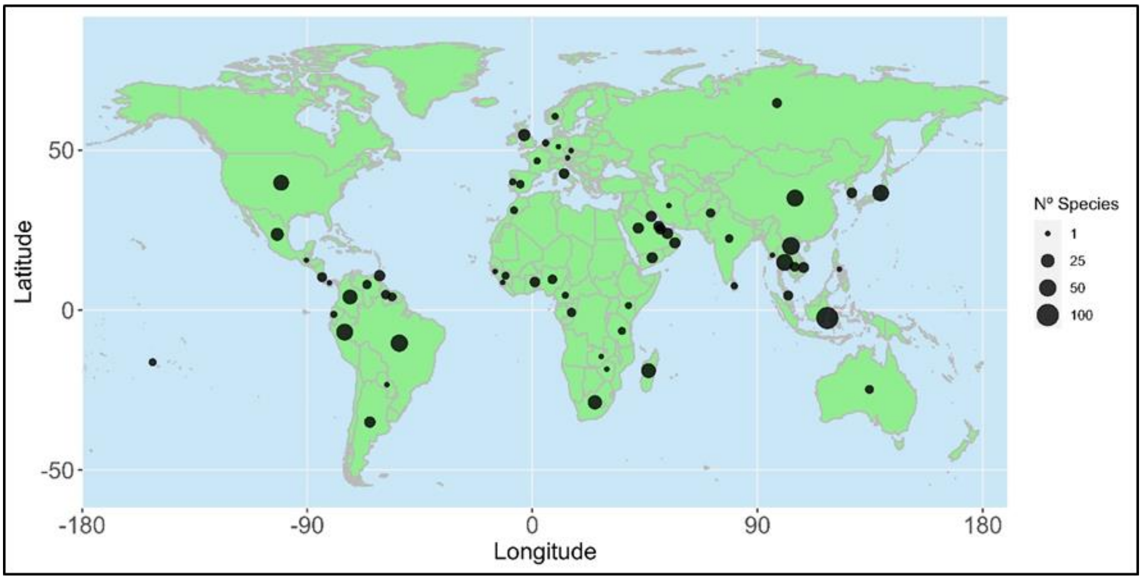

Figure 4: World map showing the number of species kept as pets by country.

Table 4: Results of linear generalised mixed models to test the effect of socio-political variables on the species and number of studies in each country.

	Estimate	Std. Error	Z value	Pr(>|z|)
Number of species				
Intercept	2.085237	0.354028	5.890	< **0.0001**
GDP *per capita*	-0.264447	0.586997	-0.451	0.652
HDI	0.473322	0.591149	0.801	0.423
HPD	-0.004788	0.171496	-0.028	0.978
Number of studies				
Intercept	0.81978	0.14846	5.522	< **0.0001**
GDP *per capita*	-0.56193	0.47603	-1.180	0.238
HDI	0.64427	0.48388	1.331	0.183
HPD	0.05618	0.14555	0.386	0.700

Discussion

The keeping of wild mammals as pets involves at least 11% of all mammal species, spanning 22 orders. Primates, Carnivora, and Rodentia account from aproximately 73% of the species used as pets in our database. These findings aling with previous studies examining the global pet trade[1,3,19,42], suggesting that most mammals kept as pets are also involved in the wildlife trade, with negative impacts on their populations.

The species recorded in our database are phylogenetically clustered within specific mammalian groups kept as pets (e.g., Figure 1 and 3; Appendix D). Accordingly, studies concerning pet use include more species from the Primates, Carnivora, Rodentia, and Artiodactyla clades. This phylogenetic pattern indicated that species from these clades are featured in more studies than those from other clades. It is also worth noting that the prders Primates, Carnivora, and Rodentia include many charismatic mammals (e.g., lemurs, capuchins, tiger, and lions)[43], which may account for the greater research focus on these groups.

Our results indicate that larger and more widespread mammal species are more likely to be kept as pets than smaller species with narrower geographical distributions. Widespread mammals are more likely to encounter diverse human populations than species with restricted ranges[44] (Blackburn et al. 2017), which may increase their likelihood of being used as pets. Additionally, widespread species tend to be more abundant, exhibit higher natural dispersal rates[45] (Blackburn et al. 1997), and tolerate a broader range of environmental conditions[46] (Gaston & Blackburn 2007), all of which may enhance their overlap with human settlements. These findings contradict our initial prediction that species with narrow ranges would be more commonly kept as pets. Most studies investigating the keeping of wildlife as pet are also associated with the wildlife trade[15–17], which implies a higher valuation of endemic species (i.e., those with restricted geographical ranges). Endemism is often perceived as a proxy for rarity, and thus endemic species are frequently more targeted in the wildlife trade[17,22].

Body mass is a key trait in the selection of vertebrate species for various human uses[3,19,47], including as pets[15,17,19]. For instance, larger bird species are more valued in pet markets in Taiwan[15] and Australia[17]. A similar pattern is observed in the trade of reptiles in Australia[17] and amphibians in the USA[16]. Regarding mammals, recent studies have shown that body mass influences both the likelihood of a species being commercially traded[3,19] and its trade frequency[19]. Overall, across all mammals species in our dataset, larger species are more frequently kept as pets than smaller ones (Figures 1a and 2a). Notably, we also found that species with lower fecundity (fewer litters *per* year) are more likely to be kept as pets than species with higher fecundity. Species with high fecundity can produce more offspring, a trait that may be advantageous when keeping animals in captivity is financially attractive, such as in the pet trade[48]. Toomes et al.[17] reported that bird and reptile species commonly traded as pets in Australia tend to have high fecundity rates. However, we suspect that spatial and management limitations in captivity may discourage the keeping of highly fecund mammal species, as larger numbers of offspring require more space, care, and resources—making them less viable or appealing in domestic or commercial settings. Additionally, larger mammal species (in our case) tend to have a longer gestation periods and greater intervals between births compared to smaller species or those with higher reproductive rates. Another factor associated with the keeping of low-fecundity species may be the demand for rare species, which typically exhibit slow life-history traits[19].

Our results regarding trophic level indicate that herbivorous and omnivorous species are more likely to be kept as pets than carnivorous ones, likely due to the higher economic costs associated with maintaining a specialised carnivorous diet comapred to the more flexible diets for captive herbivorous and omnivorous in captivity. Species that are evolutionarily distinct are also more likely to be kept as pets than those that are more evolutionarily common. This patterns is supported by Scheffers et al.[3], who show that evolutionarily distinct species possess unique traits that are more desirable in the wildlife trade. The higher desirability of threatened species as pets has also been reported in other studies of the wild vertebrate trade[15,49]. Siriwat et al.[49] found that higher prices are charged for threatened mammals in the pet market than compared to non-threatened species. A similar trend has been observed in the wild bird trade[15]. The "threatened" status is often perceived as a proxy for rarity or as an indication of prohibited use or trade in many regions of the world, and this perception can increase the market value of such animals[22,49].

The use of wild mammal as pets is widespread. According to our results, countries with a greater number of species kept as pets (more than 40 species) are primarily located in Asia and South America (Appendix C). For instance, our data show that Indonesia and Lao PDR recorded the highest number of pet species. These findings are consistent with previous studies on the use of wildlife use as pets [1,6,37]. It is important to highlight that many countries in Asia and South America are global hotspots of mammal diversity[50].

Our results also shown that most species kept as pets, as well as the majority of studies on pet-keeping of wild mammals, are concentrated in low and middle-income countries. However, we did not find a significant effect of socio-political variables on either the richness of species used or the research effort concerning wild mammals kept as pets. Recents studies suggest that countries with stronger trade networks have greater opportunities to access a wider variety of species[51,52]. Moreover, previous research has indicated that the exotic pet market expands and pet ownership increases with rising living standards[12].

Overall, our results indicate that the choice and selection of particular species is not random, but rather influenced by the recurrence of shared traits, suggesting that the utilisation of mammalian species as pets is phylogenetically clustered (supporting our first and second hypotheses). Furthermore, our findings highlight that the use of mammals as pets is concentrated within specific clades. This pattern underscore the need for further research on the species within these mammalian groups/clades, as their aggregation in the pet trade may drive overexploitation and populational declines.

Approaches aimed at understanding the influence of species traits on the selection of animals as pets are relatively recent and have largely focused on specific mammalian groups (i.e., carnivora and primates) and a limited set of traits (e.g., body mass, threat status, and presence in CITES appendices)[3,48,49]. Our findings therefore corroborate previous research on mammals[3,19] and other vertebrate groups (e.g., amphibians, reptiles, and birds)[15,17,19], while also providing novel insights into the mammalian pet trade by showing that several additional traits may influence species selection and their maintenance in captivity.

In summary, trait-based studies can assist in identifying species that are more likely to be selected for use as pets. It is important to highlight that the keeping of wildlife as pets is currently one of the major drivers of the wildlife trade[1,19], biological invasions[11], and disease transmission[14], and that demand for pets is increasing across many regions worldwide. Furthermore, trait-based selection may trigger cascading effects on wild populations, including genetic drift, loss and reduction of ecosystem services, and shifts in trophic dynamics due to the competition with invasive species[53].

This study presents the first global synthesis of wild mammal species kept as pets, demonstrating that species selection is strongly influenced by biological traits and evolutionary history, following a consistent and non-random pattern across taxa and regions. Although socio-political variables were expected to shape pet-keeping trends, they had no significant effect, suggesting that species-level characteristics and research biases may have influenced the observed patterns. These findings underscore the urgent need to expand research in underrepresented regions.

The convergence of phylogenetic clustering, ecological filtering, and global patterns of demand underscores that pet-keeping is not merely a cultural or economic phenomenon, but also an ecological process with the potential to exert selective pressures on wild populations. This trait-based selectivity may heighten exploitation risks for certain lineages, contributing to population declines, genetic erosion, and broader disruptions to ecological networks. Our findings offer a predictive framework to identify species at risk and to support more targeted, evidence-based interventions. However, given the widespread nature of wild mammal husbandry and the limited documentation of its long-term consequences, there is an urgent need to integrate pet-keeping into broader conservation and biosecurity agendas. Recognising and addressing the systemic drivers of wildlife pet ownership is essential not only for species conservation, but also for mitigating cascading impacts on ecosystems and safeguarding animal welfare.

2)Methods

2.1) Data collection

2.1.1) Species reported as pet

We conducted a systematic search using the Scopus database for articles (excluding books, conference proceedings, and unpublished reports) related to mammals used as pets, using a combination of keywords in English (Appendix A; Supplementary Table 1). We followed the ROSES protocol for systematic reviews (Appendix A; Figure 1)[27]. Only articles that provided species-level taxonomic identification were selected for further analysis, resulting in 192 research articles. The information was compiled into a comprehensive database including the following information: species name, country, and publication year. The trade price of each species was not included due to the limited availability of data (6.25% of the studies) reporting this information. The full list of articles included in our database can be found in Appendix A.

2.2.2) Species traits and phylogenetic data

Adult body mass data were obtained from Phylacine, PanTHERIA, and COMBINE databases[28–30]. Extent-of-occurrence and threat status data were based on International Union for Conservation of Nature Red List (IUCN 2022). Fecundity (number of litters per year) data were based on COMBINE[30], and trophic level data on the COMBINE and Mammal Diet databases[30,31]. Evolutionary distinctiveness (ED) was obtained from the EDGE database (EDGE/EDGE lists, 2022; https://www.edgeofexistence.org/edge-lists). We used the consensus full-sample tree for mammals from Upham et al.[32], which includes 5,804 extant species and 107 recently extinct species. We pruned the phylogeny to contain only mainland species, resulting in a phylogeny with 5,676 species. Species nomenclature followed Burgin et al.[33].

2.2.3) Socio-political variables

Gross Domestic Product per capita (GDP per capita) and Human Population Density (HPD) for each country were obtained from the World Bank database (databank.worldbank.org). These indices represent the economic output per capita and the number of people per square kilometre, respectively, and were used as proxies for economic development and natural resource consumption (Appendix C).

The Human Development Index (HDI) was taken from the UN Human Development Reports (HDR, UNPD, retrieved on 10.05.2023). This index reflects the average performance of key dimensions of human development by country, based on income, health, and education indicators (Appendix C).

2.2) Statistical analysis

2.2.1) Examining Non-Randomness in the Selection of Mammals Species Being Kept as Pets

We used both phylogenetic and taxonomic approaches to assess non-random patterns in species traits. We applied the permutation test described in Abellan et al.[34] to test whether there are differences between the observed number of species used as pets in each mammalian order and the number expected if mammalian species were randomly selected for pet use. In this analysis, S species were randomly selected without replacement, and the number of these randomly selected species in each order was summed. S is the number of mammal species used as pets in our dataset and matching with phylogeny ($S = 699$; *Bubalus bubalis, Hoolock tianxing, Pongo tapanuliensis, Prionailurus javanensis,* and *Ptaurus breviceps* were not present in the phylogeny and were removed from this analysis). This process was repeated 100,000 times to generate 100,000 lists of randomly selected species. The observed number of species from a mammalian order kept as pets was judged to be significantly greater than expected if the randomly derived values in each order were higher than those observed (i.e. if 99.95% of the 100,000 random lists contained more species from that order). The significance level was adjusted by sequential Bonferroni correction for multiple comparisons (critical value of $a/n = 0.0018$; where $a = 0.05$ and $n = 26$ (the number of mammalian orders in our dataset)).

We tested the phylogenetic signal for non-randomness in pet selection using Fritz's D[35]. This is a measure of phylogenetic signal for binary traits (1 = used as a pet; 0 = not used) and was applied here to test whether humans tend to keep closely related species as pets. Fritz's D can be interpreted as follows: $D = 1$ indicates a random distribution of use as pets; $D = 0$ indicates that pet species are phylogenetically clumped; $D > 1$ indicates phylogenetic overdispersion; and $D < 1$ indicates that species kept as pets are more clustered than expected (strong phylogenetic signal), suggesting that humans tend to use closely-related species as pets. These analyses were performed using the caper package[36] in the R program[37].

In sequence, we calculated the Net Relatedness Index (NRI) and the Nearest Taxon Index (NTI) to test whether research related to pets favours particular species lineages. The NRI describes the phylogenetic clustering or overdispersion of species in a given community with relationships closer to the root of the phylogeny, while the NTI describes patterns closer to the tips. For the null model, we randomised the community data matrix by drawing species from the pool of species equally likely to occur in the phylogenetic distance matrix. Positive values indicate that a given community contains more closely related species (phylogenetic clustering) than expected by chance, while negative values indicate phylogenetic overdispersion. These analyses were performed using the picante[38] package in the R program[37]. Hot node clades (those with more species investigated) were identified using the NODESIG function in the R program[37], adapted from Abellan et al.[34].

2.2.2) Factors Influencing the Likelihood of Mammal Species Being Kept as Pets

To examine whether certain species traits influence the likelihood of a species being kept as a pet, we used phylogenetic logistic regression[39]. The traits we analysed included body mass, geographic range size, evolutionary distinctiveness, number of litters per year, trophic level, and threat status.

To make threat status easier to interpret, we grouped species into three categories: “Not Evaluated” (including species classified as Not Evaluated - NA and Data Deficient - DD); “Least Concern” (including Least Concern - LC and Near Threatened - NT species); and “Threatened” (including Vulnerable - VU, Endangered - EN, and Critically Endangered - CR species)

First, we performed separate (univariate) phylogenetic logistic regressions for each trait. Due to a large amount of missing data and differences in data availability across traits, species with missing values were excluded from this step. Next, we built a full model including only the traits that were significant in the univariate analyses. This model was based on 1,898 species, of which 423 were kept as pets. To improve model performance, all numerical predictor variables were log-transformed, and then centred and scaled (z-transformation) to allow direct comparisons of effect sizes. We checked for multicollinearity among continuous predictors using variance inflation factors (VIFs). All continuous predictor had VIF < 4, therefore, we kept them all in the full model. The analyses were conducted using the phyloglm function in the phylolm package[39] in the R programme[37].

2.2.3) Socio-political Factors Influencing the use of Mammal Species Kept as Pets

Finally, we fitted two generalised linear mixed models to test whether socio-political variables (HDI, GDP per capita, and HPD) influence the number of species and number of studies per country. Prior to analysis, HDI, GDP *per capita*, and human population density were $\log_{10}$ – transformed, and then centred and scaled (z-transformation) to allow direct comparisons of effect sizes. We checked for multicollinearity among continuous predictors using the variance inflation factors (VIFs). All continuous predictor had VIF < 4, therefore, we kept them all in the full model. Countries with more studies tend to record more species being kept as pets. This may inflate the numbers in well-studied countries and underestimate the reality in countries with limited research. To reduce this bias, we considered country as a random variable. This analysis was performed in the glmmTMB package[40] of the R programme[37]. Residual diagnostics were assessed using diagnostic plots in the DHARMa package[41] of the R programme[37].

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Author contributions

HKLS, RRDB, and RRNA designed the project; HKLS, ALS, DNSF, RKLS, and FBP built and handling the datasets; HKLS performed the statistical analyses; HKLS, RRDB, FBP, and RRNA led the writing of the article with contributions from all authors.

Data availability statement

All data used in analyses are available in supplementary information.

Conflict of interest statement

The authors declare no conflict of interest.

Supplementary information

Appendix A

Table 1: Keywords used in systematic review.

Keywords	Downloaded papers
Wildlife AND Ethnozoology	388
Wildlife AND "Pet trade"	177
Wild Animals AND Commerce	405
Wild Animals AND Commercialization	202
Wild Animals AND Confiscation	65
Wild Animals AND Ethnobiology	422
Wild Animals AND Ethnozoology	241
Wild Animals - Kept as pets	93
Wild Animals AND "Pet trade"	130
Wild animals AND Sale	87
Wild mammals AND Ethnobiology	126
Wild mammals AND Ethnozoology	35
Wild mammals AND Pets	935
Wild mammals AND as Pets	54
Wild mammals AND "Pet trade"	22
Wild mammals AND Sale	296
Hunting AND "Pet trade"	180
Ethnozoology	294
Pet trade	766

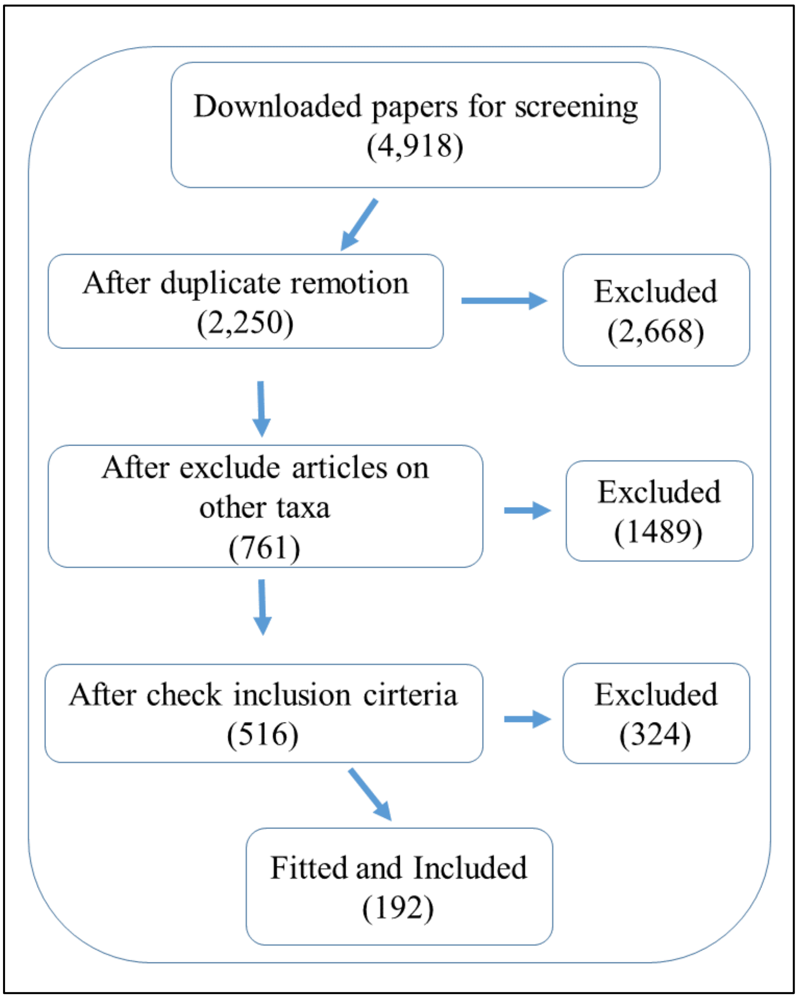

Figure S1: Flowchart of systematic review and selection of articles includes in our study.

Table 2: Number of species and studies by year.

Year	Unique_Species	Total_References
1967	5	1
1977	1	1
1986	12	1
1992	1	1
1997	7	1
1998	15	2
2000	23	3
2001	8	1
2002	1	1
2003	12	2
2004	32	4
2005	3	3
2006	9	1
2007	9	2
2008	10	3
2009	54	10

2010	20	7
2011	4	3
2012	15	6
2013	13	6
2014	62	15
2015	80	13
2016	89	16
2017	77	16
2018	54	9
2019	504	17
2020	114	26
2021	124	25

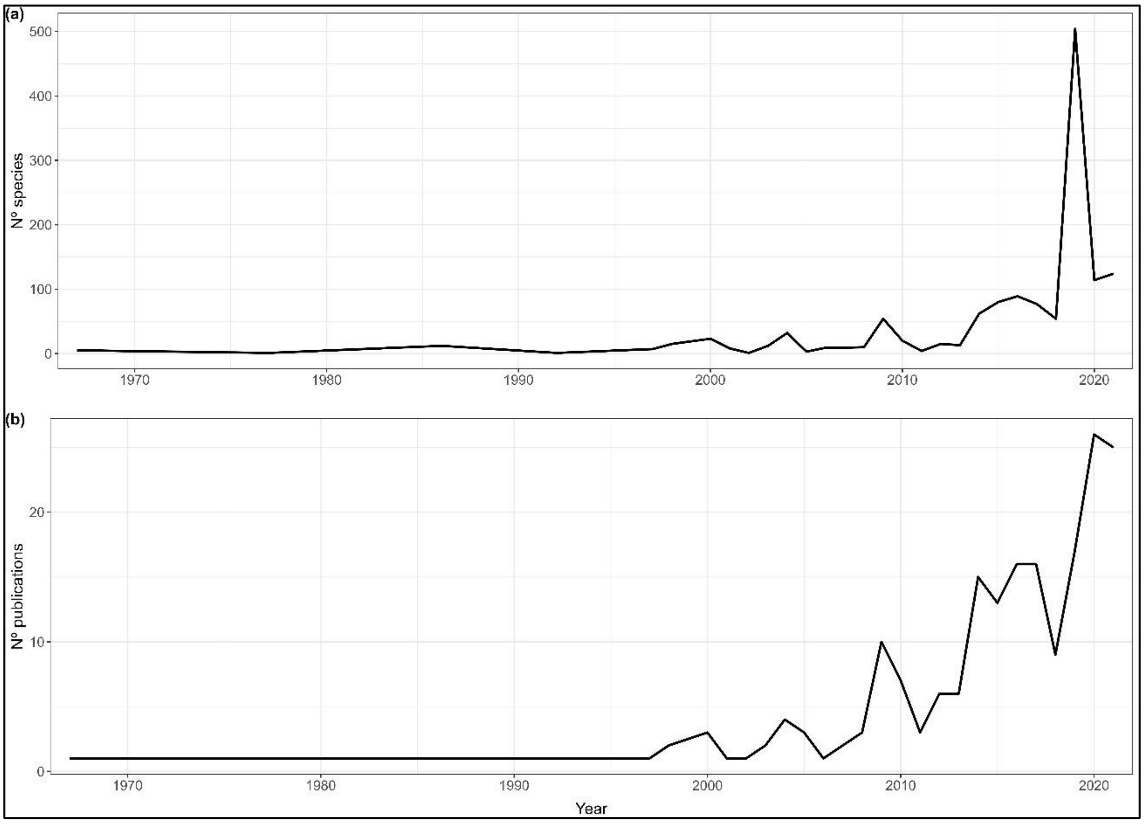

Figure S2: Plot showing the species and studies number by year.

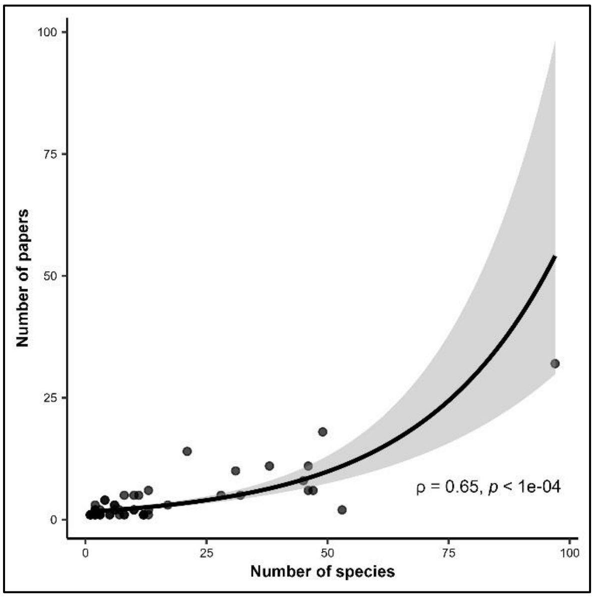

Figure S3: Plot showing the correlation among number of species and papers by country.

Articles included in our dataset

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CAPÍTULO 3

From wilderness to table: a global overview of wild mammals as human food

Submitted for: Conservation Biology

From wilderness to table: a global overview of wild mammals as human food

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Abstract

Humans have long used as wild mammals as bushmeat. In many places across the world, the harvest of bushmeat for human subsistence is secular practise. Currently, the harvest of wildlife to guarantee the human food security or for meet commercial trade pose on the main threats for conservation of many species around the world. Although many studies have investigated the topic, most of research if focus on large species and it is concentrated in tropical areas. In this sense, we performed a systematic review related to consumption of wild mammals as bushmeat and used phylogenetic comparative methods to test: (1) if species traits influence the probability of species to be used as bushmeat; (2) whether closely-related species tend to be more used as food; (3) which and how species traits influence the research on wild mammal as bushmeat; and (4) which and how socio-political variables influence research bushmeat consumption around the world. Overall, at least 1,486 species were involved in human-wildlife conflict, including 391 threatened species (176 vulnerable, 150 endangered, and 65 critically endangered). Smaller-medium bodied size, medium geographical range, and omnivore species are more likely to be used as bushmeat around the world. Closely related species are more used as bushmeat. The research effort related to bushmeat consumption is biased to specific mammal orders and species traits. The bushmeat consumption were recorded in 133 countries, mainly in Africa and South America. Developing and sub-developing countries have more wild mammals as bushmeat. Overall, our results show high species richness used as bushmeat, and emphasise the influence of species traits on the likely of bushmeat consumption and research effort. These results call attention for more research towards clades/orders with low attention, since missing information is critical to design or improve mitigation and conservations measures.

Keywords: species traits, evolutionary relatedness, wild-mammals as food, human subsistence, poverty, conservation.

Introduction

Among vertebrates, wild mammals represent one of mainly taxa used as food in the worldwide terrestrial areas (CAWTHORN; HOFFMAN, 2015; FA; BROWN, 2009; RIPPLE et al., 2016; VAN VLIET et al., 2014, 2017). In many places, these species represents the only protein source for peoples, in addition to provide income for many rural populations through the bushmeat trade (BRASHARES et al., 2004, 2011; MILNER-GULLAND et al., 2003; NIELSEN et al., 2018). To date, the bushmeat hunting for supply the commercial trade or for subsistence of rural people is one of the mainly factor responsible for stimulates hunting and cause decreasing of the mammal populations species and defaunation worldwide (LEE et al., 2020; RIPPLE et al., 2016; TAYLOR et al., 2015; YOUNG et al., 2016).

In so many places, the highest protein index and the abundance/availability of the some species associated with cultural values represents the mainly boosted of bushmeat consumption and trade worldwide (ALVES et al., 2016; CAWTHORN; HOFFMAN, 2015; VAN VLIET et al., 2015, 2017). Furthermore, the indiscriminate consume and the bushmeat hunting results not only damages for species populations, but dually for human populations due cascade effects loss for the ecosystems services provides for the mammals species (FA; BROWN, 2009; RIPPLE et al., 2016), in addition to threat human health through zoonosis transmission related to the handling and consume of bushmeat (LEE et al., 2020; ORDAZ-NÉMETH et al., 2017; SHIVAPRAKASH et al., 2021).

Previous studies suggest that bushmeat species consumption and the research effort towards to the wild mammals consumption as food is influenced for the species traits (e.g., body mass, habit, availability) (BODMER; EISENBERG; REDFORD, 1997; BRAGA-PEREIRA et al., 2021; FA; BROWN, 2009; FA; RYAN; BELL, 2005). In this sense, larger-bodied size species tend to be more intensively researched and harvested than smaller ones (BODMER; EISENBERG; REDFORD, 1997; FA; BROWN, 2009; RIPPLE et al., 2016).

Furthermore the most research effort in the both scales local and regional to date have focused on specific mammal groups, such as ungulates (RIPPLE et al., 2016; STAFFORD; PREZIOSI; SELLERS, 2017) and are concentrated in tropical areas (GROOM; TEDESCO; GAUBERT, 2023; NIELSEN et al., 2018; RIPPLE et al., 2016; STAFFORD; PREZIOSI; SELLERS, 2017; TAYLOR et al., 2015; VAN VLIET et al., 2017).

In addition to species traits, recent research suggests that socio-political factors as purchase power, poverty index, and the growth of human populations also have an influence on bushmeat consumption (BRASHARES et al., 2011; CAWTHORN; HOFFMAN, 2015; FA et al., 2009; NIELSEN et al., 2017, 2018). For example, developing and sub-developing countries (with lower gross domestic product (hereafter GPD) and Human Development Index (hereafter HDI)) tend to trust on bushmeat more than developed countries (CAWTHORN; HOFFMAN, 2015; MILNER-GULLAND et al., 2003).

Once that the bushmeat consumption encompass a complex array of biological/ecological, socio-political and cultural factors (BARBOZA et al., 2016; VAN-VLIET; NASI, 2020; VAN VLIET et al., 2014, 2017), to know which drivers and how they influence the selection of the species for consumption is critical in order to improve measures that support sustainability of harvests or reduce the impacts related to the unsustainable poaching for species exploited (MILNER-GULLAND et al., 2003; RIPPLE et al., 2016; VAN VLIET; NASI, 2019).

Here, we have compiled a global and comprehensive database of the consumption of wild mammals as bushmeat to answer the following questions: 1) How many and which wild mammal species are used as bushmeat worldwide? 2) How do species’ traits and evolutionary relatedness influence the consumption of the species as food?; 3) Is bushmeat research toward to the wild mammals biased?; 4) Which countries are have more species diversity and research effort toward to the bushmeat consumption?; and 5) What socio-political variables influence the bushmeat consumption worldwide?

Methods

Data collection

We carry out a systematic search of the Scopus and CIFOR-ICRAF (Center for International Forestry Research and World Agroforestry) databases for only scientific articles related to consumption of wild mammals as food (bushmeat or wildmeat) using a combination of keywords in English (Appendix 1; Table S1, Figure S1). We focused on these databases because Scopus it is among the largest sources of peer reviews scientific journals (MONGEON; PAUL-HUS, 2016) and CIFOR-ICRAF because it is encompass an intercontinental framework with over 750 publications/year on forest and biodiversity resources use and management across the globe (https://www.cifor-icraf.org/). Review articles were not compiled in our database, as they are compilations of secondary data (obtained from another papers or sources published), but they were used as additional sources for papers. Only papers that provide species-level taxonomic identification and mentioned the use of species as food were selected for further full text screening, resulting in 1,124 research articles. The information was compiled into an extensive database including the following information: species name, area (rural and urban), country, and publication year.

Species traits and phylogenetic data

Species traits were compiled from the following databases: Adult body mass data was taken from the Phylacine (FAURBY et al., 2018), PanTHERIA (JONES et al., 2009), and COMBINE (SORIA et al., 2021). Trophic level was obtained from the COMBINE (Soria et al. 2021) and Mammal Diet databases (KISSLING et al., 2014). Extent-of-occurrence and threat status data was obtained from International Union for Conservation Nature Red List (IUCN, 2023). The mammal phylogeny used in analyses was taken from Upham et al. (2019), which includes 5,804 extant species and 107 recently extinct species. We used the consensus full sample tree for mammals We pruned the consensus full sample phylogeny for mammals to contain only extant species, resulting in a phylogeny with 5,804 species. Species nomenclature followed Mammal diversity (BURGIN et al., 2018).

Socio-political variables

For each country, we taken the following socio-political variables: Gross Domestic Product per capita (GDP per capita), Human Population Density (HPD) and Human Development Index (HDI). These indices represent the economic output divided by its population, the number of people per square kilometre, and the average performance of key dimensions of human development by country based on wealth, health and education. They were used as proxies for economic and social development (GDP per capita and HDI) and for natural resource consumption (HPD). They were taken from the World Bank (GDP per capita and HPD) (databank.worldbank.org) and from the UN Human Development Reports (HDR, UNPD) the they were retrieved on 10.05.2023.

Statistical analysis

We used the permutation test described in previous studies (ABELLÁN et al., 2016; BLACKBURN et al., 2017) to test whether there are differences between the observed number of species used as food per mammalian order and the number that would be expected if mammalian species were randomly selected by humans. In this analysis, *S* species were randomly selected without replacement and the number of these species selected by chance in each order was summed. *S* is the number of mammal species consumed as food present in our dataset and matching with phylogeny (S = 1,460 – Table 1; *Bubalus bubalis*, *Grammomys gazellae*, *Ovis vignei*, *Pongo tapanuliensis*, and *Presbytis aygula*, were not present in the phylogeny and were removed from this analysis). This process was repeated 100,000 times to generate 100,000 lists of species selected by chance. The observed number of species from a mammal order related to the use as food was judged to be significantly greater than expected if the randomly derived values in each order were higher than those observed (i.e. if 99.95% of the 100,000 random lists contained more species from that order). The significance level was adjusted by sequential Bonferroni correction for multiple comparisons (critical value of a/n = 0.0018; where a = 0.05 and n = 27 (the number of mammalian orders in our dataset)).

Next, we fitted phylogenetic logistic regression models (PGLM) (IVES; GARLAND, 2010) to test whether species traits (log body mass, log extent of occurrence, trophic level, and threat status) influence the probability of a species being used as food. Trophic level and threat status were treated as ordinal variable with three and six levels respectively (Herbivore < Omnivore < Carnivore; DD < LC < NT < VU < EN < CR). We fitted a full model with all species for which there were not missing data in all exploratory variables. All numeric exploratory variables were log transformed and z-transformed to allow comparisons of effect sizes. This analysis was performed using the phyloglm function in the phylolm package of the R program (IVES; GARLAND, 2010).

Next, we fitted generalised linear mixed models (GLMM) using Markov chain Monte Carlo (MCMC) estimation implemented in the brms package (Bürkner, 2021) to check whether research effort (number of publications) is skewed for mammal traits (log biomass, log extent of occurrence, trophic level, and threat status). Trophic level and threat status were treated as ordinal variables of three and six levels respectively (Herbivore < Omnivore < Carnivore; DD < LC < NT < VU < EN < CR). We fitted a full model with all species for which there were not missing data in exploratory variables for. Since this research effort is counted data (number of publications for species), we used negative binomial error distribution to take into account over dispersion.

We then used the inverse phylogenetic distance matrix, represented by a variance-covariance matrix (VCV – derived from the phylogeny) to account for phylogenetic relationship between species due to shared ancestry. We used four Markov chains with 4,000 iterations in each brms model, sampling every one iteration and discarding the first 1,000 as warm-up. The models' diagnosis was performed through a visual check of density and trace plots of fixed effects. We used Rhat (potential scale reduction values) values = 1 or below of 1.02 as a parameter for good convergence models. Next, we computed the probability of direction (pd) to assess the effect of each species traits on the research effort. This parameter was generated from posterior distributions of the models and it is commonly interpreted as frequentist *p*. The values indicate the certainty of the direction of an effect, thus pd - values were considered as being significant when the likelihood of an effect in certain direction was over 95%.

We tested the phylogenetic signal for non-randomness in species use as food using Fritz's *D* (FRITZ; PURVIS, 2010). This metric is a measure of phylogenetic signal for binary traits (1 = in conflicting; 0 = not conflicting) and was applied herein to test whether species used by humans tend to be phylogenetically clustered. Fritz's *D* can be interpreted as follows: $D = 1$ corresponds to a random distribution of species used as food; $D = 0$ indicates that species used as food are phylogenetically clumped; $D > 1$ indicates phylogenetic overdispersion; and $D < 1$ indicates that species used as food are more clustered than expected (strong phylogenetic signal), and suggests that closely-related species tend to be used as food by humans. These analyses were performed in the caper package of the R program (Orme et al., 2018).

Finally, we fit generalised linear models to test whether socio-political variables (GDP, HDI, and HPD) influence the number of species and research effort (number of publications) related wild mammals used as food per country. All exploratory variables were log transformed. This analysis was performed in the MASS package of the R program (Vanables & Ripple, 2002). Residual diagnostics were assessed using diagnostic plots in the DHARMa package of the R program (Hartig, 2022).

Results

We recorded 1,124 publications on wild mammals consumptions as bushmeat/wildmeat (Appendix 1). The average number of bushmeat species and publications per year was 148.5 and 23.4 respectively (1970 – 2021). The number of species recorded and publications have increased in number since 2000s (Figure 1). Most of publications were concentrated in Africa (497 studies, 44,2%) and South America (266 studies, 23,7%) (Appendix 2).

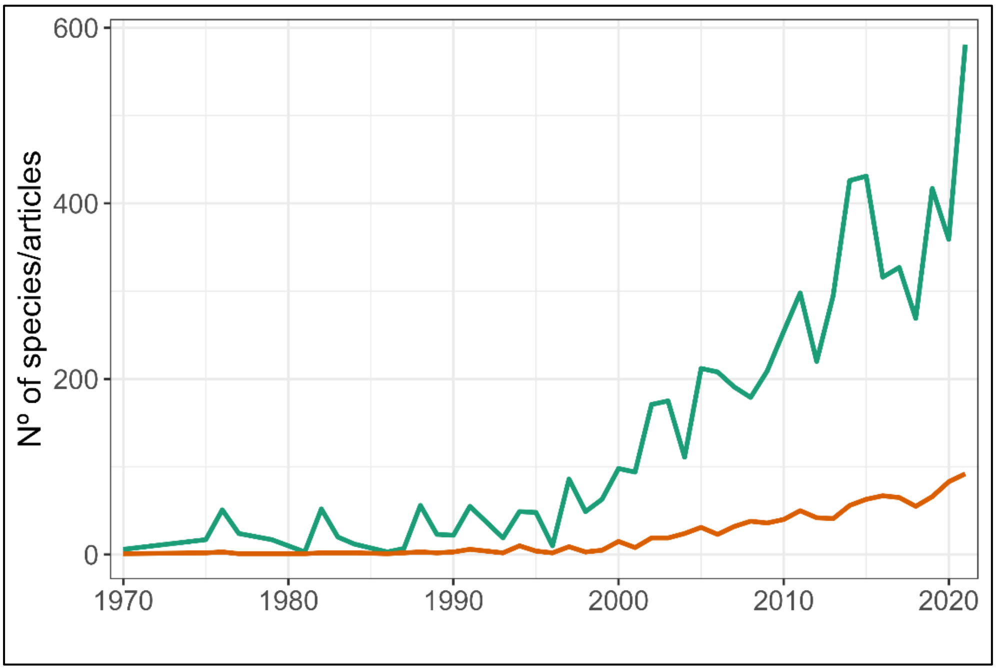

Figure 1: Number of species (green line) and publications (orange line).

Species and traits

Our results shows that at least 1,486 species from 24 orders have been used as food worldwide. The orders: Primates (286 spp, 19,2%), Chiroptera (278 spp, 18,6%), Rodentia (270 spp, 18,2%), Artiodactyla (234 spp, 16%) and Carnivore (202 spp, 13,6%) had the most bushmeat species (Table 1). These orders also had more species used as food than would be expected randomly (Table 1). At least 391 species are considered threatened (176 vulnerable, 150 endangered, and 65 critically endangered) and 114 are categorised as near threatened (Appendix 3).

Table 1: The number (Species total and observed species) of all mammals species used as bushmeat in our database (median, based on permutation test), assuming that mammal species were selected randomly.

Order	Species total	Observed species	Expected species - median	Range (min - max)
Afrosoricida	55	10	0	0 - 4
Carnivora	286	202	3	0 – 12
Cetartiodactyla	338	234	3	0 – 14
Chiroptera	1282	278	4	0 – 15
Cingulata	21	15	1	0 – 4
Dasyuromorphia	77	2	0	0 – 2
Dermoptera	2	1	1	0 – 1
Didelphimorphia	105	19	0	0 – 4
Diprotodontia	139	31	0	0 – 6
Eulipotyphla	484	30	0	0 – 5
Hyracoidea	5	5	1	1 – 3
Lagomorpha	90	22	0	0 – 4
Macroscelidea	19	5	0	0 – 3
Microbiotheria	1	0	0	0 - 0
Monotremata	5	2	0	0 – 2
Notoryctemorphia	2	0	0	0 – 0
Paucituberculata	7	0	0	0 – 0
Peramelemorphia	19	4	0	0 – 2

Perissodactyla	18	17	1	0 – 4
Pholidota	8	8	1	1 – 4
Pilosa	10	9	1	0 – 4
Primates	450	286	4	0 – 16
Proboscidea	2	2	1	1 – 2
Rodentia	2354	270	4	0 – 14
Scandentia	20	3	0	0 – 3
Sirenia	4	4	1	1 – 2
Tubulidentata	1	1	1	1 – 1

The body mass of species, the extent of their geographical occurrence, the trophic level and the threat status influence the likelihood of species be used as bushmeat (Table 2). Larger body sized species and widespread species tend to be more likely to be used as bushmeat (Table 2). Omnivore species tend to be less likely to be used as bushmeat than herbivore and carnivore species (Table 2). Critically endangered species tend to be more likely used as bushmeat than species in others threaten categories (Table 2). Species consumed as food are correlated phylogenetically ($D = 0.5273$). These results was significantly different from both phylogenetic by chance ($P < 0.0001$) and a strict Brownian motion model of evolution ($P < 0.0001$).

Table 2: Results of phylogenetic logistic regression models to test the effect of species traits on the likelihood of the mammal species are related in each conflict category.

	Estimate	Std Error	z.value	Lower CI	Upper CI	p.value
(Intercept)	-1.50019	0.102079	-4.696388	1.646141	-1.3143	< 0.0001
Body mass (g)	1.154648	0.075061	15.382759	1.047052	1.2541	**< 0.0001**
Range (Km^2)	0.924495	0.063037	14.665893	0.829252	1.046	**< 0.0001**
Herbivore	0.062315	0.114749	0.543057	-0.097669	0.2208	> 0.05

Omnivore	-0.283205	0.081441	3.477425	-0.409021	-0.1703	< **0.0001**
IUCN LC	0.785139	0.180207	4.356878	0.585133	1.1603	< **0.0001**
IUCN NT	-0.291514	0.157990	-1.845148	-0.551482	0.0182	> 0.05
IUCN VU	0.149118	0.126678	1.177149	-0.055497	0.4149	> 0.05
IUCN EN	-0.198964	0.109365	-1.819269	-0.400024	0.0283	> 0.05
IUCN CR	0.301091	0.118116	2.549103	0.065941	0.5190	< **0.0001**

Research effort

The research effort varied across mammal orders (Figure 3). Although the Primates and Chiroptera had more species used as food (Table 1), the species from Artiodactyla, Rodentia and Proboscidea orders had the higher research effort. Species from this orders were present in at least 20 articles, while the average number of studies per species as 7.2. These results shows that species these mammalian orders are more frequent in research about bushmeat/wildmeat consumption worldwide. For example, based on our results the species with higher number of publications were: *Pecari tajacu* (150, 9%), *Loxodonta africana* (130, 8%) and *Cuniculus paca* (127, 7.8%) (Appendix 3).

In relations on influence of species traits on research effort, our results shows that larger body sized species, widespread and omnivore species have more research effort (Table 3; Figure 4). We have no found effect of species threat status on research effort (Table 3; Figure 4).

Table 3: Output of the Bayesian GLMM models to test the effect of species traits on the research effort on the consumption of wild mammals as bushmeat. *pd = probability of direction.

	Estimates	Std. Error	Low CI	Upp CI	Rhat	Bulk ESS	Tail ESS	PD
(Intercept)	0.75	0.78	-0.80	2.28	1.00	6523	7511	83.33%
Body mass (g)	0.59	0.08	0.42	0.76	1.00	10883	9939	**100%**
Range (Km^2)	0.51	0.04	0.43	0.59	1.00	15180	10053	**100%**
Herbivore	0.06	0.10	-0.13	0.25	1.00	14721	10721	72.03%
Omnivore	-0.16	0.16	-0.50	0.11	1.00	14282	8931	**99.43%**
IUCN LC	-0.19	0.16	-0.50	0.11	1.00	15124	9407	88.45%
IUCN NT	-0.17	0.14	-0.44	0.11	1.00	17158	10093	89.11%
IUCN VU	0.01	0.10	-0.19	0.21	1.00	16385	9959	54.70%
IUCN EN	-0.08	0.08	-0.24	0.08	1.00	18500	8804	84.19%
IUCN CR	0.09	0.08	-0.07	0.24	1.00	19044	10238	87.32%

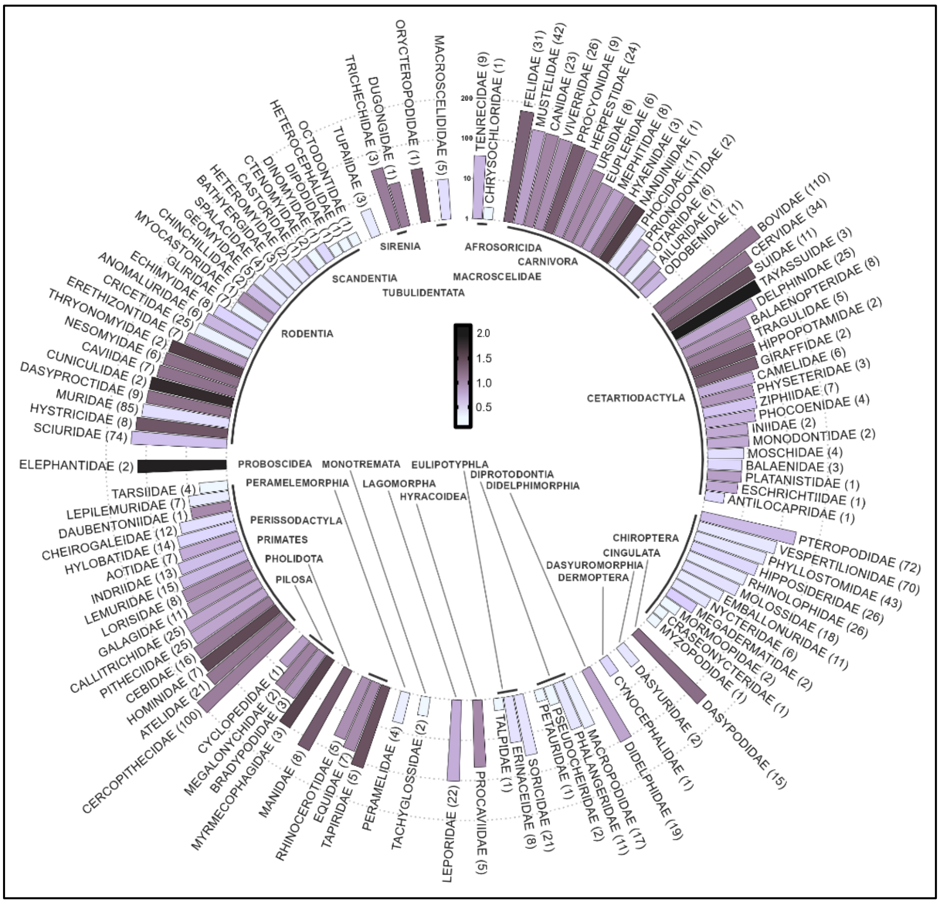

Figure 3: Research effort related to bushmeat research through mammal taxonomic families and orders. Number within brackets represents the species richness in each family. Bar height represents the total number of publications per family. Bar colour indicates the average number of articles per species within each family.

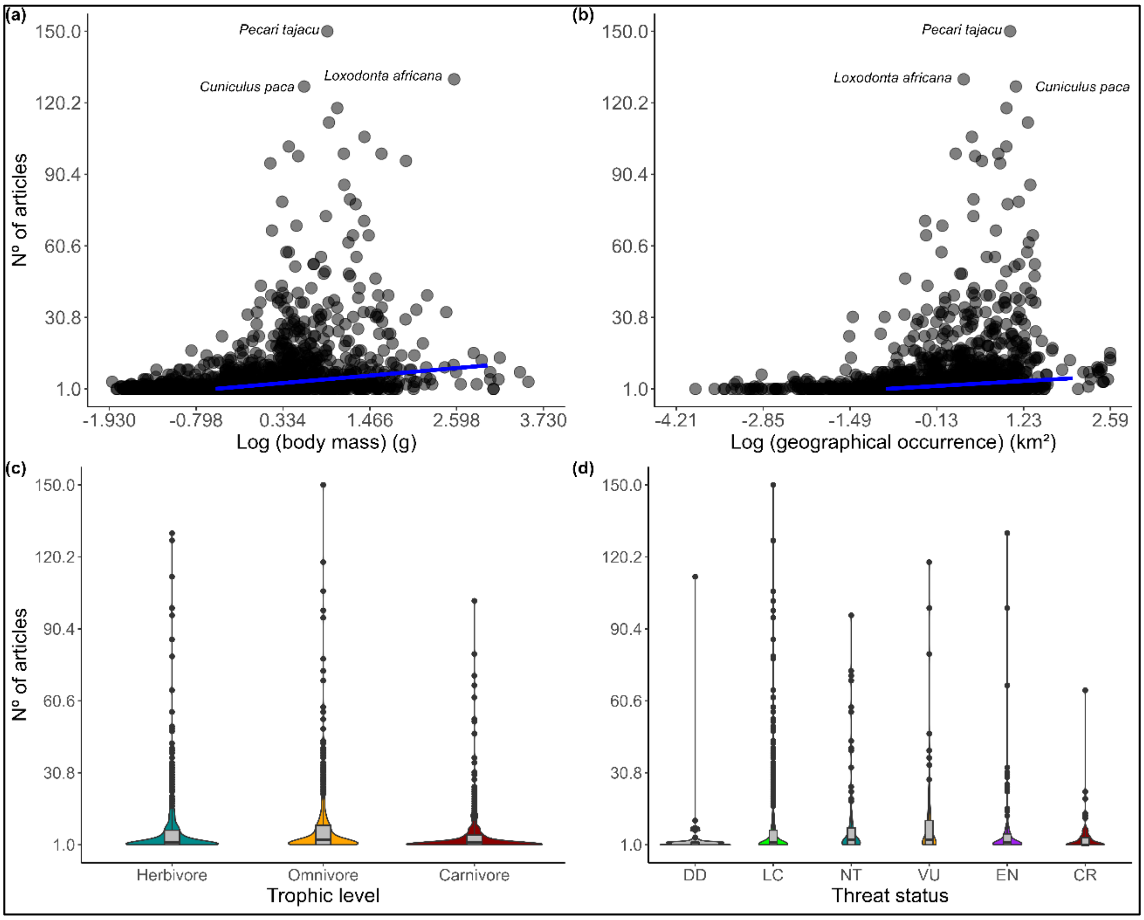

Figure 4: Influence of species traits on the bushmeat research effort as predicted by the brms models.

Geographical distributions of bushmeat consumption and research effort

The consumption of wild mammals as food is widespread, being recorded in at least 133 countries (Figure 5; Appendix 2). The countries with the highest number of mammal species used as food were: Congo, D.R (260 spp), Brazil (229 spp) and Cameroon (202 spp). The countries with the highest number of publications were: Brazil (116 studies), Peru and Tanzania (both with 57 studies) and Cameroon (52 studies). We detected a positive correlation (rho=0.87; $P < 0.0001$) (Appendix 1; Figure S2) between species diversity and the number of publications by country. Only HDI influenced the number of species by country (Table 4; Figure 6). Countries with lower lower-median HDI rates generally tend to have more species consumed as food than developed countries. We have no found support for influence of socio-political variables on research effort by country.

Table 4: Results of linear generalised models to test the effect of socio-political variables on the number of species used as bushmeat by country.

	Estimate	Std Error	z.value	Pr(>|Z|)
(Intercept)	5.115	0.05534	9.243	< 0.0001
GDP per capita	-9.780^{-06}	1.387^{-05}	-0.705	0.4806
HDI	-0.001906	8.770^{-01}	-2.174	**< 0.05**
HPD	-1.589^{-04}	1.622^{-04}	-0.980	0.3272

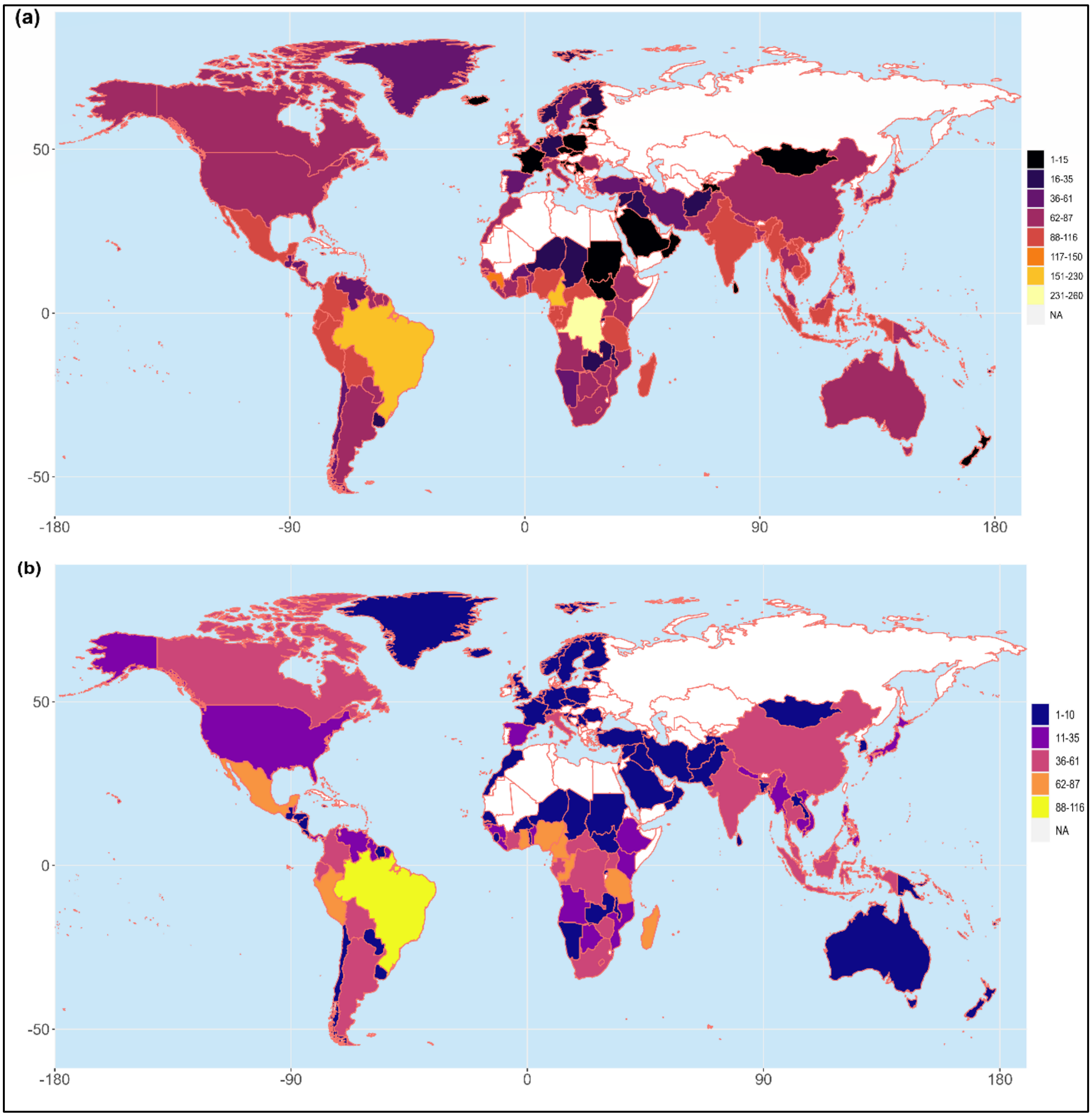

Figure 5: Global distributions of number of species (a) and research effort (b) on bushmeat consumption.

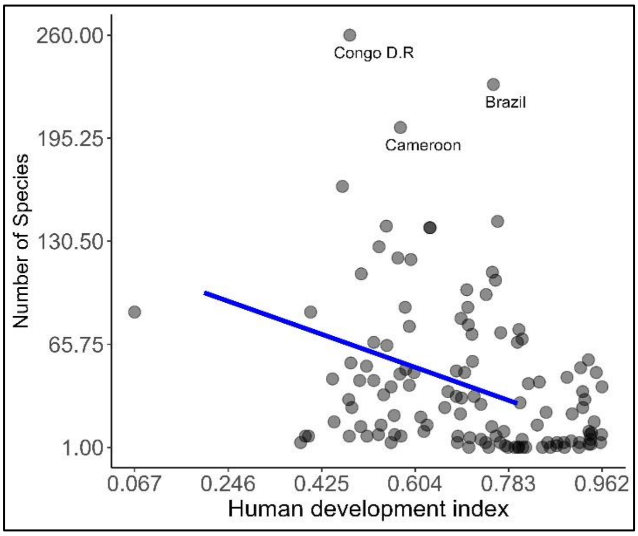

Figure 6: Influence of HDI on number of species consumed as bushmeat per country as predicted by negative binomial GLM.

Discussion

The use of wild mammals as food involves at least 22.5% (n=1,486) of living mammal species (6,611 species; Burgin et al., 2018), distributed across 24 orders. Primate, Chiroptera and Rodentia orders comprise about 56% of all species used as food in our database. These findings are aligned with those of other studies on wildlife consumption as food across the world (RIPPLE et al., 2016), indicating that a considerable number of mammal species are consumed as food worldwide. In many regions the species are used in the both communities and wildlife markets (wet markets) (LEE et al., 2020), this fact can contribute for overexploitations of the exploited species and negatively affecting their populations.

Our results shows that species used as food are grouped phylogenetically within mammal phylogenetic tree. Thus, the species used as food tend to be closely-related species within Primates, Chiroptera, Rodentia, Artiodactyla and Carnivora clades. It is no surprising once that species in these orders represents the mainly bushmeat species consumed worldwide (FA; BROWN, 2009; FA; RYAN; BELL, 2005; PERES, 2000; TANALGO et al., 2023)

Ungulates (mainly Artiodactyla), Rodents and Primates are between the mainly species hunting for bushmeat consumption worldwide (FA et al., 2009; FA; RYAN; BELL, 2005; JEROZOLIMSKI; PERES, 2003; PEREIRA et al., 2024). Between 70% and 12% of harvested biomass and consumed in local communities and bushmeat markets in West and Central Africa countries correspond to the ungulates and rodents, respectively, while no more than 20% of the species consumed as bushmeat are primates (FA; BROWN, 2009; FA; RYAN; BELL, 2005). Rodents species are widely used as food in many places of the globe (ALBRECHTSEN et al., 2007; ALVES et al., 2016; FA; BROWN, 2009; PERES, 2000), while Chiroptera species in the general are consumed in some countries of Africa and mostly in Asian countries (KAMINS et al., 2011; RANDRIANANDRIANINA; RACEY; JENKINS, 2010; TANALGO et al., 2023). Chiroptera and Rodentia species joint encompass 46.7% of the mammal’s species living (Burgin et al., 2018), this fact might justify the high number of species consumed as food.

Our results reveal that larger bodied size species (> 10kg) and species with larger extent of geographical occurrence have a greater likelihood of being used as bushmeat than smaller bodied size and narrow-range taxa. These results are aligned those found in others studies (ALVES et al., 2016; FA; BROWN, 2009; FA; RYAN; BELL, 2005). Larger species of carnivores, primates and ungulates (Artiodactyla and Perissodactyla) are more hunting for bushmeat in many countries on Africa and South America realms (FA; BROWN, 2009; FA; RYAN; BELL, 2005; PERES, 2000).

Many studies in local or regional scales (BODMER; EISENBERG; REDFORD, 1997; BRAGA-PEREIRA et al., 2021; JEROZOLIMSKI; PERES, 2003; PARRY; BARLOW; PERES, 2009) have point out that hunter´s preference is toward to the larger bodied size species, once them offer higher energetic return in comparison with smaller ones. For example, rural and indigenous communities in many places of the Amazonian Basin tend to toward the hunt effort for larger species than smaller ones (ALVARD et al., 1997; BODMER;

EISENBERG; REDFORD, 1997; PERES, 2000). Fa and Brown (2009) point out that there is a trade-off related the selection of species for bushmeat, once smaller species tend to provide more number of carcasses, while larger ones provide higher biomass in body weight. It is worth noting that in many places the absence of larger-bodied size species is results of over-exploitation, in this sense smaller-medium-bodied size species e those more available (more abundance or extremely recognizable are harvested.

Species with large extent of geographical occurrence tend to have greater home range and habitat breath (BLACKBURN et al., 1997), this might increase the likelihood of the species being hunted, once it is facilitate the recognizable of hunter on their life area in comparison with widespread species.

Regarding trophic level, our results show that omnivores have less likelihood to be used as bushmeat than carnivores and herbivores. These results are different those found by other studies investigating the bushmeat consumption across the globe (BRAGA-PEREIRA et al., 2021; FA; BROWN, 2009; PERES, 2000; RIPPLE et al., 2016). For example, herbivorous tend to be more hunted in the Congo and Amazonian basins (FA; BROWN, 2009; PERES, 2000). In the general, omnivore species tend to have more generalists habits this might facilitates the contact with human settlements and increase the likely of hunting them.

Species “Least concern” and “Critically endangered” are more likely to be used as bushmeat. The “threatened” status is perceived as rare or “prohibited” use in many places of the world (CHEN, 2016; GAULT; MEINARD; COURCHAMP, 2008). This perception might lead to high social valuation these “threatened” species and resulting in higher demand towards them (CHEN, 2016; GAULT; MEINARD; COURCHAMP, 2008). Furthermore, many species are considered a delicacy in the traditional culinary (CHABER et al., 2010; GOMBEER et al., 2020; PARRY; BARLOW; PEREIRA, 2014; VOLPATO et al., 2020), this can contributed for the selective hunting of many taxa for bushmeat consumption as pangolins and bats for example (INGRAM et al., 2018; TANALGO et al., 2023). In many Asian countries the high valuation of the traditional culinary has stimulate the overhunting of the Asian species pangolins resulting in a decreasing these species and toward the poaching for African species (INGRAM et al., 2018). In relation to the "least concern" species, they correspond to the most species in our dataset (n=856, 56.25%), this fact might increase the likelihood these species being used as food.

The research effort on bushmeat for species included in our database was focused on specific mammalian clades and species traits. Overall, although Primate and Chiroptera clades had more species used as bushmeat, Artiodactyla, Rodentia and Proboscidea clades had highest research effort. Species with larger-bodied and smaller geographical occurrence had more research effort than smaller-bodies ones and widely distributed species. In this sense the research effort is also biased for species traits. These results evidence that although small-medium bodied sized species are more likely to be used as bushmeat, most of the research effort is toward large species. Thus, our findings show how taxonomically biased is the research toward on bushmeat, and draw attention for more balanced research through mammalian orders, once these biases might impeded the complete knowledge of problem and the complexities underline the selection and used of species less iconic as bats for example. In addition, research bias on species traits emphasize for more research aiming measure the impact of the poaching on smaller species.

The consumption of wild mammals as bushmeat is widespread. Based on our results, countries with a greater number of species used as food (> 150 species) are in Africa and South America (Appendix 3). These results are consistent with other studies on bushmeat hunting and trade across the world (NIELSEN et al., 2018; RIPPLE et al., 2016; VAN VELDEN; WILSON; BIGGS, 2018). For example, Cawthorn and Hoffman (2015) point out that at least 500 and 200 species are consumed as bushmeat in Sub-Saharan Africa and Amazon tropical forests. Fa et al., (2002) estimated that approximately 148.000 tons are harvested per year in the Amazon basin with and estimates of 33 more times for the Congo basin. In addition to this, many African and South America countries shows a high diversity of mammal species (CEBALLOS; EHRLICH, 2006).

In relation to the socio-political variables, developing countries (those with lower HDI scores) have more species used as food, thus, our results confirm that countries with lower developing scores tend to consume more wild mammals species as food. These results are aligned with those found in other studies on global scale (BRASHARES et al., 2011; MILNER-GULLAND et al., 2003; NIELSEN et al., 2018), showing that developing or sub-developing countries tend to trust on wildlife species as protein source and for guarantee the minimal quantity of protein and macronutrients needs for nutritional security (CAWTHORN; HOFFMAN, 2015; SARTI et al., 2015). This also make evident how huge is the contrast in dietary needs between developing and developed countries. For example, one in four people in Sub-Saharan Africa not fulfil the amount diary of protein need for guarantee the minimal requires of food security (CAWTHORN; HOFFMAN, 2015). At other hand, approximately one billion people suffer problems related to overweight and the most of them living in developed countries (CAWTHORN; HOFFMAN, 2015).

Overall, our results show that the choice and selection of a particular species for consumption as food in not random, but influenced by the taxonomy and similar species traits, suggesting that the utilisation of mammalian species as bushmeat is phylogenetically clustered. Furthermore, our results emphasise that although the most of species used as bushmeat is concentrated in the primates, chiropteran, rodent, artiodactyl and carnivore clades, species of 24 mammalian orders are consumed.

Although there have been numerous studies on bushmeat (sustainability of harvest, subsistence, food security, commercial trade, outbreak disease) (BODMER; EISENBERG; REDFORD, 1997; CAWTHORN; HOFFMAN, 2015; LEE et al., 2020; MILNER-GULLAND; AKÇAKAYA, 2001; SARTI et al., 2015), the extent of the problems related to the consumption of bushmeat remain unclear in many places of the world (VAN-VLIET; NASI, 2020). In addition to this, the bushmeat is also used as traditional medicines (LEE et al., 2020; SOUTO et al., 2018), this might increased the demand for consumption of species already overhunting, thus, understanding the factors involved in the bushmeat consumption is critical for developing effective strategies to mitigate or reduce the impacts related to overharvest of the species hunted, as well as the risks for the human health associated with bushmeat consumption.

The studies based on species traits can help identify species which are more likely to be used as bushmeat, as well as the predict which species better support to intensive harvest levels without depletion (VAN VLIET; NASI, 2019). Moreover, the most of sustainability harvest index are based on species traits as body mass and abundancy (density) for example (CUTHBERT, 2010; MILNER-GULLAND; AKÇAKAYA, 2001; ROBINSON; BENNETT, 2000; WEINBAUM et al., 2013). The large number of species recorded in our dataset, the geographical distribution of bushmeat consumption, and the patterns associated with species traits and phylogeny make further research imperative for holistic comprehension of the factors that undermine the choice, selection and used of species as bushmeat.

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Supplementary information

Appendix 1

Table 1: Keywords used in systematic review.

Keywords	Downloaded papers
Wildlife AND "Bushmeat"	381
wildlife AND "Wild meat"	161
Wildlife AND Wildmeat	88
Wild Animals AND Bushmeat	86
Wild Animals AND Human consumption	82
Wild animals AND Subsistence	226
Wild Animals AND "Wild meat"	161
Wild Animals AND Wildmeat	34
Wild mammals AND Bushmeat	132
Wild mammals AND "Human consumption"	30
Wild mammals AND Livelihood	57
Wild mammals AND Wildmeat	8
Wild mammals AND "Wild meat"	55
Hunting AND "Human consumption"	129
Hunting AND Wildmeat	85
Hunting AND "Wild meat"	560
Hunting and Bushmeat	460
Bushmeat AND Commerce	190
Bushmeat AND Commodity	238
Bushmeat AND Commercialization	98
Bushmeat AND Defaunation	153

Bushmeat AND Ethnozoology	95
Bushmeat AND Ethnobiology	256
Bushmeat AND Extinction	783
Bushmeat AND "Illegal trade"	129
Bushmeat AND "Hunting management"	37
Bushmeat AND Luxury	75
Bushmeat AND Local Market	20
Bushmeat AND Sale	206
Bushmeat AND Seizures	56
Bushmeat AND "Socio-economic"	206
Bushmeat AND Subsistence	698
Bushmeat AND Tradition	110
Bushmeat AND "Traditional uses"	55
Bushmeat And poaching	101
Bushmeat	668
Wild meat	225
Wildmeat	85
Ethnozoology	118

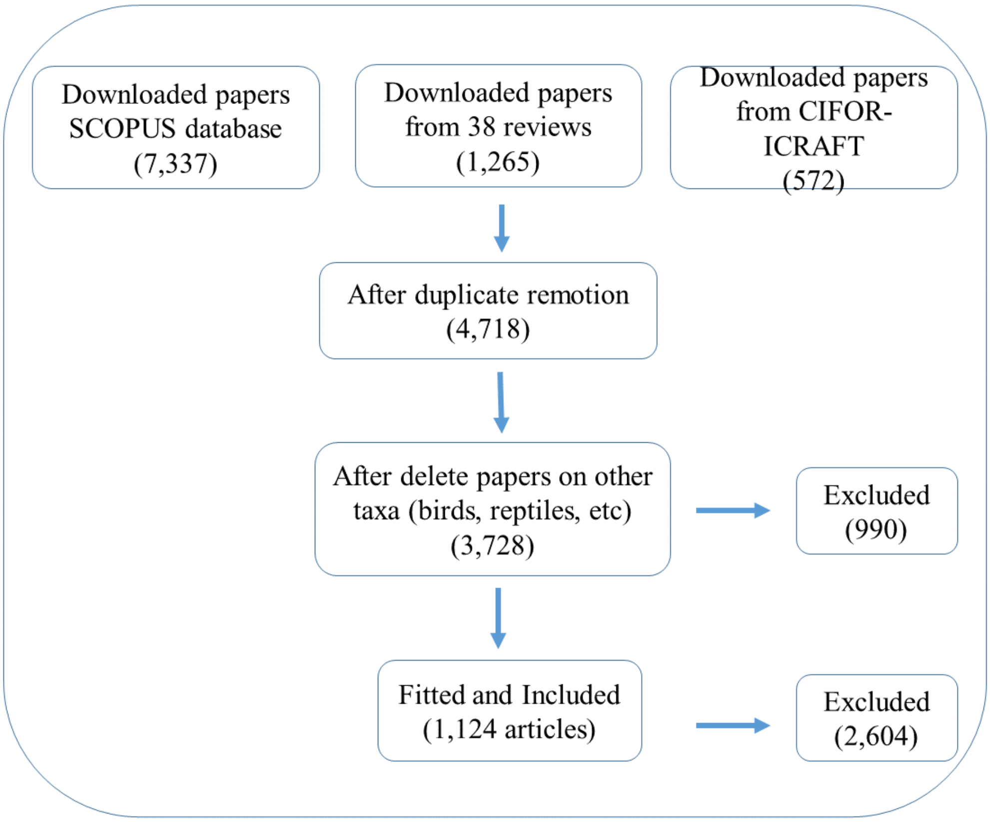

Figure 1: Flowchart of systematic review and selection of articles includes in our study.

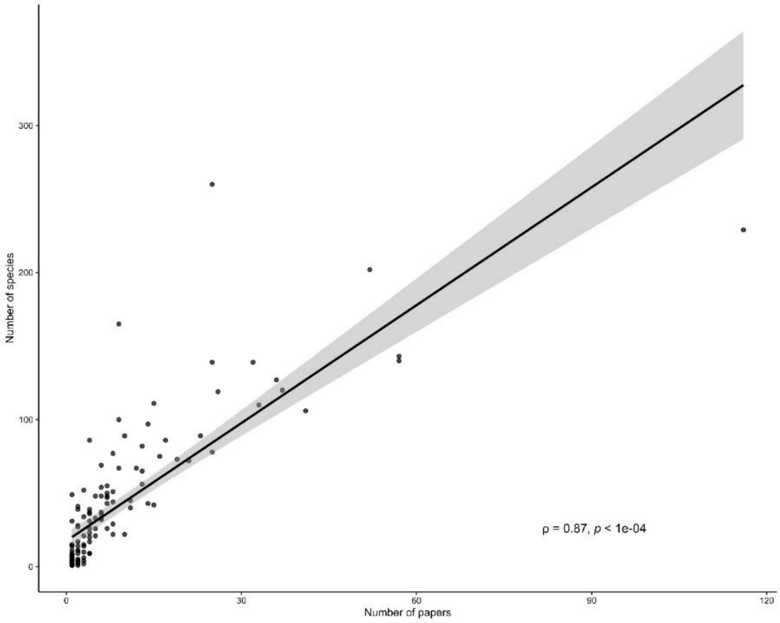

Figure 2: Plot showing the correlation among number of species and papers by country.

CAPÍTULO 4

Ecological and socio-environmental drivers of human-wild mammal conflict around the world

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Ecological and socio-environmental drivers of human-wild mammal conflict around the world

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Abstract

Human-wildlife conflicts (HWC henceforth) currently pose a significant threat to the conservation of species around the world. Here, we performed a systematic review related to HWC with a focus on wild mammals and used phylogenetic comparative methods to test: (1) if species traits influence the probability of species to be related in conflict; (2) whether closely-related species tend to be related in similar conflict categories; and (3) which and how socio-environmental variables influence research about human-wild mammal conflict around the world. Overall, at least 713 species were involved in HWC, including 160 threatened species (78 Vulnerable, 67 Endangered, and 15 Critically Endangered). Species of large-bodied size and widely distributed species are more likely to be involved in HWC around the world. Closely related species share similar conflict categories. The research effort related to human-wild mammal conflict is biased to specific mammal orders and species traits. Moreover, human-wild mammal conflicts were recorded in 125 countries, mainly in Europe, Africa and Asia. Overall, our results show high species richness involved in HWC, and emphasise the influence of species traits on conflict situations with people. These results call attention for more research towards clades/orders with low attention, since missing information is critical to design or improve mitigation and conservations measures. Furthermore, identify the species traits that are more associated with HWC is crucial for improving the effectiveness of measures aimed at mitigating or reducing the damage of HWC situations.

Keywords: species traits, evolutionary relatedness, crop damage, livestock depredation, human safety, property damage, conservation.

Introduction

Humans have interacted with wildlife since ancient times (Alves and Albuquerque, 2018; Nyhus, 2016). These interactions are complex and can have positive or/and negative feedbacks for interacting parties (Baynham-Herd et al., 2018; Nyhus, 2016). Many species are used to ensure human subsistence, traditional practices and well-being (Alves, 2012), for example, as food, materials for the production of tools, jewellery, medicines, fertiliser, as well as for agricultural, transport, entertainment, companionship and religious services (Alves and Albuquerque, 2018). At the same time, many species, including beneficial ones, can be perceived negatively since they may damage agricultural crops (Hill, 2018; Hoare, 2012; Stenseth et al., 2003; Torres et al., 2018), prey on or compete with livestock and domestic animals for space and/or resources (Nyhus, 2016; Torres et al., 2018; Treves and Karanth, 2003), and threaten the integrity of endeavours and human safety (Pagany, 2020; Peterson et al., 2010; Vercauteren et al., 2006). These negative perceptions may lead to conflict situations with people (Nyhus, 2016; Peterson et al., 2010).

Human-wildlife conflict (HWC hereafter) occurs when wildlife is perceived as a threat or directly affects the needs, welfare and livelihoods of humans (Baynham-Herd et al., 2018; Nyhus, 2016; Redpath et al., 2013; Torres et al., 2018). Wild mammals are among the most important vertebrate groups involved in conflicts with humans' worldwide (Torres et al., 2018). Many species of wild mammals regularly cause hundreds of millions US$ of economic damage worldwide through agricultural damage (Nyhus, 2016; Stenseth et al., 2003), livestock depredation (Braczkowski et al., 2023) and fatalities associated with road traffic collisions (Martin et al., 2020). It is worth noting that, wild animals´ contributions to peoples´ lives can also reach hundreds of millions of dollars annually (Chaplin-Kramer et al., 2025; Lee et al., 2020), by the direct consumption of species (e.g., bushmeat and wildlife trade) (Lee et al., 2020; Scheffers et al., 2019), cultural ecosystem services (e.g., ecotourism) (Chaplin-Kramer et al.,

2025) and invaluable ecosystems services (Chaplin-Kramer et al., 2025; Dee et al., 2017; Díaz et al., 2018).

There is currently considerable research effort investigating the factors underlying HWC situations (Holland et al., 2018; Kansky et al., 2014; Lozano et al., 2019; Nyhus, 2016; Seoraj-Pillai and Pillay, 2017; Torres et al., 2018; Venumière-Lefebvre et al., 2022), and the research output has grown exponentially (Nyhus, 2016; Su et al., 2022). However, understanding the factors that influence the likelihood of a species coming into conflict with humans is a complex task, as HWC encompasses a complex array of biological, socioeconomic, cultural, political and institutional factors, and involves a variety of participants and species (Baynham-Herd et al., 2018; Nyhus, 2016; Redpath et al., 2013; Torres et al., 2018).

The relationships between species traits and HWC have rarely been studied and most research efforts to date have focussed on specific mammalian groups, such as carnivorans (Holland et al., 2018; Lozano et al., 2019; Peterson et al., 2010; Su et al., 2022; Venumière-Lefebvre et al., 2022) and proboscideans (Di Minin et al., 2021; Hoare, 2012; Kansky et al., 2014; Su et al., 2022), as well as on certain types of HWC (i.e. livestock depredation and crop damage) (Di Minin et al., 2021; Kansky et al., 2014; Nyhus, 2016; Torres et al., 2018). These studies suggest that species composition in the context of HWC research is influenced by species traits (e.g., body mass, home range, trophic level and threat status) (Lozano et al., 2019; Ugarte et al., 2019; Venumière-Lefebvre et al., 2022). Overall, larger, carnivorous and threatened species tend to be studied more intensively than smaller, herbivorous and non-threatened species (Venumière-Lefebvre et al., 2022). However, it is unclear whether species traits can be used to recognise patterns related to factors underlying HWC. This information is crucial to clarify the ecological mechanisms underlying wildlife damage and to improve the effectiveness of policies aimed at reducing or mitigating HWC and improving conservation measures for species threatened by HWC.

In addition to species traits, previous research suggests that socio-environmental factors also influence on HWC trends (Su et al., 2022; Venumière-Lefebvre et al., 2022). For example, developed countries (with higher gross domestic product (GPD) and Human Development Index (HDI)) tend to exert greater pressure on biodiversity through consumption of natural resources and commodities than developing countries (Estrada et al., 2019; Otero et al., 2020; Ribeiro et al., 2022). In addition, the number of people in a given region (human population density (HPD)) is associated with population decline and the extinction of wild species (i.e. due to competition with livestock or abusive and unsustainable harvesting) (Cardillo et al., 2005, 2004; Estrada et al., 2019). Therefore, countries with higher HPD tend to have more conflicts with wildlife (Cardillo et al., 2004; Estrada et al., 2019; Venumière-Lefebvre et al., 2022).

Additionally, a country´s area may also be an important variable associated with HWC, as larger countries often encompass greater diversity of habitats, which can harbour a higher diversity of species (Baldi, 2020; Gaston and Blackburn, 2007; Lucas and Kebreab, 2025; Oertli et al., 2002). It is worth noting that, a greater diversity of species can increase the range of species interacting with humans, leading to potential conflicts or intensifying them (Estrada et al., 2019; Khan et al., 2024; Soulsbury and White, 2015).

It is important to know which factors and how they influence human-wild mammal conflict to design and/or improve measures that reduce the risk and perception of conflicts for humans, as well as for the populations of the species concerned. Using information from the literature, we compiled a global database of wild mammals involved in HWC to answer the following questions: 1) How many and which wild mammal species are involved in HWC worldwide? 2) How do species' traits and evolutionary relatedness influence HWC?; 3) Is HWC research biased?; 4) Which countries are involved in HWC?; and 5) What socio-political variables influence HWC worldwide and how? We focused on five categories of conflict: crop damage, livestock depredation, human security, property damage, and competition with livestock (Lozano et al., 2019; Peterson et al., 2010; Torres et al., 2018).

Based on the above information, we predict that: (1) large-bodied and geographically widespread species will have a higher likelihood of being involved to the HWC in all five categories we analysed. These species traits are associated with an increased likelihood of contact with humans (e.g., crop foraging events, attacks on people and preying on livestock) (Nyhus, 2016; Ugarte et al., 2019; Venumière-Lefebvre et al., 2022). In terms of trophic level, we predict that carnivores and omnivores are more likely to prey on livestock and threaten human safety; herbivores and omnivores are more likely to cause crop damage and jeopardise human endeavours, as well as compete with livestock. (2) We also predict that closely-related species in each conflict category will be more likely to be related in conflict, as they share ecological traits; and (3) countries with greater mammal diversity, larger country area, higher GDP, HPD, and HDI will have more conflict records. These variables are often associated with the greater pressure on natural resources due to deforestation, loss of natural habitats and higher demand for natural resources (Estrada et al., 2019; Otero et al., 2020; Su et al., 2022).

Methods

Data collection

We conducted a systematic search of the Scopus database for articles (excluding dissertations, theses, book chapters, and unpublished reports) related to mammals involved in conflict with human populations using a combination of keywords in English (Appendix 1; Table S1, Figure S1). We focused on Scopus because it is among the largest sources to perform systematic searches and reviews, encompassing higher scientific journals coverage than other sources, such as Web of Science (Guedes et al., 2023; Jiao et al., 2023; Martín and Martín et al., 2021; Mongeon and Paul-Hus, 2016; Singh et al., 2021). Review articles were not compiled in our database, as they are compilations of secondary data (obtained from another papers or sources published), but they were used as additional sources for papers. We used the ROSES protocol for systematic review (Appendix 1; Figure S1) (Haddaway et al., 2018). The dataset was compiled between January and June 2021. Only papers related to HWC that provide species-level taxonomic identification were selected for further full text screening, resulting in 2,212 research articles. The information was compiled into a comprehensive global database including the following information: species name, type of conflict (threat human safety, crop/agricultural damage, livestock (cattle, goat, and chicken) depredation, property damage (infrastructure, tools, and endeavours – automobile), and competition with domestic animals and livestock, area (rural and urban, aquatic/terrestrial), country, and publication year.

Species traits and phylogenetic data

Adult body mass data were taken from the Phylacine, PanTHERIA, and COMBINE databases (Faurby et al., 2018; Jones et al., 2009; Soria et al., 2021). Extent-of-occurrence and threat status data were obtained from IUCN (2023). Trophic level were taken from the COMBINE and Mammal Diet databases (Kissling et al., 2014; Soria et al., 2021). We used the consensus full sample tree for mammals from Upham et al. (2019), which includes 5,804 extant species and 107 recently extinct species. We pruned the phylogeny to contain only extant species, resulting in a phylogeny with 5,804 species. Species nomenclature followed Burgin et al. (2018).

Socio-environmental variables

Gross Domestic Product per capita (GDP per capita), Human Population Density (HPD), and Country area (Km^2) for each country (values refereed to 2020´s) were obtained from the World Bank database (databank.worldbank.org). These indices represent the economic output divided by its population; the number of people per square kilometre; and the size of country´s, which encompassing the total area, including areas under inland bodies of water and some coastal waterways. These variables were used as proxies for economic development, natural resource consumption, and higher diversity of species (Estrada et al., 2019; Otero et al., 2020; Su et al., 2022).

The Human Development Index (HDI) was taken from the UN Human Development Reports (HDR, UNPD, retrieved on 10.05.2023). This index reflects the average performance of key dimensions of human development by country based on income, health, and education rates.

The diversity of mammal species (number of species within country´s boundaries) was taken from the World Rainforests (https://worldrainforests.com/03mammals.htm/ retrieved on 10.06.2025). This variable is based on data from the Mammal Diversity Database of the American Society of Mammalogists (ASM).

Statistical analysis

To test whether there are differences between the observed number of species involved in each conflict category (crop damage, livestock depredation, human safety, property damage and livestock competition) per mammalian order and the number that would be expected if species were randomly involved in HWC, we used a permutation test. In this analysis, *S* species were randomly selected without replacement in each order. *S* is the number of mammal species involved in conflict with humans in each conflict category present in our dataset and matching with phylogeny (S = 708 for general conflict (sum of all conflict categories) – Table S2 for all categories of conflict; *Bubalus bubalis*, *Grammomys gazellae*, *Ovis vignei*, *Pongo tapanuliensis*, and *Presbytis aygula*, were not present in the phylogeny and were removed from this analysis. *Loxodonta africana* and *L. cyclotis* were the both classified as *L. africana*). This process generated 100,000 lists of randomly selected species. The observed number of species from a mammal order related to the conflict was judged to be significant if the randomly derived values in each order were higher than those observed (i.e. if 99.95% of the 100,000 random lists contained more species from that order). The significance level was adjusted by sequential Bonferroni correction for multiple comparisons (critical value of a/n = 0.0018; where a = 0.05 and n = 26 (the number of mammalian orders in our dataset)).

Next, to test whether species traits (log body mass, log extent of occurrence, and trophic level) influence the probability of a species being involved in each conflict category (binary response variable; presence or absence in each conflict category), we fitted five independent (one for each conflict category – crop damage, livestock fatalities, human safety, property damage, and livestock competition) phylogenetic logistic regression models (PGLM) (Ives and Garland, 2010). We fitted a full model with all species (n = 5.278 species) for which there were not missing data in all exploratory variables. This analysis was performed using the phyloglm function in the phylolm package of the R program (Ives and Garland, 2010). Residual diagnostics were assessed using diagnostic plots.

Next, to check whether research effort (number of publications) is skewed for mammal traits (log body mass, log extent of occurrence, trophic level, and threat status), we fitted generalised linear mixed models with negative binomial error distribution (GLMM) using Markov chain Monte Carlo (MCMC) estimation implemented in the brms package (Bürkner, 2021). We fitted a full model with all species recorded in our dataset related to HWC and for which there were not missing data in exploratory variables for each conflict category. Therefore, the number of species in each model was follow: conflict (n = 700), crop damage (n = 588), livestock fatalities (n = 210), human safety (n = 112), property damage (n = 88) and livestock competition (n = 86). We used four Markov chains with 4,000 iterations in each brms model, sampling every one iteration and discarding the first 1,000 as warm-up. As priors, we used a student (3, 0, 2.5) prior for matrices **R** and **G**. The models' diagnosis was performed through a visual check of density and trace plots of fixed effects. We used Rhat (potential scale reduction values) values equal or below of 1.02 as a parameter for good convergence models.

Next, we computed the probability of direction (pd) to assess the effect of each species traits on the research effort. The values indicate the certainty of the direction of an effect, thus pd - values were considered as being significant when the likelihood of an effect in certain direction was over 95%.

For all models trophic level was treated as ordinal variable with three levels respectively (Herbivore < Omnivore < Carnivore). Threat status categories were converted to numbers (DD = 1, LC = 2, NT = 3, VU = 4, EN = 5, CR = 6) and then treated as discrete variable. The inverse phylogenetic distance matrix, represented by a variance-covariance matrix (VCV – derived from the phylogeny) was used to account for phylogenetic relationship between species due to shared ancestry. All numeric exploratory variables were log transformed and z-transformed to allow comparisons of effect sizes.

We tested the phylogenetic signal for non-randomness in each conflict category using Fritz's *D* (Fritz and Purvis, 2010). This is a measure of phylogenetic signal for binary traits (1 = in conflicting; 0 = not conflicting) and was applied herein to test whether species involved in conflict with humans tend to be closely-related species. Fritz's *D* can be interpreted as follows: $D = 1$ corresponds to a random distribution of conflict; $D = 0$ indicates that conflicting species are phylogenetically clumped; $D > 1$ indicates phylogenetic overdispersion; and $D < 1$ indicates that species involved in conflict are more clustered than expected (strong phylogenetic signal), and suggests that closely-related species tend to be in [similar] conflicting situations with humans. These analyses were performed in the caper package of the R program (Orme et al., 2018).

To test whether socio-political variables (Country area, Mammal diversity, GDP, HDI, and HPD) influence the records of conflict (number of publications) in each conflict category per country we fit six generalised linear mixed models. We considered country as a random variable. All exploratory variables were log transformed (except HDI) and z-transformed to allow comparisons of effect sizes. This analysis was performed in the glmmTMB package of the R program (Brooks et al., 2017). Residual diagnostics were assessed using diagnostic plots in the DHARMa package of the R program (Hartig, 2022).

Results

General aspects

We found 2,212 publications on wild mammals involved in conflicts with humans (Appendix 1; Figure S1), with 46 publication per year on average between 1976 and 2020. The number of publications on HWC increased in number since 2000s, particularly regarding crop damage (105%), livestock depredation (102%), and human safety (95%) (Figure 1a). Most publications (taking into account all conflicting categories) were concentrated in Asia (28%), Africa (25%) and North America (20%) (Figure 1b – 1c).

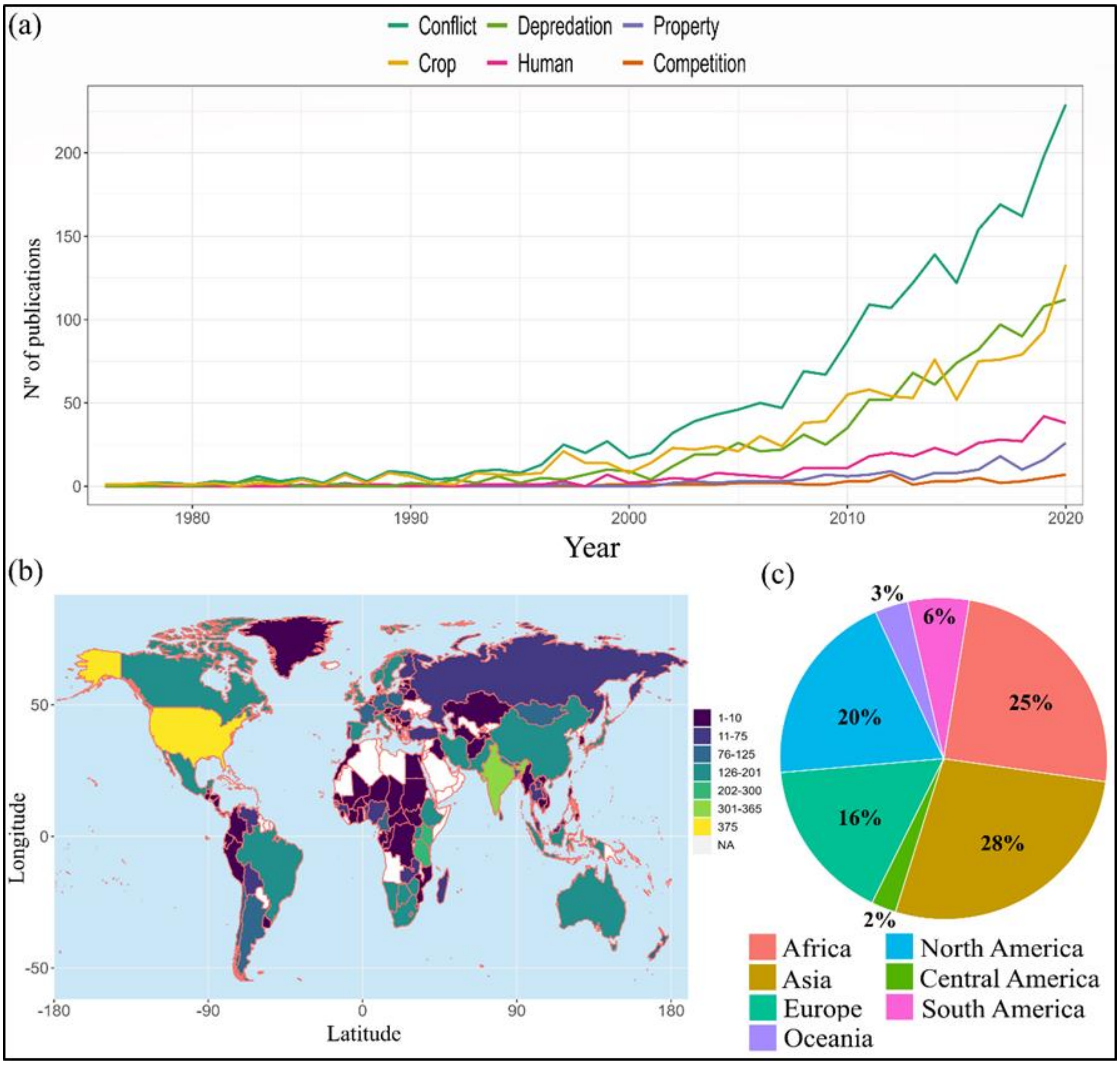

Figure 1: Number of records by conflict category over time (1976 – 2020) (a), number of publications related to the HWC by country (b), and continent (c). Conflict (green line) is a sum of all conflict categories.

Species and traits

Our review shows that at least 713 species from 19 orders were involved in conflicts with humans (Figure 2; Appendix 2). The orders with the most species involved in conflict – considering all conflict categories - were Rodentia (216, 30%), Carnivora (164, 23%), Artiodactyla (112, 16%), and Primates (95, 13%) (Appendix 1; Table S2). These mammalian orders also had more species involved in each conflict category than would be expected by chance (Appendix 1; Table S2). Other mammalian orders with more species in HWC than would be expected randomly were: Chiroptera (27, 4%), Lagomorpha (21, 3%), Eulipotyphla (15, 2.1%), and Diprotodontia (11, 1.5%).

The number of species differed by conflict category (Appendix 1; Table S2). Crop damage and livestock depredation were the categories with higher number of species (595 and 211 species, respectively; Appendix 1; Table S2). At least 160 species are considered threatened (78 Vulnerable, 67 Endangered, and 15 Critically Endangered) and 54 are categorised as near threatened (Appendix 2).

The body mass of species, the extent of their occurrence and the trophic level influence the likelihood of species coming into conflict with humans (Table 1; Appendix 1; Figure S2). Large-bodied and widespread species tend to be more likely to cause crop damage, prey on livestock and pets, jeopardise human safety, cause damage to property and materials goods, and compete with livestock or domestic animals (Table 1; Appendix 1; Figure S2). In relation to the trophic level, herbivores are less likely to be involved in conflict in the general, cause damage to crops and livestock fatalities. (Table 1; Appendix 1; Figure S2). Omnivores are less likely to be involved in conflict in the general, cause damage to crops and property, as well as cause livestock fatalities (Table 1; Appendix 1; Figure S2). Species involved in conflicts with humans are grouped phylogenetically in all five conflict categories (Figure 3; Appendix 1; Table S3).

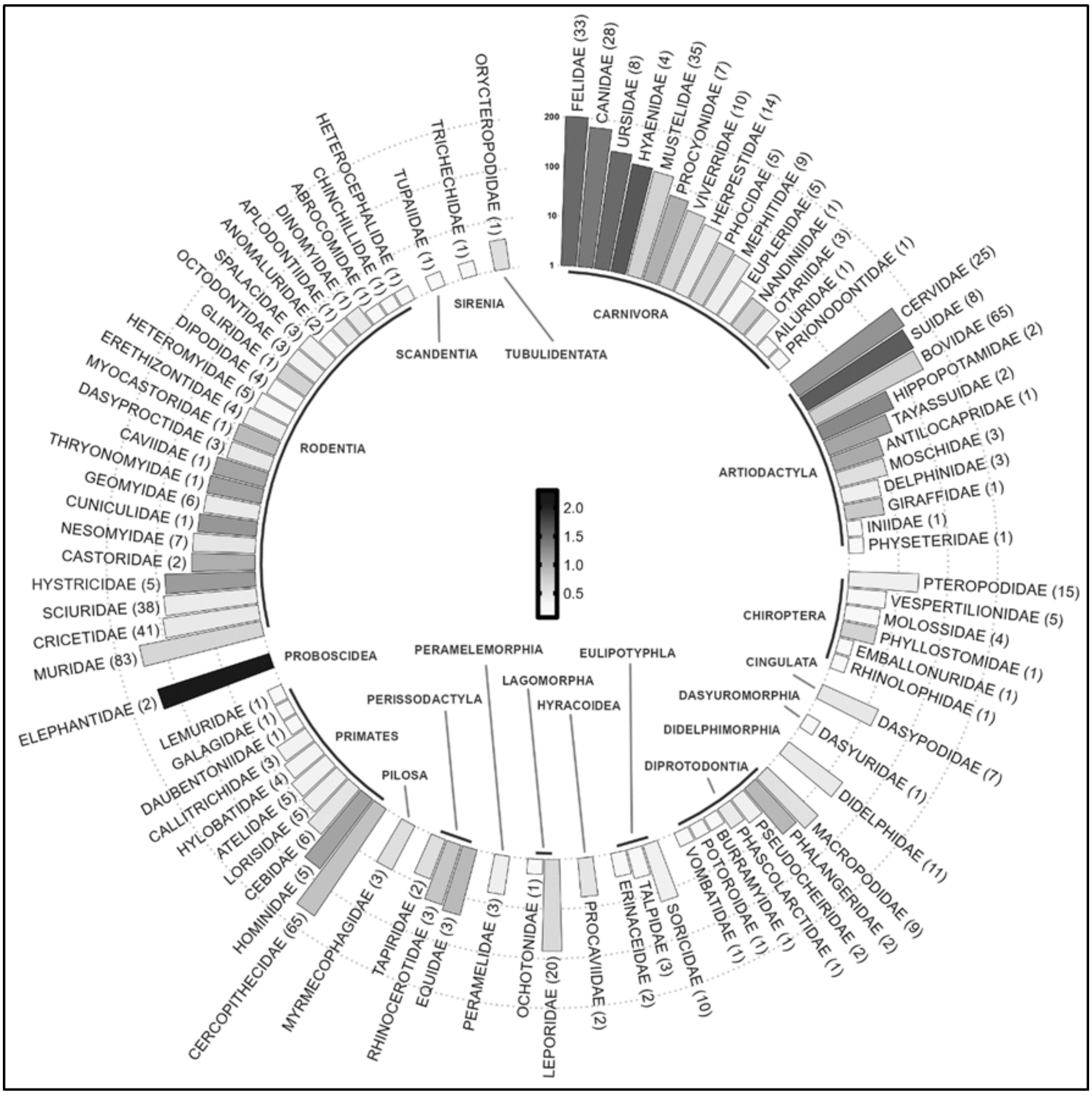

Figure 2: Research effort related to HWC considering all conflict categories across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

Table 1: Results of phylogenetic logistic regression models to test the effect of species traits on the likelihood of the mammal species are related in each conflict category. Bold values for $P < 0.05$.

	Estimate	Est. Error	z.value	CI (95%)	P - value
Conflict – R^2 = 0.341					
Intercept	-1.679457	0.190859	-8.799445	[-1.82; -1.46]	< **0.0001**
Log body mass	0.587862	0.078408	7.497450	[0.52; 0.46]	< **0.0001**
Log range	0.457462	0.044215	10.346200	[0.39; 0.51]	< **0.0001**
Trophic level (Linear)	-1.099037	0.135681	-8.100181	[-1.24; -0.90]	< **0.0001**
Trophic level (Quadratic)	-0.572391	0.083659	-6.841959	[-0.67; -0.45]	< **0.0001**
Crop damage – R^2 = 0.307					
Intercept	-3.023265	0.108980	-27.741466	[-3.21; -2.87]	< **0.0001**
Log body mass	0.669648	0.059007	11.348573	[0.55; 0.76]	< **0.0001**
Log range	1.029437	0.079426	12.960909	[0.85; 1.16]	< **0.0001**
Trophic level (Linear)	-1.252948	0.150723	-8.312938	[-1.49; -0.90]	< **0.0001**
Trophic level (Quadratic)	-0.661797	0.109121	-6.064791	[-0.84; -0.44]	< **0.0001**
Livestock depredation – R^2 = 0.500					
Intercept	-4.41954	0.30094	-14.68588	[-4.76; -3.22]	< **0.0001**
Log body mass	0.77694	0.11350	6.84529	[0.44; 0.94]	< **0.0001**
Log range	0.76834	0.14073	5.45954	[0.47; 0.91]	< **0.0001**
Trophic level (Linear)	-0.56581	0.27535	-2.05490	[-0.99; -0.007]	< **0.05**
Trophic level (Quadratic)	-0.87503	0.19055	-4.59209	[-1.20; -0.36]	< **0.0001**
Human safety – R^2 = 0.303					
Intercept	-2.754289	0.411956	-6.685885	[-3.31; -2.21]	< **0.0001**
Log body mass	0.448171	0.117611	3.810611	[0.32; 0.58]	< **0.0001**
Log range	0.328989	0.058102	5.662301	[0.21; 0.46]	< **0.0001**
Trophic level (Linear)	0.082084	0.133841	0.613297	[-0.07; 0.25]	0.5396
Trophic level (Quadratic)	0.056204	0.089257	0.629689	[-0.05; 0.19]	0.5288
Property damage – R^2 = 0.287					
Intercept	-2.591764	0.439084	-5.902663	[-4.82; -0.80]	< **0.0001**
Log body mass	0.433173	0.102474	4.227166	[0.12; 0.72]	< **0.0001**
Log range	0.146843	0.037980	3.866364	[0.03; 0.29]	< **0.0001**
Trophic level (Linear)	-0.037864	0.104156	-0.363532	[-0.37; 0.14]	0.7162
Trophic level (Quadratic)	-0.160437	0.069394	-2.311968	[-0.46; -0.002]	< **0.05**
Livestock competition – R^2 = 0.378					

Intercept	-3.073338	0.340635	-9.022392	[-3.94; -1.64]	< **0.0001**
Log body mass	0.604245	0.092162	6.556367	[0.23; 0.87]	< **0.0001**
Log range	0.227531	0.044859	5.072108	[0.07; 0.38]	< **0.0001**
Trophic level (Linear)	-0.158527	0.087183	-1.818323	[-0.47; 0.08]	0.0690
Trophic level (Quadratic)	0.104636	0.066015	1.585037	[-0.08; 0.32]	0.1129

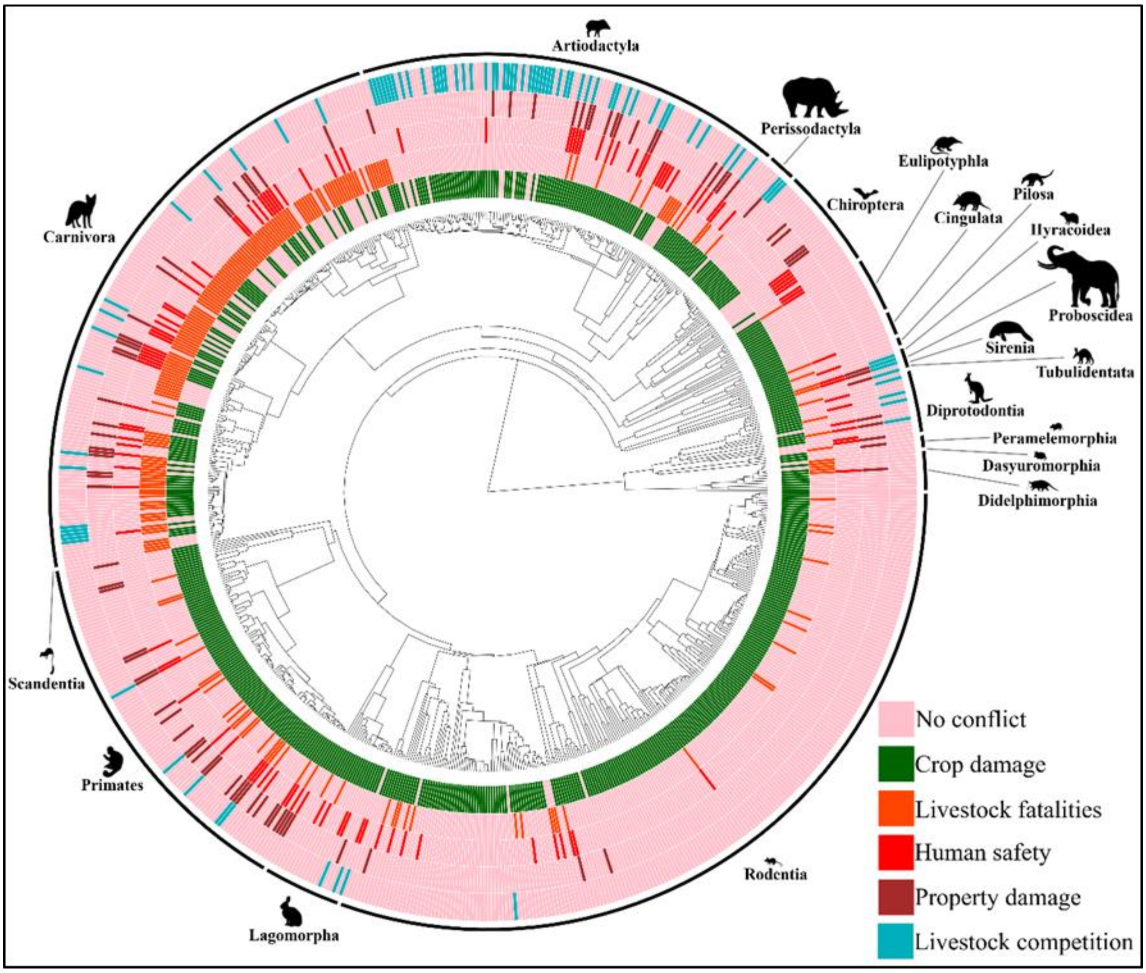

Figure 3: Phylogenetic tree of mammal species involved in conflicts with people. Each species in conflict is indicated in legend colour.

Research effort

In general, the research effort varied across mammal orders and conflicting categories. The carnivora, artiodactyla, primates, and rodentia orders had more species in HWC research (mean = 8.3 articles per species), while the average number of studies per specie was 2.4. These results indicate that research efforts on HWC are mainly focused on the abovementioned mammal orders (Figure 2). Although more species were represented in conflict research in these orders, the Proboscidea order had the higher average number of research efforts in four conflict categories, with the exception of livestock depredation (Appendix 1 – Figures S3-S7).

There were changes in species and orders involved in each individual conflict category (Appendix 1; Table S2; Figures S3-S7). For example, rodents (Rodentia) had the higher number of species for crop damage, while proboscideans (Proboscidea), even-toed ungulates (Artiodactyla), and Carnivora had more research effort (Appendix 1 – Figure S3). In terms of livestock depredation, carnivora, primates and rodents had a higher number of species (Appendix 1; Table S2), while only carnivora had a higher research effort (Appendix 1 – Figure S4). In terms of human safety, damage to property and livestock competition, carnivora and even-toed ungulates had higher number of species in all three-conflict categories, while the proboscideans species had higher research effort (Appendix 1 – Figures S5-S7).

The species trait influences the research effort, and in this sense, larger species have a higher research effort in all conflict categories (Table 2; Appendix 1; Figure S8). Species with a larger geographic range had higher research effort in two conflict categories: crop damage and livestock fatalities (Table 2; Appendix 1; Figure S8). Carnivores have a higher research effort in relation to human safety (Table 2; Appendix 1; Figure S8). We have no found effect of threat status on research effort (Table 2; Appendix 1; Figure S8).

Table 2: Output of the Bayesian GLMM models to test the effect of species traits on the research effort of mammal species in each conflict category. *PD = probability of direction (bold values for PD < 0.05). ^{c} = conditional, ^{m} = marginal.

	Estimates	Est. Error	CI (95%)	Rhat	PD – MPE (%)
Conflict - $R^2 = 0.139^m/0.315^c$					
Intercept	2.29	1.84	[0.40 – 13.74]	1.00	82.6

Log body mass	2.66	0.29	[2.14 – 3.28]	1.00	**100**
Log range	1.63	0.08	[1.47 – 1.80]	1.00	**100**
Trophic level (Linear)	1.18	0.17	[0.89 – 1.57]	1.00	87.2
Trophic level (Quadratic)	1.02	0.10	[0.85 – 1.22]	1.00	59.2
IUCN status	0.93	0.04	[0.85 – 1.01]	1.00	96.2
Crop damage - $R^2 = 0.036^m/0.318^c$					
Intercept	1.99	1.29	[0.51 – 7.75]	1.00	84.03
Log body mass	1.96	0.21	[1.59 – 2.41]	1.00	**100**
Log range	1.63	0.09	[1.47 – 1.81]	1.00	**100**
Trophic level (Linear)	0.86	0.13	[0.64 – 1.17]	1.00	83.03
Trophic level (Quadratic)	0.88	0.09	[0.72 – 1.08]	1.00	89.2
IUCN status	0.92	0.04	[0.84 – 1.01]	1.00	96.03
Livestock fatalities - $R^2 = 0.171^m/0.334^c$					
Intercept	1.87	1.72	[0.21 – 16.04]	1.00	72.3
Log body mass	2.91	0.42	[2.18 – 3.89]	1.00	**100**
Log range	1.34	0.12	[1.12 – 1.61]	1.00	**99.9**
Trophic level (Linear)	1.54	0.45	[0.86 – 2.73]	1.00	92.7
Trophic level (Quadratic)	0.96	0.18	[0.66 – 1.38]	1.00	59.5
IUCN status	1.00	0.09	[0.84 – 1.20]	1.00	51.8
Human safety - $R^2 = 0.223^m/0.432^c$					
Intercept	2.94	1.18	[0.99 – 6.69]	1.00	97.4
Log body mass	2.96	0.45	[2.17 – 3.99]	1.00	**100**
Log range	1.16	0.13	[0.93 – 1.43]	1.00	90.6
Trophic level (Linear)	2.03	0.52	[1.17 – 3.31]	1.00	**99.3**
Trophic level (Quadratic)	1.15	0.23	[0.76 – 1.71]	1.00	74.8
IUCN status	0.88	0.09	[0.72 – 1.07]	1.00	90.5
Property damage - $R^2 = 0.093^m/0.752^c$					
Intercept	1.70	0.73	[0.60 – 4.08]	1.00	86.2
Log body mass	1.72	0.25	[1.27 – 2.25]	1.00	**99.9**
Log range	1.07	0.11	[0.87 – 1.32]	1.00	73.8
Trophic level (Linear)	0.88	0.22	[0.54 – 1.48]	1.00	69.9
Trophic level (Quadratic)	0.92	0.17	[0.64 – 1.34]	1.00	66.5
IUCN status	0.89	0.09	[0.73 – 1.08]	1.00	88.9
Livestock competition - $R^2 = 0.290^m/0.305^c$					
Intercept	1.51	0.27	[0.95 – 2.32]	1.00	96.5
Log body mass	1.37	0.13	[1.13 – 1.64]	1.00	**99.9**

Log range	1.15	0.11	[0.95 – 1.41]	1.00	93.2
Trophic level (Linear)	0.80	0.18	[0.49 – 1.23]	1.00	85.08
Trophic level (Quadratic)	0.91	0.21	[0.59 – 1.43]	1.00	66.4
IUCN status	0.91	0.08	[0.77 – 1.07]	1.00	87.7

Taking all conflict categories into account, the species with higher number of publications (> 100 publications; Appendix 2) were: *Ursus arctos* (101/5% publications), *Crocuta crocuta* (106/5%), *Puma concolor* (110/5%), *Loxodonta africana* (139/6.3%), *Panthera leo* (161/7.3%), *Sus scrofa* (235/11%), *P. pardus* (241/11%), and *Canis lupus* (279/13%). In terms of crop damage, the species with higher number of publications (> 90 publications) were: *Elephas. maximus* (90/8%), *Loxodonta africana* (129/11%), and *Sus scrofa* (209/18%). For livestock fatalities, the species with higher number of publications (> 80 publications) were: *P. tigris* (85/8%), *C. crocuta, P. concolor* (103/10%), *P. leo* (154/14.3%), *P. pardus* (232/22%), and *C. lupus* (272/25.3%). In relation to the human safety, the species with higher number of publications (> 40 publications) were: *P. tigris* (40/11.3%), *E. maximus* (43/12.2%), and *P. pardus* (47/13.3%). In terms of property damage and competition with livestock, the species with the most number of publications (> 10 and 5 publications, respectively) were: *S. scrofa* (12/8%), *E. maximus* (28/18.3%), and *L. Africana* (32/21%) for damage to property; and *S. scrofa* (6/11%), *C. elaphus* (6/11%), and *L. Africana* (7/12.5%) for competition with livestock.

Conflict between humans and wild mammals was recorded in 125 countries (Figure 1b; Appendix 3). Looking at the conflict in general (Figure 1b), most countries are located in Europe (n = 36), Africa (34), and Asia (30). The categories of crop damage, livestock depredation and human safety were recorded in more countries (103, 90 and 61 countries, respectively) (Appendix 3). The number of species in each country varied by conflicts category (Figure 4 – 4). Socio-environmental variables influence the records of conflict by country in all conflict categories (Table 3; Appendix 1; Figure S9). Overall, countries with larger territorial areas have more conflict records in the follow categories: conflict in the general (taking into account all conflict categories), damage to the crops, livestock fatalities, and human safety. Most populous countries (higher HPD) have more conflict records on the crop damage, human safety and competition with livestock. Countries with more species recorded in conflict has more research effort in all conflict categories. We have no found effect of GDP and HDI on research effort (Table 3; Appendix 1; Figure S9).

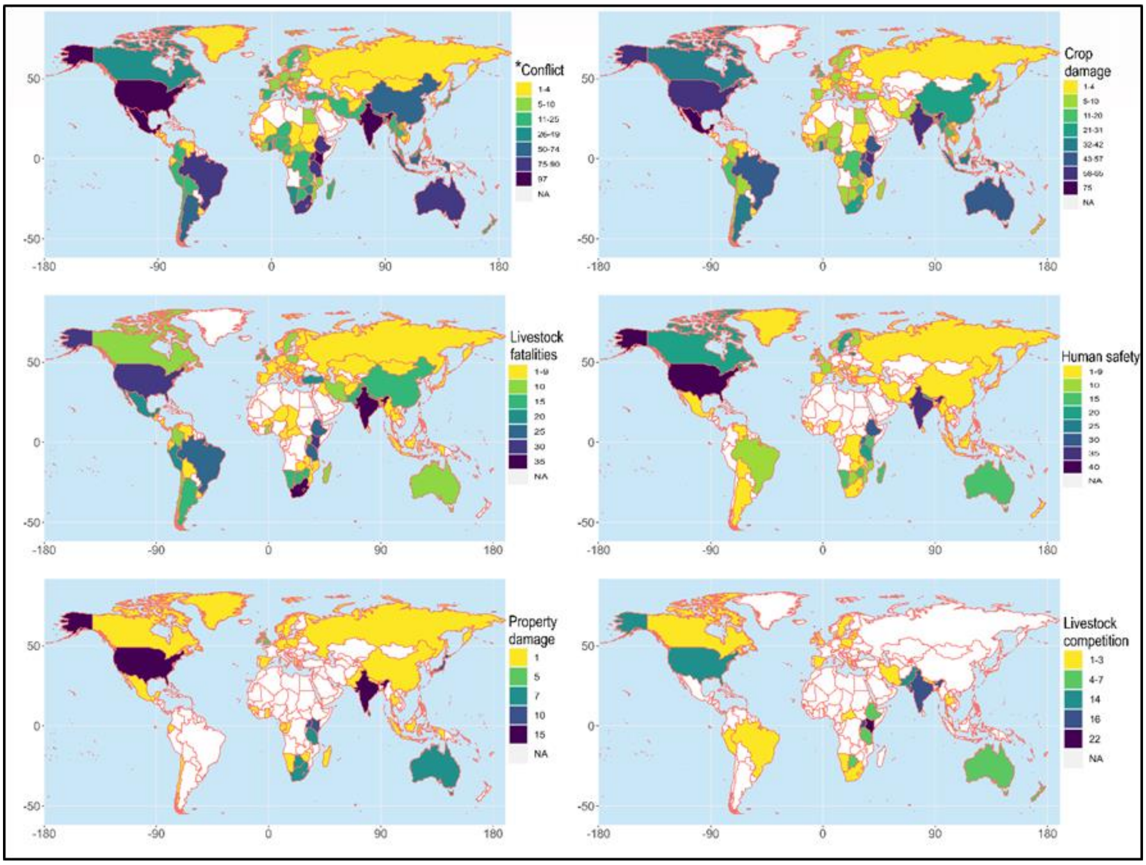

Figure 4: Number of species related to HWC by conflict category worldwide. (a) – general conflict (sum of all 5 conflict categories); (b) – crop damage; (c) – livestock depredation; (d) – human safety; (e) – property damage; (f) – livestock competition. NA – countries with no publications on HWC.

Table 3: Results of linear generalised models to test the effect of socio-political variables on the records of conflict in each conflict category by country. Bold values for P < 0.05. *Species recorded = number of species recorded in each conflict category.

	Estimate	Std. Error	CI (95%)	Pr(>|z|)
Conflict				
Intercept	7.63	0.96	[5.96 – 9.75]	< **0.001**
GDP *per capita*	1.37	0.39	[0.78 – 2.40]	0.276
HDI	1.06	0.28	[0.64 – 1.77]	0.819
HPD	1.08	0.09	[0.92 – 1.28]	0.353
Country size (km^2)	1.45	0.22	[1.08 – 1.94]	< **0.05**
Mammal diversity	0.92	0.11	[0.72 – 1.18]	0.525
*Species recorded	3.11	0.30	[2.57 – 3.77]	< **0.001**
Crop damage				
Intercept	5.72	0.80	[4.35 – 7.52]	< **0.001**
GDP *per capita*	1.59	0.54	[0.82 – 3.09]	0.174
HDI	0.81	0.25	[0.45 – 1.47]	0.490
HPD	1.28	0.12	[1.06 – 1.55]	< **0.05**
Country size (km^2)	1.63	0.26	[1.19 – 2.24]	< **0.01**
Mammal diversity	0.82	0.11	[0.63 – 1.07]	0.137
*Species recorded	2.55	0.28	[2.06 – 3.15]	< **0.001**
Livestock fatalities				
Intercept	5.17	0.76	[3.88 – 6.88]	< **0.001**
GDP *per capita*	1.40	0.54	[0.66 – 2.99]	0.384
HDI	1.02	0.36	[0.51 – 2.02]	0.963
HPD	0.97	0.10	[0.79 – 1.20]	0.777
Country size (km^2)	1.51	0.30	[1.02 – 2.24]	< **0.05**
Mammal diversity	1.02	0.15	[0.76 – 1.36]	0.917
*Species recorded	2.58	0.28	[2.09 – 3.20]	< **0.001**
Human safety				
Intercept	2.68	0.32	[2.13 – 3.38]	< **0.001**
GDP *per capita*	0.82	0.36	[0.35 – 1.95]	0.657
HDI	1.18	0.49	[0.52 – 2.68]	0.697

HPD	1.28	0.13	[1.04 – 1.57]	< **0.05**
Country size (km^2)	1.70	0.41	[1.06 – 2.72]	< **0.05**
Mammal diversity	1.01	0.19	[0.70 – 1.45]	0.975
*Species recorded	2.35	0.23	[1.94 – 2.85]	< **0.001**
Property damage				
Intercept	2.04	0.30	[1.53 – 2.73]	< **0.001**
GDP *per capita*	1.06	0.62	[0.33 – 3.35]	0.926
HDI	0.85	0.47	[0.29 – 2.53]	0.769
HPD	1.09	0.13	[0.86 – 1.38]	0.477
Country size (km^2)	1.73	0.50	[0.98 – 3.06]	0.057
Mammal diversity	0.83	0.19	[0.52 – 1.31]	0.413
*Species recorded	2.17	0.26	[1.71 – 2.75]	< **0.001**
Livestock competition				
Intercept	1.34	0.24	[0.95 – 1.89]	0.096
GDP *per capita*	3.10	2.55	[0.62 – 15.50]	0.168
HDI	0.53	0.41	[0.11 – 2.45]	0.416
HPD	1.40	0.23	[1.01 – 1.94]	< **0.05**
Country size (km^2)	1.21	0.41	[0.63 – 2.34]	0.564
Mammal diversity	1.26	0.33	[0.75 – 2.11]	0.390
*Species recorded	1.51	0.27	[1.07 – 2.14]	< **0.05**

Discussion

Our results show that the conflict between humans and wild mammals affects at least 11% of mammal species (n = 713 species), distributed across 19 orders. Rodents, carnivora, even-toed ungulates, and primates account for about 83% of species involved in conflict. These findings are consistent with other studies that have examined HWC around the world (Torres et al., 2018). Rodent species are one of the most important agricultural pests worldwide (Capizzi et al., 2014; Stenseth et al., 2003). Carnivora, even-toed ungulates and primates cause various types of conflict such as crops and property damage, livestock depredation (large and small farms), and threats to human safety in many places around the world (Kansky et al., 2014; Torres et al., 2018).

Our results show that species of large-bodied size and widely distributed species are more likely to cause crop damage and property damage, depredate livestock, threaten human safety and welfare, and compete with livestock or pets. These results support our first prediction, namely that larger and more widespread species are more likely to compete with livestock. These species have a set of biological and ecological traits that may favour their contact with humans, such as greater foraging flexibility, higher energy requirements, and overall they are able to exploit a greater variety of habitats, therefore they can inhabit a wider range of landscapes (Blackburn et al., 2017, 2009; Gaston and Blackburn, 2007, 1996). These traits may increase the likelihood that they will reside and persist in more places than small-bodied [and range-restricted] species, increasing the likelihood that they will come into contact with human settlements. For example, large-bodied species may be more easily recognised by humans (Hantak et al., 2021; Hill et al., 2019) and may also tolerate different environmental conditions (Blackburn et al., 2017, 2009; Gaston and Blackburn, 1996). All these factors may increase the likelihood of species being exposed to different human populations around the world [and, therefore, increasing conflicts].

In terms of trophic level, our prediction has been refuted, once we have detect a negative effect of herbivores and omnivores on the conflict categories that we have analysed, therefore, herbivores and omnivores has less likelihood of being in HWC. It is worth noting that, although we have not detect an positive effect of trophic level on the HWC that we have analysed, many species include in all three trophic levels are known to cause crop damage, preying on livestock and jeopardize human safety around the world (Braczkowski et al., 2023; Schley and Roper, 2003; Ugarte et al., 2019). Species such as *Alces alces*, C. *elaphus, E. maximus, S. scrofa, U. arctos, C. lupus, C. latrans, P. pardus, C. crocuta*, and *Vulpes vulpes* are generally more resilient to human disturbance, adapted to urban landscapes and more resistant to conflict prone control methods (Nyhus, 2016; Venumière-Lefebvre et al., 2022).

Research effort in HWC is particularly biased towards carnivora, even-toed ungulates and proboscideans, as well as larger-bodied sized and widespread species (see Figure 2; Figures S3-S8). Many factors can influence the higher research effort for these species traits. For example, larger-bodied size and widespread species are extremely recognizable by humans than smaller species (Dickman, 2012; dos Santos et al., 2020; Nyhus, 2016). This factor may increase scientific interest in general due to the ease of observation and data collection on behaviour and habitats (dos Santos et al., 2020). In addition, according to our results, larger species are involved in more than one conflict category (Appendix 2). Species such as *E. maximus*, *L. africana*, and *S. scrofa* were represented in all five conflict categories (Appendix 2).

In terms of trophic level, our results show that carnivore species had more research effort (just for human safety model) than herbivore and omnivore species. These results are consistent with recent research investigating HWC (Su et al., 2022; Venumière-Lefebvre et al., 2022). Since ancient times, carnivores have been a source of fear and insecurity for communities that alive with them (Newson et al., 2025). Many carnivore species compete with humans over food and space, and, in some situations, these species can attack on humans leading or increasing the HWC (Venumière-Lefebvre et al., 2022). Currently, to find an effective way of solving HWC and conserving carnivore species is widely recognised as a global priority in conservation (Lozano et al., 2019; Redpath et al., 2013).

Interestingly, our results show no significant effect of threat status on research effort. Nevertheless, the number of threatened species into in conflict (n = 160) call attention for more research effort, once the amount of research may affect the number of known threats attributed to a given species (Guedes et al., 2023), as well as the lack of knowledge about the underlying drivers of species extinction, which may impede and/or hinder the development of effective conservation measures (dos Santos et al., 2020). Therefore, our results draw attention for further research efforts on conflict prone species that are of less scientific interest (see Appendix 1; Figure S10 for families with higher likelihood of being related to HWC). For example, *C. crocuta* is the most common livestock predator in sub-Saharan Africa, but *P. leo* is the species with the most research attention, despite having lower depredation rates (Hoffmann and Montgomery, 2022).

Conflict situations are widely distributed around the world. Overall, our results show that larger countries had more conflict records in four conflict categories with exception of property damage and livestock competition. Countries with higher HPD have more conflict records for crop damage, human safety and competition with livestock. These results support partially our predictions, once larger countries by encompassing greater diversity of habitats and species (Gaston and Blackburn, 2007) can increase the range of interactions between people and wildlife, leading to potential conflicts. Likewise, highly populous countries (higher HPD) can have considerable overlap of species and humans increasing interactions between them and potentially elevates HWC (Venumière-Lefebvre et al., 2022). Additionally, our results show spatial patterns in the geographical distribution of each conflict category. Although most countries in each conflict category are located on the European, Asian and African continents, the United States and India were the countries with most publications in almost all conflict categories, with the exception of competition with livestock, for which India and Kenya had more studies. These findings are supported by other studies that looked at specific types of HWC around the world, such as livestock predation (Braczkowski et al., 2023; Torres et al., 2018) and crop damage (Torres et al., 2018).

We have no found effect of HDI and GDP on research effort, however, other studies investigating HWC (Torres et al., 2018; Venumière-Lefebvre et al., 2022) show that countries with the highest number of HWC records tend to have the lowest socio-political indicators, such as HDI and per capita income (Torres et al., 2018).

Although the United States and India have different socio-political characteristics, the United States is one of the richest and most developed nations in the world (World Bank, 2023). On the other hand, India is one of the most populous countries in the world, with 30 times more people per square kilometre than the United States (World Bank, 2023). Overall, USA and India are between the main countries in research about HWC globally (Holland et al., 2022; Su et al., 2022; Venumiére-Lefebvre et al., 2022). Additionally, the USA and India harbour some conflicting species such as *U. arctos*, *C. lupus* and *S. scrofa*, and India is a hotspot for threatened mammals (Ceballos and Ehrlich, 2006) such as "big cats" (*P. uncia, P. pardus*, *P. leo,* and *P. tigris*), Asian elephants and Rhinos (*Rhinoceros unicornis*). Given the convergence of all these factors, one might expect the greater number of conflict records for these countries.

Overall, our results show that the set of species related to each conflict category is phylogenetically clustered. Therefore, closely-related species tend to share the same conflict category, which means that a larger number of species in addition to those we recorded, can be involved in conflicting situations with humans. The high number of species, the wide range of countries involved in HWC, and the patterns associated with species traits and phylogeny make further research essential for a holistic understanding of the factors surrounding the conflict between humans and wild mammals.

Furthermore, conflict occurs at both scales (local/regional and continental/international) and there is limited evidence on the accuracy and effectiveness of many conflict mitigation measures at the both scales (local/regional), as well as the actual impact of these measures on target populations (Bergstrom, 2017; Miller et al., 2016; Treves and Karanth, 2003). Further research is therefore imperative to fill these knowledge gaps and provide detailed information to support national and international action to resolve or reduce the impacts of wild mammal conflicts with humans. In addition, future research should aim to understand how conflict mitigation measures affect the functional and phylogenetic diversity of species at both scales (local and regional), as retaliatory killing and lethal control are the main human response to control or mitigate conflict in most causes of HWC (Bergstrom, 2017; Miller et al., 2016; Seoraj-Pillai and Pillay, 2017). In summary, studies on species traits can not only help to identify the species that are more likely to be involved in HWC, but can also explain differences between HWC scenarios and guide the development of more targeted measures to reduce, mitigate or compensate for the damage caused by wild mammals. Such measures should take into account the biology, ecology and behaviour of conflict-prone species in wildlife management. Therefore, a trait-based framework provides a first step towards implementing of complex and effective conservation measures to improve the likelihood of coexistence between humans and wild mammals.

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Appendix 1

Supplementary information

Link for papers included in our dataset:
https://drive.google.com/drive/folders/1c6cwMw2HMfqS54fCBpF6coHg5EwbUIOQ?usp=drive_link

Table S1: Keywords used in systematic review.

Keywords	Downloaded papers
"Human wildlife conflict" AND extinction	713
Human-wildlife AND "conflict resolution"	204
Wildlife and "crop damage"	1,288
Wildlife AND "human damage"	0
Wildlife AND "livestock depredation"	1,014
Wildlife AND "damage livestock"	5
Wildlife AND "livestock damage"	99
Wildlife AND "livestock predation"	665
Wildlife AND "human death"	152
Wildlife AND "human dead"	0
Wildlife AND "agricultural damage"	124
"Wild Animals" AND "crop damage"	318
"Wild animals" AND "human damage"	0
"Wild animals" AND "livestock depredation"	217
"Wild animals" AND "damage livestock"	3
"Wild animals" AND "livestock damage"	10
"Wild animals" AND "livestock predation"	131
"Wild animals" AND "human death"	28
"Wild animals" AND "human dead"	0
"Wild animals" AND "agricultural damage"	24
"wild animals" AND "crop raiding"	205
"Wild mammals" AND conflict	790
"Wild mammals" AND "crop damage"	127
"Wild mammals" AND "human damage"	0
"Wild mammals" AND "livestock depredation"	76
"Wild mammals" AND "damage livestock"	0
"Wild mammals" AND "livestock damage"	4
"Wild mammals" AND "livestock predation"	59
"Wild mammals" AND "human death"	4
"Wild mammals" AND "human dead"	0
"Wild mammals" AND "agricultural damage"	17
"Wild mammals" AND plague	51
"Wild mammals" AND disservices	19
"wild mammals" AND "crop raiding"	86
Ethnozoology AND conflict	92
Negative Human-wildlife interactions	10
Human-wildlife AND "negative interactions"	62

Total	6,597

Table S2: The number of all observed mammal species and the expected number of species involved in each conflict category individually by mammalian order (median, based on 100,000 lists of the permutations test), assuming that mammal species were related to the conflict at random. The species totals are based on the taxonomy in Burgin et al., (2018). hwc – Conflict, cd – Crop damage, lf – Livestock fatalities, hs – Human safey, pd – Property damage, lc – Livestock competition. $^{\mathbf{O}}$ = Observed, $^{\mathbf{E}}$ = Expected. r = range (min – max). Bold values ($P < 0.05$).

Order	Total	hwc^{O}	hwc^{E}	r^{hwc}	cd^{O}	cd^{E}	r^{cd}	lf^{O}	lf^{E}	r^{lf}	hs^{O}	hs^{E}	r^{hs}	pd^{O}	pd^{E}	r^{pd}	lc^{O}	lc^{E}	r^{lc}
Carnivora	286	164	20	**5 – 41**	92	9	**0 – 25**	138	5	**0 – 18**	39	1	**0 – 7**	25	0	**0 – 5**	16	0	**0 – 4**
Artiodactyla	338	112	14	**2 – 31**	95	10	**0 – 23**	14	0	**0 – 5**	23	0	**0 – 5**	18	0	**0 – 4**	50	1	**0 – 6**
Chiroptera	1282	27	3	**0 – 13**	17	2	**0 – 9**	1	0	0 – 1	8	0	**0 – 3**	5	0	**0 – 2**	0	0	0 – 0
Cingulata	21	7	1	0 – 6	7	1	0 – 6	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0	0	0	0 – 0
Dasyuromorphia	77	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0
Didelphimorphia	105	11	1	0 – 8	9	1	0 – 6	5	0	0 – 4	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0
Diprotodontia	139	17	2	**0 – 9**	14	1	**0 – 7**	3	0	0 – 3	6	0	**0 – 3**	3	0	0 – 2	4	0	0 – 3
Eulipotyphla	484	15	2	**0 – 10**	15	1	**0 – 8**	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0
Hyracoidea	5	2	0	0 – 2	2	0	0 – 2	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0	1	0	0 – 1
Lagomorpha	90	21	2	**0 – 11**	20	2	**0 – 10**	2	0	0 – 2	6	0	0 – 4	1	0	0 – 1	3	0	0 – 3
Peramelemorphia	19	3	0	0 – 3	2	0	0 – 2	1	0	0 – 1	0	0	0 – 0	1	0	0 – 1	0	0	0 – 0
Perissodactyla	18	8	1	0 – 6	7	1	0 – 6	1	0	0 – 1	1	0	0 – 1	1	0	0 – 1	3	0	0 – 3
Pilosa	10	3	0	0 – 3	3	0	0 – 3	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0	0	0	0 – 0
Primates	450	95	12	**0 – 27**	96	10	**0 – 24**	21	1	**0 – 6**	15	0	**0 – 4**	27	0	**0 – 5**	5	0	0 – 3
Proboscidea	2	2	1	1 – 2	2	1	1 – 2	2	1	1 – 2	2	1	1 – 2	2	1	1 – 2	2	1	1 – 2
Rodentia	2,354	216	26	**9 – 48**	210	21	**5 – 42**	21	1	**0 – 7**	10	0	**0 – 4**	3	0	0 – 3	1	0	0 – 1
Scandentia	20	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0
Sirenia	4	1	0	0 – 1	1	0	0 – 1	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0	0	0	0 – 0
Tubulidentata	1	1	1	1 – 1	1	1	1 – 1	0	0	0 – 0	0	0	0 – 0	1	1	1 – 1	1	1	1 – 1

Table S3: Phylogenetic signal (Fritz *D*) of the six conflict categories.

Conflict categories	Number of species	*D*	p-value (Brownian)	p-value (Random)
1 – Conflict	708	0.5590056	**< 0.0001**	**< 0.0001**
2 – Crop damage	595	0.6374481	**< 0.0001**	**< 0.0001**
3 – Livestock depredation	211	0.3481746	**< 0.0001**	**< 0.0001**
4 – Human safety	113	0.617574	**< 0.0001**	**< 0.0001**
5 – Property damage	88	0.6224827	**< 0.0001**	**< 0.0001**
6 – Livestock competition	86	0.6156811	**< 0.0001**	**< 0.0001**

FIGURES

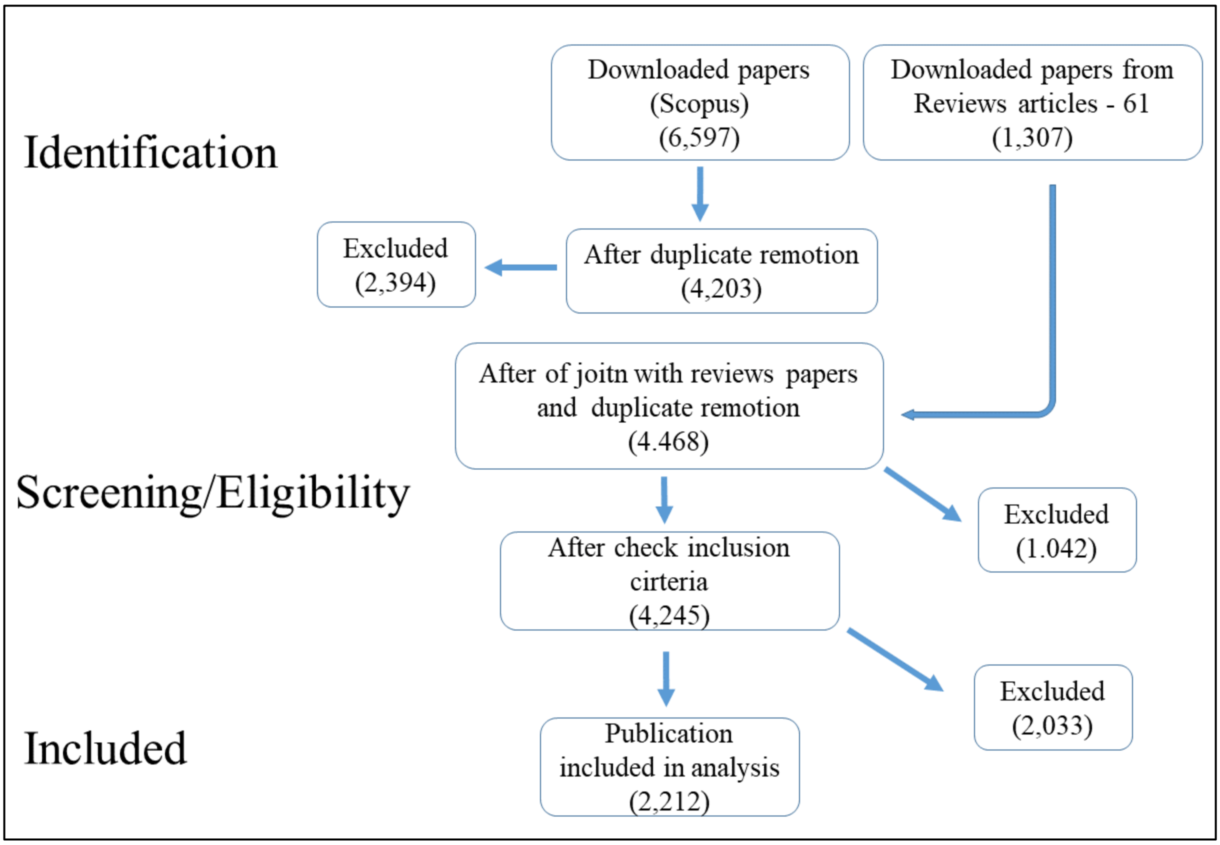

Figure S1: Flowchart of systematic review and selection of articles includes in our study.

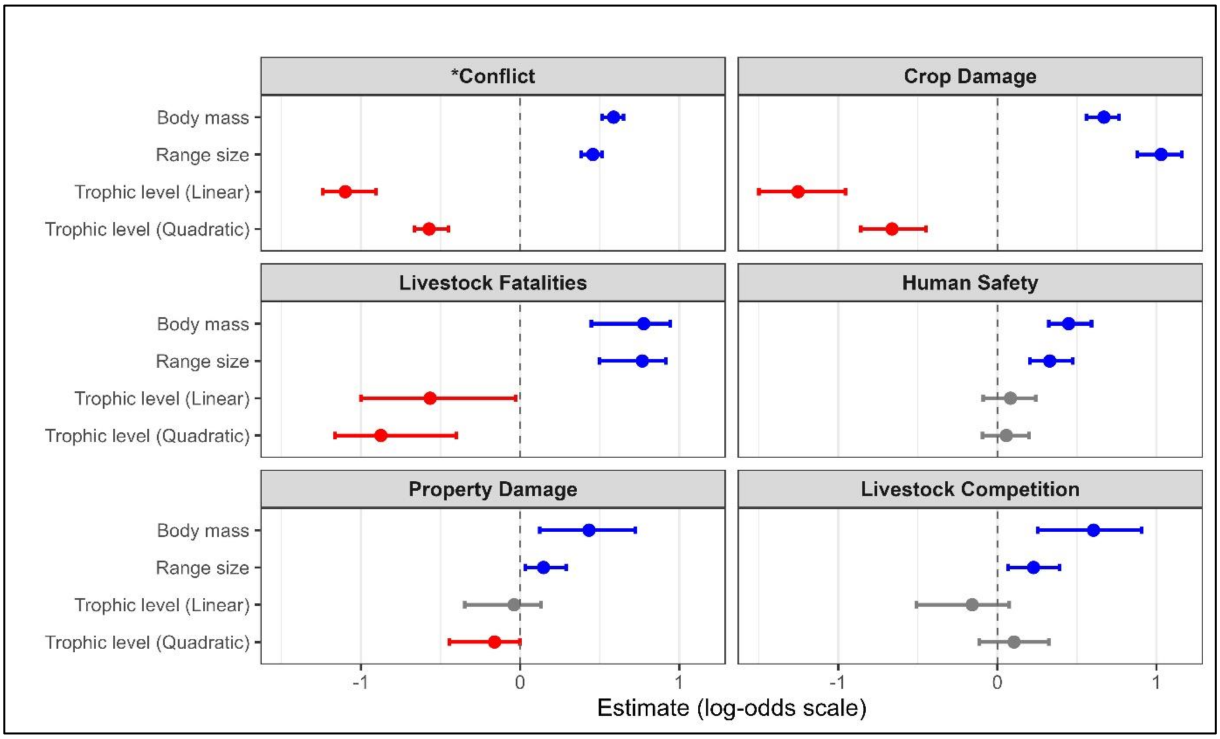

Figure S2: Species traits effects on the likelihood of species being involved in HWC as predicted by the phylogenetic logistic regression models. *Conflict taking into account all conflict categories. Blue and red dots represents either significantly positive or significantly negative effects, respectively; and grey dots represents non-significant effects.

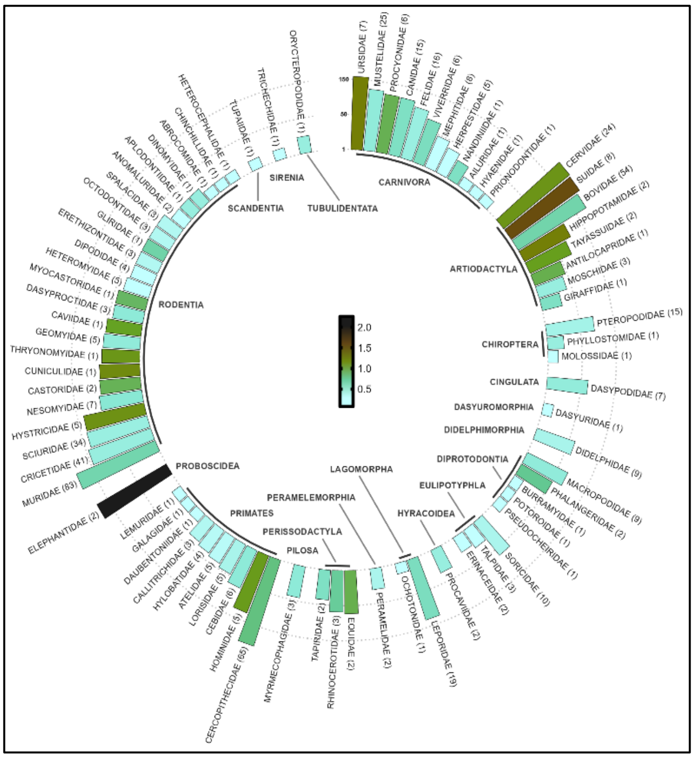

Figure S3: Research effort related to the crop damage across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

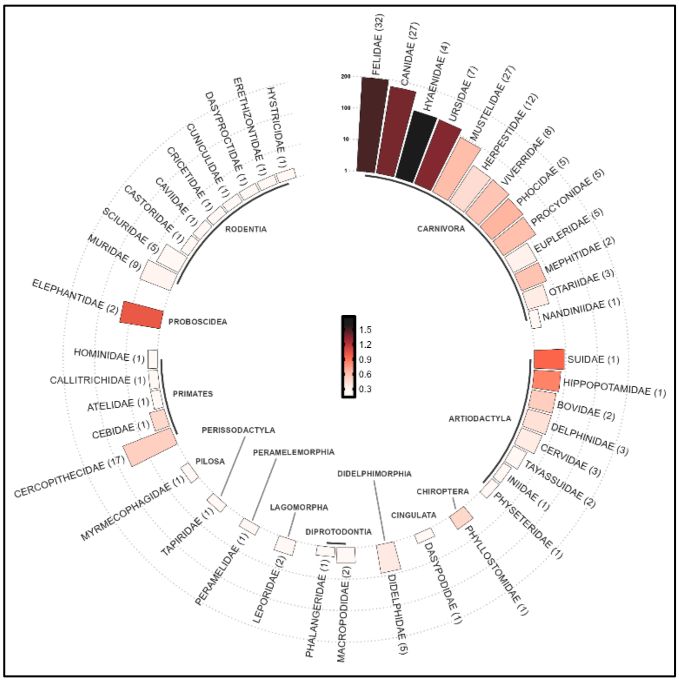

Figure S4: Research effort related to the livestock depredation across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

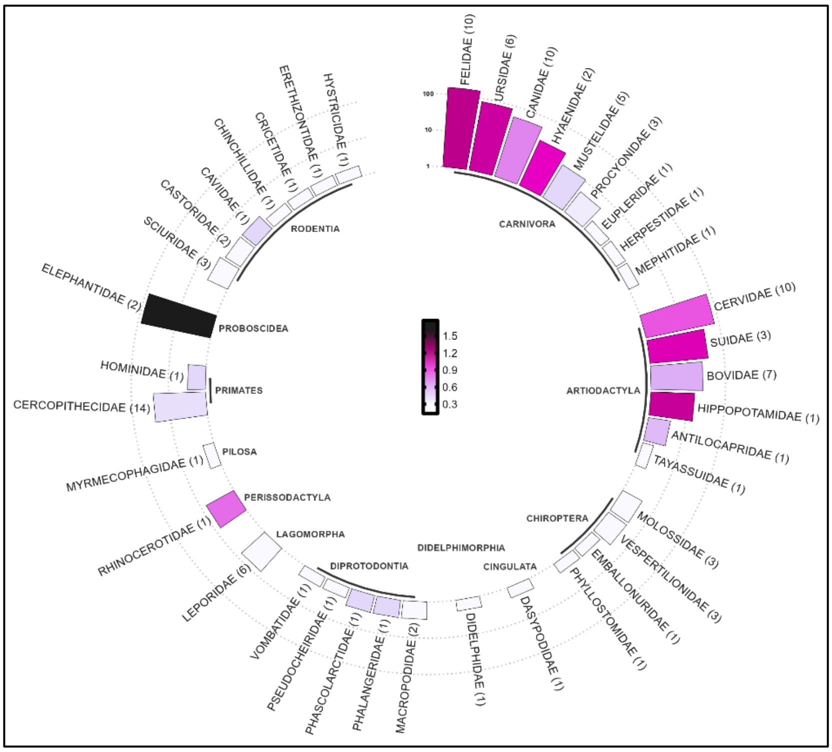

Figure S5: Research effort related to the human safety across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

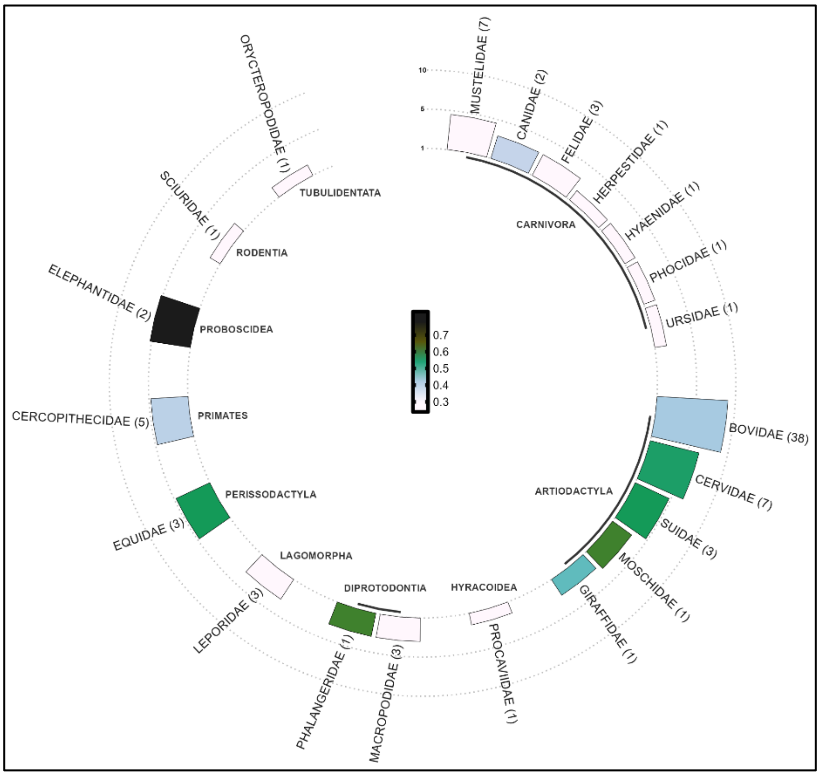

Figure S6: Research effort related to the property damage across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family.

Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

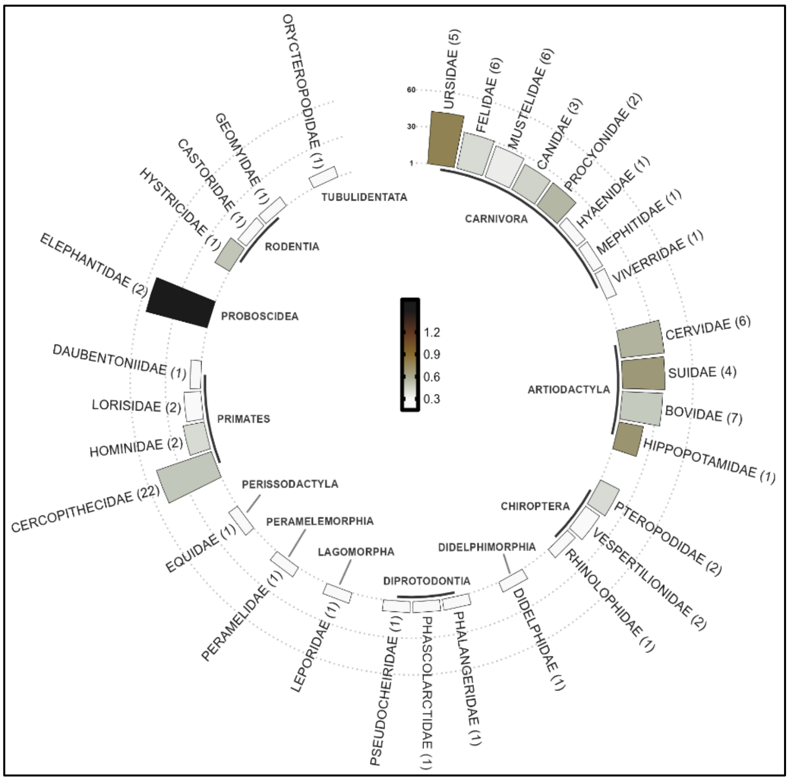

Figure S7: Research effort related to the livestock competition across mammal taxonomic families and orders. Bar colour indicates the mean number of articles per species within each family. Number within brackets represents the species richness in each family. Bar height shows the total number of publications per family.

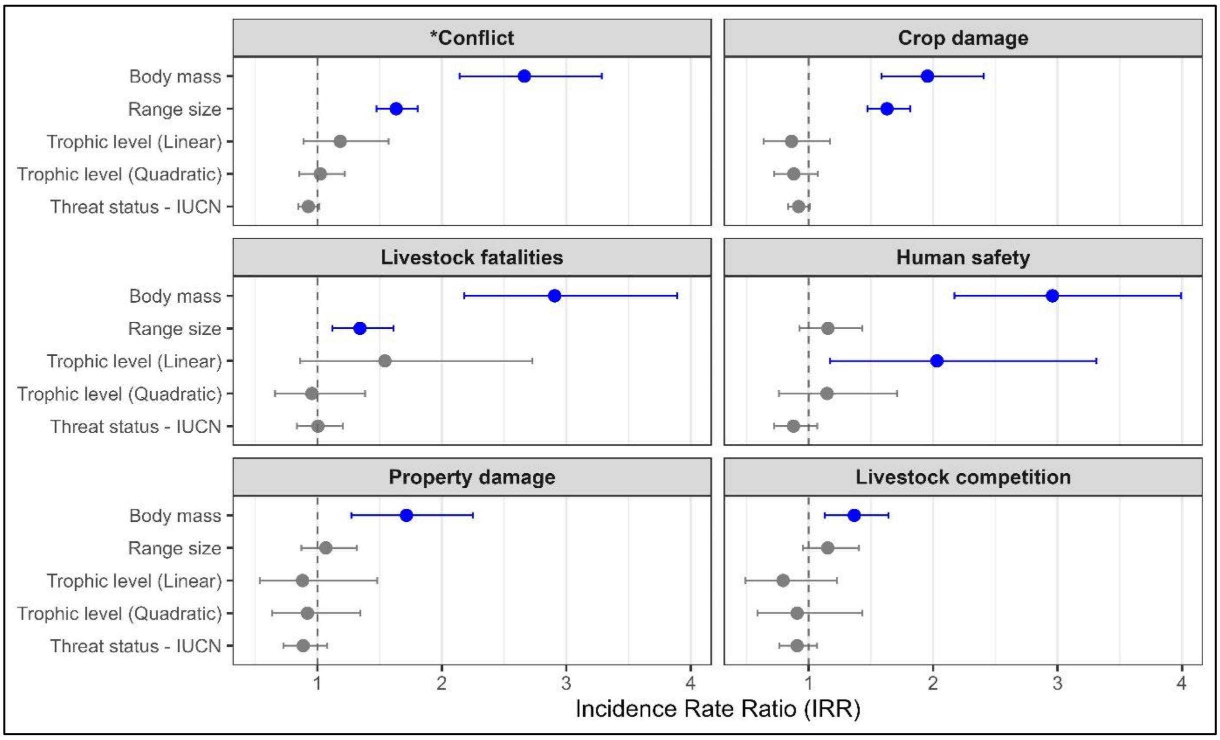

Figure S8: Species traits effects on the research effort related to conflict categories as predicted by the brms models. *Conflict taking into account all conflict categories. Blue and red dots represents either significantly positive or significantly negative effects, respectively; and grey dots represents non-significant effects.

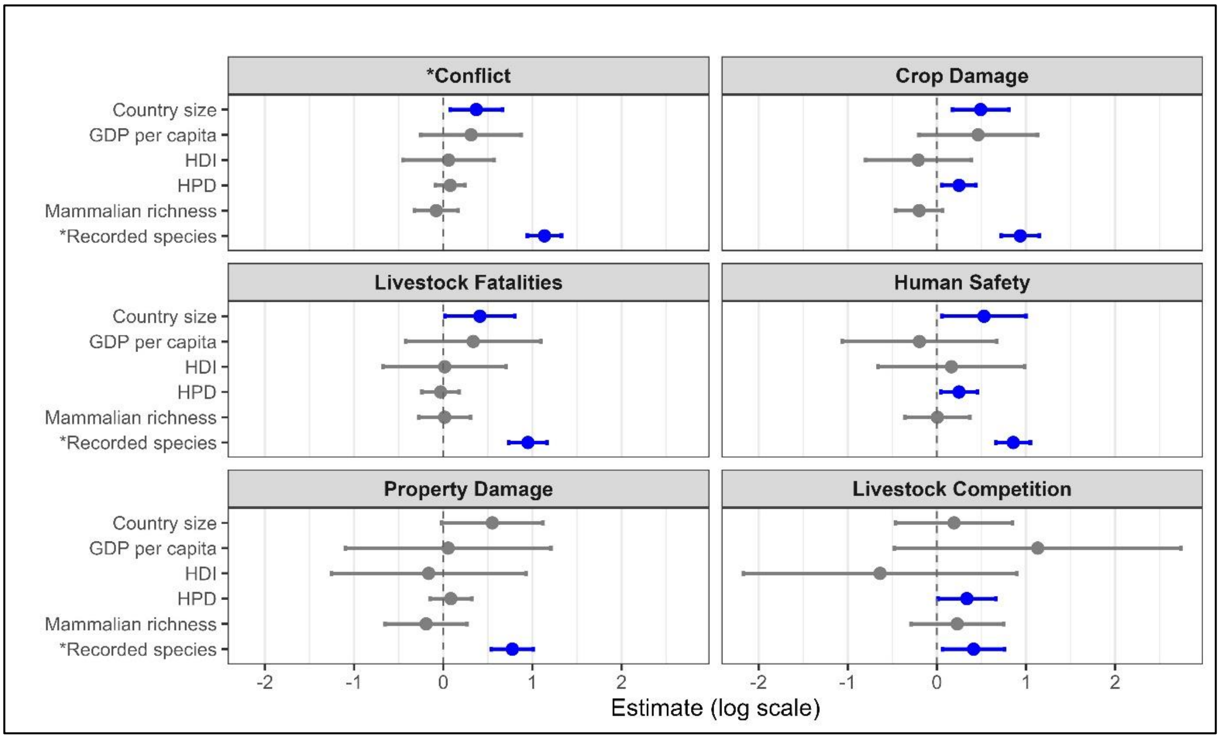

Figure S9: Effects of socio-environmental variables on the research effort related to conflict categories as predicted by the glm models. *Conflict taking into account all conflict categories. Blue and red dots represents either significantly positive or significantly negative effects, respectively; and grey dots represents non-significant effects. *Recorded species = number of species in each conflict category.

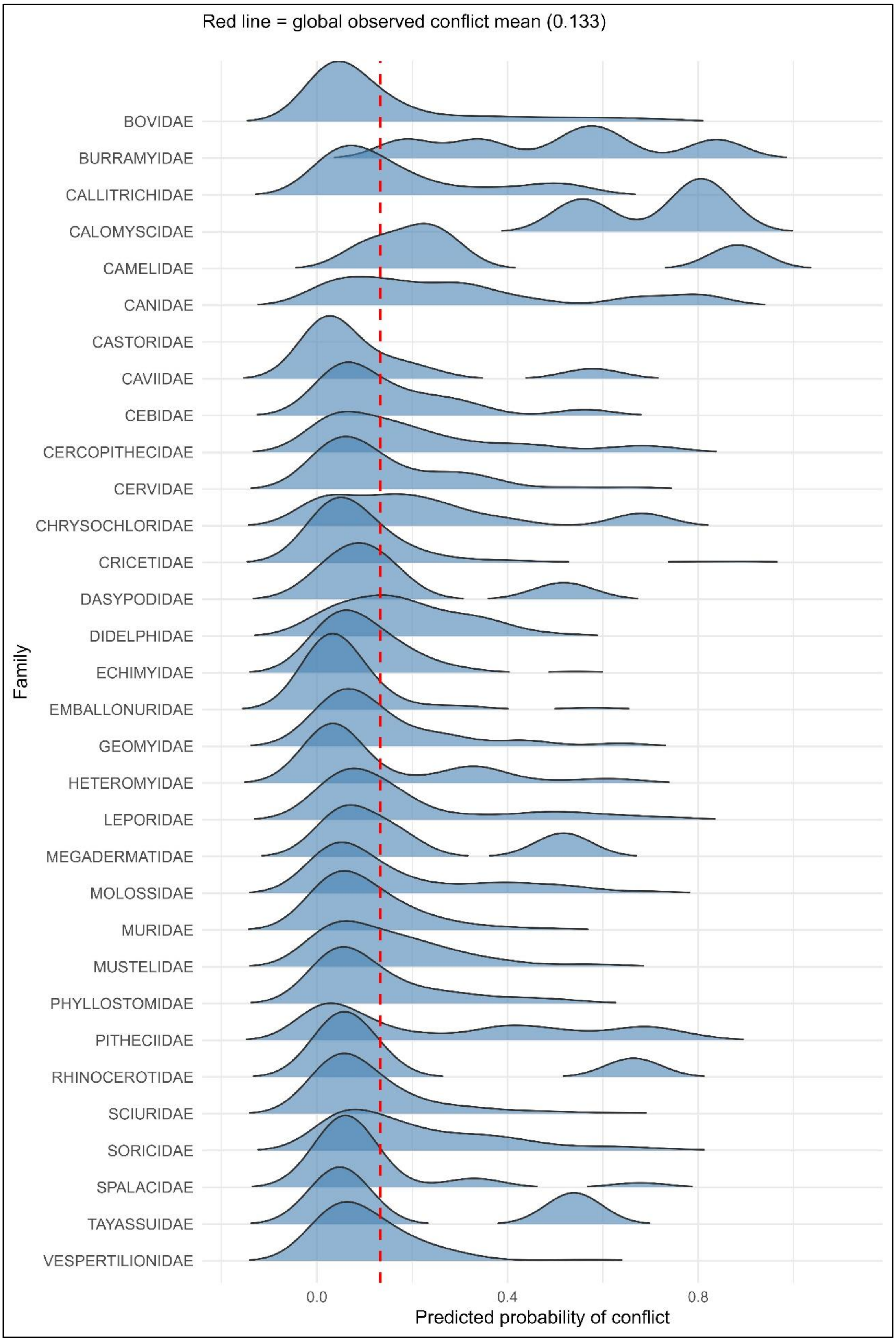

Figure S10: Taxonomic families with greater predict probability of being related to the HWC, based on predicted values of phylogenetic logistic regression models (PGLM).

CONSIDERAÇÕES FINAIS

A utilização de mamíferos selvagens representa uma prática difundida em praticamente todos os países/territórios do planeta. A captura desses animais para suprir os comércios legal/ilegal de partes e produtos, animais de estimação e carne de caça representam uma grave ameaça a muitas espécies em várias regiões onde elas são consumidas. No mesmo sentido, o abate de mamíferos em retaliação aos prejuízos causados pelas espécies ou como forma de controle populacional para evitar ou atenuar possíveis situações conflituosas com seres humanos, também tem afetado muitas populações selvagens em todo o planeta.

Com base em nossos resultados, fica evidente que as problemáticas envolvendo a escolha, coleta, comércio e usos de mamíferos são complexas, além de representar práticas difundidas em praticamente todo o planeta. Nesse sentido, determinar quais fatores determinam a escolha e utilização de mamíferos, assim como dos subprodutos extraídos dessas espécies não é uma tarefa simples.

A diversidade de espécies registradas e os padrões relacionados às características biológicas/ecológicas e história evolutiva das espécies evidencia que a escolha e utilização desses animais não é aleatória, mas associada as características das espécies que possam fornecer mais partes corpóreas e finalidades de uso em relação ao comércio, bem como para animais de estimação, consumo de carne de caça, além de também influenciarem os conflitos entre seres humanos em todo o planeta. Espécies maiores e amplamente distribuídas geograficamente são mais comercializadas (número de partes corpóreas e finalidades de comércio – usos), são mais usadas como pet e carne de caça além de estarem mais envolvidas em relações conflituosas com seres humanos.

Por outro lado, nossos dados mostram que o esforço de pesquisa em cada categoria de uso (comércio, pet e carne de caça) e conflitos é direcionado a espécies com tamanhos maiores e amplamente distribuídas, além de ser concentrado em grupos taxonômicos que contemplam espécies carismáticas ou icônicas como: carnívoros, primatas, proboscídea e artiodátilas. Esses achados evidenciam vieses nos estudos direcionado a utilização de mamíferos e chamam atenção para uma melhor e mais abrangente investigação direcionada aos grupos taxonômicos menos investigados, uma vez que a falta de informações adequadas também representa um obstáculo a conservação.

Um fator comum a todos os capítulos desse estudo, é que o embora os usos e conflitos das espécies sejam geograficamente disseminados, as regiões com maiores números de espécies estão localizadas nas regiões tropicais (Neotropicais, Afro-tropical e Sudeste e Sudoeste Asiático), enquanto que o esforço de pesquisa (número de publicações) varia entre os tipos de usos e conflitos. Adicionalmente, o consumo de mamíferos bem como de relações conflituosas entre os mamíferos silvestres e os seres humanos está concentrado em regiões subdesenvolvidas ou em desenvolvimento evidenciando que existe uma maior dependência desses animais nessas localidades para subsistência bem como para aquisição de renda.

Os padrões relacionados aos usos dos mamíferos registrados no presente estudo são provavelmente válidos não apenas para as categorias de uso estudadas, como também para medicina tradicional e caça de troféus por exemplo. Esforços urgentes são imperativos para criar estratégicas ou aparatos legais em escalas regionais e intercontinentais que busquem mitigar ou atenuar os efeitos negativos da sobre exploração, desestimulem o comércio de espécies silvestres bem como proporcione informações adequadas sobre as ameaças à saúde e bem-estar humano relacionados ao consumo de animais selvagens da mesma maneira que busquem melhorar a eficácia de medidas voltadas a conservação das espécies. O não comprometimento na solução da problemática que envolve a utilização de mamíferos selvagens, pode gerar consequências alarmantes não só para as populações das espécies exploradas, mas também para o fornecimento e manutenção de serviços ecossistêmicos, bem como da humanidade como um todo.

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