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Review article

The effects of recreational activities on wild mammals

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ABSTRACT

An increasing number of people practise nature-based recreational activities, generating great economic resources, which can become a threat to wildlife species, because wild animals may perceive human presence as a predation risk. Many studies have investigated the effects induced in wild mammals by nature-based recreation. Despite that, a thorough overview of the literature focused on this topic is lacking. We conducted a broad bibliographic search, reviewed 209 articles, and identified 672 case studies about the effect of recreational activities on terrestrial mammals. We hypothesised behavioural metrics, disturbance sources and protocols of data collection affect the probability of detecting the effect of recreational activities. We highlighted this research topic is affected by huge bias both on a taxonomical and geographical level. Studies were mostly carried out in North America or Europe and almost 90 % of them focused on Cetartiodactyla, Carnivora, and Rodentia. Nevertheless, trends in publication rates suggest that these biases are declining. Using multiple regression, we examined the study designs to understand which features were linked with a higher probability of detecting a disturbance. Although studies measuring physiological responses are scarce in the literature, these seem to be more likely to detect disturbances than behavioural ones. Studies implemented on individually recognisable animals are associated with a higher likelihood of detecting the effects of the disturbance.

Harnessing this knowledge, future studies could generate a better understanding of the effects of recreational activities. Adopting suitable study protocols is essential for efficiently managing economic resources in scientific research and can help define better conservation strategies.

1. Introduction

People practicing nature-based recreational activities have increased dramatically since the mid-twentieth century (Balmford et al., 2009), following people's growing interest in nature. Data quantifying the occurrence of recreational activities are often lacking and spatially discontinuous worldwide, but data about the amount of tourism and the activities practiced are often available for protected areas. That is because these areas, besides being essential in the protection of nature, have become hotspots for recreational activities (Reed and Merenlender, 2008). With 8 billion visits per year, protected areas are estimated to give rise to a global gross direct expenditure of 600 billion dollars/year (Balmford et al., 2015). Albeit more than 6 million of the visits to protected areas occur in

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North America and Europe, nature-based recreational activities are experiencing the steepest positive trends in Africa, Asia, and South America, with the steepness of the trend being inversely correlated to the countries' wealth (Balmford et al., 2009), giving outdoor recreation a great potential for the economic growth of low-income countries.

Besides the economic value and the beneficial effects on physical and mental health (Bowler et al., 2010; Rosenberger et al., 2009), nature-based recreational activities have been shown to play a central role in the protection of nature (Leung et al., 2018). With more and more people visiting wilderness and increasing their experience of it, the need for conservation could gain public interest and more funds could become available (Zaradic et al., 2009). Moreover, participation in wild nature experiences in childhood has been linked to the development of eco-centric beliefs (Ewert et al., 2005) and to pro-environmental behaviours in adult life (Wells and Lekies, 2006) pointing out that human closeness to nature is essential for its protection. However, tourism activities that focus on the natural environment exert several pressures and cause risks to ecosystems on which they rely (Kuenzi and McNeely, 2008). If, on the one hand, recreational activities may boost conservation efforts, on the other hand, they embody potential threats to wildlife. Because animals have evolved antipredator responses to generalised threatening stimuli, and because human beings exploit numerous species (Darimont et al., 2009), human presence is often perceived by wildlife as a predation risk, eliciting the same physiological and behavioural responses (Beale and Monaghan, 2004; Gill et al., 1996). Antipredator behaviours are often time demanding and come at the expense of energetically beneficial behaviours such as feeding or resting, potentially impairing fitness in the long run (Frid and Dill, 2002).

To date, a great body of studies about animals' reactions to outdoor recreation has highlighted negative effects including spatiotemporal avoidance (Gill et al., 2001), changes in habitat use (Gander and Ingold, 1997), changes in the group network of social animals (Gall et al., 2022), and physiological responses like manifestations of distress (MacArthur et al., 1982; Müllner et al., 2004). These behavioural and physiological responses can entail detrimental effects at the population level such as decreased breeding success (Hutfluss and Dingemanse, 2019), survival (Müllner et al., 2004), and abundance (Reed and Merenlender, 2008), ultimately causing substantial changes in species richness and composition in disturbed environments (Lei et al., 2023). As non-consumptive recreation can lead to massive declines in the abundance of sensitive species and substantial changes in community composition (Reed and Merenlender, 2008), this raises the question of whether recreation can be carried out with the objective of preserving biodiversity.

Although interest in animals' responses to recreational activities increased rapidly in the last decades, the literature is affected by huge taxonomic biases. Almost 40 % of the studies focussed on mammals (Larson et al., 2016). Nevertheless, a review of the literature about the effects of recreational activities is lacking, even for mammals. The absence of a synthesis of the information currently available in the literature does not allow us to evaluate the degree of disturbance that various recreational activities exert. Likewise, the absence of an analysis of the results from studies that have used different survey methodologies prevents us from proposing effective recommendations about study design to assess the effects of recreational activities on mammals.

Our review arises from the need to fill these knowledge gaps and provide researchers with an overview of the state-of-the-art knowledge and recommendations for future studies. More specifically, we aimed to answer the following questions: 1) In the literature on the effects of recreational activities on wild mammals are there the same major taxonomic and geographic biases as in the literature about conservation science (dos Santos et al., 2020)? 2) Are such potential biases reducing or increasing in recent times? 3) What are the different study designs and methodologies used? 4) Does the research protocol affect the probability of detecting a significant modification in the behaviour or physiology of wild mammals? For this purpose, we conducted a broad bibliographic search on Web of Science that located 2382 citations focusing on the effect of non-consumptive recreational activities on wild mammals on dry land. We reviewed the 209 most pertinent articles in detail. We outlined the main topics on which most of the literature focused by using a bibliometric approach. In particular, we were interested in identifying trending topics by looking at whether articles were grouped based on the species considered, the methodology used or other shared information. We explored research bias and knowledge gaps and looked at publication trends over time to infer future research scenarios. Moreover, we examined the designs of the studies, taking into account the behavioural/physiological metrics and disturbance sources to understand in which case the impacts were more noticeable. By doing so, we tried to address how different study designs and methodologies influence the likelihood of detecting the impacts of recreational activities on mammals and, on these bases, we suggested elements to consider when designing a research study. Lastly, we commented on the implications of our main findings for conservation management.

2. Methods

2.1. Search query

The search was carried out on Web of Science as a textual query (Appendix S1) following the Population, Exposure, Outcome (PEO, Munn et al., 2018) framework. The Population field included all animals in the class Mammalia, the Exposure defined the source of disturbance (i.e. all nature-based recreational activities), and the Outcome concerned the assessment of disturbance. These three fields were outlined by specific sets of keywords which were linked together by the boolean operator 'AND'. We used the boolean operator 'NOT' to exclude exploitative and non-recreational activities as well as studies focusing on other taxa or disease-related outcomes. The search was carried out at the beginning of January 2023 and included all the articles published until the end of 2022. We searched for English-written articles published in any type of journal pertaining to one or more of the following Web of Science categories: "Ecology or Zoology", "Environmental Sciences", "Behavioral Sciences" and "Biodiversity Conservation". We only considered "article", "review article" and "early access" document types and we did not include either preprint papers or grey literature.

2.2. Article selection and variables extraction

To be considered in this review, articles had to focus on at least one species of mammal and aim at assessing responses to human recreational activities. We considered recreational activities all outdoor activities done for exercise, relaxation or enjoyment. A caveat must be made for overflights, which are often undertaken for recreational purposes (e.g., massive sport events, supplies at mountain refuges) but their reasons are usually hidden from researchers and are unlikely to influence animal responses. For these reasons, animal responses are often recorded by researchers regardless of the purpose of the overflight (recreation or work) in order to study the overarching phenomenon. Therefore, we included all the articles on the effects of overflights on mammals, even if they did not explicitly mention that overflight was linked to recreational activities. We excluded articles focusing on exploitative activities, such as hunting. Articles had to focus on animals' responses occurring on land, whereas the source of disturbance could arise from land, air, or water bodies. Articles focusing on the reduction in human activity during the COVID-19 pandemic, referred to as the anthropause (Rutz et al., 2020), were not included, as they possess unique characteristics that warrant an in-depth and specific analysis.

From the initial set of articles, obtained using the search query on Web of Science, we screened out not pertinent articles based on previously outlined inclusion and exclusion criteria described above. A preliminary screening was done by inspecting titles and abstracts. We read the full text of the remaining articles and extracted variables about the main outcomes and the study design (see below for more details). During the full-text readings, articles that were not compliant with the inclusion criteria were discarded. Additional articles to be included in the review were identified using a snowballing approach (Wohlin et al., 2022) wherein we screened the

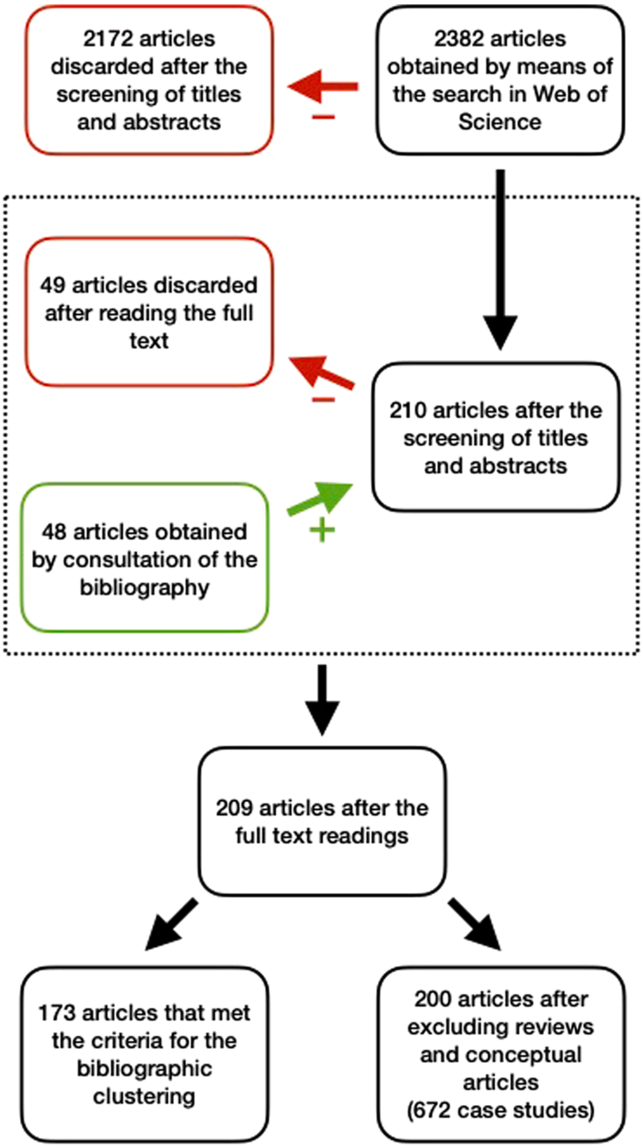

Fig. 1. Flow diagram of the procedure followed to select the articles included in this review. At each step, the number of articles retained is shown.

bibliography of each included article and added cited studies that met the inclusion criteria (Fig. 1).

Initially, we randomly selected 20 articles and each author inspected them independently, noting a list of variables that we thought best summarized the studies' outcomes and design. We then looked for mismatching results between different compilers and discussed how to reconcile them. From this comparison, we outlined a final set of unambiguous variables to be extracted from each article.

We recorded:

- Bibliometric information: year of publication, list of the authors, title of the article, and name of the scientific journal.
- Geographic information: the country and continent in which the study was carried out.
- Systematic information: order and species to which the investigated population belongs.
- Sources of disturbance: "hiking", "cycling", "aerial disturbance", "motorised vehicles", "horseback riding", "skiing", "water disturbance (watercrafts and other water-based disturbances)", "generic or multisource disturbance". The variable "other disturbances" was used for other sources of disturbance.
- Information about the study design: "experimental" or "observational".
- Whether the studies focus on individually recognisable animals: "yes" or "no".
- The metrics used to assess the disturbance: "alert or vigilance", "spatial behaviour", "activity", "flight initiation distance", and "hormones and metabolism". The field "other outcomes" was used to write down effects that differ from the above-listed ones.
- Assessment of human disturbance: NA if not assessed, 0 if assessed but no effect was statistically detected, and 1 if some effect was statistically detected.

Finally, we reported if the article assessed or detected the effects of recreational activities on some traits of life-history or population dynamics.

Following the logic of the Population, Exposure, Outcome framework, we identified a case study whenever a behavioural or physiological metric (Outcome) had been collected as a potential response to a single and defined source of disturbance (Exposure) for a population (Population). Thus, any distinct combination of Outcome, Exposure and Population was considered as a distinct case study, implying that for each article we identified at least one case study. In an article, we could have more than one case study if more than one species (Population) was involved or if more than one metric (Outcome) was used or if responses referred to different sources of disturbance (Exposure). We included a case study in our database only when numerical and/or statistical results were reported in the results chapter of the articles under analysis. Finally, we randomly divided the articles into 4 subsamples. Each author read and categorised their subset of articles according to the set of variables previously defined and entered the evaluations into the dataset (Appendix S2).

2.3. Data analysis

To explore the main themes in the literature, we performed a cluster analysis of the selected articles, by using a bibliographic coupling approach. Bibliographic coupling is a bibliometric technique that allows mapping scientific publications based on the number of citations that articles share. This number (i.e. the strength of the links in the citation network) can be considered as an indicator of the probability that two articles focused on a related subject topic. Bibliographic coupling is thus a powerful tool to outline clusters of articles that, citing the same references, likely treat a similar matter. We performed bibliographic coupling network and clustering using the open-source application VOSviewer (van Eck and Waltman, 2014). To increase the likelihood of finding relevant clusters we focused only on the articles that share at least 5 citations with one of the other articles. The minimum cluster size was set at 5 and we chose to merge smaller clusters (less than 5 articles) with the nearest cluster in the citation network. We then labelled the clusters by examining the most common words in the articles' titles and abstracts. For this purpose, we excluded conjunctions, articles, and prepositions and looked at meaningful names and adjectives. The textual analysis of titles and abstracts was performed in R (R Core Team, 2022; R version 4.2.2) with the stringr package (Wickham and Software., 2023).

In the following portion of our study, reviews, meta-analysis, and conceptual articles were excluded from the recording of case studies. To investigate the potential presence of a taxonomical bias in the literature, we counted how many case studies focused on each different taxonomical order and species. By using a χ^2 test, we compared the number of recorded case studies on each taxonomical order to the expected frequencies given by the number of species in each order (Wilson and Reeder, 2005).

We looked at the geographical distribution of the studies by counting the number of articles and case studies in each continent and country. Studies that took place in multiple countries were reported in the database on multiple rows, one for each country. We tested if the number of case studies correlated to geographic rather than economic attributes of the country in which they were carried out. Geographic attributes included the total land area and the overall human population in 2022 and gross domestic product per capita (US $ in 2022) was chosen as an economic indicator. These indicators were downloaded from the World Bank API by using the R package wbstats (Piburn and UT-Battelle., 2020). For each indicator, we run Spearman's rank correlations between the number of studies carried out in each country and the countries' values for that indicator. Spearman's rank correlation was chosen because the distributions of the considered variables did not follow a normal distribution.

We looked for temporal trends in publications, which were assessed as the number of case studies over time for the continent in which the studies were carried out and the taxonomic order involved in the research. Continents other than Europe and North America were grouped, as they accounted for a few case studies per year. Similarly, orders other than Cetartiodactyla, Carnivora, and Rodentia were grouped, as their annual rates of case studies were zero for most of the years. The study of the trends in publication rates over time was implemented by using linear regression models ("lm" R function) using the year of publication as a predictor and the number of case studies as a response variable. Then, we repeated the same analyses focusing on the last 20 years (2003–2022) to assess whether trends in more recent years were different than the overall period.

We counted how many case studies focused on each category of sources of disturbance. Similarly, we looked at which types of behavioural or physiological metrics were more frequently recorded to assess the disturbance. We used a generalised linear model (GLM -"lme4" package, Bates et al., 2017) with binomial distribution to investigate the probability of finding statistical evidence of disturbance. Starting with the full dataset of case studies, we excluded records related to flight initiation distance because, for this metric, it was impossible to define whether or not there was a significant effect. Indeed, this metric is useful for analysing the sensitivity to a disturbance, but it alone did not estimate disturbance presence. It is intuitive to expect animals to move away in all experiments when the operator approaches progressively. We also excluded cases related to species richness because these studies provided ecological metrics and were not directly related to a response of a species. The response was a binary variable that stated if a statistically significant effect of disturbance was found (1) or not (0). The explanatory variables included the type of disturbance, the metric used to assess the disturbance, the taxonomical order and two binary variables stating if the study design was experimental or observational and if the animals studied were individually recognizable or not.

2.4. Results

The search carried out on Web of Science generated 2382 articles, from which, 2172 were excluded by inspecting titles and abstracts. From the remaining 210 articles after the full-text readings, we further discarded 49 articles and added 48 chosen from the articles' bibliography, resulting in a dataset of 209 articles considered in our analysis (Fig. 1).

Only 173 of these articles have been used for the cluster analysis, after excluding articles that did not meet the criteria set for the analysis of the bibliographic coupling network (i.e., share at least 5 publications with at the minimum one of the other articles). The analysis of the bibliographic coupling network generated 5 main clusters that, grouping articles citing the same sources, embody the main themes in the literature. Labelling of the clusters by examining the most common words appearing in the articles' titles and

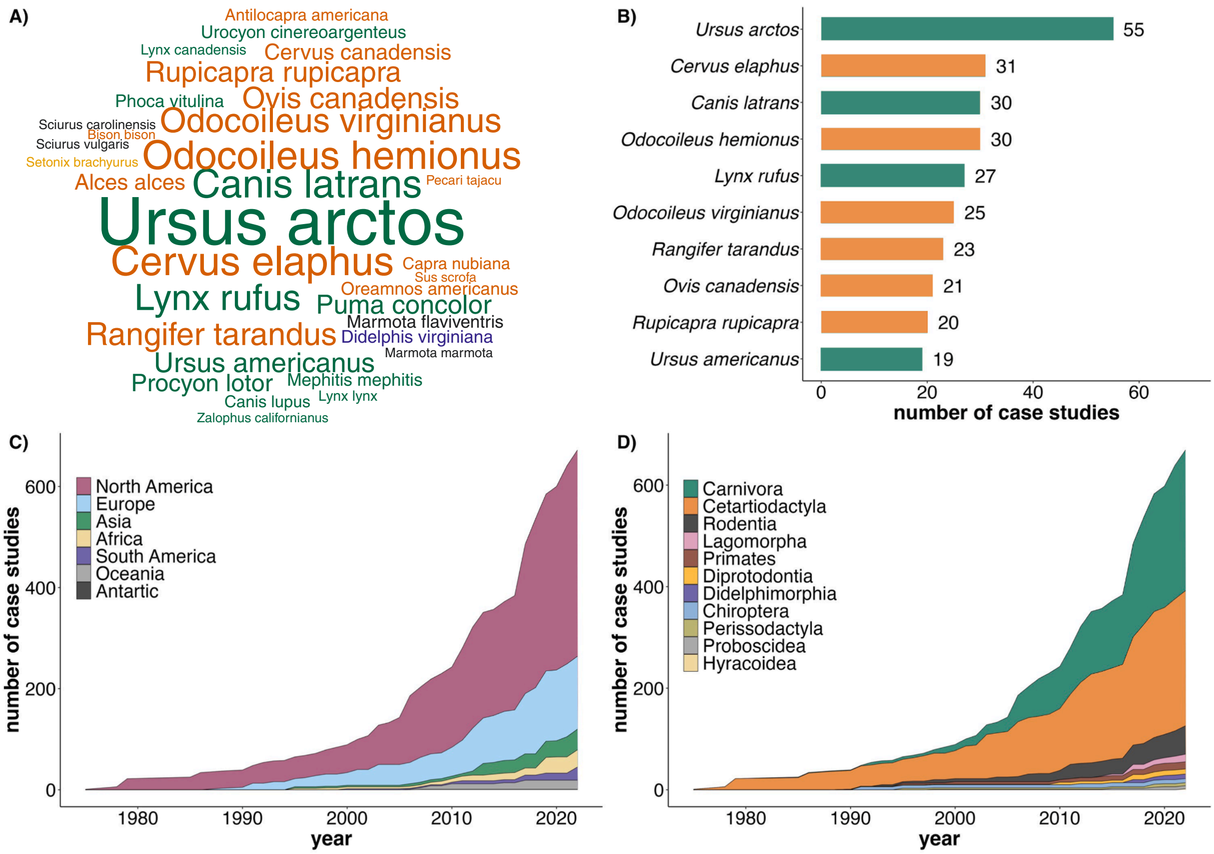

Fig. 2. Systematic and temporal distribution of the studies about the effect of recreational activities on mammals. A) Word cloud of the study subjects of the reviewed articles. Font size is proportional to the number of case studies concerning a species and different taxonomical orders are shown in different colours. For readability reasons only species appearing in at least five articles are displayed. B) The 10 most studied species (green = Carnivora species; orange = Cetartiodactyla species). C) Cumulative number of case studies relative to each continent over time. D) Cumulative number of case studies relative to each taxonomical order over time.

abstracts allowed us to define the clusters as follows: "mountain ungulates" (n = 50 – 28.9 %), "protected areas" (n = 49 – 28.3 %), "bears" (n = 39 – 22.5 %), and "aerial disturbance" (n = 21 – 12.1 %). Based on the most common words used in the titles and the abstracts, we were not able to name the 5th cluster (n = 14 – 8.1 %), because of the high heterogeneity within this group.

For the following descriptive analyses, we started with our dataset of 209 articles and excluded reviews, meta-analyses, conceptual and methodological articles. From the remaining 200 articles, we extracted 672 case studies (see the methods section for the case study definition).

2.5. About whom? – What was the target?

We were able to identify the species involved in the research in 669 case studies because 3 were focused on species richness. A large proportion of these case studies (n = 599– 89.5 %) were about a species belonging to Carnivora (n = 277 – 41.4 %), Cetartiodactyla (n = 266 – 39.8 %), or Rodentia (n = 56 – 8.4 %). The remaining 70 case studies (10.5 %) were about the other orders (Lagomorpha = 15, Primates = 14, Diprotodontia = 10, Didelphimorphia = 9, Chiroptera = 8, Proboscidea = 6, Perissodactyla = 6, Hyracoidea = 2). The number of case studies focusing on each taxonomical order did not mirror the distribution of mammal species across the different orders ($\chi^2 = 1970$, df = 10, $p < 0.001$). Of 137 species considered, 34.3 % belonged to the order Carnivora (n = 47), 31.4 % to Cetartiodactyla (n = 43), and 17.5 % to Rodentia (n = 24). The other orders together represented 16.8 % of the study species (n = 23). However, the distribution of case studies focusing on each species was considerably skewed. Only a few, mostly charismatic, species were the focus of many articles. For instance, 55 case studies (in 27 articles) focused on the effects of recreational activities on brown bears (*Ursus arctos*), making this species the most studied. The 10 most investigated species (Figs. 2a and 2b) were present in 48 % of the articles. Of 200 articles, 163 examine a single species, whereas 37 covered more than one species simultaneously.

2.6. Where? – Geographical distribution of the studies

Most of the case studies were carried out in North America (n = 408 in 104 articles), where the USA (n = 343 in 79 articles) and Canada (n = 57 in 22 articles) alone harboured the study areas of 59.8 % of the overall case studies in 51.0 % of the articles. The second continent for the number of case studies was Europe (n = 144 in 57 articles). Asia (n = 41 in 14 articles), Africa (n = 34 in 13 articles), South America (n = 26 in 6 articles), Oceania (n = 18 in 6 articles), and Antarctica (n = 1) together only accounted for 17.9 % of the case studies (Fig. 3). A single article included information from two different continents (Asia and Europe), thus the number of articles per continent sum to 201, although the number of considered articles remained at 200.

The number of case studies did not show a correlation with the total land area of the countries in which they were carried out (Spearman's rho = 0.114, p = 0.468) nor with the size of their human population (Spearman's rho = 0.118, p = 0.450). However, the number of studies carried out in a country correlated with gross domestic product per capita (Spearman's rho = 0.509, $p < 0.001$). The number of articles concerning studies conducted in North America and Europe largely exceeded the number of different studied species, whereas Africa, Asia, and South America showed the opposite pattern, with more studied species than published articles (Fig. 4). In Europe and North America few species receive the attention of most of the articles, whereas in Africa, Asia, and South America studies often focused on multiple species simultaneously.

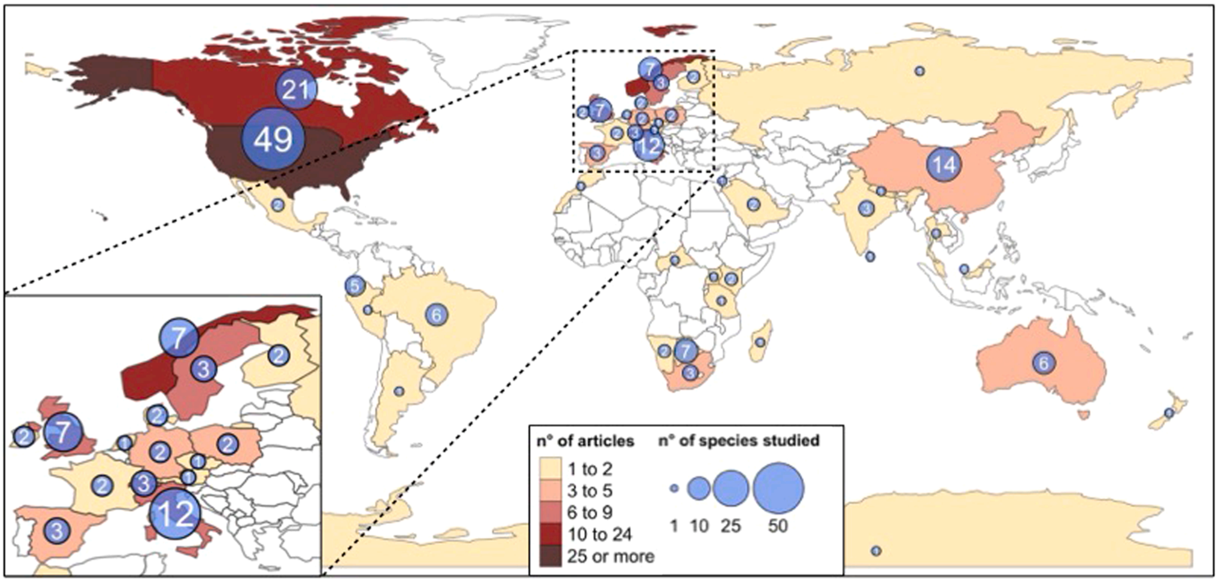

Fig. 3. Distribution around the world, with a focus on Europe, of the studies about the effect of recreational activities on mammals. Colour shades show the number of articles carried out in each country while the number of species is reported inside the blue circles.

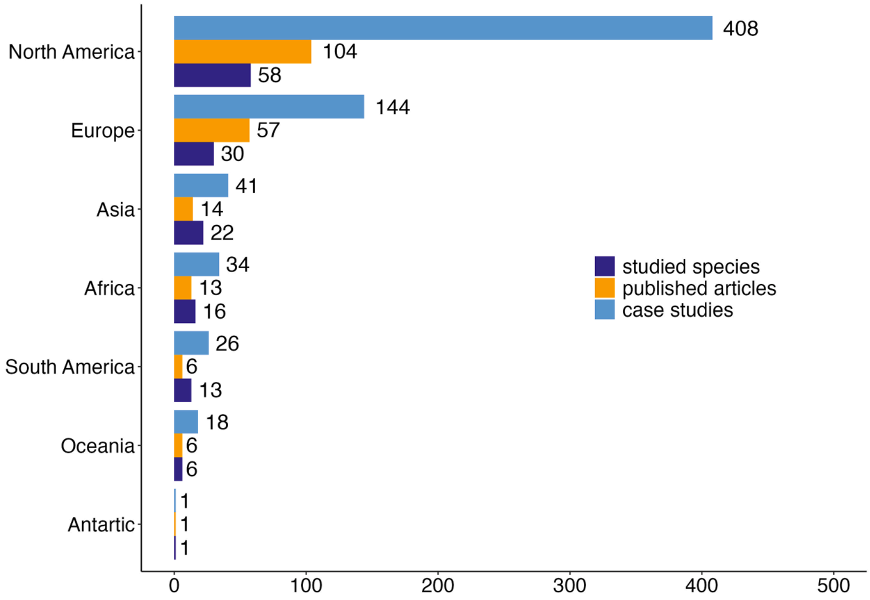

Fig. 4. Number of case studies, investigated species, and published articles about the effect of recreational activities on mammals. The results are separably reported for each continent.

2.7. When? – What are the trends in publications over time?

The first article on the topic that we found was from 1975 and was carried out in North America. The first article published from Europe was in 1988, more than a decade later, and was followed by Africa (1995), Asia (1995), South America (2000), Oceania (2006), and the only study conducted in Antarctica (2007). The increase in knowledge (i.e. the number of case studies) occurred at different pace around the world (Fig. 2c). In North America, the mean number of case studies per year increased at a fast pace ($ß = 0.520$, $t = 3.341$, $p = 0.002$), but in Europe it was slower ($ß = 0.165$, $t = 1.944$, $p = 0.061$). Although the studies carried out outside Europe and North America occurred in relatively recent times, they soon increased. Focusing on research carried out until 2003, 55 case studies (23 articles) were recorded in North America and 25 case studies in Europe (10 articles). They represent 61.8 % and 28.1 % of all the case studies, respectively. The other continents accounted for 10.1 % ($n = 9$) of case studies reported in 4 articles.

From 2003 to 2022 we found 583 case studies in 163 articles: 111 were conducted outside North America and Europe, representing 19.0 % of the case studies, and have been reported in 36 articles (22.1 %). Although it remains a small share, the contribution to the total amount of information outside North America and Europe doubled in almost 20 years. In fact, across Asia, Africa, South America, and Oceania the annual publication rate has shown a rapid increase in the last 20 years ($ß = 0.557$, $t = 2.479$, $p = 0.023$), whereas we found no trends for North America ($ß = 0.820$, $t = 1.325$, $p = 0.202$) or Europe ($ß = 0.130$, $t = 0.553$, $p = 0.587$) during that period.

Available information on species of the orders Cetartiodactyla and Carnivora showed the sharpest increases in annual publication rates (Cetartiodactyla: $ß = 0.244$, $t = 3.672$, $p < 0.001$; Carnivora: $ß = 0.603$, $t = 3.233$, $p < 0.001$), leading these orders to be the most studied nowadays (Fig. 2d). Conversely, articles focusing on Rodentia and other orders increased at a slower pace (Rodentia: $ß = 0.121$, $t = 0.048$, $p = 0.017$; other orders: $ß = 0.133$, $t = 0.066$, $p = 0.054$) compared to Cetartiodactyla and Carnivora. Until 2003, 61.8 % ($n = 55$) of 89 recorded case studies focused on the order Cetartiodactyla, 13.5 % ($n = 12$) on Carnivora, 6.7 % ($n = 6$) on Rodentia, and 18.0 % ($n = 16$) on other mammal orders. From 2003 to 2022, 45.7 % ($n = 265$) of the case studies concerned species of the order Carnivora, 36.4 % ($n = 211$) was about Cetartiodactyla, and Rodentia was the focus of 8.6 % ($n = 50$) of the case studies. All the other taxonomical orders grouped appeared in just 9.3 % ($n = 54$) of the case studies. Interestingly, the order Carnivora started to draw attention later than the order Cetartiodactyla, but showed the sharpest increase in publication rate, leading some species of this order to be deeply investigated. In the last 20 years, the annual publication rate of articles concerning the order of Cetartiodactyla did not show statistically significant linear trends ($ß = 0.094$, $t = 0.400$, $p = 0.694$). In the same period, the annual publication rate of articles focusing on the order Rodentia ($ß = 0.121$, $t = 2.537$, $p = 0.017$), other orders ($ß = 0.358$, $t = 2.257$, $p = 0.037$), and Carnivora ($ß = 0.821$, $t = 1.999$, $p = 0.061$) increased, although the latter with a trend only bordering on significance.

2.8. How was the disturbance assessed?

Hikers, with 255 case studies, were the most studied source of disturbance. Many of the case studies focused on animals' reactions to a generic disturbance or the presence of multiple sources of disturbance ($n = 183$) for which it was impossible to distinguish the single effects on animals. Far less investigated disturbances were motorised vehicles ($n = 83$), aerial disturbances ($n = 42$), bikers ($n = 36$), skiers ($n = 26$), horseback riding ($n = 19$), and water disturbances ($n = 16$). We classified 12 case studies as "other sources of disturbance".

Most of the case studies used measures of spatial behaviour (n = 309) or activity (n = 146) to assess the effects of disturbances. Flight initiation distance was used in 95 case studies, alert or vigilance behaviour in 59 studies, and only 30 investigated hormonal aspects or metabolism functioning. In 33 case studies the researchers used different metrics outside our categories that we summarised as "other metrics", including 3 cases focused on species richness. Of the 200 research articles in our database, only 7 investigated the potential effects of recreational activities on life history traits and 8 focused on their impact on population dynamics. Four (ID 53, 158, 165 and 191) of the articles that focused on life history traits measured reproductive success, one (ID 67) survival, and two (ID 64 and 177) body conditions. Three of these 7 articles detected a negative effect of recreation on reproductive success. Similarly, 3 of the 8 articles assessing population dynamics revealed negative effects of recreational activities on some population indices.

Overall, of the 669 case studies, we could assess an effect in 574 cases, after excluding data on flight initiation distance and species richness. We detected a negative effect in 325 case studies (56.6 %) of recreational activities on a species of mammal. According to the results of the GLM (Table 1), the probability of finding a disturbance effect was not significantly different among taxonomical orders. The metric used to assess the source of disturbance seemed to affect the probability of detecting a negative effect: studying hormonal aspects or metabolism functioning seemed to increase the probability of finding a disturbance effect (ß = 0.967, z = 1.768, p = 0.077). The different sources of disturbances showed differences in the overall probability of causing a disturbance: generic disturbances (ß = 0.713, z = 3.225, p = 0.001), motorised vehicles (even if close to the significance threshold, ß = 0.556, z = 1.836, p = 0.066), aerial disturbances (ß = 1.093, z = 2.168, p = 0.030), skiers (ß = 1.547, z = 2.335, p = 0.019) and water-based disturbances (ß = 1.524, z = 2.231, p = 0.026) had higher probabilities to cause a significant impact on mammals than hiking. Conversely, studies investigating the impact of horseback riding had a lower probability of finding a disturbance than those studying the impact of hiking (ß = −2.680, z = -2.547, p = 0.011). Studies focusing on individually recognizable individuals showed a higher probability of detecting a disturbance (ß = 0.951, z = 3.910, p < 0.001), whereas experimental studies were not more effective than observational ones (ß = −0.016, z = -0.049, p = 0.961).

3. Discussion

This review highlighted that the disturbances caused by recreational activities on mammals have been a trending topic in the study of wildlife biology of mammals in recent decades. However, an analysis of the results reported in 209 articles showed that this increase in knowledge was not evenly distributed based on systematic, geography, sources of disturbances considered, and metrics used to assess the response by mammals. Not surprisingly, most of the studies have been conducted in North America or Europe, where only a few, mostly charismatic, large mammal species received the most attention, confirming the general trends in scientific literature on terrestrial mammals (dos Santos et al., 2020). Most of the articles assessed variations in spatial behaviour and activity in response to hikers. However, we showed that studies investigating hormonal or metabolic traits and focusing on sources of disturbance other than hikers may have a higher probability of detecting a response to human stressors by mammals. Researchers had more probability of detecting an effect of human recreational activity when they used individually recognisable animals. Although experimental studies are generally considered more reliable than observational studies, this is not always the case (Concato, 2004). Consistently, we found no statistical difference in their ability to detect effects.

The available information in the literature is skewed towards charismatic species, often objects of hunting or management. As many

Table 1
Full output of the Generalised Linear Model analysing the features of 200 articles about recreational activities on wild mammals. See the method session for more details.

Predictors	*Estimate*	*std. Error*	*z value*	*p*
(Intercept)	−0.191	0.216	−0.883	0.377
Recognizable individuals	0.951	0.243	3.910	< 0.001
Experimental study	−0.012	0.235	0.049	0.961
Metric (reference level = spatial behaviour)				
Activity	0.294	0.222	1.322	0.186
Alert or vigilance	0.397	0.340	1.167	0.243
Hormones and metabolism	0.967	0.547	1.768	0.077
Other metrics	−0.351	0.399	−0.879	0.379
Source of disturbance (reference level = hiking)				
Aerial disturbance	1.093	0.504	2.168	0.030
Cycling	−0.609	0.435	−1.401	0.161
Horseback riding	−2.680	1.052	−2.547	0.011
Motorised vehicles	0.556	0.303	1.836	0.066
Skiing	1.547	0.663	2.335	0.019
Water disturbance	1.524	0.683	2.231	0.026
Generic or multisource disturbance	0.713	0.221	3.225	0.001
Other disturbances	−0.043	0.735	−0.058	0.954
Taxonomic order (reference level = Cetartiodactyla)				
Carnivora	−0.347	0.215	−1.619	0.106
Rodentia	−0.188	0.348	−0.540	0.589
Other taxonomic orders	−0.549	0.340	−1.615	0.106

as 9 out of the 10 species most involved in the studies we analysed (Fig. 2) are not threatened with extinction, being classified as "Least Concern" in the IUCN Red Lists, except for Rangifer tarandus which is considered "Vulnerable". This is not surprising as it reflects the taxonomical chauvinism pointed out by Bonnet et al. (2002) and Clark and May (2002). The bias in literature was also evident in the bibliographic clustering. Two of five clusters grouped articles focusing on small groups of mammals (mountain ungulates and bears) that are overly studied, compared to most other species, and they accounted for much of the research we reviewed. Notwithstanding this bias, the annual publication rates of articles over the last 20 years – stable for the orders Cetartiodactyla and Carnivora, increasing for other taxonomic orders – suggests a growing interest in different species which would be paramount to redress the taxonomical bias that characterises the literature. Different taxonomic orders did not show differences in the probability of being affected by recreational activities, even if the bias in the scientific literature may affect the statistical analysis and the model's ability to generate precise parameter estimates. The taxonomic bias can be partially explained by considering the geographical distribution of the research that was mainly carried out in North America and Europe where taxonomic chauvinism is particularly focused in favour of large mammals. All other continents accounted for a small share of the articles (18 %), in line with the patterns found by Larson et al. (2016), and reflects the widespread geographical bias in conservation science (Di Marco et al., 2017). Scientific production is a consequence of countries' wealth, leading low-income countries to carry out few studies. In our review, this is corroborated by the fact that the countries' scientific production is positively correlated with countries' per capita GDP, but not with the total land area of the countries nor their human population size. This suggests that the capacity of a country to invest money in basic research determines the contribution of that country to scientific research. On the one hand, it is expected that low-income countries face lower levels of recreation, because local people have less money and time to spend on leisure. On the other hand, some hotspots in low-income countries are heavily used by foreign tourists (likely from high-income countries) and are currently experiencing the steepest trends in nature-based recreation (Balmford et al., 2009). Moreover, it should not be forgotten that low-income countries are often hotspots of biodiversity (Palmer and Di Falco, 2012), harbouring a variety of mammal species differing from the ones living in Europe and North America. Fortunately, in the last 20 years, the interest in the disturbances caused by recreational activities has grown outside Europe and North America. If this trend were to continue, it would open new avenues to deepen the knowledge of the effects of recreational activities on mammals worldwide. Conservation science is becoming less biased from a taxonomical and geographical point of view (Di Marco et al., 2017) and the study of the effects of recreational activities on mammals is likely undergoing the same process. This increased knowledge should also lead to the revision of policies for reducing the impact of recreational activities in biodiversity hotspots, possibly including economic support to be paid by foreign users or tourists (Samal and Dash, 2023).

Hiking is a highly popular recreational activity and is potentially disturbing for mammals (Freddy et al., 1973; MacArthur et al., 1982). Therefore, most of the considered studies focused on the effects of recreation on foot. Surprisingly, our analyses showed that studies investigating their effects had less probability of detecting a significant effect compared to other recreational activities, except for disturbances by horseback riding. We believe that the key factor in this result is the fact that most of the other disturbances (i.e. disturbances by air, by terrestrial motor vehicles, and by approaches on land from the water) are related to the use of transportation. That is, these disturbances are related to people moving at an unexpected speed and that is difficult to predict. In some cases, these disturbances move in a spatial dimension (airborne or on water) that is different from what mammals are used to. In addition, in many cases, these disturbances may be related to motorized vehicles and thus noise pollution should be also considered. We cannot explain why horseback riding causes less impact than hikers, perhaps it could be related to the presence of another animal not seen as a predator. Alternatively, this result could be influenced by the small number of studies that have investigated this source of disturbance. In our analysis, we could not take into account the number of people practicing different recreational activities because this information was absent in almost all of the analysed articles, but we believe that it could be a pivotal factor in fully understanding the reaction of mammals to disturbances caused by recreational activities.

The results of our study show that sampling designs significantly affected the probabilities to detect a response to recreational activities in mammals. Interestingly, our results showed that studies carried out on individually recognizable animals raised a higher probability of finding statistically significant effects of recreation on mammals. This might be because these kinds of studies can accurately gauge the magnitude of disturbance, disentangling individual-level variations, for instance because of personality or individual plasticity, from behavioural modifications induced by environmental stressors and from random noise. Conversely, experimental studies were not found to be associated with a higher probability of detecting a disturbance. This partly unexpected result may be further evidence of the difficulty of conducting experiments on wild animal behaviour. Under free-range conditions, animal behavioural responses to experiments are influenced by many environmental factors that cannot be controlled as they can in laboratory settings. This does not seem to make experimental studies perform better than observational studies, although the former are generally associated with greater disturbance to animals and greater energy and economic investment for researchers.

Our results also showed that studies using analysis of hormone levels might be more likely to find a significant effect of recreational activities. The interpretation of wild animal behaviour is not always straightforward and may be affected by the subjective abilities and attitudes of those collecting the observations; this might affect the robustness of the behavioural studies compared with the physiological analyses. However, it should be noted that collecting physiological data is more complex, especially for elusive species and in demanding environments, and more expensive than observational behavioural studies. These considerations explain the smaller number of studies on hormonal changes but could also suggest a bias in the initial conditions of the research: physiological studies are generally associated with a high economic availability and thus with potentially more detailed information. Moreover, as hormonal analyses are expensive, there is the possibility that researchers choose to use a hormonal approach when they already have a perception of the reaction of animals to a source of disturbance.

We found that 78 % of the reviewed articles have focused on spatial behavioural and activity rhythms, with only 43 % of these focusing on individually recognisable animals. Different methods have been used to carry out such studies with reduced economic investment. For instance, direct observations by transects or advantage points and camera trapping offer cost-effective methods to study spatial distribution and activity patterns, as they enable the monitoring of multiple species simultaneously. Metrics like detectability and vigilance are commonly collected via behavioural observations, which, although inexpensive, demand substantial human capital and are prone to observer bias, potentially influencing interpretations of behaviours. Poorly designed setups can result in biased representations, while the lack of individually identifiable subjects can limit analytical power. Conversely, bio-loggers (e.g. GPS collars, which may include accelerometers) have been used to study spatial behaviour and activity rhythms more in detail, because they provide high-quality and high-frequency data continuously collected on individual and recognizable animals. The disadvantages are, however, that they are expensive and require the capture of animals. Based on the results of this review, we believe that the implementation of studies collecting physiological metrics and behavioural parameters about recognisable individuals and using bio-loggers would increase finding quality. Future studies should also aim to link physiological responses with behavioural responses to gain a comprehensive understanding of how animals are affected by recreation across different levels. Advances in cutting-edge technologies present promising opportunities to address this gap. State-of-the-art bio-loggers, which are now extremely light and small, can be adapted for use with almost any mammalian species (Ripperger et al., 2020) and enable the integration of behavioural and physiological data with information about the external environment (Wilmers et al., 2015). Although these tools offer significant potential for connecting physiological and behavioural insights, longitudinal studies will be essential to understanding the influence of recreation on life history traits and population dynamics, possibly linking short-term behavioural and physiological responses to long-term effects.

Finally, it is worth noting that studies assessing the effects of recreation on a broader scale, focusing on life history traits or population dynamics, community composition, and biodiversity are very rare. On the contrary, the understanding of the consequences of recreational activity at the population and community level should be paramount for conservation issues, allowing decision-makers to implement efficient strategies of tourism management that are aimed at the conservation of nature. It should be kept in mind that it is certainly more difficult to obtain data about modifications of some life history traits or population dynamics because they require long-term studies, which in the case of large mammals (the species more investigated) implies the implementation of research projects over many years, in some cases for a few decades, with consequent high efforts and financial commitment. Although these studies are limited in number, evidence suggests recreational activities can negatively impact life history traits like reproductive success and influence population dynamics. However, understanding of these effects remains scarce and inconsistent, as similar methods can yield different results. For instance, Phillips and Alldredge (2000) found that approaching animals, mimicking recreational pressure, reduced red deer reproductive success, whereas Frame et al. (2007) observed no such effect on wolves (*Canis lupus*). Expanding this knowledge is crucial to identify general patterns. Current research often focuses narrowly on specific traits, mainly behavioural traits, but exploring links with individual life history traits like body condition, survival, and reproduction under recreational pressure is needed. In this framework, longitudinal studies are essential to clarify how recreational impacts scale from behaviour and physiology to life history and population-level effects.

4. Conclusion

Overall, recreational activities exert a considerable disturbance, because 74.0 % of reviewed articles reported at least one negative effect of recreation on mammals. It is important to acknowledge that we cannot estimate sensitivity and specificity in detecting effects due to potential bias in the article set. Studies are likely conducted where disturbances were already suspected, meaning our review does not consider a random sample of all scenarios involving recreational activities in mammal habitats. This bias may influence the interpretation of statistical results, which we thus discussed with caution. We have generally noticed heterogeneous impacts of some types of disturbance. In addition to the different sensitivities of different species, which is not easy to point out, we must consider that the behavioural responses of animals are closely related to the environmental context in which the disturbance occurs. Moreover, the same activity may occur with different modalities and frequencies. Our review of the scientific literature on this topic has highlighted the negative potential of most recreational activities but with great heterogeneity in their impact on mammals. Despite that, recreationists appear to be unaware of their potentially harmful effect on wildlife (Gruas et al., 2020). If on the one hand, the studies considered in this review are essential to understanding the threats faced by wildlife, on the other hand, there is a compelling need to increase awareness among recreationists, tour operators and nature guides. Notwithstanding these threats, recreational activities remain essential for raising awareness in the public about the threats that nature is facing, even by the same recreationists that should gain awareness, and lastly to generate the economic interest that is essential for nature conservation. Striking a balance between recreational activities and conservation measures is crucial to contrast biodiversity loss while ensuring at the same time access to nature for people, together with all the benefits associated with it (human wellness, increased awareness on conservation issues, economic benefits) and the wealth provided by the tourism sector. These balances should be different depending on the economic and conservation interests at stake, highlighting once again the importance of understanding the effects of recreational activities on a broad range of species in different ecological and recreational contexts.

This systematic review of the effects of recreational activities on wild mammals can allow us to draw some general suggestions for future studies in order to obtain more comprehensive and robust findings which can help managers and policymakers in defining strategies for a better mammal conservation. The following are some indications that should be adopted when planning new studies on the effects of different recreational activities:

1. Although taxonomic and geographical biases in research appear to be diminishing, we encourage researchers to prioritize studies on underrepresented taxonomic orders and regions beyond North America and Europe. This is particularly important in areas

where tourism and associated recreational activities are rapidly expanding, as these regions are likely to experience increasing anthropogenic pressures on wildlife.

2. We showed that articles describing studies that were carried out on individually recognizable animals had a higher probability of detecting significant effects of recreational activities on mammals. We are aware that the capture, handling, and tagging of animals is time-consuming, expensive, and carries a risk for the captured individuals (Stiegler et al., 2024). Thus, its implementation must also be weighed against the risks for the conservation of the target species. However, generally, we urge researcher to implement projects that use individually recognizable animals considering their greater effectiveness.
3. Because the physiological modifications may have a considerable impact on the well-being of individuals, we encourage scientists and wildlife managers to consider these measures in their monitoring projects because it could deepen our understanding of the effects of recreational activities.
4. We advise researchers to carefully choose the measurements to be carried out in projects directed toward studying animal responses to recreational activities, preferring research protocols that use automated data collections (e.g., via GPS sensors or accelerometers or other bio-loggers) for behavioural studies and, where possible, to pair these behavioural studies with an investigation on physiological traits.
5. While we recognize that longitudinal studies on individual life history traits or demographic parameters are among the most challenging to conduct, especially in long-lived species such as mammals, we strongly encourage researchers to pursue such investigations. These studies are uniquely capable of distinguishing the ultimate effects on wild species from behavioural or physiological changes that may be mitigated through alternative strategies and therefore exert minimal impact on the species being studied.
6. Our last strong suggestion is to include numerical quantification of the sources of disturbance in future studies (e.g. hikers per day or number of overflights per day) to enable a better understanding of the role of different disturbances and to disentangle the effect of activities per se from the amount of disturbance. In several cases, the number of people may be more important than the kind of activity practised in modifying the perceived risk in mammals.

Ethics Statement

Not applicable: This manuscript does not include human or animal research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03485.

Data availability

We shared our data as Supplementary materials

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