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Publication trends in global biodiversity research on protected areas

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ABSTRACT

One of the main strategies to reduce the global loss of biodiversity has been the establishment of protected areas (PAs). High quality biodiversity knowledge is essential to successfully design PAs and PA networks, and to assess their conservation effectiveness. However, biodiversity knowledge is taxonomically and geographically biased. Even though PAs are typically more intensively surveyed than surrounding landscapes, they cannot avoid biodiversity knowledge shortfalls and biases. To investigate this, we performed a systematic literature review to assess publication trends in global biodiversity research taking place in PAs. Our data indicate that animals are more studied than plants, with vertebrates overrepresented in relation to invertebrates. Biodiversity in PAs has been mainly measured taxonomically (species richness or species diversity), while functional and phylogenetic diversity have rarely been considered. Finally, as predicted, there was a geographic bias towards European and USA terrestrial protected areas. These observed trends mirror more general studies of biodiversity knowledge shortfalls and could have direct negative consequences for conservation policy and practice. Reducing these biases and shortfalls is essential for more effective use of limited conservation resources.

1. Introduction

Our planet is considered in the midst of an environmental crisis (Barnosky et al., 2011). Human actions, such as land-use change, pollution, alien species introductions, emergent diseases, habitat destruction and fragmentation, and unsustainable resource exploitation are driving historically unprecedented levels of biodiversity loss (Allan et al., 2019; Sutherland et al., 2023). This biodiversity decline not only has ethical implications (May, 2011), but is negatively affecting ecosystem functioning and, consequently, jeopardizing the numerous goods and services humans obtain from nature (Worm et al., 2006; Pecl et al., 2017).

Many different conservation policies have been proposed to slow these unsustainable rates of global biodiversity loss. The most widely adopted and effective of these strategies has been the creation of protected areas (PAs) (i.e., legally protected geographic spaces), with the objective of preserving the most singular and diverse regions from different temporal and spatial perturbations (Watson et al., 2014). Ideally, conservation strategies such as PAs should be based on a comprehensive knowledge about the identity and number of organisms present in a region, their ecological and cultural characteristics, geographic distribution, evolution, and dynamics (Rands et al., 2010), as well as on the complexity and uniqueness of the existing habitats and ecosystems (Visconti et al., 2019). In reality, even though biodiversity conservation research has increased considerably during the last century (Stork and Astrin, 2014), there are still enormous shortfalls in our knowledge of global biodiversity (Hortal et al., 2015). Gaps and biases in biodiversity knowledge mean that conservation researchers and practitioners have to deal with deficient and unrepresentative data, which in turn may lead to errors in conservation prioritization and planning, and to difficulties predicting how organisms will respond to global change (Hortal et al., 2015).

One of the main knowledge biases detected in conservation literature is the taxonomic group studied (Clark and May, 2002; Donaldson et al., 2017; Troudet et al., 2017). For example, there are more conservation-related publications about vertebrates than invertebrates (Di Marco et al., 2017; Titley et al., 2017), despite invertebrates representing 95 % of animal diversity (Brusca et al., 2016). Within vertebrates, mammals and birds are more represented in the literature, but studies about fishes are less frequent (Fazey et al., 2005a; Donaldson et al., 2017). Even within well studied groups such as mammals, there is a considerable higher representation in the literature of the most charismatic taxa with

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larger body masses (dos Santos et al., 2020). Interestingly, plants seem to have a more adequate representation in conservation research that more closely relates to their relative prevalence in nature (Clark and May, 2002; Di Marco et al., 2017; Troudet et al., 2017). Taxonomic biases have direct implications for conservation policies (García-Macía et al., 2021); for example, mammals and birds, which benefit from higher conservation effort, also have the highest number of management plans (García-Macía et al., 2021). These species are frequently chosen as umbrella or flagship species, and although the protection of these well-known species might benefit other less studied ones (Roberge and Angelstam, 2004), there is an urgent need to reduce taxonomic biases in research in order to efficiently develop conservation plans that benefit all species (Di Marco et al., 2017; Troudet et al., 2017) and to ensure the most effective use of limited conservation resources.

Biases about biodiversity knowledge are not limited to taxonomic groups. Traditionally, biodiversity has been measured from a taxonomic perspective as either species richness and/or diversity (Cianciaruso et al., 2009). However, biodiversity has other facets, such as functional diversity (i.e. the range, values, and relative abundance of functional features or traits of a given community; Harrington et al., 2010) or phylogenetic diversity (i.e. the evolutionary history encompassed by a set of species; Faith, 1992), which arguably better relate to the maintenance, stability and functioning of the ecosystems (Craven et al., 2018). Although some biodiversity studies have sought to combine all diversity facets (e.g. Brum et al., 2017; Wong et al., 2018; Ottaviani et al., 2019), and some conservation projects prioritize endangered and evolutionary distinct species in conservation planning (e.g. EDGE of Existence initiative; Isaac et al., 2007), biodiversity conservation approaches continue to be dominated by the traditional taxonomic perspective (e.g. Gray et al., 2016; Rosso et al., 2018; Nori et al., 2020).

Another important knowledge bias that can impact conservation policies relates to how much is known about species geographical distributions (Cardoso et al., 2011; Di Marco et al., 2017). Inevitably, there are large regional differences in conservation research effort with knock-on effects on biodiversity knowledge (Hortal et al., 2007). The amount of published literature about biodiversity conservation thus varies across regions (Di Marco et al., 2017; Hughes et al., 2021), with North America and Western Europe contributing the highest volume of research (Lawler et al., 2006; Titley et al., 2017), while the most biodiverse countries tend to invest relatively fewer resources in the study and protection of biodiversity (Reed et al., 2020; da Silva et al., 2020). Furthermore, while temperate, broad-leafed and mixed forests are the most studied systems (Lawler et al., 2006), marine and freshwater habitats are significantly underrepresented (Di Marco et al., 2017), especially deep sea areas (Hughes et al., 2021). Biased geographic knowledge increases uncertainty about species distributions and local diversity (Boakes et al., 2010), hindering the conservation prioritization (Hortal et al., 2015; Di Marco et al., 2017).

Knowledge biases in ecology and conservation research will also affect PAs, even though these sites are often chosen with the partial objective to develop biodiversity research (Boakes et al., 2010; Velasco et al., 2015) and some PA designations have research as a strategic objective. An accurate knowledge about biodiversity hosted by PAs is particularly important to assess their effectiveness as conservation tools, improve management actions or even modify their shape, size, or location (Margules and Pressey, 2000). Identifying shortfalls in knowledge about the biodiversity safeguarded in PAs is an essential first step towards reducing or accounting for such biases, ultimately leading to more successful conservation planning.

The aim of this study was therefore to evaluate trends in biodiversity research developed in PAs through an analysis of published research, to identify the current state of knowledge and detect potential shortfalls. Specifically, we performed a systematic literature review focusing on three leading conservation journals (*Biodiversity and Conservation*, *Biological Conservation*, and *Conservation Biology*), compiling and scanning all the published articles that contributed with information about the diversity harbored in PAs. We then explored general publications trends taking into consideration different characteristics of each study, such as the taxonomic group studied, the diversity facet measured, the scale and geographic region explored, or the source of the data used. We also evaluated more specific hypotheses to assess if: (1) each taxonomic group has had proportionally the same amount of research effort in all continents; (2) the proportion between articles that generated new data and articles that used available data was the same for all taxonomic groups, and; (3) studies that contribute with new data are equitably distributed across continents.

2. Material & methods

Data gathering and selection were based on the protocols available on the updated Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement, which provides complete guidelines to correctly report systematic literature reviews (Page et al., 2021), and also on the recommendations contained in Foo et al. (2021). The workflow of the methods used is represented in Fig. 1 (see more details below).

2.1. Literature survey

We used the ISI Web of Knowledge database (http://www.webofscience.com), assessed on 15th of July 2021, to perform a systematic search of peer-reviewed literature published from 1980 until the search date, that focuses on the biodiversity of PAs. The systematic search included the following terms using Boolean characters and parentheses: ("functional diversity" OR "trait diversity" OR "phylogenetic diversity" OR "evolutionary diversity" OR "taxonomic diversity" OR "species diversity" OR "species richness") AND ("protected" OR "reserve" OR "reserves" OR "national park*" OR "natural park*" OR "conservation area*"). These terms were searched in the title, abstract and author's keywords fields, excluding those publications that included these terms exclusively in their KeyWord Plus® (words or phrases that frequently appear in the titles of an article's references, but do not appear in the title of the article itself; Clarivate Support, 2022), a parameter considered by default when searching in Topic field in Web of Knowledge (see table A.1, Appendix A for the complete search protocol).

A high volume of published literature was retrieved (~8000 articles). A subset of these publications was selected by retaining all the manuscripts published in three prominent biodiversity conservation journals: *Biodiversity and Conservation, Biological Conservation and Conservation Biology*. These journals are broadly representative of the global scientific literature on conservation, having been selected as the focus of similar literature reviews (Fazey et al., 2005a, 2005b; Velasco et al., 2015). After this procedure, a total of 800 articles were retained.

2.2. Exclusion criteria

Two further rounds of article selection were then performed (Fig. 1). The selected articles were initially screened only by title, abstract and keywords using a literature screening tool called Rayyan (Ouzzani et al., 2016). Only articles written in English were considered, excluding also narrative reviews, theoretical articles, socio-economic studies, and texts that compared methodologies of data gathering or analysis. Articles that did not measure any diversity facet or did not consider a current protected region were also discarded. We included articles focused on animals and/or plants, excluding publications that studied other kingdoms or fossil data, and also publications about the effects of parasites, pathogens and diseases on populations. Finally, articles that focused on a single species or below the individual level (e.g. cellular) were also excluded. Following these exclusion and inclusion criteria, 505 articles were retained (Fig. 1). The second round of manuscript selection was based on a full-text screening (Fig. 1). Following the same exclusion criteria as described above, 116 articles were discarded leaving 389

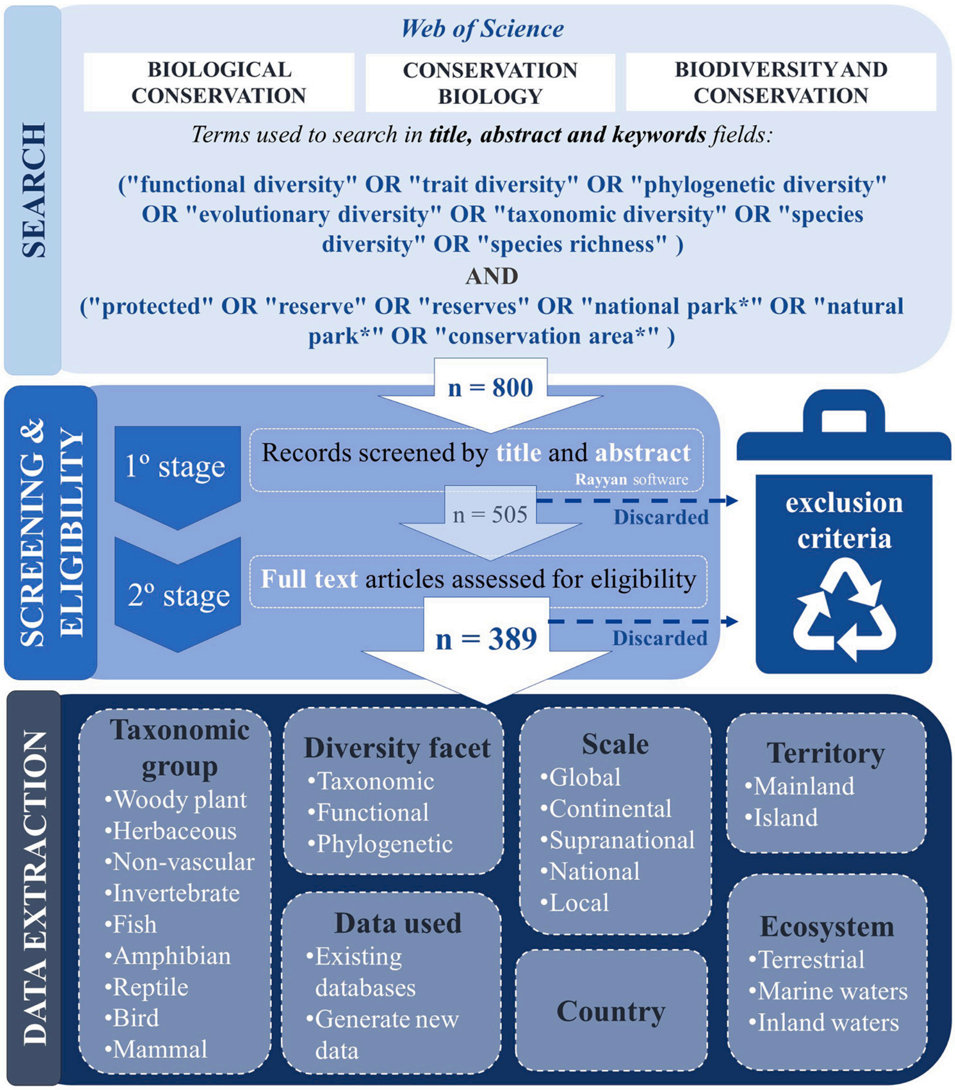

Fig. 1. Methodology workflow used to perform the systematic literature review of biodiversity research developed in protected areas. Initially, we conducted a literature search in three leading conservation journals (*Biodiversity and Conservation, Biological Conservation and Conservation Biology*), using a set of search terms ("search" rectangle) that were screened in each article title, abstract or keywords. Afterwards ("screening & eligibility" rectangle), we screened again the articles following some exclusion criteria, looking not only at the title and abstract, but also on the main text when necessary (a complete explanation of the exclusion criteria applied can be found in the main text). Finally ("data extraction" rectangle), we extracted from each of the 389 retained studies data about: i) the taxonomic group considered; ii) the diversity facet measured; iii) geographic information about the explored region (e.g., research scale, countries involved, ecosystems and territories studied) and iv) the source of the data used.

publications for data extraction (Appendix B for a detailed list of the manuscripts retained).

2.3. Data extraction and analysis

The following information related to the objectives and methodology was retrieved from each of the selected publications: i) the taxonomic group considered; ii) the diversity facet (taxonomic, functional or phylogenetic) measured; iii) geographic region, and iv) the source of the data used (see Fig. 1). We classified the taxonomic groups studied as: woody plants, herbaceous plants, non-vascular plants, invertebrates, fishes, amphibians, reptiles, birds and/or mammals. Information about invertebrate classes was also collected. Manuscripts that considered more than one taxonomic group were counted in as many categories as groups studied, meaning that the sum of articles that studied each of the taxonomic categories is greater than the net number of articles retained.

We also collected information about the spatial scale addressed by the research [i.e., global, continental, supranational (a region that involved at least two countries), national (a whole country) or local (a region smaller than the borders of a country)] and the name of the country (or countries in the case of supranational research). Articles were also classified depending on whether the explored territory was continental and/or insular, and on the type of ecosystems studied (i.e., terrestrial, inland waters or marine waters).

We also obtained information on the origin of the data, classifying articles depending on if they used available data and/or generated new data (species occurrence, trait measurements, or DNA extraction and/or sequencing).

Data compiled were explored through descriptive and inferential statistics (Chi Square tests). All analysis were performed in R Version 1.4.1103 (R Core Team, 2020).

3. Results

Woody plants were the most frequently studied group, followed by herbaceous plants (Fig. 2). However, as a whole, plants were less studied (41 %) than animals (59 %) when considering all groups together. Regarding articles on animal biodiversity, 67 % focused on vertebrates while the remaining 33 % investigated invertebrates. Insects were the most studied invertebrate group (Fig. 2), although 59 % of the articles that explored insects focused on only two of the 29 extant insect orders: Lepidoptera and Coleoptera. Birds and mammals were the most studied vertebrates, while fishes were the least investigated (Fig. 2). Studies that focused only on a single taxonomic group were more frequent (61 %) than multitaxon studies.

The vast majority of studies (92 %) only considered one diversity facet, while 24 manuscripts (6 %) explored two diversity facets, and just seven articles (2 %) measured taxonomic, functional, and phylogenetic

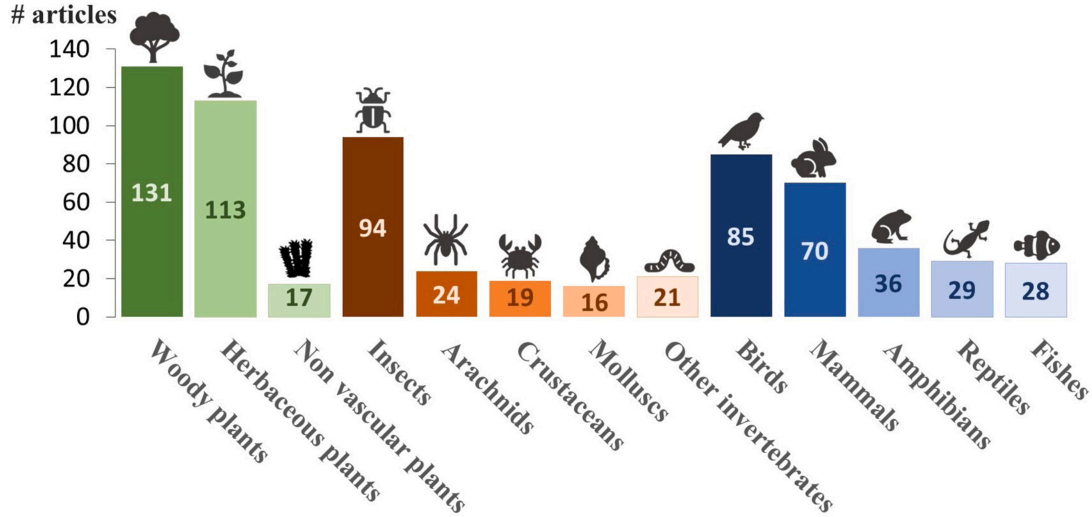

Fig. 2. Number of articles that studied each taxonomic group. Plants (woody, herbaceous and non-vascular) are represented in a green color gradient, invertebrates' classes (Insects, Arachnids, Crustaceans, Molluscs, and others, which includes the rest of invertebrates' classes) are represented in an orange color gradient, and vertebrates' classes (Birds, Mammals, Amphibians, Reptiles, and Fishes) are represented in a blue color gradient. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

diversity in PAs. Most articles (91 %) exclusively measured taxonomic diversity, while those that measured only functional or phylogenetic diversity were much less frequent (0.8 % and 0.3 % respectively; see Fig. 3).

Most articles described studies done at a local scale (i.e. a region smaller than the borders of a country; 81 %). Forty-nine manuscripts (13 %) focused on PAs from a single country, 21 (5 %) were based on PAs from at least two countries, one considered a whole continent and two articles measured diversity at the global scale. European PAs were the most frequently studied (93 articles), followed by African PAs (86 articles) (Fig. 4). However, almost 60 % of all the African focused articles were from just three countries (Uganda, Tanzania and South Africa). The countries most frequently studied were USA (31 articles), Brazil (31) and South Africa (30), and the countries with the highest proportion of published articles when taking into consideration the percentage of their terrestrial protected surface were South Africa, India and USA (Fig. 4). Many countries, especially in Africa and Asia, were not represented in the database. Although European PAs were the most frequently studied,

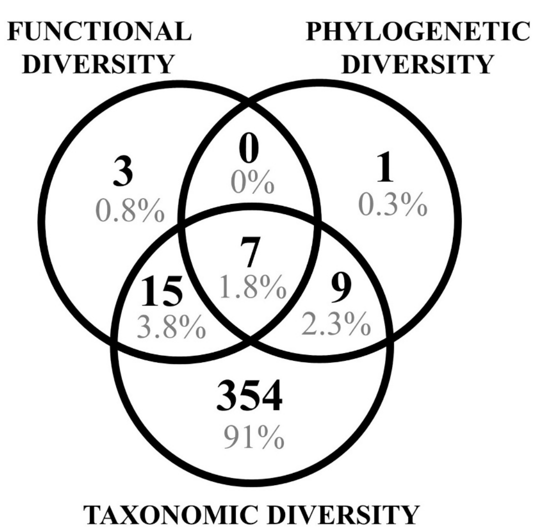

Fig. 3. Venn's diagram representation of the absolute number and percentage of retained articles that measured each diversity facet (taxonomic, functional and phylogenetic), or a combination of them.

the articles focused on them explored almost exclusively one diversity facet. Conversely, Asia was the continent with the highest percentage of articles that measured more than one diversity facet. At least one article measured a combination of taxonomic, functional and phylogenetic diversity on each continent except in North America and Oceania (Fig. 4). We found differences across continents also in the proportion of published studies about each taxonomic group (Fig. A.1, Appendix A; $\chi^2 = 114$, d.f. = 65, p-value = 0.002). For example, there were very few articles studying invertebrates in Asian PAs, with just eight studies focusing exclusively on insects. Myriapods and arachnids were also not studied in any research work of Oceania (Fig. A.1, Appendix A), and non-vascular plants were absent from African or Oceanian studies (Fig. A.1, Appendix A).

Manuscripts that measured biodiversity solely in PAs located in islands were less frequent (14.8 %) than continental research, while 7.7 % of the articles correspond to studies done considering both mainland and insular PAs. The database contained 87 % of articles focused on PAs placed in terrestrial habitats whereas articles that studied inland or marine protected waters were scarce (7 % and 6 % respectively).

Most manuscripts generated new data (75.7 %), while the rest exclusively used available datasets. However, the vast majority of the articles that produced new data (98.6 %), only contributed new taxonomic data (i.e. species identity and occurrence). Just one article contributed new phylogenetic information (DNA extraction and sequencing), and four measured new functional traits. The proportion between studies that contributed with new data and studies that used existing data was not identical for all taxonomic groups ($\chi^2 = 30.9$, d.f. = 13, p-value = 0.003). At least 60 % of the articles about invertebrates or plants generated some new data, while existing databases were most frequently used in research focused on terrestrial vertebrates (Fig. A.2, Appendix A). There were no differences between continents in the terms of studies that used existing data or that contributed new data ($\chi^2 = 2.17$, d.f. = 5, p-value = 0.82).

4. Discussion

Creating protected areas (PAs) has been the main global strategy for preserving biodiversity (Ladle and Whittaker, 2011). However, the success and robustness of conservation policies partially depends on having accurate and unbiased knowledge of the biodiversity they host (Rands et al., 2010). In this study, we clearly demonstrate that

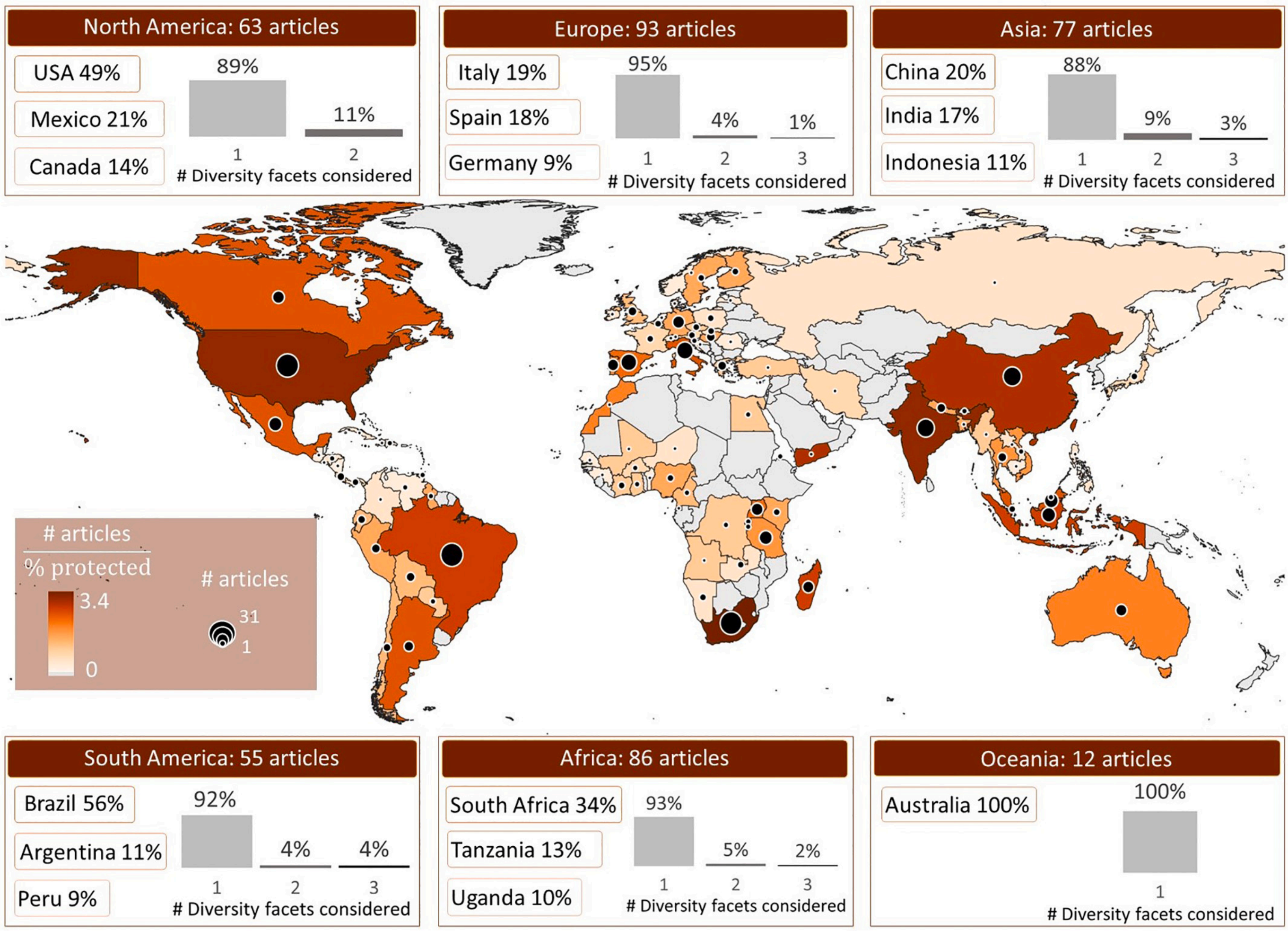

Fig. 4. Geographic distribution of the manuscripts published about the biodiversity of protected areas in the journals *Biodiversity and Conservation, Biological Conservation and Conservation Biology*. The color gradient represents the proportion between the number of articles and the percentage of protected land surface of each country (marine-focused articles were excluded). The absolute number of articles per country is represented by the black circles of proportional size. The boxes contain information about the number of articles focused on each continent, as well as the three most frequently studied countries. The small diagrams inside the boxes represent the percentage of manuscripts per continent that studied one, two or all diversity facets (i.e., taxonomic, functional and/or phylogenetic diversity).

biodiversity research in PAs has distinct biases and shortfalls. Identifying research gaps is an essential prerequisite for redirecting research efforts with the aim of achieving a comprehensive understanding of biodiversity patterns (Hortal et al., 2015), which would improve conservation practices in the long term (Rands et al., 2010).

Our systematic literature review indicated that some taxonomic groups are more studied than others in PAs. For example, although invertebrates represent 95 % of animal diversity (Brusca et al., 2016), they are much less studied than vertebrates in PAs. Even among vertebrates there are considerable biases, with a clear focus on mammals and birds. These results agree with previous trends detected in conservation literature (Lawler et al., 2006; Di Marco et al., 2017; Titley et al., 2017; Donaldson et al., 2017). Also corroborating earlier results (Titley et al., 2017; Rocha-Ortega et al., 2021), we found that insects are the invertebrate class most studied, and Lepidoptera and Coleoptera the orders most frequently assessed, probably due to their relatively larger body sizes and conspicuousness which has traditionally attracted the attention of researchers (Gaston, 1991). Interestingly, although we found less articles on plants than on animals, they are still better represented in our sample when considering the relative prevalence of this kingdom in nature (Clark and May, 2002). These taxonomic biases might reflect the conservation funding that is directed towards one taxonomic group or another. Indeed, plants receive less funding than animals (Adamo et al., 2022), and even within animal groups, there is a disproportionate distribution of conservation resources that greatly favors vertebrates and very often ignores invertebrates (Cardoso et al., 2011; Mammola et al., 2020). Taxonomic biases unavoidably lead to an unbalanced understanding of biodiversity and speculative conservation decisions (Troudet et al., 2017). Thus, accurate data about the biodiversity of PAs is crucial to improve the effectiveness of conservation actions (Troudet et al., 2017) and to monitor PAs performance (Rodrigues and Cazalis, 2020).

Functional diversity or phylogenetic diversity were only considered in a very small percentage of our articles database. This could be partially related to the more recent development of many of the concepts and metrics associated with those diversity facets (e.g. Faith, 1992; Petchey and Gaston, 2002, which represent keystone works) than the most common metrics used to measure species diversity (e.g. Shannon, 1948; Simpson, 1949). Still, as most articles we retrieved were published after 2002 (83 %), and there is no strong tendency for an increasing number of publications focusing on functional and phylogenetic diversity through time. This imbalance probably reflects a very variable uptake and use of alternative ways of measuring biodiversity by the global conservation community. Designing PAs and assessing their effectiveness based only on taxonomic diversity, assumes that all the species contribute equally to biodiversity, ignoring that some species perform pivotal ecosystem functions (Leuzinger and Rewald, 2021) or differ in terms of evolutionary history (Tucker et al., 2019). Focusing on species richness per se could lead to preserving areas characterized by high species diversity, but with similar assemblage composition, disregarding exceptionally diverse communities (Brown et al., 2015) which presumably favor optimal ecosystem functioning (Cadotte et al., 2012; Winter et al., 2013) and the continuity of services they provide (Molina-Venegas et al., 2021).

The lack of studies on functional and phylogenetic diversity in PAs may ultimately be driven by the lack of knowledge of species traits and their ecological functions (the 'Raunkiæran shortfall'; Hortal et al., 2015), and on the tree of life and the evolution of species (the 'Darwinian Shortfall'; Diniz-Filho et al., 2013). Although three quarters of the articles contributed new data, these typically provided new information about species occurrence, and very few measured new functional traits or sequenced DNA. Studies that integrate functional and phylogenetic diversity very often use public databases about species traits (e.g. Kattge et al., 2011; Wilman et al., 2014; Shirey et al., 2022) and existing phylogenies or DNA sequences (e.g. VertLife project (http://vertlife.org), GenBank (https://www.ncbi.nlm.nih.gov/genbank/)). However, such databases are usually incomplete, and taxonomically and geographically biased towards the best-known regions and taxa (Etard et al., 2020), which could hinder the development of multifaceted projects and explain the higher frequency of articles about vertebrates that used existing data. By continuing to use incomplete databases without making efforts to fill in the gaps in current knowledge, researchers are perpetuating the limitations, errors, and uncertainty that the use of such resources entails in research (Violle et al., 2015). Thus, it is crucial to increase the efforts to create new databases about the regions and taxonomic groups less studied, as well as to complete the already existing ones (Etard et al., 2020). This could be the first step to facilitate the development of projects that integrate different diversity facets.

Our study corroborates the geographic biases towards Europe and North America that were previously identified in conservation research (Lawler et al., 2006; Di Marco et al., 2017; Hughes et al., 2021). This could be because European countries and USA are the regions that have traditionally harbored the highest number of protected areas (McNeely, 1994; Protected Planet, 2022), with some of them having been established over a century ago (e.g. Yellowstone National Park, 1872). More generally, conservation research efforts are less related with the biodiversity of a place or conservation necessity, being more influenced by national and regional research capacity (Roberts et al., 2016; Titley et al., 2017). In regions with low research capacity such as Africa, research was concentrated in a handful of countries (South Africa, Tanzania and Uganda) which only represent 7.9 % of the total surface of the continent. However, it is important to highlight that these three countries harbor 40 % of all PAs of the continent (Protected Planet, 2022) which could explain the great number of articles focused on their PAs. Although some journals are implementing measures to reduce these geographic biases (Burgman et al., 2015), these publication trends still exist. An incomplete and biased knowledge about the geographic distribution of the species (the 'Wallacean shortfall'; Lomolino, 2004; Hortal et al., 2015) increases uncertainty about species distribution and local diversity (Boakes et al., 2010), hinders the selection of priority regions to be protected, and jeopardizes the efficient use of conservation resources (Cook et al., 2012; Di Marco et al., 2017). In addition, in the current context of global change, long-term studies are essential for detecting changes in population dynamics and adapt conservation strategies. One of the most effective ways to achieve this is through Long Term Ecological Research (LTER) sites, which are now widely distributed throughout the world but are much more prevalent in Europe and very sparsely represented in Africa and central Asia (Mirtl et al., 2018).

More than three-quarters of the articles considered exclusively mainland PAs. However, islands are hotspots of species diversity and endemicity (Kier et al., 2009), harboring ~50 % of the endangered species (Whittaker et al., 2017) and 75 % of the known extinctions of the last centuries (Fernández-Palacios et al., 2021). Therefore, although islands occupy a small portion of Earth's surface (~6.7 %), they should be priority sites for conservation research and practices. Research developed in PAs located in terrestrial systems is almost eight times more frequent than that conducted in aquatic systems. Several conservation studies corroborate these findings (e.g. Fazey et al., 2005a; Velasco et al., 2015; Di Marco et al., 2017); specifically, it has been found that temperate, broad-leafed and mixed forest biomes are the most studied ecosystems (Lawler et al., 2006), while research about deep sea diversity is still scarce (Hughes et al., 2021). Oceans and seas represent more than 70 % of the earth's surface, but just 8.1 % of its surface is covered by protected areas, whilst 15.8 % of mainland surface is protected (Protected planet, 2022). In addition, marine protected areas have started being established some decades after terrestrial protected areas (Everglades National Park, Florida, USA, which was the first National Park that included a coastal-marine component, was established in 1934; Salm and Clark, 1984), which may have also contributed to a lower number of articles in these areas. The fact that these systems have been less explored may contribute to the major gaps that still exist in basic knowledge of marine biodiversity (Costello et al., 2010) which should be reduced in order to create successful new conservation areas and evaluate the existing ones (Saeedi et al., 2019).

Although we present some clear publications trends in biodiversity research on PAs, we are aware that the methodological approach used has some caveats. Focusing on three of the most prominent international journals dedicated to conservation science (i.e. *Biodiversity and Conservation, Biological Conservation and Conservation Biology*) may have led to some taxonomic biases, as research focused on charismatic taxa or 'popular' organisms seem to be more frequently published in leading journals (Caro, 2007), as well as multi-taxa and broad geographic scale studies (Burgman et al., 2015). Also, publishing in these journals many times entails the payment of high fees (> USD 2000) that many researchers cannot afford, and so, these differences in researchers' ability to invest in science and publish in prominent journals could have also biased our selection towards research funded from high-income countries (Fazey et al., 2005b). The main alternative to reduce these potential biases would be searching for studies based on the name of the PA (e.g. Correia et al., 2016), an approach that is not adequate to be applied at large geographic scales. Our search is also biased towards literature published in English. Although language is recognized as one of the main barriers of biodiversity conservation science (Amano and Sutherland, 2013), there is a clear consensus on recognizing English as the universal language in science, precisely to improve the worldwide transferability of the results (Drubin and Kellogg, 2012). Research written in other languages than English, although fundamental as they are to conservation, are not easily accessible to everyone, which would also represent a knowledge shortfall for part of the scientific community. Local journals with articles written in other languages than English could increase their visibility among the scientific community by including an English version of the abstract and keywords, a strategy already in place in a reduced number of such journals (e.g., *Revista de Biología Tropical*). Finally, we are aware that some information about PAs is only available in technical reports made by, for example, the administration of each PA, local, regional, or national governments, and also NGOs. Our search did not include this information, that many times is not publicly available. Still, the journals selected are representative of the global scientific literature on conservation, so we believe that these caveats do not alter the overall trends found in this study, and that the results presented actually reflect publications trends in the research conducted in protected areas.

5. Conclusions

This systematic literature review highlights that there are biases in the publication trends in global biodiversity research on PAs. Such biases are pervasive at different levels, from: i) the focal taxonomic group, being animals more favored than plants, especially vertebrates; ii) the geographical location, as there is a clear bias towards studies in European and United States' PAs, and particularly towards terrestrial environments; to iii) the facet of biodiversity that is analyzed, as functional and phylogenetic diversity are less evaluated than taxonomic diversity. These trends highlight the topics that have traditionally received less attention in the literature, indirectly pointing to some potential knowledge shortfalls. Biodiversity knowledge shortfalls have negative effects in conservation, as these lead to inaccurate estimates of species diversity and threats, lack of ability to predict species' responses to changes, or uncertainty about conservation prioritization schemes and systematic conservation planning (Hortal et al., 2015). As protected areas are one of the main strategies to halt biodiversity loss, it is essential to maximize the effectiveness of these conservation tools (Ladle and Whittaker, 2011). An accurate knowledge of the biodiversity hosted by PAs is the first step to correctly assess their effectiveness and modify or propose successful management actions (Cook et al., 2012). Thus, detecting knowledge biases and redirecting research efforts towards a more comprehensive knowledge is essential to optimize the limited resources available for conservation.

Supplementary data to this article can be found online at .

CRediT authorship contribution statement

SLC and AMCS conceived the study. SLC gathered and analyzed the data. SLC led the writing of the manuscript with significant input of RJL and AMCS.

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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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.109988.

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