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Original research article

Changing trends and persisting biases in three decades of conservation science

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ABSTRACT

Conservation science is a rapidly developing discipline, and the knowledge base it generates is relevant for practical applications. It is therefore crucial to monitor biases and trends in conservation literature, to track the progress of the discipline and re-align efforts where needed. We evaluated past and present trends in the focus of the conservation literature, and how they relate to conservation needs. We defined the focus of the past literature from 13 published reviews referring to 18,369 article classifications, and the focus of the current literature by analysing 2553 articles published between 2011–2015. We found that some of the historically under-studied biodiversity elements are receiving significantly more attention today, despite being still under-represented. The total proportion of articles on invertebrates, genetic diversity, or aquatic systems is 50%–60% higher today than it was before 2010. However, a disconnect between scientific focus and conservation needs is still present, with greater attention devoted to areas or taxa less rich in biodiversity and threatened biodiversity. In particular, a strong geographical bias persists, with 40% of studies carried out in USA, Australia or the UK, and only 10% and 6% respectively in Africa or South East Asia. Despite some changing trends, global conservation science is still poorly aligned with biodiversity distribution and conservation priorities, especially in relation to threatened species. To overcome the biases identified here, scientists, funding agencies and journals must prioritise research adaptively, based on biodiversity conservation needs. Conservation depends on policy makers and practitioners for success, and scientists should actively provide those who make decisions with the knowledge that best addresses their needs.

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1. Introduction

Conservation science is the mission-driven discipline through which biodiversity knowledge is translated into action (Soulé, 1985; Robinson, 2006). From its inception it has undergone changes in the framing of its goals and approaches (Kareiva and Marvier, 2012; Mace, 2014), but the overall purpose of increasing our understanding of what threatens biodiversity, and what actions and policies are needed to preserve it, has remained unchanged. The continued growth in conservation science literature shows a burgeoning interest that goes well beyond the academic community, spanning practitioners, policy makers and research donors (Arlettaz et al., 2010). However, the scientific focus of the discipline, as it is represented by global peer-reviewed literature, does not always reflect the perceived priorities of biodiversity research and conservation (Stroud et al., 2014). Here we analyse the biases and trends in contemporary conservation literature, and evaluate how these trends have changed over time.

In 2002 two seminal papers analysed the ecological (Bonnet et al., 2002) and conservation (Clark and May, 2002) literature, and showed disproportional attention towards endothermic vertebrates. This was called a 'bias' because endotherms represent only a small fraction of all described vertebrate species (let alone all living species). In this context, bias is considered a concentration on – or interest in – one particular area or subject. Subsequent studies have investigated biases in conservation literature and associated research fields across a number of biodiversity elements, such as the geographical and ecological realms (e.g. Fazey et al., 2005; Velasco et al., 2015). For example, Lawler et al. (2006) found that some ecosystems, especially temperate forests in the northern hemisphere, were dominating the literature with many more articles focusing on them than any other system.

The misalignment between research interests and the needs of the conservation community can generate gaps in the evidence base on which biodiversity conservation is planned and, consequently, implemented (Lawler et al., 2006; Trimble and van Aarde, 2012). This is especially important where insufficient research attention is devoted to those groups or regions characterised by high biodiversity value and high threat levels, such as Southeast Asia (Sodhi et al., 2004). It is thus important to constantly monitor the focus of, and trends in, conservation science relative to changing biodiversity priorities (Fazey et al., 2005), in order to re-align scientific efforts for generating unbiased policy-relevant outcomes (Darwall et al., 2011; Donaldson et al., 2016).

We evaluate the current focus and trends in conservation literature across four main biodiversity elements: taxonomy, geography, ecological systems, and level of biological organisation. We first describe the focus of current literature, by presenting an analysis of all articles published in the period 2011–2015 in three leading conservation journals, one of which is analysed here for the first time. We use the year 2011 as a threshold since this year denotes the start of the 2011–2020 Strategic Plan for Biodiversity (Secretariat of the CBD, 2010). We then evaluate the trends in conservation literature over the past three decades, by comparing our results with those reported in past literature reviews. We present the results of our literature analysis in light of the current knowledge of biodiversity (number of described species), its threat status (proportion of threatened species), and level of conservation intervention (from the extent of protection).

2. Methods

2.1. The current focus of conservation literature

We analysed all articles published between 2011 and 2015 in three leading journals within the Web of Science subject "Biodiversity and Conservation": Biological Conservation, Conservation Biology and Conservation Letters. We selected *Biological Conservation* and *Conservation Biology* because of their primary focus on conservation and their usage in past reviews of conservation research (Clark and May, 2002; Fazey et al., 2005; Griffiths and Dos Santos, 2012; Velasco et al., 2015). We selected *Conservation Letters*, a much younger journal never previously used in similar analyses, as it has a specific focus on articles with a clear significance for conservation policy and practice. We included all articles published in these journals, with the exception of Comments, Editorials and Book Reviews (Table S1).

We classified all articles according to their research focus in terms of taxonomy, geography, ecological systems, and level of biological organisation (Table 1). Previous reviews have adopted these same categories to classify articles (Clark and May, 2002; Fazey et al., 2005; Velasco et al., 2015), but no single work has consistently reported a detailed investigation across all of these categories. We assigned each paper to an individual researcher who read and manually classified its content, as opposed to using an automated search engine. This was necessary to avoid false counts, where a given biodiversity element (e.g. a species) was mentioned in a paper but was not part of the research scope. The classification of articles was done by multiple researchers, and the consistency in classification was verified following the procedure described by the Collaboration for Environmental Evidence (2013) (Appendix S1 and Table S2).

We determined the taxonomic focus by identifying all species groups analysed in the paper. We classified articles dealing with genetic-level biodiversity if they had an explicit focus on genetic diversity and distinctiveness below the species level, and articles dealing with ecosystem-level biodiversity if the focus was on ecological communities above species level. We defined the geographic focus of the articles by referring to the study region in which the study was carried out (i.e. not the location hosting the authors' institutions). We also recorded the ecological system, or systems, in which the study was carried out (terrestrial, freshwater or marine). Importantly, any article could match one or more categories for each given field of classification, e.g. the same article could focus on both 'vertebrates' and 'invertebrates' if both groups were analysed.

Table 1
Details of the categories and sub-categories used to describe the focus of conservation articles.

Biodiversity element	Categories
Taxonomic group	Vertebrates: Amphibians, mammals, birds, reptiles, fish Invertebrates: Insects, molluscs, crustaceans, other invertebrates Plants & other: Plants, Algae, Fungi & Lichens.
Level of biological organisation	Genetic Species Ecosystem
Ecological system	Terrestrial Marine Freshwater
Geographic scale	National or sub-national Regional Global
Geographic location	Biogeographical realm Region Country

In order to provide context for the interpretation of our results, we contrasted the focus of current conservation literature with the following baselines: number of described species (Chapman, 2009; Mora et al., 2011), number of threatened species (IUCN, 2015), and protected area coverage for regions (Juffe-Bignoli et al., 2014) and species (Butchart et al., 2015).

2.2. *Trends and biases in the conservation literature through time*

In order to identify a representative set of past literature reviews, we employed a reverse citation searching method in Google Scholar. We created a list of all papers that cited Bonnet et al. (2002) and/or Clark and May (2002), and searched through this list to identify those papers reporting global literature reviews of conservation or associated disciplines. We then iteratively repeated the search across all the newly identified papers, until the most recent paper was found. For example, we selected Wilson et al. (2007) among the papers citing Clark and May (2002), and then selected Pyšek et al. (2008) among the papers citing Wilson et al. (2007). Our purpose here was not to perform a comprehensive "review of reviews", but rather provide a basis to compare our analysis of the current literature.

We compared the results reported in past analyses of the conservation literature with the results obtained from our analysis of the current literature (Section 2.1), and represented an overview of trends and biases for the past three decades. Past works have focused their literature reviews on a variety of ecological and conservation journals, which can make the analysis of temporal trends difficult. In order to minimise the effects of this inconsistency, we have included in our analysis of literature trends only those works that focused entirely, or mostly, on *Conservation Biology* and *Biological Conservation*. The only exception was Lawler et al. (2006), focusing on 15 different ecological and conservation journals, which we retained because they explicitly focused on conservation articles within the set of identified journals (see Section 3.2). We verified that this exception would not have changed the direction of the described trends if excluded.

2.3. *Comparing conservation literature and conservation efforts*

The focus of the conservation literature does not necessarily reflect the focus of conservation efforts on the ground, and countries (or taxa) with little representation in the literature are not necessarily subject to little conservation attention. To demonstrate that trends in the conservation literature are at least in part correlated to trends in conservation efforts, we performed two case studies: first we compared the number of conservation projects on vertebrate species funded by the IUCN Save Our Species (SOS) programme (www.SaveOurSpecies.org) in the past five years and the number of papers published during the same period. Second, we compared the number of biodiversity projects funded by the Global Environment Facility (https://www.thegef.org/projects) in 159 developing countries in the past five years, and the number of published articles referred to these countries in the same period.

3. Results

3.1. *The current focus of conservation literature*

We classified 2553 articles published between 2011 and 2015 (Fig. 1). The next sections report the overall focus of these articles across the different biodiversity elements.

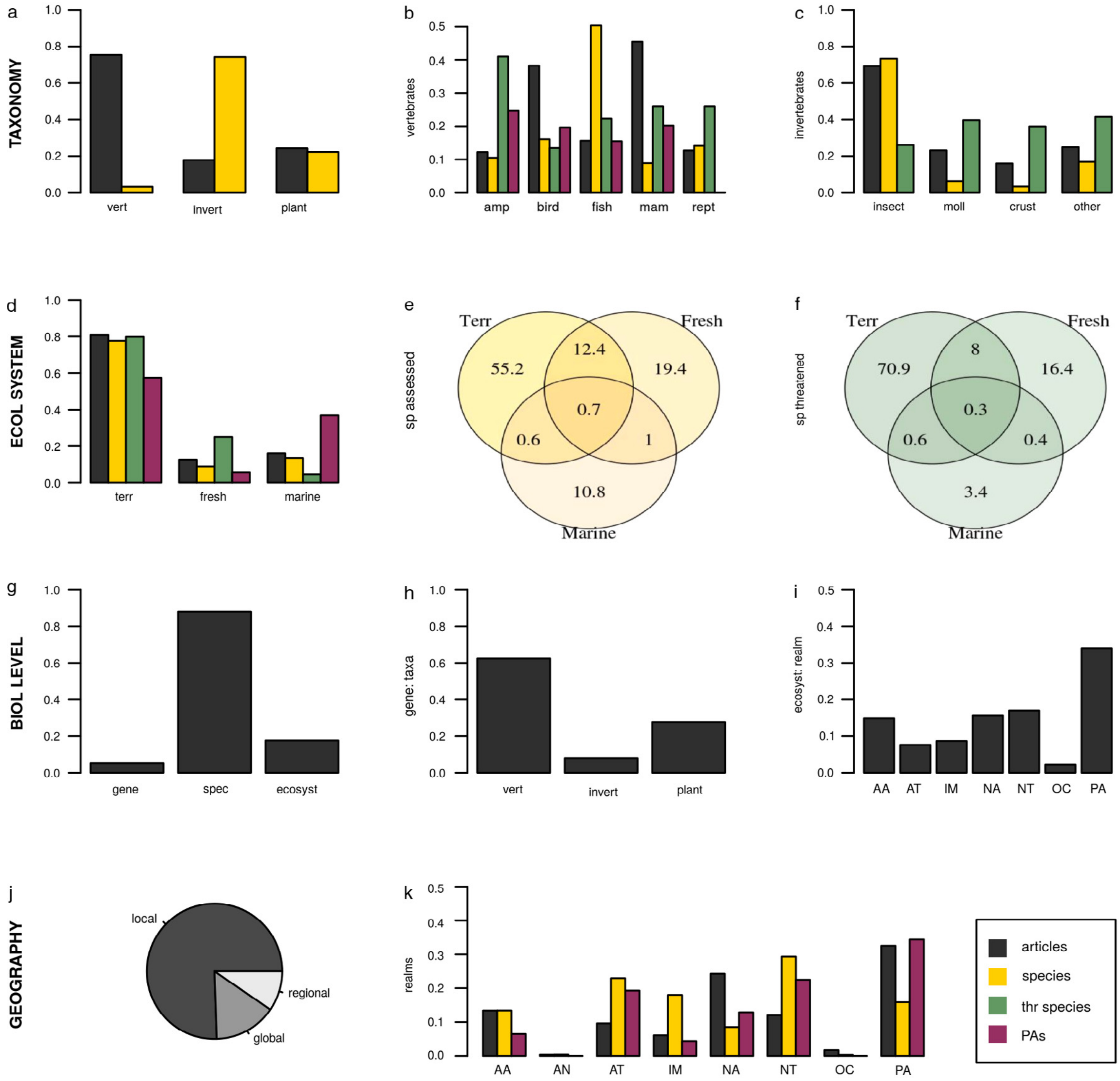

Fig. 1. Main focus of the recent conservation literature, compared to current levels of biodiversity knowledge and conservation attention. The figure illustrates the literature focus across four main biodiversity elements: taxonomy (a–c), ecological system (d–f), biological level (g–i), geography (j, k). The panels report proportional values (percentages for panels '(e)' and '(f)') referred to the variables described in the bottom-right legend. Panels description: (a) proportion of articles and number of described species for each major taxonomic group*; (b) proportion of articles, number of described species, number of threatened species, and average PA coverage for vertebrates†; (c) proportion of articles, described species, and threatened species for invertebrates‡; (d) proportion of articles, described species, threatened species, and global share of PAs of the major ecological systems; (e) percentage of species assessed by the IUCN Red List, divided according to their ecological system; (f) percentage of threatened species assessed by the IUCN Red List, divided according to their ecological system; (g) proportion of articles referring to different levels of biological organisation; (h) proportion of genetic diversity articles divided by taxonomic group; (i) proportion of ecosystem articles divided by biogeographical realm¥; (j) proportion of articles referring to different geographic scales ('local' includes national and subnational); (k) proportion of articles and mammal species, plus global share of PAs of the major biogeographical realms¥. *In this graph, fungi and algae have been aggregated with plants to ensure consistency with previous reporting (see text for individual proportions); † Information on conservation status and PA coverage for reptiles are, respectively, incomplete and unavailable; ‡ Information on conservation status for invertebrates is incomplete; ¥ List of realms: AA Australasia, AN Antarctic, AT Afrotropics, IM IndoMalay, NA Nearctic, NT Neotropics, OC Oceania, PA Palearctic.

3.1.1. The current taxonomic focus

We found that a strong taxonomic bias persists in the conservation literature, with 75% of articles focusing on vertebrates and only 18% focusing on invertebrates (Fig. 1(a)). In total, 24% of papers referred to plants, fungi (including lichens) or algae. However, while there was a slight overrepresentation of plant papers (22% of all papers) with respect to the number of known plant species (16% of all described species), very few studies focused on fungi ($n = 46$, 2%) or algae ($n = 16$, 0.8%). This situation is consistent with the fact that vertebrate groups are proportionally more represented in the IUCN Red List than invertebrates or plants (with a few exceptions on particular taxa).

The taxonomic bias in the literature was evident among vertebrate groups, both when looking at the number of described species and when looking at the number of threatened species. The proportion of articles that referred to mammals (45% of all vertebrate papers) and birds (38% of all vertebrate papers) exceeded by far the proportion of species and threatened species in these groups, while the situation for ectotherms was reversed (Fig. 1(b)). Today, amphibians are the most threatened vertebrates (41% of all species in the group are threatened; IUCN, 2015) and also the group with the highest proportion of species with no protected area coverage: 18% of species *vs* 3% and 6% for birds and mammals respectively (Butchart et al., 2015). Knowledge on the conservation status of this group has increased over the last decade (Stuart et al., 2004; Butchart et al., 2015), and our results show that there were proportionally twice as many amphibian papers currently than in the past (Clark and May, 2002). Fishes were the vertebrate group with the highest imbalance between number of published articles (16% of all vertebrate articles) and number of described species (50% of all vertebrates).

Most invertebrate articles (69%) focused on insects (Fig. 1(c)) but, when compared to the total number of described species, insects were slightly under-represented while crustaceans and molluscs were substantially overrepresented. Interestingly, these latter groups are characterised by a high proportion of threatened species. Hence, unlike vertebrates, the literature focus on invertebrates seems to have good correspondence with the level of threat for the various groups. However, we make this inference with caution since none of the invertebrate groups analysed here have been comprehensively assessed for their extinction risk.

3.1.2. The current focus on ecological systems

We found that 81% of articles focused on terrestrial systems (Fig. 1(d)). This terrestrial focus of research articles corresponds with the total number of described species and number of known threatened species found in the respective systems. Today terrestrial systems have also the largest areal coverage of PAs: 57% of the global PA surface is on land, compared with 6% in freshwater systems and 37% in marine systems (Juffe-Bignoli et al., 2014). This apparent disparity in research and conservation efforts may be a result of the key differences in marine and terrestrial ecosystems pertaining to environmental and ecological features, and of the patterns and consequences of human impacts (Carr et al., 2003). For example, the geographical patterns of marine biodiversity are less known than terrestrial patterns, with only a few comprehensive marine classifications analogous to those developed for terrestrial ecosystems (Carr et al., 2003). However, there are also historical and political factors behind these differences in conservation efforts, including the relatively high cost and lack of data for decision making that exists for the marine, compared with the terrestrial, environment (Levin and Kochin, 2004).

The three systems (terrestrial, freshwater, marine) are of course physically and biologically linked: 14.6% of all species assessed in the IUCN Red List (Fig. 1(e)), including 9.3% of all threatened species (Fig. 1(f)), are found in more than one system (IUCN, 2015). Similarly, 8% of the papers in our sample dealt with more than one system. Given that connected systems can be detrimentally affected by the same stressor, such as fine sediment moving from land to streams and into estuaries, the biological and the physical linkages among terrestrial and marine systems are now becoming acknowledged as more important in conservation (Beger et al., 2010; Alvarez-Romero et al., 2011).

3.1.3. The current focus on different levels of biological organisation

The conservation literature reports research at different levels of biological organisation: genetic, species, and ecosystem (Fig. 1(g)). Between 2011 and 2015, the main focus was on species-level research (1,968 articles; 79% of all papers with a defined focus). However, there was a small but significant proportion of articles referring to both genetic level ($n = 112$; 5%) and ecosystem level ($n = 387$; 16%) biodiversity. This is also reflected in the inclusion of these elements in global biodiversity initiatives. For example, the recent development of an IUCN Key Biodiversity Areas standard has in part considered the genetic diversity element (Brooks et al., 2015), and an IUCN Red List of Ecosystems is currently being developed (Keith et al., 2015).

While there is a broad recognition of the importance of genetic diversity and its conservation (Velasco et al., 2015), at the genetic level the conservation literature focused disproportionately on vertebrate taxa, with more than twice as much research on vertebrates (62%) as on plants (28%), and invertebrate taxa accounting for only 8% of the genetic publications (Fig. 1(h)). Predictably, genetic-level research was more likely to have an intra-specific rather than inter-specific focus.

For ecosystem-level research, there was a strong spatial skew towards the Palearctic realm (Europe, northern Africa and northern and central Asia; Fig. 1(i)). This may be a reflection of the research capacity, as represented by the number of scientists (Rodrigues et al., 2010), and/or the predominance of research in human-modified landscapes(e.g. agricultural systems) which are important for ecosystem services, especially in Europe (Trimble and van Aarde, 2012).

3.1.4. The current geographic focus

Three quarters of all articles focused on biodiversity at the national or subnational scale, while only 15% and 10% of the papers were respectively global or regional in their scope. Over half of all national and regional articles were located in European (including Russia) or North and Central American areas. This confirms a well-known geographic bias, consistently reported, and likely reflecting the density of local scientists (Lawler et al. 2006; Martin et al., 2012).

We found a strong focus on the Palearctic realm (32% of all articles), which does not align with the global distribution of biodiversity. For example, only 16% of all terrestrial mammal species (i.e. the most investigated group in conservation) live in the Palearctic (Rondinini et al., 2011). At the opposite end of the spectrum, there was a clear under-representation of the realms most rich in biodiversity and threatened biodiversity, including Afrotropical (10% of all articles, despite including 23% of all mammals), Indomalayan (6% of all articles; 18% of all mammals), and Neotropical (12% of all articles; 29% of all mammals). Studies carried out in the Afrotropical realm were typically focused on large mammal species and associated threats, such as the bushmeat trade (Packer et al., 2011). Studies carried out in the Neotropical region had a relatively well spread focus of research across vertebrate and invertebrate groups compared to other regions (e.g. Visco and Sherry, 2015). Studies carried out in the Indomalayan region were much more focused on vertebrate species; birds and mammals accounting for over 50% of all articles.

Articles reporting national- or subnational-scale analyses were based in 117 different countries (Fig. 2). Three developed countries (USA, Australia, and the UK) accounted for 40% of all studies. However, we also noted an increased number of studies being carried out in countries that were historically under-represented (Lawler et al., 2006), including China and Brazil. Studies in China varied widely in their focus, from visitor management practices in protected areas (Zhong et al., 2015) to the distribution of native orchid species (Zhang et al., 2015). Many studies in Brazil considered the impact of human activities (mining, dams and deforestation practices) on a number of taxonomic groups (Benchimol and Peres, 2015).

Alarmingly, we found that several countries, especially in Africa, received no research attention at all (Fig. 2), which may contribute to impeding the achievement of biodiversity conservation objectives there.

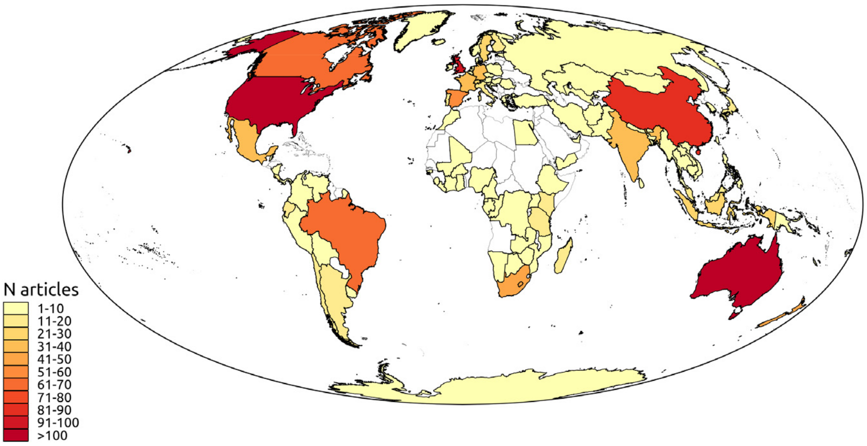

Fig. 2. Number of national or subnational research articles per country, classified according to the country where the study area was located.

3.2. Trends and biases in the conservation literature through time

We identified 13 papers presenting literature analyses of conservation and associated disciplines, with a total of 18,369 article classifications (Table 2). These works have consistently reported a taxonomic bias towards vertebrate species, with mammals and birds being especially overrepresented. While there were a few exceptions in which plants and invertebrates were found to be the most studied taxa, these referred to analyses of specific subjects, such as climate change (Felton et al., 2009) and invasion biology (Pyšek et al., 2008). Fewer works have examined biases in ecological system, level of biological diversity and geographic region. These reviews reported a stronger focus on terrestrial over aquatic systems (Felton et al., 2009; Lawler et al., 2006), species diversity over ecosystem and genetic diversity (Fazey et al., 2005; Cronin et al., 2014; Velasco et al., 2015), and North American and European studies over other regions (Lawler et al., 2006; Martin et al., 2012).

We retained five reviews of past literature as a basis for comparing current literature, since they were largely based on the same journals as those analysed here (Fig. 3). We found evidence that some of the customarily under-studied biodiversity elements are receiving increasing attention though time, even if this change is slow (Fig. 3(a)–(c)). In particular, the proportion of articles referring to invertebrate species groups is 60% higher today than it was 20–30 years ago ($\chi^2 = 45.4$, $p < 0.001$), the proportion of articles dealing with biodiversity at the genetic level has grown by 60% in 15 years ($\chi^2 = 6.4$, $p = 0.01$), and the proportion of articles on aquatic systems (marine or freshwater) has grown by 50% in 20 years ($\chi^2 = 2.6$, $p = 0.05$). Alarmingly though, we found that the research focus on some poorly studied regions, especially Africa and Southeast Asia, has remained low or has even decreased over time (Fig. 3(d)). This is particularly concerning as these regions are richer in biodiversity and threatened species than most of the better-studied regions.

Table 2
Main sources of bias (taxonomy, ecological system, biological level, geography) found in past ecological and conservation literature. The table summarises the focus and results of papers reviewing bias in ecology and conservation research in the past 35 years.

Ref.[a]	Sources	N papers	Discipl[b]	Period	Taxa	Ecol Syst	Biol Lev	Geog	Main results
B&al02	9 Ecol. journals	1171	Ecol, Behav	1992, 1996, 2000	yes	no	no	no	Birds and mammals are the most studied vertebrates in ecology.
C&M02	CB, BC	2700	Conserv, Ecol	1987–2001	yes	no	no	no	Vertebrates (birds and mammals) are better studied than invertebrates in conservation.
F&al05	CB, BC, B&C	547	Conserv	2001	yes	no	yes	yes	Birds and mammals are the most studied groups. Fish, fungi, lichens and non-arthropod inverts are the least studied. Few studies at the ecosystem level or at the continental scale.
L&al06	15 Ecol. and Conserv. journals	628	Conserv	1984, 1994, 2004	yes	yes	no	yes	Birds and mammals are the most studied groups, little focus on amphibians. The marine system is under-represented. Most studies are conducted in Europe and North America.
W&al07	Google web-search +ISI WoS search	NA	Ecol	1995–2006	yes	no	no	yes	Invasive vertebrates attract more attention than plants and invertebrates. Fewer web pages refer to tropical Africa than other tropical regions. North American species attracted more web attention than other species.
P&al08	ISI WoS search	2670	Invas. Ecol	1980–2006	yes	no	no	yes	Plants and, to a lesser extent, insects are the most investigated invasive group. North America and Europe are the most studied regions.
F&al09	ISI WoS search	248	Clim Chan	1988–2006	yes	yes	no	yes	Most studies conducted in temperate areas. North America and Europe being the most studied regions. Most studies were on terrestrial systems, especially forests. Plants and invertebrates were the most studied taxa.
G&DS12	CB, BC, Ory, B&C	160	Conserv	1992–1995, 2006–2009	yes	no	no	no	Mammals and plants are the most studied groups.
M&al12	10 Ecol. and Conserv. Jour.	2573	Ecol	2004–2009	no	no	no	yes	The majority of studies were carried out within PAs, few studies in agricultural lands. Temperate deciduous woodland were the most studied biome, while Central/North America and Europe where the most studied regions.
D&al14	Scopus search	853	Trop Forests Frag	1980–2012	yes	no	no	yes	Most deforestation studies are conducted in the Neotropics, few studies in the Afrotropics. Plants received the highest attention, while mammals and herps are respectively the most studied are the least studied among animal groups.
C&al14	ISI WoS search	5853	Wild Conserv	1993–2012	yes	no	yes	yes	Most articles on wildlife conservation deal with species, only a few deal with ecosystems. Mammals and North America are respectively the most represented group and region.
V&al15	CB, BC, B&C	966	Conserv	2000, 2011	yes	no	yes	yes	Most articles deal with species, only a few deals with ecosystems and even fewer with the genetic level. Most studies are conducted at a local scale, Europe and North America being the most studied regions. Vertebrates (mammals and birds) are the most studied group.
D&al16	ISI WoS search	NA	Conserv	NA-2012	yes	yes	no	yes	Vertebrates, especially mammals, have a much higher ratio of "article per species", than invertebrates.

[a] Reference acronyms: B&al02, (Bonnet et al., 2002); C&M02, (Clark and May 2002); F&al05, (Fazey et al., 2005); L&al06, (Lawler et al., 2006); W&al07, (Wilson et al., 2007); P&al08, (Pyšek et al. 2008); F&al09, (Felton et al. 2009); G&DS12, (Griffiths and Dos Santos 2012); M&al12, (Martin et al., 2012); D&al14, (Deikumah et al., 2014); C&al14, (Cronin et al., 2014); V&al15, (Velasco et al., 2015); D&al16, (Donaldson et al., 2016).

[b] Disciplines: Ecol, Ecology; Behav, Behaviour; Conserv, Conservation Biology; Invas Ecol, Invasion Ecology; Clim Chan, Climate Change; Trop Forest Frag, Tropical forests fragmentation; Wild Conserv, Wildlife Conservation.

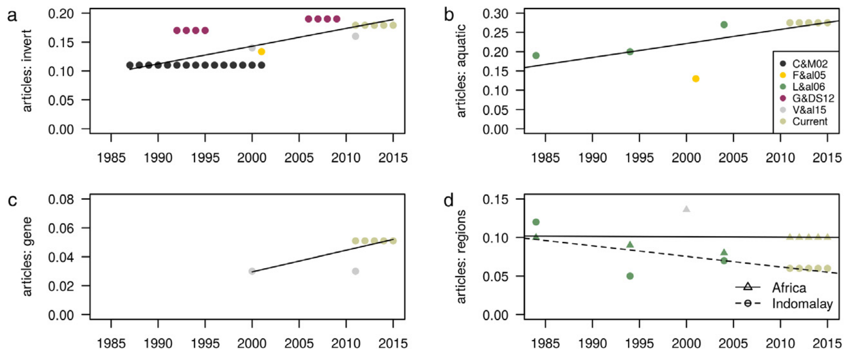

Fig. 3. Temporal trends in the conservation literature for four typically under-studied biodiversity elements. The panels report the proportion of articles referring to: (a) invertebrate species; (b) aquatic systems (combining freshwater and marine); (c) genetic diversity; (d) African and Indomalay regions. Different colours refer to data reported in different literature sources*, colour-coded in panel (b). For each literature source, the entire period covered is reported (e.g. C&M02 reported values for the period 1987–2001). Lines represent trends through years, for visual reference.
*References acronyms: C&M02 (Clark and May, 2002) ; F&al05 (Fazey et al., 2005); L&al06 (Lawler et al., 2006); G&DS12 (Griffiths and Dos Santos, 2012); V&al15 (Velasco et al., 2015); Current (present study).

3.3. Comparing conservation literature and conservation efforts

We found a good correspondence, within vertebrates, between the number of IUCN SOS projects focusing on a group (e.g. mammals) and the number of published papers focusing on the same group (Fig. S1). Specifically, there were far fewer projects (≤10%) and papers (≤16%) that referred to amphibians, reptiles, or fishes, with respect to mammals (61% of projects, 45% of papers). Birds represented a discrepancy in this case, with a relatively small proportion of projects (13%) and a relatively high proportion of articles (38%). We also found a positive correlation (Pearson's $r = 0.59$) between the number of biodiversity projects funded by the Global Environment Facility in 159 developing countries and the number of published articles that referred to the countries (Fig. S2).

4. Discussion

Biases in conservation research have implications for understanding what threatens biodiversity and, consequently, the allocation of conservation funding aimed at abating these threats (Donaldson et al., 2016). For example, the limited amount of conservation research done on invertebrate species is likely to affect the development of appropriate research methodologies aimed at understanding their conservation needs, which cannot be easily adapted from the better-studied vertebrate groups (Pawar, 2003). Similarly, the distribution of terrestrial biodiversity has proven to be a poor surrogate for freshwater biodiversity, and as such, site based efforts to conserve terrestrial species and systems might have only a limited benefit for freshwater systems (Darwall et al., 2011). For these reasons, it is important to monitor the focus and trends in conservation literature on an ongoing basis.

We found that the focus of conservation science is moving towards a less biased representation of biodiversity across taxonomic, systemic, organisational and spatial levels. Some of the typically under-studied elements of biodiversity have seen an increased representation in the recent conservation literature. This trend is also reflected in global biodiversity initiatives, such as the expansion of the taxonomic coverage of the IUCN Red List (Stuart et al., 2010). However, this shift towards a more comprehensive biodiversity focus appears to be slow, and it is likely that biases in the conservation literature will take many years to be overcome. The persisting geographic bias in the conservation literature is the most worrisome. Indeed a taxonomic focus towards charismatic and wide-ranged species, e.g. large carnivores, might still deliver broader biodiversity benefits due to the umbrella role of these species (Roberge and Angelstam, 2004). In contrast, a geographic bias will always result in poor biodiversity outcomes overall, because articles from well-studied regions cannot support conservation outputs in poorly studied regions. Our results confirm the known bias in the global allocation of conservation funds, and highlight the need for increased conservation research and action in megadiverse developing countries hosting many threatened species, especially in Africa and Southeast Asia (Waldron et al., 2013).

Research outputs and conservation outputs have a reciprocal influence, but a geographic bias in conservation literature does not necessarily translate into biases in global conservation efforts. Many conservation funding schemes, including the Global Environment Facility, focus their investments in developing countries, which host high biodiversity value. However, getting a paper published for authors based in developing countries presents inherent difficulties (Salager-Meyer, 2008), even when conservation efforts are actually in place. This might lead to a publication 'filter' process, in which the conservation research performed in developing countries is not published in leading journals, resulting in the geographic biases we described. Interestingly, we found a positive correlation between the number of biodiversity projects funded in developing countries and the number of conservation articles for the countries. This demonstrates that geographic trends in conservation literature and conservation interventions are, at least in part, correlated.

Our analysis concurs with previous studies in identifying research biases, but also shows better representation (as defined by proportionally more articles) for some biodiversity elements largely under-studied in the past. Actively filling the knowledge-policy gap implies that more efforts need to be undertaken by scientists to work – and train others – in research areas where the needs are greatest and the value of that information would make the biggest difference. Beyond the role of the researcher, organisations that fund conservation research clearly need to play more of a proactive role in closing these gaps by encouraging research on understudied taxa and regions, especially where high levels of human pressure are known to occur (Sodhi et al., 2004). This will involve ensuring that there is sufficient support for applied science aimed at solving important policy questions, but also that existing funds are invested in a more strategic manner (Rondinini et al., 2014). Influencing the focus of a discipline is a complex process, likely to take several years, yet without greater efforts made by individual scientists and donors to recognise existing shortfalls and then trying to fill them (Arlettaz et al., 2010), many of the most immediate global conservation actions will not be science-based. Emerging fields, such as citizen science, can also help fill the research gap between well-studied taxonomic groups (and regions) and under-studied groups, with the provision of freely-available dataset (Donaldson et al., 2016).

We compared the focus of conservation literature with several biodiversity 'baselines' (proportion of species, proportion of threatened species, extent of protection) to allow us to investigate research patterns over time. The number of described species is typically used as a proxy of biodiversity knowledge (Clark and May, 2002), the proportion of threatened species is used as proxy of the known threat levels (Waldron et al., 2013), and the extent of protection is used as a proxy of conservation efforts (Darwall et al., 2011). We acknowledge that these baselines can have biases themselves, e.g. the IUCN Red List has proportionally assessed more vertebrates than invertebrates, but combined they provide a somewhat comprehensive view of the current state of biodiversity.

We found that using different baselines led to different conclusions. For example, amphibians appear to be adequately represented in the literature, with the proportion of articles referring to amphibians roughly corresponding to the proportion of amphibian species within vertebrates. However, amphibians are very much underrepresented with respect to other vertebrates if considering that this group has the highest proportion of threatened species. We argue that conservation science should not be simply aimed to increase the level of knowledge so it is proportional to the biodiversity asset or state (such as the number of threatened species in a group). It should ideally relate to an expected value of information — the expected net benefit of the new information in terms of changing actions or policies on the ground (Maxwell et al., 2015). However, calculating the value of information in a globally comprehensive way is not currently possible. The best we can do practically is to define a 'null model' against which the publishing trends of leading conservation journals can be universally compared, using multiple baselines to comprehensively evaluate the focus of each publication.

Leading conservation journals, such as those we analyse here, play a central role in shaping the trends and focus of conservation science, and the research currently published in these journals is relevant for the achievement of global biodiversity goals (Butchart et al., 2015; Di Marco et al., 2016; Watson et al., 2016). As of today, there are 48 journals recognised in the Web of Science subject of 'Biodiversity and Conservation', in addition to several journals in other subjects that publish conservation research regularly. We acknowledge that our results might not reflect the focus of journals not included in our analyses, let alone non-English conservation literature. However, our journal choice ensured the comparability of our results with those reported in previous analyses (Clark and May, 2002; Fazey et al., 2005; Velasco et al., 2015).

Reducing the bias in the conservation literature will ensure that all aspects of conservation have an adequate knowledge base available. Achieving an equal representation of all biodiversity elements is unrealistic in the short term and probably not necessary to achieve efficient conservation outcomes. However, conservation science should aim to provide an acceptably comprehensive picture of the elements that are now under-represented (Pawar, 2003; Darwall et al., 2011). This may require some shift in focus and possibly some horizon scanning exercises, specifically aimed at improving the match between research focus and the requirements of biodiversity and socio-economic goals (Secretariat of the CBD, 2010; United Nations General Assembly, 2015). It is clear that more immediate action is necessary to enable conservation science to meet the needs of policy makers. Conservation depends on policy makers and practitioners for success; it makes sense to actively provide those who establish the policy with the science that addresses their needs in a comprehensive and unbiased way.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at http://dx.doi.org/10.1016/j.gecco.2017.01.008.

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