Biodiversity and Conservation (2023) 32:2611–2636
https://doi.org/10.1007/s10531-023-02626-7

REVIEW PAPER

Half century in biodiversity and conservation research in Nepal: a review

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Received: 8 August 2022 / Revised: 22 April 2023 / Accepted: 11 May 2023 /
Published online: 29 May 2023

Abstract

Scientific research on biodiversity and conservation generates the knowledge base useful in achieving sustainability targets. The knowledge gap limits our ability to design well-founded strategies and impedes the prospects of addressing myriad conservation challenges. It is therefore important to assess trends and biases in biodiversity and conservation literature to monitor progress and make corrective actions where needed. Nepal is considered among the most biodiverse regions globally, yet little is known about the progress of biodiversity and conservation science. Here we reviewed 1098 articles published over the last fifty-six years (1964–2019) and provide a snapshot of research patterns, trends and gaps in terms research lens, physiography, ecosystem, protected area, taxonomy, ecological focus, funding, research recommendation, and research authorship and collaboration. The results of our study showed a monotonic trend of article publication until 1990, which increased significantly after 1999. There is a growing trend in the number of publications with socio-economic and multidisciplinary lens. Research publications are highly biased in favour of few taxonomic groups, mainly gymnosperms and mammals, with a preponderance of certain species, while other classes of both the plant and animal kingdoms were less studied. There was disproportionately low focus on certain physiographic regions (e.g., high Himalaya, Siwalik), ecosystem types (e.g., wetlands) and non-protected areas. Articles with an ecological focus were mainly exploratory—e.g., describing general distributions—whereas specialized ecological/evolutionary research (e.g., grazing, competition, physiology), except for genetics and climate change, were rare. More than half of the articles were authored only by foreign-based researchers, who contributed up to 89% of published articles, and consistently maintained dominance as corresponding and lead authors. There is a need to realign research efforts and support home-grown researchers with training, funding and institution-building. This requires a concerted commitment by the Government of Nepal, conservation organizations, researchers and academic institutions. There remains a great need for more empirical science to inform decision-making and consequently achieve ambitious national conservation targets.

Communicated by Anurag Chaurasia.

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Keywords Biodiversity research · Nepal · Research bias · Collaboration · Conservation science

Introduction

Biodiversity is rapidly declining worldwide (Butchart et al. 2010), and there are urgent calls for its protection through various mechanisms (Rodrigues et al. 2004; de Oliveira Roque et al. 2018; McDonald et al. 2019), such as setting up a protected area network (Naughton-Treves et al. 2005), creating ex-situ conservation programs (Pritchard et al. 2012), enforcing conservation legislation (Xu et al. 1999; Dongol and Heinen 2012; Acharya et al. 2020; (Paudel et al. 2020a) and raising conservation awareness (Ramírez and Santana 2019). Biodiversity research is a prerequisite for these actions, but it remains inadequate (Donaldson et al. 2016). Given the growing and complex challenge of global environmental change and the accelerated biodiversity loss, there is a burgeoning need for more research—bridging knowledge gaps—on understudied species (Troudet et al. 2017), including multidisciplinary issues to support for biodiversity conservation.

Biodiversity and conservation research provides crucial knowledge needed to make a wide variety of conservation decisions (Flaspohler et al. 2000; Mair et al. 2018). However, research priorities do not always align with what is most needed, and change in terms of focus and approach (Di Marco et al. 2017). Studies have shown that biodiversity and conservation research is heavily biased towards certain locations and on a few aspects of ecology and conservation science, and is often biased in favour of some species (Fenton 1997; Tews et al. 2004; Cronin et al. 2014; Donaldson et al. 2016; Di Marco et al. 2017; Titley et al. 2017). There are questions regarding how species are prioritized (or not) for conservation (Paudel and Heinen, 2015a; Shrestha-Acharya and Heinen 2009). Any bias may result in unexpected repercussions in the long term for conservation in general (Butchart et al. 2010; Pereira et al. 2010). There are several reasons for such biases such as societal preferences (Wilson et al. 2007; Troudet et al. 2017), funding availability and requirements (Fazey et al. 2005a) and academic research priorities (Griffiths and Dos Santos 2012).

Nepal has made impressive achievements in the scale and speed of biodiversity conservation, which includes setting aside over 23.39% of its national area under 20 protected areas (Heinen and Shrestha 2006; Paudel and Heinen 2015b), although the faunal collapse of large mammals has been an issue in some key areas (Heinen 1995), and 41% of its forest areas are under community forestry policies (MoFE 2018).The country doubled its tiger population within 10 years, maintained small populations of elephants (Ram et al. 2021) and wild Asiatic buffalo (Heinen and Paudel 2015), and nearly eliminated rhinoceros poaching (Acharya et al. 2020). However, there are daunting challenges that require evidence-based conservation actions based on both basic and applied ecological research, including trans- and multi-disciplinary approaches (Ehrlich and Wilson 1991; Hendriks and Duarte 2008).

Although biodiversity and conservation research is limited globally (Pullin et al. 2009), it is inadequate in Nepal due to scarce funding, poor infrastructure (e.g., lab and equipment, as well as the accessibility of many remote areas), weak institutional support and poor human resource development (Paudel et al. 2012). Early biodiversity research was almost entirely carried out by foreign scholars and funded by international conservation organizations and universities based in developed countries, which greatly contributed to pioneering studies on globally-threatened species, and helped in making critical conservation

decisions, training home-grown scientists and incorporating research into Nepal's universities (Heinen et al. 2019). Brian Houghton Hodgson is recognized for his pioneering work in surveying and documenting Himalayan birds and mammals during the 1800s (Waterhouse 2004). Apart from ethnography, linguistics, architecture, religion and natural history of Nepal and the Himalayas, he worked extensively on zoological subjects, ranging from descriptions of new species to checklists of the fauna during his political/administrative tenure in Nepal. Large and organized research projects and consequently publications, however, only started after the country began experiencing major environmental changes such as massive deforestation and land-use problems, and the disappearance of many large mammals (Guthman 1997; Pandit et al. 2007; Heinen et al. 2019; Ives 2019). Here, we aim to assess the trends and gaps in biodiversity and conservation research in Nepal over the last fifty years in terms of (1) research lens, (2) physiography, (3) ecosystem, (4) protected area, (5) taxonomy, (6) ecological focus, (7) funding, (8) research recommendation, and (9) research authorship and collaboration. Since Nepal encompasses very high species diversity, mostly attributed to exceptionally diverse climatic and elevation gradients and physiographic divisions (Paudel and Heinen 2015a), these areas cover crucial ecological and conservation questions. For example, large mammals were primary targets for setting protected areas in 1970s because of their diminishing population such as tiger (Baral and Heinen 2005; Bhattarai et al. 2017), water buffaloes (Heinen and Paudel 2015) and one horned rhinoceros (DNPWC 2017; Acharya et al. 2020). Although this approach was accepted given high risk to extinction and presumed umbrella effects of such species conservation on entire ecosystem, lesser taxa—both plants and animals—are largely remained understudied and unknown in many ecological aspects. Now, it is important to make scientific and conservation advances on such lesser-known taxa.

Biodiversity conservation, in most cases, is a result of the interplay between social and ecological systems. Such interplay recognizes interdisciplinary and multidisciplinary approach in research, integrating both natural and social dimensions, for effective design of conservation policies and actions (Mascia et al. 2003; Laurance et al. 2012; Bennett et al. 2017). Therefore, we used five research lenses, each with a specific focus, ranging from pure ecological (e.g., habitat preference, predator–predator interactions, etc.) to economic foci: (1) ecological, (b) socio-cultural, (c) economic, (d) governance, policy, and legislation, and (e) multi-disciplinary. Ecological research helps to increase our understanding of how organisms interact with each other and with the biotic and abiotic environment (St. John et al. 2014). We used 10 sub-field of ecological research, including behavior, climate change, competition, demography, distribution, genetics, grazing, parasitism, physiology, and predation, which have a greater significance to the management of populations, communities and ecosystems, and the services they provide. For example, Odden et al. (2010) determined displacement of leopards by tigers to the park boundary in Bardia National Park, Nepal, mainly due to scarcity of large prey (Odden et al. 2010). Invasive species are expanding rapidly due to confounding effects of climate change and human transport/activity (Murphy et al. 2013), but little is known dispersion mechanism of such plants and their control measures (Shrestha et al. 2019).

Since Nepal is rich in social groups in terms of ethnicity and language, with specific forest conservation and management practices (Jana and Paudel 2010), research with "social-cultural", "economic" and "governance, policy, legislation" lens has a great prominence. For example, the human–wildlife conflict is pronounced in both mountain (e.g., snow leopard) and lowland (e.g., elephant) regions, each has a distinct pattern (Acharya et al. 2016). Here opportunities exist for co-existence by promoting alternative livelihoods such as ecotourism. Additionally, physiography characterizes environmental heterogeneity,

which has considerable influences on ecological patterns and processes. Such areas support high genetic and species diversity (Rosenzweig 1995) and have potential to inform climate-smart conservation (Stein et al. 2014). Overall, there are concerns about geographical, ecological, and taxonomic biases and a lack of strong links between research and conservation decisions. Therefore, it is critical to examine the gaps and trends in, and foci of, biodiversity and conservation publications to guide future research efforts.

Materials and methods

Literature review and selection criteria

We carried out an in-depth review of peer-reviewed research articles focusing on biodiversity and conservation in Nepal. "Biodiversity" and "conservation" are broad terms and cover all aspects of biological diversity, its conservation and sustainable use (Primack et al. 2013). We defined biodiversity and conservation publications as peer-reviewed articles that focus on understanding, describing, managing and protecting species, ecosystems and ecosystem services from any lens viz. ecological, social, economic, legal and institutional. Besides these, we included articles on forest and watershed conservation and management to be more inclusive but we did not include articles on domestic animals or plants (e.g., agriculture and commercial forestry).

We searched articles in Elsevier's Scopus database using several combinations of keywords representing various levels and categories of biodiversity (e.g., taxon, ecosystem, conservation) and conservation for "all years" ending December 2019 in abstracts, titles, and keywords of the papers (Table 1.). We obtained a total of 4259 articles over the past 56 years. We removed duplicate articles (n = 1103). We then excluded articles if they were (1) in a non-English language (n = 63), or (2) not peer-reviewed (n = 454); e.g., books, book chapters, conference papers, letters to editors, (3) not downloadable (n = 101), (4) not related to Nepal (n = 764), and (5) not related to biodiversity and conservation science (n = 676; Table 1.).

Article classification and metadata preparation

We carefully reviewed the articles and categorized them into nine main topics to identify patterns and/or trends and gaps. These topics included: (1) research lens, (2) physiography, (3) ecosystem type(s), (4) protected area, (5) taxonomy (name of species and its taxonomic classification up to order), (6) ecological focus, (7) funding, (8) research recommendation, and (9) research authorship and collaboration (Table 2).

We assessed each paper in terms of the research lens, which included the approach used to investigate the problem. We defined five research lenses: (a) ecological, (b) socio-cultural, (c) economic, (d) governance, policy, and legislation, and (e) multidisciplinary. Ecological research involves the scientific investigation of species and their intersections both at intra- and inter-species levels (Sutherland et al. 2009). Ecological research comprised several different branches, each of which has specialized literature of its own (Staples et al. 2019). We further categorized ecological studies into ten subtopics: (I) behaviour, (II) climate change, (III) competition, (IV) demography, (V)

Table 1 Inclusion and exclusion criteria of peer-reviewed articles on biodiversity and conservation in Nepal

	SN	Keywords	Articles
Inclusion Criteria	1	fungi OR animalia OR plantae OR mushrooms OR moulds OR lichen OR algae OR bryophytes OR pteridophytes OR gymnosperms OR angiosperms OR flowering AND plants OR fish OR amphibians OR reptiles OR birds OR mammals OR frog OR snakes OR aves OR fishes OR aquafauna) AND (Nepal OR Himalaya)	530
	2	(pisces OR insects OR snail OR butterflies OR herpetofauna OR avifauna OR carnivore OR biodiversity OR wildlife OR ecology OR conservation OR "endangered species" OR "threatened species" OR "conservation challenge" OR fern OR mosses OR "aquatic ecosystem") AND (Nepal)	1990
	3	"terrestrial ecosystem" OR "forest ecosystem" OR "grassland ecosystem" OR "mountain ecosystem" OR "ecosystem services" OR "ecosystem goods") AND Nepal	199
	4	("watershed" OR "wildlife conservation" OR "forest") AND ("Nepal")	1540
		Total (inclusion)	4259
Exclusion Criteria	1	Duplicate articles	1103
	2	Articles published in the non-English language (n=63), book chapters, books and conference papers (n=454) and articles not available to download (n=101).	618
	3	Articles not related to Nepal	764
	4	Article not focusing on biodiversity conservation.*Articles focusing on understanding, describing, managing and protecting species, ecosystems and ecosystem services from any lens viz. ecological, social, economic, legal and institutional are considered biodiversity research. Articles on agriculture and animal husbandry are not included in the list.*	676
		Total (exclusion)	3161
		Total articles included in the review	1098

Table 2 Details of the categories and sub-categories used to describe the focus of biodiversity research articles

Biodiversity elements	Categories
1. Research lens	1.1 Ecological focus, 1.2 Socio-cultural focus, 1.3 Economic focus, 1.4 Governance, policy, Legislation focus, 1.5 Multidisciplinary focus
2. Physiography	2.1 Terai, 2.2 Siwalik, 2.3 Midhills, 2.4 High mountain, 2.5 High Himalaya
3. Ecosystem	3.1 Forest, 3.2 Grassland, 3.3 Wetland/freshwater/aquatic, 3.4 farmland/agriculture
4. Protected area (PA)	4.1 Inside PA, 4.2 Outside PA
5. Taxonomy	5.1 Animalia, 5.2 Plantae, 5.3 Fungi (up to class and order level)
6. Ecological focus	6.1 Behavior, 6.2 Climate change, 6.3 Competition, 6.4 Demography, 6.5 Distribution, 6.6 Genetics, 6.7 Grazing, 6.8 Parasitism, 6.9 Physiology, 6.10 Predation
7. Funding	7.1 Yes (Name of the country) 7.2 No
8. Research recommendation	8.1 Yes (Basis of recommendation) 8.2 No
9. Research authorship and collaboration	9.1 The name of countries where the institutions of the corresponding, lead and all authors are based.

distribution, (VI) genetics, (VII) grazing, (VIII) parasitism, (IX) physiography and (X) predation.

Biodiversity and conservation research also provides conservation and management decisions in the context of underlying ecological theory (Slobodkin 1988), but such applied research recognizes people and nature linkages (Liu et al. 2007; Sutherland et al. 2009). The socio-cultural lens involves understanding the social and cultural aspects of a system that can have positive or negative effects on biodiversity conservation (Guerrero et al. 2018). The same applies to research with a governance, policy and legislation lens that focuses on planned institutional frameworks, legislations, and policies, and investigates their effects on the conservation and management of species, ecosystems and/or natural resources. The economic lens brings an interdisciplinary approach where economic science is the main focus of investigation (Daly and Farley 2011).

In taxonomic classification, we first determined if any taxa are the subject of focus in each paper and categorized it into order and sub-order following the classification available at the integrated taxonomic information system (https://www.itis.gov/). We used the land use and land cover classification of Nepal (Uddin et al. 2015) as a proxy for ecosystem type. Similarly, we followed the land resource mapping project for physiographic classification (LRMP 1986). This classification divides Nepal into five regions (see Table 2). The Terai is a flat land in the southern Nepal, which forms part of the alluvial Gangetic plain. It lies at an altitude between 60 and 300 m asl along the Nepal–India border and has a tropical climate. The Siwalik rises abruptly from the Terai and reaches an elevation of between 700 and 1500 m asl. The Midlhills (middle mountain) occupy the central region of the country. The average altitude is 2000 m with elevations ranging from 600 to 3500 m asl. High mountains are high regions with a temperate climate and are situated in the middle part between midhills and high Himalaya. The High Himalayan zone is the northern most part of the country bordering with Tibet (LRMP 1986).

We assessed if the articles provided recommendations, and further categorize those into three categories: (a) actionable recommendations, (b) recommendations based on ecological reasoning and (c) recommendations for further study. Actionable recommendations include a set of activities that relate directly to the research finding(s) and offer specific actions (van Rees et al. 2021). Recommendations based on ecological reasoning covers ecological theories and opinions rather than specific research finding, case studies, or empirical data (Heller and Zavaleta 2009).

As conservation biology is regarded as a "mission-driven crisis discipline" (Meine et al. 2006), funding is a major challenge faced by researchers worldwide. We assessed if the article was funded, and recorded sources of funding by country of funding agencies. The authorship pattern is important in understanding the dynamics of research collaboration (Fazey et al. 2005a; Harrison 2006). We extracted name of the country based on institutional affiliation of authors and evaluated trends in authorship in terms of lead (first author) and corresponding authors by the country of affiliation.

We were aware of possible misclassifications. We, therefore, organized a meeting before actual classification to arrive at a common understating by first assigning the same set of 25 papers to three individual co-authors who read and classified their content as described above. We then compared classification accuracy and discussed the areas of ambiguities to work out differences. When information about the subject of interest was not salient, we recorded it as "Not Relevant" during data preparation and classification.

Data analysis

We calculated the total number of publications by all categories, including overlapping sub-categories, where applicable. The proportions of publications under various categories were compared using the two-sample z-test, which allows a comparison of two proportions. Results were visualized using a Venn diagram. Venn diagrams allow us to graphically visualize the shared and unshared identifiers providing insight into comparisons (Venn 1880). We examined the temporal trend of article publication in terms of total publications, plants, animals, and authorship (corresponding author and first (or lead) authors in Nepal and abroad) using a Mann–Kendall test over the total period and the period post-1999. The test identifies the magnitude and direction of monotonic trends. The tau coefficient ranges between − 1 and 1, where positive values indicate an increasing trend and coefficients close to 0 indicate an absence of a trend over time (Mann 1945).

We coded each paper (0/1) in terms of its research focus separately for ecological, socio-cultural, economic, governance, policy, and legislation categories. We further classified papers as multidisciplinary if they had more than one research focus. We used the Cochrane Armitage Test for Trend to assess trend changes for research focus over time. We calculated the areas covered by Nepal's physiographic regions (LRMP 1986), protected areas (Man 2011), and ecosystem types (Uddin et al. 2015). We then analyzed whether the observed numbers of publications of each category were different from the expected numbers using a Chi-square test.

Apart from taxonomic classifications, we calculated average and standard deviation from the frequency distribution of species per class for both plants and animals. We also evaluated whether the observed diversity of studied species in each class within the plant and animal kingdoms were different from those expected based on their diversity in each corresponding class using the chi-square goodness of fit test.

We calculated the average number of authors per publication in total, including papers led by authors based in Nepal and abroad. We computed networks of corresponding and lead authors (first authors) with other authors based on their country of affiliation. We developed an adjacency matrix where nodes in our analyses represent countries and vertexes are the numbers of connections between authors (lead authors vs. others, corresponding vs. others). We used "circlize" packages (Gu et al. 2014) to construct author network plots.

Result

Publication trends of biodiversity and conservation articles

A total of 1,098 articles on biodiversity and conservation science were published over the past 56 years (1964–2019)—except between 1974 and 1978—in Nepal, with an annual average of 24.15 ± 30.43 articles. While we observed an increasing trend in the number of articles over the years, it was not significant over the last 56 years (tau b = −0.056, p = 0.613) (Fig. 1). However, the number of publications increased significantly

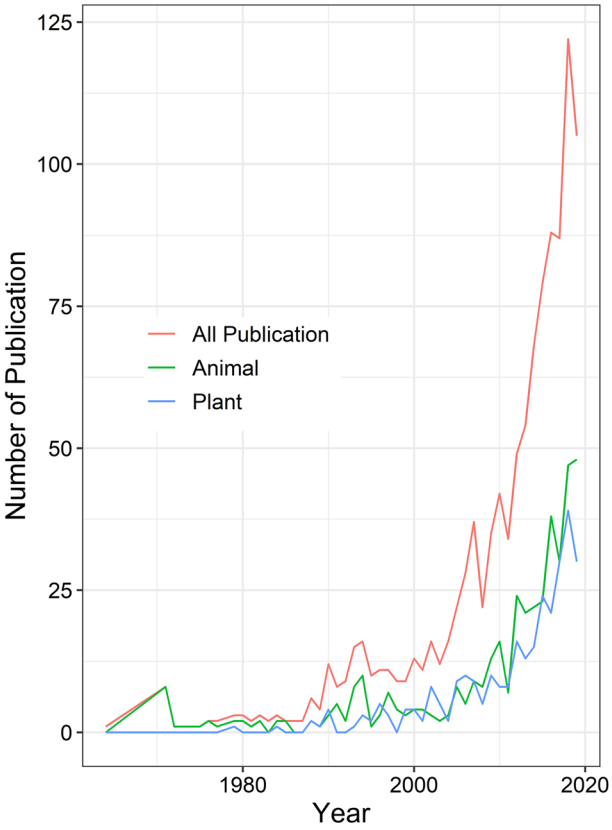

Fig. 1 Publication trend of articles on biodiversity and conservation in Nepal between 1964 and 2019

after 1999 (tau b = 0.878, p < 0.001), with an annual average 47 ± 33.58. A consistently similar pattern was observed for both plants and animals (Fig. 1).

Research lens: socio-cultural, economical, ecological, and governance, policy and legislative focus

There was a significant difference in the numbers of research articles in terms of their main research lenses: (a) socio-cultural, (b) economical, (c) ecological, (d) governance, policy and legislative and (e) multidisciplinary ($X^2 = 768.46$, df = 4, P < 0.0001). The vast majority of articles had ecological lens (n = 650, 59%), followed by the socio-cultural (n = 354, 32%), multidisciplinary (n = 219, 20%) and each of economic and governance, policy and legislation lens (n = 92, 8%). Research articles with a multidisciplinary lens (more than one focus area) comprised a large proportion of articles with socio-cultural and economic lens, whereas articles with an ecological focus were mostly specialized in that lens (Fig. 2). The Cochran–Armitage test showed significant upward temporal trends in the publication of articles with only socio-cultural (p = 0.023) and multidisciplinary lenses (p = 0.028).

About 18% of articles with a socio-cultural lens (n = 63) were about conservation conflict (e.g., human–wildlife conflict) and 28% were about community forests. It was a major domain of research that comprised 14% of total articles (n = 156) in terms of management, community participation and involvement.

Physiography

A total of 811 research articles had a geographical focus, with a majority of papers on the middle mountain (44%) and terai (43%), followed by high mountains (32%), Siwalik (21%) and high Himalaya (16%). The number of publications per physiographic region was not proportional to the region's area ($\chi^2 = 12.67$, df = 4, p = 0.01). However, there was a high overlap among regions (Figs. 3b and 4).

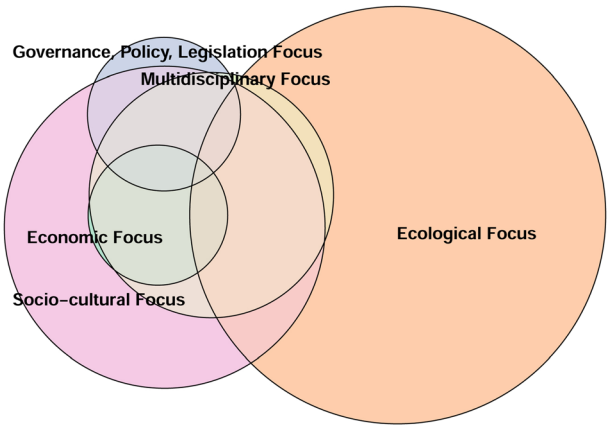

Fig. 2 A Venn diagram of research articles with five research lenses published in Nepal between 1964 and 2019. The diagram indicates the total number and the extent of overlap among different research lenses

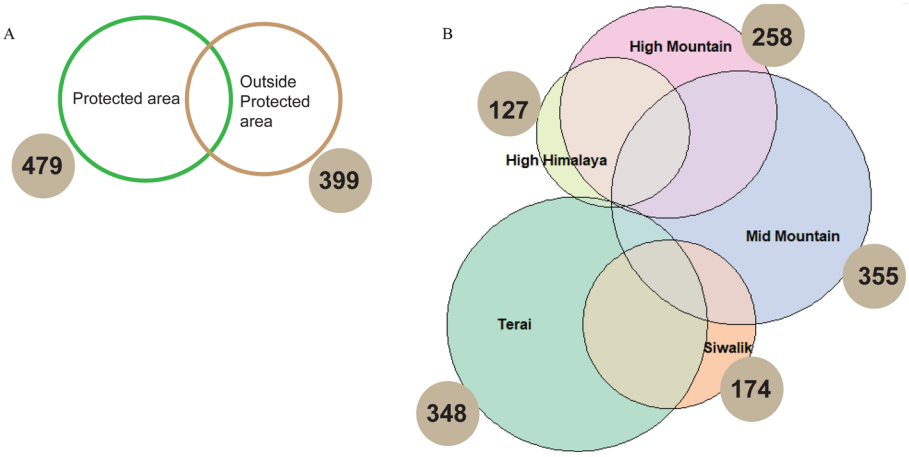

Fig. 3 A Venn diagram of research articles showing coverage of research articles in term of (**a**) protected area (n = 752) and (**b**) physiography (n = 811). The diagram indicates the total number and the extent of overlap

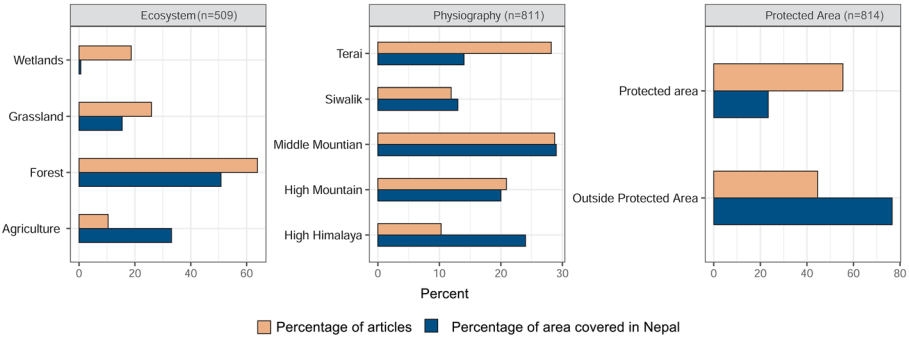

Fig. 4 Distribution of the research articles by ecosystem, physiography and protected area, and the area covered by respective their categories (in %). Total number articles in these three categories are given at the top of the plots

Ecosystem

There were 509 papers with a focus or/and related to various aspects of ecosystem (habitat) type, where the forest was the most prevalent ecosystem type (64%), followed by shrublands/grasslands (26%), wetlands/water bodies (18%) and farmland/agriculture (10%). The number of publications per habitat type was not proportional to their corresponding areas ($\chi 2 = 31.38$, df = 3, $p < 0.0001$) (Figs. 3 and 4).

Protected area

Research articles were predominately focused on the protected area (59%), which was not proportional to their areas, suggesting that significantly more publications were devoted to the protected areas ($X^2 = 20.21$, df = 1, $P < 0.000$). Additionally, 8% of papers covered areas that were both inside and outside protected areas (Figs. 3a and 4).

Taxonomic group and research biases

The number of articles on specific taxonomic groups was 745, where 55% articles were focused on animals and 40% articles were on plants. Articles on other taxonomic groups were negligible, with 5% on fungi and 0.13% on protists.

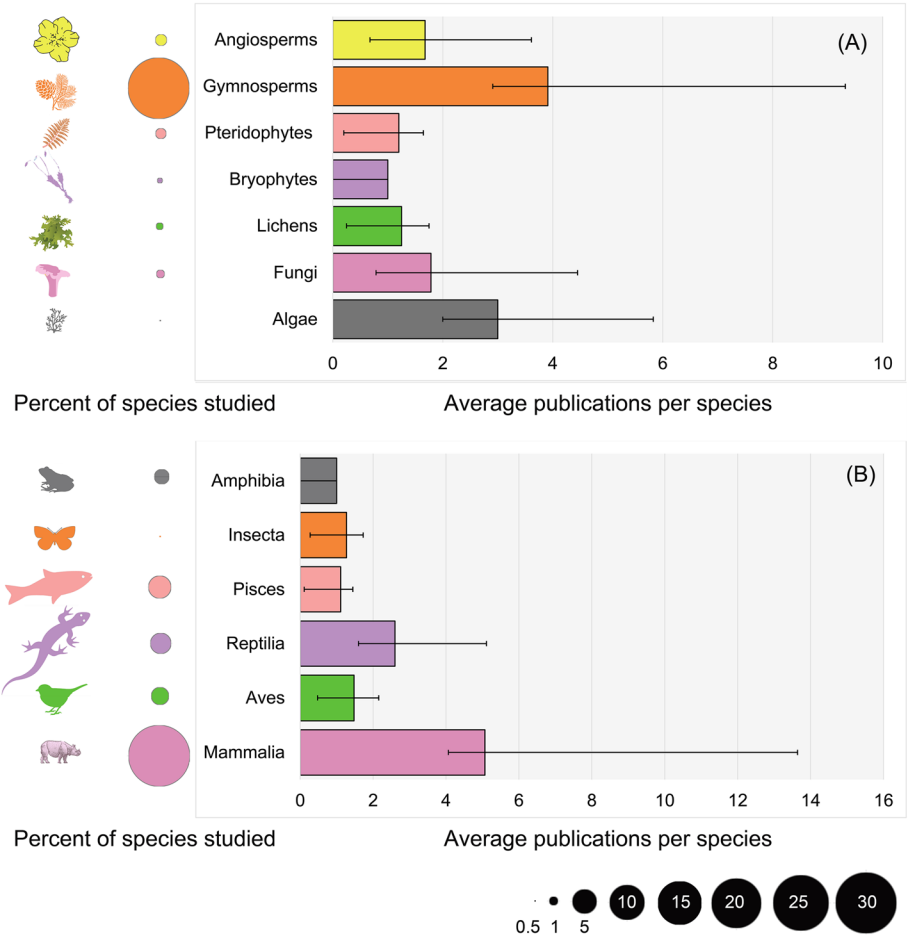

Fig. 5 Percent of species studied (left pan) and average species per classes (right pan) studied in Nepal over period between 1964 and 2019

In plants, the gymnosperms covered highest proportion of species described in the corresponding class in Nepal (26.83% of the gymnosperms species recorded in Nepal), followed by angiosperms (1%), pteridophytes (0.86%), fungi (0.57%), lichens (0.47%) and bryophytes (0.33%) (Fig. 5a). Within animals, the largest proportion of studied species were mammals (29% of the species recorded in Nepal), followed by fish (3%), reptiles (2%), birds (2%) and amphibians (2%). Articles on invertebrates (n = 32) were mostly on insects, which covered just 0.22% of insect described in Nepal. (Fig. 5b). The average publication per species within those corresponding taxonomic groups was higher (value greater than 1) in mammals, algae, reptile, and gymnosperms.

Tiger (*Panthera tigris tigris*) was the most studied/focused species, which alone comprised 8.45% of the total frequency of studied species (n = 639). The snow leopard (*panthera uncia)*, received the second most attention (4.38%), followed by elephant (*Elephas maxiums*) (3.75%), red panda (*Ailurus fulgens)* (3.12%), and one horned rhinoceros (*Rhinoceros uncornis)* (2.93). *Abies spectabilies* (2.66%), *Betula utlis* (1.87%), and *Pinus wallichiana* (1.56%) were the most studied plants (Fig. 6).

Ecological research

There were 464 publications on animals (71%, n = 329) and plants (29%, n = 135) with an ecological focus, whereas 94 publications had multiple foci. Publications on species distribution and habitat use dominated ecological research (40%), followed by behaviour (15%), demography (13%), climate change (10%) and genetics (9%). The proportions of studies on competition (3%), grazing (3%), parasitism (2%), predation (3%) and physiology (2%) were very small in comparison (Fig. 7).

Ecological publications focusing on climate change started to appear in 2000 and increased rapidly, mainly on plants. The same pattern was observed in studies with a

Fig. 6 Word cloud of species reported in articles on biodiversity and conservation science in Nepal

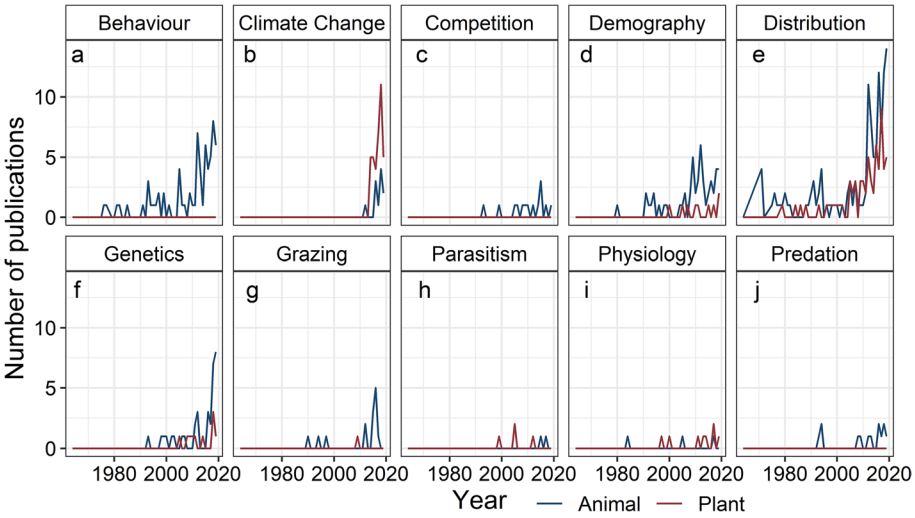

Fig. 7 Publication trend of articles with different aspect of animal and plant ecology in Nepal between 1964 and 2019

genetic approach. There were a few publications on competition, grazing, parasitism, physiology and predation (Fig. 7).

Research recommendation and funding

A total of 431 (43%) papers provided explicit recommendations. The basis of such recommendations varied considerably, with most coming from research findings (n = 86%, n = 372) and ecological reasoning (14%, n = 59). Among them, 42 publications recommended further study. Of the total published research papers, only 64% (n = 700) were funded. Among them, a small proportion of papers received funding from institutions, either governmental or non-governmental, based in Nepal (15%, n = 108 papers).

Biodiversity research: authorship and collaboration

The average number of authors per publication was 3.77 ± 2.95, with a median of 3. Among total publications, 51% (n = 555) were solely published by authors belonging to institutions based in foreign countries, and foreign-based authors were involved in up to 89% (982) of all publications, and consistently maintained dominance as corresponding and lead authors (Fig. 8). Overall, authors from Nepal-based institutions contributed a significantly low proportion of publications—as compared to their foreign counterpart—as a corresponding (24%, n = 264) or lead (first) (30%, n = 329) authors. Only 16% of total publications had both lead (first) and corresponding authors from Nepal-based institutions (n = 175).

A network analysis of research collaboration based on the country of affiliation of corresponding and lead authors showed consistently high intra-country collaboration in terms of both corresponding and lead authors. Inter-country collaborations were mainly with authors from the United States, the United Kingdom, India, Australia, Germany, and

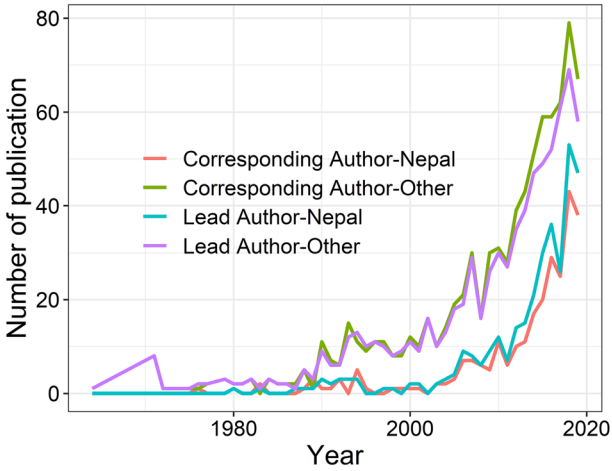

Fig. 8 Publication trend of articles based on country of author's affiliation as corresponding and lead authors

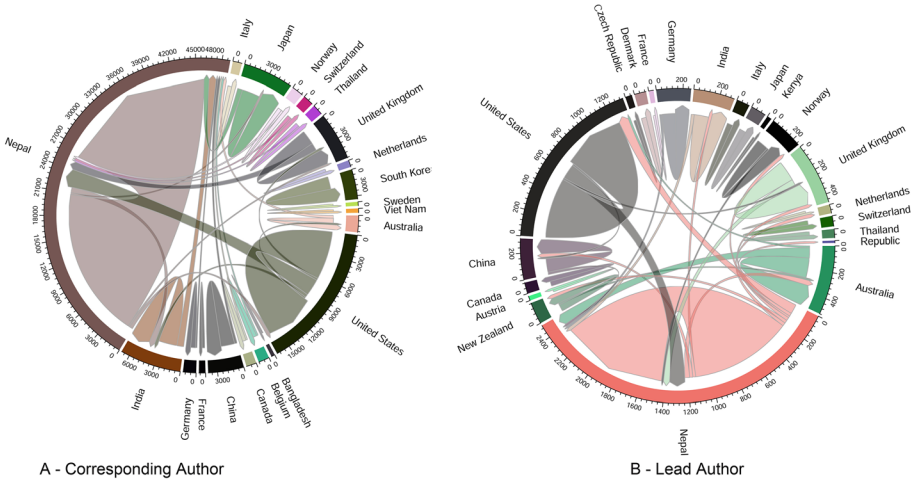

Fig. 9 Authorship network based on country of author's affiliation. The width of each band in the circular plot represents the number of collaborations as a (**a**) corresponding author and (**b**) lead authors. The circular plot is scaled to the total connectivity of each collaboration

France (Fig. 9). Nepal-based authors collaborated with researchers from 66 countries as lead authors and with researchers from 175 countries as corresponding authors (Fig. 9).

Discussion

Our comprehensive analyses of articles provide the first synopsis of biodiversity and conservation research over the last 56 years in Nepal, providing a detailed outlook on conservation publication patterns in terms of taxonomy, ecology, ecosystem, policy, and funding sources. Scientific publications are good indices of research productivity. Our findings

suggest a growing trend in conservation research, as demonstrated by the constant increase in the number of publications since 1990, with increasingly multidisciplinary and new-frontiers research (e.g., genetics, climatic change). However, there are gaps requiring an appropriate strategy to overcome them.

Publication trends of biodiversity and conservation articles

From our analysis, the publication trend was monotonic from 1960s to 1989, then increased slightly afterwards, but a significant increase was observed after 1999. Very little research before this era can be attributed to Nepal's isolation from the rest of world until the fall of the Rana regime in the 1950s (Brown 1971) and, later, the subsequent autocratic panchayat system that ended in 1990 (Baral et al. 2012). Biodiversity and conservation research was limited to a few foreign scholars, including a few foreign-trained local researchers. The rise of publications after the 1990s suggests the influence of the development of Nepal as a liberal democracy in 1990 (Heinen et al. 2019), the growth of local researcher and institutions (Gautam 2017), and increased access to global research and conservation communities. There were, however, fluctuations in the total number of publications between 1998 and 2006, which may be due to the Maoist insurgency that started in 1995 and ended in 2006 and seriously hindered research activities in the country (Baral and Heinen 2005). Additionally, a drastic drop in publications in 2008 and 2011 can be attributed to, among others, political turmoil during the constitution drafting process.

Research lens: socio-cultural, economical, ecological, and governance, policy and legislative focus

We discussed five broad research lenses covering natural, social, economic, and interdisciplinary approaches. Articles with an ecological lens were more than the combined social-cultural, economic and governance, policy, and legislative lenses, suggesting a dominance of ecological studies. These findings are consistent with global biodiversity publication patterns (Velasco et al. 2015; Mair et al. 2018). However, there is an increasing focus on socio-ecological studies. Since ecological research focuses on understanding of how species interact and function and of the processes underlying patterns in biodiversity, such research nevertheless makes a big impact in applications (Müller et al. 2010). The reintroduction of Asiatic water buffaloes to Chitwan National Park from Koshi Tappu Wildlife Reserve and rhinoceros to Bardia and Shuklaphanta from Chitwan National Park was made possible by feasibility study of habitat preference of these species (Acharya et al. 2016, Jhala et al. 2021). The Arna population failed to establish in Chitwan demands specialized ecological research such as population dynamics etc. Terai Arc Landscape project helped to increase wildlife populations, but the region become conflict hotspots, demanding social aspects of research (Fletcher and Toncheva 2021). Such studies are important to understanding socio-ecological dynamics of the conflict and are critical for a strong policy and management recommendation (Struebig et al. 2018). Biodiversity components correlate with several factors such as resource consumption, institution and land use and land cover, and multidisciplinary studies covering these aspects provide for strong recommendations using social, economic and institutional pathways to inform future policy (Miller et al. 2012; Rissman and Gillon 2017).

In our results, articles with multidisciplinary foci comprised a small proportion of published articles but steadily increased over time. This is consistent with global

publication trends (Velasco et al. 2015), indicating the expanding number of journals and articles in the field of conservation biology (Cronin et al. 2014). Multidisciplinary foci, although they can produce fascinating insights, are limited due to traditional disciplinary boundaries, epistemologies, methodological ambiguities and/or complexities and limited funding (Metzger and Zare 1999; Pooley et al. 2014; Bromham et al. 2016). The increasing trend in the multidisciplinary foci in Nepal in later years may be attributed to an increase in acknowledgement of biodiversity and conservation science in other disciplines (e.g., social science, economics, sustainable development), growth in international collaborations, and donor agencies, and initiation of multidisciplinary subjects into undergraduate and graduate degrees in Nepal and elsewhere (Heinen et al. 2019).

One of the contributing factors in expanding multidisciplinary research in Nepal is the evolution of community forestry (Timilsina and Heinen 2008). It is regarded as one of the most successful community-led forest management programs worldwide and has helped in the restoration of biodiversity throughout much of the country (Brendler and Carey 1998; Acharya 2002). The program brought experts from diverse social and natural science backgrounds together to study various aspects of forestry and biodiversity conservation. Another contributing factor to more multidisciplinary research recently is that protected areas are visited by nearly 70% of tourists in Nepal, and research involving various dimensions (e.g., disturbance, economic valuation, tourism-conservation nexus) is expanding (Baral et al. 2017).

We call for specialized research to see the extent of impact taking multiple stressors such as climate change, pollution, and forest degradation, on biodiversity and ecosystem services. There are reports of climate induced change in distribution of medicinal and aromatic plants (Shrestha et al. 2022) and expansion of invasive align species (Bhattarai et al. 2017), threatening both aquatic and terrestrial biodiversity of Himalayan region (Kattel 2022)). There are social consequences of change in ecosystem services. For instance, non-timber forest products are susceptible to degradation due to a variety of factors including deforestation, climate change, and over-harvesting. This can have significant negative impacts on the livelihoods of local communities who rely on these products for income (Gurung et al. 2021).

Physiography

We found a bias in terms of physiographic focus, with a disproportionately high number of articles covering the terai and a disproportionately low number of articles covering the high Himalayas. While these biases are reasonable on several grounds, we call for some corrections. First, the terai, or lowland areas of Nepal, has been a priority for researchers because it is the last sanctuary of globally-endangered species such as tiger, one-horned rhinoceros and elephant, and it supports a very high diversity of birds (Paudel and Šipoš 2014; Primack et al., 2013). Second, the region has six protected areas, which naturally get a high priority for research as compared to non-protected areas (Orlikowska et al. 2016). Third, the region supports nearly half of the Nepali population, and as such it is more accessible via roads than most places in the mountains. We call to bridge the knowledge gaps in the high mountains, which are experiencing some of the earliest and greatest impacts of climate change; understanding these changes is critical for securing biodiversity (Xu et al. 2009).

Ecosystem

Forests were investigated proportionate to their area, similar to previous studies (Fazey et al. 2005a). Agricultural ecosystems, however, were studied disproportionately less compared to their area. Agricultural lands are important biodiversity repositories, particularly for butterflies (Stefanescu et al. 2005), avifauna (Li et al. 2020) and ecosystem services (Benton et al. 2003). Such areas are under heavy pressure for agricultural intensification and modernization, requiring more conservation research to determine the effects of change on native species living within them (Stefanescu et al. 2005; Orlikowska et al. 2016; Li et al. 2020).

Protected area

Protected areas (PA) are cornerstones of biodiversity conservation, but they have been inadequate for protecting representative samples of biodiversity and areas of high conservation importance due to their small sizes and inappropriate placements (Rodrigues et al. 2004). A disproportionately high number of articles covering protected areas in Nepal is expected, but we recommend considering knowledge gaps resulting from such discrepancies. Nepal's protected areas under-represent elevational ranges below 2000 m asl, and thus middle mountains remain largely outside the PA network (Paudel and Heinen, 2015b), including areas supporting a high diversity of fauna (Hunter and Yonzon 1993) and many endemic seed plants (Shrestha et al. 2021). As protected areas alone are insufficient in representing all forms and ecosystem services (Rodrigues et al. 2004; Leverington et al. 2010), research biases in favour of protected areas may result in huge knowledge gaps (Heinen et al. 2019). Moreover, conservation challenges such as human–wildlife conflicts, climate change, habitat loss and fragmentation, and expansion of invasive species are serious outside of protected areas (Panta et al. 2008; Bhattarai et al. 2014; Acharya et al. 2016, 2017), thereby requiring more biodiversity related conservation studies in such places.

Taxonomic group and research biases

Given a biased publication frequency in favor of gymnosperms and mammals, and under-representation of most biota, with a high focus on certain species, our overall results are in concordance with studies on taxonomic bias elsewhere (Amori and Gippoliti 2000; Cronin et al. 2014; (Velasco et al. 2015; Donaldson et al. 2016; Di Marco et al. 2017; Titley et al. 2017) but offer some important insights (below). Taxonomic bias, a condition where some taxa are studied more often while some others are ignored, is a common problem in biodiversity research worldwide (Tews et al. 2004; Cronin et al. 2014; Donaldson et al. 2016; Di Marco et al. 2017; Titley et al. 2017). In our results, tigers alone accounted for 8% of the total frequency of species records, which together with globally threatened iconic species such as snow leopard, elephant, red panda, and one-horned rhinoceros, collectively accounted for 22% of all records in our database. Such conditions emanate from a disproportionate focus on certain geographies, habitat types, the interest of researchers and their expertise, and the priorities of funding agencies and journals (Fazey et al. 2005b; Griffiths and Dos Santos 2012). This is similar to other studies that showed that threatened species, those that are large-bodied and

those having large ranges, are studied most often (Fazey et al. 2005b; Trimble and Van Aarde 2010; Brooke et al. 2014; Titley et al. 2017). While large mammalian herbivores (e.g., elephant, rhinoceros) and carnivores (tiger, snow leopard and common leopard) are disproportionately at higher risk of extinction, research efforts on these species are warranted (Trimble and Van Aarde 2010). But ignorance of myriad data-deficient species, including most species of fungi, algae, bryophytes, insects, amphibia and reptiles, is a matter of serious concern (Bland et al. 2015). This shortfall needs to be addressed urgently.

Ecological research

Although there was a preponderance of ecological articles, a large proportion of such publications were based on general ecological surveys such as distribution and habitat use. While explorative research is important for smaller taxa with a high chance of new species description to science and/or a certain location, such research on well-known species in certain areas (e.g., protected areas) may have a little contribution. Recent reports suggest that new species are continuing described to science in Nepal such as *Gastrochilus nepalensis* (Orchids) (Raskoti 2015), *Microhyla taraiensis* (frog) (Khatiwada et al. 2017), and five species of the diatom *Lindavia biswashanti*, *E. igorii*, *E. zechii, E. panchpokharensis and E. paramuscicola* (Krstić et al. 2013; Mohan et al. 2018).

There were few articles on other forms of ecological research such as physiology, competition and predation, which would require long-term data or/and more specialized skills and equipment (Vucetich et al. 2020). Such research provides the basic knowledge required to answer applied questions to make informed decisions (Belovsky et al. 2004; Sutherland et al. 2006). Physiological ecology, for example, is effective in the conservation of several endangered species sensitive to changing climates and emerging pathogens and diseases (Carey 2005; Tracy et al. 2006). Such studies could even provide important insights into population dynamics, species distributions, competition, and predator-prey interactions (Lawton 1991). Similarly, research on competition and predation ecology are equally important in understanding predator-prey interactions, intraguild relationships among predators, cost-benefits of prey or predator reintroduction, and in minimizing the chances or ecological consequences of meso-predator or invasive plant releases (Ripple and Beschta 2004; Prugh et al. 2009). Ecological research focusing on climate change and genetics is new and growing rapidly, similar to publication patterns in the USA (Stroud et al. 2014) and other South Asian countries (Bhattacharjee et al. 2017). The major concern here is that such studies were also limited mostly to flagship mammal species such as elephants and leopards in the region (Di Marco et al. 2017).

As the Himalayan region has already experienced climate change-induced impacts (Wester et al. 2019; Kattel 2022), the need for ecological studies (e.g., physiology, inter/intra species interactions) focusing on climate-mediated impacts could be very important to identify physiological thresholds of individual species and to understand the population dynamics of interspecies interactions (Bhattacharjee et al. 2017). Species have been documented to be moving upslope (Gaire et al. 2014). Research in decision science, interdisciplinary field that uses systematic and data-driven approaches to improve the decision-making process (Simon 1977), is particularly important in conservation planning and design of protected areas. We call on the Government of Nepal and Nepali universities/research institutions to place greater emphasis on specialized and long-term ecological research that

requires not only funding, but also capacity building of researchers and institutions (Bhattacharjee et al. 2017).

Research recommendation and funding

One of the major expected outcomes of ecological and conservation research is to make recommendations for conservation actions (Fazey et al. 2005a). Our findings showed that few articles had explicit research-based recommendations, indicating an ever-increasing gap between conservation research and actions happening worldwide (Knight et al., 2008; Fazey et al., 2005a). We found that the vast majority of articles were of very general ecological surveys and conservation aspects, which are less likely to provide definite recommendations (Knight et al. 2008).

We observed that 64% of the articles were based on funded research, and only 15% had support from Nepal-based institutions, which is consistent with findings globally that show international funding was vital for conservation-related research in low-income countries in general (Fazey et al., 2005a). This has been identified as one of the major causes of geographically-biased research publications, thereby limiting the achievements of many international conservation targets (e.g., Wilson et al., 2016).

Biodiversity research: authorship and collaboration

That more than half of the articles we summarize here were authored only by foreign-based researchers, who consistently maintained dominance as lead (first) and corresponding authors, came as no surprise. This is similar throughout developing economies that rely on international funding for conservation-related studies (Fazey et al., 2005a). Several factors potentially may have contributed to this pattern such as lack of research-based universities, poor research environments, feelings of inferiority in research quality, publication costs, and English language barriers (Fazey et al., 2005a; K. A. Wilson et al., 2016). Here, It is important to note that while some of the foreign-based authors may be Nepali citizens working in foreign universities and research organizations, we believe that this population is relatively small, and the country of the institution plays a crucial role in research productivity. Scientists from developed countries can and should support the capacity-building of researchers from developing countries (Fazey et al., 2005a; Griffiths and Dos Santos, 2012). Much of the world's biodiversity hotspots are disproportionately located in developing regions (Myers et al. 2000), and collaboration between researchers from developing and developed nations is needed (Wilson et al. 2016). While primary goal should be better conservation, Nepali researchers need to have better participation in research to ensure that conservation efforts are tailored to the local context. Thus, there is a need for funding local researchers and strengthening their capacity and that of their institutions, which is important for highly specialized and long-term ecological research.

Conclusions and the way forward

The results of our study revealed a significantly increasing trend in biodiversity publications based on research in Nepal, especially after the country restored liberal democracy in 1992. Although articles with ecological lenses dominated the list of publications, the growing trends of article publication on socio-cultural and multi-disciplinary lenses suggest a

widening conservation focus, which is highly essential for effective conservation interventions (Miller et al. 2012; Rissman and Gillon 2017).

There is a huge bias in research in favour of lowland (Terai), protected areas, forested ecosystem and certain species of gymnosperms and mammals. A large proportion of ecological articles were based on general ecological surveys (e.g., distribution and habitat use), whereas articles based on long-term data, extensive field surveys and specialized knowledge (physiology, competition and predation, evolution) were very few, suggesting a widening gap of research and conservation needs. Even fewer published articles had explicit research-based recommendations, indicating an ever-increasing gap between conservation research and actions happening here. Additionally, foreign-based researchers have consistently dominated biodiversity and conservation research as lead and corresponding authors, who contribute up to 89% of authorship to published articles. There is a need to correct biases, including support for local researchers and strengthening their capacity, which is important for highly specialized and long-term ecological research.

Beside various aspects of biodiversity and conservation research discussed in the earlier sections, new frontiers of research covering multidisciplinary approaches are emerging. For example, conservation strategies for managing biodiversity responding to the risk of climate change and its consequences are in urgent priority. Recent studies have shown that invasive alien plants are likely to expand new areas, including at higher elevations under future climate change scenarios (Shrestha and Shrestha 2019). Medicinal and aromatic plants—the main income source of mountain people—could ultimately decline and even loss due to confounding impacts of climate change and overharvesting (Kunwar et al. 2016; Shrestha et al. 2022). We call for future research focusing on climate change mediated impacts given its far-reaching negative repercussions on wildlife habitat, ecosystem services, agriculture production and people's livelihoods.

Research on wetlands is also very few in Nepal. Recent studies from different parts of Nepal revealed that aquatic habitats are rich in macroinvertebrates (Devi Tachamo Shah et al. 2020), but are threatened due to ongoing infrastructure development (e.g., water diversion) (Shah et al. 2020) with rapidly changing natural flow regimes (Kattel and Wu 2023). Another important research focus is ecosystem services, which are critical for meeting current and future societal needs by providing provisioning, regulating, supporting and cultural services (Kattel 2022). There is a big knowledge gap where research could generate new evidence of the functioning of ecosystem services specific to the Nepal Himalaya such as climate regulation, erosion regulation, disease control, genetic resources and water purification etc.

Limitations

While we obtained articles from journals indexed in Elsevier's Scopus database and selected articles published in the English language, we believe that there was very little influence due to these selection biases. Scopus includes a large collection of biodiversity and conservation journals. Our database included 425 journals, providing most of the international (e.g., Conservation Biology, Biological Conservation, Oryx, Global Ecology and Conservation, Environmental Conservation, and Biodiversity and Conservation etc.) and regional journals of reputed in the field (e.g., Asian Herpetological Research, Journal of Asia-Pacific Biodiversity). We are aware that local journals occasionally publish biodiversity and conservation articles in Nepal. None of these journals is indexed in the major databases (e.g., Scopus and WoS). While some of them may have quality concerns (Paudel

et al. 2020b), they do provide some important sources of knowledge. However, rather few significant papers are published in such outlets, so we feel that our synthesis provides valuable representational insights into the patterns and trends of research in biodiversity and conservation in Nepal, and the articles that report on these topics.

Our data did not include information on the nationality of the researchers, so we used the country where their institutions were based as a proxy to examine authorship and collaboration patterns. While we acknowledge that there are foreign researchers working in Nepal-based institutions, and Nepali researchers working in foreign countries, we believe that this limitation has a small or negligible impact on the overall pattern, given the large dataset and the relatively small proportion of foreign researchers in Nepal. It is worth noting that scientific outputs of institutions are often associated with the country where they are located, due to factors such as government funding and national priorities. Therefore, our approach of using the country of the institution is justifiable, even though it has limitations.

Acknowledgements We would like to thank Prof. Joel T. Heinen for his useful suggestion and English corrections.

Author contributions PKP conceived the idea, supervised data collection team, conducted formal analyses, wrote the first draft of manuscript and prepared subsequent refinements. All authors contributed to the data collection and literature review.

Data availability The datasets generated during study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

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