REVIEW

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Five Decades of Research on Bhutan's Amphibian and Reptile—Priorities and Opportunities for the Future

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Abstract Bhutan is a biodiverse country, yet there are relatively few scientific studies on its herpetofauna. To determine research gaps and opportunities for scientific advances, we completed a literature review on amphibians and reptiles of Bhutanese origin from online databases including ResearchGate, Google Scholar, the Integrated Taxonomic Information System (ITIS), and relevant authors. Of the 63 studies on herpetofauna of Bhutan between 1972 and 2022, most focused on reptiles (45%) followed by amphibians (32%), while fewer (23%) included both taxa. Most studies were field-based (*n*=44), followed by desktop research (*n*=14), and then laboratory work (*n*=5). Ecology and natural history studies (*n*=35) dominated the literature, while other disciplines included conservation and anthropogenic interactions (*n*=22), then evolution, taxonomy, and systematics (*n*=4). Single reports existed on disease, and on genetic studies. After 2009, the quantity of literature rose considerably to a total of 52 publications on Bhutanese herpetofauna. Most studies have been conducted by Bhutanese researchers (*n*=36), followed by collaborations with scientists from outside the country (*n*=15), and work published by foreign scientists alone (*n*=12) contributed some of the earliest studies. There was a bias in the taxa studied, the type of research, and the location of study. Research concentrating on anatomy or physiology was absent, while studies on disease, genetics, taxonomy, and systematic classification are scarce. There is a pressing need for increased conservation-oriented studies, as they were poorly represented. These gaps offer direction for further research. In particular, there are few studies on the diversity and distribution of amphibians and reptiles —such information is key to analysing threats and developing effective conservation strategies. Such knowledge would contribute greatly towards the conservation and management of Bhutan's native amphibians and reptiles.

Bhutan currently harbours ca. 83 amphibian species (31 genera, 8 families, 3 orders: Anura, Caudata, Gymnophiona) and ca. 138 reptile species (58 genera, 17 families, 2 orders: Squamata, Testudines). Bhutan does have crocodiles, but they are in captivity only.

Keywords amphibians, conservation, diversity, ecology, reptiles, review

1. Introduction

Bhutan, a carbon-negative nation spanning 14 824 square miles, hosts exceptional biodiversity in the Eastern Himalayas, recognized as a global hotspot (Mittermeier *et al*., 2004; Myers *et al*., 2000). Species richness in Bhutan includes 5 114 animals, 5 369 plants, and more than 690 fungi (Gyeltshen and Prasad, 2022; National Biodiversity Centre, 2019). Every year, the number of species recognised in Bhutan continues to increase (Gyeltshen *et al*., 2020). A diversity of habitats in Bhutan ranges from subtropical forests and grasslands to alpine steppes,

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shrubland, and forest, enabling a high local biodiversity (Gyamtsho, 1996; Sherpa, 1994; MacKinnon, 1991).

Amphibians and reptiles play a vital role in Bhutan's diverse ecosystems, consistent with their ecological contributions globally (Halliday, 2008). As predators and prey, they regulate insect and rodent populations, contributing to natural pest control (Ghosh and Borzée, 2024) and nutrient cycling in forests and wetlands (Cortés-Gómez *et al*., 2014). Amphibians, serving as bioindicators of environmental health (Saber *et al*., 2017), thrive in Bhutan's critical marshlands and high-altitude lakes (Wangyal *et al*., 2022) but face threats from hydropower development, climate change, and agricultural expansion (Tariq *et al*., 2021), highlighting their conservation importance within Bhutan's environmental stewardship policies.

With over 52% of its land designated as protected areas, including national parks and wildlife sanctuaries, Bhutan prioritizes conservation over development (The Constitution of Bhutan, 2008). The government's commitment to maintaining forest cover and implementing sustainable practices has contributed significantly to its successful protection of biodiversity (Forest and Nature Conservation Act of Bhutan, 2023; The Constitution of Bhutan, 2008; Royal Government of Bhutan, 1997, 2002, 2009).

Bhutan's unique flora with as many as 144 endemic plant species (Yangzom and Thomas, 2017) and endemic herpetofauna — *Calotes bhutanensis*, *Eutropis quadratilobus*, *Scutiger bhutanensis*, etc. (Wangyal *et al*., 2022), cultural values rooted in harmony with nature, and conservation policies guided by the concept of Gross National Happiness (Richardson, 2023; Gyeltshen, 2022; Long and Long, 2019) further demonstrate its status as a biodiverse nation. However, comprehensive research is needed to fully assess the diversity of understudied taxa like amphibians and reptiles, which receive less attention compared to other groups.

Unlocking the potential of Bhutan's herpetofauna through comprehensive research holds immense importance for progressing the ecology, conservation, and management of the region's herpetofauna, yet investigations in this area have been notably constrained. Firstly, research contributes to our understanding of the diversity and distribution of existing herpetofauna, which is important as a first step to knowing what is there (Do *et al*., 2022; Wangyal *et al*., 2022). Secondly, research plays a crucial role in pinpointing threats to populations, enabling the implementation of precise conservation measures (Walls, 2018). Finally, by understanding the value of herpetofauna and their function in the ecosystem (e.g., vermin control and contribution to the food chain), research can play a role in promoting conservation efforts (Gibbons *et al*., 2000).

In the neighbouring country of India, Susruta authored the earliest information on herpetofauna found in a compilation known as *Sushruta Samhita*, dating to the sixth century BCE. This Sanskrit medical text sheds light on zoonotic diseases caused by reptile species occurring in Bhutan. However, it was Patrick Russel who conducted the first formal study on herpetofauna in India during the early 1790s, probably encompassing species found in Bhutan (Russel, 1796; Aengals *et al*., 2018). Regarding China, the pharmacopoeia *Bencao Gangmu*, written by Li Shizhen in 1596, features a chapter detailing the medicinal properties of reptiles, including snakes, lizards, and turtles, species which are shared with Bhutan.

The earliest published literature specifically on reptiles in Bhutan was a report describing a new species of agamid lizard, *Calotes bhutanensis* Biswas, 1975 (Biswas, 1976). It also included four additional reptile species (described by British herpetologists working in pre-independent India) collected by a team of zoologists from the Zoological Survey of India during their 1969 expedition into Bhutan to gather ornithological specimens. This report remained the only publication on reptiles until 1991. The first formal collection of reptile specimens in Bhutan was conducted by Naturhistorisches Museum Basel in 1972 from Samtse, Chukha, and Wangduephodrang districts. However, the collection was not reported until 1992 when Bauer and Günther moved the specimens to Germany. Since 1991, many new records have been published on reptiles and amphibians of Bhutan. These have primarily involved species' descriptions, range extensions, and natural history observations (Wangyal *et al*., 2022; Lhendup and Koirala, 2021; Wangyal *et al*., 2021a, b, c, d, e; Koirala *et al*., 2021; Wangyal *et al*., 2020a; Koirala *et al*., 2019; Tenzin and Wangyal, 2019; Koirala *et al*., 2018; Wangyal and Gurung, 2017; Koirala *et al*., 2016; Wangyal and Das, 2014; Wangyal, 2014, 2013, 2012, 2011; Wangyal and Tenzin, 2009; Mitra, 2009; Das and Palden, 2000).

Wangyal and Das (2021) pioneered the first field guide to Bhutan's reptiles in 2021, followed by Wangyal (2022) releasing a subsequent guide dedicated to amphibians in the following year. However, despite significant progress in research on Bhutan's herpetofauna over the last 50 years, there is still a lack of consolidated information on the trends of herpetofauna and related research in Bhutan. This gap in knowledge hinders the development of effective prioritisation of research and conservation and management strategies. Therefore, our goal was to review and evaluate literature on amphibians and reptiles of Bhutan over the last 50 years, summarize current information on species accumulation, identify priority areas for research, and explore biases in research from individual researchers or in certain locations or methods. Expected outcomes include a comprehensive

baseline for herpetofaunal research, identification of knowledge gaps forming research priorities for Bhutan's reptiles and amphibians, and recommendations for conservation policies, contributing to Bhutan's environmental goals and global efforts to mitigate herpetofaunal declines in the Himalayan region.

2. Materials and Methods

2.1. Data collection We conducted a comprehensive literature search for publications on amphibians and reptiles in Bhutan using various online databases to synthesize their diversity, distribution, and conservation status. The primary sources included Google Scholar (https://scholar.google.com/), ResearchGate (https://www.researchgate.net), the Integrated Taxonomic Information System (https://www.itis.gov/), the Bhutan biodiversity portal (https://biodiversity.bt/), Web of Science (https://clarivate.com/academia-government/scientific-and-academic-research/research-discovery-and-referencing/web-of-science/), and JSTOR (https://www.jstor.org/). We also contacted relevant authors directly to request copies of articles they authored that were not available in the public domain. To supplement peer-reviewed literature, we incorporated 10 grey literature sources comprising one thesis, one conference paper, three international reports, and five government reports on Bhutan's amphibians and reptiles. Authorship was verified through institutional affiliations listed in metadata or direct correspondence with authors. Validity was ensured by cross-referencing species records with the expert-verified data from the herpetofauna researchers. All sources are listed and access details provided in Appendix I. Inclusion criteria required verified species records with location data. Data were extracted manually into a standardized spreadsheet, recording species, location, and conservation status. To ensure data accuracy, we conducted duplicate checks and eliminated redundant counts during data compilation.

We used general keywords such as "amphibians", "amphibians and reptiles", and "reptiles". Later, we specified more related terms such as "herpetofauna Bhutan", "Bhutan reptiles", and "Bhutan amphibians" to enhance the searches. We also included studies conducted outside Bhutan if samples or records from Bhutan were used; this was ascertained by reading the methods and appendices of the papers. However, we could not include the general biodiversity inventory reports as they could not be accessed, and even when accessible, verifying authorship was difficult.

Studies were categorized into three groups: "amphibians", "amphibians and reptiles", and "reptiles" to reflect their taxonomic and ecological focus, facilitating analysis of research trends and knowledge gaps in Bhutan's herpetofaunal literature. This classification aligned with the scope of studies (1972–2022) and simplified data synthesis. Amphibians were separated due to their sensitivity as bioindicators, reptiles for their distinct ecological roles, and the combined group for studies addressing both taxa holistically. To enhance literature retrieval, we compiled a list of Bhutanese-endemic and regionally significant species, including the Bhutan cat-eyed toad and Bhutan agama, using their scientific names *Scutiger bhutanensis* and *Calotes bhutanensis*, respectively, as search keywords in the search sites mentioned above. This targets under-researched taxa, addressing knowledge gaps.

Literature that included both amphibians and reptiles was classified as publications on both amphibians and reptiles. We tracked the growth of research on Bhutan's herpetofauna by counting the annual number of publications over time. To allow us to assess how knowledge was obtained, we classified each publication as either "field-based", "laboratory-based", or "literature-based" as determined from the reporting of the methods used. "Field-based" studies involved direct field surveys and observations, "laboratory-based" studies included laboratory analyses such as reports of new species from descriptions of museum collections (including DNA tissue samples), while "literature-based" studies included work based on existing literature without a field or laboratory component.

To identify research gaps, we categorized each study by its main research themes: (1) anatomy and physiology; (2) conservation and herpetofauna—human interactions; (3) ecology and natural history; (4) evolution, taxonomy, and systematics; (5) diseases; and (6) genetics (Table 1). We also categorized studies by the authors' research affiliations: Bhutanese researchers, foreign researchers, or joint collaborations.

To examine the regional/provincial distribution of publications, we divided Bhutan into central (Trongsa, Wangdue Phodrang, Zhemgang, Dagana, southern part of Bumthang) eastern (Lhuntse, Mongar, Pema Gatshel, Samdrup Jongkhar, Trashigang, Trashi Yangtse), southern (Sarpang, Tsirang, Samtse, southern part of Chukha), and western regions (Haa, Paro, Punakha, southern part of Thimphu, southern part of Gasa), excluding the northern region (Gasa, northern part of Wangdue Phodrang and Thimphu) due to insufficient data. Studies lacking regional specificity were classified as national-level publications, that is country.

To compare the number of species occurrence by area with neighbouring countries, the total number of species of amphibians (Frost, 2022) and reptiles (Uetz *et al.*, 2022) was tallied for India, China, Bangladesh, Sri Lanka, Myanmar, Nepal, and Pakistan.

Table 1 Types of research on Bhutan herpetofauna and their description. SREA (Species-research effort) is a measure of research effort where 1 indicates an average research effort, >1.00 indicates a higher effort, and <1.00 indicates lower than average effort.

Type of research	Description and remarks	Number of studies (*n*)	SREA
Genetics	Research on genetics (e.g., polymorphism of one gene), the role of genes in traits, genome sequencing of species, and new gene discovery	1	0.02
Diseases	Studies using animals as test subjects include virology, parasitology, microbiology, and veterinary	1	0.02
Evolution, taxonomy, and systematics	Evidence of evolutionary processes, classifications, and relationships of the species, etc.	4	0.08
Conservation and herp-human interaction	Practical methods and policies on herp conservation, and the interface between herps and humans	22	0.44
Ecology and natural history	Ecology-based research, which includes reports on distribution	35	0.70
Anatomy and physiology	Anatomy, morphology, and physiology of herp species	0	0

2.2. Data analysis We used R to analyse these data (R Core Team, 2018). To determine the differences in publication rate over the years, we counted the number of species reported and the number of publications per year and plotted them over time using the R package "ggplot2". This showed us the research trend over the last 50 years.

We used the base R package stats that included the hclust () function for hierarchical clustering and the kmeans () function for K-means clustering of species reported and publications over time to determine temporal trends in research effort. The K-means clustering method commonly groups similar data points together into clusters based on their features by repeatedly adjusting the centroids, which represent the average of points in each cluster (Sharma, 2023). In hierarchical clustering of our dataset, the cluster count initially relied on a height threshold for clear separation (Banerji, 2023). However, the final decision to choose three clusters prioritized inherent data characteristics over a specific threshold, ensuring meaningful pattern capture.

To assess potential biases in the allocation of research effort towards particular species, we employed the species-research effort allocation (SREA) metric (Tanalgo and Hughes, 2018). This metric offers a straightforward approach to comparing effort over a dedined time period, with the formula: SREA(x) = R°/y, where x represents the species being evaluated, R° represents the number of times species x was documented in publications, and y represents the number of years covered by the review. A value of 1.00 for the SREA metric indicated an average research effort; values > 1.00 suggest a higher effort, and values < 1.00 indicate lower than average effort. The SREA metric, introduced by Tanalgo and Huges in 2018, serves as a valuable tool for assessing research effort within a specified timeframe and represents the number of studies per amphibian or reptile species in Bhutan (1972–2022). SREA quantifies research effort, identifying under-studied taxa (low SREA) to prioritize future studies and inform conservation strategies, addressing knowledge gaps in Bhutan's herpetofaunal diversity. The SREA metric was calculated to assess research effort distribution across Bhutan's amphibians and reptiles. SREA highlights under-researched species (low SREA), guiding future research priorities and supporting conservation planning to address knowledge gaps in Bhutan's biodiverse herpetofauna.

We also employed linear regression analysis to determine the relationship between the number of publications and the number of species reported over the last 50 years.

We used the available literature to compile a list of described species in Bhutan as of December 2022 (Appendix I) and categorised them according to the IUCN classification schemes (IUCN Red List, 2022). We calculated the number of species in each threat category (e. g., Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and grouped those species not identified in a Not Evaluated (NE) category).

To compare Bhutan with neighbouring countries, we obtained the size of the countries from the world atlas (https://www.worldatlas.com/articles/sizes of Asian countries-by-area, accessed on July 10, 2022) by 1 000 km^2. To ensure consistent species counts for each country, we relied on the available figures for reptiles (Uetz *et al*., 2022) and amphibians (Frost, 2022) from their respective websites. The number of species per 1 000 km^2 was determined by dividing the total number of species by the size of the country, calculated in 1 000 km^2.

3. Results

3.1. Count of species and publications A total of 63 research papers on amphibians and reptiles in Bhutan were identified, most of which were published after 2009 (*n*=52).

Most research was classified as peer-reviewed journal articles (*n*=47), but there were also a few technical reports (*n*=6), books (*n*=6), two newsletters, a magazine article, and a research thesis.

The total number of species (amphibians and reptiles combined) and publications rose slowly from 0 documented species or publications in 1972 to 221 species and 63 publications in 2022 (Figure 1). Five species of reptiles were reported in 1976, followed by 20 more in 1992.

3.2. Cluster analysis Three clusters were identified from 1972–2022 for numbers of described species occurring in Bhutan, and total number of publications relating to herpetology in Bhutan (Figure 2). In the first cluster, there was a consistently low number of species from 1972–1990 (*n*=8, amphibians and reptile species combined) and the total number of publications from 1972–2011 (*n*=16) demonstrating limited research activity during these periods. In the second cluster, there was a moderate increase in the count of species from 1992 to 2011 (*n*=92) and total publications from 2012 to 2019 (*n*=38). However, in the third cluster, there was a more rapid increase in both metrics from 2010–2022 (*n*=221) and 2020–2022 (*n*=63), indicating a growth in herpetological research and a corresponding increase in published scientific literature.

3.3. Research efforts by researchers, data collection methods, regions, and species groups Bhutanese researchers authored the most publications (*n*=37), predominantly on ecology and natural history, followed by collaborative efforts (*n*=15) that often prioritize conservation discussions, and foreigners authored the least (*n*=11) in taxonomy and diseases. Most data were collected directly from the field (*n*=44), followed by library research (*n*=14), and laboratory work (*n*=5). Regionally or provincially, the number of reports varied, with some studies representing the entire country (*n*=16), while others focused on specific regions dominated in the south (*n*=17), then east (*n*=12), and west (*n*=10), and central Bhutan (*n*=8) (Figure 3). Most publications focused on reptiles (*n*=29), followed by amphibians (*n*=21) and reports covering both (*n*=13).

3.4. Species research effort allocation The highest research effort allocation (SREA = 0.70) was observed in "ecology and natural history" studies (*n*=35), followed by research on "conservation and herp-human interaction" (*n*=22; SREA = 0.44), "evolution, taxonomy and systematics" (*n*=4; SREA = 0.08), while "diseases" (*n*=1; SREA = 0.02), and "genetics" (*n*=1; SREA = 0.02) were the least represented, with "anatomy and physiology" unstudied (Table 1).

3.5. Published studies on "amphibians", "amphibians and reptiles", and "reptiles" Research that focussed on "amphibians" was spread across ecology (Wangyal and Jamtsho, 2022; Limbu *et al.*, 2020; Norbu, 2018a; Tenzin and Dendup, 2017; Nidup *et al.*, 2016; Wangyal, 2012a; Deuti, 2010; Palden, 2003), conservation (Norbu, 2018b; Wangyal

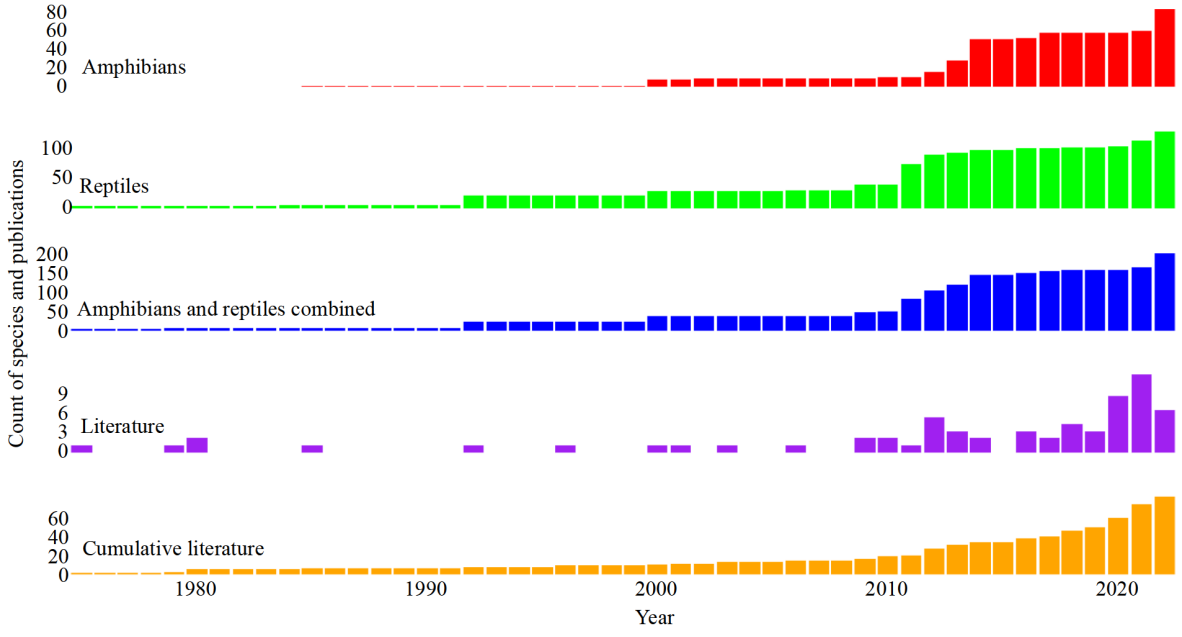


Figure 1 The number of species and publications over five decades (1972–2022). The blue bars represent the combined number of amphibian and reptile species, while green, red, orange, and purple bars represent the number of reptiles, amphibians, cumulative publications, and publications per year, respectively.

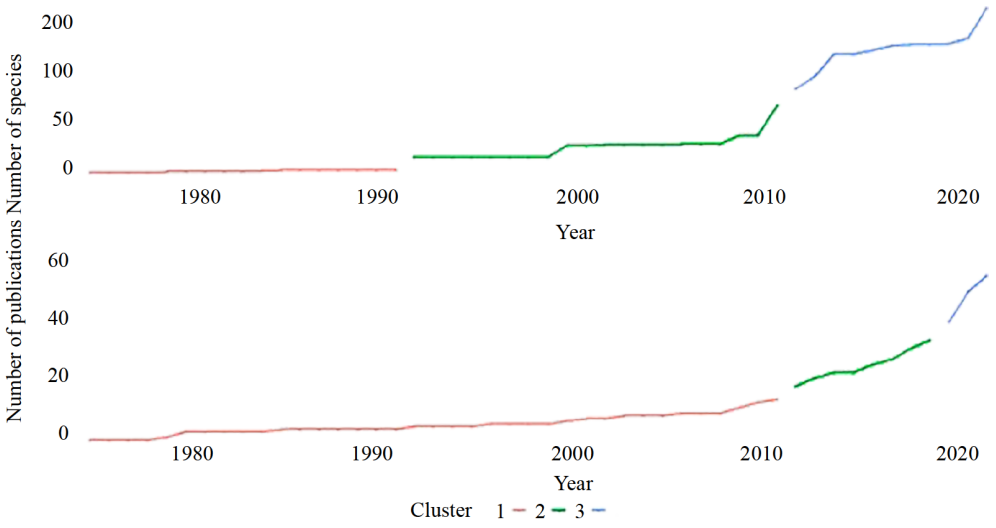


Figure 2 Cluster analyses for the number of publications and number of species of reptiles and/or amphibians over time (1972–2022). The data points are clustered into three groups 1 in red colour (1972–1990 for number of species; 1972–2011 for number of publications), 2 in green colour (1992–2011 for number of species; 2012–2019 for number of publications), and 3 in blue colour (2010–2022 for number of species; 2020–2022 for number of publications) represented by red, green, and blue line graphs respectively based on their features, with centroids representing the mean of the points within each cluster.

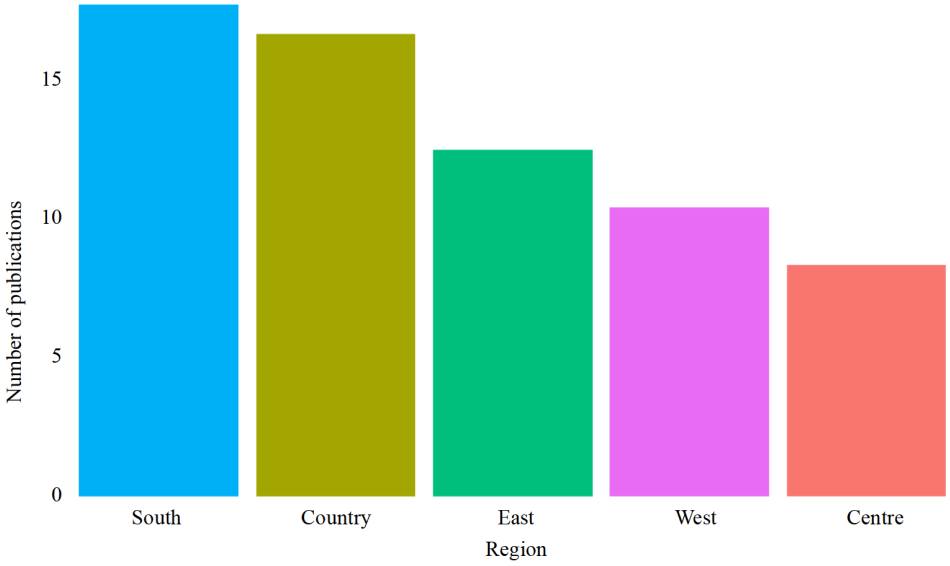


Figure 3 Number of publications on reptiles and amphibians of Bhutan by Region or Province within Bhutan. The northern region is not included due to insufficient data on reptile and amphibian studies, likely attributable to the region's cold climate and limited research activity.

and Gurung, 2012;), taxonomy (Delorme and Dubois, 2001; Frost, 1985), disease (Streicher *et al.*, 2020), and genetics (Mahony *et al.*, 2022) while studies that covered both "amphibians and reptiles" just focussed on ecology (Das *et al.*, 2016; Wangyal, 2013) and conservation (Tenzin *et al.*, 2022; Wangyal *et al.*, 2020b; Phibsoo Wildlife Sanctuary, 2020; Tshewang and Letro, 2018; Das, 1996). Most research on "reptiles" focussed on ecology (Koirala and Tshering, 2021; Phuntsho and Wangyal, 2021; Bauer and Günther, 1992) followed by conservation (Wangyal, 2021; Chaida *et al.*, 2020; Sapkota *et al.*, 2020; Wangyal, 2012b; Wangyal, 2012c; Wangyal and Gurung, 2010; Bustard, 1980a; Bustard, 1980b; Bustard, 1979;) and taxonomy (Dorji, 2019; Tillack, 2006) (Figure 4). Amongst reptiles, studies covered snakes (*n*=33

studies) and lizards (n=19) more than testudines (Phuntsho *et al.*, 2022; Drukpa *et al.*, 2020; Wangyal *et al.*, 2012) despite being the most threatened reptilian group.

3.6. Publication growth trend The number of species described increased with the increase in the number of publications over the years on amphibians, reptiles, and amphibians and reptiles combined (P<0.000 1; Table 2). A considerable number of species were reported in the last two decades of this study period.

3.7. Species conservation status and density Bhutan has approximately 83 native amphibian species (including 2 undescribed Ichthyophiid, 1 urodele, and 80 anurans, Appendix I) and 138 native reptile species, which include 88 snakes, 43 lizards, and 7 testudines (Appendix II). In terms of conservation, there are 24 Data Deficient (DD), 4 Critically Endangered (CR), 4 Endangered (EN), 9 Near Threatened (NT), 12 Vulnerable (VU), 157 Least Concerned (LC), and 11 Not Evaluated (NE) species (Figure 5). Turtles were the most threatened group with 86% of them falling into a category of threat (CR = 2, EN=1, VU = 2, NT = 1) followed by lizards (12%) and snakes (9%). At least 12% of amphibians were threatened. The status of *Tylototriton* cf. *verrucosus*, the only salamander species in the country, is considered as Near Threatened, although Bhutan has yet to confirm the species identification.

3.8. Comparison of species occurrence with neighbouring countries In comparison with neighbouring countries, Sri Lanka has the highest amphibian (1.84 species/1 000 km^2) as well as reptile (3.81 species/1 000 km^2) species density, while Pakistan has the lowest amphibian species density per 1 000 km^2 (0.03). China has the lowest reptile species per 1 000 km^2 (0.065). Bhutan, though small in land area, has 1.62 amphibians and 2.32 reptiles per 1 000 km^2, which demonstrates that it is more biodiverse relative to its landmass than surrounding mainland countries (Table 3).

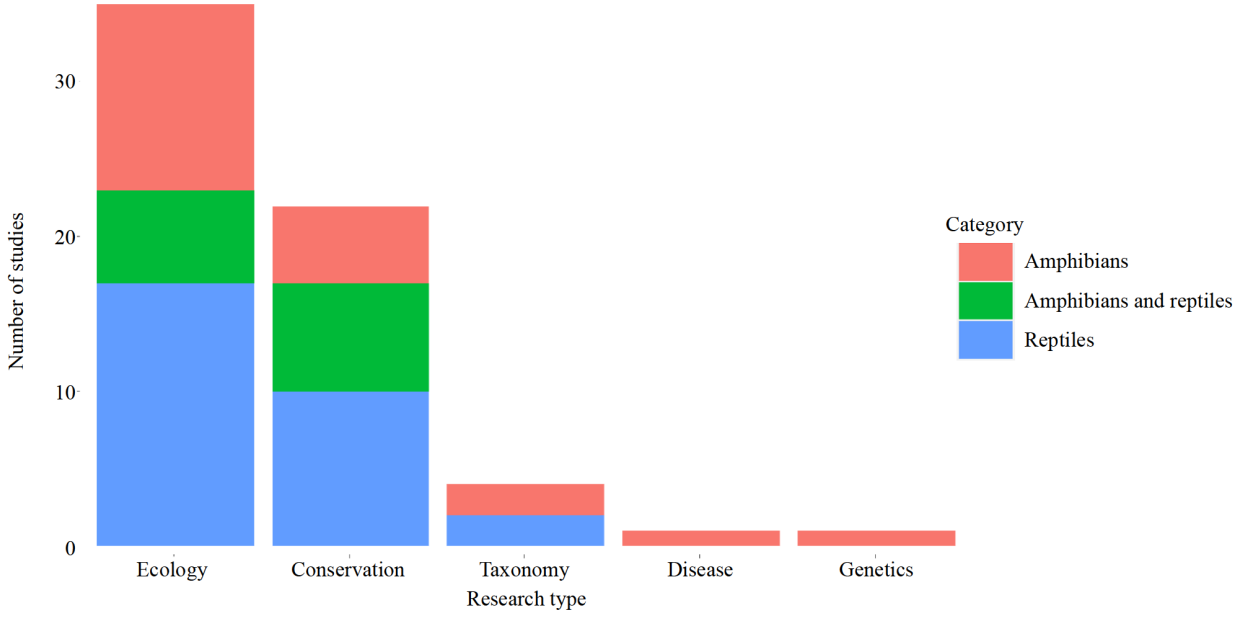


Figure 4 The number of different studies conducted on just "amphibians" "amphibians and reptiles", and just "reptiles", showing the distribution of research discipline per taxa (ecology, conservation, taxonomy, disease, and genetics).

Table 2 Linear regression result showing the relationship between the number of species reported and the number of publications, which is significant based on the *P*-value column.

Group	Coefficient estimate	Std. error	*t*-value	*P*-value	Multiple R^2	Adjusted R^2
Amphibians and reptiles combined	4.22	0.21	20.19	0.001	0.90	0.89
Reptiles	2.65	0.15	17.28	0.001	0.87	0.86
Amphibians	1.49	0.07	21.45	0.001	0.91	0.90

4. Discussion

4.1. Last fifty years of amphibians and reptile research in Bhutan The paucity of research publications prior to 1972 is attributable to early government restrictions on expatriate scientific exploration (Choden, 2004; Mathou, 2000) and limited local access to research and education. Bhutan has historically lacked herpetologists and focused on policies that prioritized the conservation of mammals (Seeland, 1998), birds, and plants (National Biodiversity Centre, 2017).

Our synthesis of 63 studies (1972–2022) on Bhutan's amphibian and reptile species reveals significant research effort disparities, with the highest Species Research Effort Allocation (SREA) in ecology and natural history (53% of studies), likely driven by accessibility and research infrastructure (Abdullah *et al*., 2023). The consistently low number of amphibian and reptile species recorded in Bhutan from 1972 to 1990 likely reflects limited research efforts during this period. Herpetological studies were globally underrepresented, with less focus on cryptic taxa like reptiles (Speight *et al*., 2025) and amphibians compared to mammals. The country's rugged terrain and lack of modern infrastructure further hindered access to diverse habitats, such as high-altitude wetlands. Additionally, the absence of centralized biodiversity databases before the National Biodiversity Centre's establishment post-1990 likely contributed to sparse documentation. Increased global awareness of herpetofaunal declines post-1990 likely drove subsequent research surges.

The considerable increase in the number of species and publications in Bhutan from the initial to the final study periods (1972–2022) could be explained by increased global awareness of amphibian declines (41% threatened; IUCN, 2022), increased engagement of citizen scientists (Wangyal *et al*., 2022) and collaborations boosted by exposure to modern education and technology (Allen and Ulrich, 2023; Gyeltshen, 2022). Natural history reports, particularly those documenting species occurrences as first national records, constitute the majority of the literature. Research efforts are largely concentrated on general information or widespread and

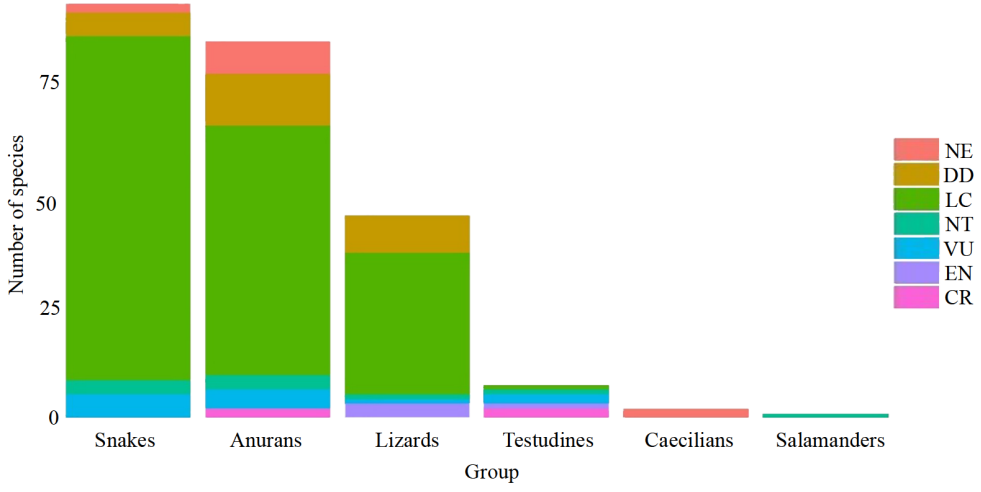


Figure 5 Bhutan's species richness across IUCN taxa categories.

Table 3 Comparison of species occurrence per 1 000 km² in South Asian countries.

Sl. No.	Countries	Number of amphibian species	Number of reptile species	Area (1 000 km²)	Number of amphibian species /1 000 km²	Number of reptile species /1 000 km²
1	Sri Lanka	121	250	65.610	1.844	3.810
2	Bhutan	62	89	38.394	1.615	2.318
3	Bangladesh	67	145	147.570	0.454	0.983
4	Nepal	61	143	147.181	0.414	0.972
5	Myanmar	206	375	676.578	0.304	0.554
6	Pakistan	24	215	796.095	0.030	0.270
7	India	470	789	3 287.263	0.143	0.240
8	China	659	626	9 596.961	0.069	0.065

easily encountered species such as agama lizards, rat snakes, and common frogs and toads. In contrast, larger and more charismatic species like the king cobra tend to receive attention due to their high detectability and conservation significance (Guedes *et al*., 2023).

The lack of herpetological focus contrasts with the publication rates in other countries, particularly those with well-established research infrastructures and more extensive scientific networks. For example, India (Das, 2004; Cyriac *et al*., 2022) and China (Murphy, 2016) have a continuous stream of publications, supported by well-resourced, advanced research facilities, and a deep-rooted culture of scientific inquiry (Cyriac *et al*., 2022; Fei *et al*., 2010). The overall low number and breadth of publications on amphibians and reptiles in Bhutan contrasts with neighbouring countries where extensive studies have been conducted (Cyriac *et al*., 2022; Pratihar *et al*., 2014; Wangyal, 2013; Molur, 2008; Matsui and Ota, 1995). For example, none of the Bhutanese herpetofauna species have associated genetic analyses despite the wide use of genetic methods in India (Hebbar *et al*., 2019; Ghosh, 2018) and China (Asian Scientist Newsroom, 2016; Liang *et al*., 2010) to understand relationships between species and populations.

Bhutan's publications have predominantly focused on reptile and amphibian presence, distribution, and natural history, neglecting other scientific aspects like systematics, diseases, genetics, anatomy, and physiology. The techniques required for these more advanced studies often require specimen preservation, yet harming animals is discouraged under the Buddhist religion (Allison, 2023; Keown, 2020; Kanthik and Khiewngamdee, 2018). It is likely, therefore, that Bhutan's dominant religion has influenced its scientific trajectory in herpetology and the bias towards non-destructive sampling techniques (Lubow, 2008; Long, 2021). Thus, incorporating cultural and traditional beliefs into education programs will be critical to justify scientific exploration and research in these areas, so that gaps in knowledge about herpetofauna can be reduced. However, this focus on ecological and natural history studies is a logical starting point in a context with limited baseline data, as understanding a species' ecology provides essential background information that informs and supports more specialized fields of research.

4.2. Regional research biasness and congruence Our review also reveals pronounced spatial biases, with southern districts (Sarpang, Samtse, Samdrup Jongkhar) accounting for 17% of 63 studies, while northern regions (Thimphu, Paro, Gasa, Haa), constrained by remoteness, cold climate, and rugged terrain, contribute <5%. This pattern parallels urban-proximate research biases in the Philippines (Abdullah *et al*., 2023). Temporally, only 5 of 63 studies predate 1990, limited by resource scarcity, topographic challenges, and cultural perceptions of herpetofauna as dangerous (Wangyal *et al*., 2022).

Although amphibians and reptiles, unlike mammals and birds, can be studied together due to shared habitats and survey methods (Dela Cruz *et al*., 2023), only 21% of research (SREA=0.26) addressed both taxa, indicating limited congruence and suggesting a lack of systematic or integrated research efforts. Our findings further highlighted under-studied disciplines (e.g., anatomy and physiology), suggesting future research will be needed to address knowledge gaps in these areas. Enhanced surveys in remote districts and for less charismatic species could support Bhutan's conservation goals and global herpetofaunal efforts.

4.3. Bhutan's biodiversity conservation in global perspective Bhutan's exceptional biodiversity derives from its biogeographical position, connecting with megadiverse countries (Wester *et al*., 2019) like China and India. This is reflected in the relatively high species richness for Bhutan's land area and makes it an important contributor to conservation outcomes for the region. To date, Bhutan's conservation success is strengthened through the constitutional mandate to maintain perpetual 60% forest cover, 71% extant forest cover, and 52% of land areas under the protected areas system (DoFPS, 2018; DoFPS, 2021).

However, despite the success, climate change impacts, disease, and human-wildlife conflicts remain a challenge and will require ongoing conservation efforts for specific species. There are two CR (*Indotestudo elongata* and *Pangshura sylhetensis*), an EN (*Cuora mouhotii*), two VU (*Cuora amboinensis* and *Melanochelys tricarinata*), and an NT (*Cyclemys gemelli*) species of freshwater turtles, and two CR (*Raorchestes shillongensis* and *Scutiger spinosus*), four VU (*Nanorana minica*, *Ingerana borealis*, *Nanorana rostandi*, and *Atympanophrys nankiangensis*), three NT (*Nanorana ercepeae*, *Nanorana annandalii*, and *Rhacophorus translineatus*) species of frogs, and these taxa will require particular conservation focus. The proportion of threatened turtles in Bhutan is higher than the global background rate (Stanford *et al*., 2020), and these species will require additional research focus. Despite numerous species assigned a threat category, there is very little information on population trends over time; these species should be a focus of future conservation efforts.

5. Conclusion

To overcome the existing gap in herpetofauna knowledge, Bhutan must focus on crucial research areas such as genetics, diseases, and physiology to learn more about these important

disciplines. Interdisciplinary collaborations amongst conservationists, scientists, policymakers, and local community members would benefit production to achieve holistic conservation of biodiversity and ecosystems (Valdez *et al*., 2023; Sanborn and Jung, 2021; Chua *et al*., 2020). Bhutan must focus on educating its citizens (Tobden and Ham, 2022), investing in the expansion of scientific infrastructure to enhance the research capabilities in the country (Munro, 1989). Additionally, efforts to integrate traditional knowledge with modern scientific methods must be improved to enhance the understanding of conservation and management of species (Yanou *et al*., 2023; Jessen *et al*., 2022; Ogar *et al*., 2020; Gadgil *et al*., 1993). Enforcing conservation measures grounded in evidence from scientific research is crucial to safeguard and sustainably manage Bhutan's distinct biodiversity. Furthermore, supporting global partnerships and collaborations is necessary for harnessing expertise and resources, enhancing Bhutan's scientific developments, and contributing to global conservation efforts. Emphasizing these strategies will strengthen Bhutan's scientific landscape, protecting its diverse biodiversity and making substantial contributions to global scientific knowledge and conservation initiatives.

National collaborations with government's conservation agencies such as Department of Forest and Park Service, and non-governmental agencies like Royal Society for Protection of Nature, Bhutan Environment Conservation Trust Fund, Bhutan Ecological Society and local communities can standardize data and share resources, while transboundary partnerships with India and Nepal, sharing Eastern Himalayan species (e.g., Himalayan newt, King Cobra, Agama lizards, etc.), will align conservation strategies. Engaging global networks like IUCN can provide expertise, reducing knowledge gaps, and supporting Bhutan's biodiversity goals.

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