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Employing citizen science to understand amphibian and reptile diversity and distribution in the Himalayan Kingdom of Bhutan

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ABSTRACT

In the absence of systematic research institutions and local or long-term resident systematists added by Buddhist culture that discourages lethal sampling of animals, scientific collections are particularly sparse in Bhutan. Consequently, less charismatic taxa such as the reptile and amphibian fauna of Bhutan, including the Eastern-Himalayas, are poorly known. Citizen science was employed to better understand the occupancy and distribution of reptile and amphibian fauna in Bhutan. Using a dedicated amphibian and reptile Facebook group, we gathered 929 species records from 235 individuals between May 2014 and December 2019. Of the participants 70% were foresters, 10% were members of the general public, 6% were school teachers, 6% were college students, 5% were non-forester civil servants, and 3% were tour guides. Citizen scientists submitted records for 99 species of snakes, 70 species of amphibians, 87 species of lizards and 5 species of testudines. Of these, 70% of the records extended the published range of the species in Bhutan, and more than 48 species were new records for Bhutan. Our study demonstrates the potential of citizen science in developing countries with poorly documented fauna.

1. Introduction

Citizen science (CS) is a useful method to advance knowledge of biodiversity, especially in places where resource limitations hinder the collection of robust scientific data (Cooper et al., 2007; Danielsen et al., 2009; Cosquer et al., 2012; Theobald et al., 2015). CS initiatives have increased in number, size and scope over time (Burgess et al., 2017) which has enabled a variety of ecological studies (Chandler et al., 2016). One of the more popular forms of biodiversity-related CS is documenting the distribution of species, examples of which include the Christmas Bird Count, FeederWatch, and iNaturalist (Chandler et al., 2016). With concern for the environment among the general public rising but funding for science declining (James et al., 2001), CS is considered a cost-effective method to enhance traditional flora and fauna surveys (Ballard et al., 2018; Frost-Nerbonne and Nelson, 2004; (Schmeller et al., 2009)). Especially in developing and underdeveloped countries, where funding for surveys of most taxonomic groups is scarce, CS offers a potentially powerful method of collecting species distribution data that can aid conservation (Toomey and Domroese, 2013).

Situated in the Himalayan Global Biodiversity Hotspot (Mittermeier et al., 2004; Myers et al., 2000), the Himalayan Kingdom of Bhutan is a developing country. Like many other biodiversity hotspots around the world, it is underrepresented in scientific research and conservation (Basnet et al., 2019; Wilson et al., 2016). This is particularly the case for reptiles and amphibians, for which even

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basic distributional knowledge is poor (Wangyal, 2014; Wangyal and Das, 2014; Wangyal and Gurung, 2017). Three factors contribute to this knowledge gap. First, funding is scarce for science, and has typically been funneled into other 'charismatic' vertebrate groups such as mammals and birds. Second, Bhutan is geographically a mountainous and rugged country (Tshering et al., 2020), making it difficult to conduct wildlife surveys. Lastly, the majority Buddhist culture of Bhutan (Thinley et al., 2019a,2019b) has historically prevented live capture, collection and preservation of specimens, thus hindering research of reptiles and amphibians that usually require direct handling for identification. Consequently, the conservation status of Bhutan's reptiles and amphibians remains largely unknown and there is a strong need to generate scientific data on their distribution, habitat suitability and conservation threats.

There exists, however, a tremendous opportunity to employ CS to uncover the distribution of amphibians and reptiles in Bhutan. Due to high forest cover (71%; FRMD, 2016) and a low human population of < 740,000 people (National Statistics Bureau, 2017), Bhutan is comparatively less degraded than its neighboring countries and thus presents an excellent opportunity to explore and even discover new species. Additionally, most Bhutanese people carry handheld mobile phones with inbuilt cameras and internet connectivity, and photographs of animals are routinely shared on various social media platforms demonstrating a large untapped potential for CS to aid in generating information for poorly-known taxonomic groups like reptiles and amphibians.

Following the success of CS elsewhere in recording species occurrences and mapping their distributions (Chandler et al., 2016), we explored the role that CS could play in contributing to distributional knowledge of amphibians and reptiles across Bhutan. We aimed to quantify social media submissions of images of reptiles and amphibians by Bhutanese citizens from different professional backgrounds and examined encounter rates among different broad taxonomic groups. When rare and threatened species were encountered, we examined these records further in an attempt to identify threats based on mortality factors reported.

No conservation actions on amphibians and reptiles are recorded in the country of this research, that's Bhutan.

2. Methods

2.1. Study area

Situated in the eastern Himalayas, Bhutan is bordered by China in the north and India in the south, east and west. Despite its small

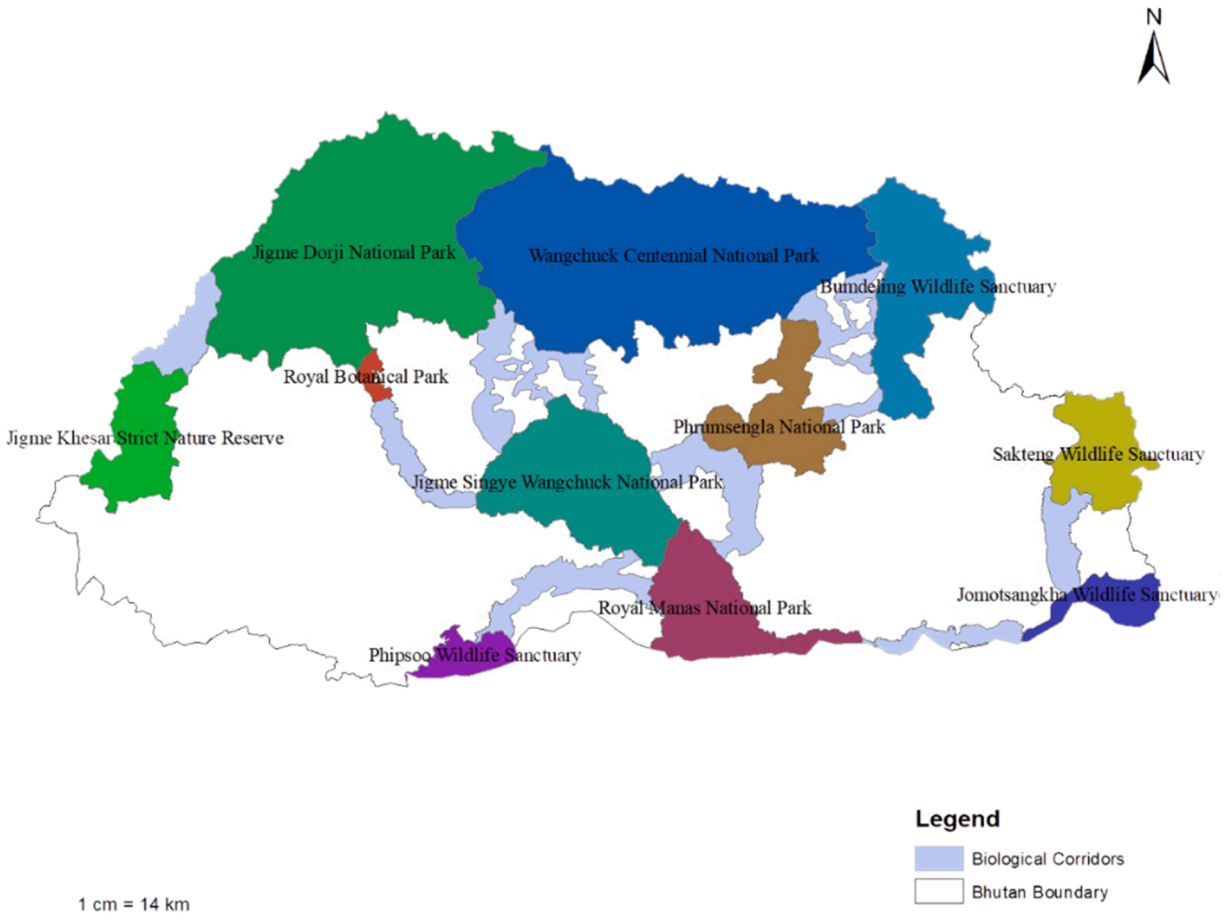

Fig. 1. Bhutan and its network of protected areas for biodiversity conservation.

geographical size of 38,394 km^2 (National Statistics Bureau, 2017), it is recognized for its strong conservation policy. Bhutan's constitution mandates the government to maintain at least 60% forest cover in perpetuity. To this end, approximately half of the country is designated as part of Bhutan's protected areas network (Fig. 1) with 40% protected as national parks, wildlife sanctuaries and strict nature reserves, and 10% as biological corridors (Dorji et al., 2019).

2.2. Data collection

The majority of people in Bhutan use mobile phones with inbuilt cameras for communication, including a strong use of various social media platforms, especially Facebook (Dema, 2016; Thinley et al., 2020). Accordingly, we created a Facebook group called "Amphibians and Reptiles of Bhutan – Search Group" in the last week of May 2014 (administered by JTW). We initially promoted the tool to forestry staff situated in various locations across the country who then promoted it to the wider community including schoolteachers, villagers, school students, tour guides and general commuters on major and peripheral highways. Members of the Facebook group were encouraged to post photographs and details of amphibians and reptiles that they saw in Bhutan. In each post, members recorded their profession, name of the locality where a particular photo was taken, date, time, and wherever possible the geographical coordinates, the habitat type (forest, roadside, village, or riverbanks) and elevation in meters above sea level (masl). If the animal photographed was dead, we asked the provider to mention the plausible cause of mortality such as road-kill or kill by humans. Users also confirmed that the record was found by them, and within Bhutan. We examined all posts in the Facebook group from 27 May 2014–31 December 2019. For species identification, the first author used relevant guide books such as Smith (1931, 1943); (Smith, 1935) Frost (1985); Schleich and Kästle (2002); Yang and Rao (2008); Ahmed et al., 2009; Fei et al. (2010); Vasudevan and Sondhi (2010); Subba et al. (2017); and Ohler et al. (2018) and crosschecked with interested experts from outside the country who were also given membership to the group. We also used Bhutan Biodiversity, an online web portal maintained by the National Biodiversity Center of the Ministry of Agriculture and Forests (Gyelshen et al., 2019) to authenticate species identification and descriptions. Those species which were reported but could not be identified were considered as "unidentified"; this included live animals that could not be reliably resolved to the level of species, and dead animals that were mutilated beyond recognition, such as occurs for some road-killed specimens. Once the species was reported from a site, core group members who has knowledge of the species would visit the spot where the animal was sighted to confirm its identity.

2.3. Data analysis

We used the R statistical program Version 3.6.3 (R Core Team, 2020) to analyze our data. We determined the number of records submitted for each broad taxonomic grouping, namely, amphibians (frogs, toads and salamanders), lizards, snakes and testudines (tortoises and turtles) and performed a Kruskal-Wallis multiple comparison p-values adjusted with Holm method post-hoc test to determine if mean ranks differed between the taxa. The number of records submitted was the response variable while the taxonomic grouping was the categorical variable. We used a paired t-test to compare the mean number of records submitted between the foresters and non-foresters. We used Arc GIS (version 10.5) to create a hotspot map using the spatial attributes of the species observations records to visualize the trends of records submitted by members across Bhutan.

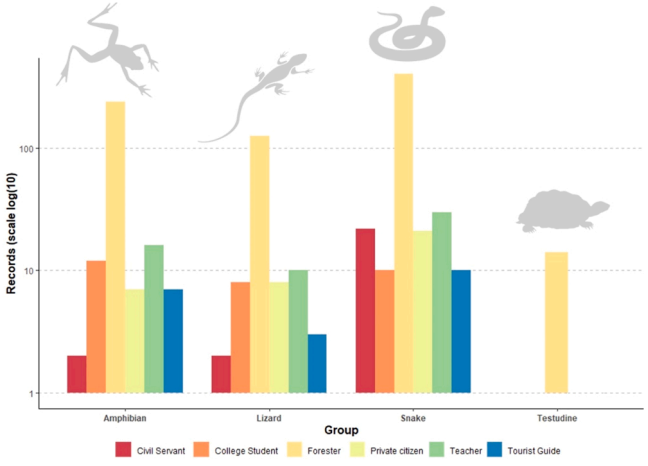

Fig. 2. Data contribution by citizen scientists in different taxa species groups.

3. Results

3.1. Observations by respondent types

We gathered a total of 929 observations of amphibians and reptiles submitted by 235 individuals, of which 70.2% (n = 165) were foresters, 9.8% (n = 23) were members of the general public, 6.4% (n = 15) were school teachers, 6.0% (n = 14) were college students, 5.1% (n = 12) were non-forester civil servants and 2.6% (n = 6) were tour guides. The majority of the total submissions were made by foresters (81.6%; n = 758), followed by school teachers (6.0%; n = 56), private citizens (4.2%; n = 39), college students (3%; n = 31), non-forester civil servants (3.3%; n = 26) and tourist guides (2.0%; n = 19; Fig. 2). Foresters submitted an average (± SE) of 126 ± 16 records per year, which was significantly greater ($p = 0.04$) than non-foresters who submitted an average of 29 ± 16 records per year. Foresters submitted more data (M=126, SD=44) than non-Foresters (M=29, SD=9; $t = 2.6819$, $df = 5$, $p = 0.04$).

3.2. Observations by taxa

The highest number of submissions were of snakes (52.2%; n = 485), followed by amphibians (29.49%; n = 274), lizards (16.57%; n = 154) and turtles (1.72%; n = 16) (Fig. 2). There was a statistically significant difference in the number of observations submitted between the different taxonomic groupings ($\chi 2(3) = 16.894$, $p < 0.001$). Comparison of the number of records submitted between the taxonomic groupings revealed that there were significantly more records of snakes ($p = 0.0003$) and amphibians ($p = 0.03$) than testudines while other groups did not differ significantly such as snake and amphibians ($p = 0.4$) or lizards and snakes ($p = 0.15$) (Table 1). The maximum number of records were submitted in 2019 when we confirmed more than twenty species as new records for the country (Fig. 6).

The average number of observation of snakes was 83.2 ± 36.5 records per year, which was similar to the number of observations per year for amphibians (43.33 ± 36.5 records per year; $p = 0.05$) but higher than for testudines (2.66 ± 36.5 records per year; $p = 0.97$). We verified and listed a total of 89 species of snakes (77 confirmed, 12 unidentified), 80 species of amphibians (59 confirmed, 21 unidentified), 34 species of lizards (29 confirmed, 5 unidentified) and 6 species of testudines (Table 2). Of these total submissions, 70% of records contributed to a range extension for almost all the species and 48 submissions contributed to new records for 22 amphibian and 26 reptile species not previously known from Bhutan (Wangyal et al., 2020).

The agamid lizard, *Calotes versicolor* was the most reported species (44 records), followed by the false cobra *Pseudoxenodon macrops* (41 records), monocellate cobra, *Naja kaouthia* (32 records), mountain pit viper, *Ovophis monticola* (30 records) and eastern trinket, *Orthriophis cantoris* (26 records). The common Asiatic toad, *Duttaphrynus melanostictus* (29 records) and common skittering frog, *Euphlyctis cyanophlyctis* (26 records) were the most commonly recorded amphibians.

Two species, one frog *Raorchestes shillongensis* and the only recorded land tortoise *Indotestudo elongata* were the only species recorded that are listed as Critically Endangered by the IUCN. One turtle species, *Cuora mouhotii* recorded is listed as Endangered, while seven other species *Melanochelys tricarinata*, *Nanorana minica, Oligodon juglandifer, Ohpiophagus hannah, Naja naja, Python bevittatus* and *P. molurus* are listed as Vulnerable. There are three critically endangered (CR), four endangered (EN), five vulnerable (VU), 10 near threatened (NT), 125 least concerned (LC), 16 data deficient (DD), eight not evaluated (NE) and 38 unknown (UK) species in this report (Table 2).

3.3. Observation hotspots, timing of observations, and mortality

Geographically, citizen scientists were clustered around densely populated areas (Fig. 3). The greatest number of records were reported from the districts of Trashigang, Trashiyangtse, Mongar, Pemagatshel and Samdrupjongkhar in the east, Punakha and Wangdiphodrang in the west, Trongsa, Tsirang and Zhemgang in the centre, and Chukha, Sarpang, Samtse, and Dagana in the south.

The majority of observations (90%) occurred during daylight hours and no records were noted at night after 2200 h (Fig. 4). Mortality had occurred to 11.3% (N = 108) of snake observations; this was considerably higher than for lizards (0.7%; N = 7) and amphibians (0.7%; N = 7). No mortality of turtles was recorded. The percent of the recorded observations killed by humans was the highest for snakes (3.87%; N = 37), following by amphibians (0.21%; N = 2) and lizards (0.1%; n = 1) (Table 3).

Table 1
Dunn (1964) Kruskal-Wallis multiple comparison p-values adjusted with the Holm method.

Comparison	Z	P. unadj	P. adj
Amphibians - Lizards	0.816	4.141	0.4141
Amphibians - Snakes	-1.265	2.061	0.4111
Lizards - Snakes	-2.082	3.732	0.1491
Amphibians - Testudines	2.735	6.223	0.0311
Lizards - Testudines	1.919	5.502	0.1648
Snakes - Testudines	4.001	6.295	0.0003

Table 2
Total counts of each species (as well as some unknown species) data records collected from 2014 to 2019 (n = (929). Synonyms are: UK=Unknown; DD=Data Deficient; LC=Least Concern; NT=Near Threatened, VU=Vulnerable; EN=Endangered; CR=Critically Endangered; NE = Not Evaluated.

Order/ Family (no. of species)/Common Name	Scientific Name	IUCN Status	Total observations	Literature source
Anura				
Bufonidae (10)				
Chanda's Nagaland Toad	*Duttaphrynus chandai*	NE	1	Wangyal et al. (2020)
Himalayan Toad	*Duttaphrynus himalayanus*	LC	13	Wangyal and Gurung (2012)
Common Asiatic Toad	*Duttaphrynus melanostictus*	LC	29	Das and Palden (2000)
Nagaland Toad	*Duttaphrynus nagalandensis*	NE	1	Wangyal et al. (2020)
Schneider's (dwarf) Toad	*Duttaphrynus scaber*	LC	4	New record
Stuart's Toad	*Duttaphrynus stuarti*	DD	3	Wangyal and Gurung (2012)
Marbled Toad	*Duttaphrynus stomaticus*	LC	1	Wangyal et al. (2020)
Common Toad Group	*Duttaphrynus* sp. 1	UK	2	iNaturalist Observation #111162593
Common Toad Group	*Duttaphrynus* sp. 2	UK	2	iNaturalist Observation #116639341
Common Toad Group	*Duttaphrynus* sp. 3	UK	1	iNaturalist Observation #116639736
Dicroglossidae (18)				
Cona Spiny Frog	*Nanorana* cf. *conaensis*	DD	1	Wangyal (2013)
Common Skittering Frog	*Euphlyctis cyanophlyctis*	LC	26	Das and Palden (2000)
Nepal Cricket Frog	*Minervarya nepalensis*	LC	6	Wangyal (2013)
Terai Cricket Frog	*Minervarya teraiensis*	LC	8	Wangyal (2013)
Indian Bull Frog	*Hoplobatrachus tigerinus*	LC	11	Das and Palden (2000)
Liebig's Mountain Frog	*Nanorana liebigii*	LC	2	Deuti (2010)
Himalayan Paa Frog	*Nanorana vicina*	LC	2	New record
Coastal Bullfrog	*Hoplobatrachus litoralis*	NE	1	Wangyal et al. (2020)
Arnold's Paa Frog	*Nanorana arnoldii*	NT	1	Wangyal and Das (2014)
Qinghai Tibetan Plateau Frog	*Nanorana pleski*	NT	1	Wangyal (2013)
Nepal Paa Frog	*Nanorana minica*	VU	2	Wangyal et al. (2020)
Torrent Paa Frog	*Nanorana ercepeae*	NT	2	Wangyal et al. (2020)
Common Skittering Frog Group	*Euphlyctis* sp.	UK	2	iNaturalist Observation #116641520
Skittering Frog Group	*Fejervarya* sp. 1	UK	6	iNaturalist Observation #116640096
Skittering Frog Group	*Fejervarya* sp. 2	UK	1	iNaturalist Observation #116640264
Paddy Frog Group	*Fejervarya* sp. 1	UK	1	iNaturalist Observation #iNaturalist Observation #116640508
Paddy Frog Group	*Fejervarya* sp. 2	UK	8	iNaturalist Observation #116640814
Mountain Frog Group	*Nanorana* sp.	UK	8	iNaturalist Observation #111063895
Hylidae (1)				
Jerdon's Tree Frog	*Hyla annectans*	LC	1	Wangyal (2011)
Megophryidae (13)				
Glandular Horned Toad	*Xenophrys glandulosa*	LC	2	Wangyal (2013)
White-lipped Horned Toad	*Xenophrys major*	LC	2	Wangyal (2013)
Concave-crowned Horned Toad	*Xenophrys parva*	LC	8	Das and Palden (2000)
Sikkim Alpine Toad	*Scutiger sikimmensis*	LC	6	Wangyal and Das (2014)
Bompu Frog	*Leptobrachium bompu*	NE	1	Tenzin and Wangyal (2019)
Piebald Alpine Toad	*Scutiger spinosus*	NE	1	Wangyal et al. (2020)
Xizang Alpine Toad	*Scutiger boulengeri*	LC	1	Wangyal et al. (2020)
Nyingchi Alpine Toad	*Scutiger* cf. *nyingchiensis*	LC	1	Wangyal et al. (2020)
Horned Toad Group	*Xenophrys* sp. 1	UK	1	iNaturalist Observation #111165834
Horned Toad Group	*Xenophrys* sp. 2	UK	1	iNaturalist Observation #111161627
Horned Toad Group	*Xenophrys* sp. 3	UK	1	iNaturalist Observation #116641827
Horned Toad Group	*Xenophrys* sp. 4	UK	1	iNaturalist Observation #116642064
Horned Toad Group	*Xenophrys* sp. 5	UK	1	iNaturalist Observation #116642339
Microhylidae (2)				
Mymensingh Narrow-mouthed Frog	*Microhyla mymensinghensis*	NE	2	Wangyal et al. (2020)
Nilphamari Narrow-mouthed Frog	*Microhyla nilphamariensis*	NE	1	Wangyal et al. (2020)
Ranidae (18)				
Assam Cascade Frog	*Amolops assamensis*	DD	2	New record
Assam Sucker Frog	*Amolops formosus*	LC	1	Wangyal and Das (2014)
Yembung Sucker Frog	*Amolops* cf. *gerbillus*	LC	2	New record
Himalayan Cascade Frog	*Amolops himalayanus*	LC	4	Nidup et al. (2016)
Mouping Sucker Frog	*Amolops mantzorum*	LC	2	Wangyal (2013)
Marbled Sucker Frog	*Amolops marmoratus*	LC	5	Das and Palden (2000)
Montane Cascade Frog	*Amolops monticola*	LC	5	Wangyal and Gurung (2012)
Cope's Assam Frog	*Hydrophylax leptoglossa*	LC	4	Wangyal and Das (2014)
Theobald's Ranid Frog	*Hylarana tytleri*	LC	1	Wangyal (2013)
Gunther's Amoy Frog	*Sylvirana* cf. *guentheri*	LC	1	Wangyal (2014)
Wenshan Cascade Frog	*Amolops wenshanensis*	DD	1	Wangyal et al. (2020)
Assam Sucker Frog	*Amolops* sp. 1	UK	1	iNaturalist Observation #116379931
Cascade Frog Group	*Amolops* sp. 2	UK	1	iNaturalist Observation #111167986

(*continued on next page*)

Table 2 (*continued*)

Order/ Family (no. of species)/Common Name	Scientific Name	IUCN Status	Total observations	Literature source
Cascade Frog Group	*Amolops* sp. 3	UK	1	iNaturalist Observation #111063250
Cascade Frog Group	*Amolops* sp. 4	UK	1	iNaturalist Observation #116643577
Cascade Frog Group	*Amolops* sp. 5	UK	1	iNaturalist Observation #116643343
Cascade Frog Group	*Amolops* sp. 6	UK	1	iNaturalist Observation #116642871
Cascade Frog Group	*Amolops* sp. 7	UK	1	iNaturalist Observation #116642591
Rhacophoridae (17)				
Shillong Bush Frog	*Raorchestes shillongensis*	CR	1	Wangyal et al. (2020)
Bush Frog Group	*Raorchestes* cf. *menglaensis*	LC	1	Wangyal et al. (2020)
Large Flying Frog	*Rhacophorus* cf. *tuberculatus*	DD	1	New record
Four-lined Tree Frog	*Polypedates leucomystax*	LC	10	New record
Common Tree Frog	*Polypedates maculatus*	LC	12	Wangyal (2014)
Terai Tree Frog	*Polypedates teraiensis*	LC	2	Wangyal (2013)
Annandale's Bush Frog	*Raorchestes annandalii*	LC	4	Wangyal et al. (2020)
Baibung Small Treefrog	*Theloderma baibungense*	DD	1	New record
Giant Treefrog	*Zhangixalus smaragdinus*	LC	8	Wangyal (2014)
Himalayan Tree Frog	*Polypedates himalayensis*	LC	7	Wangyal and Das (2014)
Annandale's Pigmy Tree Frog, Assam Asian Treefrog	*Chiromantis simus*	LC	2	Wangyal et al. (2020)
Uphill Tree Frog	*Kurixalus naso*	DD	1	Wangyal et al. (2020)
Jerdon's Bubble-nest Frog	*Nasutixalus jerdonii*	DD	1	Wangyal et al. (2020)
Terai Tree frog	*Polypedates taeniatus*	LC	2	Wangyal et al. (2020)
Longchuan Small Treefrog	*Raorchestes longchuanensis*	LC	1	Wangyal et al. (2020)
Large Flying Frog	*Zhangixalus burmanus*	NT	1	Wangyal et al. (2020)
Flying Frog	*Zhangixalus suffry*	LC	1	Wangyal et al. (2020)
Caudata, Salamandridae (1)				
Crocodile Newt	*Tylototriton verrucosus*	NT	6	Frost (1985)
Squamata				
Colubridae (59)				
Blyth's Reticulated Snake	*Blythia reticulata*	DD	1	Wangyal et al. (2020)
Many Banded Cat Snake	*Boiga multifasciata*	LC	8	Wangyal and Tenzin (2009)
Himalayan Stripe-necked Snake	*Liopeltis rappi*	LC	2	Wangyal et al. (2020)
Northeast Indian Kukri Snake	*Oligodon cyclurus*	LC	1	Wangyal (2014)
Oriental Whip Snake	*Ahaetulla prasina*	LC	8	Wangyal and Tenzin (2009)
Black-headed Cat Snake	*Boiga* cf. *nigriceps*	LC	4	New record
Copper-headed Trinket Snake	*Coelognathus radiatus*	LC	12	Wangyal (2011)
Wall's Bronzeback	*Dendrelaphis cyanochloris*	LC	2	Wangyal (2011)
Yellow Speckled Wolf Snake	*Lycodon jara*	LC	2	Wangyal (2012)
White-barred Kukri Snake	*Oligodon albocinctus*	LC	9	Wangyal (2011)
Chinese Kukri Snake	*Oligodon chinensis*	LC	1	Wangyal et al. (2020)
Banded Kukri Snake	*Oligodon fasciolatus*	LC	1	New record
Black Kukri Snake	*Oligodon taeniolatus*	LC	1	Wangyal and Tenzin (2009)
Walnut Kukri Snake	*Oligodon juglandifer*	VU	3	Wangyal (2014)
Karlschmidti's False Cobra	*Pseudoxenodon* cf. *karlschmidti*	LC	5	New record
False Cobra	*Pseudoxenodon macrops*	LC	41	Bauer and Günther (1992)
Red-necked Keelback	*Rhabdophis subminiatus*	LC	14	Wangyal (2012)
Green Trinket Snake	*Rhadinophis prasinum*	LC	2	Wangyal et al. (2020)
Khasi Hills Trinket snake	*Rhadinophis frenatum*	LC	2	Wangyal et al. (2020)
Collared Black-headed Snake	*Sibynophis collaris*	LC	8	Wangyal (2011)
Checkered Keelback	*Fowlea piscator*	LC	5	Bauer and Günther (1992)
Short-nosed Vine Snake	*Ahaetulla nasuta*	LC	4	Wangyal (2011)
Clerk's Keelback	*Amphiesma clerki*	LC	3	Wangyal et al. (2020)
Khasi Hill Keelback	*Hebius khasiensis*	LC	1	New record
Himalayan Keelback	*Herpetoreas platyceps*	LC	10	Biswas (1976)
Buff Striped Keelback	*Amphiesma stolatum*	LC	2	Bauer and Günther (1992)
Green Cat Snake	*Boiga cyanea*	LC	3	Wangyal (2011)
Gokool's Cat Snake	*Boiga gokool*	LC	1	Wangyal (2014)
Tawny Cat Snake	*Boiga ochracea*	LC	14	Bauer and Günther (1992)
Assamese Cat Snake	*Boiga quincunciata*	LC	1	Chaida et al. (2020)
Siamese Cat Snake	*Boiga siamensis*	LC	1	New record
Golden Tree Snake	*Chrysopelea ornata*	LC	4	Wangyal (2012)
Common Trinket Snake	*Coelognathus helena*	LC	3	Wangyal et al. (2020)
Painted Bronzeback	*Dendrelaphis pictus*	LC	3	New record
Common Bronzeback Tree Snake	*Dendrelaphis tristis*	LC	1	Wangyal (2012)
Common Wolf Snake	*Lycodon aulicus*	LC	12	Wangyal (2012)
Zaw's Wolf Snake	*Lycodon zawi*	LC	1	Wangyal et al. (2020)
Gammie's Wolf Snake	*Lycodon gammiei*	NT	3	Wangyal (2013)

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Table 2 (*continued*)

Order/ Family (no. of species)/Common Name	Scientific Name	IUCN Status	Total observations	Literature source
White-banded Wolf Snake	*Lycodon septentrionalis*	LC	3	Wangyal (2011)
Spot-Tailed Kukri Snake	*Oligodon dorsalis*	LC	1	Das and Palden (2000)
Black-banded Trinket Snake	*Oreocryptophis porphyraceus*	LC	8	Wangyal (2011)
Eastern Trinket Snake	*Orthriophis cantoris*	LC	26	Wangyal (2011)
Himalayan Trinket Snake	*Orthriophis hodgsoni*	LC	3	Wangyal et al. (2020)
Striped Trinket Snake	*Orthriophis taeniurus*	VU	8	Wangyal (2011)
Mock Viper	*Psammodynastes pulverulentus*	NE	2	Das and Palden (2000)
Indo-Chinese Rat Snake	*Ptyas korros*	NT	7	Wangyal (2011)
Indian Rat Snake	*Ptyas mucosa*	LC	6	Wangyal (2014)
Green Rat Snake	*Ptyas nigromarginata*	LC	16	Bauer and Günther (1992)
Orange-collared Keelback	*Rhabdophis himalayanus*	LC	18	Wangyal (2011)
Brown Trapezoid Snake	*Rhabdops* or *Smithophis bicolor*	LC	1	Wangyal and Das (2021)
Mountain Worm-eating Snake	*Trachischium monticola*	LC	1	Wangyal et al. (2020)
Blackbelly Worm-eating Snake	*Trachischium fuscum*	LC	1	Wangyal et al. (2020)
Himalayan Keelback Group	*Hebius* sp.	UK	3	
Assam Kukri Snake	*Oligodon* cf.*arnensis*	LC	3	New record
Kukri Snake Group	*Oligodon* cf.*venustus*	LC	1	Wangyal et al. (2020)
Kukri Snake Group	*Oligodon* sp. 2	UK	1	iNaturalist Observation #116637510
Kukri Snake Group	*Oligodon* sp. 3	UK	1	iNaturalist Observation #116637758
Worm-eating Snake Group	*Trachischium* sp. 1	UK	1	iNaturalist Observation #111165506
Worm-eating Snake Group	*Trachischium* sp. 2	UK	1	iNaturalist Observation #116636737
Elapidae (10)				
Banded Krait	*Bungarus fasciatus*	LC	4	Das and Palden (2000)
Monocled Cobra	*Naja kaouthia*	LC	32	Wangyal (2011)
Himalayan Krait	*Bungarus bungaroides*	LC	4	Wangyal (2011)
Lesser Black Krait	*Bungarus* cf. *lividus*	LC	1	Tshewang and Letro (2018)
Black Krait	*Bungarus niger*	LC	19	Bauer and Günther (1992)
Wall's Krait	*Bungarus walli*	LC	2	Wangyal et al. (2020)
MacClelland's Coral Snake	*Sinomicrurus macclellandi*	LC	7	Wangyal (2011)
Krait Group	*Bungarus* sp.	UK	1	iNaturalist Observation #116635993
Spectacled Cobra	*Naja naja*	LC	4	Das and Palden (2000)
King Cobra	*Ophiophagus hannah*	VU	25	Biswas (1976)
Homalopsidae (1)				
Rainbow Water Snake	*Enhydris enhydris*	LC	1	Wangyal (2011)
Typhlopidae (4)				
Brahminy Blind Snake	*Indotyphlops braminus*	LC	4	Bauer and Günther (1992)
Blind Snake Group	*Indotyphlops* sp.	UK	1	iNaturalist Observation #116635714
Diard's Blind Snake	*Argyrophis diardii*	LC	1	Wangyal (2014)
Blind Snake Group	*Typhlops* sp.	UK	1	iNaturalist Observation #111164249
Viperidae (12)				
Kaulback's Lance-headed Pit Viper	*Protobothrops kaulbacki*	DD	1	Wangyal et al. (2020)
Mountain Pit Viper	*Ovophis monticola*	LC	30	Wangyal (2011)
Jerdon's Pit Viper	*Protobothrops jerdonii*	LC	4	Wangyal (2011)
White-lipped Pit Viper	*Trimeresurus albolabris*	LC	4	Wangyal (2012)
Pope's Pit viper	*Trimeresurus popeiorum*	LC	2	Das et al. (2016)
Yunnan Bamboo Pit Viper	*Trimeresurus yunnanensis*	LC	2	Wangyal (2014)
Bejewelled Lance-Headed Himalayan Pit Viper	*Protobothrops himalayanus*	LC	6	Wangyal (2014)
Russel's Viper	*Daboia russelii*	LC	1	Wangyal (2014)
Pit Viper Group	*Trimeresurus* sp. 1	UK	1	iNaturalist Observation #116378190
Pit Viper Group	*Trimeresurus* sp. 2	UK	1	iNaturalist Observation #116634829
Pit Viper Group	*Trimeresurus* sp. 3	UK	1	iNaturalist Observation #116635105
Pit Viper Group	*Trimeresurus* sp. 4	UK	1	iNaturalist Observation #116635296
Pareatidae (1)				
Common Slug Snake	*Pareas monticola*	LC	3	Wangyal et al. (2020)
Pythonidae (2)				
Burmese Python	*Python bivittatus*	VU	8	Wangyal (2012)
Indian Rock Python	*Python* cf. *molurus molurus*	NT	2	Bauer and Günther (1992)
Agamidae (11)				
Ayeyarwaddy Agama	*Calotes irawadi*	LC	1	Wangyal et al. (2020)
Variegated Mountain Lizard	*Japalura variegata*	LC	12	Biswas (1976)
Bhutan Lizard	*Calotes bhutanensis*	DD	6	Biswas (1976)
Jerdon's Forest Lizard	*Calotes jerdoni*	LC	6	Wangyal (2011)
Khasi Hills Forest Lizard	*Calotes maria*	LC	5	Das et al. (2016)
Oriental Garden Lizard	*Calotes versicolor*	LC	44	Biswas (1976)

(*continued on next page*)

Table 2 (*continued*)

Order/ Family (no. of species)/Common Name	Scientific Name	IUCN Status	Total observations	Literature source
Anderson's Mountain lizard	*Japalura andersoniana*	LC	8	Wangyal (2014)
Smooth-scaled Mountain Lizard	*Japalura planidorsata*	LC	5	New record
Abor Hills Agama	*Japalura austeniana*	LC	8	Wangyal et al. (2020)
Ota's Mountain Lizard	*Cristidorsa otai*	DD	1	Wangyal et al. (2020)
Three Keeled Mountain Lizard	*Japalura tricarinata*	LC	1	Wangyal et al. (2020)
Anguidae (1)				
Asian Glass lizard	*Dopasia gracilis*	LC	5	Wangyal (2013)
Gekkonidae (10)				
Common House Gecko	*Hemidactylus frenatus*	LC	3	Bauer and Günther (1992)
Tokay Gecko	*Gecko gecko*	LC	2	Wangyal (2012)
Nagaland Bent-toed Gecko	*Cyrtodactylus nagalandensis*	DD	1	Wangyal et al. (2020)
Bent-toed Lizard Group	*Cyrtodactylus septentrionalis*	DD	1	Wangyal et al. (2020)
Brook's House Gecko	*Hemidactylus brookii*	LC	2	Bauer and Günther (1992)
Northern House Gecko	*Hemidactylus flaviviridis*	LC	3	Wangyal et al. (2020)
Flat-tailed Gecko	*Hemidactylus platyurus*	LC	8	Bauer and Günther (1992)
Bhupathy's Bent-toed Gecko	*Cyrtodactylus bhupathyi*	DD	1	Wangyal et al. (2020)
Sikkimese Bent-toed Gecko	*Cyrtodactylus gubernatoris*	DD	1	Wangyal et al. (2020)
Leaf-toed Lizard Group	*Hemidactylus* sp.	UK	1	iNaturalist Observation #116638303
Varanidae (3)				
Bengal Monitor Lizard	*Varanus bengalensis*	NT	1	Bauer and Günther (1992)
Yellow Monitor Lizard	*Varanus flavescens*	EN	1	Wangyal (2011)
Water Monitor Lizard	*Varanus salvator*	LC	3	Das et al. (2016)
Lacertidae (2)				
Sikkimese Long-tailed Lizard	*Takydromus* cf. *sikkimensis*	EN	1	Wangyal et al. (2020)
Long-tailed Lizard	*Takydromus* sp.	UK	1	iNaturalist Observation #110816947
Scincidae (7)				
Common Skink	*Eutropis carinata*	LC	4	Wangyal (2011)
Sikkim Ground Skink	*Scincella sikimmensis*	LC	3	Bauer and Günther (1992)
Himalayan Forest Skink	*Sphenomorphus indicus*	LC	6	Bauer and Günther (1992)
Maculated Forest Skink	*Sphenomorphus maculatus*	LC	6	Bauer and Günther (1992)
Himalayan Skink Group	*Asymblepharus* sp.	UK	1	iNaturalist Observation #116638664
Litter Skink Group	*Sphenomorphus* sp. 1	UK	1	iNaturalist Observation #111168874
Litter Skink Group	*Sphenomorphus* sp. 2	UK	1	iNaturalist Observation #116638954
Geoemydidae (5)				
Indian Leaf Turtle	*Cyclemys gemeli*	NT	2	Wangyal et al. (2012)
Indian Black Turtle	*Melanochelys trijuga*	LC	2	Wangyal et al. (2012)
Keeled Box Turtle	*Cuora mouhotii*	EN	8	Wangyal et al. (2012)
Tricarinated Hill Turtle	*Melanochelys tricarinata*	EN	1	Wangyal et al. (2012)
Assam Roofed Turtle	*Pangshura sylhetensis*	CR	1	Wangyal et al. (2020)
Testudinidae (1)				
Yellow Tortoise	*Indotestudo elongata*	CR	2	Wangyal et al. (2012)

3.4. Comparison of records submitted by taxa and year

In our analysis, snakes emerged as the most diverse species reported (Fig. 5) and while maximum records of all animal groups were collected in 2019 (Fig. 6).

4. Discussion

By providing a platform for citizen scientists to submit and identify species of reptiles and amphibians in Bhutan, we received many records to contribute to the country's overall scientific knowledge. Our study clearly demonstrates the tremendous potential of citizen science in collecting information on the ecology of reptiles and amphibians in Bhutan; to the present day, scientific study and collection records for these groups in Bhutan have been limited. The CS group contained more than 1800 plus members (as of 7th February 2022) and the group administrator (JTW) was able to answer queries regarding the records, thereby providing a public service and education role for members of the group. Using this membership, we confirmed a total richness of 225 species of amphibians and reptiles in Bhutan which represents an increase of 67 species not previously known from the country (a 65% increase from the previous tally of 158 species).

4.1. Contribution by respondent type

The maximum number of contributions came from foresters working in the field (Fig. 2), which is similar to the results observed by Thinley et al. (2020), who demonstrated the importance of field foresters reporting threats to the endangered golden langur,

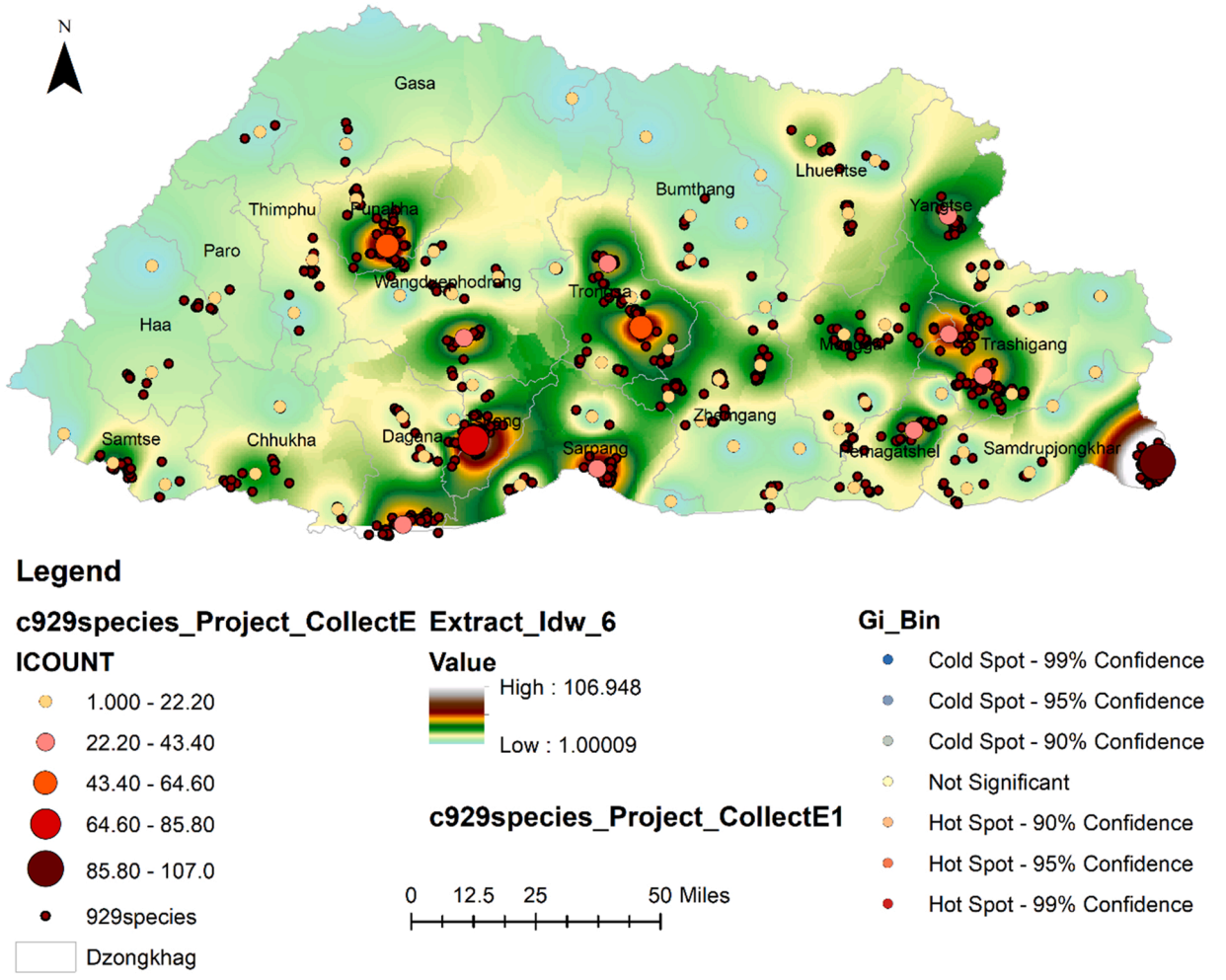

Fig. 3. Hotspot map showing the data contribution points from different places in Bhutan.

Trachypithecus geei in Bhutan. It is logical for field foresters to make submissions as this is part of their employment and they have a natural interest and willingness to contribute to citizen science (Geoghegan et al., 2016), driven by their vested interest to know more about biodiversity for conservation decision making. Thus, including stake-holders that have interests in their employment was a useful strategy to increase involvement.

4.2. Contribution of different taxa in different years

In most Asian countries, the diversity of snakes is higher than other reptiles such as lizards, crocodiles, tortoises and turtles. Consequently, snakes emerged as the most species rich and reported animal group throughout our data collection (Fig. 5), reflecting a reptile fauna dominated in richness by snakes followed by lizards and testudines. Snakes may also be preferentially reported because some species are dangerous so people seek out more information on their biology. Indeed, in our study, 11.3% (N = 108) of recorded snake species had been killed, primarily by people (Table 3). Education campaigns for people to understand that many snake bites occur in the process of trying to kill or catch snakes (Johnston et al., 2017) may reduce this behavior and aid in snake conservation in Bhutan. The maximum number of species were recorded in 2019 (Fig. 6) since many citizen scientists started picking interest due to availability of hand-held mobiles with cameras.

4.3. Hotspots, observations timing, and mortality

The hotspots of record submissions (Fig. 3) may reflect either the higher population density in southern Bhutan (National Statistics Bureau of Bhutan, 2017), or a higher density of the target taxa in these regions. Generally, reptile and frog diversity are higher in subtropical and tropical ecosystems where the weather is warm, moist and the temporal window of reptile reproductive activity is longer (Olson and Saenz, 2013). Thus, the warm and humid climate and higher population density in south-eastern Bhutan would

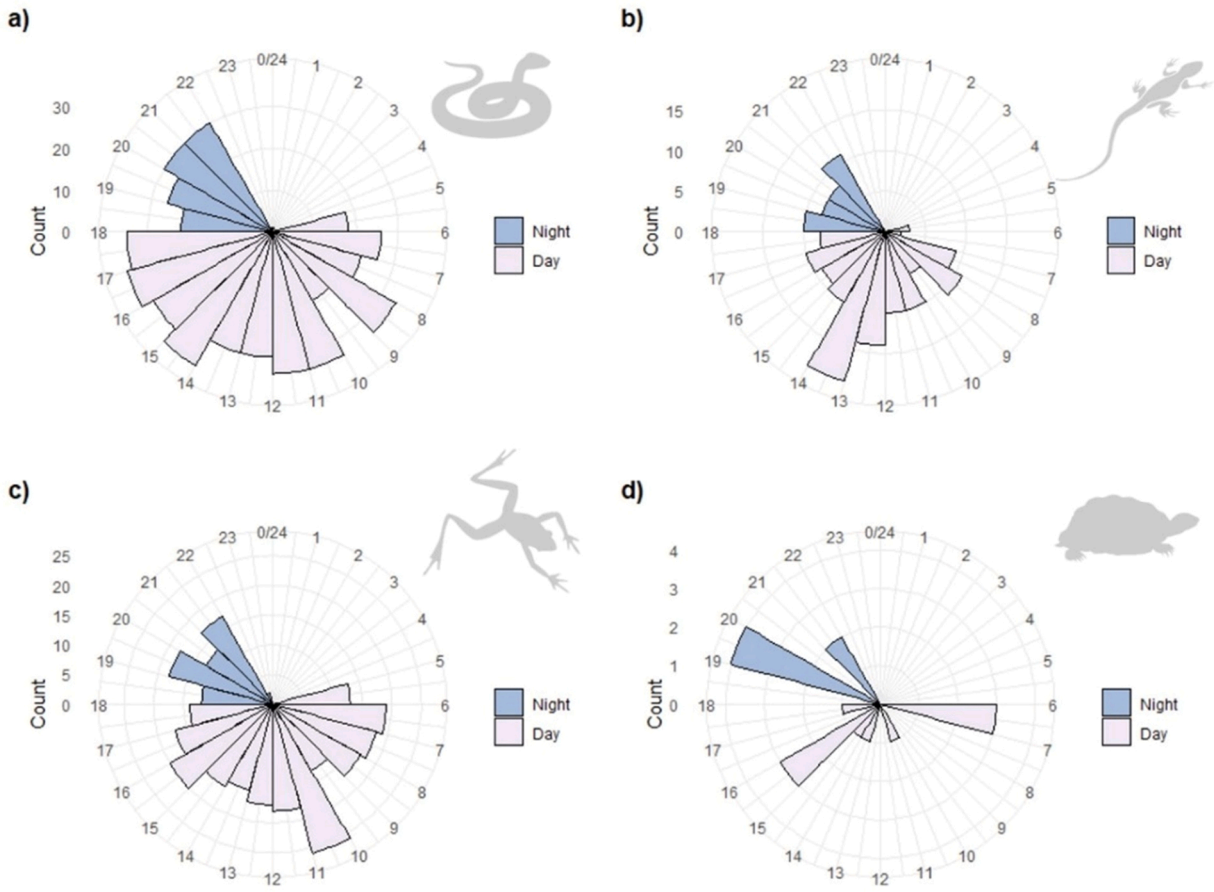

Fig. 4. Recorded observations by time of day for a) snakes, b) lizards, c) amphibians, and d) testudines.

Table 3
Status of animal when recorded: Live = the animal was alive in the record post; Dead = the animal was dead in the record post, but not killed by humans; Killed = the animal was killed by humans prior to the record post.

Group	Status	Total	Percent
	Dead	7	0.73%
Amphibian	Killed	2	0.21%
	Live	276	28.84%
	Dead	7	0.73%
Lizard	Killed	1	0.10%
	Live	150	15.67%
	Dead	108	11.29%
Snake	Killed	37	3.87%
	Live	353	36.89%
Testudines	Live	16	1.67%

result in more animals to document and more people interacting with those animals, while the central north of Bhutan is constrained by rugged topography and cold climate (Tshering et al., 2020) which likely resulted in less opportunities for human-herpetofaunal interactions. Because, our research data depended entirely on the interest of citizen scientists and their willingness to report sightings, our hotspot data provides a useful starting point for follow-up systematic surveys of reptiles and amphibians that could refine the geographical distribution of these groups across Bhutan, and reveal the correlates of diversity at a regional scale which can boost conservation. Most of the observations and mortality records were made during the day since it is based on citizen's encounter with species.

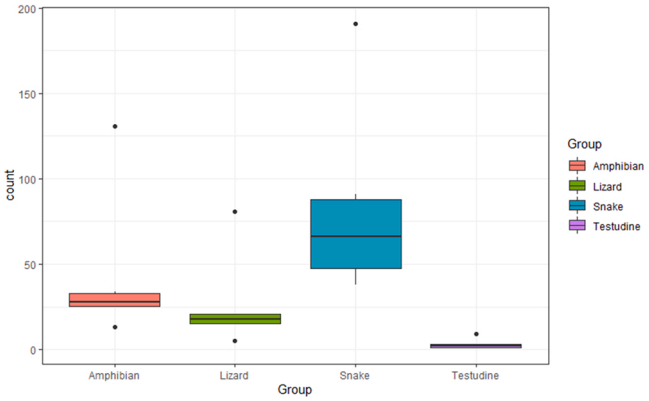

Fig. 5. Comparison of records submitted by taxa.

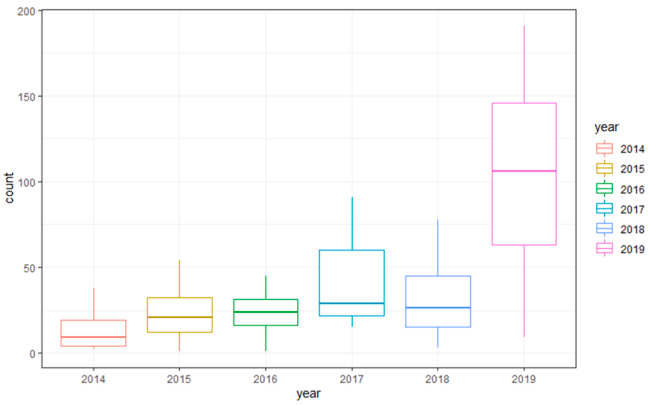

Fig. 6. Comparison of data submission by year for all animal groups.

4.4. Conservation implications

The listed conservation status of many of the submitted records demonstrates that citizen science will be a useful aid to conservation (Wiggins and Crowston, 2011; Follett and Strezov, 2015; Theobald et al., 2015; Bonney et al., 2016) in Bhutan. Our data will be useful to assist with conservation planning such as determining the level of protection of Bhutan's protected system and for informing IUCN species assessments (Irga et al., 2018; Santori et al., 2018). Our research identified the habitats of the Critically Endangered, Endangered and other threatened species which can be used for developing operational conservation management plans which Bhutan does annually in its protected areas and critical habitats. Based on our results, Bhutan can prioritise specific locations where Critically Endangered and Endangered tortoises and turtles such as *Indotestudo elongata* and *Pangshura sylhetensis* were reported, to aid in their conservation.

Amphibian and reptile research in Bhutan has not been a priority because these taxa are perceived to have been conserved holistically along with the forest conservation which receives primary attention in Bhutan. However, our data suggests that a high number of snakes and anurans are being killed along highways, lateral roads and farm roads (nearly 50% (n = 929) of the data submissions were of road killed animals) demonstrating road traffic is a potential threat to the persistence of rare species in these areas. Athough there are no studies on the impacts of roads on wildlife in Bhutan, Thinley et al. (2020) reported 28% of mortality was caused by road kill in a sample of golden langurs in Bhutan. Our work has identified that the impacts of roads on wildlife in Bhutan should be a priority area for future research.

Citizen science has obvious benefits for researchers, but there are also clear benefits for the citizen scientists. Submitting data allows citizens to develop their observation skills (Masters et al., 2016; van der Wal et al., 2016) build their awareness and knowledge of biodiversity, such as distinguishing between venomous and harmless snake species (Schuttler et al., 2018). We also saw submissions increase over time as the project increased in engagement. Nearly 50% of the new species recorded for Bhutan in this study were from the 2019 entry, the last year for which we analyzed data (Fig. 2). Initiatives like our citizen science project add weight to assertions that public participation can make a powerful contribution to the study and conservation of species (Measham and Barnett, 2008; Stepenuck and Green, 2015; Lewandowski and Oberhauser, 2017).

Another 25 species of amphibian, including the Sikkimese caecilian *Ichthyophis sikkimensis,* a species assumed to occur in Bhutan (Das and Palden, 2000; Wangyal and Das, 2014), were not recorded by citizen scientists. This may reflect a true absence of these

species or a lack of detectability by citizen scientists. Such species of interest could be prioritized through targeted campaigns contacting citizens in regions where target species occur.

5. Conclusion

Our study has demonstrated the enormous potential of CS in cataloguing the poorly-known herpetofauna of Bhutan, and the contribution a relatively small population can make to the biodiversity knowledge using nothing more than a mobile phone. The Facebook group created for this project continues to function, and continues to be flooded with data from interested citizen scientists. It also provides a place for anyone to learn more about Bhutan's biodiversity, the habitat affiliations and relative rarity of species, and which species of snakes are (and are not) dangerous to humans. The group, therefore, continues to have positive outcomes for species conservation through education of the public, and a useful tool for ordinary people to engaged positively with the natural environment (Cohn, 2008; Stepenuck and Green, 2015; Bela et al., 2016; Bonney et al., 2016).

Glossary

Amphibians and Reptiles of Bhutan – Search Group.
ANNOVA.
Arc GIS (version 10.5).
Biodiversity Hotspot.
Biological Corridors Network.
Caecilians.
Charismatic vertebrate.
Citizen Science.
College students.
Conservation.
Conservation potential.
Constitution mandates the government to maintain at least 60% forest cover in perpetuity.
Contribution by different groups and regions – mostly foresters.
Contribution of different taxa – mostly snakes.
Facebook.
Foresters.
General public.
Herpetofauna.
Hotspots.
Kruskal-Wallis's.
Ministry of Agriculture and Forests.
National Biodiversity Center of the.
National Parks and Nature Reserves.
Non-forester civil servants.
Protected areas network.
R statistical program Version 3.6.3.
Social media.
Taxonomic groups.
Testudines.
Tour guides.
Traditional flora and fauna surveys.

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Declaration of Competing Interest

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

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