



Mammalian research, diversity and conservation in the Far Eastern Himalaya Landscape: A review

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ABSTRACT

We conducted a systematic review on the research on mammals in the Far Eastern Himalaya Landscape using the SALSA approach, with a focus on opportunities for cross-border collaboration among India, Myanmar and China. A total of 124 literatures from 1962 to 2021 were identified and reviewed. Over the decades, there has been a steady increase in research and publications on the subject and their thematic focuses have been on inventory, distribution, conservation, behaviour, taxonomy and discovery of new species. There are more inter-region than intra-region collaborations in the researches with contributions from 408 authors from 30 countries. The review recorded a total of 240 mammal species in the landscape belonging to 11 orders, 36 families, and 123 genera. Sixty-one species were common to all three countries while eighteen to twenty two species have cross-border distribution between the two countries. At least eleven new mammal species unknown to science have been discovered from the region in recent decades out of which eight are endemic to the region. There is a clear comparative data deficit in Myanmar as well as areas outside the existing protected area of the landscape. Mammals in the landscape are facing multiple anthropogenic threats such as illegal hunting, wildlife trade, and habitat loss and fragmentation. According to the IUCN Red List, 19.6% (n = 47) of the total species recorded in the landscape are threatened with extinction, including five Critically Endangered, 19 Endangered and 23 Vulnerable species. We recommend strengthening joint research to address data deficit, improving regional or transboundary collaboration for conservation management, bridging the gaps of protected area network, and empowering local communities for effective mammal conservation in the landscape.

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Abbreviations

FEHL	Far Eastern Himalaya Landscape
NNPTR	Namdapha National Park and Tiger Reserve
HVWS	Hukaung Valley Wildlife Sanctuary and Extension
HWS	Hponkanrazi Wildlife Sanctuary
BWS	Bumhpabum Wildlife Sanctuary
HNP	Hkakabo Razi National Park
GNNR	Gaoligongshan National Nature Reserve

1. Introduction

Biodiversity affects many ecosystem functions and services where mammalian communities play a significant role in maintaining ecological integrity. Mammals provide various ecosystem services that are crucial for human well-being ranging from maintaining energy flow and productivity through herbivory, predation and granivory to shaping other biodiversity and their habitats from pollination, seed dispersal, insect-pest control and ecosystem engineering (Lacher et al., 2019). Despite the crucial role of mammals in ecosystem, approximately 25% of all mammals are threatened with extinction and the major threats to their survival are habitat loss and degradation, and biological resource extraction (Schipper et al., 2008; Ceballos et al., 2020). Many species of mammals, went extinct in the last century and many more are on the verge of extinction (Ceballos et al., 2020).

Biodiversity distribution is not limited to political boundaries. The conservation features such as the endangered species and their habitats are often spread over large spatial scales and cross multiple political boundaries (Kark et al., 2015; Liu et al., 2020; Mason et al., 2020). As many as 55.6% of all terrestrial mammals are distributed across national borders (Mason et al., 2020). They are imperiled due to existing physical barriers, uncoordinated management, and a lack of joint collaboration efforts among the neighboring countries (Liu et al., 2020; Mason et al., 2020; Thornton et al., 2018). Global initiatives such as the Convention on Biological Diversity (CBD, 2010, 1992), Intergovernmental Science-Policy Platform on Ecosystem Services (IPBES, 2019), and Sustainable Development Goals (UN, 2015) all encourage the adoption of landscape approach to avert biodiversity loss. Regional biodiversity conservation initiatives beyond national borders thus have gained momentum in recent years (Gurung et al., 2019; ICIMOD, 2009).

The vast landscape at the easternmost part of the Himalayas that spans from North-West Yunnan of China to North-East India through Northern Myanmar is among the most biologically and culturally diverse regions of the earth (CEPF, 2020; ICIMOD, 2015). The landscape is located at the confluence of two biogeographical realms: the Indo-Malayan Realm in the lowlands and the elevated Palearctic Realm to the north (Olson et al., 2001; WWF, 2012), and three global biodiversity hotspots, namely: Indo Burma, Himalaya, and Mountains of Southwest China (Mittermeier et al., 2004, 2011). It is home to eight globally important “ecoregions”, and hailed by scholars as “centres of plant endemism” and “key biodiversity areas” (Brooks et al., 2006; CEPF, 2020; López-Pujol et al., 2011; Mittermeier et al., 2011; Olson et al., 2001). The Indo-China sub-tropical forest of the region is one of the three ecoregions known to have the richest mammal assemblages globally (Olson et al., 2001). Besides, one-fourth of the forest in the landscape is intact, which provides a substantial amount of suitable habitat for mammals inside as well as outside the existing protected areas (Uddin et al., 2020). The fact that new species of mammals kept being discovered and described from the region (Amato et al., 1999; Fan et al., 2017; Geissmann et al., 2011; Li et al., 2019a, 2019b; Rabinowitz et al., 1999; Soisook et al., 2017) speaks enormously of the mammal richness of the landscape, the potential for more discoveries as well as the need for more studies.

Though the landscape is divided by national borders among China, India, and Myanmar, species habitat, animal population, eco-regions as well as socio-economic systems and conservation challenges are highly transboundary. Protected areas established by respective countries are also physically connected. To achieve improved biodiversity conservation and sustainable development in the landscape a transboundary conservation initiative namely Landscape Initiative for Far-Eastern Himalaya (HILIFE) was jointly designed and implemented by the International Centre for Integrated Mountain Development (ICIMOD) and its national partners in China, India, and Myanmar. A working area for the Initiative was defined and delineated as the Far Eastern Himalaya Landscape (hereinafter referred to as FEHL) through a participatory process, taking into account the ecosystem integrity, watershed, socioeconomic linkages, administrative boundaries, transboundary connectivity and issues, practical feasibility as well as political and geopolitical considerations (ICIMOD, 2014).

In the FEHL, mammals have been a taxon of great interest among researchers and comparatively the most studied taxa (Basnet et al., 2019). However, the information is mostly limited to China and India, scattered in geographical coverage and mostly from the protected areas. Thus; a comprehensive knowledge of mammal richness of the landscape, their status and cross-border distribution is lacking. We conducted a systematic review of literature on the mammals considering diversity, cross-border distribution, status and conservation interventions in the landscape to support informed policy decisions and transboundary collaboration. In line with the aim of the study, three broad research questions were set:

- What is the temporal, thematic and bibliographical trends of mammal literature in FEHL?
- What is the mammal species richness and how are they distributed across the landscape?
- What are the research and conservation gaps and opportunities for transboundary cooperation?

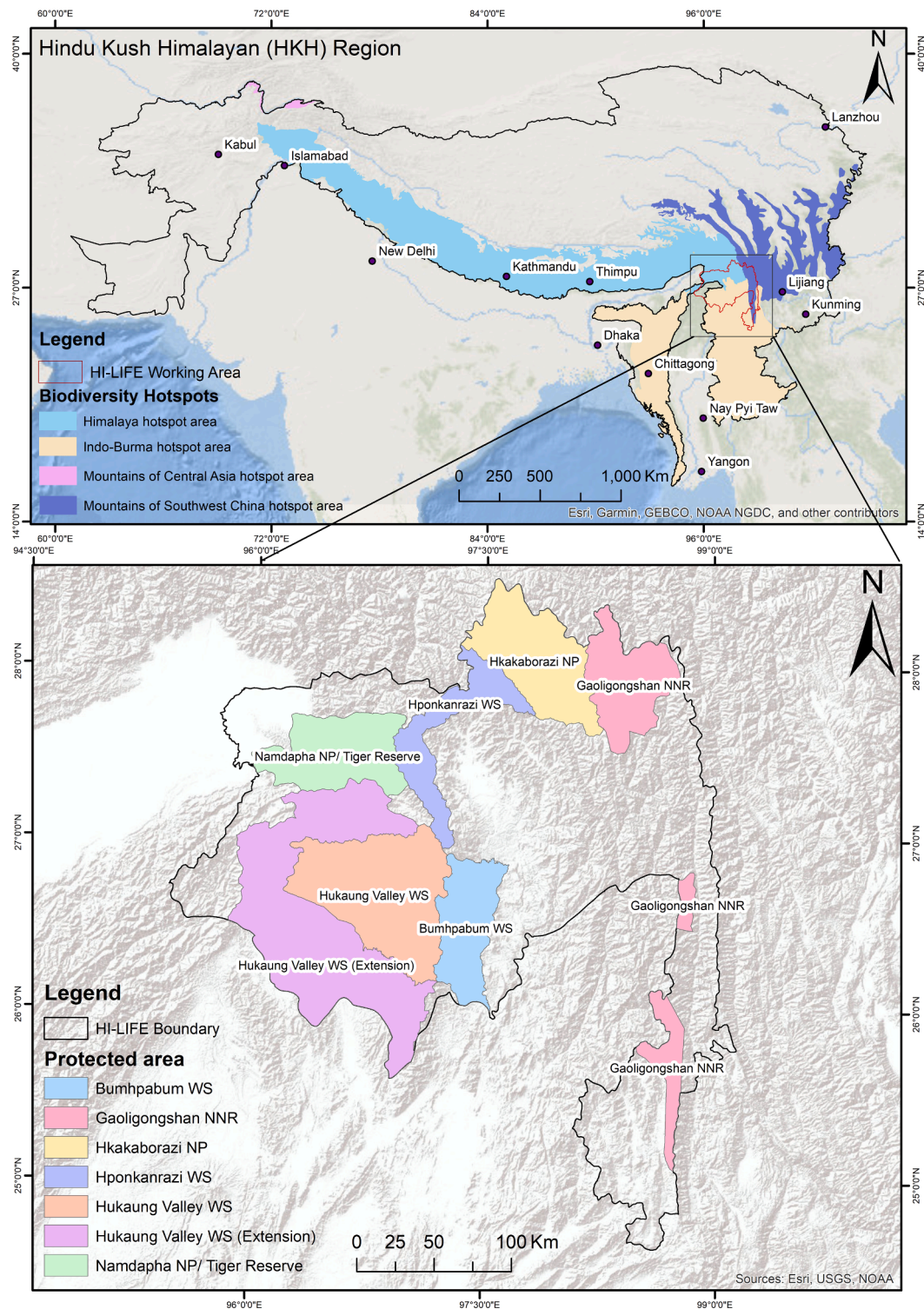


Fig. 1. Working area of the Far Eastern Himalayan Landscape.

2. Materials and methods

2.1. Study area

The demarcated FEHL is situated between 24° 37' 40.09" - 28° 32' 35.3" N and 95° 27' 13.75" - 99° 8' 15.57" E and spans across North-West Yunnan of China, Changlang District of North-East India, and Northern Kachin State of Myanmar. It covers a total area of 71,452 km² of which 22% falls in China, 12% in India, and 66% in Myanmar. The landscape is the head water area of Myanmar's most important river, the Irrawaddy River and its major tributaries, and an important catchment area of Asia's other two major rivers, namely, the Salween River (*Thanlwin* in Burmese, and *Nujiang* in Chinese) in the east and the Brahmaputra River (*Yarlung Dzangbo* in Tibetan) in the west. Over 73.0% of the landscape is covered by forests - mainly broadleaved (Uddin et al., 2020).

The FEHL is the conservation priority area for all three countries. Over 50% of the landscape have been designated as official protected areas including Namdapha National Park and Tiger Reserve (NNPTR) of India; Hukaung Valley Wildlife Sanctuary and Extension (HVWS), Hponkanrazi Wildlife Sanctuary (HWS), Bumhpabum Wildlife Sanctuary (BWS) and Hkakabo Razi National Park (HNP) of Myanmar; and Gaoligongshan National Nature Reserve (GNNR) of China, most of which are adjoining or physically connected (Fig. 1).

2.2. Data collection, management, and analysis

In this systematic literature review, we adopted Search, Appraisal, Synthesis, and Analysis (SALSA) framework (Grant and Booth, 2009) following Mengist et al. (2020). Initially, literature "Search" was performed in Scopus, Google Scholar, and Google. For Scopus, the Boolean search strategy was adopted where two groups of keywords, in either title, abstract, or keywords of the documents, were used in the search: one defining mammal and the other describing the geographical area (Supplementary Table S1). Likewise, the same keywords combination was used in Google Scholar and Google search engine to identify more studies including the gray literature which was then added to the literature database. Search was performed separately for individual countries resulting a total of 1724 literature records at first and after removing the duplicates, 1670 documents remained.

In the "Appraisal" stage, the documents were first screened against the objectives of the review through the title, abstract, and keyword screening. The studies dealing with mammals and conducted in the broader boundaries of FEHL (Northwest Yunnan, Arunachal Pradesh, Kachin State) were included for further screening. Studies not related to mammals and those with paleontological, and pathological domains were excluded. This reduced the literature number eligible for final screening to 163 which were then

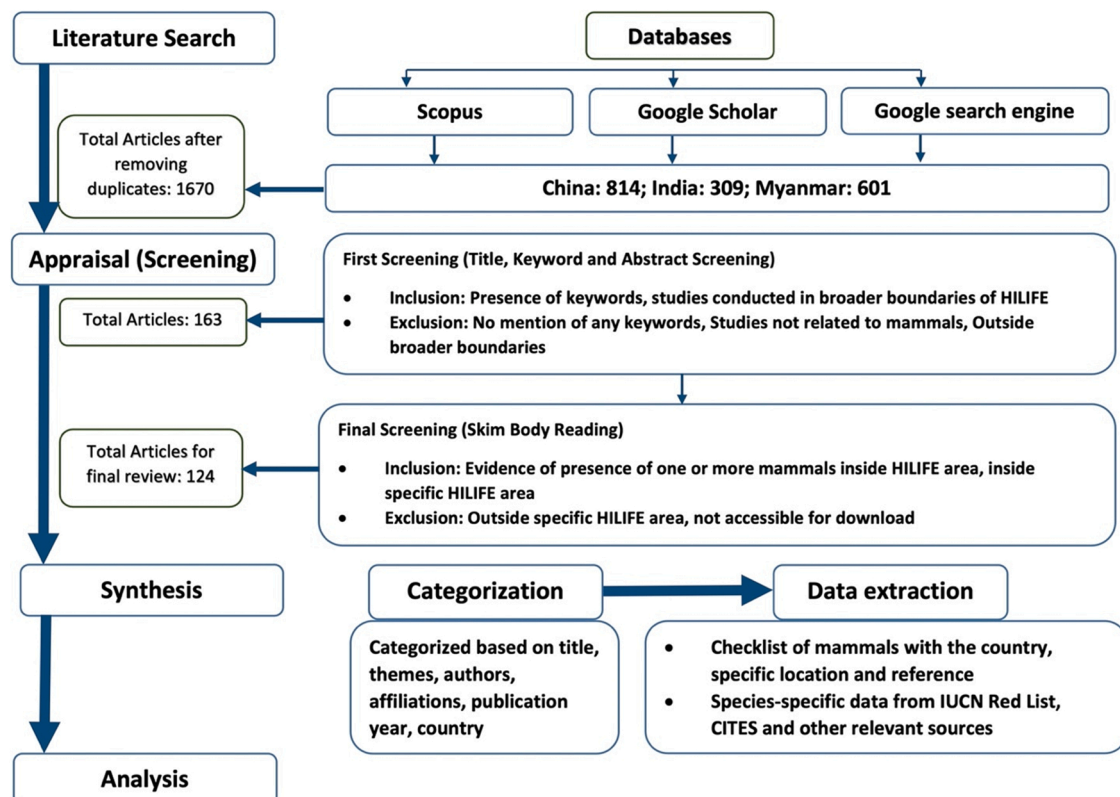


Fig. 2. Flow diagram for methods used in the review.

downloaded. Through skim body reading, literatures providing evidence of the presence of one or more mammal species inside specific FEHL boundary were included for final review, and those that were studied outside the study area and that were inaccessible for download were omitted. This resulted in a total of 124 literatures for in-depth review (Fig. 2).

In the “**Synthesis**” phase, the studies were first categorized based on the variable of interests such as title, authors, affiliations, publication year, thematic focus, and country for bibliometric analysis. Then, the checklist of mammal species was prepared by reviewing the final sorted documents along with the extraction of information from the literature on threats and the geographical distribution including country occurrence and specific location. The correction of scientific names and collection of additional information on each species’ taxonomy, threat status, population, habitat, ecology, threats, and trades were done referring largely to the International Union for Conservation of Nature (IUCN) Red List (IUCN, 2020a). The data on few species which were not evaluated under the IUCN Red List were collected from other sources like Animal Diversity Web of Museum of Zoology, University of Michigan (University of Michigan, 2020), and relevant literatures. Likewise, CITES appendices of species were noted from the CITES-listed species database (UNEP, 2020), Red List of China’s mammals from Jiang et al. (2016), China’s protected wildlife species from (SFGA and MARA, 2021), India’s protected species from India’s Wildlife Protection Act, 1972 (Government of India, 1972), and Myanmar’s protected mammal species from Notification of Protected wild fauna in Myanmar (Forest Department, 2020).

Both bibliometric and species-specific “**Analyses**” was done to meet the pre-defined research objectives. For analyzing the co-authorship of authors and countries, we used VOSviewer 1.6.16 (van Eck and Waltman, 2020) where the number of documents and links was used as the weight for mapping. The temporal trends, thematic focus of publications, mammal species richness, their distribution, and conservation status were analyzed through Microsoft Excel. Lastly, to understand the spatial distribution of mammals inside FEHL, the location of the threatened mammals records were noted from the reviewed literatures. The species were coded with numbers and their distribution was shown in FEHL map using a geospatial platform of ArcGIS 10.8.1. It is however important to note that the coded number does not indicate the exact location but rather the species presence in a particular area.

3. Results

3.1. Temporal research trends

A total of 124 literatures on mammals of the FEHL were collated and reviewed over a span of 60 years (1962–2021). Although the first reported study was from the year 1962 (Hill, 1962), early biodiversity studies in the FEHL can be traced back to 1833 (Basnet et al., 2019). Among mammals, Shortridge’s Langur (*Trachypithecus shortridgei*), a primate species endemic to the Far Eastern Himalaya (Cui et al., 2016) was discovered in 1915 (Long and Htun, 2020), long before the first research recorded in our review. This indicates that mammalian studies started much early that are inaccessible online. From 1962–2021, there has been a continuous increase in publication (Fig. 3). Documents from 2002 and beyond contributes to 86.3% (n = 107) of the total studies, which is in line with the findings of Basnet et al. (2019), stating the year 2000 and onwards as an important period for biodiversity research in the region (Supplementary Table S2). This overall trend was also echoed by Mi et al. (2021) that the number of papers and publications on biodiversity published by Chinese scientists in international journals has grown from a few dozen in 2000 to over 1700 in 2019. This seems to reflect the increasing interest and investment in biodiversity studies in response to the Aichi Target of CBD (CBD, 2010), of which, China, India, and Myanmar are all signatory countries.

Almost all the studies deal with mammal species from one of the three countries of FEHL whereas transboundary research are still few and scattered.

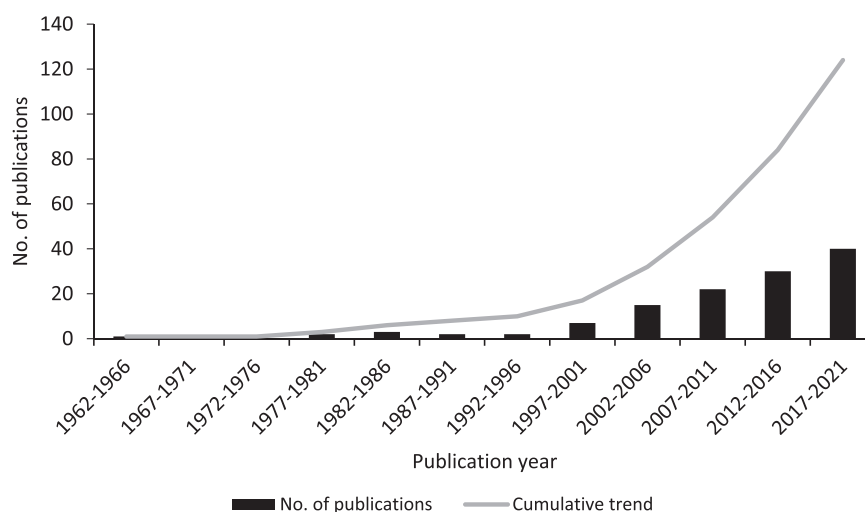


Fig. 3. Temporal trends of mammal research in FEHL.

3.2. Thematic focus

Out of 124 documents reviewed, the highest number of studies were on mammal inventories ($n = 26$) and mammal distribution ($n = 19$). A significant amount of research also focused on the conservation of mammals ($n = 18$), the behavior of individual species ($n = 15$), and taxonomy ($n = 9$) (Fig. 4).

About 9.7% ($n = 12$) of the publications reported discoveries of new species and we noted that at least eleven new species from FEHL have been discovered in the past four decades with at least seven of them being endemic to the region (Table 1). There is a visible increase in the use of modern technologies especially large scale camera trapping in the studies of wildlife in general and mammal in particular in the landscape (Fang et al., 2019; Hu et al., 2020; Lwin et al., 2021).

3.3. Co-authorship networks

A total of 408 authors contributed to all 124 reviewed documents. The highest contribution was from Xiao, W., Datta, A., Fan, P.-F., Myint, T., Htun, S., Kumar, A., Li, Qi., Lynam, A. J., Rabinowitz, A., Wang, Y., Cui, L.-W., Wang, X., Li, S., Bates, P.J.J., and Zaw, T. in descending order. Most of these authors are from the three FEHL countries: China, India, and Myanmar altogether having contributed to approximately 80% ($n = 88$) of all the studies. The publication with the most authors was Fan et al. (2017) on the discovery of Skywalker Hoolock Gibbon (*Hoolock tianxing*) with 15 coauthors.

Furthermore, authors from 30 countries contributed to the publications. The highest number of literatures was published by the authors from China ($n = 59$). This is obvious as the highest number of studies were also conducted in China (Supplementary Table S2). The subsequent highest number of literatures were from authors of India ($n = 29$) and Myanmar ($n = 29$). Authors from other countries such as the United States ($n = 26$), United Kingdom ($n = 17$) and Australia ($n = 10$) also contributed to a significant number of studies. This shows a substantial interest from researchers outside the region in the mammalian fauna of the landscape. Among the three countries in the FEHL, authors from Myanmar and China have collaborated with authors from other 18 and 17 countries respectively. In contrast, authors from India showed less collaboration with authors from other countries (link=6) (Fig. 5). From Fig. 5, it can be noted that the three countries have collaborated more with other nations in mammal research than they have among themselves.

3.4. Species richness and taxonomic distribution of mammals in FEHL

A total of 240 mammal species belonging to 11 orders, 36 families, and 123 genera were reported from the FEHL landscape (Supplementary Table S3). They represent 4.4% of the 5416 global mammal species (Wilson and Reeder, 2005) and 94% of the 255 resident mammals of Eastern Himalaya (Dorji et al., 2018). The highest number of genera and species is from the Order Rodentia (30 genera and 71 species), followed by Carnivora (29 genera and 41 species) and Chiroptera (25 genera and 55 species) (Fig. 6). Notably, the landscape is home to 13 primate species, including the Myanmar Snub-nosed Monkey (Geissmann et al., 2011), White-cheeked Macaque (Li et al., 2015) and Skywalker Hoolock Gibbon (Fan et al., 2017) that were discovered only in recent years.

Approximately, 9% ($n = 21$) of the total mammals were discovered only in the past 40 years (since 1980) (Supplementary Table S3). Among them, about 11 new mammal species have been described from the landscape and 72.7% ($n = 8$) of which is endemic to the local area (Table 1).

The high endemism and frequent discovery of new species from the region can be explained by the fact that the study area is an

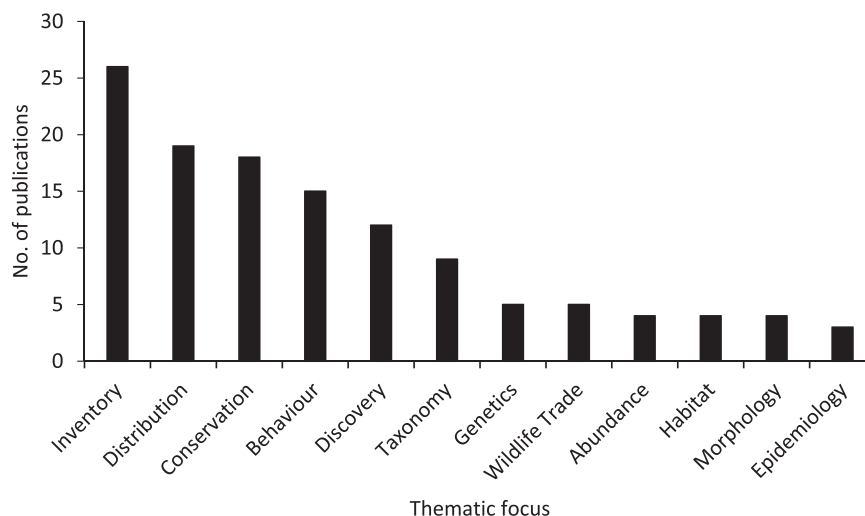
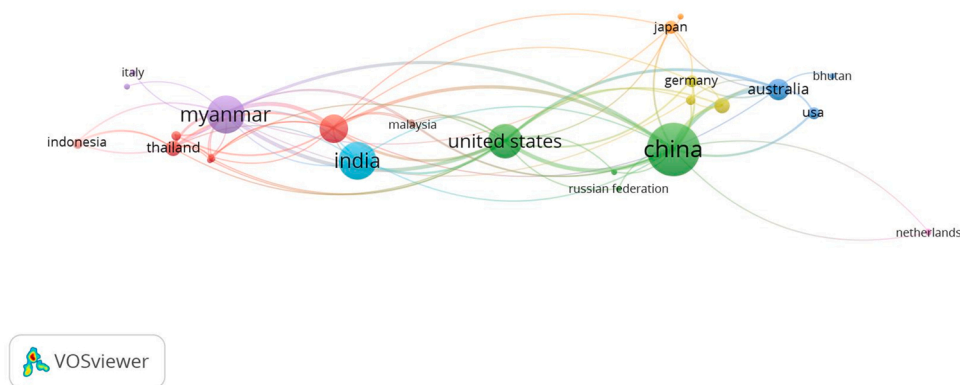
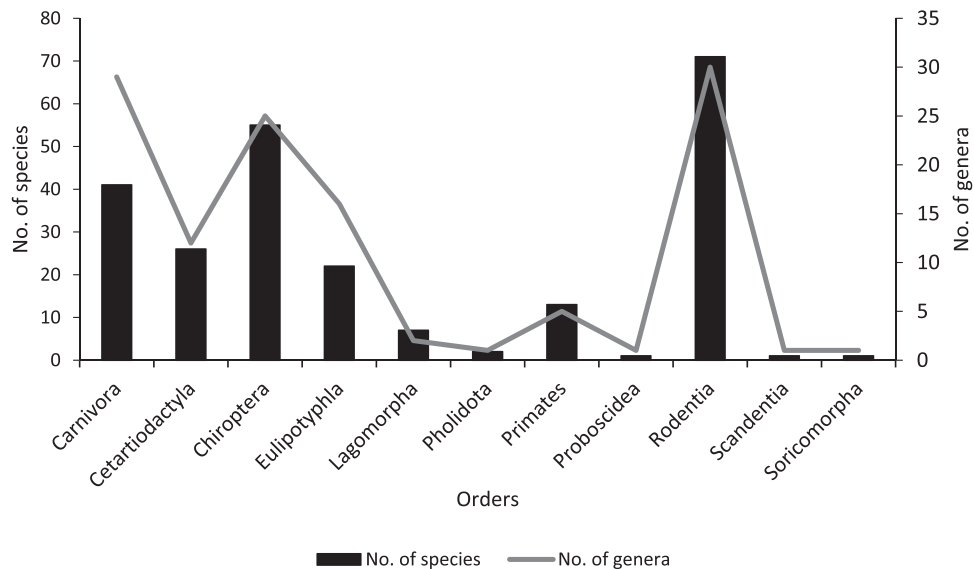


Fig. 4. Thematic focus of mammal research in FEHL.

Table 1

New species discovered from the landscape in the past 40 years.

S. No.	New species	Citation	IUCN Threat Categories	Endemism
1	Mount Gaoligong Flying Squirrel (<i>Biswamoyopterus gaoligongensis</i>)	(Li et al., 2019a)	Not Evaluated	Endemic
2	Gaoligong forest Hedgehog (<i>Mesechinus wangi</i>)	(Ai et al., 2018; Li et al., 2019a)	Not Evaluated	Endemic
3	Skywalker Hoolock Gibbon (<i>Hoolock tianxing</i>)	(Fan et al., 2017)	Endangered	Endemic
4	Hkakabo Razi tube-nosed bat (<i>Murina hkakaboraziensis</i>)	(Soisook et al., 2017)	Not Evaluated	Endemic
5	Myanmar Snub-nosed Monkey (<i>Rhinopithecus strykeri</i>)	(Geissmann et al., 2011)	Critically Endangered	Endemic
6	Black Pika (<i>Ochotona nigrizia</i>)	(Gong et al., 2000)	Not Evaluated	Not Evaluated
7	Leaf Deer (<i>Muntiacus putaoensis</i>)	(Amato et al., 1999; Rabinowitz and Khaing, 1998)	Data Deficient	
8	Gongshan Muntjak (<i>Muntiacus gongshanensis</i>)	(Ma et al., 1990; Shi and Ma, 1988)	Data Deficient	
9	Gaoligong Pika (<i>Ochotona gaoligongensis</i>)	(Wang et al., 1988)	Not Evaluated	Endemic
10	Namdapha Flying Squirrel (<i>Biswamoyopterus biswasi</i>)	(Saha, 1981)	Critically Endangered	Endemic
11	Yunnan Woolly Flying Squirrel (<i>Eupetaurus nivamons</i>)	(Jackson et al., 2021)	Not Evaluated	Endemic

**Fig. 5.** Co-authorship collaboration country networks of mammal research in FEHL.**Fig. 6.** Mammal genus and species distribution across different orders.

unexplored part of the Eastern Himalaya where at least 211 new species were discovered between 2009 and 2014 (WWF, 2015). It is also part of Indo-Burma and Mountains of South-West China hotspots which together support 2.7% of the global endemic vertebrates (Myers et al., 2000). Scholars believe that the FEHL holds great potential for the discovery of new species given the wilderness and less

explored areas of the region (Basnet et al., 2019; WWF, 2015).

3.5. Distribution of species across FEHL

Among the total 240 mammal species, 141 were recorded in China, 134 in India, and 137 in Myanmar (Fig. 7). The number of mammalian species from the landscape part of individual FEHL countries accounts for 25.4% of the total mammals ($n = 556$) from China (Hoffmann et al., 2008), 31.4% of that of India ($n = 427$) (Kamalakaran et al., 2018; Sharma et al., 2014) and 54.6% of that Myanmar ($n=251$) (MoECAF, 2011). Approximately, 25.4% ($n = 61$) of the total species were common to all three transboundary countries, including some threatened species such as Chinese Pangolin, Red panda, Tiger, Bengal Slow Loris, among others (Supplementary Table S3).

3.6. Conservation status and distribution of threatened species

The global population for most mammal species recorded in FEHL was reportedly decreasing ($n = 86$) with the continuous decline of mature individuals in 35 species and a severely fragmented population in 11 species (IUCN, 2020a). Likewise in the reviewed literatures, authors have reported declining population of several mammal species in the landscape (Rabinowitz et al., 1998; Ray et al., 2015; Sethy and Chauhan, 2018; Tun, 2001; Yang et al., 2018; Zhao et al., 2019). According to the IUCN Red List, 47 (19.6%) of the 240 mammal species were threatened, of which five (2.1% of total) are Critically Endangered (CR), 19 species (7.9% of total) are Endangered (EN) and remaining 23 species or 9.6% of the total are Vulnerable (VU) (Fig. 8). This accounts for almost 29% of the 163 globally threatened wildlife species found in the Eastern Himalayas (CEPF, 2007). Additionally, 11 species (4.6% of total) are Near Threatened (Supplementary Table S3).

The five CR species in the FEHL landscape include Namdapha Flying Squirrel (*Biswamoyopterus biswasi*), Myanmar Snub-nosed Monkey (*Rhinopithecus strykeri*), Sunda Pangolin (*Manis javanica*), Chinese Pangolin (*Manis pentadactyla*) and Black Crested Gibbon (*Nomascus concolor*) (IUCN 2020a). Namdapha Flying Squirrel is found only in Namdapha National Park of India (Saha, 1985, 1981) and Myanmar Snub-nosed Monkey is distributed only along the border of China and Myanmar of FEHL (Geissmann et al., 2011; Ren et al., 2017a), making both of the species endemic to the region (Fig. 9, Table 2). They are listed as CR due to their global population decline of 80% or more over three generations for Chinese Pangolin, Sunda Pangolin, Black Crested Gibbon and Myanmar Snub-nosed Monkey, and very less extent of occurrence of $> 100 \text{ km}^2$ for Namdapha Flying Squirrel (Challender et al., 2019b, 2019a; Geissmann et al., 2020; Molur, 2016).

Species like Red Panda, Hog deer, Dhole, Asian Elephant, Western Hoolock Gibbon, Skywalker Hoolock Gibbon, Bengal Slow Loris, Tiger, Phayre's Leaf Monkey, Shortridge's Langur among others are categorized as EN mainly due to their past, ongoing, or suspected global population decline of 50% or more over three generations (IUCN, 2020a).

Species from the region listed as Vulnerable in IUCN Red List include Gaur, Takin, Fishing Cat, Sun Bear, Eastern Hoolock Gibbon, Stump-tailed Macaque, Capped Langur, Asiatic Black Bear, Leopards, and others (Fig. 10, Table 3). They are categorized as VU largely due to their "past, ongoing, or suspected global population decline of 30% or more over three generations" (IUCN, 2020a).

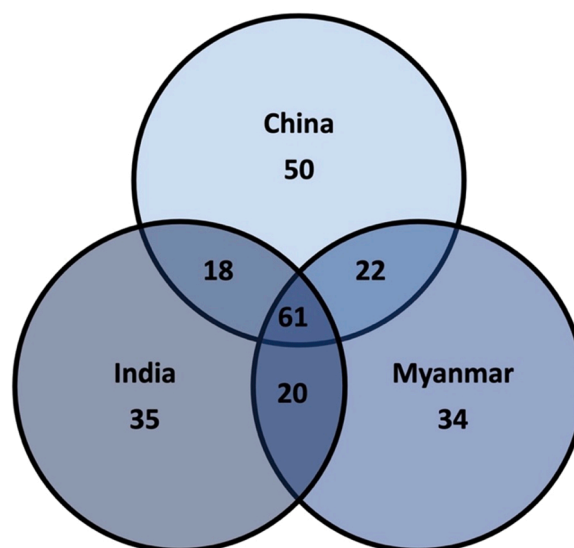


Fig. 7. Mammal species distribution across countries.

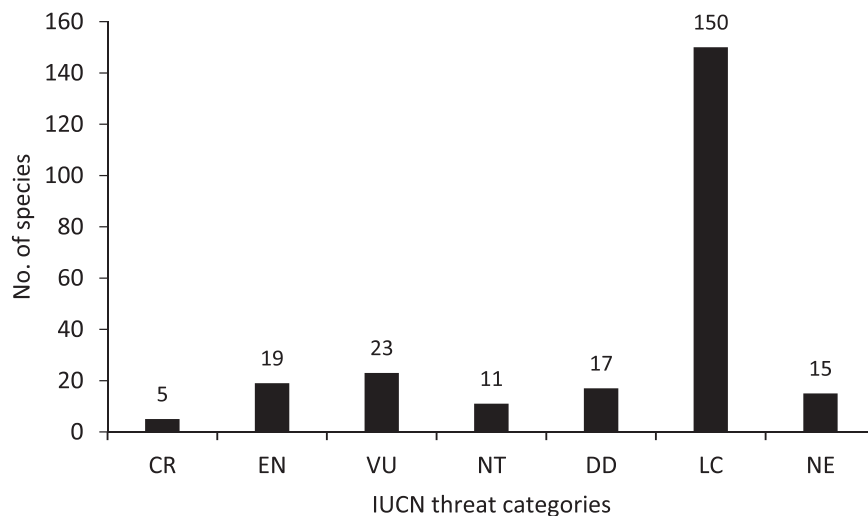


Fig. 8. Threat status of mammal species in FEHL (IUCN Red List, 2020).

3.7. Major threats to the mammals of FEHL

Threats to the mammal species in FEHL are mainly anthropogenic such as poaching, wildlife trade, and habitat degradation, fragmentation and loss. Encroachment of the forest habitats by local people for settlements, agriculture, and livestock grazing have been posing significant adverse impact on the mammal population and their continuity across the FEHL (Choudhury, 2014; Fan and Ai, 2011; Fei et al., 2017; Geissmann et al., 2011; Li et al., 2016; Lwin et al., 2011; Lynam, 2003; Naing et al., 2015; Rao et al., 2002; Ren et al., 2017b; Zhao et al., 2019). Other activities resulting in habitat degradation and loss includes collection and trade of non-timber forest products, (Cui et al., 2016; Kumar et al., 2009; Meyer et al., 2017; Naing et al., 2015; Rao et al., 2002), commercial and illegal logging, monoculture plantations, road and dam construction, (Chan et al., 2017; Choudhury, 2014; Das et al., 2015; Geissmann et al., 2011; Li et al., 2019a; Ma et al., 1995; Meyer et al., 2017; Nijman, 2015; Ray et al., 2015), forest fires, tourism and patrolling activities (Pan et al., 2019).

Hunting and poaching have been stated to be a serious and a major threat to several mammal species of the FEHL both outside and inside the protected areas (Geissmann et al., 2011; Li et al., 2018, 2019a, 2016; Lwin et al., 2011; Lynam, 2003; Ren et al., 2017b; Yin et al., 2016) though a drastic decrease was reported in Chinese part of the landscape (Pan et al., 2019). Local ethnic communities of the region traditionally hunt wildlife for food and medicine (Chan et al., 2017; Meyer et al., 2017; Naniwadekar et al., 2013; Ray et al., 2015; Ren et al., 2017a). The species hunted for bushmeat include porcupines, primates, wild pigs, deer, and civets (Choudhury, 2014; Datta et al., 2008; Naniwadekar et al., 2013; Talukdar et al., 2019), and those hunted for medicinal use include slow loris, squirrels, and hoolock gibbon (Chan et al., 2017; Das et al., 2015; Krishna et al., 2015; Ma et al., 1995; Naniwadekar et al., 2013). Bears and macaques were hunted especially when they raided the crops (Ma et al., 1995; Ray et al., 2015).

Furthermore, cross-border trade of wildlife parts has been frequently mentioned as the greatest and long-term threat to wildlife species in the FEHL, particularly in the Myanmar-China border (Cui et al., 2016; Li et al., 2018, 2019a; Min, 2012; Rabinowitz et al., 1999, 1998; Rao et al., 2005; Tun, 2001; Zhang et al., 2017). Northern Kachin and Shan State in Myanmar allows easy access to trading in Myanmar-China border where many borders have been indicated as major routes for illegal trade in the region (Rao et al., 2011, 2010; Zhang et al., 2017). Wild animals are traded for their skin, body parts, meat, or even the whole animals for pets (Li et al., 2018; Min, 2012). The most-traded species are slow loris, pangolins, otters, musk deer, Malayan porcupine, bears, and sambar (Li et al., 2019a; Rao et al., 2010).

Some species including the Myanmar Snub-nosed monkey face a high risk of extinction naturally due to their vulnerability to climatic, environmental, demographic, and genetic stochasticity (Meyer et al., 2017).

3.8. Protection and conservation efforts

At the international level, 65 of the 240 mammal species recorded from the reviewed documents, are protected by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (UNEP, 2020). Among them, 33 species are listed in Appendix I, 13 species in Appendix II, 6 species in Appendix I for some countries, and II for other countries, and two species are listed in Appendix III. Further, eight species are listed in Appendix III for India.

At the national level, 64 species from the FEHL are listed as threatened by China's Red List for Vertebrate, among which 18 species are listed as "critically endangered", 21 as "endangered" and 24 as "vulnerable" (Jiang et al., 2016). Besides, 63 mammal species from the landscape are protected under the newly revised Protected Wildlife Species of China (SFGA and MARA, 2021) where 34 species are listed under first-class protection and 29 species under second-class protection. China has formulated and implemented more than 20

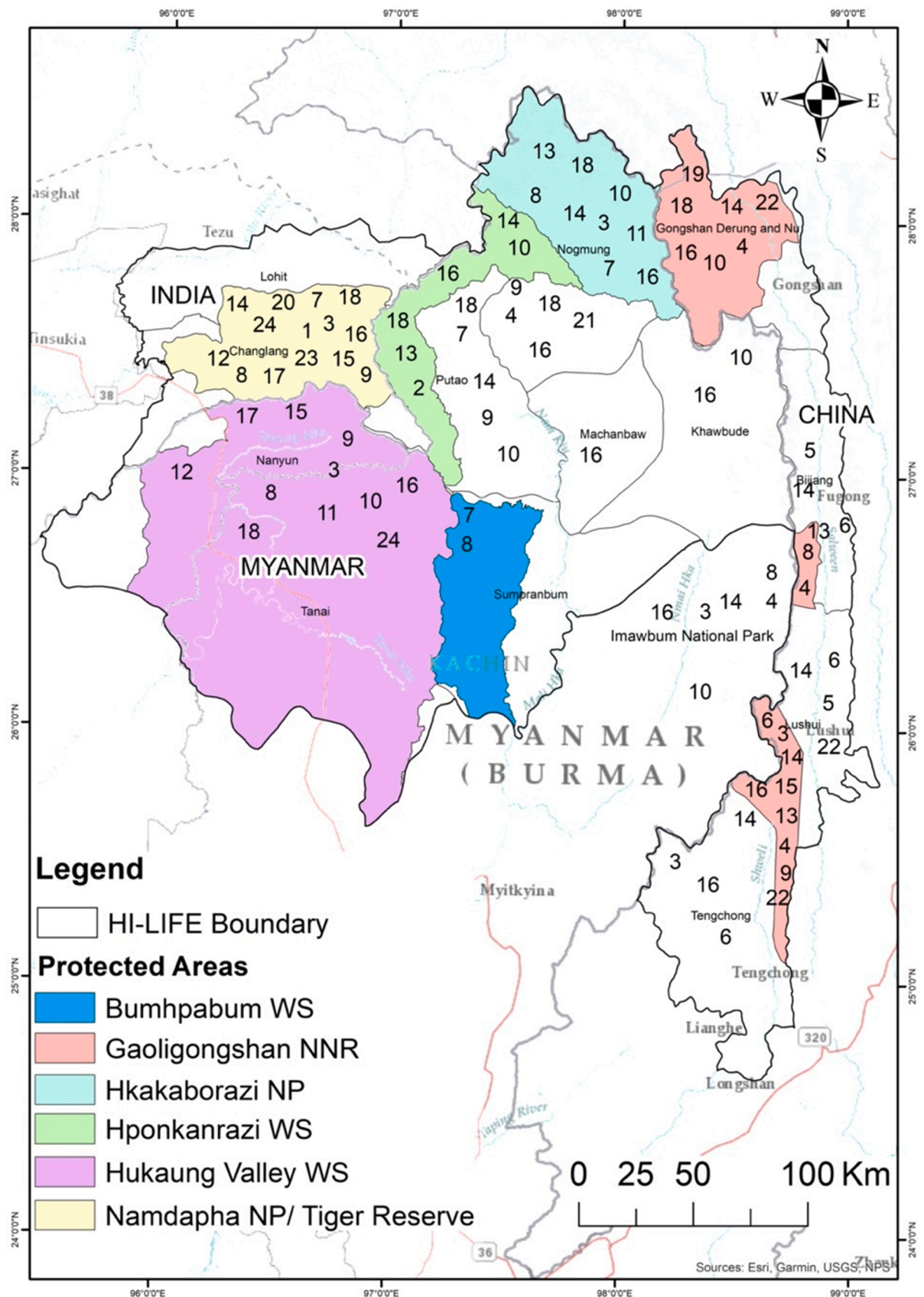


Fig. 9. Spatial distribution of CR and EN mammal species across FEHL *Note: The presence of Tiger in GNNR was recorded in one document but contradicted by other publications, highlighting the lack of systematic survey, and monitoring in the landscape. For the numerical representation in the map, please refer to Table 2.

laws, 40 administrative regulations, and 50 departmental regulations concerning biodiversity conservation (Wang et al., 2020). Specific projects for the conservation of species that have extremely small populations including the Myanmar Snub-nosed Monkey have been implemented (Meyer et al., 2017). In addition, much of the Chinese part of the FEHL fall into China's "priority conservation area" and "ecological red line" area for strict eco-conservation (Meyer et al., 2017). The northern part of FEHL in China also falls into the core zone of the Three Parallel Rivers Protected Areas World Heritage Site (UNESCO, 2003).

In India, 56 species recorded from FEHL are protected under the Wildlife Protection Act 1972 (Government of India, 1972) with the categorization of 27 species under Schedule 1 for absolute protection, 27 species under Schedule 2 and 2 species in Schedule 3. Wildlife in India are protected by a series of national laws, acts and rules, and state-level regulations, such as the Forest Reserve Act 1981, Wildlife Protection Act 1972, and Biological Diversity Act 2002. The NNPTN has prepared the "Namdapha National Park Management Plan" to conserve the forests and wildlife and support local livelihood. Projects targeting the conservation of specific species such as Hoolock Gibbons (Chetry and Chetry, 2011) and Tiger conservation activities by National Tiger Conservation Authority (NTCA) have also been actively implemented in the region (MoEF and WWF, 2012). In addition, various projects and training programs are being facilitated in and around the area for conservation education and capacity building of the forest staff, non-governmental organizations and related stakeholders aiming tiger conservation (Marimuthu, 2018a, 2018b).

Myanmar has listed 81 species from the FEHL as protected under the Conservation of Biodiversity and Protected Areas Law (2018) where 51 of them are included in the list of completely protected species and 30 species under the normally protected species (Forest Department, 2020). Biodiversity conservation in Myanmar is governed by Myanmar's several national laws, rules, regulations, and guidelines. The newly passed Conservation of Biodiversity and Protected Area Law (2018) gives special space for the establishment of community-conserved protected areas as well as co-management with local communities inside the existing protected areas (Government of Myanmar, 2018). The Northern Forest Complex is one of its major conservation priority areas in Myanmar side of FEHL. Several major protected areas have been established in FEHL (HNP, BWS, HWS, and HVWS) where mammals are the major target for conservation. Inawbun National Park was recently set up immediately next to the FEHL to protect the critically endangered Myanmar Snub-nosed Monkey (Meyer et al., 2017; IUCN, 2020b).

4. Discussion

4.1. Strengthening joint research to address data deficit

Though the research trend in the landscape is improving, considerable gaps exist in both the thematic and geographical coverage of mammal studies in the landscape, especially in Myanmar and outside the protected areas. To have an effective conservation at a landscape level, systematic and representative studies covering the entire landscape are needed. Basic information on the population, genetics, habitat ecology, food web, climate change vulnerability, migration pattern and cross-border connectivity of the mammal species is important for collective conservation interventions. In particular, the population size of several critically endangered and flagship species, is still not clear. For instance, with the recognition of the Skywalker Hoolock Gibbon as a different species from the Eastern Hoolock Gibbon (Fan et al., 2017), it is important to re-assess the status of these two species in terms of their respective population size, actual distribution, geographical boundary, habitat conditions and ecological inter-relations.

More in-depth and specific research focusing on the impact of illegal trade, hunting, and habitat loss to the mammal species are also required. Hunting and wildlife trade are often described as a major threat to the mammal species in the Far Eastern Himalaya, however only 5 literatures (4.5% of the total) are particularly dealing in this topic (Min, 2012; Rao et al., 2011, 2010, 2005; Zhang et al., 2017).

Similarly, climate change has been identified as a major driver of global biodiversity and ecosystem degradation which deserves more attention in the landscape. There are a few modelling-based studies focusing on the region (Tse-ring et al., 2010), but evidence-based ground studies on the impact of climate change on the wildlife species and their habitats are still limited.

Geographically, Myanmar part of the landscape and the area outside the existing protected areas are largely understudied as can be easily seen from Fig. 9 and Fig. 10 in which very few threatened species ($n = 2$) have been recorded from the BWS and southern part of the Hukaung Valley WS. In Myanmar part, there is a lack of baseline information from almost all the protected areas. The fact that at least eleven new species were discovered from the landscape in the past four decades indicates the need for further studies. Besides, very few studies on mammals are conducted outside the existing protected areas though they support equally impressive biodiversity (Uddin et al., 2020; Lwin et al., 2021).

The review indicates the research focus are largely on inventories and distributions restricting to small areas and sporadic geographical representations. Though the landscape is contiguous ecosystem across political boundaries, the cross-border or regional collaborations in research across the landscape are negligible. There are much more collaborations between scientists from the region, and scientists from other countries like USA (Yang et al., 2019a), and UK, than collaborations among scientists from Myanmar, China, and India (Fig. 5). There is an increase in joint research and publications between scientists from China and Myanmar (Lwin et al., 2021; Yang et al., 2019a), but collaboration between scientists from Myanmar and India and India and China are still very limited.

Strengthening regional or transboundary collaborations in research and monitoring will greatly improve the information on the health of ecosystem, climate change impact and habitat and population status of endangered and critically endangered species such as

Table 2

Numerical representation in map and corresponding CR and EN mammal species of FEHL.

S. N.	Common Name	Scientific Name	IUCN category	CITES Score
1	Namdapha Flying Squirrel	<i>Biswamoyopterus biswasi</i>	CR	
2	Sunda Pangolin	<i>Manis javanica</i>	CR	I
3	Chinese Pangolin	<i>Manis pentadactyla</i>	CR	I
4	Myanmar Snub-nosed Monkey	<i>Rhinopithecus strykeri</i>	CR	I
5	Black Crested Gibbon	<i>Nomascus concolor</i>	CR	I
6	Skywalker Hoolock Gibbon	<i>Hoolock tianxing</i>	EN	I
7	Black Musk Deer	<i>Moschus fuscus</i>	EN	I
8	Bengal Slow Loris	<i>Nycticebus bengalensis</i>	EN	I
9	Tiger	<i>Panthera tigris</i>	EN	I
10	Shortridge's Langur	<i>Trachypithecus shortridgei</i>	EN	I
11	Large Spotted Civet	<i>Viverra zibetha</i>	EN	
12	Wild Water Buffalo	<i>Bubalus arnee</i>	EN	III for Nepal
13	Phayre's Leaf Monkey	<i>Trachypithecus phayrei</i>	EN	II
14	Chinese Red Panda ^a	<i>Ailurus styani</i>	EN	I
15	Hog Deer	<i>Axis porcinus</i>	EN	III for Pakistan
16	Dhole	<i>Canis lupus</i>	EN	II
17	Asian Elephant	<i>Elephas maximus</i>	EN	I
18	Western Hoolock Gibbon	<i>Hoolock hoolock</i>	EN	I
19	Woolly Flying Squirrel	<i>Eupetaurus cinereus</i>	EN	
20	Hume's Rat	<i>Hadromys humei</i>	EN	
21	Hairy-nosed Otter	<i>Lutra sumatrana</i>	EN	II
22	Forest Musk Deer	<i>Moschus berezovskii</i>	EN	I for populations of Afghanistan, Bhutan, India, Myanmar, Nepal and Pakistan
23	Himalayan Muskdeer	<i>Moschus leucogaster</i>	EN	and II for others
24	Andersen's Leaf-nosed Bat	<i>Hipposideros pomona</i>	EN	

^a Note: Red Panda was recently classified into two species as *Ailurus fulgens* (Himalayan Red Panda) and *Ailurus styani* (Chinese Red Panda) (Hu et al., 2020). It is believed that the previously called "red panda" in FEHL should be the Chinese Red Panda.

the Myanmar snub-nosed monkey, the Skywalker gibbon, and the Takins.

4.2. Harnessing opportunities for regional or transboundary conservation

The review confirmed the urgency and opportunities for regional collaboration and transboundary conservation in the FEHL. Sixty-one species (25.4% of the total) are common to all three countries (Fig. 9). These include the CR Chinese Pangolin, six EN species (viz. Chinese Red Panda, Hog Deer, Dhole, Western Hoolock Gibbon, Bengal Slow Loris, and Tiger), and 14 VU species (IUCN 2020). Twenty species have a transboundary range between Myanmar and India, 22 other species are common in Myanmar and China including the Critically Endangered Myanmar Snub-nosed monkey and 16 species are common in China and India (Supplementary Table S3). Some critically endangered or endangered species such as the Myanmar Snub-nosed monkey are distributed narrowly along the China-Myanmar border. The common species across these cross-country borders and their habitats should be the priority targets for joint conservation efforts in the landscape. Although the Namdapha Flying Squirrel was recorded only in NNP of India (Saha, 1985, 1981) and Sunda Pangolin only in the Hponkanrazi WS (Rao et al., 2010, 2005), the possibility of their cross-border existence cannot be excluded as there are insufficient studies in the broad area of Northern Myanmar and between India and Myanmar. In addition, Myanmar snub-nosed monkey (CR) and Skywalker hoolock gibbons (EN) have an extremely small population and are only distributed in isolated groups along the border area between China and Myanmar (Chan et al., 2017; Chen et al., 2015; Chi et al., 2014; Fan et al., 2017; Geissmann et al., 2011). Moreover, many of the prevalent issues, challenges and threats facing mammal conservation in the landscape are of transboundary nature, thus, effective protection and conservation of these species requires close regional or cross-border collaboration and coordination at various levels among China, India, and Myanmar in scientific research, monitoring, patrolling, habitat restoration, combating illegal activities, protected area management, and conservation-related policy coordination and implementation.

Meanwhile, the study area stands for good opportunities in developing transboundary conservation areas (Yang et al., 2019b) or even a shared transboundary Heritage site as identified by IUCN (Jaeger, 2021). As can be seen from Fig. 1, all the seven major protected areas in the landscape set up by China, India, and Myanmar are physically connected to form a vast and contiguous conservation area. The GNNR of China and the HNP of Myanmar are naturally connected and the newly declared Imawbum National Park, though outside the boundary of the working area of HILIFE, provides connectivity to the southern and northern part of the GNNR and it makes all senses to include it into the FEHL for better transboundary collaboration between China and Myanmar. Along the Myanmar-India border, NNPTR, HWS, and HVWS are connected across the national border and provide contiguous habitat for the wildlife species across borders (Uddin et al., 2020). Furthermore, the study area has been identified as one of the thirteen landscapes in the Eastern Himalaya, where the development of habitat linkages connecting sites within the landscape is required to support the

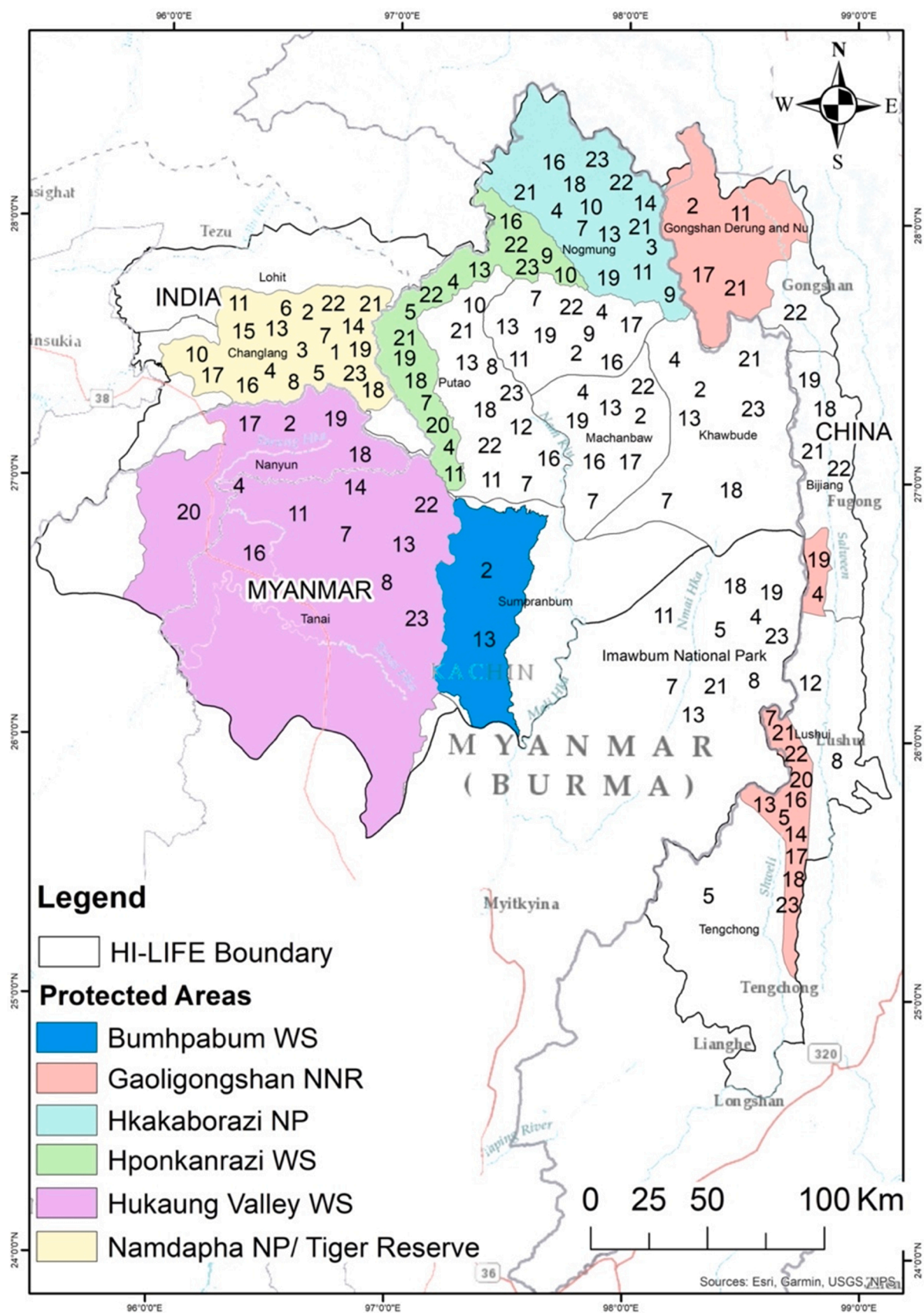


Fig. 10. Spatial distribution of VU species across FEHL *Note: For the numerical representation in the map, please refer to Table 2.

wildlife population (WWF-US, 2005). One of the most effective paths to transboundary conservation could be identifying and implementing potential conservation corridors to support the viable mammal population across borders. All of these present ideal conditions for regional collaboration and transboundary conservation provided the political commitment and adequate external facilitation in the region. The recent signing of MOU between Myanmar and India on Tiger Conservation is a good step toward this collaboration (ICIMOD, 2020).

4.3. Bridging the gaps of protected area network

Despite over 50% coverage of the protected area in the landscape, considerable habitats of the threatened species remain outside the existing protected area network. According to a study by Yang et al. (2019b) on five threatened flagship species including the Myanmar snub-nosed monkey (*Rhinopithecus strykeri*) and the Takin (*Budorcas taxicolor*), approximately 83.4% of the remaining habitat with high biodiversity conservation value along the China-Myanmar border area are unprotected. This gap is evident in the Chinese part of the FEHL working area, where the GNNR is composed of three far-spaced discrete northern, middle, and southern parts (Fig. 1) but many species like Takins and Phayre's leaf monkey are recorded in the northern and southern parts. The endangered Skywalker hoolock gibbons are dispersed in more than a dozen of isolated groups along the China-Myanmar border, and only a fragment of their habitats are located within the protected area (Fan et al., 2017). There is thus, a need of connectivity in the China part of FEHL for better conservation outcomes. The designation of the Imawbum National Park by the Myanmar Government could help to bridge the gaps of protection of several important species like the Myanmar snub-nosed Monkey. Identifying and establishing biological corridors for cross-border migration of wildlife migration is of particular importance in the landscape.

4.4. Empowering local communities for effective conservation

In the FEHL, it is crucial to mobilize, empower and motivate the participation of local communities in wildlife conservation, mainly for the following reasons:

First, most of the threats faced by wildlife are either related to the livelihoods of local people and communities or with the involvement of local people. People living within or close to the protected areas of the FEHL primarily depend on agricultural activities, extractive use of local forest resources, hunting and trading of wildlife, given their traditional culture and limited economic resources from outside (Rao et al., 2011, 2010; Renner et al., 2007). Many of the ethnic communities in the landscape are residing inside the officially designated protected area. The existing protected areas were mostly established in areas where these indigenous people have traditional use rights. Conservation thus needs to be balanced with the human needs in the area. Supporting local communities for more sustainable use of the goods and services from local ecosystems could help to achieve the multiple goals of conservation, socioeconomic development and preservation of traditional culture and ways of production and consumption as envisaged by global communities (IPBES, 2019).

Secondly, as already a high percentage of the landscape are designated as protected areas, it is difficult to further expand the geographical area for official protection. However, areas of the landscape outside the existing protected area network are harboring equally important biodiversity (Lwin et al., 2021). Community participation in wildlife conservation by establishing community-managed conservation areas and ecological corridors, implementing sustainable forest management, and engaging the local people in wildlife monitoring and patrolling with public awareness can strengthen the overall effectiveness of conservation.

Lastly, due to the remoteness and inaccessibility of this vast area, government management costs is very high. Moreover, the reach of government is often quite limited especially in the Myanmar part of the landscape, due to insurgencies and conflicts between government and local communities and lack of sufficient resources.

To tackle these conservation issues, necessary policies, legal framework, and institutional arrangement are crucial to empower and involve local communities for wildlife conservation. Respective governments have already taken some good steps. For instance, in Myanmar, the Conservation of Biodiversity and Protected Areas Law (2018) has explicitly stated support of community conservation initiatives (Government of Myanmar, 2018) and some good experiences are also happening on the ground (Meyer et al., 2017).

5. Conclusion

The landscape is extremely rich in mammal species with high endemism and new species being discovered from time to time. We are confident that with the application of new technologies such as camera trapping many more species will be added to the list in the future. Mammal research in the Far Eastern Himalaya Landscape has significantly increased in the past four decades. More research are needed on the population, genetics, habitat ecology, food web, climate change vulnerability, and cross-border connectivity of the mammal species. A very high percentage of mammals are under the threatened categories of the IUCN Red List. Human-related drivers such as illegal hunting and trade, and habitat degradation and loss are major threats to the mammal diversity and their habitats. In-depth and specific research on the impact of these threats as well climate change on the mammal population and ecology are needed. More researches and inventories on the Myanmar part as well as areas outside the protected network of the landscape need to be carried out to have a more complete understanding of the mammalian diversity and their status in the landscape. Strengthened regional or cross-border collaboration in such research, inventories and monitoring will greatly help in developing informed decision

Table 3
Numerical representation in map and corresponding VU mammal species of FEHL.

S.N.	Common Name	Scientific Name	IUCN category	CITES Score
1	Asian Small-clawed Otter	<i>Aonyx cinereus</i>	VU	
2	Binturong	<i>Arctictis binturong</i>	VU	I
3	Fishing Cat	<i>Felis viverrina</i>	VU	II
4	Sun Bear	<i>Helarctos malayanus</i>	VU	I
5	Eastern Hoolock Gibbon	<i>Hoolock leuconedys</i>	VU	I
6	Smooth-coated Otter	<i>Lutrogale perspicillata</i>	VU	I
7	Stump-tailed Macaque	<i>Macaca arctoides</i>	VU	II
8	Northern pig-tailed Macaque	<i>Macaca leonina</i>	VU	I
9	Siberian Musk Deer	<i>Moschus moschiferus</i>	VU	I
10	Black Muntjac	<i>Muntiacus crinifrons</i>	VU	I
11	Red Goral	<i>Naemorhedus baileyi</i>	VU	
12	Long-tailed Goral	<i>Naemorhedus caudatus</i>	VU	I
13	Clouded Leopard	<i>Neofelis nebulosa</i>	VU	I
14	Leopard	<i>Panthera pardus</i>	VU	III for India
15	Snow Leopard	<i>Panthera uncia</i>	VU	I
16	Sambar	<i>Rusa unicolor</i>	VU	
17	Capped Langur	<i>Trachypithecus pileatus</i>	VU	I
18	Asiatic Black Bear	<i>Ursus thibetanus</i>	VU	I
19	Greater Hog Badger	<i>Arctonyx collaris</i>	VU	
20	Gaur	<i>Bos gaurus</i>	VU	I
21	Takin	<i>Budorcas taxicolor</i>	VU	II
22	Mainland Serow	<i>Capricornis sumatraensis</i>	VU	I
23	Red Serow	<i>Capricornis rubidus</i>	VU	I

making, policy formulation, inclusive planning and collaborative management of the landscape.

There are good opportunities as well as urgent needs for regional and cross-border collaboration for research, monitoring, creating habitat corridors, protected area management and conservation-related policy formulation and implementation using a landscape approach. Mobilizing, empowering and motivating the participation of local communities in wildlife conservation and sustainable use of the ecosystem goods and services in the landscape is critical for achieving the goals of conserving globally important biodiversity and delivering sustainable development for local communities.

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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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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.gecco.2022.e02003](https://doi.org/10.1016/j.gecco.2022.e02003).

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