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Review Article

Biodiversity Research Trends and Gaps from the Confluence of Three Global Biodiversity Hotspots in the Far-Eastern Himalaya

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The Far-Eastern Himalaya Landscape (FHL), a shared transboundary landscape between China, India, and Myanmar, is one of the most intact and biologically rich landscapes in the Eastern Himalaya. Yet, the state of biodiversity and its significance are comparatively poorly known to conservationists and policy makers due to low priority in research, inaccessibility, and remoteness. We collated and reviewed 1032 articles relating to biodiversity of the FHL to understand research trends, identify knowledge gaps, and suggest priority research areas for future biodiversity conservation and management in the landscape. Our review showed that the Myanmar part of the landscape is the most studied, followed by the Indian and Chinese parts. The trend of publications in the landscape showed that the earliest publication on biodiversity in the FHL dates back to 1833, while the years from 2001 to 2017 account for almost 80% of the total publications. Most studies focused on species (73.6%), followed by ecosystems (25%) and genetics (1.4%). Mammals were the most studied taxa (22.6%), with a greater focus on charismatic megafauna, followed by arthropods (15.6%), angiosperms (14.8%), insects (13.4%), and birds (10.8%). There were very few publications on lower invertebrates and lower kingdoms, Monera, Protista, Fungi, and Viruses. At the ecosystem level, most studies focused on forests (58.5%) followed by freshwater (32%), agroecosystems (9%), and alpine/tundra ecosystem (0.5%); there were only 14 studies at genetic level. In the FHL, new species have been discovered and rediscovered starting from the early 1930s until 2017. The majority of newly discovered species in the last 18 years are arthropods. The paper reviews past research areas, identifies gaps for future research and intervention, and recommends transboundary collaboration to address these gaps for conservation and sustainable development of the FHL landscape.

1. Introduction

Human induced habitat loss is among the primary threats to biological diversity [1–3]. As a result, most facets of biological diversity defined by the Convention on Biological Diversity (CBD) are dwindling and show decreasing trends [4, 5]. Protected areas (PAs) are considered as an integral element of global biodiversity conservation and have often been used as a key indicator of the global commitment to increasing the area under protection [6]. However, PAs are not immune to threats and larger landscape level change and have been compared to land-bridge islands within a sea of hostile habitat [7–9]. Over the past decades, there has been a shift in emphasis among conservation biologists from managing populations of threatened species at a single site to considering larger landscapes as conservation units [10–12]. Such landscape scale approaches to conservation make sense because the drivers of biodiversity loss—land use and land cover change, fragmentation, overexploitation, and climate change—tend to operate at large scales [13–15]. In many instances, the landscape approach makes better sense when considered

at transboundary level considering the contiguous habitat across borders [16, 17].

The Far-Eastern Himalaya Landscape (FHL hereafter) is a shared transboundary landscape between China, India, and Myanmar [18]. The landscape is a meeting point of three biodiversity hotspots—Himalaya, Indo-Burma, and Mountain of Southeast China—and parts of the landscape are counted among the "crisis ecoregions", "endemic bird areas", "mega diverse countries", and "global 200 ecoregions" [13, 19]. As a result of continental drift, the region has a low latitude along with a wide altitudinal range making it geologically diverse. The convergence of the Indo-Malayan and Palearctic biogeographical realms in the landscape has resulted in rich flora and fauna [20–22]. It is one of the most intact and biodiversity rich transboundary biodiversity complexes of the Eastern Himalaya and has been described variously as a "Centre of Plant Biodiversity", "Eastern Asiatic Regional Centre for Endemism" [23], "Museum", and "Cradle" of plant diversity [24]. A study of the world's frontier forests by the World Resources Institute shows that the complex contains mainland Southeast Asia's last remaining tracts of large, intact natural forest ecosystems which are relatively undisturbed and large enough to maintain biodiversity [25]. The landscape is also significant in terms of freshwater biodiversity with rich species diversity and a high proportion of threatened species [26].

So far, the state of biodiversity and its significance are comparatively poorly known to conservationists and policy makers due to low priority in research, inaccessibility and remoteness [27]. Many species groups have been inadequately studied and the real extent of the biodiversity of the landscape is undoubtedly underestimated. This is reflected in the 353 new species discovered in the Eastern Himalaya between 1998 and 2008, equating to an average of 35 new species finds every year [28]. Even as our knowledge of the FHL remains poor and incomplete, it is facing multiple threats from intensification of farming systems, family fragmentation, encroachments, unregulated tourism, developmental projects, poaching, and land use and climate change [27, 29–32]. The FHL, being an important transboundary landscape, designated through a consultative process for long term cooperation [33], needs immediate attention in terms of effective conservation measures [34]. Therefore, understanding the knowledge base, information gaps, and priority areas for future interventions are critical steps in making any transboundary landscape functional [35]. Reviewing available research can serve as a starting point for much needed conservation and management interventions within a given landscape. Here, we synthesize the existing and accessible peer-reviewed literature covering biodiversity aspects in the FHL to understand research trends, identify knowledge gaps, and suggest priority research areas for future biodiversity conservation and management in the landscape.

2. Materials and Methods

2.1. Study Area. Situated between 24° 37′ 40.09″- 28° 32′ 35.3″N and 95° 27′ 13.75″ - 99° 8′ 15.57″ E, the FHL covers an area of over 71,400 km^2 with an elevational range extending from 200 to 5,800 masl. The FHL spans across parts of Northern Myanmar (Namyun in the Sagaing Region, and Tanai, Sumprabum, Putao, Machanbaw, Nawngmun, and Khaunglanphu in Kachin District), including Hkakabo Razi National Park (HNP). In India, it includes Namdapha National Park and Tiger Reserve (NNP & TR) and adjoining buffer areas in Changlang District. In China, the three segments of Gaoligongshan National Nature Reserve (GNNR henceforth) and the intervening areas between them in North-west Yunnan form an integral part of FHL (Figure 1). The HNP of Myanmar is contiguous with the dense temperate forests of Yunnan Province of China and Hponkanrazi Wildlife Sanctuary (HWS) connects the NNP & TR in Arunachal Pradesh, India. The NNP & TR has a high potential to be connected with biological corridors to GNNR in Yunnan Province through the HWS which can be further linked with the HNP in Myanmar [18].

About 53.5% of the FHL is under formal protection in the form of PAs (National Parks, Wildlife Sanctuaries, and Nature Reserves) comprising almost 90% of undisturbed broad- and needle-leaved forests (see Table 1). The landscape is comprised of eight ecoregions [36], nine important bird and biodiversity areas [37], and one World Heritage site, the Three Parallel Rivers of Yunnan Protected Areas in China, with a variety of ecosystems and habitats, biodiversity, genetic resources, and cultural heritage [18]. The landscape is home to a wide variety of globally threatened and endangered mammal species [27]. Some of these include the clouded leopard (*Neofelis nebulosa)*, Bengal tiger (*Panthera tigris tigris)*, Asiatic black bear (*Ursus thibetanus)*, Namdapha flying squirrel (*Biswamoyopterus biswasi),* and Western hoolock gibbon (*Hoolock hoolock)*. The landscape is also rich in avian diversity, with 525 species recorded in GNNR, 490 in Namdapha National Park, and 311 in Hkakabo Razi National Park [38].

The landscape is home to approximately 213,600 people [18] from over 20 different ethnic and linguistic groups who add to the region's historical, cultural and traditional diversity [39]. They include the Chakma, Lisu, Singpho, and Rawang. Around 70% of the rural population depend on natural resource-based livelihoods. The region is facing vulnerabilities due to climate change and anthropogenic activities and therefore there is a need for conservation and management of its rich biodiversity [27].

Recognizing the global and regional significance and challenges that lie within the landscape, the governments of China, India, and Myanmar endorsed and initiated the Far-Eastern Himalayan Landscape Initiative (HI-LIFE henceforth) that focuses on regional cooperation for integrated landscape conservation and development [18]. The conservation of biodiversity together with improved livelihoods is a prime objective of the initiative. The review and synthesis of existing literature on the FHL is a critical first step in understanding the status of biodiversity, recognizing knowledge gaps, and suggesting potential areas for future research in the landscape. This would also help to direct much needed future interventions and investments for conservation and management of the landscape.

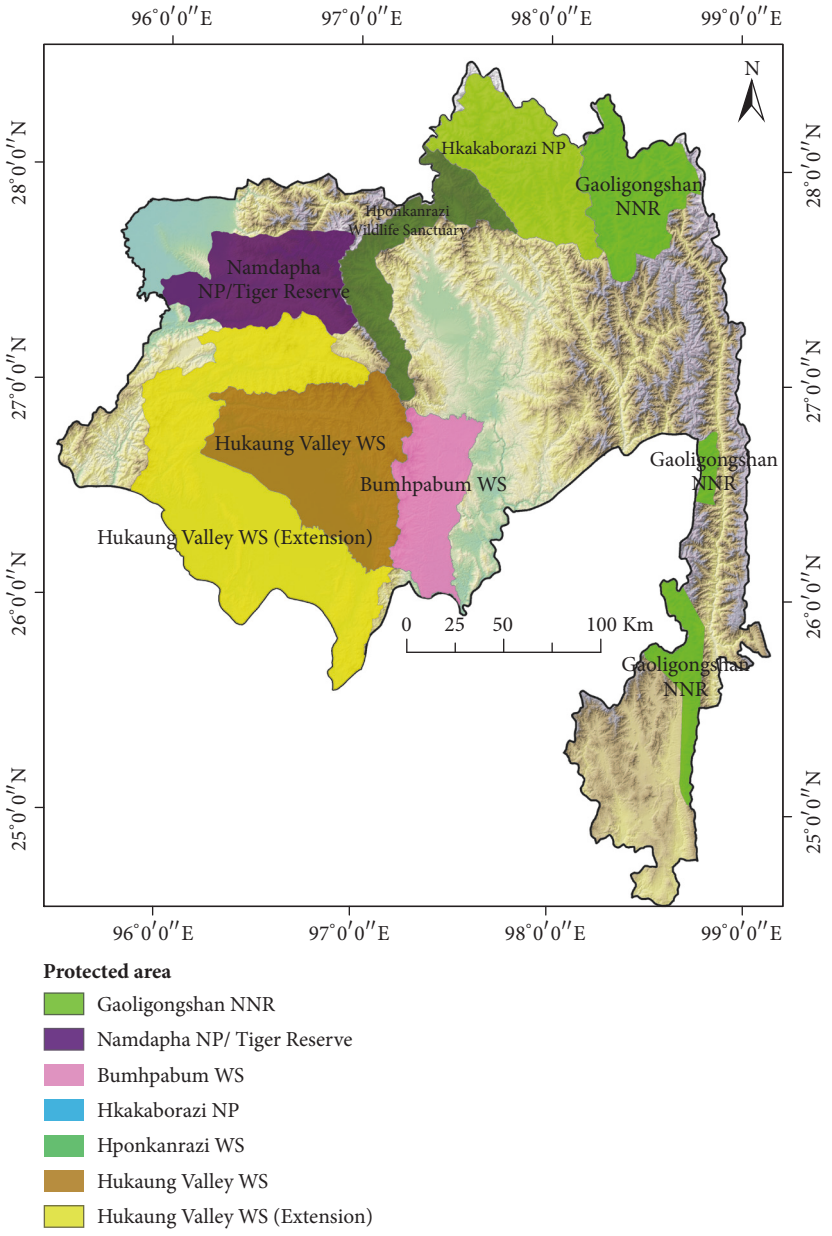

Figure 1: The Far-Eastern Himalayan Landscape showing protected areas.

2.2. Methodology. The study is based on the review of literature pertaining to the biodiversity of the FHL, carried out between June 2017 and May 2018. As the objective was to document the status of biodiversity research and identify gaps for future interventions, the review adopted multiple approaches. Initially, articles were collected using search engines such as Scopus and Google Scholar following Kandel et al. [35] and Chaudhary et al. [40]. In the search for literature, three broad categories of keywords were used: the names of countries and provinces or districts within the landscape and names of PAs within the landscape, followed by keywords for biodiversity (mammals, birds, amphibians, insects, fish, etc.) used interchangeably with the above two.

We considered the literature with such key words when they appeared in the title, key words, or the abstract. The rigorous search process for extant literature included journal articles, books/chapters, dissertations, institutional reports, proceedings, management, and development plans. The collected list of articles was then again validated with "Publish or Perish" software [41], which enabled us to add grey literature to the list. We also considered reports of new discoveries or rediscovered species of flora and fauna from the landscape. In addition, we also reviewed the national and global policy interventions contributing to biodiversity conservation with special focus on Multilateral Environmental Agreements. The entire inventory of publications has been made available at ICIMOD's Regional Database Initiative.

Table 1: Protected areas in the Far-Eastern Himalayan Landscape.

S No	Protected Area	Country	Established year	Area (km^2)	IUCN category	Ecosystem	Key mammal species
1	Gaoligongshan National Nature Reserve (GNNR)	China	1983	4,055	V	Subtropical evergreen broad-leaved forests, subalpine conifer forests & alpine meadows	Asiatic golden cat Chinese pangolin, Dwarf musk deer Eastern hoolock gibbon, Dhole, Red panda, Tiger
2	Namdapha National Park & Tiger Reserve (NNP/NTR)	India	1983	1,985	II	Subtropical broad-leaved forests, subtropical pine forests, temperate broad-leaved forests, alpine meadows, perennial snow	Clouded leopard, Dhole, Dwarf musk deer Namdapha flying squirrel Red goral, Snow leopard, Takin, Tiger
3	Hkakabo Razi National Park (HNP)	Myanmar	1998	3,810	II	Alpine meadow & shrub, sub-alpine conifer forest, rhododendron forest, montane wet temperate forest, subtropical lowland forest	Black musk deer, Gongshan muntjac, Leaf deer, Red panda, Red goral, Shortridge's langur Takin
4	Hponkanrazi Wildlife Sanctuary (HWS)	Myanmar	2003	2,703	IV	Tropical moist forest, subtropical moist hill forest, temperate forest, deciduous forest, alpine forest	Bengal slow loris Clouded leopard, Chinese pangolin, Dhole Eastern hoolock gibbon, Red goral, Takin
5	Hukaung Valley Wildlife Sanctuary/ Extension (HVWS/HVWSE)	Myanmar	2004	6,371/ 15,431	IV	Evergreen forest, mixed deciduous forest (moist upper), hill forest (evergreen and pine)	Asiatic black bear, Asiatic elephant, Dhole, Gaur, Hog deer, Indian water buffalo, Sun bear, Shortridge's langur, Sambar Tiger
6	Bumhpabum Wildlife Sanctuary (BWS)	Myanmar	2004	1,854	IV	Evergreen forest, evergreen	Asiatic elephant, Asiatic golden cat, Chinese serow, Clouded leopard, Gaur, Red goral

3. Results and Discussion

The research led to 30 different sets of datasets considering the set of interchangeable keywords. The list was then combined in Microsoft Excel to eliminate duplicates. The final list of 1032 published documents from the landscape was then considered for analysis. It is important to note here that this research may not have covered all the research conducted in the landscape. However, it does contribute to the baseline information. More importantly, it provides a foundation for examining the existing research gaps for future interventions and priorities.

3.1. Geographical Distribution of Publication. Our results show that research interest appears to be higher in Myanmar, followed by India and China, whereas the least interest appears to be in the transboundary region of the landscape (publications which included more than one country as their study area were categorized under "transboundary" group for the purpose of this study; see Figure 2). Myanmar makes

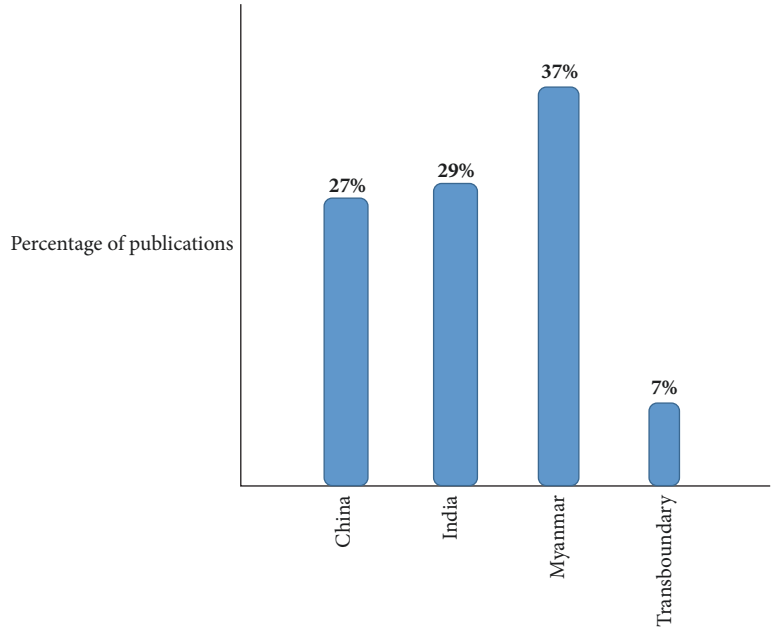

Figure 2: Site specific records of publications from the Far-Eastern Himalayan Landscape (FHL).

up a large portion of the landscape (66%) as compared to China (22%) and India (12%), which probably explains why it has the largest number of publications. Out of the 37% of the studies that were carried out in the Myanmar portion, the majority were in three protected areas, Hkakabo Razi National Park, Hponkanrazi Wildlife Sanctuary, and Hukaung Valley Wildlife Sanctuary Extension [42]. Around 50% of the landscape is covered by PAs and therefore it is not surprising that the bulk of the research was carried out within PAs.

The transboundary region accounted for 7% of the publications and 42% of these carried out at the transboundary level (on the Brahmaputra basin) were published in 2017 alone. This indicates that transboundary conservation using landscape approach has gained popularity in recent years. Furthermore, various organizations including ICIMOD, UNESCO World Heritage Centre, and Mac Arthur Foundation are working for integrating conservation and development through transboundary cooperation in the region. This has resulted in greater research in the region that is transboundary in scale. The increasing number of such studies can promote shared ownership, trust and cooperation. Furthermore, such research has the potential to assist in integrating science and management in wake of the elevated rate of floral and faunal species loss [43].

3.2. Historical Trends of Publications. The trend of publications was analyzed for nearly two centuries (1820 to 2017) on a three decadal basis. The linear line (see Figure 3) for almost one and a half century suggests less interest and investments in research [44]. There is no evidence of literature on biodiversity during 1851-1880, suggesting either no research or no publications in the public domain. The number of publications for about one and half century thereafter was 39 only, almost one-fourth of what was published from 1971 to 2000. However, the upward trend of publications after the 1970s confirms that the scientific community started becoming active and vocal against the loss and extinction of magnificent mammalian and avian species [45]. The years from 2001 to 2017 mark an important period for biodiversity research in the landscape accounting for almost 80% of the total publications. This is in line with global trends in biodiversity research following the Convention on Biological Diversity (CBD), which was held in 1992 and focused global interest on the topic of "biodiversity". Together with 188 other member countries, China, India, and Myanmar are signatories to CBD. Similar patterns of publication on biodiversity can be seen in other parts of the HKH, including in the Kangchenjunga Landscape in the Eastern Himalayas [35].

The conservation value of the region was only realized in the 21st century when international NGOs and national research institutions started investing in conservation issues here [46]. These include regional institutions such as ICIMOD; Kunming Institute of Botany (KIB), Chinese Academy of Sciences (CAS); Southeast Asia Biodiversity Research Institute, Chinese Academy of Sciences (CAS-SEABRI); and national institutions like GB Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), India, and Ministry of Natural Resources and Environmental Conservation (MONREC), Myanmar, working on and promoting research and development of the landscape in this region.

The analyses of the literature also showed that from 1820 to 2017 the journals *Biodiversity and Conservation* of Springer, Elsevier, Records of the Zoological Survey of India, *Journal*

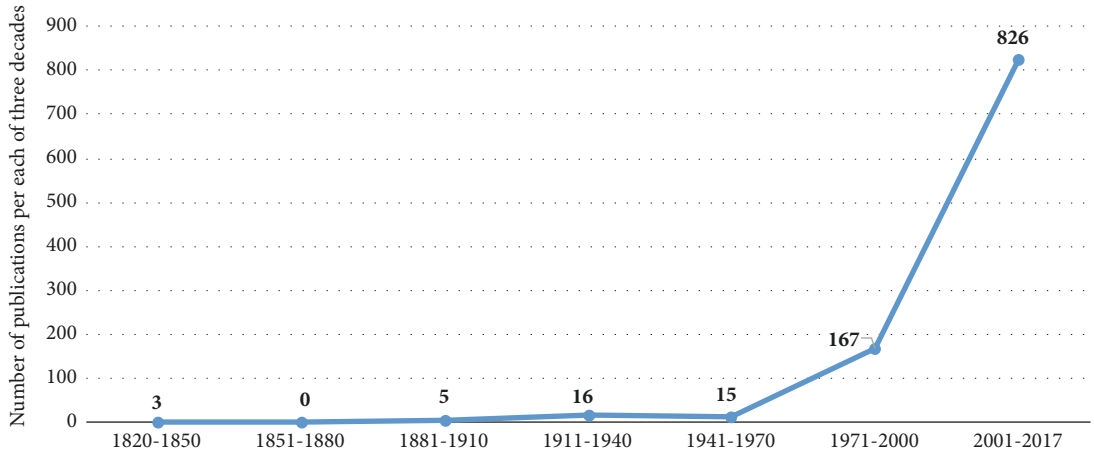

Figure 3: Pattern of publications from the Far-Eastern Himalayan Landscape.

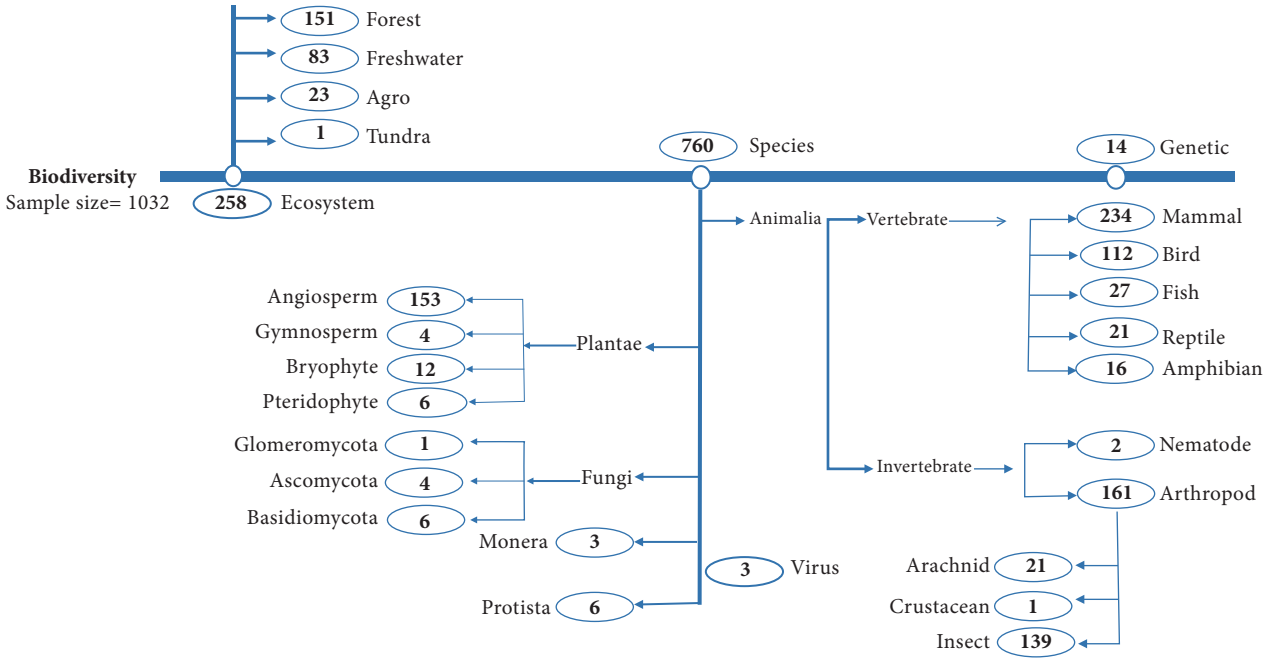

Figure 4: Total number of publications for different biodiversity levels in the Far-Eastern Himalayan Landscape.

of Systematic Palaeontology, Taylor & Francis, *Zootaxa*, and *BioOne* published the highest number of publications from this landscape mainly from the protected areas of China, India, and Myanmar.

Research on Biodiversity. Our results reveal that 73.6% of the studies were conducted at the species level, 25% at the ecosystem level, and 1.4% at the genetic level (Figure 4). A large number of papers focused on forest ecosystems, mammals, fossilized mesofauna of amber of Hukaung valley, and angiosperms. A few studies also considered multiple case studies from the landscape. For example, [47] investigated fish, amphibians, and reptiles in a single case study at GNNR and [48] in phytodiversity of Arunachal Pradesh and [49] documented mammals, birds, reptiles, and amphibians. The cited articles mentioned in other scientific and research papers were also noted to understand the major interests of the authors [50], which was the most cited publication, 695 times for Asian elephant (*Elephas maximus*), [51] 354 times for hunted mammals, and [52] 217 times for ecology. This process helped to identify the foremost research interest and species of interest (usually large mammals) in the field of biodiversity.

3.3. Publications at Ecosystem Level. A large part of the landscape consists of natural ecosystems: forests supporting a wide variety of habitats, species, and gene pool. The publications were dominated by forest ecosystem (58.5%), followed by freshwater (32%), agroecosystems (9%), and alpine/tundra ecosystem (0.5%). The results show that topics touching upon

protected areas of Myanmar (46.6%) dominated the database in forest ecosystem category, followed by India (27.4%) and China (26%). The available literature pays more attention to anthropogenic threats/biotic [53–55], conservation biology [31, 56, 57], and ecosystem services and function [58]. Most of the research in conservation biology and anthropogenic threats indicate that there is a need for greater synergies between conservation and development in the study sites. Further, climate adaptation research also stresses on complementary actions among people to adapt to and enhance resilience of both people and environment. This is extremely vital in wake of the changing climate and its projected adverse impacts here [59].

There were 83 researches conducted on freshwater ecosystem including hydrological modelling, limnological parameters and sediment/chemical flux, among others [60, 61]. The landscape has rich agro-biodiversity with different agricultural practices, including shifting cultivation being practised in the region [62, 63] and has been documented from across the Himalayas [64, 65]. A few studies were also carried out in the regions of Myanmar and China to understand the agricultural development here [66]. Unfortunately, the alpine ecosystem of Northwest Yunnan was the solo research subject investigated in the tundra zone [67]. There were only a handful of studies that looked at ecosystems at a transboundary scale [68–71].

3.4. Publications at Species Level. With regard to species, 760 studies were conducted on different kingdoms: Animalia (73.5%), Plantae (23.3%), Fungi (1.5%), Monera (0.4%), Protista (0.8%), and Virus (0.4%). Charismatic megafauna accounted for 22.6% of total faunal studies, followed by arthropods (15.6%), angiosperms (14.8%), insects (13.4%), and birds (10.8%). Data deficiency was recorded for smaller mammals due to less research and conservation awareness [72]. There were very few publications on lower kingdoms such as Monera, Protista, Fungi, and Viruses, and these are major gaps that need comprehensive studies on taxonomy, distribution, and population trends.

The first research in the landscape was on rufous-necked hornbill *(Aceros nipalensis),* Vulnerable in 1829 [73]. Birds are environmental indicators; many researchers preferred to carry out avifaunal surveys [74] and develop checklists of birds [75, 76] in order to understand the distribution, abundance, and updated status of birds in the protected areas. The landscape is home to mountain hawk eagle (*Nisaetus nipalensis)* [77], rufous-necked hornbill [78], and Naung Mung scimitar babbler *(Jabouilleia naungmungensis)* [79]. The Sclater's monal *(Lophophorous sclateri)* [66], a keystone bird species of GNNR, has been studied for its diet and a threat assessment of the species has also been done. The GNNR is rich in avian diversity and hence bird watching has been promoted as high-end tourism product [80]. However, as of 2017, transboundary research is limited only to a study on greater rufous-headed parrotbill *(Psittiparus bakeri)* [81] and overall bird diversity [82].

Data on the distribution of research on mammals was strikingly clear. The Bengal tiger *(Panthera tigris tigris)* and clouded leopard *(Neofelis nebulosa)* received most of the attention in terms of their distribution and conservation status [83, 84], with very less focus on ungulates. The hoolock gibbon is a keystone mammal species in the landscape which has been studied for its distribution, population size, habitat, behavior, and conservation status [85, 86]. Since rodents were viewed as a challenge to the agroecosystem, more than 162 studies have been conducted on them between 1910 and 2015 [87].

Another interesting phylum was Arthropoda, which was studied mainly in fossilized form in the Cretaceous amber of Hukaung valley, Kachin, and Myanmar. Additionally, 87.9% of the researches carried out were for insects, 13.3% for arachnids, and 0.6% for crustaceans in the GNNR, Namdapha, Hukaung valley, Ayeyarwady, and the upper Chindwin catchment. Butterflies, moths [88, 89], beetles [90, 91], and wasps [92] have been abundantly studied too.

Studies for Plantae were prevalent due to the traditional use of medicinal plants and animals [93, 94], flowers [95], orchids [96], seed plants [97], wild tea [98], and bamboo [99] in the landscape. Shen et al. [100] and Paul et al. [101] have also studied the rhododendron species in the Indo-Burma biodiversity hotspot at transboundary scale.

3.5. Publications at Genetic Level. The review encountered only 14 publications on genetic level studies for the landscape, with only one study at the transboundary scale for the Indo-Burma Biodiversity hotspot [102]. Seven of the genetic studies were conducted in the GNNR, two in Namdapha National Park and Tiger Reserve, two in the Hukaung valley, and two in both the Hkakabo Razi and Hukaung valley. These publications were on nitrogen-fixing filamentous bacteria [103], evolutionary microbiology [104], frog species [105], encephalitis virus [106], elephant [107], cobra *(Naja mandalayensis)* [108], balsams *(Impatiens casseabriae* and *Impatiens putaoensis)* [109], leaf muntjac *(Muntiacus putaoensis)* [110], flowering plant (*Remusatia* sp.) [111], conifer *(Pinus yunnanensis)* [112], Cyprinidae fish (*Gymnodiptychus integrigymnatus*) [113], and golden snub-nosed monkey *(Rhinopithecus roxellana)* [114]. There was no genetic research on agro-ecosystem within this landscape. Fewer studies at genetic level compared to research at ecosystem and species level could be due to limited financial resources, lack of sophisticated equipment and restrictive government policies to carry out genetic research in developing countries.

3.6. Species Discovered and Rediscovered. In the FHL, several new species have been discovered starting from the early 1930s until 2017 (Figure 5). The species are categorized under flora and fauna and it can be noted that the discovery of fauna has been increasing since 1991 and is highest in the decade from 2011–2020. New discoveries of flora are comparatively low which have also increased over the last decade (Figure 5). Though there are increasing threats to biodiversity in the landscape, new species continue to be discovered as there are still several unexplored areas with high potential for new species [28]. As conservation interventions, terrestrial PAs have increased only by 0.3% and forest cover by 2.5% (North East Asia by 22.9% and South Asia by 5.8%) in the region in the past 25 years [115]. There are evidences of

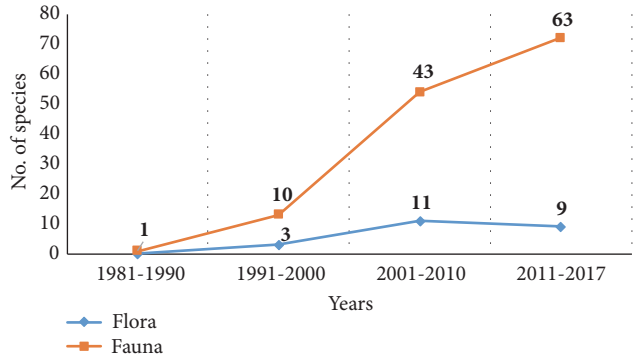

Figure 5: Species discovered in the Far-Eastern Himalayan Landscape.

evolutionary significance of ancient flora in the landscape as well [116]. While new species of mammals, amphibians, arthropods, birds, reptiles, angiosperms, and bryophytes are being discovered. The majority of the newly discovered species in the last 18 years were typically arthropods (52 out of 72 are arthropods).

Some recent discoveries that are new to science include the snub-nosed monkey, which was discovered in 2010 near the Myanmar-China border [117] and spurred demands for a transboundary landscape conservation approach for species and habitat protection. The fossilized booklice (*Psocorrhyncha burmitica*) was discovered from Burmese amber [118]. During a survey in 2017, three new angiosperms were discovered, one from the turnipwood family [119], an orchid [120], and a balsam [109]. Likewise, new species of fish [121] and vesper bat [122] have been discovered.

The rediscovery category contains some species which were not reported by scientists for decades or due to their small species range, anthropogenic/natural threats, and illegal trade. Some examples include a freshly defined spider (after detailed investigation based on the male holotype) from Yunnan, China [123], *Bufo* spp. recorded for a second time at a different location in Arunachal Pradesh [124], jester butterfly seen after 90 years in the Namdapha National Park and Tiger Reserve [125], and several Mesozoic arthropods rediscovered in Burmese Cretaceous amber [126].

3.7. Past Research Areas and Gaps for Future. Considering the results of numerical bibliographic analysis from 1820 to 2017, the existing challenges and gaps were analyzed so as to provide directions for prioritizing future research and sustainable management of biodiversity. These data were examined and categorized into the different biodiversity levels as shown in Table 2. The forest ecosystems in the protected areas may have attracted a lot of research interest and funding because of the national level forest protection scheme and programmes that incentivize protection, such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and National Forest Protection Program (NFPP) and National-level Nature Reserves (NNRs) [127, 128]. There was no study on the biomes of rainforest, desert, grassland, and savanna as large areas of the landscape are within the PAs of the three countries. On a few studies focused on agro-ecosystems compared to forest ecosystems, which might be due to less research funding and limited access to these least studied geographical areas.

At the species level, there was a greater focus on charismatic fauna, and there is a need to focus on small mammals and invertebrates. The greater research focus on charismatic and threatened fauna has led to a dearth of information on smaller animals, putting them at higher risk of extinction with not even a basic checklist of their distribution and population status, as also reported in the Kangchenjunga Landscape [35]. Minimal studies at the genetic level have been carried out since the 1990s [129]. The research mainly focused on measuring genetic diversity at species level. More number of inventories at each biodiversity level of organization is required to supplement gap analysis with 100% accuracy.

However, the key identified areas for the above-mentioned gaps and challenges require transboundary collaboration for reaching consensus on the prioritized gaps and actions. There is a need to identify the direction for future collaboration and provide basis for clarified task divisions on each side of the landscape. Higher level leadership and policy support is needed to make local collaborations easier and more effective. Protection, joint conservation of forest and biodiversity resources and sustainable community development in the border areas can be priority areas and actions for future collaboration.

3.8. Major Multilateral Environmental Agreements. The three countries sharing this landscape are signatory to major multilateral environmental agreement (Table 3). Most major agreements, treaties, and protocols related to biodiversity conservation (CBD, CITES, and Ramsar) and climate change (UNFCCC) have been ratified by the countries, indicating national commitment to conservation and encouraging green investments to reduce detrimental effects of climate change. For example, all three countries signed the Convention on Biological Diversity (CBD) between 1993 and 1994. Similarly, [130] China committed to protecting water quality, forest resources, and marine ecosystems and reducing wastelands in order to stem biodiversity loss by 2010. The Ramsar Convention on Wetlands of International Importance is meant for protecting wetlands and was signed by India in 1982. During 1992-1993, the first ever systematic mapping of

Table 2: Past research areas, gaps/investments for future.

Biodiversity level	Past research areas	Research gaps
Ecosystem	Forest: ecosystem functions, ecosystem services flow, ecosystem valuation	Ecological footprint, forest bio-economy, carbon flux between forests and air, researches on edge effects, Incentivizing effects on forest conservation, wetland ecosystem, rangeland ecosystem
	Transboundary landscape, interlinkage between migration and forest degradation	Assessment of landscape linkage/corridors, climate change and wildfire and their impacts
	Protected area conservation and management, evaluation, integrated conservation and development, environmental governance, ecotourism, community conservation linkage, diversity and priority conservation, significance of biodiversity, biodiversity assessment, in-situ and ex-situ conservation	Encroachment in protected areas, functional interaction between land cover and biodiversity, carrying capacity of protected areas
	Mangrove community forestry restoration, forest cover change, land use/land cover change, ecology of forest soil, carbon sequestration	Assessment of land use risk, effects of rising atmospheric CO_2 on forest ecosystem
	Indigenous agro-ecological knowledge, ethnic conflict in conservation, ecological ethics	Environmentally sensitive species, forest engineering, human-wildlife conflict
	Use of ecological modelling and geospatial tools	Forest monitoring/landscape change, regional scale vegetation mapping/biodiversity; transboundary perspectives; ecological informatics, abatement policies
	Ecological survey (i.e.: biodiversity hotspots, Eastern Himalayas, India, Namdapha National Park and Tiger Reserve, Hkakaborazi National Park)	Environmental Impact Assessment (EIA) and environmental auditing
	Freshwater: eco-hydrology, alluvial morphology, integrated river basin management, sediment flux, water quality assessment, mercury bioaccumulation, nutrient dynamics, benthic macroinvertebrate	Human-induced environmental gradient, species richness of invertebrate, contamination status of water bodies
	Agro: agro ecosystem function, agricultural intensification and mechanization, ecological agriculture, agriculture practices, shifting agriculture, ethnobotanical study of indigenous knowledge, conservation/potential of wild relatives of crops	commercialization of agriculture, gene pool, genetically modified crops and animals, threat to native species, bio-fertilizer, soil biodiversity, soil carbon and nitrogen dynamics
	Tundra: conservation of alpine ecosystem	Effects of global warming on terrestrial ecosystem, microbial community change
Species	Taxonomy, ecology and distribution (i.e. small carnivores, birds)	Population ecology
	Dendro-ecology, biodiversity characterization and regeneration	Phylogenetic pattern of species
	Ecology and habitat use of fauna	Species interaction/predator-prey interaction, resource competition of fauna, silviculture
	Diversity and conservation of flora and fauna (angiosperms, ant, tortoise, fish, amphibian etc.)	Interlinkage between species diversity and ecosystem function, diversity and ecology, checklist of Protozoa's, Coelenterates, Platyhelminthes, small mammals
	Checklist of birds, insects, fishes etc.	
	Rediscovery of insects and endangered plants, regeneration ecology of tree	Terrestrial invasive plants, pests and pathogens
	Illegal hunting and motivation, long-term monitoring, conservation plans for tiger and dolphin	Use of mathematical modelling in population ecology
	Microhabitat in soil, nutritional physiology of mammals, ethno-medico-botany	
Genetic	Diversity of micro-organisms and angiosperms	Genetic engineering, genetic pollution
	Genetic structure and analysis of flora/fauna	Genetic variation of native species, genetic response to environmental stress
	Molecular genetic method	Wildlife forensic

Table 3: International/regional environmental agreements, treaties and protocols ratified/accessioned by China, India & Myanmar.

Convention/Agreement	China	India	Myanmar
ASEAN Agreement on the Conservation of Nature and Natural Resources *(Regional)*	-	-	√
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	√	√	√
Cartagena Protocol on Biosafety to the CBD	√	√	√
Convention Concerning the Protection of the World Cultural and Natural Heritage	√	√	√
Convention on Biological Diversity	√	√	√
Convention on International Trade in Endangered Species of Wild Fauna	√	√	√
Convention on Migratory Species of Wild Animals	-	√	-
Convention on the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean	√	-	-
International Tropical Timber Agreement	√	-	√
Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management	√	-	-
Kyoto Protocol to the UNFCCC	√	√	√
Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity	√	√	√
Plant Protection Agreement for the Southeast Asia and the Pacific Region *(Regional)*	-	-	√
Ramsar Convention on Wetlands of International Importance	√	√	√
United Nations Convention to Combat Desertification	√	√	√
United Nations Framework Convention on Climate Change	√	√	√
Vienna Convention for the Protection of the Ozone Layer	√	√	√

wetlands and species diversity was carried out in India [131]. Myanmar has worked in partnership with CITES signatories including China, India, Thailand and Bangladesh to curb illegal wildlife trade in the international borders [132].

4. Conclusion

The FHL has been in the limelight for its rich diversity and for new species discoveries in recent years. The initiative taken towards transboundary cooperation and landscape approach by the three countries is timely and our review clearly indicates that the region is of interest to researchers and has the potential for effective conservation interventions. The initiative is also forward looking for the landscape as the three countries share contiguous habitats for many charismatic species. The rich biodiversity of the landscape is still largely intact and could be conserved and managed sustainably if there is greater cooperation among the countries.

At this point, species are the key focus of biodiversity research in this landscape, although many taxa do not even have inventories. The trend shows that Myanmar has the highest number of publications, with maximum focus on arthropods, whereas most research in China is on angiosperms and on mammals in India. The bibliometric study of biodiversity research exhibits a sudden and marked increase in publications from 1990 to 2017 after the three countries signed Multilateral Environmental Agreements and began implementing them. The major challenge is to address the gap of limited research on lower taxa of vertebrates and invertebrates with small geographical range. There are still major gaps in our understanding of habitat use by some of the charismatic species and the potential for conservation corridors to support viable populations. Studies in population ecology are yet to be initiated for most of the taxonomic groups. The study is an important contribution to the understanding of historical and contemporary research trends and gaps in the landscape and provides practitioners, policy makers, conservationists, wildlife managers, and biologists with directions for future biodiversity research, conservation planning, and management of the landscape.

Conflicts of Interest

No potential conflicts of interest were reported by the authors.

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