State of India's Bats

2024-2025

BAT CONSERVATION INTERNATIONAL

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The State of India's Bats (2024–2025) (SoIBats) is undoubtedly a monumental report: all projects of this magnitude and ambition are built by the hard work, passion, support, and enthusiasm of countless people. The entire report is a testimony to the contributions of the people named in the following paragraphs.

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This exhaustive report of two and a half years of painstaking effort is now out for everyone to make use of. Everyone involved in making this report a reality certainly hopes that it will leave an indelible impact on bat research and conservation in India in the coming decade.

Photo: Tikily Tayeng

Contents

Section IV.
Policy and Public Engagement
112

Section V.
Research and Conservation Priorities
158

Appendices
191

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Foreword I

When I sat to put down on paper the rough outline of what it would take to write a field guide to the mammals of India around the dawn of this millennium, three categories of animals troubled me. My lack of any real knowledge on bats, rodents, and insectivores was daunting. Bats, for example, were more than a quarter of all living Indian mammals. And rodents represented another quarter. Should I attempt to write about a subject of which half of them were fuzzy in my understanding? It took me some time to muster courage to attempt the first volume – although I took care to render it in my manuscript in three colours: red for those species where my sources were historical or old, blue where I had some recent research that I believed in and a researcher I could talk to, and black where I personally had access to that knowledge. Bats were almost uniformly in red with only Bates and Harrison's *Bats of the Indian Subcontinent* and a 2002 *Status of South Asian Chiroptera* report from a Zoo Outreach Organisation (ZOO) workshop to guide me. I was worried but went ahead. I need not have been as clearly there were not many people who knew Indian bats to any great extent, as time has shown me.

Since I wrote the first version of my field guide for Dorling Kindersley, at least 15 more bat species have been added to the Indian species list and some more taken out of the list due to misidentification or splitting of species. The scourge of the SARS-CoV-2, Nipah, and Ebola viruses has heightened the fear of bats and spawned a hundred different misconceptions about them. As these increased, so too did information on bats. A species supposed to be only confined to one cave in central India has been found in the north east several hundred kilometres away. And a new cadre of batty researchers and conservationists has started to emerge.

I met some of them in Bengaluru as they were gearing up for a great challenge of putting together this pioneering volume of the *State of India's Bats*. Reading it now, I am amazed at what the authors refer to as the understanding of 30 odd bat researchers on the 130 odd species that exist in India and indeed the myriad gaps in knowledge that exist. Following roughly the format of *State of India's Birds*, to which my organisation was also a partner, I find this volume to be prescient in the annals of Indian conservation. It is reassuring at first glance to know that only seven bat species are threatened (with only one critically endangered, five endangered, and one vulnerable). Does this mean that we know enough about all bats and protect them well? Go through the remaining sections, and one realises that the data is deficient for most species. Populations, unlike in larger vertebrates, are not understood for almost all bats. Similarly, the fact that bats don't fall in the threatened category does not seem to have been due to any targeted conservation measure but by their own sheer resilience. A lacuna of this report, if I could find one, is the lack of a chapter on conservation. Is it that absolutely nothing has been done or has what negligible little had been done, fallen through the cracks of this eminent brainstorming?

The volume makes me think and worry about bats. Of the 16 endemic bats of India, most are in the threatened category or the data deficient category. These, at least, must have the urgent attention of the government, academic institutions, and civil society. The volume lists where bats really live. These include forts and temples, caves and large tree hollows, monuments and drainpipes, none of which form a part of India's protected area network that is designed to conserve biodiversity but excludes bats. In fact, in many of them, authorities eradicate bats chemically and manually to avoid the despoiling of cultural treasures and to render a hygienic and sterile experience for tourists. There has to be a way that is both tourist-friendly and bat-friendly!

I congratulate the team of bat researchers who have authored this important volume. I hope, however, that they will come together a little earlier than in a decade to produce a new volume. Bat species are being discovered or taxonomically split each year. Manifold threats also increase annually. Hopefully, policy and conservation changes will match them. But an academic exercise that is not more immediate, seems to go against the need for biodiversity conservation. May the best minds think and make the best decisions for bats, these many-splendoured and misunderstood mammals of our wonderful country.

Vivek Menon, FLS
Founder and Executive Director, Wildlife Trust of India (WTI) | Chair, International Union for the Conservation of Nature (IUCN) | Species Survival Commission (SSC)

Foreword II

Throughout the COVID-19 pandemic years, we had all become accustomed to online meetings, navigating across time zones, and coordinating mainly via e-mails. As such, it was even more special to gather for a few days as a group of like-minded professionals, marking the first time in two decades that India's leading and upcoming bat biologists and managers came together in 2024 in Bangalore to discuss the state of India's bats. The in-person workshop was a success from the start, as different working groups and colleagues met enthusiastically. My role as main facilitator was made easy by the high level of engagement and commitment all participants exhibited throughout the workshop – even when activities ended up taking longer than anticipated. It was truly remarkable to witness all the authors and contributors collaborate to produce this report, a first of its kind for the Indian context.

While gathering all available information on Indian bats from across various topics, we came to realise how much was still unknown: from taxonomic clarification and the ecology and behaviour of most Indian bat species to the lack of knowledge on how the modern world affects bat populations. Identifying these critical knowledge gaps has been a crucial and productive outcome of compiling the report – it has set the foundation for a collaborative approach to protecting Indian bats nationwide.

As one of the fastest growing economies worldwide, India is a global forerunner for development. As seen in many different places before, this rapid development comes with a further decrease in natural habitat and the loss of important resources for bats. Connection and collaboration between stakeholders working in the bats' best interest has never been as important as it is today. In assessing the state of India's bats during the many online meetings and day-long workshops, frequent discussions, reviews, and much exchange of experience have formed the basis for a strong nation-wide network of stakeholders consisting of bat experts, managers, and academics. Amid an ever-changing environment, a national network of this calibre will be able to address the identified knowledge gaps, forward the public understanding of bats, and advocate for them in policymaking. In the 21st century, collaborations such as this are more needed than ever before: advancing scientific knowledge and supporting conservation-based decision-making is critical to protect the natural world, including the ecosystems services that bats provide.

The past years have laid the foundations for a bright future for India's bats, for a united front to protect some of the most undervalued animals on the planet!

Dr Isabella Mandl
Regional Director (South Asia & Africa), Endangered Species Intervention, Bat Conservation International (BCI)

Foreword III

The State of India's Bats is a remarkable achievement for many reasons, standing unique as the only assessment of its kind for any mammal group in the country. It is the result of a massive collaborative effort by an amazing group of 33 bat ecologists and conservationists. Through more than 15 online meetings and a two-day workshop, they have charted a roadmap for research and conservation of India's common, rare, and threatened species alike.

It has taken the team of 34 researchers representing 27 academic institutions, nearly two years to synthesise all available knowledge into 16 chapters. The resulting report covers every aspect of bat ecology and conservation in India, creating an invaluable resource for decades to come.

My role as a mentor was made easy by their dedication. Coordinating such a large group from multiple institutions is a complex challenge, often likened to herding cats. Therefore, I offer my special congratulations to the leadership of this initiative for making the process inclusive, transparent, and efficient. I am certain the team grew in both capacity and confidence during this journey.

Historically, bats have not been at the forefront of conservation priorities in India. This report changes that trajectory through a science-led effort to highlight crucial knowledge gaps. It is a treasure trove of information, covering a vast range of topics: from taxonomy, population monitoring, and disease ecology to ecosystem services, policy, and the human dimensions of bat conservation. Most importantly, it provides a critical assessment of the threats these animals face.

Earlier this year, Uttam Saikia and colleagues described a new species of bat, *Myotis himalaicus*, from the western Himalayas. The description of a new mammal species in the 21st century indicates two things: the significant gaps that still exist in our understanding of these fascinating creatures and the gathering momentum of interest in addressing their conservation challenges.

I am hopeful that *The State of India's Bats* will herald a new era of renewed interest in the research and conservation of these magnificent, but unsung, animals.

Dr Kulbhushansingh Suryawanshi
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Executive Summary

Spread across a staggering land area of 3.3 million km2, India is home to 1.43 billion people and a remarkably vast diversity of wildlife. With 135 species currently described, bats form the largest order of mammals in the country. Despite their crucial roles in the ecosystem as seed dispersers, pollinators, and predators of pest insects, bats receive an insignificant amount of attention from the country's research and conservation communities and scant recognition in government policies and programs. Less than 50 dedicated bat researchers can be found throughout India, each trying to study and conserve these misunderstood animals with limited resources and support when compared to those available for the preservation and study of more charismatic animals. Exacerbating these challenges are the burgeoning threats bats face from human population growth and migration, expanding urbanisation and land-use change, human-bat conflict, and the widespread effects of climate change. Amidst this complex social and ecological backdrop, the central question emerges: how do we shape bat conservation in India to benefit bats, humans, and the ecosystems that they share? The State of India's Bats (SoIBats) project was launched to collectively tackle this question and to make huge leaps forward in bat conservation.

SoIBats is a flagship project of the partnership between Nature Conservation Foundation (NCF) and Bat Conservation International (BCI). The project aimed to bring bat experts together to review our current state of knowledge of Indian bats, to assess threats to these taxa, and to identify opportunities for future research and conservation actions - in effect, charting a roadmap for bat research and conservation in India for the next decade.

In total, 36 chiropterologists and speleologists representing 27 institutions contributed to this project, leading to the development of this report. Participants were divided into four working groups to panoramically cover the various facets of bat research and conservation: 1. Taxonomy, Systematics, and Monitoring, 2. Ecology and Biology, 3. Ecosystem Services, and 4. Policy and Public Engagement. Irrespective of their working groups, SoIBats participants also identified and assessed the threats faced by different bat species across the country. The project was undertaken through a combination of interactive virtual and in-person workshops and an online survey.

The **Taxonomy, Systematics, and Monitoring** section **(Section I)** of the report offers a comprehensive overview of the taxonomic diversity and endemism of Indian bats. This section provides an updated checklist of India's 135 species of bats, of which 16 are endemic to the country. The value of the vanishing natural ecosystems of West Bengal, Meghalaya, and Uttarakhand are highlighted in their supporting the highest bat diversity in the country. On the other hand, Punjab and Haryana have only five recorded bat species, underscoring the need for more surveys and expanded conservation of existing habitats in these regions (Chapter 1). This section also draws attention to several key challenges for the practice of taxonomy and systematics, such as the paucity of taxonomic training and capacity, the lack of importance given to taxonomy as a discipline, challenges in accessing type specimens housed in Western museums, and the poor integration of morphology, anatomy, and genetics in taxonomic and systematic research (Chapter 2). Participants emphasised the need for collaborations to improve taxonomic knowledge, to scale up surveys, and to initiate improved monitoring of data deficient and threatened bat species (Chapter 3 and 4).

The **Ecology and Biology** section **(Section II)** is sub-divided into five topical chapters: diet (Chapter 5), habitat use (Chapter 6), movement ecology (Chapter 7), disease ecology (Chapter 8), and toxicology (Chapter 9). Each of these thematic chapters reviews the current state of knowledge, key challenges, and priority opportunities for the respective field of study. A systematic literature review revealed that, until recently, the ecology and biology of Indian bats was inferred from sporadic natural history observations, fundamental baseline data are rarely available and only at a broad resolution when they exist, and there are clear temporal and geographic biases in ecological and biological research on bats in India. In Chapters 5-7, the authors recommend prioritising studies on threatened and data deficient species since diet, habitat use, and movement data are fundamental in designing conservation plans. A key recommendation from Chapter 8 includes leveraging the growing interest in One Health to forge interdisciplinary collaborations to study the interconnections between human-bat interactions, climate change, extreme weather events, and zoonotic disease ecology for better disease outbreak preparedness. The newly emerging field of toxicology (Chapter 9) in India would benefit from nationwide monitoring programs for select bat species (e.g., those that are widespread or partial to aquatic ecosystems), the establishment of toxicity thresholds for various species, and the investigation of heavy metal exposure, especially in cave-dwelling bats. All chapters in this section stress the critical importance of building capacity, developing standardised sampling protocols, initiating long-term studies, collecting fundamental, baseline data, and focusing on understudied taxa and regions to expand application-based research on bats throughout India not only to better understand these remarkable species but also to inform effective conservation strategies for their protection.

The standalone chapter in Section III on **Ecosystem Services** (Chapter 10) acts as a bridge between the **Ecology and Biology** section **(Section II)** and the section on **Policy and Public Engagement (Section IV)** because it combines the ecological functions of bats with their importance to human culture, society, and economy. The authors review the importance of bats through their provision of "regulating services" (e.g., pollination, seed dispersal, insect pest control), "supporting services" (e.g., nutrient cycling in forests and cave ecosystems), "cultural services" (e.g., as literary symbols and components of traditional tribal practices), and "provisioning services" (e.g., use as meat and medicine, use of their guano as fertiliser). Although over 25 Indian bat species were identified as providing some or all of these types of benefits to human and ecological communities, limited quantification of these ecosystem services prevents their effective use in education and conservation marketing to change people's negative perceptions of bats and to engender support for policies in favour of bats. Interdisciplinary collaborations between ecologists and economists are a pressing need towards this end.

After focusing on the natural science fields that support bat conservation, the report then shifts focus to efforts grounded in the social sciences and humanities. The **Policy and Public Engagement section (Section IV)** aims to make readers aware of the existing government policies and initiatives for protecting Indian bats (Chapter 11), the Human Dimensions of bats and their conservation in India (Chapter 14), and evolving methods for collaborating with members of the public, the media, and other stakeholder groups to promote pro-bat education, outreach, and integrated science (Chapters 11-14). For the first time in India, chiropterologists have comprehensively identified the entire spectrum of stakeholders related to bat research and conservation, including governmental, nongovernmental, academic, private sector, and community actors (Chapter 12). Through inclusive, ethical, and respectful collaboration with these diverse stakeholders, bat researchers and conservationists can: 1. improve and expand holistic research on bats, 2. support the drafting and implementation of policies that conserve and responsibly manage Indian bats, and 3. mitigate human-bat conflicts while promoting human-bat coexistence from the community to the national levels (Chapters 11-14).

The final section of this report **(Section V)** delves into the threats faced by Indian bats, the potential drivers of those threats, and the effects of these threats on bat individuals, populations, and species (Chapter 15). The primary threats affecting all bat species are anthropogenic, such as poorly planned urban expansion, disturbance from recreational and national security activities, resource extraction, and shifts in fire and water management. Climate change, including a corresponding increase in the frequency of extreme weather events, was rated as the most common future threat across biodiversity hotspots and threatened species. Addressing these threats, Chapter 16 presents the top ten research and conservation action priorities collectively ranked by SoIBats participants. These priorities target both the fundamental requirements for enabling successful bat research and the major threats affecting Indian bats now and into the future. For example, among the research priorities, enhancing taxonomic knowledge, building comprehensive call libraries, and developing genomic resources were identified as tasks that will greatly amplify research and conservation outcomes. Among the conservation priorities, conducting International Union for Conservation of Nature (IUCN) Red List of Threatened Species assessments of Indian bats and building a network of conservation stakeholders will support bat conservation efforts.

In summary, the SoIBats report is an exhaustive treatise providing invaluable guidance on advancing conservation of these misunderstood animals. The data, perspectives, and recommendations contained herein provide an overview of the most pressing challenges and opportunities facing Indian chiropterology, which are useful not only for bat researchers and conservationists but also, more broadly, for funding agencies, wildlife and natural resource managers, policymakers, and other decision-makers. The preparation of this report has also united contemporary Indian bat researchers like no former initiative has. In alignment with the objectives outlined in this SOIBats report, we, as a collective, will continue to advance Indian bat research and conservation as a model for bat conservation efforts worldwide.

Preface

Author: Priya Hazra

Bats represent one of the most diverse and ecologically important groups of mammals. They are the only mammals capable of true flight, which enables them to disperse widely[1]. Bats exhibit several unique traits: despite their high metabolic rate, they have remarkably prolonged lifespans when compared with other mammals of similar body size, possess exceptional disease tolerance, have evolved specialised morphological adaptations for resource utilisation, and, in the case of insectivorous species, possess echolocation[1]. They have diverse feeding habits, consuming a wide range of food items, including fruit, pollen, nectar, flowers, leaves, invertebrates, blood, small mammals, and even fish[1]. With 1,500 species worldwide, bats comprise nearly 20% of all mammal species[2]. India is home to 135 bat species[3][4][5], making this the most diverse mammalian group in the country (Chapter 1). Until 2022, most bat species in India were classified as "vermin" under the Wild Life (Protection) Act, 1972 (WLPA). Over time, only 12 bat species were upgraded to Schedules I and II[6]. Currently, seven bat species are listed under a threatened category by the International Union for Conservation of Nature (IUCN) on the Red List of Threatened Species, while 35 species are either data deficient or have not yet been assessed[4][5].

Bats provide crucial ecosystem services, including controlling insect populations, pollinating plants, dispersing seeds, and introducing key nutrients to soil via their guano[7][8][9]. Some bat species are also reservoirs for zoonotic viruses, including the Hendra virus, Nipah virus, and severe acute respiratory syndrome (SARS)-associated coronaviruses[10], some of which cause serious illnesses in humans and other animals[11]. The increasing frequency of human–bat interactions, driven by habitat destruction and land-use changes, create opportunities for pathogen spillovers[10].

While bats are the most diverse group of mammals in India, they remain understudied due to multiple challenges, such as their nocturnal and elusive nature, the limited number of subject experts, and the lack of comprehensive natural history, ecological, and molecular knowledge. Bureaucratic hurdles in obtaining research permits, societal stigma (especially after the COVID-19 pandemic), and the high cost of advanced research tools has further hindered studies on bats in the country. Rapid land-use and environmental changes in India (e.g., climate change and the conversion of forested landscape to agricultural land) along with conflicts over the usage of old buildings and archaeological sites for bat roosts necessitate a better, more holistic understanding of bat ecology and conservation.

The conservation community in India has largely focused on charismatic megafauna, while bats are often misunderstood, feared, and perceived as evil creatures of the night[12][13][14]. Although bats have received limited research and conservation attention in India, several notable initiatives are worth mentioning. Following the Conservation Assessment and Management Plan (C.A.M.P.) Workshop for Indian Mammals in 1997, the Chiroptera Conservation and Information Network of South Asia was founded by a group of academics and conservationists dedicate to the study and protection of bats. The 2002 Status of South Asian Chiroptera C.A.M.P. workshop was a first of its kind and assessed 120 bat species based on the expertise of 43 chiropterologists from across South Asia[15]. The workshop addressed substantial data deficiencies and created a robust network of bat specialists. It also helped to create more effective strategies to protect vulnerable bat species in India, including lobbying for enhanced protection of bats under the WLPA. In 2020, the COVID-19 pandemic significantly escalated myths regarding bats and bat-borne viruses. Amidst growing concerns, Indian bat researchers were once again united and developed a bat information campaign in multiple languages to dispel myths and to highlight the importance of bats to the ecosystem and the economy. Riding on this momentum, in 2024, the Nature Conservation Foundation and Bat Conservation International initiated the State of India's Bats (2024–2025) project to unite national bat experts and to chart the way forward for research and collaboration.

The objectives of the State of India's Bats (2024–2025) project included:

- Convening experts in the fields of chiropterology and speleology to critically assess the advancements in bat research and management since the publication of the 2002 Status of South Asian Chiroptera C.A.M.P. workshop report;
- Identifying and fully elucidating critical knowledge gaps, challenges, opportunities for improvement, and immediate needs to guide bat research and conservation planning;
- Establishing and widely communicating bat research and conservation priorities for India; and
- Fostering and expanding a transdisciplinary network of chiropterologists, speleologists, and other experts to collaboratively support integrated and adaptive research and conservation of bats across India.

State of India's Bats (2024–2025) Methods

Author: Bonnie E. Gulas-Wroblewski

Design and Facilitation

The State of India's Bats (2024–2025) process was designed and implemented by a core planning team from the Nature Conservation Foundation and Bat Conservation International (Table 1) to be an equitable and collaborative participatory process to fulfil the key objectives detailed above in Background.

Table 1. State of India's Bats (2024–2025) core planning team members.

Member	Affiliation
Rohit Chakravarty	Nature Conservation Foundation; Bat Conservation International
Bonnie E. Gulas-Wroblewski	Independent
Priya Hazra	Nature Conservation Foundation
Isabella Mandl	Bat Conservation International
Muhammedmaaz Mukardamwala	Nature Conservation Foundation

Neutral facilitation was provided by Dr Bonnie E. Gulas-Wroblewski and was guided by the principles within the International Union for Conservation of Nature (IUCN) Species Survival Commission (SSC) Conservation Planning Working Group's Species Conservation Planning Principles and Steps (Table 2)[16].

Table 2. Guiding principles for the State of India's Bats (2024–2025) project[16].

Principle	Description
Plan to Act	The underlying objective of planning was to support effective action to promote bat research and conservation in the future.
Promote Inclusive Participation	Not only were a diversity of participants integrated into the process, but their contributions were also incorporated, respected, and valued throughout.
Use Sound Science	The best available science informed decision-making throughout the process and was used to collate, analyse, and assess information contained herein.
Ensure Good Design and Neutral Facilitation	This process was designed in a structured way to conscientiously support participants and effectively produce implementable results that represent a diversity of views and the best available science. Neutral, third-party facilitation was used to safeguard against actual and perceived bias and to ensure participants could share their thoughts and ideas freely and equally throughout the process.
Reach Decisions Through Consensus	Key decision-making was reached through consensus of contributors to ensure the results reflected all perspectives and, therefore, secured approval and backing from all participants.
Generate Shared Products Quickly	The various products of the process were shared freely and widely in a timely manner in order to sustain the project's momentum.
Adapt to Changing Circumstances	The process incorporated the most recent, available information and strived to reflect the complex, constantly-changing nature of the social-ecological systems to which it applies. The recommendations herein should be considered within the context that they were written and are intended to be continuously reviewed, adapted, and improved to fit changing conditions.

Participants were conscientiously selected to equitably and comprehensively represent a broad variety of career stages (e.g., early, mid-, to late), institutional affiliations, backgrounds, ages, gender, and fields of expertise as well as experience in and knowledge of geographic regions, habitat types, bat taxa, and threats to bats across India. Initially, 36 chiropterologists and speleologists were invited to an inaugural online meeting for the State of India's Bats (2024–2025) project held on April 9, 2024. Of these 36 invitees, 28 experts actively contributed to one or more participatory workshops to support the development of this report (Appendix 1), the details of which are described below.

Process Overview

The process guiding the development of the *State of India's Bats (2024–2025)* report was divided into the following facilitated activities:

- An inaugural online meeting to introduce the process and to provide participants with the opportunity to shape the format and content of the subsequent online workshops.
- Four online workshops (one for each thematic working group) between May 14 and 18, 2024 to evaluate key knowledge gaps, challenges, and opportunities for each field of bat research and practice.
- An in-person workshop in Bengaluru, India from June 17-18, 2024 to collaboratively design the *State of India's Bats (2024–2025)* report and to collectively identify and prioritise bat-related research and conservation actions.
- Post-workshop online meetings of the working groups to support and advance the compilation and composition of this report.
- An online Threats Mapping survey to identify, critically assess, and detail the significant threats affecting bats throughout India.
- Four online workshops (one for each biodiversity hotspot) between January 25 and February 26, 2025 to cooperatively collect and synthesise information pertaining to threats to bats in each region as well as the drivers of these threats, the specific impacts of these threats on bats, and the cause-and-effect linkages between these factors.

Inaugural Meeting

Fifteen invitees and all members of the core planning team attended a 1.5-hour kick-off meeting for the State of India's Bats (2024–2025) project on April 9, 2024. The virtual session provided an opportunity for participants to meet one another and for the planning team to outline the main justification for and objectives of the project within a proposed timeline. The latter half of the meeting was a facilitated, interactive session during which attendees discussed whether the working groups developed to support the project's outputs (i.e., report, peer-reviewed paper, outreach materials) should be organised on the basis of thematic topics, bat taxa, and/or geographic regions in India. Consensus was reached that the focal topics "Ecology and Biology", "Ecosystem Services", "Policy and Public Engagement", and "Taxonomy, Systematics, and Monitoring" would comprehensively encompass the current breadth of natural and social scientific understanding of bats in India and, therefore, should form the project's four distinct working groups. It was agreed that some degree of overlap in topics would inescapably exist within each of these thematic categories, but that oversight by the core planning team and participants who engaged in multiple groups would ensure there was no duplication of efforts between the various outputs of each working group.

Pre-meeting Online Workshops

Following the inaugural meeting of April 9th, all invitees to the State of India's Bats project had the opportunity to signup for any working group in which they were interested and to which they could contribute based on their time and expertise. Membership was not restricted, so people were welcome to join more than one working group. After initial membership was confirmed, each thematic working group engaged in a 2-hour participatory online workshop to compile information and to collaboratively plan for presentations at the in-person State of India's Bats (2024–2025) workshop in Bengaluru, India. Eight members of the Policy and Public Engagement

Working Group (PPE WG) met on May 14, 2024; five members of the Ecosystem Services Working Group (ES WG) met on May 17, 2024; nine members of the Taxonomy, Systematics, and Monitoring Working Group (TSM WG) met on May 18, 2024; and nine members of the Ecology and Biology Working Group (E&B WG) met on May 18, 2024 (Appendix 1).

Each working group online session was divided into three main facilitated exercises:

1. Brainstorming "Knowledge Gaps" or "Opportunities for Improvement".
The ES WG, TSM WG, and E&B WG were prompted to consider the key knowledge gaps related to their fields of study in relation to bats in India. Members of the PPE WG were instructed to consider any opportunities for improvement to current bat-related policy and/or public engagement initiatives in India since this concept was better aligned with their focal theme than "knowledge gaps." Using a Miro virtual whiteboard, participants were asked to anonymously write down any ideas that they had pertaining to this topic. After group members had completed the task, they were invited during an open discussion to ask for clarification or to share any feedback or additional thoughts they had related to the points outlined on the board.

2. Brainstorming "Challenges".
Following the same steps as described above, all working groups used the Miro board to critically assess the topic of "Challenges" as it related to their bat-focused research and practice in India. Participants were asked to address not only logistical challenges they faced in their work but also any environmental, cultural, or other types of obstacles that hindered or prevented them (or their colleagues) from achieving their desired objectives and activities.

3. Planning for working group presentations at the State of India's Bats (2024–2025) workshop in Bengaluru.
In order to facilitate data collection and synthesis to inform decision-making during the in-person State of India's Bats (2024–2025) workshop in June 2024, working group members outlined the most significant topics within each of their thematic areas. These points were used to populate a shared "data collection" document to which group members added detailed information, case studies, and supporting citations to inform their workshop presentations as well as their subsequent chapters in this report. Participants were instructed to concentrate on the current state of knowledge in relation to these points, specifically any advancements in the field since the publication of the 2002 Status of South Asian Chiroptera Conservation Assessment and Management Plan (C.A.M.P.) workshop report[15]. During this planning exercise, participants also volunteered to build and lead the working group presentations for the Bengaluru workshop.

The information related to advancements in the field, knowledge gaps, opportunities for improvement, and challenges that was collectively generated through these participatory activities served as the foundation for the identification, definition, and prioritisation of research needs and conservation interventions during the State of India's Bats (2024–2025) workshop in Bengaluru. These points were further incorporated into the chapters of this report as highlighted in the various discussions of opportunities and challenges for each focal chapter.

State of India's Bats (2024–2025) Workshop

The Nature Conservation Foundation, Bat Conservation International, and National Centre for Biological Sciences hosted the State of India's Bats (2024–2025) Workshop from June 17-18, 2024 in Bengaluru, India. Twenty-seven members of the State of India's Bats project actively participated in the facilitated activities, with one person only able to attend the first day of the workshop and two participants joining online via hybrid sessions (Appendix 1). Two meeting participants were invited to the workshop by colleagues and continued to contribute to working group outputs following the in-person workshop.

The primary objectives of the in-person workshop were:

- Develop, finalise, and accept an organisational strategy for the State of India's Bats (2024–2025) report;
- Outline and agree on how each thematic working group would contribute to the final report;
- Identify any additional stakeholders that should be integrated into the process to produce a high-quality and implementable report;

- Compile a list of research and conservation action priorities for bats in India; and
- Foster a supportive, collaborative, and motivated community of bat professionals to magnify dynamic bat research and conservation efforts across India.

Attendees participated in facilitated exercises both as a full team and broken into smaller thematic working groups (the same pre-meeting thematic working groups described above). Workshop participants had the opportunity to contribute to one working group throughout the entire workshop or to switch between working groups for different activities. Neutral facilitation was provided by Dr Isabella Mandl who was assisted by Mahalakshmi Chelladurai, Priya Hazra, Sreejith Jayakumar, Kunapareddy Kezia, Arjun Menon, Muhammedmaaz Mukardamwala, Darshan S, and Tikily Tayeng. Facilitation was guided by a plan developed by the core planning team (Table 1).

On the first day of the meeting (June 17, 2024), each working group shared a presentation that focused on: 1. a general overview of the state of bat knowledge in their respective field(s), 2. a review of the most significant developments to that base of knowledge since 2002, 3. important knowledge gaps identified during their pre-meeting online workshop, 4. the main challenges that researchers and practitioners face in their field(s), and 5. any fundamental, apposite points not encompassed by topics 1 through 4. Based on this information and with reference to the design of similar scientific reports (i.e., *State of India's Birds 2023*[17]), attendees spent the remainder of Day 1 collectively outlining the desired content of the *State of India's Bats (2024–2025)* report, delineating for which material each working group would be responsible, and organising these topics into a cohesive report structure.

During the first half of the second day of the workshop (June 18), working group members focused on developing and finalising strategies for researching and drafting their respective report sections. Each team agreed on tasks and a specific timeline to guide their subsequent outputs for the report. After these plans were accepted by the full group's consensus, Dr. Sanjay Molur presented on the undertaking of a multistakeholder One Plan Approach[18] to develop a conservation action plan for the bats of India. Dr Molur's presentation and the ensuing group discussion served as the basis for the stakeholder mapping exercise underlying Chapter 12 and also provided context for the wider implications of the State of India's Bats (2024–2025) project. Namely, the multidisciplinary work of this team would not only lay the foundation for the collaboration of a more diverse stakeholder group but also compile, generate, and synthesise vital data, knowledge gaps, and priorities to inform any future national conservation action plan for bats.

The Bengaluru workshop concluded with working group members brainstorming and critiquing research needs and conservation activities that could benefit the bats of India, reflecting on:

- Their own experience,
- The information from Day 1's working group presentations, and
- Discussions about the knowledge gaps, opportunities for improvement, and challenges during the pre-meeting online workshops.

Each working group provided a list of the ten research ideas and the ten conservation activities that they considered the most important to pursue in the future based on the criteria:

- Is realistically achievable based on the current capacity of the State of India's Bats team,
- Is feasible (e.g., in light of logistical limitations related to technology, funding, and other resources),
- Effectually addresses key knowledge gaps, opportunities for improvement, and/or challenges that have already been identified,
- Serves as a foundation for other research and/or conservation activities (i.e., accomplishing this priority is necessary to start other research or conservation activities),
- Is urgent or time-sensitive,
- Holds interest for other stakeholder groups (e.g., policy- and decision-makers, funders, community members), and
- Has value in the training it can provide to students, new researchers, field or lab assistants, and others seeking to study and conserve bats.

These working group lists were then amalgamated and presented to the full State of India's Bats team to employ the "How-Now-Wow" voting technique (see Chapter 16 for more details about this method). In this manner, participants collectively ranked the top ten research and the top ten conservation action priorities for the State of India's Bats group overall. The results of this structured assessment of bat research ideas and conservation interventions are presented in Chapter 16 and Appendix 4.

Post-workshop Working Group Meetings

The E&B WG held monthly meetings starting directly after the workshop and lasting until the completion of the initial draft of their report section in December 2024. Although meetings were less frequent, the PPE WG and ES WG also met regularly throughout the months following the workshop until their report drafts were completed. These working group meetings served to provide updates and feedback for in-progress chapters drafts as well as to refine and reassign writing tasks and focal topics as the need arose. The TSM WG chose to complete their chapters via shared Google documents and direct online communications. During these working group discussions, authorship order was defined for each individual chapter by all contributing authors.

Threats Mapping Exercises

Although threats to bats were addressed to varying degrees by the thematic chapters of the *State of India's Bats (2024–2025)* report, a systematic and comprehensive characterisation of well-defined factors and processes that have indirect and direct adverse effects on bats at the individual, population, and species levels was essential to:

1. Qualitatively and quantitatively demarcate causal relationships among drivers, threats, and the effects of threats on bats in India,
2. Investigate trends and other patterns in threats to bats as they relate to bat taxonomy, behaviour, habitat use, conservation status, and biogeographic distribution, and
3. Evaluate critical knowledge gaps and other limitations in our understanding of the threats impacting bats across India.

An improved understanding of these points can facilitate:

4. Better informed and more targeted research into the unknowns related to threats, their causes, and/or their effects on bats,
5. The design, implementation, and adaptation of more effective and sustainable bat conservation interventions (Appendix 5), and
6. The identification of more suitable indicators to evaluate bat conservation actions and policies.

To this end, the core planning team (Table 1) conducted a "Threats Mapping Survey" and four 3- to 4-hour virtual threats mapping workshops to voluntarily elicit threats-related information from State of India's Bats project members. A detailed description of the processes guiding these threat assessment activities is provided in Chapter 15. A summary analysis of the information and conclusions from the survey and four virtual workshops are available in Chapter 15 and Appendices 5-7.

Peer Review Process

Following an initial editorial review by the State of India's Bats (2024–2025) core planning team members (Table 1), the entire State of India's Bats group was invited to provide peer review comments on the resulting draft of the complete report. Concurrently, Chapters 1-16 were each critically reviewed by at least one recognised expert in the related field or specific topic, all of whom were external to and independent from the State of India's Bats process. The subsequent internal and external peer review comments were addressed by the State of India's Bats (2024–2025) core planning team members (Table 1) and the relevant chapter authors as appropriate. Drs Rohit Chakravarty, Bonnie Gulas-Wroblewski, and Isabella Mandl were responsible for final editorial decisions.

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Section I.

Taxonomy, Systematics, and Monitoring

The Taxonomy, Systematics, and Monitoring Working Group members listed below contributed to the following chapters through conceptual design, critical content review, and providing additional data and perspectives:

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Greater Short-nosed Fruit Bat *(Cynopterus sphinx)* harem.
Photo: Rajesh Puttaswamaiah

Chapter 1
Status of Taxonomy of Indian Bats

Authors: Chelmala Srinivasulu, Uttam Saikia, Bhargavi Srinivasulu, and Aditya Srinivasulu

Diversity of Indian Bats

India is home to a rich diversity of chiropteran fauna, with 135 species of bats belonging to nine families (See Table 1.1)[1][2][3]. This remarkable diversity underscores the critical importance of robust taxonomic and systematic studies in the field of bat conservation. As we delve into the status of bat taxonomy in India, it is essential to recognise this discipline's pivotal role in shaping our understanding and protection of these often-misunderstood creatures.

Table 1.1 List of bat species in India grouped according to family.

Family Pteropodidae	
Greater Short-nosed Fruit Bat	*Cynopterus sphinx* (Vahl, 1797)
Lesser Short-nosed Fruit Bat	*Cynopterus brachyotis* (Müller, 1838)
Lesser Dawn Bat	*Eonycteris spelaea* (Dobson, 1871)
Salim Ali's Fruit Bat	*Latidens salimalii* Thonglongya, 1972
Greater Long-nosed Fruit Bat	*Macroglossus sobrinus* K. Andersen, 1911
Ratanaworabhan's Fruit Bat	*Megaerops niphanae* Yenbutra & Fenten, 1983
Indian Flying Fox	*Pteropus medius* Temminck, 1825
Variable Flying Fox	*Pteropus hypomelanus* Temminck, 1853
Black-eared Flying Fox	*Pteropus melanotus* Blyth, 1863
Nicobar Flying Fox	*Pteropus faunulus* Miller, 1902
Leschenault's Rousette	*Rousettus leschenaultii* (Desmarest, 1820)
Blanford's Fruit Bat	*Sphaerias blanfordi* (Thomas, 1891)

Family Rhinolophidae	
Greater Horseshoe Bat	*Rhinolophus ferrumequinum* (Schreber, 1774)
Lesser Horseshoe Bat	*Rhinolophus hipposideros* (Borkhausen, 1797)
Intermediate Horseshoe Bat	*Rhinolophus affinis* Horsfield, 1823
Least Horseshoe Bat	*Rhinolophus pusillus* Temminck, 1834
Trefoil Horseshoe Bat	*Rhinolophus trifoliatus* Temminck, 1834
Northern Woolly Horseshoe Bat	*Rhinolophus perniger* Temminck, 1843
Greater Japanese Horseshoe Bat	*Rhinolophus nippon* Temminck, 1835
Lesser Rufous Horseshoe Bat	*Rhinolophus rouxii* Temminck, 1835
Blyth's Horseshoe Bat	*Rhinolophus lepidus* Blyth, 1844
Big-eared Horseshoe Bat	*Rhinolophus macrotis* Blyth, 1844
Mitred Horseshoe Bat	*Rhinolophus mitratus* Blyth, 1844
Little Nepalese Horseshoe Bat	*Rhinolophus subbadius* Blyth, 1844
Pearson's Horseshoe Bat	*Rhinolophus pearsonii* Horsfield, 1851
Homfray's Horseshoe Bat	*Rhinolophus andamanensis* Dobson, 1872
Dobson's Horseshoe Bat	*Rhinolophus yunanensis* Dobson, 1872
Beddome's Horseshoe Bat	*Rhinolophus beddomei* K. Andersen, 1905

Family Rhinolophidae, continued	
Chinese Horseshoe Bat	*Rhinolophus sinicus* K. Andersen, 1905
Andaman Horseshoe Bat	*Rhinolophus cognatus* K. Andersen, 1906
Shortridge's Horseshoe Bat	*Rhinolophus shortridgei* K. Andersen, 1918

Family Hipposideridae	
Geoffroy's Trident Leaf-nosed Bat	*Asellia tridens* (E. Geoffroy, 1813)
East Asian Tail-less Leaf-nosed Bat	*Coelops frithii* Blyth, 1848
Schneider's Leaf-nosed Bat	*Hipposideros speoris* (Schneider, 1800)
Diadem Leaf-nosed Bat	*Hipposideros diadema* (E. Geoffroy, 1813)
Great Leaf-nosed Bat	*Hipposideros armiger* (Hodgson, 1835)
Fulvus Leaf-nosed Bat	*Hipposideros fulvus* Gray, 1838
Dobson's Leaf-nosed Bat	*Hipposideros brachyotus* Dobson,1874
Dusky Leaf-nosed Bat	*Hipposideros ater* Templeton, 1848
Kelaart's Leaf-nosed Bat	*Hipposideros lankadiva* Kelaart, 1850
Ashy Leaf-nosed Bat	*Hipposideros cineraceus* Blyth, 1853
Nicobar Leaf-nosed Bat	*Hipposideros nicobarulae* Miller, 1902
Andersen's Leaf-nosed Bat	*Hipposideros gentilis* K. Andersen, 1918
Pomona Leaf-nosed Bat	*Hipposideros pomona* K. Andersen, 1918
Horsefield's Leaf-nosed Bat	*Hipposideros larvatus* (Horsfield, 1823)
Durga Das's Leaf-nosed Bat	*Hipposideros durgadasi* Khajuria, 1970
Kolar Leaf-nosed Bat	*Hipposideros hypophyllus* Kock and Bhat, 1994

Family Megadermatidae	
Greater False Vampire Bat	*Lyroderma lyra* (E. Geoffroy, 1810)
Lesser False Vampire Bat	*Megaderma spasma* (Linnaeus, 1758)

Family Rhinopomatidae	
Lesser Mouse-tailed Bat	*Rhinopoma hardwickii* Gray, 1831
Greater Mouse-tailed Bat	*Rhinopoma microphyllum* (Brünnich, 1872)

Family Emballonuridae	
Pouch-bearing Tomb Bat	*Saccolaimus saccolaimus* (Temminck, 1838)
Egyptian Tomb Bat	*Taphozous perforatus* E. Geoffroy, 1818
Long-winged Tomb Bat	*Taphozous longimanus* Hardwicke, 1825
Naked-rumped Tomb Bat	*Taphozous nudiventris* Cretzschmar, 1830
Black-bearded Tomb Bat	*Taphozous melanopogon* Temminck, 1841
Theobald's Tomb Bat	*Taphozous theobaldi* Dobson, 1872

Family Molossidae	
Wrinkle-lipped Free-tailed Bat	*Mops plicatus* (Buchanan, 1800)
Wroughton's Giant Mastiff Bat	*Otomops wroughtoni* (Thomas, 1913)
East Asian Free-tailed Bat	*Tadarida insignis* (Blyth, 1862)
Egyptian Free-tailed Bat	*Nyctinomus aegyptiacus* (E. Geoffroy, 1818)

Family Vespertilionidae	
Bronze Sprite	*Arielulus circumdatus* (Temminck, 1840)
Oriental Serotine	*Cnephaeus pachyomus* (Tomes, 1857)
Thick-eared Bat	*Cnephaeus pachyotis* (Dobson, 1871)
Ognev's Serotine	*Cnephaeus ognevi* Bobrinskii, 1918
Gobi Big Brown Bat	*Cnephaeus gobiensis* Bobrinskii, 1926
Sombre Bat	*Cnephaeus tatei* Ellerman & Morrison-Scott, 1951
Tickell's Bat	*Hesperoptenus tickelli* (Blyth, 1851)
Desert Yellow Lesser House Bat	*Scotoecus pallidus* (Dobson, 1876)
Harlequin Bat	*Scotomanes ornatus* (Blyth, 1851)
Lesser Asiatic Yellow House Bat	*Scotophilus kuhlii* Leach, 1821
Greater Asiatic Yellow House Bat	*Scotophilus heathii* (Horsfield, 1831)
Chinese Noctule	*Nyctalus plancyi* (Gerbe, 1880)
Leisler's Noctule	*Nyctalus leisleri* (Kuhl, 1817)
Mountain Noctule	*Nyctalus montanus* (Barret-Hamilton, 1906)
Common Pipistrelle	*Pipistrellus pipistrellus* (Schreber, 1774)
Indian Pipistrelle	*Alionoctula coromandra* (Gray, 1838)
Babu's Pipistrelle	*Alionoctula babu* (Gray, 1838)
Japanese Pipistrelle	*Alionoctula abramus* (Temminck, 1840)
Least Pipistrelle	*Alionoctula tenuis* (Temminck, 1840)
Kelaart's Pipistrelle	*Alionoctula ceylonicus* (Kelaart, 1852)
Mount Popa Pipistrelle	*Alionoctula paterculus* Thomas, 1915
Dormer's Pipistrelle	*Scotozous dormeri* Dobson, 1875
Eastern Barbastelle	*Barbastella darjelingensis* Hodgson [in Horsfield], 1855
Turkestani Long-eared Bat	*Otonycteris leucophaea* Severcov, 1873
Hodgson's Long-eared Bat	*Plecotus homochrous* Hodgson, 1847
Ward's Long-eared Bat	*Plecotus wardi* Thomas, 1911
Chocolate Pipistrelle	*Hypsugo affinis* (Dobson, 1871)
Savi's Pipistrelle	*Hypsugo savii* (Bonaparte, 1837)
Cadorna's Pipistrelle	*Hypsugo cadornae* (Thomas, 1916)
Joffre's Pipistrelle	*Mirostrellus joffrei* (Thomas, 1915)
Great Evening Bat	*Ia io* Thomas, 1902
Meghalaya Thick-thumbed Bat	*Glischropus meghalayanus* Saikia, Ruedi & Csorba, 2022
Disk-footed bat	*Eudiscopus denticulus* (Osgood, 1932)
Blyth's Lesser Bamboo Bat	*Tylonycteris fulvida* (Blyth, 1859)
Malayan Greater Bamboo Bat	*Tylonycteris malayana* Chasen, 1940
Hodgson's Myotis	*Myotis formosus* (Hodgson, 1835)
Lesser Large-footed Myotis	*Myotis hasseltii* (Temminck, 1840)
Horsfield's Myotis	*Myotis horsfieldii* (Temminck, 1840)

Family Vespertilionidae, continued	
Hairy-faced Myotis	*Myotis muricola* (Gray, 1846)
Himalayan Whiskered Myotis	*Myotis siligorensis* (Horsfield, 1855)
Lesser Myotis	*Myotis blythii* (Tomes, 1857)
Rickett's Big-footed Myotis	*Myotis pilosus* (Peters, 1869)
Nepal Myotis	*Myotis nipalensis* (Dobson, 1871)
Hairy-faced Myotis	*Myotis annectans* (Dobson, 1871)
Chinese Water Myotis	*Myotis laniger* (Peters, 1870)
Kashmir Cave Myotis	*Myotis longipes* (Dobson, 1873)
Burmese Whiskered Myotis	*Myotis montivagus* (Dobson, 1874)
Sichuan Myotis	*Myotis altarium* Thomas, 1911
Peyton’s Whiskered Myotis	*Myotis peytoni* Wroughton & Ryley, 1913
Mendelli’s Mouse-eared Myotis	*Myotis sicarius* Thomas, 1915
Himalayan Long-tailed Myotis	*Myotis himalaicus* Ruedi, Chakravarty, Saikia & Csorba, 2025
Tomes’ Hairy-faced Myotis	*Submyotodon caliginosus* (Tomes, 1859)
Lesser Hairy-winged Bat	*Harpiocephalus harpia* (Temminck, 1840)
Little Tube-nosed Bat	*Murina aurata* Milne-Edwards, 1872
Round-eared Tube-nosed Bat	*Murina cyclotis* Dobson, 1872
Hutton’s Tube-nosed Bat	*Murina huttoni* (Peters, 1872)
Greater Tube-nosed Bat	*Murina leucogaster* Milne-Edwards, 1872
Scully’s Tube-nosed Bat	*Murina tubinaris* (Scully, 1881)
Rainforest Tube-nosed Bat	*Murina pluvialis* Ruedi, Biswas & Csorba, 2012
Jaintia Tube-nosed Bat	*Murina jaintiana* Ruedi, Biswas & Csorba, 2012
Guillen’s Tube-nosed Bat	*Murina guilleni* Soisook, Karapan, Satasook, et al., 2013
Peters' Tube-nosed Bat	*Harpiola grisea* (Peters, 1872)
Formosan Golden Tube-nosed Bat	*Harpiola isodon* Kuo, Fang, Csorba & Lee, 2006
Peters' Trumpet-eared Bat	*Phoniscus jagorii* (Peters, 1866)
Painted Woolly Bat	*Kerivoula picta* (Pallas, 1767)
Cryptic Woolly Bat	*Kerivoula crypta* Wroughton & Ryley, 1913
Lenis Woolly Bat	*Kerivoula lenis* Thomas, 1916
Kachin Woolly Bat	*Kerivoula kachinensis* Bates, Struebig, Rossiter, et al., 2004
Dark Woolly Bat	*Kerivoula furva* Kuo, Soisook, Ho, et al., 2017

Family Miniopteridae	
Eastern Long-fingered Bat	*Miniopterus fuliginosus* (Hodgson, 1835)
Small Long-fingered Bat	*Miniopterus pusillus* Dobson, 1876
Phillip's Long-fingered Bat	*Miniopterus phillipsi* Kusuminda, Mannakkara, Ukuwela, et al., 2022
Western Long-fingered Bat	*Miniopterus magnater* Sanborn, 1931
Srini's Long-fingered Bat	*Miniopterus srinii* Srinivasulu & Srinivasulu, 2023

Vespertilionid (evening) bats are the dominant ones, representing about 51 percent of the bat diversity of India, followed by rhinolophid (horse-shoe) bats (14 percent), hipposiderid (leaf-nosed) bats (12 percent), and pteropodid (fruit) bats (9 percent). Others, contributing to the rest of the diversity, include emballonurid (tomb) bats, miniop-terid (long-fingered) bats, molossid (free-tailed) bats, megadermatid (false vampire) bats, and rhinopomatid (mouse-tailed) bats (Table 1.2).

The field of bat taxonomy in India can be divided into two periods: pre-independence and post-independence. The pre-independence period (between 1758 and 1947, chiefly pioneered by the British and Europeans) was marked with the discovery and description of most (121 species) bat species known to be present in India, while only 13 species of bats were discovered and described after 1947 (Figure. 1.1).

Table 1.2 Generic and species diversity of bats in India within each family.

Family	Number of Genera	Number of Species
Pteropodidae	8	12
Rhinolophidae	1	19
Hipposideridae	3	16
Megadermatidae	2	2
Rhinopomatidae	1	2
Emballonuridae	2	6
Molossidae	4	4
Vespertilionidae	26	69
Miniopteridae	1	5

Post 2000, identification of new or cryptic species or elevation from synonymy has resulted in nine new bat species and two elevations from synonymies, including – *Kerivoula kachinensis*[4], *Murina jaintiana*[5], *Murina pluvialis*[5], *Murina guilleni*[6], *Kerivoula furva*[7], *Glischropus meghalayanus*[8], *Miniopterus phillipsi*[9], *Miniopterus srinii*[10], and *Myotis himalaicus*[3]. Elevations from synonymy include *Rhinolophus andamanensis*[11], *Hipposideros brachyotus*[12], and *Alionoctula babu*[3][13].

Modern genetic techniques have revolutionised taxonomic and systematics discoveries, particularly in uncover-ing cryptic species and previously unrecognised diversity. This is especially relevant for bats, where morphological similarities can mask significant genetic differences. This surge in taxonomic activity highlights the dynamic nature of our understanding of bat diversity and emphasises the need for continued research in the Indian context. Most species descriptions are from the biodiverse-rich regions of the Himalayas, Northeast India, and the Western Ghats.

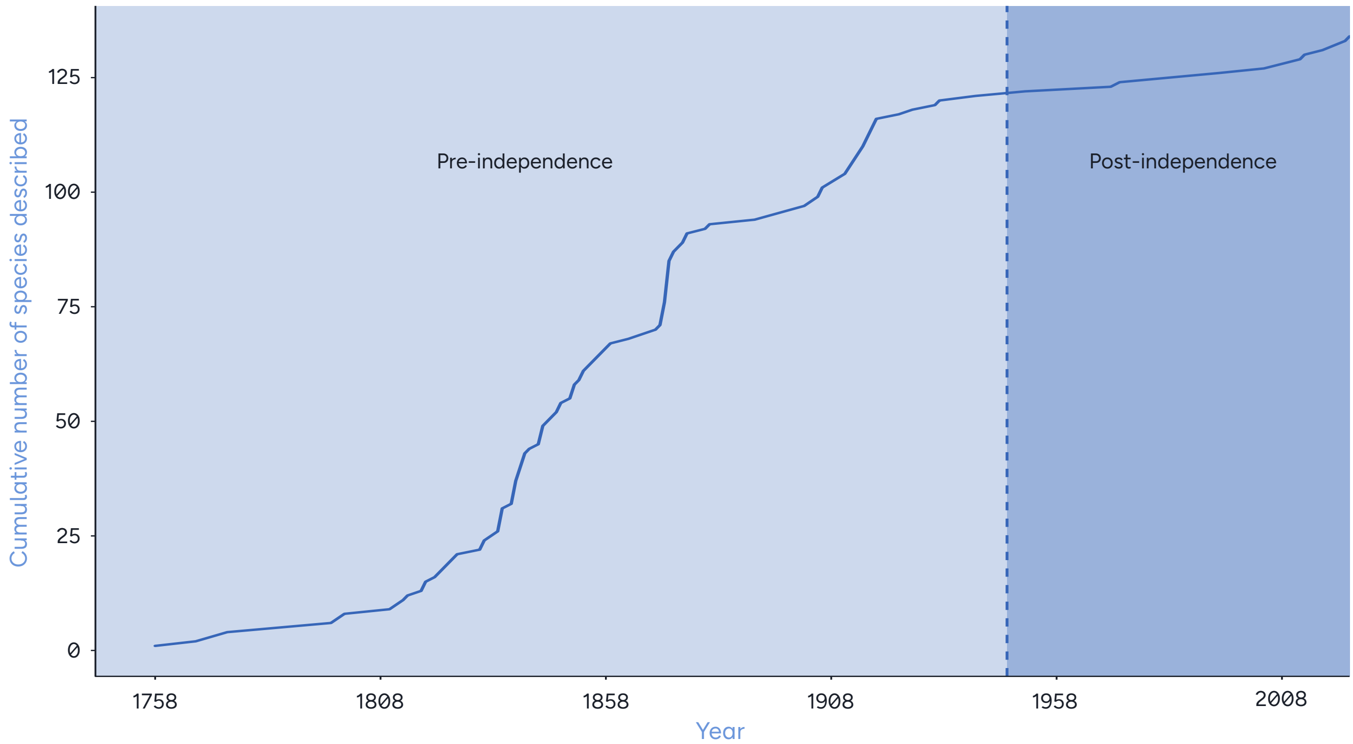


Figure. 1.1 Trends in new descriptions for bat species present in India since 1758.

Endemicity of Indian Bats

Sixteen species, about 12 percent of the total bat diversity, are endemic to India. Of these, four species (the Sombre Bat [*Cnephaeus tatei*], the Meghalaya Thick-thumbed Bat [*Glischropus meghalayanus*], the Rainforest Tube-nosed Bat [*Murina pluvialis*], and Peter's Tube-nosed Bat [*Harpiola grisea*]) are endemic to the Himalayas and Northeast India[5][8][14][15]. Four species are endemic to the Western Ghats: Salim Ali's Fruit Bat (*Latidens salimalii*), the Pomona Leaf-nosed Bat (*Hipposideros pomona*), Peyton's Whiskered Myotis (*Myotis peytoni*), and Srini's Long-fingered Bat (*Miniopterus srinii*)[10][16][17]. Four species (the Nicobar Flying Fox [*Pteropus faunulus*], Homfray's Horseshoe Bat [*Rhinolophus andamanensis*], the Andaman Horseshoe Bat [*Rhinolophus cognatus*], and the Nicobar Leaf-nosed bat [*Hipposideros nicobarulae*]) are endemic to the Andaman and Nicobar Islands[18][19][20].

Two species (the Kolar Leaf-nosed Bat [*Hipposideros hypophyllus*] and the Cryptic Woolly Bat [*Kerivoula crypta*]) are endemic to peninsular India[17][21], one species (Durga Das's Leaf-nosed Bat [*Hipposideros durgadasi*]) is endemic to the Gangetic Plains and Deccan Plateau regions[22], and the Mitred Horseshoe Bat (*Rhinolophus mitratus*) is endemic to the Chota Nagpur plateau[23].

Meghalaya Thick-thumbed Bat (*Glischropus meghalayanus*). Photo: Uttam Saikia

Diversity of Indian Bats within States and Union Territories

The distribution of bat species across Indian states and union territories reveals significant variations in diversity (Figure. 1.2), reflecting both environmental factors and the level of exploration and study in these regions. Understanding the distribution patterns and diversity of bat species across these states and union territories is crucial for targeted conservation efforts.

The high diversity of bat taxa in specific states and union territories highlights the presence of critical habitats in these regions that need protection. Conversely, areas with low recorded diversity may require more comprehensive surveys to uncover cryptic species and to better assess the bat populations. Conservation strategies should be region-specific, focusing on habitat preservation in areas of high taxonomic diversity while enhancing research efforts in underexplored regions.

Diversity across states

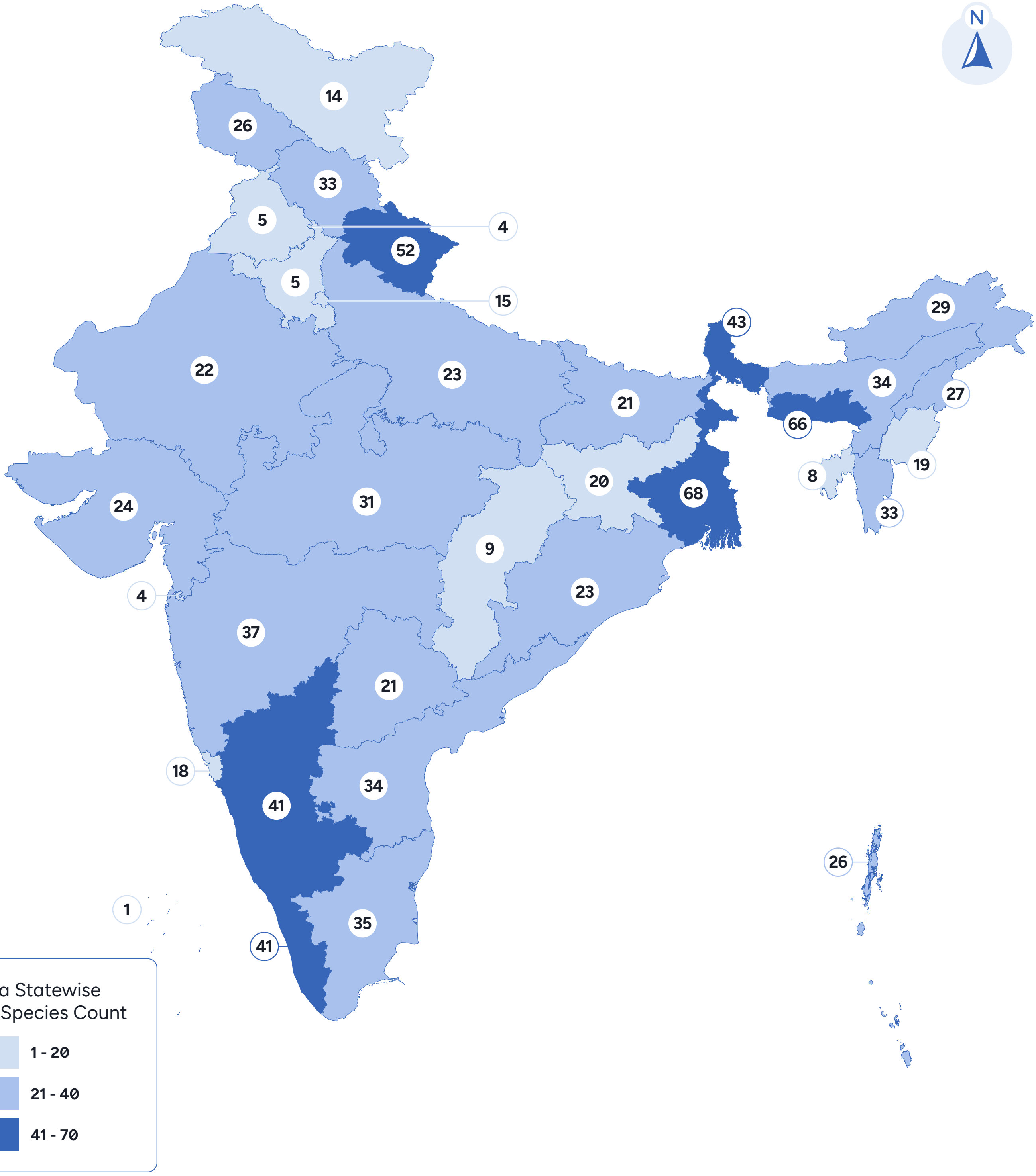
Certain states stand out for their exceptionally high taxonomic diversity. West Bengal leads with 68 bat species, followed by Meghalaya (66 species), and Uttarakhand (52 species). States like Kerala and Karnataka (41 species each), and Sikkim (43 species[24]) also showcase notable diversity. These regions likely benefit from diverse ecosystems contributing to the rich chiropteran fauna. Meghalaya, known for its extensive cave systems, offers unique habitats that support a wide range of bat species, accounting for its high diversity.

On the other hand, several states display low bat diversity, such as Haryana and Punjab, each with only five recorded species. Factors such as limited forest cover, urbanisation, and agricultural expansion could be responsible for the restricted diversity in these states. Chhattisgarh (9 species) and Tripura (8 species) also have comparatively lower species counts, which might be attributable to insufficient taxonomic surveys rather than an actual lack of species.

Diversity across union territories

In the union territories, the Andaman and Nicobar Islands have the highest bat diversity, with 26 species, reflecting the region's isolation and unique biogeographical history. Jammu and Kashmir and Ladakh also exhibit significant diversity with 26 and 14 species, respectively, driven by their varied elevational gradients and distinct habitats.

In contrast, union territories such as Lakshadweep (1 species), Chandigarh (4 species), Dadra and Nagar Haveli, and Daman and Diu (4 species) show very low bat diversity. The limited land area and highly urbanised landscape of these regions likely restricts bat populations and diversity. The relatively higher number of bat species in Delhi (15 species) might be linked to the diverse habitats within and surrounding the urban area, although urban pressure still limits the number of bat species.



State/Region boundaries are representative

Figure. 1.2 Variation in the number of bat species recorded in the states and union territories of India.

Importance of Understanding Taxonomy and Systematics

Taxonomic research plays a crucial role in understanding and conserving bat diversity. However, this field faces significant challenges that hinder its progress and impact. Despite its importance, taxonomic research on bats is impeded by several factors, including insufficient financial support, limited institutional backing, villainisation of bats as carriers of disease, and difficulties in training and retaining skilled taxonomists. These challenges collectively hamper efforts to advance our understanding of Indian bat diversity and implementation of effective conservation measures.

As technological advancements enable finer resolution in species delimitation, researchers must exercise caution and adhere to rigorous standards. New species descriptions should be supported by multiple lines of evidence (e.g., morphological as well as molecular data), and the species concept employed must be clearly articulated. Researchers must take precaution to ensure the availability of nomen by carefully studying the available synonyms for bat species (Appendix 2). Researchers should also consider the broad implications of taxonomic decisions beyond the immediate fields of taxonomy and systematics. These methodological considerations are essential to ensure the accuracy and reliability of taxonomic research in the face of advancing technologies.

Fostering collaboration between taxonomists and citizen scientists is essential for bat conservation in increasingly fragile ecosystems. This inclusive approach can yield several benefits, including enhanced public understanding of bat diversity, improved conservation strategies, and increased support for taxonomic research. By bridging the gap between experts and novices, we can create a more holistic approach to bat conservation that incorporates diverse perspectives and expertise (Chapter 13).

Addressing the challenges in bat taxonomic research requires a multifaceted approach. By securing adequate funding, strengthening institutional support, and promoting collaboration between experts and citizen scientists, we can advance our understanding of bat diversity and develop more effective conservation strategies. As we move forward, it is crucial to recognise the importance of taxonomic and systematics research in conservation efforts and to work towards overcoming the obstacles that currently limit their potential impact.

Taxonomy and systematics serve as the cornerstones of effective conservation efforts. These disciplines provide a fundamental framework for clarifying the status of populations, recognising distinct species and lineages, developing tailored conservation strategies, and ultimately, increasing the probability of species recovery. By fostering a robust taxonomic foundation, we can ensure more effective conservation strategies, ultimately safeguarding the future of India's diverse bat fauna in the face of mounting environmental challenges.

A mixed colony of Phillip's Long-fingered Bat (*Miniopterus phillipsi*) and Leschenault's Rousette (*Rousettus leschenaultii*).
Photo: Dhanusha Kawalkar

Chapter 2
Key Challenges to Taxonomy

Author: Sreehari Raman

Overcoming the Expertise Deficit in Indian Bat Research: A call for enhanced training and support

The field of bat research in India is hampered significantly by a lack of expertise and the belief that bats carry pathogens that cause several deadly diseases. While bats constitute one of the most diverse groups of mammals in India, with 135 species reported[1], the number of scientists specialising in chiropterology is disproportionately small. Bats are extremely difficult to study due to their nocturnal habits, small size, morphological similarity, and cryptic behaviour[25]. As a result, misidentification is common, leading to errors in species distribution records and population assessments. This lack of expertise affects every stage of research, from field identification and data collection to taxonomic classification and conservation planning[26]. This has led to knowledge gaps, especially in bat ecology, behaviour, and population dynamics. Consequently, many species remain poorly studied, and conservation efforts are hampered by a lack of critical data[25]. This situation underscores the urgent need for increased investment in training and capacity building for bat researchers in India.

Challenging Cryptic Diversity among Indian Bats: The need for advanced techniques and resources

Cryptic diversity, where multiple species are incorrectly identified as a single species due to their morphological similarities, is a significant challenge in studying Indian bats. Many bat species exhibit subtle morphological differences that are difficult to evaluate without using comprehensive reference collections and detailed genetic analyses (see[3][9][11][12]). Cryptic species complexes are common, leading to an underestimation of species richness and an incomplete understanding of bat biodiversity in India. This challenge is compounded by the lack of comprehensive genetic databases for Indian bats, making it difficult to compare new findings with existing data (see[27]). Recognising cryptic diversity is crucial for effective conservation planning as different species may have distinct ecological requirements and face differing threats[28],[29].

Dobson's Leaf-nosed Bat (*Hipposideros brachyotus*). Photo: Rajesh Puttaswamaiah

Bronze Sprite (*Arielulus circumdatus*). Photo: Rohit Chakravarty

Expanding Bat Research in India: Addressing gaps in sampling and taxonomic coverage

Despite their widespread distribution across the country, bats remain understudied in many geographic areas, particularly in the northeastern states, western Himalayas, and central regions of India. These regions are often characterised by difficult terrain, limited accessibility, and socio-political challenges, making fieldwork logistically challenging and costly. As a result, bat diversity in these areas is poorly documented, and many species may remain undiscovered or underreported. In addition, certain taxonomic groups of bats are also understudied. For example, vespertilionids, which comprise most bat species in India, are often overlooked in favour of larger, more conspicuous species, such as fruit bats. This taxonomic bias in sampling efforts has led to a skewed understanding of bat diversity and ecology in India. To address this issue, targeted sampling efforts in underexplored regions and taxonomic groups are needed along with increased funding and logistical support for field research.

Challenges in Taxonomic Research due to the Absence of Type Specimens in India

Formal scientific studies on bats in India began during the 19th-century British colonial period (for example[19],[23]). Many type specimens that were collected and described by foreign researchers during this period are now housed in museums abroad and not available within the country. The unavailability of these type specimens in India poses a significant challenge for taxonomic research as it makes it difficult to verify the identity of species and to resolve taxonomic ambiguities[30]. This challenge is particularly acute in the case of cryptic species complexes, where subtle morphological differences are often the only means of distinguishing species. To address this issue, efforts should be made to repatriate type specimens to India or to at least provide Indian researchers with access to high-quality images and detailed descriptions of these specimens.

The Need for a Comprehensive Acoustic Database for Indian Bats

Acoustic monitoring is a valuable tool for studying bats as many species can be identified based on their echolocation calls. With a reference database of bat calls, it is easier to identify species in the field and to assess their distribution and abundance. In India, echolocation call libraries are available for certain regions, providing valuable reference data for species identification and acoustic analyses[27][31][32][33][34][35]. However, the lack of a comprehensive acoustic database for Indian bats is a significant challenge for researchers. The absence of such a database also limits the ability to use acoustic monitoring as a non-invasive method for studying bat populations and behaviour.

Reconciling Genetic and Taxonomic Data for Accurate Bat Classification

The United States National Institutes of Health's National Center for Biotechnology Information (NCBI) database is a crucial resource for genetic research, providing a repository for genetic sequences for various organisms, including bats. However, there is often a mismatch between the currently-accepted taxonomy of bats and the molecular data available in the NCBI database. This mismatch arises due to inconsistencies in species identification, outdated taxonomic classifications, and the presence of cryptic species complexes. This challenge highlights the need to comprehensively revise bat taxonomy in India, incorporating morphological and genetic data to provide a more accurate and up-to-date classification of bat species.

Facilitating Bat Research in India: The need for simplified collection permit procedures

Obtaining collection permits for bat research in India is often cumbersome and time-consuming. The collection of bats for scientific research is regulated by various government agencies, and obtaining the necessary permits requires navigating a complex and bureaucratic process. This can lead to significant delays in research, especially for time-sensitive projects such as ecological studies that require sampling during specific seasons. In some cases, researchers may be forced to abandon their projects, to modify their study objectives, to restrict study sites, or to shorten their study's duration due to their inability to obtain permits in a timely manner. Streamlining the permit process and providing clear guidelines for researchers applying for these permits would greatly facilitate bat research in India.

Avoiding Taxonomic Pitfalls: The importance of adhering to the International Code of Zoological Nomenclature guidelines in bat species descriptions

Discovering new diversity, particularly a species-level lineage, using molecular and other non-morphological methods should be accompanied by a sufficient description of the species through a type specimen following the International Code of Zoological Nomenclature (ICZN) guidelines whenever possible. Lack of a type specimen can render any new name technically void to the broader community and end up undermining formal recognition of new diversity Inaccurate species designations can result in misidentification, overestimation of biodiversity, and ineffective conservation strategies. Any taxa that have been previously described without adhering to ICZN guidelines should be re-evaluated and formally published as soon as possible to ensure their taxonomic validity. This is essential for maintaining the integrity of taxonomic classifications, advancing our understanding of bat diversity, and developing effective conservation strategies.

Chapter 3
Way Forward for Taxonomy

Author: Uttam Saikia

Unravelling the fundamental nature of biodiversity is a profound human endeavour, and taxonomy and systematics are key tools for enhancing that understanding. Notwithstanding their widespread distribution, high species diversity, and immense ecological and economic roles, bats continue to be threatened globally with the ominous threat of extinction looming large for many of their species[25]. In a developing, yet biodiversity-rich, country like India, economic aspirations are often at conflict with conservation goals. To make matters worse, we don't have a clear understanding of bats species' boundaries, both biological and geographical.

During the last few decades, significant strides have been taken in documenting the biodiversity of our country. For example, from the 117 species of bats known within India two decades ago[36] has increased to 135 species today with the description of several new species (Chapter 1). This has been made possible with a resurgence of interest in studying bats coupled with advances in taxonomic tools and techniques for bat research.

In alignment with the global trend in taxonomy, which utilises the integrative approach of combining classical taxonomy with molecular, behavioural, ecological, and biogeographic data[37], bat taxonomy in India is catching up, albeit slowly, to the progress made in other regions worldwide. The key is to sustain this momentum in the long run. This is particularly important in the Indian context in view of the myriad cryptic species complexes and unknown species' boundaries. An integrative approach to taxonomy is the only way to tackle such issues. Towards this end, the following tasks are recommended as priorities for the future:

- In order to buttress traditional taxonomic tools and evidence, it is essential to generate DNA barcodes for all Indian species of bats. Whenever possible, each barcode should be duly supported by a voucher specimen that is vetted by experts.
- Once DNA barcodes have been generated for all Indian bat species, protocols should be developed for depositing, storing, and sharing these data in a publicly-accessible depository, which will serve as the reference DNA barcode library for Indian bats. This can be achieved through collaboration between researchers working in different geographic regions across the country.
- Best practice guidelines should be drafted to help researchers design taxonomic studies should they find unique haplotypes or phonic types. These guidelines should include clear direction on evolutionary signatures that are routinely assessed in molecular taxonomy, such as genetic divergence, reciprocal monophyly, fixed mutations, and supporting monophyly signature in nuclear gene phylogenies (e.g., nuclear introns).

Lesser Hairy-winged Bat (*Harpiocephalus harpia*).
Photo: Nithin Divakar

Unfortunately, research interest in bat taxonomy in India is low, which can be partly attributed to the general misconception of taxonomy being a dull subject and more so to a lack of funding. To circumvent the problem of limited funding, as well as to underline the relevance and societal importance of taxonomic and biodiversity research, bat researchers should link taxonomic research with issues such as public health and economic benefits. Considering the huge impediments to studying bat taxonomy and the urgent need for biodiversity documentation, it is high time to dedicate our efforts towards capacity building in taxonomic research in India. Notwithstanding the obvious lack of financial support for purely taxonomy-based work, bat researchers should not be deterred from their goal of understanding the true diversity and distribution of bat species in India.

Chapter 4
Monitoring of Bats in India

Author: Sanjay Molur

Although India is home to an impressive diversity of bat species that play crucial roles in ecosystems as pollinators, seed dispersers, and insect controllers, bat populations remain understudied and under-monitored, leading to significant gaps in knowledge about their statuses and trends.

Indian Flying Fox (*Pteropus medius*). Photo: Nithin Divakar

Lack of Systematic Monitoring

Systematic monitoring of wildlife populations is a major challenge in India and more so with smaller, lesser-known organisms like bats. Unlike other charismatic wildlife groups, bats have not received consistent attention in terms of short-, medium-, or long-term population studies. The absence of regular, systematic, and comprehensive monitoring efforts for bats has resulted in insufficient data, making it difficult to assess their presence/absence, evaluate their population trends, understand the direct and indirect threats affecting them, and implement effective conservation strategies.

Monitoring Data Deficient Species

India hosts several Data Deficient (DD; per the IUCN Red List of Threatened Species[38]) bat species (e.g., Peters's Tube-nosed Bat [*Harpiola grisea*] and Wroughton's Free-tailed Bat [*Otomops wroughtoni]*), for which we have inadequate information on their taxonomy, distribution, population size, and/or ecology. These species are often neglected in conservation planning due to the lack of baseline data, and addressing this requires targeted surveys and research to fill knowledge gaps such as distribution range, habitat preferences, roosting sites, feeding habits, reproductive biology, and dispersal capacities (Chapter 16). Without such efforts, these species are likely to decline unnoticed, both locally and globally.

Monitoring Trends of Common Species

While threatened species require conservation research and action focus, the Least Concern or "common" species of bats (as categorised by the IUCN Red List of Threatened Species[36]) require systematic monitoring as population trends of such species often serve as indicators of ecosystem health and potentially act as "canaries in a coalmine," reflecting and predicting broader environmental changes. Regular population assessments of these common and widely distributed species, be it rapid or detailed and systematic in approach, can provide early signs of degradation to habitats, effects of pollution, or impacts of the climate crisis. Systematic monitoring of not threatened and common bats can guide holistic conservation efforts complementing those for threatened and/or DD taxa.Unfortunately, research interest in bat taxonomy in India is low, which can be partly attributed to the general misconception of taxonomy being a dull subject and more so to a lack of funding. To circumvent the problem of limited funding, as well as to underline the relevance and societal importance of taxonomic and biodiversity research, bat researchers should link taxonomic research with issues such as public health and economic benefits. Considering the huge impediments to studying bat taxonomy and the urgent need for biodiversity documentation, it is high time to dedicate our efforts towards capacity building in taxonomic research in India. Notwithstanding the obvious lack of financial support for purely taxonomy-based work, bat researchers should not be deterred from their goal of understanding the true diversity and distribution of bat species in India.

The Way Forward with a Bat Monitoring Programme

A comprehensive bat monitoring programme with specific objectives, design, and responsibilities is crucial (Chapter 16). The required features of such a programme are outlined as follows:

Specific objectives

- Assess the distribution and population trends of bat species across various habitats.
- Identify, select, and monitor key roosting sites.
- Identify key foraging areas.
- Document and evaluate the impact of anthropogenic pressures on bat populations.
- Document and evaluate the impact of environmental changes on bat populations.
- Gather baseline information on DD species to inform their conservation status and actions.

Programme design

- **Priority regions:** Develop a strategy and identify priority regions for bat monitoring activities in the country.
- **Standardised protocols:** Develop standardised bat monitoring protocols for consistency in data collection across the country and across taxonomic groups (e.g., both *Yinpterochiroptera* and *Yangochiroptera*).
- **Acoustics:** Develop standardised protocols for acoustic recording, analysis, and monitoring along with establishing a repository for reference calls (Chapter 16).
- **Implementation:** Implement the evaluated and standardised bat monitoring protocols in selected priority regions across the country.
- **Long-term studies:** Establish long-term monitoring sites (10-15 years duration) across different habitats, including forested, agricultural, rural, peri-urban, urban, home garden, and degraded areas.
- **Citizen science:** Encourage, build capacity, and engage enthusiasts, local communities, amateur biologists, and researchers in citizen science initiatives to promote regular and standardized data collection (Chapter 13).
- **Technology:** Use invasive technologies (e.g., radio telemetry) as well as non-invasive technologies (e.g., acoustic monitoring, eDNA) for accurately studying species identification, distribution and range, and movement ecology (Chapter 7).

Responsibilities

Identify agencies and individuals responsible for the following activities:

- Conduct a holistic plan to incorporate stakeholder decisions for research and conservation.
- Conduct detailed studies, monitoring, and analyses.
- Provide scientific expertise and training.
- Facilitate community surveys and engagement.
- Conduct on-ground monitoring activities.
- Lead and follow-up with all the above activities.
- Raise funds for the monitoring programmes.
- Ensure integration with national and international wildlife conservation laws and legislation.

Strengthening Existing Bat Monitoring Programmes

Project PteroCount is an initiative focused on monitoring the Indian Flying Fox roosts in South Asia since 2005 under Zoo Outreach Organisation's Chiroptera Conservation and Information Network of South Asia (CCINSA). This project needs to be strengthened, expanded, and supported in the following, broad areas:

- **Expanding coverage:** Increase the taxonomic scope to cover selected groups representing different trophic guilds.
- **Capacity building:** Train more volunteers, researchers, amateurs, local communities, and forest department staff in bat monitoring techniques.
- **Data sharing:** Develop an online database for data sharing, analysis, and dissemination as well as create projects in existing citizen science platforms (e.g., iNaturalist) with creative commons at their core.

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Section II.

Ecology and Biology

The Ecology and Biology Working Group members listed below contributed to the following chapters through conceptual design, critical content review, and providing additional data and perspectives:

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Lesser Mouse-tailed Bat (*Rhinopoma hardwickii*).
Photo: Harish Prakash

Introduction

Section I thoroughly reviewed the state of taxonomic research on Indian bats – how many species there are, where new species can be found, and how their populations are monitored. Once a species is described, the next logical step is to understand its biology and ecology. How has the animal evolved to survive, reproduce, and respond to its environment? What does the animal eat? What habitat is it found in? Where does it migrate? How does the animal interact with other species, including humans? And, most importantly, how do human activities threaten the species' survival? These and many other questions come under the purview of biological and ecological research.

Early naturalists who described Indian bat species also recorded information on the species' diet, reproduction, habitat, and other aspects of their natural history. Their observations formed the basis of what we know about the ecology and behaviour of most of our bats today. However, the means to quantify observations of an elusive and nocturnal taxon prohibited further growth in Indian bat ecology. Now aided by improved access to data collection technology, such as acoustic devices, very high frequency (VHF) and Global Positioning System (GPS) transmitters, and molecular tools, ecological studies on Indian bats are on the rise.

The fields of bat biology and ecology are vast, encompassing topics as diverse as trophic interactions, habitat selection, physiology, breeding and social structure, and species' interactions. Participants in the Ecology and Biology Working Group identified five focal themes for this report: 1. diet, 2. habitat use, 3. movement ecology, 4. disease ecology, and 5. toxicology. These five themes were selected because they have either immediate management implications or the potential to tremendously advance our knowledge of Indian bats.

Within **The Diet of Indian Bats (Chapter 5)**, we discuss what is known about the diet of Indian bats and how we can make use of conventional and modern tools to link diet to ecosystem services (e.g., pollination and pest control). In **Habitat Use of Indian Bats (Chapter 6)**, we address the habitat selection of various species to understand their sensitivity to habitat disturbance and fragmentation. **Movement Ecology of Bats (Chapter 7)** reviews the knowledge on short- and long-distance movement of Indian bat species and how we can leverage technology and human resources to improve our knowledge of these topics. Given recent incidents of zoonotic diseases, such as COVID-19 and Nipah virus, **Disease Ecology Research on Indian Bats: Status and Future Prospects (Chapter 8)** identifies key knowledge gaps in the field and charts a roadmap for preventing future disease outbreaks in the country. **Toxicological Studies on Indian Bats (Chapter 9)** introduces and discusses the pertinent issues of environmental pollution and their potential to adversely affect Indian bats. All chapters review some of the key challenges and opportunities for future progress within each respective theme. As readers will appreciate, many opportunities are interconnected, highlighting the broad scope for interdisciplinary research for a holistic understanding of Indian bat biology and ecology.

Literature Review Methods

In order to compile a comprehensive understanding on the current state of knowledge related to the ecology and biology of Indian bats, we conducted a systematic review covering the literature on bat-related diet, habitat use, movement patterns, disease ecology, and ecotoxicology research. To this end, we developed a search strategy, using citation tracking and keyword searches via multiple search databases, including Google Scholar, Semantic Scholar, and Google Search. The literature review was not intended to be exhaustive but rather representative of the general trends in ecological and biological research on Indian bats.

For **diet**, we used diverse combinations of keywords such as "diet", "bat", "India", "insectivorous", "frugivorous", "nectarivorous", "piscivorous", "carnivorous", "foraging", "food type", "prey composition", "foraging behaviour", "prey capture". These were combined with taxonomic family names (i.e., "Pteropodidae", "Hipposideridae", "Rhinolophidae", "Emballonuridae", "Molossidae", "Rhinopomatidae", "Megadermatidae") to identify family-specific feeding patterns.

For understanding **habitat use**, we utilised a similar approach, combining the core keywords "bats" and "India" and "habitat" with modifiers such as "roosting habitat", "foraging habitat", "caves", "forest", "open space", “crevices”, “plantation”, “cavities”, “bamboo patches”, “rural”, “urban”, “mines”, “elevation”, “elevational distribution”, “anthropogenic activities”, “anthropogenic disturbances”, and “land-use change”. Additional peer-reviewed publications (e.g., review papers, research publications, and book chapters) related to habitat utilisation and selection were also included in the literature review.

In terms of **movement ecology**, one of our major objectives was to capture studies based on telemetry and tracking technologies that have been recently used to understand bat mobility. We conducted literature searches using combinations of keywords like “bats” and “India” or “global” and “movement” with modifiers such as “GPS”, “telemetry”, “habitat selection”, and “home range”.

For the chapter on **disease ecology**, we searched using the terms “bats” and “India” followed by a combination of epidemiologically-relevant words such as “zoonoses”, “spillover”, “surveillance”, “microbiome”, “bacteria”, “One Health”, “virus”, “Nipah virus”, “coronavirus”, and “filovirus”.

For **toxicology**, various combinations of the keywords “bat”, “bats”, “India”, “bat guano”, “heavy metals”, “toxicology”, “urban”, “pollutants”, “pesticides”, and “South Asia” were used. Through this method, we identified eight studies from India that were published between 1999 and 2024 along with several global reviews on both trace elements and organic contaminants found in bat tissues and guano.

For all of the searches described above, we selected studies that included direct observations or quantification of the data of interest. For example, to qualify under the diet category, authors must have either observed a feeding event, quantified the diet of a study subject, or definitively identified dietary items. Similar criteria were applied to studies belonging to the other themes. The report of an isolated observation or capture of a bat in a particular habitat was not enough justify its inclusion within the habitat use review. Habitat use studies were only included when they were: 1. based on repeated sampling (i.e., in the case of field studies) or 2. analysed a collection of occurrence data (i.e., in the case of meta-analyses) with the aim of describing or quantifying the habitat choice, selection, or use of a species or a community of species.

Given the dearth of peer-reviewed, published information on Indian bats, in rare cases, we also included natural history observations from unpublished and grey literature from credible sources. The inclusion of personal observations was restricted to descriptive observations (e.g., “the observer saw a given species feeding on a particular tree”). Any specific claim from an anecdotal source (e.g., “the observer reported that 5% of a given bat species’ diet is composed of a particular tree”) was excluded. We applied the same criterion when considering papers published in journals that may be classified as predatory.

Our search was conducted using English terms and, thus, was biased towards papers published in English. However, this is unlikely to cause a major loss of information as vernacular language journals are uncommon in India. Moreover, as mentioned above, the purpose of this literature review was to highlight general trends in research to identify opportunities for the future.

Results

Our search returned a total of 98 papers of ecological and biological interest published between 1965 and 2024. In decreasing order of the total number of papers retrieved by each thematic category, disease ecology ranked highest (31 papers), followed by diet (25 papers), habitat use (24 papers), movement ecology (10 papers), and toxicology (8 papers) (Figure 1). Published research has steadily increased over time for all thematic categories, a trend that has undoubtedly been reinforced by the Status of South Asian Chiroptera Conservation Assessment and Management Plan (C.A.M.P.) workshop and its subsequent report in 2002[1].

Although published studies on all thematic topics have been growing over the past two decades, those focused on disease ecology and habitat use have exhibited the most rapid rise, particularly in the previous 15 years. The exponential increase in bat-related disease ecology papers since 2010 likely reflects the combined effects of: 1. increased global One Health concern over bat-origin viral emerging infectious diseases (EIDs) since the late 1990s[2][3], 2. recurrent zoonotic disease outbreaks across South Asia that have been associated with wildlife reservoirs, particularly bats (e.g., Nipah virus outbreaks in India and Bangladesh since 2001[4]), and 3. the growth of

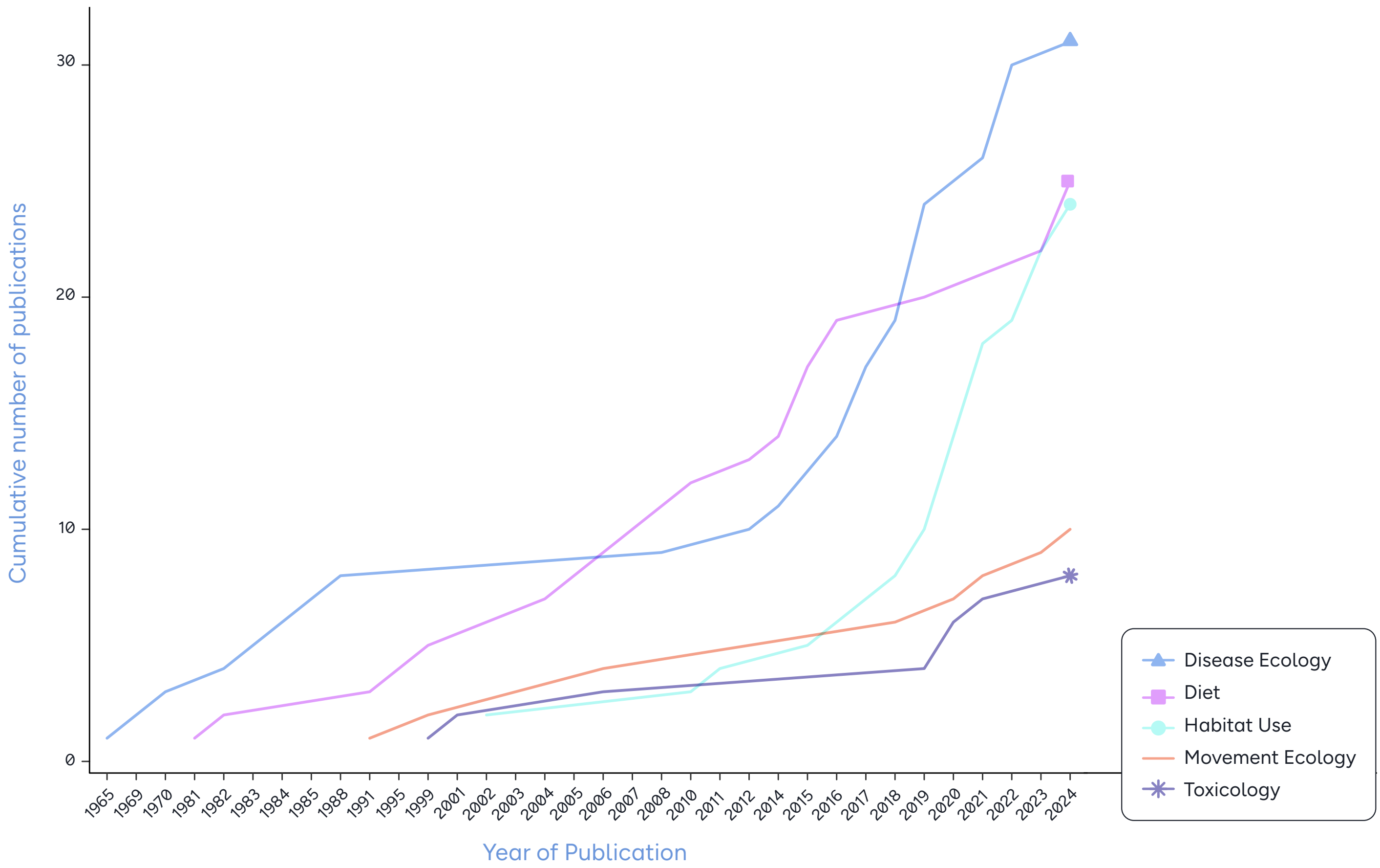

Figure 1 Cumulative number of publications from 1965-2024 that reported bat-relevant biological and ecological research in India.

the wildlife disease ecology field and recognition of the importance of EIDs to wildlife management and conservation, especially following the emergence of White Nose Syndrome in North American bats in 2007[2]. A similar increase in bat-centric habitat use research over the past decade mirrors the trend exhibited by habitat use and movement ecology studies for Indian wildlife in general, resulting from advancements in technological tools (e.g., acoustic sampling equipment), expanded accessibility to this technology, and the development of specific statistical techniques to analyse these types of data[5].

An evaluation of the geographic scope of these published studies on bat biology and ecology also revealed a strong geographic bias. To date, most natural history research on bats has been conducted in the southern states of Tamil Nadu, Karnataka, and Kerala (Figure 2). Critical reviews of the literature for wildlife movement studies and landscape ecology studies supporting species and habitat conservation demonstrated similar patterns of clustering in the southern states of India[5][6][7]. Indeed, even citizen science-based reporting of bats on iNaturalist over the past 30 years exhibits an analogous geographic concentration of reports in Tamil Nadu, Karnataka, and Kerala (Chapter 13). This pattern can largely be explained by the disproportionately high number of studies that are conducted on wildlife and their habitats in the biodiversity hotspot of the Western Ghats as well as the relatively easily accessible surrounding areas[5][6][7]. This finding is also likely influenced by the presence of universities within these states (e.g., Madurai Kamaraj University in Madurai, Tamil Nadu) that are some of the oldest and most prominent centres for bat research in India.

Conversely, we found that other Indian biodiversity hotspots (e.g., the Himalayas, Northeast India, and the Andaman and Nicobar Islands) remain relatively understudied in terms of bat biology and ecology. The states located within the Eastern Ghats and Terai Lowland biogeographic regions are similarly undersampled (Figure 2). Once again, the paucity of wildlife- and conservation-related research as well as citizen science sightings of bats tracks the geographic bias we recovered in the bat-centric literature[5][6][7] (Chapter 13). The comparatively limited bat (and other wildlife) research initiated in these biogeographic regions can largely be attributed to difficulties in accessing these regions due to their remoteness, lack of infrastructure, harsh climatic conditions, challenging terrain, national security concerns, and/or political, economic, or sociocultural conflicts[5][6][7] (Chapter 15).

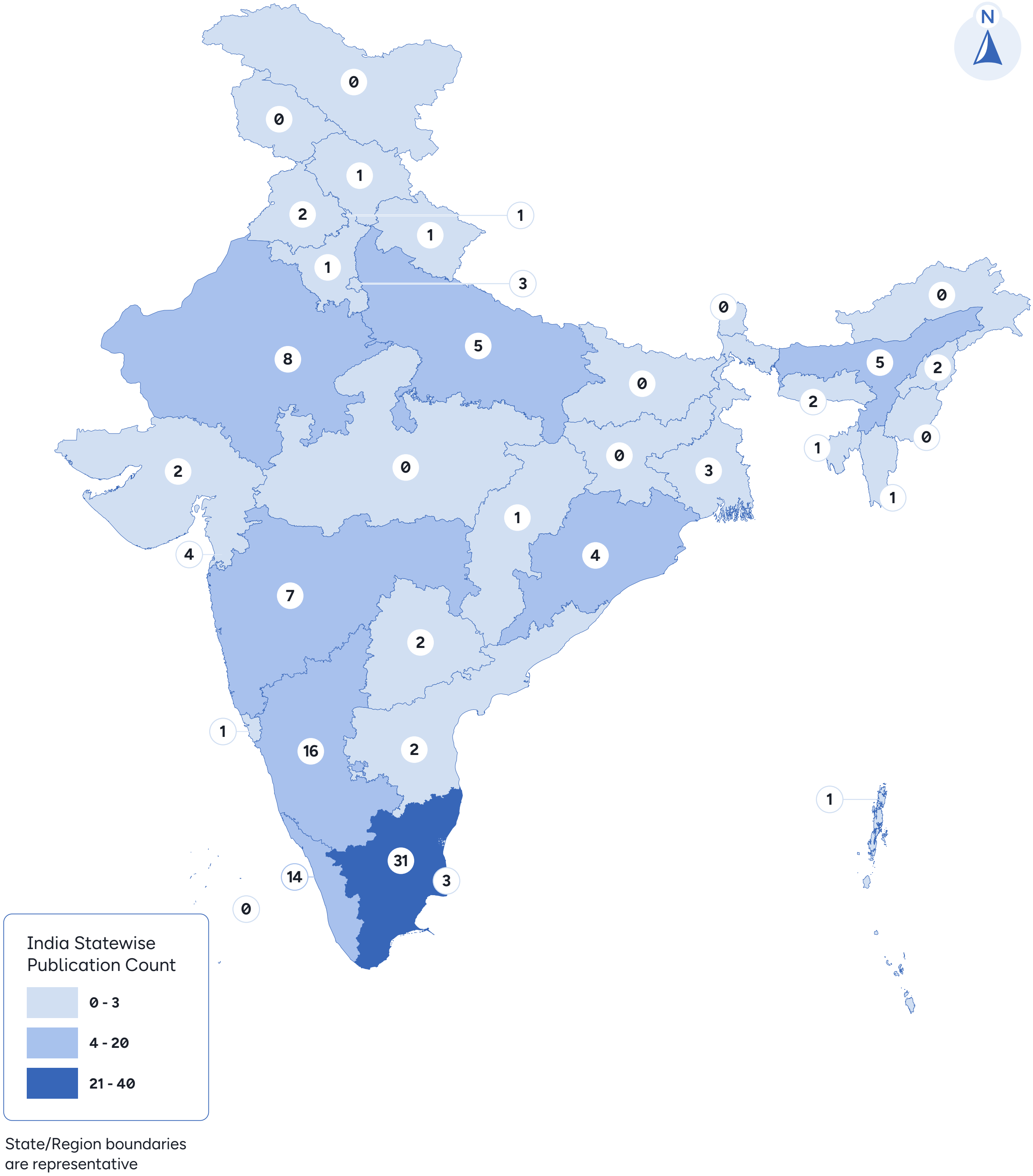

Figure 2 Number of publications per state or union territory for topics related to bat biology and ecology. If a published study was conducted in multiple locations in more than one state or union territory, then the publication was counted for each state and union territory in which the study was conducted. We excluded studies (e.g., review papers or meta-analyses) if: 1. their focal location(s) could not be mapped to a specific state or union territory, or 2. they reviewed original data reported by another publication that was already included in our analysis. As a result, the total number of publications presented in this figure is greater than the total number of publications depicted above in Figure 1.

Understanding the underlying patterns and biases in bat natural history research throughout India sets the stage for the topic-specific syntheses of each chapter within the following section. Some of these trends are appraised as challenges by the authors, but many others open a wide field of possibilities for advancing Indian bat biological and ecological research into the future.

Chapter 5
The Diet of Indian Bats

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Diet is one of the most important biotic components defining an organism's ecological niche. It can influence the habitat of an organism, where it forages, and who it competes with[8][9]. Diet also provides nutritional benefits for different life history stages[9]. Most importantly, diet links an animal to its functions in the ecosystem. In some contexts, the animal's role in the ecosystem provides benefits to humans, such as pest control, pollination of economically or culturally important plants, or maintaining the stability of the ecosystem[10] (Chapter 10).

Given the importance of diet in an organism's ecology, it is no surprise that it has received ample attention in bat research across the world[11]. Globally, the diet and foraging of bats have generated interest in both fundamental, academic research and applied, conservation-oriented research. An exhaustive review of literature from all over the world is beyond the scope of this report; however, broad themes of diet research are reviewed below.

For almost a century, descriptions of bat diets were conducted based on the morphological identification of plant or animal prey from bat faeces, stomach contents, or regurgitated remains (see Vaughan 1997[12]). These methods have important caveats, such as the lack of taxonomic resolution of prey identification and a bias towards detections of larger insects or hard seeds[13]. Consequently, the past decade has seen an increasing number of studies abandoning this approach for newer technologies, such as stable isotope analysis and DNA metabarcoding. When expanded to a group of co-occurring species, the natural follow-up questions became: do species compete if they eat similar prey species, and, if so, how do they partition resources to coexist[14][15][16][17]?

Lastly, and most importantly, diet studies have been used to understand the role of bats in the ecosystem as pest controllers, pollinators, and trophic mediators[18][19]. The identification of what bats eat and where they eat it is, therefore, critical for understanding how to protect them. For detailed reviews on each of these themes, we point the reader to classic bat ecology textbooks[11][20].

Diet studies on Indian bats

The diverse bat species in India show diverse dietary habits, mostly including frugivorous, nectarivorous, insectivorous, and carnivorous diets[21]. Our literature search revealed studies on 24 bat species belonging to seven families conducted in approximately 72 different locations over the last four decades (see Introduction to Section II). Studies utilised various approaches, mostly faecal analyses, field observations, and, more recently, molecular techniques. The most well-represented species in diet studies are two of our commonest and most widespread bats: the Indian Flying Fox (*Pteropus medius*) and the Greater Short-nosed Fruit Bat (*Cynopterus sphinx*). Studies on the diets of insectivorous bat species are fewer. Studies seem to have been focused on cave-roosting species such as the Dusky Leaf-nosed Bat (*Hipposideros ater*), Schneider's Leaf-nosed Bat (*H. speoris*), the Kolar Leaf-nosed Bat (*H. hypophyllus*), Durgadas's Leaf-nosed Bat (*H. durgadasi*), and the Fulvous Leaf-nosed Bat (*H. fulvus*), with a geographical bias towards southern India. Synanthropic insectivorous species such as *Alionoctula* spp. (formerly *Pipistrellus*) that are commonly found in cities and villages are less represented in studies.

Diet of fruit bats

In this chapter, we use the term "fruit bat" to refer to all bats belonging to the family Pteropodidae. There are 12 species of fruit bats in India. Of these, the diets of the Indian Flying Fox, the Greater Short-nosed Fruit Bat, and the Fulvous Fruit Bat (*Rousettus leschenaultii*) are best studied. These species of fruit bats are known to feed on more than 20 species of plants throughout the year. Fruits that have been frequently detected in their diet (through faecal or chewed remains from the roost or direct observations) are *Psidium guajava, Syzigium cumini, Manilkara zapota, Terminalia catappa, Monoon (Polyalthia) longifolia,* and various *Ficus* spp. [10][22][23][24][25][26].

Additionally, the smaller fruit bats (*Cynopterus sphinx* and *Rousettus leschenaultii*) also voraciously consume the berries of *Muntingia calabura*. This introduced shrub is common in Indian cities and likely heavily subsidises the diet of synanthropic fruit bats. Other plant parts are also consumed[22][23]. For example, nectar is commonly fed on or the flowers are consumed from *Ceiba pentandra* and *Musa paradisiaca*[23][26]. The leaves of trees such as *Cassia fistula* and *Albizia lebbeck* are also consumed extensively in some seasons, particularly by *Cynopterus sphinx*[23]. *Pteropus medius* seems to consume chewy leaves such as *Mangifera indica* and *Ficus religiosa* among others [26]. Also, their diet varies across seasons (e.g., for *Rousettus leschenaultii*[27]). In the diet of *Pteropus medius*, it was found that they consume seasonal plant species more than the perennial species[26]. The three fruit bats mentioned above are common, synanthropic species, and their diet of common avenue and park trees of Indian cities typically reflects their ecology.

Fruit bats are also important pollinators and seed dispersers[10]; however, limited data are available from India (Chapter 10). As an example, *Cynopterus sphinx* has been found to be an important pollinator and seed disperser of the mahua tree (*Madhuca latifolia*), which is revered in many indigenous cultures and tradition[28]. Deshpande et al. (2022)[29] found high consumption of cashew and areca nuts by pteropodid bats in different parts of the Western Ghats. Instead of leading to conflict, locals perceived this frugivory as a benefit since fruit bats dropped seeds in clumps, which could then be collected easily[29]. Extralimital studies on genera like *Eonycteris* and *Macroglossus* suggest that they are important pollinators of bananas and mangroves[10], but no information is currently available from India.

In addition to plant parts, Mahandran et al. (2016) documented geophagy (i.e., the consumption of soil) in *Cynopterus sphinx*[30]. In total, 91 bouts of salt licking were observed between August and September 2013 during the mahua tree fruiting season. Nutrient analysis of the soil samples revealed that the soil was rich in magnesium, calcium, iron, sodium, and potassium, suggesting that the bats gain essential nutrients. These nutrients may also neutralise the tannins of the mahua fruits[30].

Diet of insectivorous bats

A majority of Indian bat species are insectivorous (123 out of 135) (Chapter 1). Our literature review showed that diet studies on insectivorous bats from India are not biased towards any particular species, although some preference is seen towards studying bats that roost in caves or abandoned monuments (perhaps due to the ease of collecting guano). Most studies have been conducted by analysing morphological remains of insect orders in faecal pellets, while some studies dissected bats and identified insect remains in the gut[31][32]. Through both methods, insects and other arthropods can only be identified up to the order or family level (in rare cases, to the species level). Irrespective of the bat species, a vast majority of insectivorous bats prey on Coleoptera (beetles), Lepidoptera (moths and butterflies), and Diptera ("true flies", such as mosquitoes, midges, and botflies). The selection of these insect orders likely reflects their availability (i.e., insects of these orders are more abundant than others) [31][32]. Whitaker et al. (1999) attempted to correlate natural insect abundances with the diet of the Least Pipistrelle (*Alionoctula tenuis*) (*Pipistrellus mimus* in their paper)[33]. However, the insect diversity observed on their light trap was quite different from those in the bats' diets, perhaps a reflection of differing attraction propensities of different insect orders to the light source used[33].

Insect remains collected from the roost of Lesser False Vampire Bats (*Megaderma spasma*). Photo: Aswathy Nair & Harish Prakash

Diet studies conducted over a year showed distinct peak proportions of certain insect orders and families, often observed whenever the diet was tracked for an entire year. For example, Greater Mouse-tailed Bats (*Rhinopoma microphyllum*) and *Alionoctula tenuis* consumed a lot of ant and termite alates during the monsoon season[32][33]. Additionally, in *Alionoctula tenuis*, an unidentified scarabaeid beetle was detected as the most common prey from late April to late August[33]. This period coincides with the parturition and the growth of *A. tenuis* pups in peninsular India. The diet of the Lesser

Mouse-tailed Bat (*Rhinopoma hardwickii*) showed marked differences across seasons. In Rajasthan, this species consumed Orthoptera and Coleoptera in summer, termites in the monsoon season, and Coleoptera in the post-monsoon season[31]. Some of the seasonally-consumed insects in the diets of *Rhinopoma microphyllum* and *R. hardwickii* are known agricultural pest insects, such as *Holotrichia* spp. (white grub beetles) and *Amsacta moorei* (a species of tiger moth)[31][32]. The Lesser False Vampire (*Megaderma spasma*) near Kudremukh Wildlife Sanctuary switches to consuming large moths from its routine diet of katydids during the wet season[34][35]. In the East Khasi Hills of Meghalaya, the Great Evening Bat (*Ia io*), one of the largest members of the Vespertilionidae family in India, seasonally shifts to a bird-rich diet predominantly in March[36]. This was the first documented record of carnivory in *Ia io*. Its selection for birds as prey coincided with the onset of the local dry season and the return migration of wintering birds. During the rest of the year (especially in winter), the main diet of *Ia io* was composed of beetles[36].

Diet of rare, threatened, or endemic species

Although few in number, some studies have been conducted on rare, range-restricted, and endangered bat species. Through a radio telemetry study on the little-known Nicobar Flying Fox (*Pteropus faunulus*), Aul et al. (2007) found that this species fed on *Artocarpus lacucha, Bentinckia nicobarica, Ceiba pentandra, Diospyros* sp., and *Psidium guajava*, among others, across seasons[37]. Although it remains unpublished, this study currently contains the sole information available on the diet of *Pteropus faunulus*. Vanitharani (2015) documented the diet of Salim Ali's Fruit Bat (*Latidens salimalii*) by sampling leftovers in three cave roosts and found that the bats fed on seeds and seedlings belonging to 34 plant species, including Western Ghats endemics such as *Cullenia exarillata*. Other fruits that were recorded were fruits found in the diets of other peninsular Indian fruit bats[38].

A recent study on the diet of four *Hipposideros* species utilised DNA metabarcoding to identify prey organisms to the species level, which revealed the presence of 49 taxa belonging to 10 orders with no overlap in the diet[39], though another study on the same bat colonies showed overlap in their diet based on order-level identification of prey organisms[40].

Blanford's Fruit Bat (*Sphaerias blanfordi*), a rare species with no published information on its diet. Photo: Rohit Chakravarty

Opportunities for Diet Studies in India

Although diet is among the better studied aspects of bat ecology in India, several open questions remain - some of academic value, others of conservation relevance. Most importantly, it must be noted that, except for one study that used DNA metabarcoding[39], all dietary studies to date have relied on conventional morphological identification of prey remains. As discussed above, this approach is known to be biased towards hard-bodied insects or harder fruits or seeds that have a higher probability of being undigested. Moreover, prey can only be identified up to the order or family level. Considering the ways in which the fields of diet and trophic ecology are evolving globally, we recommend the following opportunities for Indian bat researchers:

Diet of range-restricted, threatened, or data deficient species

Specialisation on certain prey species can often restrict the geographical range of species. This may be true for some of our endangered bat species. Such studies also have the potential to guide conservation policies. The top-priority threatened species identified for this theme are Salim Ali's Fruit Bat, the Nicobar Flying Fox, the Nicobar Leaf-nosed Bat (*Hipposideros nicobarulae*), and the Andaman Horseshoe Bat (*Rhinolophus cognatus*).

Additionally, several data deficient or unevaluated species may also benefit from studies on their distributions and diet. These include the Sombre Bat (*Cnephaeus tatei*), the Meghalayan Thick-thumbed Bat (*Glischropus meghalayanus*), Peyton's Whiskered Bat (*Myotis peytoni*), the Rainforest Tube-nosed Bat (*Murina pluvialis*), Peters' Tube-nosed Bat (*Harpiola grisea*), the Cryptic Woolly Bat (*Kerivoula crypta*), Srini's Long-fingered Bat (*Miniopterus srinii*), and Wroughton's Free-tailed Bat (*Otomops wroughtoni*). If non-endemic Least Concern species (based on the International Union for the Conservation of Nature's Red List of Threatened Species) are taken into consideration, the absence of published studies on the diet of Blanford's Fruit Bat (*Sphaerias blanfordi*) from anywhere in the world provides an opportunity for Himalayan bat researchers.

The role of bats as insect pest controllers

Most prior studies missed the opportunity to identify insect pests since conventional morphological diet analysis only permitted identification up to the order or family level. We recommend using DNA metabarcoding to identify pest insects. Ideal model organisms for such a study are common, synanthropic, and/or gregarious species, such as *Alionoctula* spp., *Rhinopoma* spp., and *Taphozous melanopogon*. Such studies may be implemented in different crop types (e.g., Bhalla et al. 2023[41]) and have the potential for quantifying the economic value of bats, which can further influence policy and public opinion in favour of bats (Chapter 10).

Quantification of bat pollination and seed dispersal

There are many studies on the diets of common and rare fruit bats, yet very little is known about how this diet translates into ecosystem functioning or acts as an ecosystem service (Chapter 10). We recommend studies quantifying the extent of bat pollination and seed dispersal for keystone and culturally- and commercially-important tree species. Examples of trees for which there is anecdotal evidence of bat pollination or seed dispersal are *Oroxylum indicum, Elaeocarpus angustifolius, Gynocardia odorata*, and *Canarium resiniferum* (B. Basu pers. comm.).

Comparisons of diet and nutrition in urban vs. rural areas

Except for Srinivasulu and Srinivasulu (2005)[42], we could not find any studies comparing the diets of the same species in urban vs. semi-urban or rural areas. Such studies will have the potential to help us understand the propensity for urban adaptation among our common bat species. Additionally, these studies may also help us understand the hidden consequences of urbanisation (e.g., through reduced or enhanced nutritional quality of the diet). We recommend investigating how artificial light influences bats' foraging behaviours and diets, especially in urban and semi-urban environments where light pollution might change insect availability and disrupt typical bat foraging patterns.

Dietary niche partitioning in animal communities

Competition and coexistence of ecologically similar species are fundamental themes in ecology. There is a severe dearth of studies on niche partitioning in Indian bats (with the exception of Chakravarty et al. 2023[43]). While this topic is largely academic, quantifying the dietary niches of bats allows us to identify dietary specialist species (e.g., *Plecotus homochrous* and *P. wardi* in the western Himalayas[43]). As explained above, specialist species may be at greater risk due to human-made or stochastic threats.

Dietary preferences during breeding and non-breeding seasons

This will help uncover bats' nutritional requirements during different life stages (e.g., non-breeding, pregnant, and lactating)[44]. This research can also enhance our knowledge about how bats are adapting to changes in food availability in changing habitats. Such insights are essential for conservation planning, enabling targeted habitat management, supporting healthy bat populations, and sustaining the valuable ecosystem services that bats provide.

Impact of pesticides on resource availability and health

Agricultural pesticides reduce and change the distribution of insect populations and other prey organisms for many species of bats. Hence, these chemicals reduce the prey availability for bats and force them to travel further in search of food, affecting their fitness and population health in the long-term (Chapter 15). Also, in feeding on insects contaminated with pesticides, bats bioaccumulate chemical residues that affect them adversely (Chapter 9)[45].

Challenges

The opportunities mentioned above are not free of challenges. Major challenges for dietary studies of bats in India are briefly as follows:

Sampling or field survey challenges

Direct observation of bats during foraging is a non-invasive and cost-effective method to study their diet ecology. However, this approach is often impractical due to the nocturnal nature and high mobility of bats, making it difficult to observe their foraging activities. Furthermore, India's rich bat diversity and their wide range of habitats necessitate varied sampling strategies, adding logistical complexity.

In addition, researchers face a number of environmental challenges. For example, many bat roosting sites are not accessible during the rainy season, which makes it difficult to explore their diet across seasons. It is important to understand their diet over the long-term because bats usually demonstrate seasonal changes in food.

High cost of advanced tools

Traditional methods, such as analysing prey remnants in faecal pellets under a microscope, are limited in precision and typically allow identification only up to the order level due to the effects of digestion. In contrast, advanced techniques like DNA metabarcoding enable identification of prey to the genus or species level, making it the most effective tool to date. However, the high cost of DNA metabarcoding often renders it inaccessible to Indian researchers.

Lack of resources

Insufficient funding for basic ecological research, such as dietary studies of bats, is a significant hurdle for Indian researchers. Additionally, there is a shortage of skilled professionals in bat research, such as trained laboratory personnel. Also, we lack baseline data for prey and plant diversity and abundance in bat foraging habitats, which is critical for comprehensive dietary studies.

Societal and cultural challenges

People from many parts of India view bats as a bad omen and fear getting diseases from bats, which makes it hard to conduct field work in urban, semi-urban, and rural areas.

Bureaucratic and logistic constraints

Research on rare and lesser-known bats in the Andaman and Nicobar Islands is hampered by bureaucratic and logistic hurdles.

To address these challenges, researchers and conservationists must explore collaborations with relevant stakeholders, including government bodies, academic institutions, and funding agencies (Chapter 12). Strategic partnerships and capacity-building initiatives can help overcome the barriers described above and advance bat dietary research in India.

Chapter 6
Habitat Use of Indian Bats

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“Habitat” is defined as the physical environment where a species lives and has access to essential resources for its survival and reproduction, such as food, water, shelter, and mates[46]. Therefore, the selection and use of a habitat is critical to the survival of a species. India is home to a vast variety of habitats, ranging from cold deserts to scrub and dry deciduous forests to tropical and temperate rainforests[47]. The high diversity of habitats results in a rich diversity of wildlife, including bats.

Unfortunately, habitat loss is one of the greatest threats to wildlife today[48]. More than half of the world’s threatened bat species are impacted by activities such as logging, urban development, mining, and dam construction that lead to habitat loss[49]. This only includes species for which sufficient information is available. Eighteen percent of the world’s bat species are data deficient[49], and many species have not been evaluated by the International Union for Conservation of Nature’s Red List of Threatened Species (IUCN Red List), which means that we do not know the true number of bat species that are impacted by habitat loss.

Across biodiversity hotspots in India, habitats are being lost to make way for linear infrastructure, human settlements, and mining projects (Chapter 15). According to Global Forest Watch, between 2002 and 2024, India lost 21,300 km^2 of tree cover. This statistic does not include the modification of dry thorn forests and savannas that are spread across much of peninsular India. In India, where ecological research on bats is in its early stages and habitat loss is escalating, there is an urgent need to investigate habitat use to inform conservation measures. In this chapter, we review the current state of knowledge on the habitat use of Indian bats and outline some key opportunities for the coming years.

Roosting Habitats

Bats spend most of their time roosting. Roosts are not only important for sleeping but also for hibernation and mating, rearing young, and other social interactions[50]. Therefore, bats select their roosts carefully, considering key factors such as the risk of predation, microclimate, space available for breeding and hibernation, and commuting distance to their foraging grounds[51][52][53][54]. Multiple studies show that several species, genera, and families of bats frequently select specific types of roosts, with some taxa even exhibiting morphological or anatomical adaptations for occupying specialised roosts like hollow bamboo culms and rolled up leaves[20]. In this chapter, we broadly categorise the roosts of bats as “caves”, “plants”, and “human-made structures”. Below, we discuss the classification of these roosts and the association of Indian bat species with each of them.

Caves as roosts

Bats are among the most well-known animals to inhabit caves. The stable microclimate and diversity of microhabitats within caves provides protection from environmental fluctuations, reduces predation pressure, and supports diverse bat communities[55]. Apart from roosting, different bat species use caves for breeding, hibernation, or both[56]. Indeed, the largest congregations of bats, and mammals as a whole, are found in caves (e.g., Bracken Cave in Texas, United States[57]). The large numbers of bats also shape cave biodiversity as bat guano is a key source of nutrition for countless cave-dwelling arthropods (Chapter 10)[58].

In India, species belonging to all nine endemic bat families have been observed roosting in caves[21]. The most widespread and commonly encountered cave-roosting bats are *Rousettus leschenaultii, Rhinolophus lepidus, Hipposideros fulvus, Hipposideros speoris, Hipposideros lankadiva, Rhinopoma hardwickii,* and *Taphozous melanopogon*[1][21]. *Nyctinomus aegyptiacus* and several species of the family Vespertilionidae (especially *Myotis* and *Alionoctula* spp.) also roost in caves across the country but are harder to detect as they typically squeeze into cracks and crevices[21].

While the bats listed above are common across much of India, some species of cave-dwelling bats are more prominent in specific regions. For example, in addition to the above species, *Rhinolophus rouxii* and *Rhinolophus beddomei* are frequently observed in caves in the Western Ghats[21][59]. Robber's Cave in Mahabaleshwar, Maharashtra houses perhaps the largest known roost of *Miniopterus phillipsi* with an estimated 1,00,000 individuals during the breeding season[59]. In the Himalayas and Northeast India, *Hipposideros armiger* is one of the most common cave-roosting bats[60][61]. Meghalaya is renowned for its high density of caves, which support a rich diversity of cave-roosting bats. Several bats that are rare in the country, such as *Coelops frithii, Hipposideros khasiana, Otomops wroughtoni, Myotis altarium, Myotis pilosus,* and *Miniopterus magnater*, have been reported from caves in Meghalaya[61]. In the Andaman Islands, the most common and widespread cave-dwelling bats are *Eonycteris spelaea, Rhinolophus andamanensis,* and *Hipposideros gentilis*[62][63][64].

Several threatened and endemic species are also known to roost almost exclusively in caves. The critically endangered *Hipposideros hypophyllus* (classification per the IUCN Red List) is known from only one cave at the base of a granite hill in Kolar district, Karnataka[65]. *Hipposideros durgadasi*, an endemic species classified as vulnerable on the IUCN Red List, is also found in the same cave as *Hipposideros hypophyllus* and in another narrow cave on a limestone hillock in Jabalpur district, Madhya Pradesh[66]. All known roosts of the endangered *Latidens salimalii* are in caves in Kerala and Tamil Nadu and are situated in dense forests with low human disturbance, either near streams or with streams flowing under the roost[67][68]. The largest roost of *L. salimalii* in Mankulam, Kerala is on a steep overhang[69], while another one in Sholayar (also in Kerala) is in a vertical slit on a rockface[68]. All observations indicate that moisture and predation avoidance play an important role in the species' roost selection. In the Andaman Islands, the endemic *Rhinolophus andamanensis* and *Rhinolophus cognatus* (both endangered per the IUCN Red List) have been reported from a variety of limestone caves, with the latter species being less common and range-restricted[62][63][64][70]. *Hipposideros nicobarulae,* endemic to the central and southern Nicobar Islands, has been reported mainly from seashore caves[71].

Although there are a number of opportunistic observations and occurrence records for several other species of cave-roosting bats from across the country, any quantification of the drivers of roost selection (e.g., microclimate, surrounding landscape features, interspecific interactions, human disturbance) are generally lacking for both threatened and non-threatened species.

Plants as roosts

Despite the importance of caves as roosting habitats, the majority of Indian bat species use plants for roosting at least some of the time[59]. Bats use various plant parts as roosts, including exposed branches, clusters of leaves, leaves that are naturally rolled up or those that bats can bite to furl into a tent (e.g., palm fronds), tree holes, bamboo culms, and flaking bark[20][72]. It is difficult to quantify the number of plant-roosting bat species as plant roosts are usually harder to detect than cave roosts. In addition, bats that roost on plants often change their roosts frequently[73]. In temperate areas, plant-roosting bats often shift to caves for hibernation[74].

The most familiar tree-roosting bat in mainland India is *Pteropus medius,* which commonly roosts around human habitations[1][21]. Indian Flying Foxes have been observed roosting on a variety of exotic and native tree species of varying heights, canopy cover, and girth[75]. In the Andaman and Nicobar Islands, *Pteropus melanotus* and *Pteropus hypomelanus* are the primary flying foxes that rely on trees for roosts. *Pteropus melanotus* primarily roosts in mangroves, while *P. hypomelanus* uses tall trees on isolated islands[37][59].

Apart from the flying foxes, several other species across different families also roost in trees and foliage. *Saccolaimus saccolaimus* has been observed roosting in holes in palms such as *Areca catechu* and *Caryota urens*[21]. From observations made in Europe, we know

Greater Short-nosed Fruit Bat (*Cynopterus sphinx*) roosting under a palm frond. Photo: Nithin Divakar that *Nyctalus leisleri*, which also occurs in the Himalayas, roosts and hibernates in tree holes[59]. In Southeast Asia, *Scotophilus kuhlii* often roosts in palm leaves and tree hollows, whereas *Myotis muricola* has been observed inside tightly rolled-up leaves[59]. However, all of these species also roost in houses, rock crevices, or caves[59].

While many species of bats use plants facultatively for roosting, there are others that show morphological or anatomical characteristics that aid in their use of plant roosts. The orange pelage and particoloured wing patterns of *Kerivoula picta, Hesperoptenus tickelli,* and *Myotis formosus* are thought to help camouflage these bats against dried leaves amidst which they typically roost[21][59]. *Cynopterus sphinx* and C. *brachyotis* make "tents" in which to roost by biting through large leaves (typically palm leaves) to fold the leaf inwards, making them the only two known tent-making bat species in India[76]. *Tylonycteris* spp., *Glischropus meghalayanus*, and *Eudiscopus denticulus* have thick thumbs and foot pads with which they cling to the inside of bamboo culms[21][59]. Additionally, the flattened skull of *Tylonycteris* spp. is thought to help these bats enter bamboo culms through narrow holes made by beetle larvae[21][59]. However, despite these morphological, anatomical, and behavioural characteristics, these species do not strictly associate with these specific roosts. The orange-coloured bats, the bamboo-associated species, and both *Cynopterus* species have been variously observed roosting in fresh foliage, weaver bird nests, rock crevices, and buildings[21][59][76].

Among India's endemic or threatened species, only *Pteropus faunulus* is positively known to primarily roost on plants[37]. This species typically roosts singly, well-camouflaged in tall canopies (~20-30 m) within dried leaves. Tree species on which *P. faunulus* roosts have been observed are *Sandoricum koetjape, Fagrea racemosa,* and *Buchanania* sp.[37]. Three of the six day roosts described for Nicobar Flying Foxes were within 2 km of the nearest village[37]. Aul (2002) also found a colony of 25 *Rhinolophus cognatus* roosting in a hollow "teepok" tree (probably a dipterocarp found in the Nicobar Islands)[70]; however, the species appears to be more partial to caves where it forms larger colonies[63][70]. Several data-deficient species such as *Cnephaeus tatei, Harpiola grisea, Murina pluvialis*, and *Myotis peytoni* also likely roost in tree holes, foliage, and other similar vegetative roosts, but there is currently no data on their roosting ecology.

Human-made structures as roosts

Several human-made structures serve as roosts for bats. These include mines, tunnels, rock-cut caves, bridges, culverts, several parts of houses (e.g., crevices in outer walls, gaps in wooden frames, tiled roofs), and abandoned buildings[20]. Most species that roost in human-made structures, especially in mines, tunnels, and abandoned buildings, are commonly also found in caves. For example, Saikia et al. (2011) found colonies of typically cave-dwelling *Rhinolophus ferrumequinum*, *Rhinolophus affinis*, and *Miniopterus fuliginosus* in tunnels in Himachal Pradesh (notably, in Barog Tunnel along the Kalka-Shimla route)[77]. *Myotis longipes* has also been observed roosting in a tunnel in Kashmir (T.A. Shah pers. obs.). *Megaderma spasma* is commonly observed roosting in bunkers that were constructed by the Japanese army during World War II in the Andaman Islands[70] and in abandoned parts of houses (e.g., attics) in the Western Ghats[35][78]. The only record of *Asellia tridens* in India comes from a capture made in a tunnel in Jaisalmer district, Rajasthan[79].

By far, the largest bat colonies in human-made structures in India are encountered in historical monuments, including rock-cut caves. The most gregarious colonies in monuments, with over a thousand individuals, are formed by *Rousettus leschenaultii*, *Rhinopoma microphyllum, Rhinopoma hardwickii,* and *Taphozous melanopogon*[21][80][81][82]. In the temples of Tirunelveli and Thoothukudi districts, Tamil Nadu, *Hipposideros speoris* is the most common and abundant roosting bat species[83]. Other species commonly observed in these temples include *Rousettus leschenaultii, Rhinopoma hardwickii, Hipposideros speoris, Lyroderma lyra, Taphozous melanopogon, Nyctinomus aegyptiacus*, and *Alionoctula* spp.[83]. The only known roost of *Rhinolophus hipposideros* in India is in Bumzuva Cave, Kashmir, which is a rock-cut cave (T.A. Shah pers. comm)[84].

Bats also roost in cracks, crevices, and other narrow dark spaces in human-made structures. *Alionoctula* spp. are most frequently encountered in such roosts[21]. For example, a colony of *Alionoctula ceylonicus* was discovered roosting behind a wooden beam in a house in Nagpur (R. Chakravarty unpublished data). The molossid species *Nyctinomus aegyptiacus* and *Tadarida insignis* have been observed roosting in crevices or behind vertical pipelines in old stone buildings, such as the Fergusson College campus in Pune, the Forest Research Institute (FRI) in Dehradun[21][85], and the Indian Institute of Science (IISc) main building in Bengaluru (R. Chakravarty pers. obs.).

These opportunistic observations have been further corroborated by Ganesh et al. (2022)'s study on roost selection patterns, which quantified microhabitat selection of bats roosting in temples in Tamil Nadu[83]. *Hipposideros speoris* and *Lyroderma lyra* roosted in all chambers of the temples, while *Rhinopoma hardwickii, Taphozous melanopogon,* and *Rousettus leschenaultii* selected wide walkways, and *Alionoctula* spp. and *Nyctinomus aegyptiacus* chose crevices[83]. Despite the widespread appropriation of human-made structures as roosts by several Indian bat species, it is unclear whether these bats use human structures as roosts by choice or due to a lack of suitable natural roosts.

Foraging Habitats

While some species of bats are easily observed at their roost, their nocturnal activity, which includes use of their foraging habitat, remains largely unknown. Much of what we know about the foraging habitats of Indian bats stems from opportunistic captures in mistnets and harp traps. While useful, the inferences drawn from these observations are usually biased. It is difficult to determine whether bats were simply caught while commuting, were roosting nearby, or were indeed foraging in the habitat. Additionally, traps are usually placed in areas where bats might be easier to catch (e.g., along trails or waterways) and not necessarily where they forage[86]. Very few studies have systematically sampled bat communities in different habitats through trapping or acoustic recordings (or both) or have tracked individuals through very high frequency (VHF) or Global Positioning System (GPS) telemetry to quantify the habitat selection of various species[78][87][88][89]. In this section, we review insights from studies that aimed to measure foraging habitat selection or use by Indian bat species.

Forests as foraging habitats

Employing a systematic, multi-year study design, Wordley et al. captured bats and acoustically recorded their activity in the heterogenous landscape of the Valparai plateau in the southern Western Ghats[87][88]. The authors found that species like *Megaderma spasma* and *Rhinolophus beddomei* occur exclusively in forested habitats, including forest fragments amid tea plantations[87][88]. The preference of *Megaderma spasma* for forested foraging habitats over open habitats in heterogenous landscapes was corroborated by a radio telemetry study in the Western Ghats of Karnataka[78]. The endemic and endangered *Hipposideros pomona* was also found in forested fragments and riparian corridors in tea plantations[87].

To date, the only published data on the foraging habitat use of Himalayan bats comes from Bhutan, where bat activity has been systematically monitored in five habitats (old-growth forest, remnant forest, citrus orchard, corn field, and paddy field) using acoustic surveillance[90]. The open space foragers *Scotophilus kuhlii*, *Taphozous* spp., *Otomops wroughtoni*, and *Nyctalus leisleri* were active across all habitats. *Scotophilus kuhlii* and *Taphozous* spp. foraged extensively in citrus and corn fields[90]. *Rhinolophus perniger* was only found in forested habitats, wherein its activity was ten times higher in old-growth forests than in remnant forests[90]. In Kedarnath Wildlife Sanctuary of the Indian Himalayas, passive bat detectors have been deployed in three forest, forest-edge, and open habitats at 1,500 m, 2,000 m, 2,700 m, and 3,500 m above sea level (asl) from March to May in 2018 and 2019 (R. Chakravarty unpublished data). The feeding activity of *Myotis muricola* was detected in forested habitats at 2,000 m asl and 2,700 m asl. *Murina aurata* and *M. huttoni* were also detected only in forests. *Barbastella darjelingensis* was recorded in edge habitats across elevations and in an open alpine meadow, while *Tadarida insignis* and *Alionoctula babu* were active in all habitats across all elevations. *Rhinolophus* spp. were rarely detected: *Rhinolophus perniger, R. sinicus,* and *R. pearsonii* only in forests, and *R. lepidus* in both forests and open habitats (R. Chakravarty unpublished data).

Apart from in the Himalayas and the Western Ghats, bats' foraging in forest habitats remains poorly studied in India. Although wing morphology and acoustics can be used to predict clutter-adapted species[91][92], empirical data on their habitat use from much of India is lacking.

Open habitats as foraging habitats

Acoustic monitoring studies from Tal Chhapar Wildlife Sanctuary in Rajasthan and an open lateritic plateau in western Maharashtra show that some common species that forage in open, dry environments include *Alionoctula tenuis*, *Scotophilus heathii, Nyctinomus aegyptiacus, Rhinolophus lepidus, Rhinopoma* spp., *Taphozous melanopogon*, and *T. nudiventris*[93][94]. In western Maharashtra, the data-deficient *Otomops wroughtoni* was also detected several times in open habitats during the dry and wet seasons[95]. In the Tal Chhapar Wildlife Sanctuary, bat activity was found to be associated with small water bodies[94]. Additionally, the two-season study (early summer and early winter) found that *Nyctinomus aegyptiacus* was active predominantly in early summer, while *Rhinolophus lepidus* was predominantly active in early winter, perhaps indicating seasonal migration[94]. As reviewed above, *Barbastella darjelingensis*, *Tadarida insignis*, *Alionoctula babu*, and *Rhinolophus lepidus* have all been detected in open habitats at varying elevations in the Himalayas of Uttarakhand (R. Chakravarty unpublished data).

Human-dominated landscapes as foraging habitats

Surprisingly few studies have monitored Indian bat activity in the urban areas. The most common fruit bats found in urban areas in India are *Pteropus medius* and *Cynopterus sphinx*. A study tracking the foraging activity of *Pteropus medius* during the summer at four foraging sites in Kolkata found high foraging activity with more than 100 individuals per night per foraging site[96]. *Ficus bengalensis* trees in the monitored sites attracted the highest number of foraging individuals[96]. Kezia (2024) acoustically monitored bat activity in urban and peri-urban areas of Bengaluru during the early summer[97]. Her results show that *Alionoctula tenuis* and *Scotophilus heathii*/*Alionoctula ceylonicus* (these two could not be conclusively told apart) were active in both urban and peri-urban areas, whereas *Nyctinomus aegyptiacus* and *Taphozous* spp. were significantly less active in highly built-up areas[97].

Apart from urban areas, agricultural fields and plantations are another example of human-dominated landscapes with high bat activity. For example, in paddy fields in Assam, 13,263 "bat passes" (an echolocation call sequence) were detected in 481 hours of acoustic sampling[98]. This study also found that landscape heterogeneity and distance to forest patches were positively associated with bat activity, while the amount of urban land within 1 km of sampling negatively affected bat activity[98]. These results have important implications for organic agroforestry practices. In Valparai plateau, Tamil Nadu, *Alionoctula ceylonicus*, *Miniopterus phillipsi*, *Miniopterus pusillus*, *Rhinolophus rouxii,* and *R. lepidus* were active in tea plantations[87][88]. Among fruit bats, *Cynopterus sphinx* and *Pteropus medius* are observed the most foraging in orchards and vineyards[21]. A study quantifying the damage caused by *Cynopterus sphinx* in vineyards estimated the damage at the periphery to be about 90%, while the central parts of the vineyards were practically unaffected[99]. Across plantations of cashew, areca nut, banana, and other fruits (e.g., mango, guava, sapota) in the Western Ghats, systematic tree watches showed that *Pteropus medius* accounted for more than 90% of the visitations[29].

Foraging habitats of endemic threatened species

Nicobar Flying Fox (*Pteropus faunulus*)

Aul (2007) conducted diet and radio telemetry studies on *Pteropus faunulus,* which is endemic to the Central Nicobar Islands[37]. Although the study is not peer-reviewed, this report serves as the only reference for the ecology of this rare, range-restricted, and endangered species. Individuals maintained home ranges of 31.63 – 1602 ha in which they appeared to track the fruiting of seasonal fruits (e.g., *Dillenia andamanica, Ceiba pentandra, Artocarpus lakoocha,* and *Psidium guajava*) rather than perennial fruits (e.g., *Ficus* spp.) in forests and near villages[37].

Salim Ali's Fruit Bat (*Latidens salimalii*)

Data on the potential foraging habitat of this endangered species endemic to the southern Western Ghats come from scattered mistnet captures[67][69][100]. Telemetry studies have not yet been conducted to measure the species' habitat selection. However, these fruit bats appear to maintain active night roosts less than 1 km from their day roosts[67]. This observation suggests that the home range of *Latidens salimalii* may not be very large (at least in certain seasons) and that the habitats surrounding its day and night roosts are representative of its foraging habitat. Both in Meghamalai and Agasthyamalai in Tamil Nadu, day and night roosts were situated in dense, broad-leaved montane forests at elevations above 460 m asl.[67]. Mistnet captures of *L. salimalii* also come from riparian forests and rainforest fragments in the vicinity of cardamom, tea, or abandoned vanilla plantations[100]. Multi-year mistnetting and harp trapping data from suitable habitats in Kerala and Tamil Nadu suggest that this species is rarely encountered in these regions[69][100].

Pomona Leaf-nosed Bat (*Hipposideros pomona*)

Multi-year mistnetting, harp trapping, and acoustic sampling data suggest that the foraging habitat of this endangered species, which is also endemic to the southern Western Ghats, is predominantly along riparian forests and trails in primary forest and forest fragments[69][87][88].

Pomona Leaf-nosed Bat (*Hipposideros pomona*).
Photo: Nithin Divakar

Apart from the above species, what we know about the foraging habitats of other threatened and data deficient species (per the IUCN Red List) comes from opportunistic mistnet captures, often only of single individuals. Telemetry studies are currently underway for the critically endangered *Hipposideros hypophyllus* and the vulnerable *Hipposideros durgadasi* (R. Puttaswamaiah and S. Devnikar pers. comm.).

Sensitivity to Anthropogenic Threats

Species threatened by urbanisation

The Economic Survey (2023-24) of the Government of India estimates that over 40% of India's population will live in urban areas by 2030. Despite the rapid urbanisation, the impacts of urban expansion and light pollution on Indian bats and several other wildlife remain relatively poorly studied (Chapter 16). Ensemble ecological niche modelling on a dataset comprising occurrences of 48 South Asian bat species from nine families showed that areas with high median night-time light (which can be correlated with high urbanisation) consistently emerged as less suitable habitats for bats[101]. In contrast, the model and field observations indicate that some species (e.g., *Pteropus medius, Cynopterus sphinx,* and *Alionoctula* spp.) appear to be more common near human habitations than away from them[21][59], possibly indicating that these species have adapted to urban areas.

However, it is often suggested that urban areas may act as ecological traps for some species of bats[102][103]. For example, Tella et al. (2020) recorded 300 electrocuted *Pteropus medius* over 925 km of power lines in Sri Lanka[104]. All electrocutions were recorded in the immediate vicinity of exotic fruiting trees in gardens. The authors suggested that, while *Pteropus medius* is adept at roosting and foraging in urban areas, the risk of electrocution pits urbanisation as a potential ecological trap[104]. In a recent study from Pakistan, *Escherichia coli* isolated from faecal samples of *Pteropus medius* in different habitat types were tested for antimicrobial resistance (AMR)[105]. Moderate to high AMR was recorded in five out of 12 tested samples with the level of AMR higher in bacteria collected from fruit bats in human-dominated landscapes and in areas with cattle and poultry farms[105]. This pattern of AMR raises concerns about the One Health impacts of urbanisation on a highly synanthropic species (Chapter 8).

More field studies are needed to compare bat diversities along urban-rural gradients to determine which species across the country are filtered out of assemblages with increasing urbanisation. Concurrently, future research should investigate the comparative benefits and hazards of urban, suburban, and rural habitat use by Indian bat species.

Species threatened by forest fragmentation

Studies from different parts of the Western Ghats indicate that *Megaderma spasma* and *Rhinolophus* spp. (especially *Rhinolophus beddomei*) depend on forest fragments and are, hence, vulnerable to habitat fragmentation[78][87][88][89]. Tea and intensely managed rubber plantations have the most drastic impacts on forest understorey bats in the Western Ghats[88][89]. Unfortunately, studies on the effects of forest fragmentation for bat species are lacking for other biodiversity hotspots where habitat loss is a growing concern (e.g., Northeast India and the Himalayas) (Chapter 15).

In general, bats with short and broad wings and high echolocation call frequencies or gleaning carnivorous bats are thought to be adapted to dense forests and similarly cluttered environments[91][92]. Several studies

Indian Flying Fox (*Pteropus medius*): a species likely to be susceptible to urbanisation. Photo: Tariq Ahmed Shah from other parts of the world have found that species adapted to these types of cluttered environments do not withstand high levels of forest fragmentation (see references in Meyer et al. 2016[106]). Examples of forest-adapted species in India belong to the genera *Murina* and *Kerivoula*[107][108]. However, not all species from these genera are found exclusively in dense forests (e.g., *Kerivoula picta* occurs in dry forests[59]). Consequently, studies are needed to identify Indian species that are the most vulnerable to forest fragmentation.

Species threatened by roost disturbance

It is obvious that any bat species can be threatened by disturbance to its roost. However, different species may tolerate different levels of disturbance. This tolerance may vary by the time of the year, for example, due to differing roost requirements during breeding or hibernation[109]. Moreover, resilience to disturbance is also likely to vary within and across species[110][111].

Insights on the impacts of roost disturbance on Indian bats are limited to anecdotal records and informed assumptions. In Gupteswar Cave, Odisha, Debata et al. (2021)[112] monitored bat species richness and abundance as well as tourist visitations for a year. Their findings showed that peak tourist visitations (1,500–2,500 tourists per day) coincided with the peak breeding seasons of *Rhinolophus lepidus*, *Hipposideros ater, Hipposideros brachyotus, Lyroderma lyra,* and *Taphozous melanopogon*[112]. In Baratang, Andaman Islands, Aul et al. (2014) observed that, between 2003 and 2006, cave-dwelling bats had evacuated the caves in which tourism had taken place[62]. Although the specific taxa of cave-dwelling bats were unnamed, they likely included the endemic *Rhinolophus andamanensis,* which is common in the archipelago[62].

Based on undated records from Bates and Harrison (1997), monuments such as Champa Baoli in Madhya Pradesh and Kanheri Caves in Maharashtra previously had colonies of *Taphozous melanopogon* and *Rousettus leschenaultii,* respectively[21][84]. None of these colonies exists today, possibly due to burgeoning tourism pressure at these sites. In the absence of systematic roost monitoring for bats inhabiting historical monuments, it is hard to be sure of the causes of colony decline or roost abandonment in different species across India.

Some species of bats are known to hibernate or to enter torpor periodically in the northern parts of the country that have temperate winters (per the Köppen climate classification). In northern India, *Rhinopoma microphyllum* and *R. hardwickii* have been observed to be in torpor or hibernation in forts and monuments[113], where they are prone to be disturbed by humans. Arousal from hibernation can often be fatal for hibernating animals[114].

Species threatened by renewable energy expansion

Solar and wind power are the fastest growing renewable energy sectors in India. As of August 2025, India ranks third globally in installed solar power capacity (approximately 119.02 GW) and fourth in installed wind power capacity (approximately 51.67 GW)[115][116]. As a part of India's climate commitments, efforts are being made to achieve 500 GW power capacity through renewables by 2030[117]. Unfortunately, "green energy" projects are exempt from Environmental Impact Assessments (EIAs) as per Indian law. Therefore, the impacts of renewable energy on bats must be treated as an extremely pertinent issue for bat conservation, especially in the coming decade in India (Chapter 15).

Despite the rapid expansion of wind energy projects, their impacts on Indian bats remain poorly studied. In Kutch, Gujarat, Kumar et al. (2013)[118] found two carcasses of *Rhinopoma microphyllum* in 918 carcass searches (51 turbines sampled 18 times each) over a year. In a similar search effort over a year in Chitradurga and Gadag districts, Karnataka, Kumara et al. (2022) found four carcasses of unidentified bats[119]. By incorporating data on the mean duration for which carcasses persist before being scavenged, Kumara et al. (2022) estimated the combined fatality rate of birds and bats to be 0.26 animals per turbine per year[119]. While sampling for bird carcasses in the Thar Desert, Rajasthan, Roy et al. (2025) detected eight unidentified bat carcasses in 630 carcass searches[120]. While these results may not seem alarming, the above studies have not accounted for searcher efficiency, and it is likely that these mortality statistics are underestimates[121][122]. On the other hand, it is also possible that the estimates are close to the true mortality rate in certain regions. Considering the dry, arid, or semi-arid habitats, it is likely that bat activity was inherently low (see[93][94]), thereby reducing the probability of individuals colliding with turbines.

Unlike wind turbines, solar panels do not cause any direct mortality to bats. However, solar power projects cause large-scale habitat modification, which is likely to impact insect diversities and, hence, foraging opportunities for bats. In England, bat activity (but not species richness) was found to be lower for six species in solar farms than in the surrounding landscape[123]. In contrast, in Hungary, species' activity was not reduced in solar farms, but species that are less adapted to anthropogenic habitats (e.g., *Myotis* spp. and *Barbastella barbastellus*) seemed to avoid solar farms[124]. To date, no studies have investigated the direct or indirect impacts of solar farms on Indian bats and their habitat use.

So far, no globally threatened bat species has been detected in the vicinity of wind or solar farms in India. However, Jayakumar and Chakravarty (2025)[95]reported multiple acoustic detections of *Otomops wroughtoni* (a Schedule I species under the Wild Life (Protection) Act, 1972) at Chalkewadi plateau, Maharashtra. The recently discovered *Miniopterus phillipsi* is also likely to occur near wind turbines in peninsular India and the Western Ghats based on its distribution and habitat use patterns[21]. Another species of interest is *Scotoecus pallidus*, which is endemic and patchily distributed in semi-arid areas of Pakistan and India. Very little is known about the species' habitat ecology[59], including whether it is susceptible to being threatened by wind or solar energy projects.

Opportunities for Habitat Ecology Research in India

India's vast and diverse landscape presents immense opportunities to explore bat habitat use, particularly in the light of increasing habitat modification and fragmentation. Below are the key areas where further research in habitat ecology can contribute significantly to bat conservation efforts in India.

Quantifying foraging habitat selection

Much of what we know about the habitat use of Indian bat species comes from observations at the roost or opportunistic captures in different habitats. Many data-deficient species are only known from single captures, which preclude an IUCN Red List assessment. Very few studies have systematically sampled bat species or communities in heterogenous landscapes or over gradients of different land use types to quantify habitat selection by different bat species. We recommend that researchers prioritise such studies on threatened, endemic, and data-deficient species.

Investigating the impacts of land-use change

Further to the above point, the same study design can be used to quantify the impacts of land-use change on different species of bats by quantifying changes in species richness and abundance. Wordley et al. (2015)[87] and Deshpande et al. (2021)[89] are great examples of such studies from the Western Ghats, which should be replicated in other biodiversity hotspots. These studies have the potential to identify which species of bats are susceptible to land-use changes. While changes in bat community composition are a simpler way to understand the impacts of habitat fragmentation, they do not present the full picture. In a global review of habitat fragmentation studies on bats, Meyer et al. (2016) recommend that, wherever possible, researchers must also aim to quantify the impacts of fragmentation on gene flow, genetic diversity, immune responses, parasite loads, and ecosystem service provisioning[106]. In biodiversity hotspots such as the Western Ghats and Northeast India, researchers are also encouraged to design their studies around forest fragment size and fragmentation history to identify species that may show resilience to forest fragmentation. The impacts of habitat fragmentation are also poorly studied globally for species with specific roosting requirements, such as *Tylonycteris* spp. and *Glischropus meghalayanus*. For example, studies on the selective extraction of bamboos and its impacts on bamboo-adapted species are presently quite relevant.

Hodgson's Myotis (*Myotis formosus*) hibernating in a cave.
Photo: Rohit Chakravarty

Investigating roost site selection

Studies incorporating measurements of microclimatic conditions in roost sites, habitat variables of the surrounding landscape, resource availability, and human disturbance variables can generate an extremely meaningful understanding of roost site selection by various Indian bat species. Knowing what different species look for while selecting their roosts can help develop scientific measures for their conservation[125]. To facilitate such studies, researchers must collaborate to create databases of bat roost locations. The easiest species to study are those found in urban areas and in archaeological sites. For example, there are very few studies investigating the drivers of roost site selection of our most familiar bat, *Pteropus medius*. Another question of academic and conservation interest is whether bats choose to roost in historical monuments out of choice or due to the lack of natural roosts.

Surveying and monitoring hibernacula

Further, in regards to the study of roost site selection, it is particularly important to understand roost selection during specific life stages of bats. Roosts that are used for resting are often different from the ones selected for hibernation[60]. The timing of hibernation, the species that hibernate, factors that determine the selection of hibernacula, and threats faced by hibernacula are all open questions in the Indian context. We recommend more surveys to map hibernacula so that roost selection can be studied and the hibernacula can be protected from disturbance. While these studies are most pertinent in the Himalayas (Baniya et al. 2024 serves as a great example from Nepal[60]), *Rhinopoma* spp. are also known to hibernate in historical monuments in northern India[113], where they may be particularly vulnerable to disturbance.

Researching habitat use in poorly studied ecosystems

Habitats in which sampling bats is challenging (e.g., mountains, mangroves, arid zones) remain largely unexplored in terms of bat species richness and activity. Systematic sampling across different elevations is lacking both in the Himalayas and in the Western Ghats, which restricts our knowledge of the elevational distributions of Indian bats. Knowing present-day elevational distributions of bat species is crucial for identifying future range expansions of bats due to climate change (Chapter 16). Considering the scientific evidence for bats' pollination of certain mangrove species[126][127], studies investigating habitat use of bats in Indian mangrove ecosystems are also likely to contribute valuable data on ecosystem services (Chapter 10).

Challenges

The challenges in conducting research on the habitat use of Indian bats are predominantly of scientific, bureaucratic, and logistical natures. In addition, there is growing acknowledgement of the urgency in investigating habitat selection of endemic and threatened species, yet these studies are impeded by the absence of comprehensive regional call libraries and call identification keys. Therefore, it is not surprising that the State of India's Bats participants unanimously voted that the building of comprehensive call libraries are a top research priority for this decade (Chapter 16). Despite over a century of bat research in the country, baseline data (e.g., consolidated databases of occurrence locations and echolocation calls) are still much needed.

Acoustic monitoring is not a viable option for fruit bats and insectivorous bats that call at very high frequencies. In such cases, telemetry studies are the more viable option. However, tiny transmitters that fit the weight criteria of bats are expensive and not readily available domestically. Moreover, permits are needed from both the forest department(s) and the telecommunications department(s), which may drastically slow down the project's timeline. When the study species is legally protected (e.g., *Latidens salimalii* and *Pteropus faunulus*), the process of obtaining these permits can be even more arduous, hindering the development of scientifically-guided conservation solutions.

Conclusion

While these challenges may sound demotivating, Global South researchers are known for their creativity in converting challenges into opportunities. We are confident that Indian bat researchers are also doing the same. For example, domestic innovators are jumping on the bioacoustics, big data, and artificial intelligence (AI) bandwagons to develop indigenous, low-cost recorders and telemetry devices. "BatEchoMon", developed by Kadambari Deshpande and Vedant Barje, and "Bat-Eye", developed by RV College of Engineering, Bat Conservation India Trust, and the Centre for Wildlife Studies, are examples of outstanding innovation. Additionally, Indian researchers are forming international collaborations and embedding themselves in global networks more than ever before, which will help reduce the challenges and enhance the opportunities in all areas of bat research.

Chapter 7
Movement Ecology of Bats

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Animals move in search of and to defend resources (e.g., food, mates, and shelter) and to escape predators[128][129]. Since a species' survival depends on its movement, studying where, how, when, and why they move is crucial to understanding their spatial and temporal needs and planning for conservation action. Animal movement also contributes immensely to various ecosystem services that positively impact human lives.

Traditionally, research on movement ecology was dominated by ringing individuals of various taxa at a continental scale. Although recaptures are low, these banding studies have contributed immensely to our understanding of migration, especially of birds and bats[130][131][132]. Other ways in which researchers have tracked the movement of animals across continents is through the analysis of stable hydrogen isotopes[133]. Stable hydrogen isotope ratios vary latitudinally across continents due to precipitation gradients[133]. Anecdotal evidence of the elevational migration of bats over time has also been obtained by acoustic surveys[134]. However, studies conducted on such broad scales are unable to identify the reasons for and patterns of fine-scale habitat use and the routes taken by long-distance migrants. The usage of weather radars to monitor flying foxes has been effective in understanding long-term movement in Australia[135].

Published studies in movement ecology have grown by leaps and bounds globally in the last two decades. Two main contributing factors to this development are the movement ecology paradigm framework, which holistically attempts to address why, how, when, and where animals move[136], and advances in technology using satellites and miniaturised Global Positioning System (GPS) tracking devices with multiple sensors[137][138][139]. These have resulted in an increasing number of publications in the field[5][140] but also addressed varied research questions that could not be tackled earlier. For example, studies have identified the routes of a migrating species across countries, continents, and even hemispheres[141][142][143]. Tracking animal movement is also necessary for evaluating conservation decisions, such as if protected areas meet the species' spatial needs, since organisms are unlikely to be confined to specific boundaries[138][144].

East Asian Free-tailed Bat *(Tadarida insignis)*. Photo: Rohit Chakravarty

Studies on bats have been conducted in various contexts in the last few years to address both large-scale and fine-scale movement. To cite some examples, bat species have shifted their overall range to a higher elevation due to climate change[145], changed their foraging across seasons based on insect resource availability[146], and moved between cave roosts for social interaction[147]. In urban areas, where food resources are scarce, bat species might slow their food acquisition rate in comparison to rural areas[148]. For exhaustive reviews, we point the readers to various chapters in bat textbooks[149][150][151].

Bat Movement Studies from India

The first known published movement study, specifically of navigation, of bats in India was carried out from 1976 to 1977 on four insectivorous bat species: *Rhinopoma microphyllum*, *R. hardwickii*, *Taphozous perforatus*, and *Hipposideros fulvus*[152]. The study, using visually-marked individuals, showed that their homing ability decreases as the distance from the bat species' roost increases[152]. However, the bats in the study were only visually marked, and their movement was not tracked using any transmitters.

Movement studies using transmitters in Chiroptera began in the 1980s in India. However, they have been confined to two taxonomic families: the Pteropodidae (fruit-feeding bats) and the Megadermatidae (insect- and small vertebrate-feeding bats). Species belonging to these families weigh above 20g. One of the reasons for studying these species was likely because tracking devices for heavier bats are readily available and relatively affordable.

All studies (except one) tracked bat species using Very High Frequency (VHF) radio transmitters. Radio-tracking involves catching the bat in its foraging habitat or roost, glueing the radio transmitter onto its back, and then releasing the individual. The radio signals are then tracked using receivers, and the position of the tagged animal is triangulated. Despite being relatively inexpensive and suitable for tracking small mammals, like insectivorous bats, VHF telemetry is labour-intensive and does not offer relatively fine-scale information of an animal's location when compared to satellite or GPS technology. In addition, satellite or GPS transmitters can be programmed to obtain locations over a continuous stretch of time, whereas the frequency of movement information using VHF is dependent on manual observers following the tagged individuals. Thus, the choice of movement tracking technology is based on the questions asked, the species studied, logistics, and available funding.

Pteropodidae

The first movement study conducted in India for a bat species focused on the Indian Flying Fox (*Pteropus medius*) using VHF radio transmitters (unpublished, see supplementary table in Habib et al. 2014[6]). The first published study on this species was from Sri Lanka and described the difficulties of tracking the species and the feeding movement of two individuals[153]. The most recent study tracked the movement of *P. medius* using GPS tags and showed that the moon phase did not impact the time the bat species spent outside the roost, the distance commuted, or the number of patches visited[154].

Multiple studies have examined the movement of smaller fruit bats belonging to the genus *Cynopterus*[155][156][157][158][159]. Since this genus has the social structure of a harem, studies have examined how males and females differ in their movement from their roosts. Females of *Cynopterus sphinx* emerged earlier from the roost and had a greater average foraging distance and lower roost fidelity than did males[159]. Additionally, females of *C. sphinx* also used multiple foraging locations, while males used only one foraging location and stuck close to their tent roosts[160]. Similarly, females of *Cynopterus brachyotis* commuted longer distances than did males and used more than one foraging area[161]. In addition, a study of *Rousettus leschenaultii* in China also found females foraging over multiple areas and commuting farther away from the roost than did males[162].

Megadermatidae

Bat species belonging to the family Megadermatidae feed on insects and small vertebrates and typically roost in caves and tree hollows but are also found in abandoned buildings in human-altered landscapes[21][84][163] (Chapter 6). Females of the bat species *Lyroderma lyra* showed less fidelity to their cave roost than did males across multiple years[164]. Both males and females in their sister species *Megaderma spasma* showed fidelity to their roosts in buildings within a single season[165]. *Lyroderma lyra* also foraged mostly within 500 m of its roost, and males and females showed differences in the time they spent foraging[166]. Individuals of the species *M. spasma* tracked using

VHF radio transmitters also foraged within 500 m of their roosts, specifically selecting forest patches over plantations in a heterogeneous, human-altered landscape[78][165]. Insect prey availability was suggested as the main factor driving this decision to select forests[78], but their foraging in forests might be due to their short-broad wing morphology, which is well-suited for flying in cluttered habitats[92]. Additionally, individual *M. spasma* showed fidelity to the forest patches in which they foraged at night and the roost in which they rested during the day[165].

Opportunities for Conducting Bat Movement Studies in India

Two of the essential ecological pieces of information needed to develop conservation action plans are an estimation of bats' home ranges and the identification of the specific habitats in which they forage, roost, and travel across. Of the 135 bat species found in India (Chapter 1), to date, only six species (~4%) have been tracked, emphasising the need to focus on more species, thus expanding opportunities. However, tracking all bat species across the country is impossible and probably unnecessary. Instead, to optimise the use of limited resources, future research should prioritise bat movement studies based on the following factors:

The need to understand the ecosystem functions contributed by different bat species.
These include studies tracking the pollination and seed dispersal potential of flying foxes and other fruit bats and analysing the foraging activity of insectivorous bats in agricultural landscapes (Chapter 10).

Species that are under threat or are likely to be declining.
Understanding the habitat used by critically endangered and/or endemic species is crucial in terms of conserving both the species and their habitats. Some examples of these priority species are *Hipposideros hypophyllus*, *Pteropus faunulus*, *Latidens salimalii*, and *Rhinolophus cognatus* (Chapter 16).

Lesser False Vampire Bats *(Megaderma spasma)*. Photo: Harish Prakash

Species that are likely associated with zoonotic disease spillovers to aid in an understanding of their local and seasonal movements.
For example, fruit bats in areas with high zoonotic disease transmission risk, such as in Kerala, should be a priority subject of movement ecology research. The resulting data will enhance our understanding of potential interfaces for disease transmission, which is the first step towards devising mitigation measures. Tracking studies of individuals have the scope to identify sites visited by infected individuals if the individuals are sampled appropriately. This would enable the direct mapping of locations with high(er) risk of secondary disease transmission to humans or intermediate hosts (Chapter 7).

Potential migratory species.
Some key migratory bat taxa for future studies include *Taphozous* spp., *Rhinopoma* spp., *Tadarida insignis*, and other Himalayan species that may migrate elevationally.

Species that are under threat from wind turbines.
Bats are attracted to forest gap habitats with wind turbines and face the threat of collision with turbine blades[167] (Chapter 15). Tracking bat habitat preferences and their flyways will help balance new green energy infrastructures and conservation priorities.

Use of alternate tracking methods without the involvement of costly transmitters.
Low-cost devices, such as Bluetooth low-energy (BLE) beacons, could potentially be used for tracking bats in urban areas[168]. Wherever possible, researchers must consider using alternative means of answering movement ecology questions. Passive acoustic monitoring of echolocating species can be used effectively to understand habitat selection and movement over smaller geographical areas. Collaborations with weather stations to use radar data will be valuable to study the movement of the Indian Flying Fox, a species that is harder to study due to epidemiological and practical concerns. Researchers should also consider leveraging the potential for citizen science in gathering nationwide data to track potential movements of flying foxes (Chapter 13). Wherever researchers are engaged in periodic sampling of bats, they should consider banding bats (with due precautions and training) to understand local or long-distance movement.

Challenges in Conducting Bat Movement Studies in India

There are some clear downfalls in applying tracking technology; while it can give the most fine-scale data on home range, habitat use, and migratory corridors, the costs and paperwork are prohibitive. Also, according to international recommendations, trackers and attachments to animals should not exceed 5% of an individual's body weight[169], severely limiting both the range of species that can be equipped with trackers and the battery life of GPS devices. New technology is being developed to reduce the weight of GPS transmitters with sensors; however, the prices of the tags are nearly five to ten times more expensive than radio transmitters, further limiting their accessibility. Another barrier to conducting movement ecology studies is put in place through restrictions from the country's telecommunication departments for using imported devices that transmit and receive information at different frequencies. This situation highlights the need for collaboration with local engineers and electronics and telecommunication experts in India to develop such devices within the country. This approach can reduce the costs and limitations of the currently available technology and enable custom solutions for difficult-to-track species (e.g., due to weight limitations, biological considerations). In addition, using nationally-built devices would circumvent issues related to national telecommunication regulations, ensuring that devices can be used across the country.

Conclusion

There is a definite need to fill knowledge gaps on bat movement ecology in India. Limited resources and available equipment currently make it difficult to implement studies using high-resolution tracking technology. Thus, the future of studying bat movement ecology in India should take advantage of India's fast growing technology sector, creating collaborations and partnerships between ecologists, conservation managers, and engineers, as well as enhancing public awareness.

Chapter 8

Disease Ecology Research on Indian Bats: Status and Future Prospects

Authors: B.R. Ansil and Darshan S.

Background

Bats perform key ecological functions by providing ecosystem services such as pollination, seed dispersal, pest control, and nutrient cycling through guano[10][170] (Chapter 10). At the same time, some bat species are also known reservoirs for zoonotic pathogens, such as Hendra virus, Nipah virus (NiV), and severe acute respiratory syndrome (SARS)- like coronaviruses (CoVs) among others[171]. Some of these pathogens cause serious disease in humans and other mammals[172]. Recent studies suggest a long history of coevolution of bats with these pathogens, and unique physiological adaptations facilitate bats to carry these pathogens without manifesting evident symptoms[173]. In recent years, there has been a growing concern about disease transmission from bats to humans, especially in tropical regions, where bat diversity is high and natural habitats are being rapidly converted to human landscapes, leading to frequent human–bat interactions[174]. These factors can individually or collectively increase the risk of pathogens jumping from reservoir to susceptible species (spillover)[175][176]. Therefore, understanding the complex relationships between bats, pathogens, and the environment is crucial for preventing or mitigating spillover risks while also conserving these enigmatic mammals and the ecosystems they support. Globally, bat biologists and disease ecologists are working together to decipher this complex system, with a motivation to balance biodiversity conservation and public health priorities.

Leschenault's Rousettes *(Rousettus leschenaultii)* roosting in a monument in Delhi. Photo: Rohit Chakravarty

In India, research on bat-associated diseases is emerging, with a few institutions taking the lead in studying bat species diversity, their role as reservoirs, and the range of pathogens they harbour. Some of the earlier efforts have identified the presence of a diverse group of viruses in Indian bats, including the NiV, CoVs, and lyssaviruses, which include the viruses that cause rabies[177][178][179]. Human infection with these viruses can lead to respiratory (i.e., CoVs and NiV) and neurological illnesses (i.e., NiV and rabies). Among these, NiV poses significant public health risks due to intermittent spillover events that often result in fatal human cases[172]. Such events have prompted researchers and authorities to intensively sample bat populations to identify the reservoir species, pathogen prevalence (i.e., the proportion of individuals carrying a specific pathogen at a given point in time), and their genetic diversity. However, many critical questions persist: Why have spillover incidents increased alarmingly in the last two decades? Could similar events have been missed in the past? Is there any association between bat biology and changing environmental variables that might be triggering these spillover events? Answering these questions demands a multidisciplinary approach grounded in strong ecological and evolutionary principles, incorporating tools from epidemiology, virology, microbiology, physiology, immunology, climate science, animal behaviour, landscape ecology, mathematical modelling, and other fields.

State of Knowledge of Pathogens in Indian Bats

In 1969, a group of researchers isolated Kyasanur Forest disease virus (KFDV), a tick-borne pathogen endemic to southern India, from *Rhinolophus rouxii* and its ectoparasites[180]. This was part of a broader effort to solve the mystery of human infections linked to this virus and to identify its reservoir hosts. Although KFDV was isolated from *R. rouxii*, these bats were not confirmed as reservoirs for this virulent virus. Despite few studies reporting other known pathogens, bats remained largely out of the limelight for the next three decades until 2001, when NiV outbreaks happened in West Bengal, India[181] and Bangladesh[182]. Subsequent studies confirmed the presence of NiV in *Pteropus medius* and identified consumption of date palm sap contaminated with bat urine as the primary route of human infection in this region[183][184]. Date palm sap consumption is a common cultural practice in this part of the subcontinent.

Following these discoveries, several subsequent studies began to focus on other pathogens in Indian bats, reflecting the growing recognition of their potential as zoonotic reservoirs. In this section, we summarise the current knowledge of bat-borne pathogens in India, highlighting some key bat–pathogen systems as well as current research needs and challenges.

Nipah virus (NiV) in Indian bats

Recognising its public health significance, NiV has become a priority subject for biomedical research. The 2018 outbreak in Kerala[185] served as a catalyst, intensifying research efforts in disease ecology and surveillance, which led to several Indian studies on NiV. Similar to the West Bengal outbreak, NiV has been detected in *P. medius* near the outbreak epicentre in Kerala[178]. Additionally, studies from South and Southeast Asia have provided serological evidence (i.e., the presence of antibodies) indicating previous exposures to NiV in several species of fruit and insectivorous bats including *Cynopterus sphinx*, *C. brachyotis*, *Eonycteris spelaea*, *Rousettus leschenaultii*, *Hipposideros pomona*, *H. larvatus*, *Scotophilus kuhlii*, *Rhinolophus affinis*, and *Rhinolophus sinicus*[186]. Using a trait-based machine learning approach, Plowright et al. (2019) predicted that four additional Indian bat species (*Taphozous longimanus*, *T. melanopogon*, *Rhinolophus perniger*, and *Mops plicatus*) are likely to be exposed to NiV or NiV-like viruses[186]. While these species have not yet been sampled for NiV testing, a subsequent study in Maharashtra detected NiV RNA and antibodies in co-roosting *Rousettus leschenaultii* and *Pipistrellus pipistrellus*, suggesting additional Indian species with NiV presence and exposure[187].

Although *P. medius* has been identified as a reservoir species for NiV, the exact transmission mechanism from bats to humans in Kerala remains unknown[188][189]. It has been hypothesised that handling or consuming bat-bitten fruits may serve as a potential spillover route; however, there is currently no evidence to support this hypothesis, necessitating further research in this direction. In addition, comprehensive studies are needed to understand the role of other sympatric species as potential reservoirs for NiV and their role in intermittent outbreaks. Beyond identifying spillover pathways, it is also crucial to understand the key drivers of such spillovers in different socio-ecological settings[29][190].

Serological evidence for filoviruses in Indian bats

Filoviruses are a group of RNA viruses that include Marburgvirus, for which bats are recognised reservoirs[191]. Some members of this family have been implicated in causing severe haemorrhagic fevers in humans and non-human primates. Studies from Africa and Asia suggest pteropodid bats are primary reservoirs for some of these viruses[191][192]. However, the reservoir species for some filoviruses, as well as the transmission routes from known reservoirs to humans, remain to be conclusively established. In 2013, a study from Bangladesh provided serological evidence of filovirus exposure in *Rousettus leschenaultii*[193], a fruit bat species also found in India. Aligning with these findings, Dovih et al. (2019) found serological evidence of filoviruses in the fruit bats *R. leschenaultii* and *E. spelaea* from northeast India and serological evidence in people involved in traditional bat harvesting, suggesting previous human exposure to bat filoviruses in the region[194]. However, filoviruses have not yet been isolated from bats in India, and, to date, there are no documented cases of human illnesses associated with these viruses in the country.

To advance these findings, future research should prioritise active surveillance of filoviruses in bats and humans in India, especially in regions with significant human–bat interactions. Longitudinal studies focusing on bat species with known exposure can help pinpoint periods of elevated pathogen presence within colonies, thereby enabling targeted sampling for viral genetic material. Analysing viral sequences from such samples could offer critical insights into the spillover risk and will help strengthen preparedness for zoonotic outbreaks.

Coronaviruses (CoVs) and other clinically important viruses

Coronaviruses are another group of viruses of public health significance that have been identified in Indian bats[179]. They are among the most diverse groups of viruses, found in both mammals and birds[195]. These viruses cause respiratory illnesses and are primarily transmitted through respiratory droplets and contaminated surfaces. The World Health Organization (WHO) classifies CoVs as priority pathogens[196]. Among these, sarbecoviruses (SARS-like CoVs) and merbecoviruses (Middle East Respiratory Syndrome-like CoVs) are known for their zoonotic potential, with rhinolophid and vespertilionid bats serving as their primary reservoirs[197]. Large-scale empirical studies identify bats as an important reservoir group and suggest that CoV diversity is positively influenced by bat diversity[198]. To date, only one study on bat CoVs has been published from India, describing CoV diversity in *Pteropus* sp. (possibly *P. medius*, given

Indian Rufous Horseshoe Bat (*Rhinolophus indorouxii*). Photo: Nithin Divakar.

the study's focus on mainland India) and *Rousettus* sp. across multiple states[179]. Phylogenetic analysis from this study revealed the presence of multiple lineages of bat CoVs in these fruit bats. These results, along with emerging global research, suggest a high likelihood that many novel bat CoVs hosted within India's bat diversity remain to be identified[199]. Given the bat-associated evolutionary origin of several pathogenic CoVs[197], characterising this diversity is crucial; therefore, research should prioritise undersampled bat species and geographic regions for CoV surveillance.

In addition to the above-mentioned viruses, a few opportunistic studies have reported other clinically-important viruses in Indian bats. In May 2020, 52 *P. medius* individuals were found dead in the Gorakhpur district of Uttar Pradesh, with heat-induced brain haemorrhage as the likely cause of death[200]. Samples collected from these bats were subsequently tested for Japanese encephalitis virus (JEV), and 15% tested positive[200]. Japanese encephalitis virus is a mosquito-borne disease of public health concern in India, with several northern and southern states facing significant high incidence rates annually[201][202]. Although JEV was detected in *P. medius*, it could not be concluded that these bats serve as a reservoir for JEV in India nor could it be confirmed that JEV was the direct cause of bat deaths in this case. However, this study expands the known host range for JEV and raises important questions, such as the role of bats in the natural maintenance of JEV, the potential effects of JEV on open-roosting bats, and how rising temperatures during summer months in India may exacerbate these effects. Considering that heat stress-related mortality in bats is reported annually across the country (e.g., Dey et al., 2015[203]), focused efforts are needed to better understand the role of extreme weather events and their association with pathogen presence in bats (see Opportunities, below).

Bacterial diversity

Like other wildlife reservoir species (e.g., rodents), bats harbour various bacterial pathogens[204]. These pathogens can be transmitted among bats as well as to humans and other mammals either directly or through environmental exposure (e.g., as in some species of *Mycoplasma* and *Leptospira*) or via vectors (e.g., as in some species of *Rickettsia*, *Bartonella*, and *Borrelia*)[205]. Some of the bacterial pathogens associated with wide-ranging Indian bats have been investigated in studies conducted outside India. For example, a study conducted in Malaysia examined ectoparasites collected from various fruit and insectivorous bat species, including *E. spelaea*, *C. brachyotis*, *R. affinis*, and *R. pusillus*, to determine the presence of *Bartonella* spp., bacterial pathogens known to cause disease in humans[206]. The study reported a high prevalence and diversity of *Bartonella* spp. in bat flies, highlighting their potential role as vectors for this pathogen[206]. A similar study from Bangladesh focused on *P. medius* and their bat flies observed an increasing prevalence of *Bartonella* and bat flies corresponding to the larger proportion of young bats in the population, suggesting demographic factors can be used as predictors for pathogen occurrence[207].

Studies on bacterial pathogens associated with Indian bats are limited, with only a few focusing on the bacterial diversity in the gut microbiome. As part of NiV surveillance, Banskar et al. (2016) explored gut microbiomes of *R. leschenaultii, Cynopterus* sp. indet., *P. medius, Lyroderma lyra*, and *Rhinolophus* sp. indet. collected across several locations and revealed substantial overlap in gut microbiomes between insectivorous and frugivorous bats[208]. This overlap in microbial communities was unexpected considering the pronounced dietary and evolutionary differences between these two groups[208]. In addition to identifying characteristic bacterial groups in the gut, this study also detected the presence of *Mycoplasma* in these bats, with a notably higher abundance in *Cynopterus*[208]. Another such study combining bacterial culturing and sequencing of guano samples from *R. leschenaultii* detected the human pathogens *Escherichia coli* and *Staphylococcus aureus*[209]. A similar approach employed by Selvin et al. (2019) identified *Bacillus cereus* and *B. anthracis* from *Rhinolophus* bats[209]. Despite these detections in a limited number of species, the field remains largely underexplored with respect to bacterial diversity, the range of bat hosts studied, and the functional relationships between bat ecology and microbial communities. In addition to strengthening these research areas, targeting specific host-pathogen systems is also necessary to elucidate how bats acquire these microbes, determine their impacts on bat health, and evaluate their zoonotic potential.

Opportunities

Disease ecology studies involving Indian bats offer unique opportunities for the advancement of the field. Investigating 135 bat species (Chapter 1) across diverse ecosystems representing varied ecology and evolutionary history will be an ideal system for developing a better understanding of host-pathogen interactions and zoonotic disease emergence. Such high priority research should be implemented through a One Health approach, which integrates science and policy while examining how bat physiology and immunology interact with environmental factors (e.g., climate change) to influence bat health and spillover risk (Chapter 16).

One Health approach

The One Health framework represents an integrated and unifying approach designed to sustainably balance and optimise the health of humans, animals, plants, and ecosystems. It highlights the inherent interdependence between human health and the wider natural environment[210]. The growing interest in One Health in India (e.g., the National One Health Mission) creates promising avenues for disease ecology research. The interdisciplinary nature of this field, fostered through collaborations among ecologists, conservation biologists, epidemiologists, and public health researchers, has the potential to transform bat-pathogen studies and to add new dimensions to our current understanding. Additionally, having such an integrated and holistic approach will be essential for maximising public health outcomes while simultaneously addressing conservation priorities.

Research-to-policy integration

Findings from disease ecology research hold significant potential to inform public health policy. Identifying potential zoonotic risks and guiding surveillance efforts to strengthen preparedness against disease outbreaks are direct and immediate intersections of epidemiological science and public health policy and practice. Socio-ecological enquiries can assist in reconciling the trade-offs between the essential ecosystem services provided by bats and any zoonotic risks they might pose[29]. These integrated approaches can generate a more nuanced understanding for holistic disease management, including habitat management and conservation-informed One Health interventions aimed at minimising bat-borne zoonotic risks[29][190].

Bat physiology and immunology

As highlighted earlier, many pathogens have co-evolved with bats, and bats have unique physiological and immunological adaptations to overcome the adverse effects of pathogen presence[173]. Evolutionary studies further emphasise this association, revealing a significant integration of viral genetic elements within bat genomes[211][212]. While most focus goes into the discovery and detection of zoonotic pathogens, the specific trade-offs bats undergo to coexist with specific pathogens (e.g., NiV) remain poorly understood. Investigating bat physiology and immunity will offer insights into the mechanistic understanding of pathogen maintenance and the impacts of these pathogens on specific hosts and their populations.

Climate change, zoonoses, and bat health

Another intriguing area of research is the impact of climate change and extreme weather events on bat health and zoonotic disease risk (Chapter 16). Increasing temperatures allow vectors like mosquitoes, ticks, and flies to spread into new regions, raising the risk of pathogen transmission[213]. As hosts for various pathogens and vectors, bats may encounter these pathogens more frequently and potentially facilitate their persistence and spread. Furthermore, changes in the frequency and duration of heatwaves coupled with high humidity may inhibit thermoregulation and cause bat mortality (e.g., Dey et al. 2015[203]). Similarly, extreme cold events also pose risks to bat populations, though bats often cope with cold stress through thermoregulatory strategies (e.g., torpor, hibernation) or by migrating to warmer regions. However, the extent of bat diversity impacted by these climate extremes remains poorly understood. Also, there is limited understanding of how these conditions affect bat physiology, immunity, overall susceptibility to diseases (e.g., white-nose syndrome, a deadly fungal infection that devastated hibernating bat populations in North America), and shedding of pathogens.

Challenges

As highlighted above, research on bat disease ecology presents unique opportunities and directions. However, its success hinges on how researchers tackle inherent challenges posed by bat biology and pathogen research. Some of these challenges are outlined below.

Field sampling

Bats are highly diverse and occupy various habitats. This diversity creates logistical challenges for field studies, especially during the night when bats are the most active. Sampling at roosts can be an alternative here, but many bats inhabit inaccessible locations such as caves or tall trees, which adds further complexity to sample collection efforts.

High research cost

Research on bat-borne pathogens (in the field and laboratory) involves adhering to stringent biosafety guidelines and protective measures to safeguard researchers and society. Similarly, pathogen exchange from humans to bats is also a concern during bat handling. Therefore, these precautions are essential to ensure safety, but they also significantly increase overall research costs. Additionally, storing and transporting biological samples require specialised media and specific temperature control (cold-chain), further contributing to these high costs.

Low and varying prevalence of key pathogens

While many bat-borne pathogens can infect and cause illness in humans and other mammals, they may not cause disease in bats[214]. Importantly, not all individuals within a bat population will carry pathogens at a single time (e.g., Dhanze et al., 2022[200]). Instead, only a subset does, much like in other wildlife species that also host pathogens (e.g., rodents). Low prevalence of target pathogens (e.g., NiV) poses challenges to researchers by reducing the number of opportunities for the detection and surveillance of pathogens in bat populations. Prevalence can also fluctuate over space and time (e.g., seasonal variation) and can be influenced by various biological and environmental factors[215]. In such cases, larger sample sizes and spatial as well as temporal coverage are required, which can amplify logistical complexities.

Lack of ecological framework

Many studies on bat-borne pathogens are opportunistic, cross-sectional (data collection at a single time point), and often lack an ecological framework. This limits a deeper understanding of the complex ecological pathways involved in pathogen transmission and their dynamics. Additionally, host species are sometimes misidentified in studies, which is a critical limitation. Accurate identification of host species is essential as it carries significant implications for both public health and conservation. Addressing these challenges requires a well-coordinated, multidisciplinary approach and long-term commitment to effectively study bats and their role in pathogen maintenance.

Funding for disease ecology

Despite growing interest in bat-borne pathogens and their relevance to public health, limited funding support for disease ecology research persists. This is partly due to the novel and interdisciplinary nature of the field, situated at the intersection of health and ecological and conservation research. As a result, these studies are often not aligned with the goal of traditional health or conservation funding agencies. Additionally, understanding pathogen ecology within populations requires long-term studies not only on the focal species but also on other species within the ecological community. However, funding is often limited in duration and does not necessarily support the extended research needed to uncover the complexities of pathogen ecology.

Societal and bureaucratic challenges

The COVID-19 pandemic significantly increased the fear and stigma associated with bats, often portraying them just as pathogen reservoirs rather than an ecologically important species. This perception has fuelled negative public attitudes, in some cases leading to persecution of bats and reduced community support for their conservation (Chapter 14). At the same time, concerns about zoonotic spillover have translated into more restrictive regulations on studies of bats, their pathogens, and their ecology. While such measures aim to mitigate public health risk, they can inadvertently limit opportunities to conduct essential ecological and disease ecology studies, thereby constraining the very research needed to understand zoonotic risks more effectively.

Conclusion

In summary, disease ecology research on Indian bats is an emerging field with significant implications for both public health and biodiversity conservation. While current research has made substantial progress in identifying key pathogens and reservoirs, a comprehensive understanding of their ecological dynamics remains limited. India's unique bat diversity and existing research gaps present tremendous opportunities for advancement, mainly through interdisciplinary collaborations that bridge gaps between ecology and public health. However, these opportunities come with inherent challenges. Overcoming these challenges and deepening our understanding of interactions between bats, pathogens, and the environment will be crucial for advancement of the field, mitigating zoonotic risks and, at the same time, ensuring the continued conservation of these unique mammals.

Chapter 9
Toxicological Studies on Indian Bats

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Studies worldwide indicate that bat populations are declining[49][216]. A significant factor contributing to this decline is exposure to potentially toxic levels of contaminants. Specifically, exposure to organic contaminants, particularly pesticides, has been identified as a possible cause of bat population declines[217-225]. These effects manifest both directly through the bioaccumulation of pesticides and heavy metals, which causes physiological dysfunction, and indirectly via the reduction of insect prey populations. The latter represents an indirect pathway of contaminant impact, wherein pesticide-driven trophic disruptions lead to nutritional stress and altered foraging behaviour. Thus, toxic exposure, whether direct or mediated through prey depletion, constitutes a primary driver of bat population declines worldwide[226]. Studies to support these claims for bats in India are still greatly needed as bat toxicological studies in India remain limited.

The current chapter presents a comprehensive national assessment of toxicology studies on Indian bats along with a comparison to similar species in other countries and a global overview of bat toxicology research. Through this chapter, the questions I aim to address include:

- What are the different contaminants studied in different bats across India?
- What are the different scientific approaches adopted to study contaminant exposure in Indian bats?
- Should there be any alarming concern about the concentration of contaminants in any species?
- Are there any data on the effects of contaminant exposure on bats?
- Are there any particular trends in toxicology studies on Indian bats over the years?
- How do we navigate the current review of research in this field, and what is the way forward within the Indian context?

Background

Contaminants in the environment

Globally, environmental pollution is one of the leading drivers of species decline[49]. In the modern anthropogenic era of industrialisation, urbanisation, and population expansion, the global environment's poisoning by a complex mixture of xenobiotics (chemicals in an organism or environment that did not produce them) has become a major environmental threat worldwide. Pesticides, fertilisers, heavy metals (ionic state), trace elements (in excess), polychlorinated biphenyls, polycyclic aromatic hydrocarbons, persistent organic pollutants, and oil derivatives are prominent environmental contaminants found in soil, sediment, air, and water that adversely affect the environment, causing widespread ecosystem contamination by their long-term persistence and slow or no biodegradation in the ecosystems[227]. Contaminants of Emerging Concern (CECs) are another class of compounds that can be a problem, including microplastics, per- and polyfluoroalkyl substances (PFAS), and pharmaceuticals[45][228][229].

Eleven elements are recognised as the greatest concern for wildlife: arsenic, cadmium, cobalt, chromium, copper, mercury, manganese, nickel, lead, tin, and thallium[230]. The heavier metals, such as lead, mercury, arsenic, and cadmium, are amongst the most hazardous; however, even light metals such as aluminium and selenium can be toxic to living organisms at higher concentrations[227]. Defined as elements with a density greater than 6 g/cm^3 [231], heavy metals are widely utilised in industrial, agricultural, and domestic activities[232][233]. While some metals (e.g., iron and zinc) are essential nutrients[234], others (e.g., arsenic and mercury) are toxic[233]. Some heavy metals play no physiological role in living organisms and can be toxic even at low concentrations, while others are essential for biological functions but become harmful when present in elevated concentrations[235]. Further, while all heavy metals are potentially hazardous to health, local environmental conditions such as alkalinity, pH, or water hardness can affect both the bioavailability and toxicity of the elements[235]. In all living organisms, heavy metal ion levels tend to be strictly controlled at the cellular level[236] as free ions and can cause many serious problems, including oxidative stress or permanent signalling within the cell[237].

Pesticides and heavy metals are significant pollutants that negatively impact wildlife[238]. Farmers frequently apply these chemicals to enhance crop yields[239]. While pesticides are designed to target specific pests, they can also harm non-target species[240]. Organochlorine (OC) pesticides, introduced in the 1940s for agricultural pest control, faced restrictions and bans in the 1970s and 1980s due to concerns over their persistence and toxicity. Nevertheless, residues from these pesticides remain in the environment, and their use continues in some developing countries[241][242]. Similarly, polychlorinated biphenyls (PCBs) were commonly used until their ban in 1979. Chemical contaminants, particularly Persistent Organic Pollutants (POPs), are a growing threat to human health and the environment. Research indicates a connection between POPs levels and various diseases in humans (e.g., diabetes, obesity, endocrine disorders, cancer, cardiovascular and reproductive problems)[243][244][245]. This concern has prompted a global effort to control and ban POPs emissions through treaties and agreements. A key treaty in this regard is the Stockholm Convention of 2001, which many countries have signed to commit to protecting human and environmental health from POPs[246][247]. POPs primarily accumulate in living organisms through the consumption of contaminated water and food[248][249]. However, both accidental and incidental releases have led to their continued presence in the environment. Both OC pesticides and PCBs are included in the Stockholm Convention on Persistent Organic Pollutants (POPs)[250][251].

Contaminants are recognised as a significant global stressor on aquatic ecosystems[252][253][254], influencing emergence production, insect assemblage composition, the timing of adult insect emergence, contaminant levels in adult tissues, and the flux of contaminants across aquatic-terrestrial ecosystems via food web linkages[255][256][257][258]. There exists a strong correlation between terrestrial and aquatic ecosystems regarding the effects of toxic components. Different contaminants exert varying impacts on aquatic insects, which in turn affect terrestrial insectivores, including aerial insectivorous bats and other mammalian species[259]. The heavy metals that pose the greatest threat to aquatic ecosystems include copper, zinc, cadmium, mercury, and lead[260][261]. Understanding the mechanisms by which metals kill aquatic insects is critical for assessing contaminant transfer across linked aquatic–terrestrial ecosystems. As Kraus (2019) emphasises, emergent aquatic insects serve as a key trophic bridge, transporting nutrients and potentially contaminants from freshwater systems to terrestrial insectivores such as bats[259]. Metals like cadmium, mercury, and lead can disrupt insect physiology through oxidative stress, enzymatic inhibition, and neurotoxicity, leading to reduced emergence rates, impaired reproduction, and increased mortality. These effects not only diminish prey availability for terrestrial consumers but also elevate the risk of contaminant exposure via ingestion of metal-laden insects[259][261]. Thus, elucidating insect-level toxicity pathways is essential for predicting ecological consequences at higher trophic levels and for developing integrative contaminant risk assessments across ecosystem boundaries[259].

Alionoctula sp. roosting in a house. Photo: Nithin Divakar.

Health issues related to environmental xenobiotics affecting both humans and wildlife include neurotoxicity, immunotoxicity, nephrotoxicity, hepatotoxicity, genetic damage, decreased reproductive fitness, and cancer[45][227][262–265], and, unfortunately, many people are not fully informed about the toxicities of these substances and the routes through which exposure may occur.

Bat ecology and ecotoxicology

Bats are flying mammals found across a wide geographic area and occupy many different ecological niches. This diversity means they may encounter various contaminants, which can have different effects on their health[266][267]. Bats display a variety of feeding habits (Chapter 5), which enhances their role in providing ecosystem services like controlling pest insects in crops, managing disease-carrying insects, promoting pollination, and facilitating the seed dispersal of pioneer plants[268] (Chapter 10). They also play a significant role in redistributing nutrients and energy through guano in the ecosystem[269][270]. Additionally, bats feed at a high trophic level and possess a high metabolic rate, which increases their caloric needs and, consequently, their exposure to contaminants in food[271]. Some bat species thrive in urbanised areas, where their proximity to anthropogenic pollution sources heightens their risk of metal contamination[237](Chapter 6). These attributes make bats effective environmental bioindicators for contaminant exposure[271]. However, bats' nocturnal and elusive nature makes bat die-offs hard to detect (except for flying foxes).

Although bats may be vulnerable to both direct exposure and the indirect effects of contaminants, scarce data are available to allow for an evaluation of impacts on bats or to assess whether the roles of bats in the ecosystem are being lost as a result. Most of the published literature merely includes data on POPs concentrations, while very few studies have reported changes in bat health and behaviour[45][272]. Although most pollutants assessed in Tourquetti et al. (2021)'s literature review were banned in the 1970s, contamination was still reported in the years after 2000[272]. Residues persist in the environment today and, indeed, the use of banned contaminants continues in some developing countries[241][242].

Organochlorine pesticides (e.g., DDT, dieldrin, lindane) are highly lipophilic and environmentally persistent, leading to their bioaccumulation in fat-rich tissues and biomagnification up the food chain. As long-lived insectivores with

Wrinkle-lipped Free-tailed Bat (*Mops plicatus*) is known to feed on agricultural pests. Photo: Rohit Chakravarty high trophic positions and large fat reserves, bats are particularly vulnerable to these compounds. Studies have documented high OC residues in bat tissues, with associated effects including reproductive failure, endocrine disruption, and mortality[273][274]. In contrast, organophosphate (OP) pesticides (e.g., malathion, chlorpyrifos) are less persistent and do not bioaccumulate to the same extent. However, they act as potent acetylcholinesterase inhibitors, leading to acute neurotoxic effects. Experimental studies have shown that OP exposure in bats can cause ataxia, tremors, and spasms, impairing coordination and likely reducing foraging efficiency and predator avoidance[45][275]. These effects are particularly concerning in agricultural landscapes where bats forage over treated fields and consume contaminated insects.

The data available in the literature regarding accumulated pesticide concentrations suggests that bats are currently being exposed to lower concentrations than before[272]. The decrease in concentrations of OCs residues occurred mainly after the prohibition and restriction of the use of these insecticides[273]. There is a gap in the scientific literature on the contamination and effects of POPs recently listed in the Stockholm Convention (PFAS, bromides, and Short Chain Chlorinated Paraffins) as well as on emerging contaminants that have not been listed by the Convention (chlorpyrifos and pyrethroids)[276]. Despite the fact that certain POPs bioaccumulate in bats, few studies have investigated POPs as a possible threat to their health or a cause of behavioural changes. In one recent review paper, 55 of the 68 publications evaluated only recorded POPs residues and concentrations without reporting on their effects on individuals[276]. Several studies have demonstrated the sublethal impacts of pyrethroids on mammals[277–281], while others posed questions regarding their effects on bats[282].

Recent studies have increasingly demonstrated that neonicotinoid insecticides (NNIs) exert detrimental effects on bat populations through both indirect and direct mechanisms[283]. Indirectly, these chemicals reduce the abundance and diversity of insect prey, thereby limiting food availability for insectivorous bats and potentially disrupting foraging behaviour and energy balance. Direct exposure, though less frequently documented, has been associated with physiological and neurological impairments, including disruptions in echolocation, motor coordination, and immune function[283]. These findings underscore the broader ecological consequences of NNIs use and highlight the need for further investigation into their sublethal effects on non-target vertebrate species like bats, particularly those occupying critical roles in ecosystem functioning.

Current trends in toxicological research

Given the vital ecological roles that bats play, it becomes essential to investigate the health impacts on these animals from their exposure to significant concentrations of contaminants. Researchers across the globe are conducting both independent and collaborative studies to deepen our understanding of the ecotoxicology of bats, including but not limited to ongoing research that aims to:

- Investigate the patterns of metal and metalloid accumulation across different tissues of bats[284][285].
- Investigate the patterns of metal and metalloid accumulation across different bat species[284][285].
- Analyse the influence of diet on trace element accumulation in bats[284][286][287].
- Justify whether bats are good indicators of environmental pollution from metals and metalloids[237][288].
- Investigate the relationship between the years of various POPs bans and their effects on POPs concentrations in bat tissues[276].
- Identify the knowledge gaps existing for bat species and regions represented in formal toxicological studies[272][285].

Globally, most studies on bat toxicology have been conducted in the United States and Europe, which have lower bat species richness than the Global South. In Asia, less than ten papers each have been published on bat toxicology from China, Malaysia, Pakistan, and India. Brazil, even while having the highest bat species richness, still has only nine research publications[284][289]. The earliest publication in the field of heavy metals research on wild bat populations dates back to 1970, and it describes lead poisoning in three captive Australian fruit bats (Grey-headed Flying Fox, *Pteropus poliocephalus*) based on clinical and histological findings[290]. Since then, the number of research publications has steadily increased each decade. Notably, the publication rate of new studies on the ecotoxicology of metals in bats nearly doubled from 2010 to 2019, reaching 38 publications, followed by 19 more publications from 2021 to mid-2024, marking the highest growth period of trace element contaminant research in bat species[284]. These studies also encompass different habitats, such as caves (40% of the studies), forests (18%), and industrial areas (15%)[276].

Bats are increasingly exposed to a suite of anthropogenic stressors that may interact in complex and often synergistic ways, yet the combined effects of these exposures remain poorly understood. These stressors include heavy metals, organic pollutants, natural toxins, and infectious agents, all of which may co-occur in degraded habitats. While most ecotoxicological studies focus on single-contaminant effects, emerging evidence suggests that multi-stressor interactions can amplify physiological and ecological consequences. For instance, Skerratt et al. (1998) documented lyssaviral infection in *Pteropus alecto* individuals concurrently suffering from lead poisoning, raising concerns about contaminant-induced immunosuppression[291]. Similarly, Courtin et al. (2010) reported elevated levels of lead and arsenic in the liver tissues of bats affected by white-nose syndrome, suggesting that toxic metal exposure may exacerbate individuals' vulnerability to fungal pathogens[292]. These findings underscore the need for integrative research frameworks that move beyond single-exposure models to assess the cumulative and interactive effects of multiple stressors on bat health, behaviour, and population viability.

Trends in focal species

A literature review of global studies on the trace metals detected in bat tissues included 121 bat species belonging to 12 families[284]. While the majority of the studied species are insectivorous, a few studies were conducted on frugivorous species belonging to the families Pteropodidae and Phyllostomidae as well as carnivorous and sanguivorous species of Phyllostomidae[284]. The four most studied species were *Eptesicus fuscus* (insectivorous), *Myotis daubentonii* (insectivorous and carnivorous), *Myotis lucifugus* (insectivorous), and *Myotis myotis* (insectivorous). A recent review paper on POPs in bats indicated that 64 bat species were evaluated with over half in the family Vespertilionidae (~59%)[276].

Trends in sample type, sampling technique, methodology, and standard measurements

For metals and related elements: A recent review paper on trace elements in bats assessed 75 publications for their analysis of: metals (silver, aluminium, barium, beryllium, calcium, cadmium, chromium, cobalt, copper, iron, mercury, potassium, lithium, magnesium, manganese, molybdenum, sodium, nickel, lead, rubidium, tin, strontium, thorium, titanium, thallium, vanadium, tungsten, yttrium, zinc, zirconium), metalloids (arsenic, silicon), and nonmetals (argon, bromine, oxygen, selenium)[284]. This global review revealed that the following samples have been used for studying the contamination of metals, metalloids, and non-metals in bats: tissues (fur, liver, kidney, whole body, bone, brain, blood, stomach, muscle, heart, wing, lung, patagium, spleen, gut) and excrement (guano)[284]. Heavy metals have been analysed in various matrices with liver, kidney, whole body/carcasses, and guano[284]. Whole

Kashmir Cave Myotis (*Myotis longipes*), a species dependent on water bodies. Photo: Rohit Chakravarty body/carcasses or guano are frequently used as they offer sample sizes large enough for chemical analysis[237]. A review of the global literature indicates that bat tissues vary in terms of their accumulation of trace element constituents, with the highest concentrations in hair, followed by liver, kidney, and guano. Additionally, bat species may differ in their propensity to accumulate environmental contaminants[284]. In India, most research papers have analysed guano samples, while only a few have utilised tissue samples for their analyses (Table 9.1).

Further, the only two studies on bats' patagia for determining trace element concentrations come from India[293][294]. The studies reviewed by Giunta et al. (2024) exhibited inconsistent methodologies with no standardised procedures among research teams concerning sampling, tissue analysis, and reporting[284]. The only comparable parameter was found to be the measurement unit, expressed in ppm, µg/g, or mg/kg[284].

For pesticides and related compounds: According to Monteiro-Alves and his colleagues (2024), out of the 68 articles studied in their review paper, about 61% of the focal contaminants were classified as pesticides, 35% as industrial chemicals, and almost 10% as unintentional production chemicals[276]. The POPs more commonly assessed in the studies were dichloro-diphenyl-trichloroethane (DDT) and/or its metabolites (dichlorodiphenyldichloroethylene [DDE] and dichlorodiphenyldichloroethane [DDD]), followed by dieldrin and PCBs[276]. The reviewed studies confirmed the presence of various POPs in a variety of bat tissues (muscle, liver, kidney, brain, fat, fur, spleen, whole carcass), breast milk, and guano[276]. A review of the literature from India reveals samples taken from whole-body soft tissue[295] and guano[296] to evaluate pesticide exposure.

Organic contaminant studies have historically suffered from difficulties with compound identification, method variability, and interferences[273]. Multi-residue methods were used to analyse POPs in either bat muscles, liver, whole carcass, or hair in global studies[276]. The procedures used for analysing bat guano tend to focus on a limited number of pesticides, primarily older OCs, POPs, and OPs that are no longer in use. A similar limitation was observed in a recent Indian research study where the types of pesticides chosen for bat guano analysis were only OPs, OCs, and synthetic pyrethroids (SPs)[296]. This narrow focus on a small subset of related compounds restricts the analytical scope of these methods. Expansion of contaminant testing in bat populations has been recently facilitated by the development of a multi-residue method that enables the simultaneous quantification of 119 analytes, including a variety of pesticides, POPs, active pharmaceutical ingredients (APIs), polycyclic aromatic hydrocarbons (PAHs), UV blockers, plasticisers, and other emerging pollutants that can be detected in bat guano[297].

POPs concentrations in the literature are presented in ppm, ppt, mg/kg, g or µg/g of wet weight. A review of the global literature (not only that including bats) indicates that researchers commonly utilise two measuring units: nanograms per gram of wet weight (ng/g ww) and nanograms per gram of lipid weight (ng/g lw)[298]. It is recommended that these concentration measurements be standardised based on wet weight, while data on OCs should account for lipid concentrations given their lipophilic nature. Thus, both ng/g ww and ng/g lw can be used in this context[276].

State of Knowledge in India

In comparison to global research trends, India has shown a significantly lower rate of growth for toxicological studies on bats (see Figure 1 in Introduction to Section II). According to this literature review (see Introduction to Section II), India has eight publications in total on bat toxicology research, which are broadly trace element studies and with only three studies on pesticide residue analysis. The reviewed literature of India shows a regional disparity in research within the country. Four out of eight studies have been carried out in the southern region (with the very first being conducted in 1999 on *Alionoctula coromandra*), three studies since 2018 in the eastern region, and one from the northern region of India. Nonetheless, these studies encompass a variety of habitats, such as forests, agricultural areas, rural and urban settlements, industrial areas, and caves and mines.

Species studied

India is home to 135 species of bats belonging to nine families (Chapter 1). However, the available data for toxicology research studies on bats in India is limited to just nine species, although these species represent five families: Pteropodidae, Megadermatidae, Hipposideridae, Emballonuridae, and Vespertilionidae (Table 9.1). The most frequently studied species is the frugivorous bat species *Pteropus medius*.

Table 9.1 A review of available toxicological studies on different contaminant concentrations in various bat species studied in India.

Family	Species	Contaminants	Mean concentration		Maximum concentration			Sample Type	Location of the study	Reference (study year)
					In ppm					
					Site I	Site II	Site III			
Pteropodidae	*Pteropus medius* (n=4)	Cr	NR		-	-	26.3	Guano (dry weight)	Three roosting sites in Punjab - 1. Site I - Chatpat Bani, district Pathankot. 2. Site II - Village Katani Kalan, district Ludhiana. 3. Site III - Village Longowal, district Sangrur.	Kaur & Singh, 2024[296]
		Pb			-	-	10.03			
		Ni			-	-	9.2			
		As			-	3.7	-			
		Cd			-	-	1.72			
		K			16927.17	-	-			
		Mg			-	-	3516.1			
		Ca			-	-	1247.8			
		P			1173.52	-	-			
		Na			-	-	804.47			
		Fe			-	2069.45	-			
		Zn			-	126.02	-			
		Mn			-	85.05	-			
		B			-	-	80.05			
		Cu			62.38	-	-			
		OCs			<DL (<0.05)	<DL (<0.05)	<DL (<0.05)			
		OPs			<DL (<0.05)	<DL (<0.05)	<DL (<0.05)			
		SPs			<DL (<0.05)	<DL (<0.05)	<DL (<0.05)			
	P. medius (n=4)		Avg. mass (%)		NR			Guano (dry weight)	Rural and urban areas in Kerala - 1. Rural - Irinjalakuda, district Thrissur. 2. Urban - Mangalavanam Bird Sanctuary and Tripunithura, district Ernakulam.	Johnson & Vincent, 2020[301]
			Rural	Urban						
		K	35.3471	36.4112						
		Ca	21.221	21.1739						
		Fe	4.1669	6.8953						
		Zn	1.8369	0.5562						
		Cu	1.3149	0.1164						
		Al	<DL (≈0)	<DL (≈0)						
		Mo	0.0003	0.0002						
		O	27.7743	27.3338						
		Si	8.335	7.2244						
		Ti	<DL (≈0)	<DL (≈0)						
			In ppm							
		Hg	0.221#, 0.204#							
	P. medius (n=4)		Mean±SD (%)		(%)				A huge banyan tree (*Ficus benghalensis*) located at Moodbidri, southwest Karnataka.	Goveas et al., 2006[299]
		N	2.6 ± 0.5		3.3			Guano (dry weight)		
			3.3 ± 0.82		4			Bolus (dry weight)		
		P	4.2 ± 0.8		5.2			Guano (dry weight)		
			4.3 ± 0.6		5			Bolus (dry weight)		
		K	0.6 ± 0.04		0.7			Guano (dry weight)		
			0.7 ± 0.04		0.7			Bolus (dry weight)		

Table 9.1, continued

Hipposideridae	*Hipposideros speoris* (n=12)		Mean±SD (mg/g dw)				NR	Guano (dry weight)	Two roosting sites in Tamil Nadu - 1. Farm roost in Chinnampalli - an abandoned hut near a village (Varagoorankottai, Dharmapuri, India: 12°2′09″N, 77°58′05″E). 2. Mine roost in Salem - was in a natural cave where bauxite and magnesite were excavated (Vellakalpatti, Salem, India: 11°42′58″N, 78°07′02″E)	Murugan et al., 2021[314]
			Farm		Mine					
			Dry Season	Wet Season	Dry Season	Wet Season				
		Al	2.52 ± 0.40	3.28 ± 0.92	7.03 ± 0.60	7.10 ± 1.44				
		Co	0.66 ± 0.18	1.02 ± 0.02	2.05 ± 0.03	2.43 ± 0.74				
		Ni	0.24 ± 0.04	0.01 ± 0.01	0.51 ± 0.23	1.15 ± 0.08				
		Cr	0.02 ± 0.0	0.05 ± 0.05	0.61 ± 0.42	0.65 ± 0.45				
		Pb	0.01 ± 0.01	0.09 ± 0.02	0.47 ± 0.46	0.67 ± 0.38				
		Hg	0.01 ± 0.01	0.14 ± 0.06	0.14 ± 0.16	0.40 ± 0.37				
Megadermatidae	*Lyroderma lyra* (n=18)		Mean±SD (µg/g dw)				(µg/g dw)		District Cachar of Barak Valley, Assam	Rahman et al., 2020[294]
		Zn	53.4 ± 2.27				56.8	Kidney (dry weight)		
			45.6 ± 2.93				49.5	Liver (dry weight)		
			56.4 ± 3.15				60.7	Lungs (dry weight)		
			58.2 ± 3.42				62.4	Patagium (dry weight)		
		Cu	2.4 ± 0.35				2.9	Kidney (dry weight)		
			1.8 ± 0.36				2.5	Liver (dry weight)		
			3 ± 0.43				3.9	Lungs (dry weight)		
			1.8 ± 0.37				2.4	Patagium (dry weight)		
		Mn	1.3 ± 0.34				1.7	Kidney (dry weight)		
			1.2 ± 0.21				1.5	Liver (dry weight)		
			1.2 ± 0.25				1.6	Lungs (dry weight)		
			1.1 ± 0.27				1.7	Patagium (dry weight)		
		Fe	65.4 ± 2.58				68.7	Kidney (dry weight)		
			93.6 ± 2.81				96.6	Liver (dry weight)		
			35.4 ± 3.06				39.5	Lungs (dry weight)		
			16.8 ± 1.95				20.2	Patagium (dry weight)		
Megadermatidae	*Megaderma spasma* (n=4)		Avg. mass (%)				NR	Guano (dry weight)	Rural and urban areas in Kerala - 1. Rural - Irinjalakuda, district Thrissur. 2. Urban - Mangalavanam Bird Sanctuary and Tripunithura, district Ernakulam.	Johnson & Vincent, 2020[301]
		Al	5.5846							
		Ca	17.0122							
		Cu	0.4237							
		Fe	15.2537							
		K	3.1887							
		Mo	0.0002							
		O	39.3272							
		Si	16.8635							
		Ti	1.1079							
		Zn	1.2382							
			In ppm							
			Rural							
		Hg	0.189							

Table 9.1, continued

Emballonuridae	*Taphozous melanopogon* (n=4)		Avg. mass (%)		NR	Guano (dry weight)	Rural and urban areas in Kerala - 1. Rural - Irinjalakuda, district Thrissur. 2. Urban - Mangalavanam Bird Sanctuary and Tripunithura, district Ernakulam.	Johnson & Vincent, 2020[301]
		Al	4.6105#					
		Ca	10.7272#					
		Cu	<DL (≈0)#					
		Fe	42.8869#					
		K	<DL (≈0)#					
		Mo	0.0001#					
		O	34.7198#					
		Si	6.7776#					
		Ti	0.278#					
		Zn	<DL (≈0)#					
			In ppm					
			Urban					
		Hg	0.249					
Pteropodidae, Megadermatidae, Emballonuridae	Three bat species (*P. medius*, *M. spasma*, *T. melanopogon*) (n=12)		Mean±SD (mg/kg ww)		NR	Guano (wet weight)	Rural and urban areas in Kerala - 1. Rural - Irinjalakuda, district Thrissur. 2. Urban - Mangalavanam Bird Sanctuary and Tripunithura, district Ernakulam.	Johnson & Vincent, 2020[301]
			Rural	Urban				
		Cr	24.93±10.56	79.69±35.56				
		Cu	2869.22±503.13	3973.68±418.38				
		Mn	76.92±38.62	820.12±464.26				
		Ni	24.61±16.68	60.03±22.23				
Pteropodidae	*Eonycteris spelaea* (male) (n=6)		Mean±SD (µg/g dw)		(µg/g dw)		Two caves of Bhuban Hills in Barak Valley, Assam - 1. Small cave - known as Soto-rodmukh (24° 38′ 58.44″ N and 93° 01′ 19.11″ E). 2. Main cave - known as Boro-rodmukh (24° 38′ 53.53″ N and 93° 01′ 20.84″ E).	Rahman et al., 2019[293]
		Zn	61.8±0.32a		63.02	Kidney (dry weight)		
			61.2±0.14b		61.76	Liver (dry weight)		
			58.8±0.19c		59.46	Lungs (dry weight)		
			46.8±0.16d		47.82	Patagium (dry weight)		
		Mn	1.2±0.15a		1.25	Kidney (dry weight)		
			0.6±0.11b		0.68	Liver (dry weight)		
			0.6±0.13c		0.65	Lungs (dry weight)		
			46.8±0.16d		0.66	Patagium (dry weight)		
		Fe	25.8±0.23a		26.81	Kidney (dry weight)		
			98.4±0.22b		99.14	Liver (dry weight)		
			78.6±0.47c		79.18	Lungs (dry weight)		
			16.2±0.26d		0.66	Patagium (dry weight)		
		Cu	1.8±0.10a		1.93	Kidney (dry weight)		
			3±0.11b		3.25	Liver (dry weight)		
			2.4±0.14c		2.64	Lungs (dry weight)		
			1.8±0.06d		1.83	Patagium (dry weight)		

Key: n = number of bats, NR = not reported, ND = not detected, <DL = below detection limit, SD = standard deviation, Avg. = average, ppm = parts per million, ng = nanogram, µg = microgram, mg = milligram, g = gram, kg = kilogram, dw = dry weight, ww = wet weight, Cr = Chromium, Pb = Lead, Ni = Nickel, As = Arsenic, Cd = Cadmium, K = Potassium, Mg = Magnesium, Ca = Calcium, P = Phosphorus, Na = Sodium, Fe = Iron, Zn = Zinc, Mn = Manganese, B = Boron, Cu = Copper, OCs = Organochlorines, OPs = Organophosphates, SPs = Synthetic pyrethroids, Al = Aluminium, Mo = Molybdenum, O = Oxygen, Si = Silicon, Ti = Titanium, Hg = Mercury, N = Nitrogen, Co = Cobalt, Cr = Chromium a, b, c, d = Superscripts denote concentrations statistically different among different organs at 0.05 levels, # = no clear indication of site/ location of collection for these values.

Factors impacting exposure to and accumulation of contaminants in Indian bats

Factors such as diet, roosting location, foraging habitat, and bat metabolism are known to influence the accumulation of various contaminants in bats[273]. However, it must be noted that these comparisons are between species belonging to different families, and the effect of evolutionary history has not been accounted for.

Diet significantly influences the accumulation of trace elements in bats as it specifically affects which tissues are more impacted[284]. Frugivorous and nectarivorous species tend to show higher levels of trace elements in their internal organs (e.g., liver and kidneys) than insectivorous bats do. For example, the mean concentrations of arsenic in the liver and kidney tissues are significantly higher in frugivorous bats compared to insectivorous bats[237][284]. The mean concentrations of zinc in the liver and kidney tissues of *Eonycteris spelaea* were found to be higher than those in *Lyroderma lyra*[293][294]. In the case of iron and copper, higher values were reported only in the liver tissues of *E. spelaea*[293][294] (Table 9.1). The composition of bat guano varies with the dietary strategy of a bat. This variation includes differences in concentrations of elemental nutrients as well as dissimilarities in stoichiometric relationships among nutrients[287]. High levels of phosphorus have been reported in the guano of *Pteropus medius* (frugivore) (Table 9.1)[299].

Several studies demonstrate that bats adjacent to agricultural areas are exposed to various pesticides used to optimise production. Synthetic pyrethroid insecticides (used in agricultural pesticides and timber remedial treatments) have been recovered from the guano of *Pteropus medius*, indicating the use of these insecticides by farmers in the agricultural lands surrounding the roost site[296]. In addition, very low concentrations of OP residues (<0.005 mean ppm) were reported from all of the study sites that were sampled by Kaur and Singh in Punjab, indicating that limited spraying of OPs in adjacent agricultural fields and plantations was leading to low levels of OPs in nearby water bodies that were the source of water for bats[296] (Table 9.1).

Notably, differences in organic pesticide accumulation among bat species are more pronounced than are differences in heavy metals. This implies that the pathways of heavy metal exposure may vary between frugivorous and insectivorous bats, highlighting areas for further study. Sources of heavy metal contamination in fruit bats include airborne pollution, wastewater drinking sources, supplementary feeding on contaminated insects, and secondary contamination by coming into contact with contaminated foliage while foraging for food[285]. According to Hariono and Sutton (1993), these contaminants can be ingested rapidly when the bats groom themselves after eating[300]. For frugivorous species, like flying foxes, exposure to metals can be related to the land use of their roost sites[300]. This is because metal-based agrochemicals are often used in agricultural areas where these species reside[300]. Various studies conducted in rural parts of India with agricultural lands nearby have revealed the presence of heavy metals in the guano produced by the frugivorous bat *Pteropus medius*[296][299][301] (Table 9.1). Kaur and Singh (2024) analysed Indian Flying Fox's faecal pellets for metals and found all measured elements to be under permissible limits except for magnesium and potassium[296]. Furthermore, frugivorous bats captured in areas with greater human impact tend to show higher levels of metal accumulation[302]. Significantly higher contamination levels of mercury, copper, chromium, manganese, and nickel were reported among bats found in urban areas than in those in rural areas, indicating an elevated pollution level in urban areas[301].

Nectarivorous bat species are likely to obtain metals and metalloids through the plants they consume. Metals in flowers can originate from contaminated soil, water, or air in regions affected by metal pollution[303]. When grown in metal-contaminated soils, some plants can passively absorb and accumulate these metals in their nectar[304][305][306]. Pollen generally contains a high amount of iron (21–123 μg/g dw), manganese (21–134 μg/g dw), and zinc (22–58 μg/g dw)[307], while nectar can also be rich in copper (0.05–17.30 μg/g dw) and zinc (0.23 to 73.60 μg/g dw)[308]. In India, higher concentrations of zinc and copper were recorded in various tissues of *Eonycteris spelaea*, a cave-dwelling nectarivorous bat species whose diet chiefly consists of pollen and nectar[293] (Table 9.1).

Insectivorous bat species become contaminated with metals mainly through bioaccumulation and biomagnification within the food chain. Heavy metals can be transferred from sediments, water, soil, and plants to insect larvae and adults, eventually reaching the bats themselves[266][309][310]. Bats generally consume between 40% and 100% of their body weight in prey each night[311]. Some species primarily feed on emerging insects, such as Trichoptera and Diptera, which spend their larval stages in sediments where toxic metals can accumulate[309][312][313]. In India, the dietary analysis of *Hipposideros speoris* showed the presence of insects in their guano from six orders: Lepidoptera, Coleoptera, Diptera, Hymenoptera, Hemiptera, and Homoptera[314].

The toxicological effects of mines and mining activities on Indian bats

Mining operations pose multifaceted threats to bat populations through habitat destruction, contaminant exposure, and trophic disruption (Chapter 15). Roosting habitats such as caves and forested crevices are often disturbed or destroyed by excavation, blasting, and infrastructure development, leading to colony displacement and reduced reproductive success[315]. In India, there have been studies reporting heavy metal accumulation in wildlife due to mining activities[316].

Gold mining involves the use of cyanide for ore leaching, a process that releases highly toxic compounds into surrounding environments. Cyanide spills or leaching into water bodies can kill aquatic organisms and contaminate insect prey, indirectly exposing insectivorous bats to cyanide through ingestion or drinking from polluted sources[259][317][318]. Researchers have yet to investigate Indian bats' exposure to and health effects from cyanide despite the expansion of mining in bats' habitats throughout India (Chapter 15).

Mercury contamination poses a significant ecotoxicological threat to bats, particularly in regions impacted by artisanal and small-scale gold mining (ASGM), coal combustion, and industrial discharge. Bats are primarily exposed to mercury through dietary intake, especially via insect prey that bioaccumulate methylmercury in aquatic systems. Once ingested, mercury accumulates in bat tissues, most notably in the fur, liver, and kidneys, where it can elicit a range of sublethal and potentially lethal effects. Documented impacts include neurotoxicity (which impairs echolocation and motor coordination), oxidative stress (leading to cellular damage), and reproductive impairment (e.g., reduced fertility and pup survival[319][320]). Mercury has also been linked to immune suppression, increasing susceptibility to pathogens like *Pseudogymnoascus destructans*, the causative agent of white-nose syndrome[292]. In parts of Karnataka, Andhra Pradesh and Jharkhand, ASGM occurs with the potential to cause mercury contamination in the tissues of bats residing in these mines in addition to the habitat disturbance (or destruction) that directly affects their roosting populations. While studies in Latin America and Africa have documented mercury exposure in bats near gold mining sites[321][322], no published studies from India currently assess this risk in Indian bat populations. However, detectable levels of mercury have been recovered from *P. medius*, *Megaderma spasma*, and *Taphozous melanopogon* in Kerala[301] and *Hipposideros speoris* in Tamil Nadu[314] (Table 9.1).

Insects inhabiting mining areas can accumulate several non-essential elements, making them significant sources of metals for bats[323]. When comparing the mean concentration of heavy metal residues traced in the guano samples of *Hipposideros speoris* at two different sites during two distinct seasons, higher values of all metals were found in samples collected near mines in the following decreasing order of concentrations, irrespective of the season of collection: aluminium>cobalt>nickel>chromium>lead>mercury[314] (Table 9.1). Additionally, insectivorous bats consume considerable amounts of water, which may also be contaminated with metals from industrial and coal mining regions. The lower pH value of a waterbody at a mine site in comparison to a farm site could contribute to higher heavy metal availability at the mine site as the solubility of heavy metals increases with decreasing pH of water[314][324]. It is essential to recognise that toxicity pathways can differ throughout the food chain and are contingent upon the specific type of toxicant present[284]. Johnson and Vincent (2020) reported notable variations in metal content within guano samples collected from insectivorous and frugivorous bat species, revealing that aluminium and titanium were exclusively found in the guano of insectivorous species[301] (Table 9.1).

Juvenile Black-bearded Tomb Bats (*Taphozous melanopogon*). Photo: Rohit Chakravarty

Mining also generates large volumes of wastewater, which is often stored in holding ponds or tailings dams. These artificial water bodies may attract bats due to their open surface and potential insect activity, but they frequently contain elevated levels of heavy metals, cyanide, and acidic effluents[323]. For example, recent research from Bangladesh evaluated the heavy metal contamination around the wastewater from granite mines and reported high levels of heavy metals including nickel, zinc, iron, and lead that exceeded recommended limits for safe irrigation and drinking water[325]. Such contamination can suppress aquatic insect emergence, reducing prey availability and altering bat foraging behaviour[259]. In some cases, these ponds may act as ecological traps, drawing bats to hazardous sites that increase their exposure[326]. Griffiths et al. (2014) found that insectivorous bats show high activity at gold mine wastewater ponds, increasing their risk of cyanide exposure[317]. Future toxicological investigations of bats adjacent to wastewater holdings in India could shed light on this key knowledge gap in the national literature and provide data to support policy interventions (e.g., modifying the International Cyanide Management Code, which currently does not account for bat interactions[317]) that promote the conservation of not only bats but also all wildlife in the affected regions.

Opportunities for Future Research

While toxicological studies on bats in India are alarmingly scarce, it is important to recognise that research in bat toxicology as a whole needs to be more extensive. Below, I identify many opportunities for future work to be conducted in this particular field of bat research in India.

A nationwide bat monitoring program

There is a need to develop and standardise a nationwide bat ecotoxicological monitoring program, which incorporates modern analytical technologies to improve data precision for various contaminants found in Indian bat species. The recent report of the Stakeholder Engagement Workshop for National Biomonitoring Programme for Chemical Toxicants[327] set the precedent for establishing a National Surveillance System to assess and report human exposure to environmental chemicals and heavy metals. This provides a useful reference to establish a concurrent program for monitoring the exposure of bats to toxicants.

Bat-specific Ecological Risk Assessment (ERA)

There is a need to develop a bat-specific risk assessment scheme for prioritised toxic contaminants in India as it would help in limiting potential health hazards to bat populations in the future. An ERA for various chemicals in bats would need to involve: 1. the identification of any potential hazards of these chemicals on bat individuals and populations, 2. an assessment of the probability of exposure via different pathways (e.g., consumption, inhalation, or direct contact), 3. a dose-response assessment, and 4. risk characterisation with methods such as laboratory toxicity tests, field monitoring, and modelling techniques to analyse levels of exposure and possible ecological consequences. This would assist in characterising the potential impacts on the health of bats due to factors like species sensitivity, life stage, and environmental conditions.

Identifying toxicity thresholds for Indian bats

It is not currently possible to predict bat sensitivity to various contaminants due to a paucity of acute and chronic level toxicity studies on bat species. There is a need to create a more extensive and standardised bat exposure database to assess the effects of exposure to various toxicants, especially for sublethal effects. To do so, researchers can conduct risk assessment studies to determine these bat-specific toxicity thresholds for different species under varying conditions.

Conducting training in toxicology research

Considering the state of environmental pollution in the country and the lack of research on the effects of toxicants on wildlife, conducting workshops on toxicology are of priority. Such workshops will lead to more interest and capacity to investigate the effects of pollution on bats.

Identifying priority areas for toxicological research

While looking at the vast geographical variation of India, it indeed becomes important to identify priority areas for conducting bat toxicological research. Prioritised localities should include areas with rich bat species diversity (e.g., the southern Western Ghats), caves and other important roosting sites, mines with potential heavy metal contamination, agricultural areas and other regions with high use of POPs and pesticides, and urban areas that have been identified as highly contaminated per the Central Pollution Control Board[328][329]. Researchers should also consider leveraging the power of analytical tools such as remote sensing methods for mapping these prioritised regions and monitoring soils contaminated with heavy metals (e.g., zinc, manganese, mercury, and copper in industrial regions)[330].

Applying genetic approaches in bat ecotoxicology

Using non-destructive genetic approaches offers a valuable way to assess the health impacts of pollution on bats (Chapter 16). As reviewed by Sotero et al. (2022), heavy metals, pesticides, and other contaminants can adversely impact the DNA of bats[331]. Therefore, the analysis of genotoxic and mutagenic biomarkers can be employed to evaluate bats' genetic health when exposed to varying types and levels of toxins. By focusing on these non-destructive and cost-effective biomarkers, we can improve our understanding of the negative effects of contaminants on bats to better support their conservation[331][332].

Impact of pollution on the health of bats

Exposure to toxic contaminants can severely harm bat health by resulting in physiological, genetic, and behavioural changes (e.g., tremors and spasms, DNA damage, tissue damage, oxidative stress, neurochemical alterations, slowness, ataxia)[45][266][331]. Beyond quantifying the amount of exposure, researchers must also attempt to investigate the diverse health impacts of pollutants on different species of bats under varying conditions.

Impact of heavy metal exposure on cave-dwelling species of bats

As detailed above, mining activities have significant, multifaceted impacts on the health of flora and fauna in and around caves, including bats[333]. Researchers should continue to investigate the impacts of heavy metal pollution on bats roosting in abandoned mines or in the vicinity of active mines, especially in the case of threatened bat taxa. A cave-dwelling species endemic to India and of global conservation concern is *Hipposideros hypophyllus*, whose habitat was once under threat due to illegal granite mining. The recovery of elevated levels of heavy metal contamination from water sources near granite mines[325] underscores the importance of studying heavy metal exposure of this critically endangered species.

Impact of pesticides and other pollutants on water-dependent bats

India is home to several species of *Myotis* (fishing bats like *Myotis longipes*, *Myotis laniger*, *Myotis horsfieldii*, and *Myotis pilosus*) that actively hunt aquatic insects or fish. As pesticides and other pollutants commonly leach into waterbodies, these bats are at higher risk of exposure to these contaminants, including via trophic bioaccumulation.

Bats as bioindicators for pollution

As discussed above, the measurable responses that bats exhibit when exposed to heavy metals, pesticides, and other contaminants makes them potentially useful as bioindicators for environmental pollution[237][288]. Future studies in India should explore which species under what conditions may be effectively employed as bioindicators for specific xenotoxins. In particular, Indian chiropterologists and toxicologists should collaborate to evaluate the geographic and taxonomic consistency of bats when used as bioindicators for various contaminants across ecosystems. These results will not only benefit bat conservation and wildlife-focused ecotoxicological studies but can also inform India's National Biomonitoring Programme for Chemical Toxicants.

Bats as indicators of ecosystem health

Bats have emerged as valuable bioindicators of freshwater ecosystem health due to their sensitivity to environmental changes and their reliance on aquatic insect prey. Vaughan et al. (1996) demonstrated that bat activity over water bodies in Britain varied significantly with water quality, vegetation structure, and insect abundance[334]. Their findings suggest that bats respond both to the direct availability of prey and to broader habitat conditions shaped by aquatic ecosystem integrity. Given their wide distribution, ease of acoustic monitoring, and trophic position as insectivores, bats offer a non-invasive and ecologically meaningful means of assessing freshwater quality[334]. Their use as bioindicators complements traditional aquatic monitoring approaches and provides a landscape-scale perspective on ecosystem health.

Challenges in Research

There are several challenges facing toxicological studies of bats in India, including but not limited to:

Limited number of available studies

This chapter highlights the limited availability of studies regarding the toxicity of heavy metals and other contaminants found in bats within India. There is a notable scarcity in the species diversity and region-specific research leading to the lack of baseline data with which to compare future studies (Table 9.1).

Understudied threats to bats in India

Several widespread anthropogenic activities in India, such as gold mining, plastic pollution, and agrochemical use, have not been adequately studied for their impacts on bats, despite their likely ecological consequences. For example, in India, over 3 million tonnes of plastic waste is generated annually with hotspots like the Ganga River Basin facing severe pollution[335]. Despite growing concern over plastic pollution in aquatic and terrestrial systems, no studies have yet assessed microplastic exposure in or ingestion by Indian bats, even in heavily polluted regions like the Ganga River Basin.

Small sample size

As with most ecotoxicological research worldwide, Indian studies have been limited by the small sample size of bats that were able to be assessed (Table 9.1). Small sample sizes often fail to adequately represent the broader population, leading to biases and reduced transferability of the results.

Lack of established permissible limits for bat samples

There is currently a lack of established permissible limits for heavy metals and other contaminants in bat tissues, fur, and guano. This issue is pertinent not only to studies in India but also to bat research globally.

Inconsistent measurement units across different studies

As described above, researchers have used a variety of units without consistent conversion or justification. This variability complicates cross-study comparisons and meta-analyses. Establishing standardised measurement units in ecotoxicology will also aid in establishing standardised safety thresholds through policy recommendations[284][285].

Lack of toxicity thresholds

For most metals and organic contaminants (e.g., mercury, lead, neonicotinoids), no species-specific toxicity reference values (TRVs) exist for bats. This makes it difficult to interpret whether detected concentrations are sublethal, harmful, or lethal[285].

Tissue-specific variability

Contaminant concentrations vary significantly across tissues (e.g., liver, kidney, fur, blood), and studies often fail to report or standardize tissue selection, further complicating ecological risk assessments[284].

Diverse habitats

India is notable for its rich diversity of bat species, each adapted to various habitats, including caves, forests, wetlands, and urban areas. Researching bat toxicology in these environments presents significant challenges as their variability complicates standardisation and meaningful comparisons. The unique behaviours of each species further complicate the development of a universal research approach. Additionally, logistical difficulties in accessing remote habitats lead to under-researching many species, resulting in critical data gaps that hinder conservation efforts.

Lack of funding and capacity

Funding presents a considerable challenge for conducting bat toxicological research in India, which is influenced by several interrelated factors. Firstly, the availability of financial resources is limited, resulting in difficulties in obtaining the necessary support for essential research components, such as equipment, field supplies, laboratory supplies, and trained personnel. This issue is further exacerbated by the tendency of funding bodies and government agencies to prioritise research in areas such as human health, agriculture, and industrial development, consequently relegating wildlife and conservation research, including studies focused on bats, to a lesser priority. Furthermore, the inherent complexity of bat toxicological research (particularly the investigation of various toxins' effects on bat populations) renders such studies time-consuming and intricate. This complexity may discourage potential funders who prefer projects with clearer outcomes, complicating the funding landscape for Indian bat toxicological research.

Obtaining legal permits

Bat toxicological research in India faces numerous challenges due to the complexities in the country's legal and bureaucratic framework. Researchers face bureaucratic delays in obtaining permits from state and union territory forest departments and securing all of the necessary biosafety clearances. A lack of awareness among decision-makers of the importance of bats to ecosystems often leads to less willingness from them to support bat research in general.

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Section III.

Ecosystem Services

The Ecosystem Services Working Group members listed below contributed to the following chapters through conceptual design, critical content review, and providing additional data and perspectives:

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Indian Flying Fox (*Pteropus medius*)
foraging and pollinating a Kapok tree.
Photo: Ram Mohan

Chapter 10

Ecosystem Services from Bats: The State of Knowledge in India

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Chapter Summary

Ecosystem services to people are usually assessed at the level of entire ecosystems or of large groups of organisms. However, the direct and indirect contributions of biodiversity to ecosystem services, especially at the species level, are complex to understand. Additionally, elements of biodiversity can be both beneficial and harmful to people. This may lead to biodiversity-driven ecosystem services as well as disservices, creating both synergies and trade-offs for people. Bats are one such element of biodiversity, with the potential for simultaneous beneficial and harmful effects on human well-being.

Bats provide essential ecosystem services to people. Plant-visiting bats are important seed dispersers and pollinators of many forest trees, as well as commercial crops, but are also known to cause crop damage and loss. Insectivorous bats predate on and suppress agricultural pests, and their guano is used as an agricultural fertiliser worldwide. However, guano may negatively affect people by causing bio-fouling of property and exposing individuals who collect and handle it to potential health risks from zoonotic pathogens (e.g., histoplasmosis-causing *Histoplasma capsulatum*). Bats are known to be reservoirs of emerging viral pathogens[1]. Growing human–bat interfaces are leading to an increase in zoonotic spillovers, which, in turn, are leading to negative outcomes for both bats and people (Chapter 8).

In this context, a conceptual understanding of ecosystem services from bats, assessment of the status of knowledge in the Indian context, and their application to bat conservation planning and prioritisation need to be imperatives for ecological research on bats and policymaking. Robust and systematic studies of ecosystem services from bats still form a nascent field in India, owing to multiple constraints. While there have been a few studies on fruit bats and seed dispersal, insectivorous bats do not feature much in Indian studies on bat ecosystem services. Additionally, most of these studies are qualitative descriptions, lacking the quantitative assessments of bat ecosystem functions that are necessary to be able to translate them into ecosystem services. Moreover, many quantitative studies for pteropodids have used methods that are mainly suitable for assessing diet or foraging behaviour rather than ecological function and, yet, have claimed to provide evidence for pollination and seed dispersal services.

In this chapter, we identify such gaps and challenges along with an overview of the existing literature on ecosystem services of bats in the Indian context. We also suggest ways forward in the form of recommendations for research and beyond, to inspire researchers and bat enthusiasts to elevate the current knowledge on the topic and to promote research on bats using these new approaches.

Greater Long-nosed Fruit Bat (*Macroglossus sobrinus*).
Photo: Rohit Chakravarty

The Concept of "Ecosystem Services"

Biodiversity and the environment constantly interact with each other. As a result, many species maintain multiple ecosystem functions, such as pollination, seed dispersal, forest regeneration, and nutrient cycling[2]. When such ecological functions benefit people, they are termed "ecosystem services." Ecosystem services have been formally defined as "the functions and products of ecosystems that directly or indirectly benefit humans, or yield welfare to the society" in the Ecosystem Services (ES) framework[3][4]. The Millennium Ecosystem Assessment (2005)[3] describes four types of ecosystem services: provisioning, regulating, supporting, and cultural services, which encompass both material and nonmaterial values derived from natural systems by society[5]. Provisioning services include the contribution of ecosystems to food, resources, raw materials, products of direct use, etc., whereas supporting services may include primary productivity, nutrient cycling, microclimate maintenance, and hydrological services along with habitat availability and other enabling conditions for ecology and biodiversity[3][6]. Regulating services include diverse processes, such as pollination, seed dispersal, pest regulation, natural hazard protection, etc.[7] Cultural services relate to aesthetic, religious, or spiritual values that local people assign to biodiversity, habitats, or specific locations within ecosystems[8][9].

The direct connections between biodiversity and ecosystem services need to be investigated on two fronts: 1. identification of ecosystem services directly connected to processes maintained by biodiversity rather than by abiotic processes, and 2. quantification of these ecosystem services to evaluate actual benefits, as well as costs to human beneficiaries[10]. With respect to bats, studying these aspects is challenging, with over 1,400 species worldwide[11] and their remarkable diversity of life histories and functional traits.

On all continents, except Antarctica, bats are ubiquitous, occurring in forested areas, agricultural systems, peri-urban spaces, and even megacities. As a result, bats and people frequently interact with each other. This is what makes them a fascinating system through which to understand the linkages between the ecological functions they maintain and the ecosystem services they provide to people. Bats have shared spaces and interacted with people throughout human history (see Sieradzki and Mikkola 2022[12] for a global review). While the most common perception about bats is that of cryptic, dingy animals living in dark places with mysterious lives, bats are a part of many complex ecosystem processes that are important for human food production systems. Plant-visiting bats pollinate and disperse the seeds of over 300 forest trees and commercial fruit crops[13][14][15][16]. Insectivorous bats contribute to human food security and public health by controlling more than 200 species of major agricultural insect pests as well as disease-causing insect vectors such as mosquitoes and midges[13][17][18], and their droppings (guano) are used as agricultural fertiliser worldwide[14][19][20].

Table 10.1 is a summary of globally known provisioning, regulating, supporting, and cultural ecosystem services provided by bats compiled based on a review of the available literature for different regions worldwide[10][11][13][14][15][21][22]. India is rich with over 100 different species of bats, and there is evidence from both Indian and international studies indicating the ecosystem services of these species (Table 10.2).

Table 10.1 Categories and examples of ecosystem services provided by fruit bats and insectivorous bat species worldwide based on a literature review [10][11][13][14][15][21][22].

Types of Ecosystem Services	Fruit Bats	Insectivorous bats
Provisioning services	Seed aggregations and seed transfers; meat	Guano as agricultural fertiliser; meat
Regulating services	Seed dispersal; pollination; forest regeneration	Pest control for agriculture; control of disease-causing insect vectors
Supporting services	Seed germination success; nutrient cycling	Guano: nutrient recycling; phosphate mineralization; palaeo-environmental indicators in caves; a significant food source for cave systems
Cultural services	Cultural emblems; sites of worship support bat roosts; indicators of disturbance; medicinal use	Good omen; caves as sites of worship; indicators of good fortune or wealth; medicinal use

Table 10.2 The types of ecosystem services provided by Indian bat species in India and abroad based on empirical evidence. *indicates a study conducted outside India.

Ecosystem Service Classification	Ecosystem Service	Species	Citation
Provisioning services	Seed aggregation	*Pteropus medius*	Deshpande & Kelkar 2015[21]; Deshpande et al. 2022[22]
	Meat	*Eonycteris spelaea*	Dovih 2015[23]
		Hipposideros armiger	Dovih 2015[23]
		Pteropus medius	Kumar et al. 2021[24]; Low et al. 2021[25]
		Rousettus leschenaultii	Dovih 2015[23]
	Guano as fertiliser	*Hipposideros pomona*	Aye & Oo 2022*[26]
		Hipposideros speoris	Sridhar et al. 2006[27]
		Lyroderma lyra	Misra et al. 2019[28]; Shetty et al. 2013[20]; Sakthi et al. 2023[29]
		Mops plicatus	Furey et al. 2018*[30]; Boonpha et al. 2019*[31]
		Rhinopoma hardwickii	Misra et al. 2019[28]; Yadav et al. 2017[28]
		Rhinopoma microphyllum	Misra et al. 2019[28]
		Scotophilus heathii	Misra et al. 2019[28]
		Scotophilus kuhlii	Sothearen et al. 2014*[32] Misra et al. 2019[28]
		Taphozous nudiventris	Misra et al. 2019[28]
		Taphozous melanopogon	Palita et al. 2021[33]; Deshpande et al. 2025[34]
Regulating services	Seed dispersal	*Cynopterus brachyotis*	Aul et al. 2007[35]
		Cynopterus sphinx	Singaravelan & Marimuthu 2006[36]; Sudhakaran & Swami Doss 2012[37]; Mahandran et al. 2018[38]
		Latidens salimalii	Vanitharani 2015[39]
		Pteropus faunulus	Aul 2007[35]
		Pteropus medius	Deshpande et al. 2022[22]; Goveas et al. 2006[40]; Nathan et al. 2009[41]; Raghuram et al. 2011[42]; Sudhakaran & Swami Doss 2012[37]
		Pteropus melanotus	Aul 2007[35]
		Rousettus leschenaultii	Singaravelan et al. 2009[37]; Sudhakaran & Swami Doss 2012[37]; Mahandran et al. 2018[38]
	Pollination	*Cynopterus brachyotis*	Aul et al. 2007[35]
		Cynopterus sphinx	Singaravelan & Marimuthu 2006[36]; Nathan et al. 2005[43]; Nathan et al. 2009[41]
		Eonycteris spelaea	Bumrungsri et al. 2013*[44]; Acharya et al. 2011*[45]; Sritongchuay & Bumrungsri*[46]; Bumrungsri et al. 2009*[47]; Nor Zalipah et al. 2016*[48]; Nuevo Diego 2018*[49]; Chaiyarat et al. 2020*[50]; Sheherazade et al. 2019*[51]
		Latidens salimalii	Vanitharani 2015[39]
		Macroglossus sobrinus	Stewart & Dudash 2016*[52]; Itino et al. 1991*[53]; Liu et al. 2002*[54]
		Pteropus faunulus	Aul 2007[35]
		Pteropus hypomelanus	Aziz et al. 2017*[55]

Table 10.2, continued

Ecosystem Service Classification	Ecosystem Service	Species	Citation
Regulating services, continued	Pollination, continued	*Pteropus medius*	Nathan et al. 2009[41]; Raghuram et al. 2011[42]; Sudhakaran & Swami Doss 2012[37]
		Pteropus melanotus	Aul 2007[35]
		Rousettus leschenaultii	Singaravelan et al. 2009[56]; Nathan et al. 2005[43]
	Agricultural pest control	*Alionoctula coromandra*	Misra & Elangovan 2016[57]
		Hipposideros armiger	Wang et al. 2024*[58]; Zhu et al. 2024*[59]
		Hipposideros ater	Sophia 2010[60]
		Hipposideros fulvus	Misra & Elangovan 2016[57]
		Hipposideros larvatus	Wang et al. 2024*[58]; Ruadreo et al. 2018*[61]; Abdullah et al. 2024*[62]
		Hypsugo savii	Baroja et al. 2021*[63]; Ancillotto et al. 2023*[64]; Ancillotto et al. 2024*[65]
		Ia io	Liu et al. 2023*[66]; BaoYin & HongZao 2012*[67]; Wang et al. 2024*[58]
		Lyroderma lyra	Misra & Elangovan 2016[57]; Jeya Praba et al. 2023[68]; Sakthi et al. 2023[29]
		Miniopterus fuliginosus	Zhu et al. 2024*[59]
		Mops plicatus	Nguyen et al. 2019*[69]; Srilopan et al. 2018*[70]; Wanger et al. 2014*[17]; Leelapaibul et al. 2005*[71]; Thongjued et al. 2021*[72]
		Myotis altarium	Liu et al. 2023*[66]
		Myotis laniger	Wang et al. 2024*[58]
		Myotis pilosus	Wang et al. 2024*[58]
		Pipistrellus pipistrellus	Tuneu-Corral et al. 2024*[73]
		Rhinolophus beddomei	Ponmalar & Vanitharani 2014[74]
		Rhinolophus lepidus	Ponmalar & Vanitharani 2014[74]
		Rhinolophus pearsonii	Liu et al. 2023*[66]; Wang et al. 2024*[58]
		Rhinolophus pusillus	Ponmalar & Vanitharani 2014[74]
		Rhinolophus sinicus	Wang et al. 2024*[58]
		Rhinopoma hardwickii	Misra & Elangovan 2016[57]; Sunitha et al. 2022[75]
		Rhinopoma microphyllum	Misra & Elangovan 2016[57]
		Scotophilus heathii	Misra & Elangovan 2016[57]
		Scotophilus kuhlii	Bhartiy & Elangovan 2021[76]; Misra & Elangovan 2016[57]
		Tadarida insignis	Kahnonitch et al. 2018*[77]; Baroja et al. 2021*[63]
		Taphozous melanopogon	Abdullah et al. 2024*[62]; Zhu et al. 2024*[59]
		Taphozous nudiventris	Misra & Elangovan 2016[57]
	Disease vector control	*Hypsugo savii*	Ancillotto et al. 2023*[64]
		Mops plicatus	Thongjued et al. 2021*[78]
		Pipistrellus pipistrellus	Puig-Montserrat et al. 2020*[18]
		Taphozous longimanus	Weterings et al. 2015*[79]

Table 10.2, continued

Ecosystem Service Classification	Ecosystem Service	Species	Citation
Supporting services	Seed germination success	*Pteropus medius*	Goveas et al. 2006[40]
	Nutrient cycling	*Mops plicatus*	Lundberg et al. 2022*[80]
Cultural services	Cultural symbols, roosts overlap with sites of worship and/or part of belief systems	*Pteropus medius*	Tangavelou et al. 2013[81]; Low et al. 2021[82]; Murugavel 2023[83]
		Rousettus leschenaultii	Dovih 2015[23]; Murugan et al. 2020[84]; Jugli et al. 2020[85]
	Medicinal use	*Alionoctula coromandra*	Molur et al. 2002[86]
		Cynopterus sphinx	Molur et al. 2002[86]; Jugli et al. 2020[85]
		Eonycteris spelaea	Dovih et al. 2015[23]
		Hesperoptenus tickelli	Molur et al. 2002[86]
		Hipposideros armiger	Molur et al. 2002[86]
		Hipposideros larvatus	Supiandi et al. 2023*[87]
		Hipposideros speoris	Molur et al. 2002[86]
		Latidens salimalii	Molur et al. 2002[86]
		Megaderma spasma	Molur et al. 2002[86]
		Pteropus faunulus	Aul & Vijayakumar 2007[35]; Aul et al. 2014[88]
		Pteropus medius	Molur et al. 2002[86]; Mickleburgh et al. 1992[89]; Molur et al. 2007[87]; Murugan et al. 2020[84]; Kumar et al. 2021[24]; Low et al. 2021[82]
		Pteropus melanotus	Aul & Vijayakumar 2007[35]
		Rousettus leschenaultii	Molur et al. 2002[86]; Dovih 2015[23]

Old World Fruit Bats: Ecosystem services of relevance to India

Many commercially-important plants, such as bananas, mangoes, sapotas, figs, etc., are a part of the diet of commonly occurring fruit bat species in India (Figure 10.1). Diet has been relatively more studied in some Pteropodidae genera of India, such as *Cynopterus*, *Rousettus*, and *Pteropus*, but little is known in the other genera and species[37][42][90][91]. In general, fruit bats, being highly mobile and able to travel long distances, are potential long-distance seed dispersers of many wild fruits[15] as well as of commercial fruits[21], with notable relevance in maintaining the forest ecosystems and for direct benefits to people. However, translation of frugivory to seed dispersal as an ecosystem service has not yet been studied in finer detail and, thus, requires attention (but see Deshpande et al. 2022[22] for detailed study and quantification of seed dispersal services for commercial fruit crops, such as cashew and areca nut).

Most bat-visited plants have nocturnal flowering patterns and may be largely dependent on bats for pollination[92]. Bats also visit plants that are pollinated by other pollinators. For instance, some flowering plants visited by bats open at night but also extend their flowering into the day, thus attracting both bats and diurnal pollinators, including bees, wasps, and birds[93][94]. Nevertheless, many bat-pollinated plants (e.g., *Careya arborea, Ceiba pentandra, Pajanelia longifolia*) exhibit flower characteristics that attract bats, also known as "bat-flower syndromes". Despite being pollinated by other pollinators, these plants are dependent on bats for the best or most successful pollination outcome (i.e., the highest or greater-quality seed set) (Figure 10.2a, b). Hence, many wild as well as commercial plants are potentially dependent on bats for their pollination[93][94].

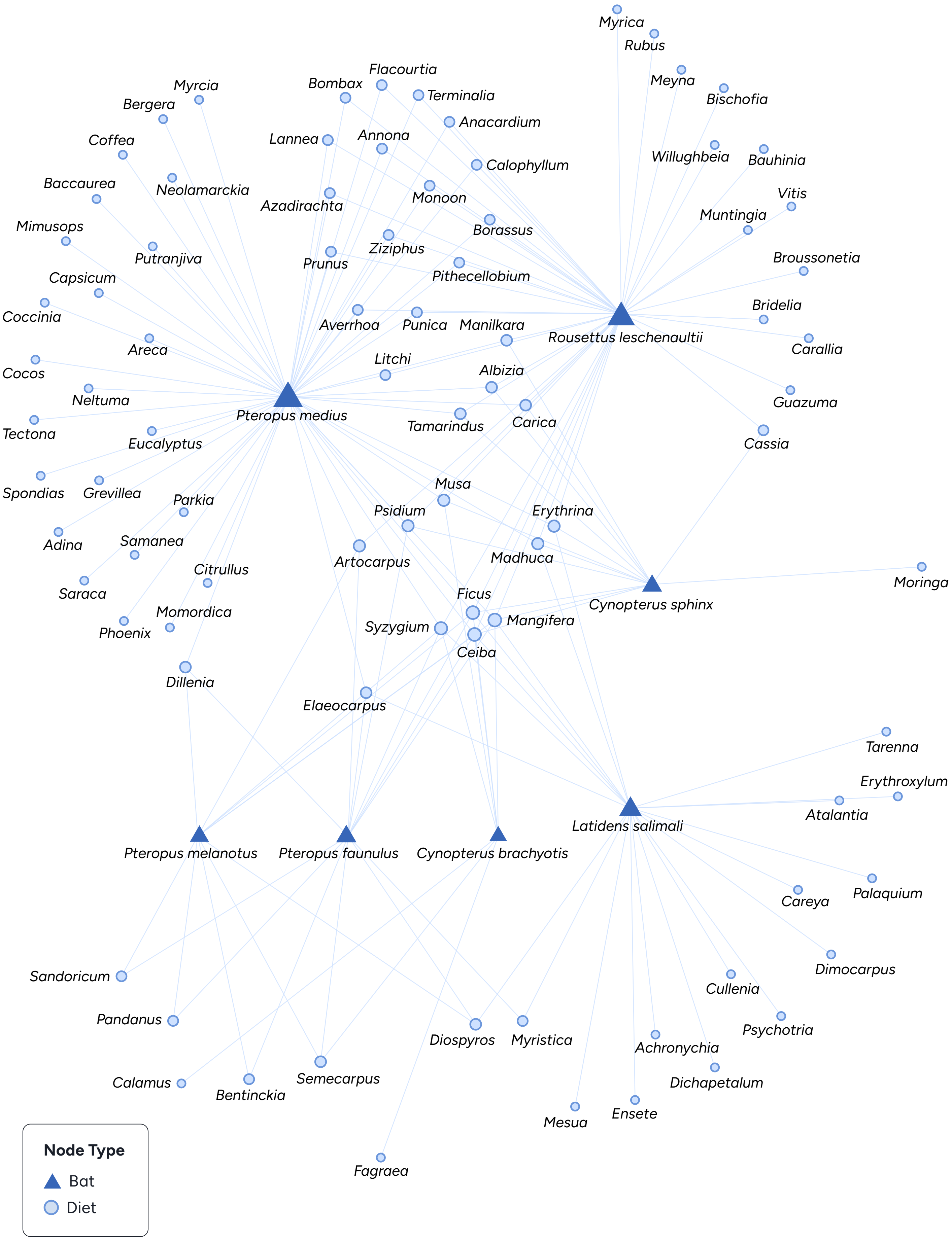

Figure 10.1 Diet network of pteropodid bats based on the available literature for India. Dark blue triangles represent bat species, and light blue circles represent plant genera. Bat visitations to and feeding on flowers and/or fruits of the plant genus constitutes inclusion as a dietary item. Larger node size represents a greater number of connections.

Fruit bats also hold a notable economic value due to their pollination service. In Southeast Asia, pteropodid bats are crucial pollinators and seed dispersers of many commercially-important plants, adding to their economic value[51][52][82][95]. Some bat species, such as *Eonycteris spelaea, Rousettus* spp., *Pteropus* spp., and *Acerodon* spp., are key pollinators of durian plants (*Durio* spp.) in Southeast Asia and are conservatively estimated to have a direct economic value of approximately USD 117 per hectare per fruiting season[51]. Importantly, some of these species and genera are also found in India and visit many commercial plants of India (Figure 10.1), but we still lack a proper understanding of these services from an economic point of view.

In Thailand, *Eonycteris* spp. and *Macroglossus* spp. are crucial pollinators for mangrove apple (*Sonneratia* spp.), thus playing a crucial role in mangrove conservation[96]. Moreover, the critically endangered *Sonneratia griffithii* is dependent on bat pollinators for reproductive success and suffers from inbreeding depression due to low bat visitation rates in Thailand[96][97]. These mangroves are also found in the Andaman Islands[98], but little is known about their pollination dynamics in India. Overall, India requires detailed studies on how bat foraging and ecosystem functions can be quantified and then measured in terms of their ecological and socio-economic values. The dependence of plants, both commercial and critically endangered species such as mangroves, on bats also requires further study in terms of bats' overall economic and conservation values.

Figure 10.2 Ecosystem services provided by pteropodid bats. **Pollination:** (a) *Cynopterus* sp. visiting flowers of the night-blooming *Pajanelia longifolia* in the Western Ghats. (b) Indian Flying Fox *(Pteropus medius)* and *Cynopterus* sp. simultaneously visiting the flowers of *Ceiba pentandra*. **Seed dispersal:** (c) An Indian Flying Fox feeding on a guava fruit *(Psidium gujava)*. (d) Greater Short-nosed Fruit Bat feeding on a fig fruit (*Ficus* sp.). Photo credits: a, b - Sachin Bhaskar and Sivachand MP.; c, d - Rajesh Puttaswamaiah.

Insectivorous Bats: Ecosystem services of relevance to India

Insectivorous bats feed on a plethora of insects (Figure 10.3) and also vertebrates, many of which are potential agricultural pests, predating, for example, coleopteran beetles and rodents (Figures 10.3, 10.4a, b). Empirical studies in Indian agricultural areas provide evidence of pest control services by bats such as *Rhinolophus* spp., *Hipposideros* spp., *Lyroderma lyra, Rhinopoma* spp., *Taphozous nudiventris, Scotophilus heathii,* and *Alionoctula coromandra*[29][57][60][68][99]. In addition, many bat species that are known to control common insect pests in the rice fields of our neighbouring countries, such as *Hipposideros larvatus* and *Taphozous melanopogon* in Malaysia[62], *Mops plicatus* in Thailand[69], and *Ia io* in China[67], are also found in India, potentially performing similar services. Several studies in India on insectivorous bats foraging over rice fields[10][100] have found bats significantly contributing to insect predation in rice-paddies[10]. In Spain, the pest control services by bats like *Pipistrellus pipistrel-*

lus, a species which is also present in India, prevents the loss of 70 kg of rice per hectare every year[73]. Similarly, an exclusion experiment in apple orchards in Italy shows that *Hypsugo savii*, which is also distributed in India, along with other bats, contributes to a 50% reduction in the weight of damaged apples per tree, which translates to saving 551 euros per hectare per year that would have been spent on insecticides[65]. Moreover, a study in China shows the possibility of invasive pest surveillance through bats, which also mentions Indian bat species, such as *Rhinolophus pearsonii, Ia io, Myotis pilosus,* and *Myotis altarium*[66].

Bats from the family Megadermatidae are carnivorous and feed on large insects, beetles, rodents, birds, and even other bats[101]. In addition to controlling insect pests, these species are potential controllers of rodent pests, which are also largely nocturnal (Figure 10.4b). From an agricultural point of view, the relevance of carnivorous bats in pest control is potentially highly valuable and needs to be quantified.

In addition to insect pest control, insectivorous bat guano is used as fertiliser by many farmer communities all over the world. Using experimental and laboratory analyses, several studies in India have examined bat guano's potential as an organic fertiliser[20][26][28][34]. These studies demonstrate that bat guano can act as an effective alternative to chemical fertilisers used by farms, thus adding more value to the Indian agricultural ecosystem. The accessibility and uptake of bat guano by larger populations in the context of its potential zoonotic disease risks (Chapter 8) and potential for disturbance to cave ecosystems during its collection needs to be examined in detail to address sustainability concerns[34] (Figure 10.4c).

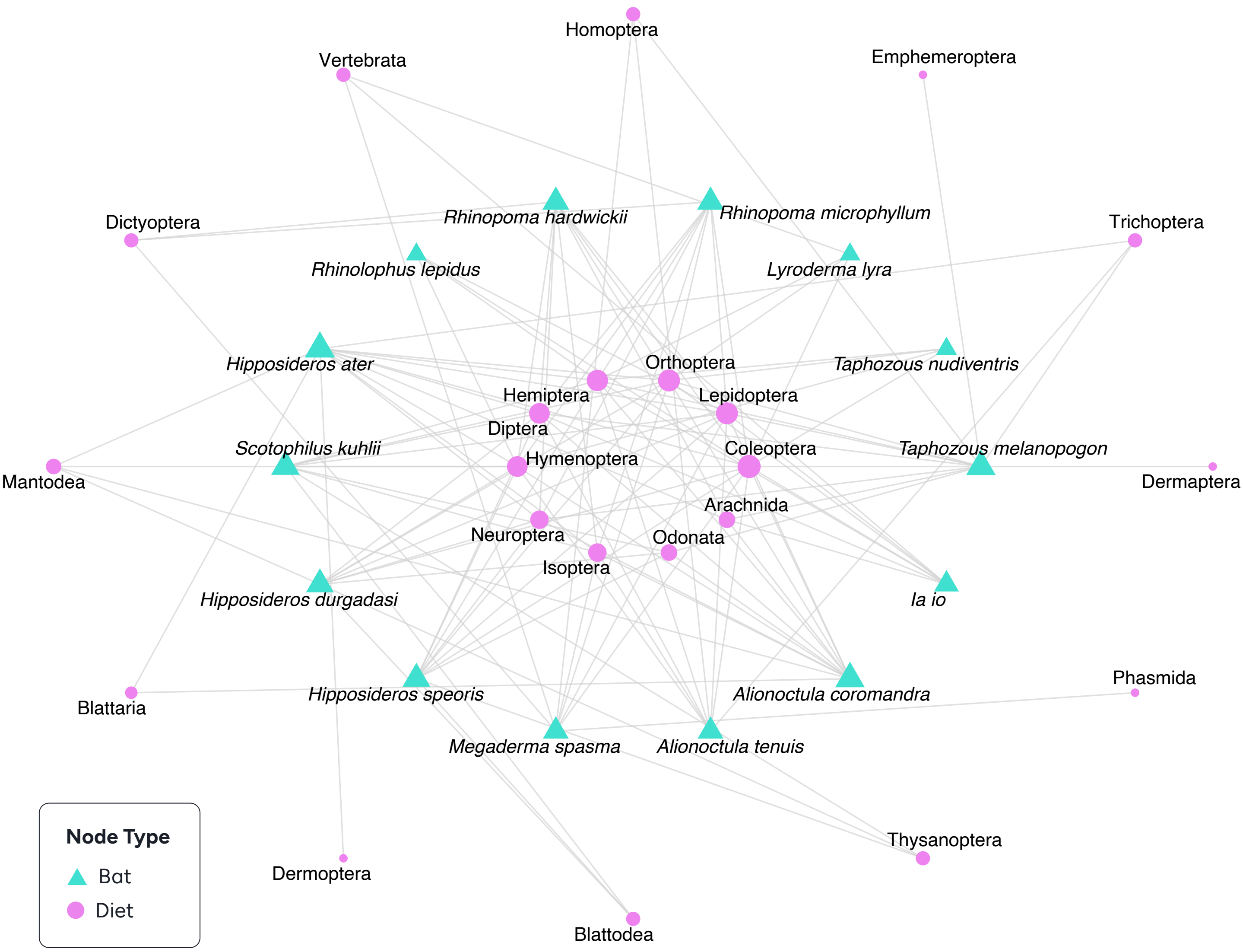

Figure 10.3 Diet network of insectivorous bats based on the available literature for India. Triangles represent bat species, and circles represent orders of insects. Larger node size represents a greater number of connections.

Apart from benefits to agriculture, some insectivorous bats can be important for direct health benefits to humans by being potential controllers of animal and human disease vectors; however, the finer details and the wide-ranging evidence for this service remain less explored. Some Indian species such as *Taphozous longimanus, Mops plicatus, Pipistrellus pipistrellus,* and *Hypsugo savii* have been reported to control disease vector insects (e.g., mosquitoes) in other countries[18][28][66][102]. It is unfortunate that these species are still understudied in India, but these examples from other countries indicate the potential significance of their health-related ecosystem services that needs to be further explored in the future.

Hence, the agricultural sector as well as the public health sector can potentially benefit from both economic and environmental gains if effective management strategies are implemented to support the ecosystem services provided by bats.

Figure 10.4 Ecosystem services provided by insectivorous and carnivorous bats. **Pest control:** (a) Lesser Mouse-tailed Bat *(Rhinopoma hardwickii)* in predatory position near a cockroach. (b) Remains of Little Indian Field Mouse *(Mus booduga)* below a roost of Greater False Vampire Bats *(Lyroderma lyra)*. **Guano:** (c) Guano extracted from a bat cave in the Western Ghats and left for drying in the open before being packed.
Photo credits: a - Ram Mohan; b, c - Rajesh Puttaswamiah.

Cultural Services of Bats of Relevance to India

Known for its rich cultural heritage, India has had a positive cultural association with bats for centuries (Chapter 14). Recent systematic documentation in the southern Western Ghats of India highlighted more positive than negative perceptions about bats[103]. The mention of bats as symbols of love, cues for time, and proxies for a kingdom's prosperity are found in poetry dating back to the 1st century BCE[82] (pers.obs, author B.M.). In present-day India, bats are associated with cultural belief systems that aid co-existence and add conservation value to many species. For instance, Indian Flying Foxes (*Pteropus medius*) are considered sacred in many parts of southern India, and communities in Tamil Nadu have been conserving Indian Flying Fox roosting trees largely because those trees are associated with local deities[81][104][105]. Cave temples are also places of conservation where bats can coexist with places of worship[106]. At the same time, pilgrimage activities in Hindu and Buddhist cave temples have also displaced bat colonies, so negative impacts may attenuate positive cultural perceptions of bats and their habitat[107][108]. Culture-driven belief systems also extend to the consumption of bat meat in different parts of India[23][82][109]. While such consumption is largely considered to have medicinal value, systematic documentation and scientific studies of the purported medicinal benefits of bat meat are lacking[110]. In addition, meat consumption directly exposes bat handlers to higher risks of zoonotic disease transmission, highlighting the need for exploring these trade-offs in benefits and risks in further detail.

Challenges

Conceptual challenges

Bat conservation based on arguments related to their ecosystem services alone can be challenging due to the complex nature of bats' functions in the ecosystems. For example, while fruit bats are highly important seed dispersers, they are also responsible for fruit crop damage in orchards. Hence, along with seed dispersal and pollination benefits, there can also be costs from bats as perceived by people (i.e., ecosystem "disservices" from bats[10][22]). Similarly, the diet of insectivorous bats might be constituted from insect pests as well as beneficial insect species. The resulting trade-offs in ecosystem services and the so-called ecosystem disservices are therefore important to address[22]. However, it is quite challenging to factor such nuances into empirical studies[58].

Methodological challenges

An important methodological challenge is the quantification of ecosystem services. Many ecosystem processes and functions maintained by bats are difficult to track and to directly measure their magnitudes. Moreover, Old World fruit bats are particularly difficult to study as pollinators due to their volant, nocturnal, and elusive habits[96]. Therefore, the link between bat functions in ecosystems and their services is usually based on correlative evidence[10]. More specifically, for certain services of bats such as pollination, seed dispersal, and insect pest control, the conversion of bat-maintained functions to a realized service is not always possible and will require creative methodological approaches in the future.

Logistical and resource challenges

In India, studying bats at night, especially with certain methods that require tree watches and focal scans to study natural behaviours, is difficult due to safety and security concerns in different landscapes. Risks from humans as well as large animals at night pose some of the biggest challenges, especially for women scientists. This limits research not only in terms of documenting bat behaviour and natural history but also in terms of limited human resources to study these interesting creatures.

Along with a lack of human power, limited availability of advanced approaches, technology, and resources are important challenges that need to be addressed in the near future to advance our knowledge of bat ecosystem services. For instance, studying bat movement is crucial for quantifying seed dispersal and pollination services, but it is a challenge to capture large bat species (e.g., *Pteropus medius*), to tag smaller species or ones in caves, to secure funding to procure suitable equipment, and to use technologically-advanced methods for longer-term data collection, which is critical for understanding ecosystem services (Chapter 7). One possible way to address these challenges is to develop indigenous technology (e.g., tracking systems within the country to reduce the costs of movement studies). However, a potential challenge in this could be finding the right kind of collaborators (e.g., engineers or technologists).

Regulatory challenges

To delve deeper into the ecosystem services of bats would require long-term as well as large, landscape-scale studies to assess and quantify the bat-related ecosystem functions. However, securing permissions for long-term, large-scale studies in forested areas can be a difficult and time-consuming task. Securing permissions in state-owned as well as privately-owned lands has become especially challenging after the COVID-19 pandemic and recurring Nipah virus outbreaks, where bats, being potential reservoirs for zoonotic viruses, are perceived to be more harmful to than useful for human well-being. Additionally, as the study of ecosystem services is a relatively new field, convincing authorities or local people (on whose lands bat studies can be conducted) with evidence is a challenge due to a lack of sufficient data or limited knowledge of the existing literature.

Leaf-nosed Bat (*Hipposideros* sp.) chasing a mosquito.
Photo: Rajesh Puttaswamaiah

Critical Knowledge Gaps and Opportunities for Future Research

Multiple research gaps remain to be addressed in the study of ecosystem services provided by frugivorous and insectivorous bats, globally and within India. These knowledge gaps can be broadly categorized into the following categories.

Conceptual understanding of ecosystem services

Ecosystem services as a framework is still an understudied topic, especially with reference to bat conservation. The understanding of ecosystem services as a concept (see above) is a major gap that makes it difficult to address bat conservation issues through an ecosystem services lens, which can be effective for on-the-ground conservation with local people and in policy-making[10]. There have been very few systematic ecological studies, especially in India, that can potentially be related to ecosystem services from bats[10][100], their actual linkages with people's well-being[22], and their effects on conservation action for bats.

Lack of quantification of ecosystem services by bats

In India, studying bats at night, especially with certain methods that require tree watches and focal scans to study natural behaviours, is difficult due to safety and security concerns in different landscapes. Risks from humans as well as large animals at night pose some of the biggest challenges, especially for women scientists. This limits research not only in terms of documenting bat behaviour and natural history but also in terms of limited human resources to study these interesting creatures.

Along with a lack of human power, limited availability of advanced approaches, technology, and resources are important challenges that need to be addressed in the near future to advance our knowledge of bat ecosystem services. For instance, studying bat movement is crucial for quantifying seed dispersal and pollination services, but it is a challenge to capture large bat species (e.g., *Pteropus medius*), to tag smaller species or ones in caves, to secure funding to procure suitable equipment, and to use technologically-advanced methods for longer-term

A bat exclusion experiment to measure pest insect infestation in a rice paddy field. Photo: Cárol Sierra-Durán data collection, which is critical for understanding ecosystem services (Chapter 7). One possible way to address these challenges is to develop indigenous technology (e.g., tracking systems within the country to reduce the costs of movement studies). However, a potential challenge in this could be finding the right kind of collaborators (e.g., engineers or technologists).

Lack of interdisciplinary approaches and training to study bat ecosystem services

The limited understanding of the relevance of ecosystem services from bats is due to the lack of approaches that combine multidisciplinary perspectives, from ecological, socio-economic, and cultural angles, which would help connect bat conservation with human well-being. Bat studies from India have largely focused on systematics, anatomy, acoustics, diet, behaviour, and habitat use by bats until recently (Section II). However, there are few studies that have focused specifically on bat ecosystem services, which also suggests that many ecosystem services from bats in India have yet to be documented (e.g., the possible control of disease vectors by bats like the mosquito control documented in Australia by Gonsalves et al. 2013[111]). Very few detailed studies from India[21][22] have attempted taking an interdisciplinary approach to connect ecological responses of bats to landscape-scale and agroforestry plantation/farm-scale ecological and environmental variables, with local ecological knowledge, cultural beliefs, perceptions, and attitudes towards bats, and their effects on bat conservation (vis-à-vis human well-being) in the diverse socio-ecological settings of India.

Lack of research focus on bat ecosystem services in India

Studying ecosystem services, as elaborated above, needs an understanding of multiple perspectives beyond biology. This can only be fulfilled with an open mindset and willingness to engage with other approaches such as sociology, economics, disease vector biology, and agricultural sciences to build capacity among bat researchers to study such topics for bat conservation. However, there is a general lack of scientific engagement among bat biologists to pursue the non-biological aspects of bat conservation in order to study bat ecosystem services systematically. Collaborations between social scientists, conservationists, and bat biologists are very important to counter existing biases, as is capacity building for bat biologists to look beyond biological and ecological data alone as inputs for conservation planning and outreach. This trend is also interestingly reflected in the limited number of core authors of this chapter. Systematic, ethnographic documentation of local ecological knowledge and people's lived experiences in close proximity to bats, like near forest fringes and in agricultural settings, may provide clues to many aspects of bat ecosystem services that natural scientists may be unaware of[21].

Due to these gaps, research on bat ecosystem services in India is still a very nascent field. Building the baseline literature on bat biology itself is going to have its own trajectory, only after which can further interesting questions be asked. Some future directions for ecosystem service research in India are related to:

- The loss of ecosystem services from insectivorous bats in increasingly pesticide-laden farms,
- Bat dispersal of native fruits as well as exotic fruits that are increasingly grown in plantations,
- The guano yield from bats in caves and its utilisation in the context of high-yielding chemical fertilisers, and
- Spatio-temporal and seasonal factors influencing the provisioning of different ecosystem services by different bat species.

To this end, we offer several recommendations for advancing the study of bat-related ecosystem services and the application of this research to bat conservation in India.

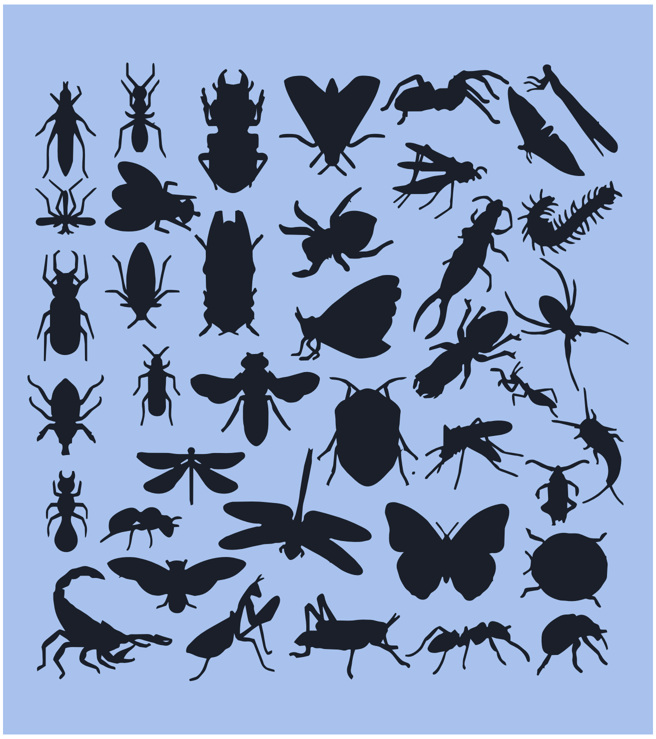

Illustration of arthropods that feature in the diet of bats.
Illustration: Adwait Pawar

Research opportunities related to pollination and seed dispersal

Systematic and species-level studies need to be undertaken with the primary objective of quantifying ecosystem services. Studies of plant–bat interactions are lacking in India, and it is high time to focus on the plant perspectives of these interactions, which occur during flowering (pollination), fruiting (seed dispersal), or both stages (double mutualisms). For prioritisation, researchers may choose ecologically or socially relevant contexts such as pollination and seed dispersal of economically important plants, including exotic species, and mangroves.

Research opportunities related to pest control

India has a rich diversity of bats and insects. However, institutions studying these taxa remain separate domains, and long-term collaborations among them is lacking. Interdisciplinary collaborations among bat researchers and agricultural pest monitoring agencies to get lists of insect and rodent pests and comparing them with bat diets will aid in understanding and establishing the role of bat species as agricultural pest controllers. Specific crop-based studies focusing on the kinds of pest control provided by bat species need to be quantified. Site-specific and/or crop-specific studies on bat diet along with controlled field experiments that prevent access of bats to insects feeding on crops will help in quantifying the economic value of pest control by bats.

Research opportunities related to disease vector control

Similar to the case with pest insects, collaborations between bat researchers and disease vector control research institutions will be important to obtain lists of potential animal and human disease vectors to compare with bat diets. This will be critical, especially in the context of increasing threats from certain diseases.

Research opportunities related to guano

Systematic quantification of bat guano and their nutritional value in comparison with existing biofertilisers needs to be conducted. These data will be crucial for the recommendation of bat guano as an alternative, and likely low-cost, supplement for crops in Indian agricultural ecosystems. However, simultaneous studies on the risks of exposure to zoonotic pathogens and disturbance to cave ecosystems through long-term use of bat guano need to be conducted to assess the overall value of using bat guano in the future.

Accessing funds for research

Using this report and other publications, appeals and proposals can be submitted to various committees (government and private) requesting the promotion and support of research related to bat-provided ecosystem services with a special highlight on the potential economic value associated with these services. This can be done by estimating the direct economic value with respect to: 1. yield increase by pollination and seed dispersal of commercially important crops, and 2. decrease in cost for pesticide and fertiliser applications in agricultural fields.

Ecosystem services concept in education

The concepts of biodiversity functions, their interconnectedness, and ecosystem services can be introduced in the formal education curriculum, starting in school-level textbooks. The significance of this education goes beyond bats as this is necessary to understand the importance of other wildlife and their habitats as well.

General awareness

Different media platforms can generate awareness about the ecosystem services of bats and their economic value (Chapter 14).

Across-field collaborations

Focused multidisciplinary workshops and conferences that include medical professionals, entomologists, engineers, economists, and farmers are important to brainstorm collaborative ideas to understand and utilise the ecosystem services of bats (Chapter 12).

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Section IV.

Policy and Public Engagement

The Policy and Public Engagement Working Group members listed below contributed to the following chapters through conceptual design, critical content review, and providing additional data and perspectives:

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Researchers from Osmania University showing a bat to local community members near Kolar. Photo: Aditya Srinivasulu

Chapter 11

Overview of Policy and Public Engagement: History to Present

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India hosts 135 bat species (Chapter 1), which are pivotal in pest control, pollination, and seed dispersal and essential to agriculture and forest regeneration. Despite their ecological importance, bats face persecution fuelled by misinformation, fear, and habitat destruction. Over the years, human activity, urbanisation, and climate change have compounded their plight (Chapter 15). Government bodies, researchers, and communities have initiated measures to protect bats, such as the documentation and awareness programmes enacted by state biodiversity boards, new additions of bat species in the Wild Life (Protection) Amendment Act, 2022[1], and the formulation of a Kolar Leaf-nosed Bat (*Hipposideros hypophyllus*) conservation plan by the Karnataka Forest Department[2]. However, these efforts remain fragmented and have been marred by gaps in policy and public understanding. Notable gaps in bat-related policy include the lack of species-specific conservation guidelines, with most bat species left unprotected, and the absence of coordinated strategies to address bat conservation issues. Indeed, policies governing bat species have been almost non-existent in India, except for a few instances where some states have taken positive initiatives to protect specific populations and species (e.g., the addition of annual bat monitoring protocols to the management plan of the Wayanad Wildlife Sanctuary, Kerala in 2023). These scattered efforts highlight the urgent need for a focused and structured policy to address the diverse gaps in understanding and protecting bat species in India. Below, we capture some key policy and public engagement initiatives implemented by different stakeholders across India and then dwell upon what actions are required in the future to support effective bat conservation.

National Wildlife Policy

Several changes to national policy over the last 50 years have impacted the legal status and protections of bats in India. The first significant national wildlife policy was the Indian Wild Life (Protection) Act, 1972 (WLPA), which was enacted to protect and manage India's rich wildlife and their habitats and to combat the illegal trade in wildlife and wildlife products. The major objectives of the WLPA included the protection of endangered flora and fauna, the management of ecologically important areas, and the assurance of environmental and ecological security. In addition, plants and animals were listed under different schedules and afforded varying protection and monitoring priorities. Species-specific programmes, such as Project Tiger (1973), its successor the National Tiger Conservation Authority, and Project Elephant (1992), were initiated under the WLPA to ensure focused protection of priority species[3]. Various bodies such as the National Board for Wildlife, State Board for Wildlife, Central Zoo Authority, and Wildlife Crime Control Bureau were also constituted under this act to ensure wildlife protection and security.

Although the 1972 WLPA was a welcome move for broad wildlife protection, it did not serve to protect bat species. The act was created with five schedules that determined the level of protection accorded to wildlife species. Schedule I and Part II of Schedule II provide the highest degree of protection to critically endangered and endangered species such as the Bengal Tiger (*Panthera tigris tigris*) and the Indian Rhinoceros (*Rhinoceros unicornis*). Schedules III and IV list species that are protected but with less severe penalties for violations. Schedule IV regulates the trade and cultivation of specific plant species. Finally, Schedule V lists animals considered to be "vermin", which can be legally hunted. When passed, the WLPA listed fruit bats under Schedule V, alongside wild boar (*Sus scrofa*), rodents, and the House Crow (*Corvus splendens*), allowing for their unrestricted killing as agricultural pests rather than ecologically important fauna[3]. Furthermore, insectivorous bat species were not included in any schedule, leaving them unprotected and as a grey area left open for subjective interpretation of the law[3]. It was not until 2002 that the central government added Wroughton's Giant Mastiff Bat (*Otomops wroughtoni*) and Salim Ali's Fruit Bat (*Latidens salimalii*) to Schedule I of the WLPA, affording these two species the highest level of protection. The other 112 species of bats in India (as of 2002) were not affected.

However, in the most recent amendment, the Wild Life (Protection) Amendment Act, 2022, bats were given increased protection compared with the previous acts[1]. Instead of the previous six schedules, the new amendment streamlined the list of protected species into four schedules. A total of six bat species were uplisted to the Schedule I category and six were uplisted to the Schedule II category, placing these bat species in the same level of protection as Bengal Tigers and Indian Elephants (*Elephas maximus indicus*)[1]. The Schedule I category now includes bat species such as Salim Ali's Fruit Bat (*Latidens salimalii*), Wroughton's Giant Mastiff Bat (*Otomops wroughtoni*), the Kolar Leaf-nosed Bat (*Hipposideros hypophyllus*), the Nicobar Flying Fox (*Pteropus faunulus*), the Andaman Horseshoe Bat (*Rhinolophus cognatus*), and the Black-eared Flying Fox (*Pteropus melanotus*)[1]. The Schedule II category includes bat species such as Durga Das's Leaf-nosed Bat (*Hipposideros durgadasi*), the Indian Flying Fox (*Pteropus medius*), the Mitred Horseshoe Bat (*Rhinolophus mitratus*), Peters's Tube-nosed Bat (*Harpiola grisea*), the Rainforest Tube-nosed Bat (*Murina pluvialis*), and the Sombre Bat (*Eptesicus tatei*)[1]. The removal of fruit bats, vital pollinators and seed dispersers, from the "vermin" list ensures stricter penalties for hunting or harming these species.

In some cases, these changes to the WLPA empowered state agencies to more effectively safeguard local bats. For instance, increased protections for bats enabled forest officers in Karnataka to arrest four persons in connection with the killing of eight bats for meat in Tumakuru district[4]. However, without systematic and widespread dissemination of these 2022 amendments among wildlife agencies, effective implementation of the WLPA suffers. As an example, although the Wild Life Protection (Amendment) Act, 2022 came into force in early 2023, bat killing is increasing in prevalence in the jungles of the Mahuadanr range of the Palamau Tiger Reserve in Jharkhand because the enforcement personnel responsible for the region were not informed of bats being reclassified from "vermin". Consequently, legal action has not been taken against any hunters of bats across the region.

Overall, the 2022 amendment to the WLPA reflects a growing recognition of bats' ecological roles by increasing the number of species protected from two to fourteen[1]. Yet the number of bat species protected under the WLPA remains less than 10% of the total bat species in India. Of the species remaining unprotected under the WLPA, three are listed as Vulnerable, eight as Near Threatened, and 15 as Data Deficient on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species. Population declines due to habitat loss, habitat fragmentation, and hunting have been observed for several species protected by the WLPA, including endemic bats (e.g., *Latidens salimalii*) and more geographically widespread ones (e.g., *Pteropus medius*) (Chapter 15). This underscores the significant gaps in legislative coverage of bats and the need for more proactive planning when considering long-term conservation strategies in India.

Significantly, the 2022 amendment was strengthened to combat illegal wildlife imports with the introduction of a new Schedule IV for non-native species listed by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), including 11 bat species from the Pteropodidae. This provision is supported by the Customs Act, 1962, which serves as a tool to govern wildlife trade, enforce CITES restrictions, and regulate cross-border wildlife supply chains[5]. While the revised Schedule IV of the WLPA included many pteropodids, it failed to include Microchiroptera bats (e.g., Painted Bats [*Kerivoula picta*]) that are traded significantly from the South East Asian countries[6].

International Bat Appreciation Day celebrations at Kerala Forest Research Institute. Photo: Nithin Divakar

Despite being in effect for over five decades, the WLPA continues to face significant challenges. Overcoming these obstacles necessitates a collaborative approach involving the government, civil society, and the public. Effective enforcement, community engagement, systematic research, and widespread awareness campaigns are essential measures to safeguard India's bat diversity, which contributes more than 31% to the terrestrial mammalian diversity of India[7].

Other Government Initiatives

There are multiple institutions, nongovernmental organisations (NGOs), state and union territory Forests and Wildlife Departments, and local communities that collaboratively work for bat conservation in India. One such example is Bat Conservation India Trust's initiative on educating and guiding the Karnataka Forest Department to protect bats and their habitats in the biodiversity-rich Western Ghats. This collaboration has helped protect several caves, including one in Muroor Village, Kumta Taluk that is the only known roost site of Lesser Dawn Bats (*Eonycteris spelaea*) and one in Devarayasamudra village in Kolar district, South Karnataka that hosts multiple *Hipposideros* species. In addition, the cooperative project has widened protection for the habitats surrounding these caves from the detrimental effects of hunting and mining. These interventions and collaborations have helped the population of Lesser Dawn Bats bounce back from a low of 150 individuals up to 500 individuals within 5 years (pers. comm., author R.P.).

State and union territory initiatives

At the state and union territory level, the additions of annual bat monitoring programmes in the management plans (e.g., in Kerala and Karnataka) and capacity-building programmes for frontline staff are positive signs of improvement for state-level bat conservation. In February 2010, the Karnataka Forest Department established the Bhimgad Wildlife Sanctuary, covering about 190 km^2 and encompassing the Barapede caves, in order to protect the rare Wroughton's Giant Mastiff Bat and its cave habitats from bauxite mining[8]. Similarly, in June 2019, the Karnataka Forest Department declared the Hanumanahalli Hill and the surrounding area as the Kolar Leaf-nosed Bat Conservation Reserve to save the last known population of the critically endangered *Hipposideros hypophyllus*[9].

In Rajasthan, municipal authorities implemented measures to mitigate bat deaths during extreme heatwaves, including sprinkling water near bat roosts in Menar. These efforts followed mass die-offs of flying foxes due to temperatures above 45°C. While a reactive approach, such measures highlight the potential for government intervention in urban wildlife crises[10]. The capacity for government agencies to adaptively react to bat emergencies were further evidenced in the involvement of the Forest Departments of Karnataka and Rajasthan during the COVID-19 pandemic to protect bats from persecution by the general public.

A campaign to protect the only roost of the Kolar Leaf-nosed Bat (*Hipposideros hypophyllus*). Photo: Aditya Srinivasulu

Archaeological Survey of India

The Archaeological Survey of India (ASI) frequently prioritises tourism and monument preservation over ecological considerations (Chapter 12). The ASI, responsible for managing thousands of historical monuments, has often been critical of bats onsite. At sites like Qutb Minar, Khirki Mosque, Feroz Shah Kotla, and Agrasen ki Baoli in Delhi and Daulatabad Fort in Maharashtra, restoration efforts have included installing bright lights and sealing off roosting spaces, which disrupted resident bat colonies. In some instances, chemical cleaning was used to remove bat guano, further deterring roosting by bats[11][12][13]. However, in rare cases, ASI allowed bats to remain in monuments where their presence did not interfere with tourism or preservation activities. For example, the ASI team in Golconda Fort, Hyderabad attempted to dissuade bat roosting in the ruin on multiple occasions but eventually gave up and left a small portion of the fort in which bats were permitted to roost. In other instances, the ASI has allowed bat colonies to coexist with heritage preservation, particularly at less-frequented sites like Zafar Mahal, where bats roost in unused chambers. This demonstrates a limited, but noteworthy, willingness to accommodate bats when their presence does not interfere with tourism[14].

Community Initiatives

Community perceptions towards bats are generally considered negative in India (Chapter 14); however, a few exceptions are illustrated by regional and local practices that benefit bats. In Tamil Nadu, villages near sacred groves protect bats by adopting unique cultural practices. For instance, locals avoid using firecrackers during festivals so as not to disturb bat colonies roosting in these groves[15]. Similarly, some communities in Assam regard bats as sacred and actively discourage hunting of these species[16]. In some villages in Telangana, villagers perform puja on trees where bats roost, and they fondly call these flying mammals “tapas paskhulu” (praying birds) because of their habit of hanging upside down from branches “as if doing penance”[17]. The people of Sarsari village in Bihar associate bats with the goddess Lakshmi and believe the protection of bats brings wealth[18]. In all of these cases, culturally-driven positive attitudes towards bats and their habitats results in the de facto protection of these bat populations.

Overview of Bat-Related Public Engagement

The successful development and implementation of policies that protect bats and their habitats are largely dependent on effective public engagement. Public engagement is vital in changing perceptions and fostering support for conservation efforts. In India, where bats are often misunderstood and feared, community outreach, educational programmes, and grassroots movements have emerged as powerful tools to shift public attitudes (Chapter 14). Types of public engagement have ranged from addressing myths and misconceptions to promoting coexistence and advocating for policy changes. Below, we explore the various efforts in public engagement undertaken to raise awareness about bats, their ecological roles, and their conservation needs.

School-focused educational campaigns

Organisations such as Wildlife SOS, the Bombay Natural History Society (BNHS), Ashoka Trust for Research in Ecology and the Environment (ATREE), Zoo Outreach Organisation (ZOO), Kerala Forest Research Institute (KFRI), Bat Conservation India Trust (BCIT), and other NGOs have conducted workshops in schools and colleges across India with the aim to educate students about bats’ ecological importance in pest control, pollination, and seed dispersal. Activities often include:

- Interactive sessions using visuals and live demonstrations (where permitted);
- Distribution of educational materials, such as pamphlets and posters, highlighting the benefits of bats;
- Creative learning activities, such as ZOO’s South Asian Bats Colouring Book; and
- Guided field trips to observe bats in their natural habitats.

The goal of these efforts is to instil a sense of curiosity and appreciation for bats among younger generations.

Community-based education

From rural to urban areas, general community engagement is critical for promoting tolerance of bats at the local level, and a variety of NGOs, government agencies, academic groups, and collaborative associations have used diverse methods to foster community support for bats and their conservation. For example, conservationists in the Western Ghats engage local communities through storytelling sessions and nature walks with the intention of generating a deeper appreciation for bats. In regions like Tamil Nadu and Assam, where bats are linked to cultural beliefs, local festivals have been used as platforms to educate communities. Events such as environmental fairs feature sessions that explain bats' roles in ecosystems and dispel myths about bats being harbingers of disease or bad luck. Local animal welfare associations and environmental groups have hosted interactive sessions to educate urban dwellers about bats' benefits and to debunk fears related to their presence in urban settings. Collaborations between scientific institutions and NGOs have resulted in local workshops for the general public, where participants learn about bats' ecological importance and the threats they face. These workshops often culminate in field surveys, providing attendees the opportunity to experience bats in their natural habitats.

Bat-centric events

Bat Awareness Month, bat nights, and other bat-centric events have been a platform for global to local public engagement in bat conservation. During Bat Awareness Month in October, multiple groups distribute materials that inform the public on how bats help to control mosquito populations and prevent the spread of insect-borne diseases like malaria[19]. In Maharashtra and Karnataka, "Wildlife Week" celebrations have included special sessions on bats, focusing on their conservation and the need for bat habitat protection. All of these events attract diverse audiences, from school children to policymakers, extending the reach of these bat awareness campaigns generationally as well as societally and geographically.

Citizen Science programmes

Citizen science serves as not only an important source of invaluable bat data that would otherwise not be available but also an interactive form of public engagement (Chapter 13). There are several citizen science initiatives that have encouraged public participation in bat research in India, including:

- Collaborations between community groups, the Indian Institute of Science, and Osmania University to map bat habitats and study bat behaviour;
- PteroCount, the South Asian Bat Monitoring Programme, a volunteer-driven project that monitors Indian Flying Fox (*Pteropus medius*) populations across South Asia, providing valuable data on bat roosts and aiding fruit bat conservation efforts;

Figure 11.1 Examples of bat-positive social media posts using eye-catching imagery. Images credit: Bat Conservation India Trust.

- "The Fruit Bat Project" from KFRI, which identifies and maps Indian Flying Fox roosting sites; and
- "The Bat Roost Database" managed by the Indian Bat Conservation Research Unit, which collates information about bat roosting sites provided by an extensive network of trekkers and nature enthusiasts.

Public advocacy campaigns

A number of grassroots campaigns have called for improving bat-related policies in India. The primary focus of these advocacy initiatives is generating public support to drive the amendment of the WLPA to include all bat species in India. These regulatory change campaigns include the circulation of petitions and appeals that have been signed by thousands of concerned citizens. One such example is the campaign initiated by researchers from Osmania University to include the Kolar Leaf-nosed Bat under Schedule I of the WLPA[20].

Engagement through media

Organisations throughout India have leveraged traditional and digital media to spread positive messages about bats. Social media platforms have been especially instrumental in reaching urban and tech-savvy audiences, such as through the use of eye-catching infographics and videos debunking myths about bats (Figure 11.1). NGOs (e.g., BCIT, People for Animals, Wildlife SOS) have launched myth-busting campaigns through digital media, while newspapers like *The Hindu* and *Citizen Matters* have featured stories about bats' ecological roles and the threats they face. The regulatory change campaign described above successfully employed social media drives using hashtags like #SaveTheBats and #BatProtectionNow to boost signatures on their petitions.

During the COVID-19 pandemic, 64 researchers, scientists, and conservationists from India led educational campaigns to counter misinformation that wrongly vilified bats as the primary reservoirs of the virus (for more details, see Chapter 14, Box 2)[21][22]. These efforts were amplified by the publication of a special issue of *Zoo's Print* that featured material on bats and Covid-19 outreach. These initiatives emphasised bats' ecological contributions and the risks of indiscriminate bat killings, targeting an audience of policymakers, the media, and the general public.

Opportunities for Bat-related Policy and Public Engagement in India

Although the Indian community of bat researchers and practitioners has made great strides in improving bat-related policy and public engagement, particularly in the previous decade, there are still innumerable opportunities to continue this trend in bat conservation from the local to the national level. Below is a brief summary of some of the most promising directions for Indian bat policy and public engagement in the future.

Improving national to local policies

Including 14 species of bats under Schedules I and II in the WLPA is a great start to protect threatened bat species, but it represents only a small step towards ensuring that other bat species and their habitats are protected in the long-term. We recommend that government-led forums be initiated to enable multi-stakeholder participation in a collaborative evaluation of the ways in which state, union territory, and national regulations can provide more stringent protection for all bat species and for critical bat habitats. In particular, ASI and bat conservationists should cooperate to improve bat-related policies and practices at archaeological sites, including the identification of sites at which to launch bat-related educational outreach and integrated, ethical bat management projects. A comprehensive bat management plan to identify, monitor, and protect key bat roosts and other habitats should be prepared by a diverse group of stakeholders and shared with all state and union territory Forest Departments so that they can incorporate these into their respective states' and union territories' local plans. Another area of policy focus for the benefit of both bats and human communities should be the development of guidelines for handling zoonotic disease outbreaks at the local to national levels.

Facilitating the effective implementation of existing policies

Even when policies exist for the protection of bats and their habitats, the implementation of these protective measures is often hampered by a lack of awareness, resources, or appropriate data to inform their application in the real world. In order to inform policy- and decision-making related to land management and the implementation of wildlife regulations, we recommend that known bat roosting site localities should be prioritised by using standardised indices such as the Bat Cave Vulnerability Index[23]. In addition, the best available bat data (e.g., data compiled from citizen science projects like those listed above) should be included in both Environmental Impact Assessments and Ecological Impact Assessments.

While the WLPA remains the primary legal protective framework for wildlife, bats can also benefit from indirect protection through other existing legislation. For example, the Food Safety and Standards Act, 2006 prohibits the sale of bats for consumption in meat markets[24]; the Arms Act, 1959 prohibits the use of firearms in hunting bats[25]; and the Prevention of Cruelty to Animals Act, 1960, the Prevention of Cruelty to Animals (Pet Shop) Rules, 2018, and the Breeding of and Experiments on Animals (Control and Supervision) Rules, 2006 prevent bats from being kept as pets, traded, or used in harmful experiments without independent ethical oversight[26][27][28]. In addition, the Prevention of Cruelty to Animals (Regulation of Livestock Markets) Rules, 2017 provides a legal avenue to regulate trade practices that may include bats[29], while applicable sections of the Indian Penal Code (IPC) and the Bharatiya Nyaya Sanhita address illegal killing or trade of wildlife[30][31]. Together, these legislations broaden the potential avenues for bat protection, even though they have rarely been invoked specifically for bat conservation. In the future, bat conservationists should leverage these diverse regulations to protect bats and their habitats from the local to the national levels.

Wildlife law enforcement personnel should also be trained in the current local, state, union territory, and national laws as they apply to bats and other wildlife. Concurrently, NGOs (especially international ones with greater resources) and academic partnerships should strive to provide financial assistance, physical assets, human resources, and other support to parties implementing bat protective measures on the ground.

Engaging in more targeted education and outreach with stakeholders directly involved in human–bat conflict

In order to mitigate human–bat conflict, promote bat tolerance, and engender support for policies protecting bats and their habitats, bat researchers and practitioners should continue to expand their education and outreach efforts to focus on stakeholders that live with bats. One of the first steps towards developing this type of targeted outreach is identifying which stakeholders interact directly with bats at these human–bat interfaces for each specific region and context (Chapter 12). After these target audiences are prioritised, bat conservationists can collaborate with local communities, social scientists, and other stakeholders to co-design and disseminate persuasive, bat-centric educational resources and outreach messages (Chapter 14). Increased research on bats' diversity of ecosystem services (Chapter 10) can assist in improving the salience of these behaviour change interventions.

Building capacity of bat stakeholders

By improving the capacity of all bat stakeholders to put conservation measures into action, we can better safeguard bats and their habitats throughout India. We should expand education and outreach to and professional training of not only law enforcement agents but also policy- and decision-makers to ensure: 1. bat-related regulations are enforced, and 2. bat protective measures continue to be improved for the benefit of all bat species from the community to the national levels of governance. We recommend that a gap analysis be conducted on the challenges that environmental law enforcement personnel and wildlife managers face in implementing bat protections. In this way, obstructive issues can be identified and prioritised such that these constraints can be addressed more efficiently, particularly when designing conservation action plans for different bat taxa. We further recognise the great opportunity in fostering community-based bat conservation initiatives (e.g., monitoring of roost sites through citizen science programmes) to build capacity for the strengthening and effective implementation of bat protection policies.

Conducting applied research on the Human Dimensions of bats and bat management

As reviewed in Chapter 14, our understanding of the Human Dimensions of bats and bat conservation (HD) in India is limited. However, bat-related public engagement and policy-making provide extensive opportunities for social scientists to delve into issues related to bats, their management, and the interrelationships between bats and people. In turn, efforts to promote bat-friendly policy and to expand, diversify, and scale bat-related education and outreach could benefit immensely from the invaluable findings of HD researchers.

Challenges

While current bat policy and public engagement efforts have been impactful, they face significant challenges including, but not limited to the following issues.

The spread of misinformation during crises

Zoonotic disease outbreaks, instances of human–bat conflict, and other events that could frame bats in a negative light can spark the viral spread of misinformation about bats. For example, the COVID-19 pandemic saw bats unfairly blamed as disease vectors, undermining years of conservation awareness (Chapter 14).

Resistance from local communities

In areas where bats are considered pests (e.g., fruit-growing regions), disease transmitters, or bad luck, public acceptance of conservation efforts remains limited. Negative attitudes towards bats can be difficult to overcome and can be significant challenges to developing and implementing bat policy and conservation actions (Chapter 14).

Lack of awareness and limited information-sharing among and between policy- and decision-makers.

As discussed in the Opportunities section above, effective policy- and decision-making as well as wildlife law enforcement is significantly restricted by the limited dissemination of information about bats, their distributions and location, their ecosystem benefits, and the regulations protecting them and their habitats. Compounding this challenge is the relative paucity of bat-related education, outreach efforts, and training that have been designed specifically to target policy-makers, law enforcement personnel, wildlife managers, and other stakeholders involved directly in the development and implementation of bat-related regulations.

Conflict of interests among parties responsible for managing habitats and species

Diverse public and private individuals and organisations are responsible for bat management from the community to the global scale. Unfortunately, the interests of these Indian bat stakeholders are frequently misaligned and often in opposition with one another. The description of the ASI's bat management practices above underscores the complications that arise when wildlife and land use managers have interests at odds with the conservation of bats and/or their habitats.

Logistical challenges

As with most other endeavours related to bat conservation, efforts to improve bat policy and to extend the reach of public engagement are constrained by limited:

- Resources (especially funding);
- Trained personnel;
- Research, citizen science, and community conservation support materials (e.g., echolocation call libraries for all regions of India, advanced bat monitoring devices, user-friendly bat field guides);
- Accessible information and open knowledge-sharing (especially related to local language and dialect needs);
- Collaborations, both within and between, different bat stakeholder groups;
- Capacity-building opportunities (e.g., transdisciplinary training);
- Granting of permits required for bat research and conservation actions, which is exacerbated by bureaucratic barriers; and
- Advancements in affordable and accessible technology for research and for the dissemination of educational resources and messages.

Conclusion

To save bats in India in the long-term, we need to develop more effective policies and develop a multi-stakeholder implementation plan for integrated conservation. While some species have been protected, we must focus on protecting their roosts and other key habitats as well. To develop any firm policy, it is crucial to have a good understanding of the species, so there must be specific plans to conduct bat research, education, and conservation. Concurrent with developing and implementing adaptive bat-related policy, we must expand public engagement to all sectors of India to promote coexistence and conservation of all bat species.

Chapter 12
Stakeholders in Bat Conservation and Research in India

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Conservation is a multifaceted endeavour, that involves collaboration among a wide range of stakeholders, each with their own interests, responsibilities, and perspectives. Therefore, a successful bat conservation strategy must take these diverse groups into account and foster partnerships that balance ecological, social, and economic needs. A multi-stakeholder engagement approach is crucial for addressing diverse challenges such as habitat loss, hunting, human–wildlife conflict, and the effects of climate change. By involving a broad spectrum of stakeholders, bat conservation in India can be a more effective, holistic, inclusive, and sustainable strategy, ensuring the preservation of these species. Understanding the stakeholders and their roles is essential for strategic networking and the successful implementation of conservation efforts. The relationships between and within all of these stakeholder groups are illustrated in Appendix 3. As a comprehensive effort towards conserving bat species in India, this chapter reviews the critical roles played by the main stakeholders that have been identified by the State of India's Bats (2024–2025) project.

Government of India

Wildlife conservation is an interdisciplinary, multifaceted process, including multiple stakeholders from various public sectors. The related objectives and roles of each relevant central ministry (and their respective central, state, and union territory departments) of the Government of India in bat conservation are summarised below and in the figure in Appendix 3.

Tomb bats (*Taphozous* spp.) roosting in an old monument. Photo: Tariq Ahmed Shah

Ministry of Environment, Forest and Climate Change (MoEFCC) and forest departments

The MoEFCC plays a central role in bat conservation by formulating and implementing policies that protect bat species and their habitats. It oversees the enforcement of wildlife protection laws, such as the Indian Wild Life (Protection) Act, 1972 (WLPA), which provides legal safeguards for bat species (Chapter 11). The WLPA has been instrumental in providing a legal framework for the conservation of wildlife, including bats, in India. However, the effective implementation of this Act, along with the development of targeted conservation strategies, is crucial for the long-term survival of these ecologically important mammals.

The Ministry supports research on bats' ecology and their ecological services, such as pest control and pollination. The agency also facilitates habitat restoration initiatives, particularly for forests and caves that are crucial to bats. Through public awareness campaigns and collaboration with state and union territory governments, research institutions, and nongovernmental organisations (NGOs), the MoEFCC ensures that conservation strategies are integrated into national biodiversity and climate action plans, addressing the impacts of habitat loss, pollution, and climate change on bats.

One of the MoEFCC's oldest institutions is the Zoological Survey of India (ZSI), which was established in 1916 to promote the advancement of knowledge about the diverse fauna of the then British Indian Empire. By gradually strengthening its staff and expanding its research programme, the ZSI has been instrumental in discovering, describing, and documenting India's wildlife, including bats. The ZSI has also functioned as an important public repository for bat specimens.

At the state and union territory level, forest departments are tasked with implementing wildlife protection laws. The departments play a key role in identifying and safeguarding bat roosting and breeding sites in forests and caves. Through regular monitoring and research, they contribute to understanding bat populations and their ecological roles. State and union territory forest departments also engage with local communities to promote awareness about bats' importance in pest control, pollination, seed dispersal, and other ecosystem services.

Ministry of Culture

Under the Ministry of Culture, the Archaeological Survey of India (ASI) has a unique role in bat conservation. India is culturally rich in monuments and heritage sites, with an extensive network of temples, mosques, caves, and monuments under the supervision of the ASI. Many of these also serve as roosting sites for multiple bat species, which are stressed by human visitation and threatened when sites are modified to better accommodate tourists' sensibilities (e.g., artificial light installation, removal of roosting bat colonies to reduce guano and smell) (Chapter 15). Large bat colonies may cause structural damage to monuments and deter tourists from visiting. ASI can work with bat researchers and conservationists to use these sites as an opportunity for bat-related education, the development of ethical guidelines for tourism around bat colonies, and finding ways to prevent bat-related damage to monuments. Such a collaboration can go a long way in protecting the bats and their habitats[32].

Ministry of Mines

The Ministry of Mines manages the surveying, exploration, and mining of all minerals within India. Although the Ministry is not responsible for coal, natural gas, or petroleum resources, its operations impact bats that depend on the habitats affected by activities related to limestone, sand, and mineral mining and quarrying (Chapter 15). The Ministry can contribute to bat conservation primarily by managing mining activities to ensure that they do not negatively impact bat habitats. Also, bat researchers can collaborate with them to develop guidelines for restoring bat roosting sites in abandoned mines.

Ministry of New and Renewable Energy

The Ministry of New and Renewable Energy can play a role in bat conservation by promoting energy development practices that minimize harm to bat populations and their habitats. Sustainable and renewable energy will play a critical role in reducing India's contributions to global climate change in the future, benefiting bats and their habitats in the long term. However, the construction of dams, solar farms, wind turbines, and the infrastructure that supports them can lead to bat habitat loss and fragmentation, modification and pollution of freshwater resources, and direct mortality and morbidity of bats (Chapter 15). In particular, the devastating effect that wind farms can have on bat populations from wind turbine collision has been widely reported[33]. Bat researchers can collaborate with the Ministry to mitigate these negative consequences of renewable energy expansion, ensuring that the energy needs of India are balanced with the protection of its wildlife and ecosystems.

Ministry of Agriculture and Farmers Welfare

The Ministry of Agriculture and Farmers Welfare plays a pivotal role in bat conservation by promoting sustainable agricultural practices that can protect bat habitats. By encouraging organic farming, reducing pesticide usage, and supporting agroforestry systems, the Ministry helps maintain ecosystems on which bats rely for foraging and roosting. Through its policies and programmes, the Ministry can bridge the gap between agricultural productivity and biodiversity conservation, ensuring that farming practices contribute to preserving vital species like bats. Additionally, guano harvested in monuments (under the Ministry of Culture) could be marketed as natural fertiliser with the help of the Ministry of Agriculture and Farmers Welfare (Chapter 10).

Ministry of Tourism

The Ministry of Tourism plays a significant role in bat conservation by promoting eco-tourism initiatives that highlight the ecological importance of bats and their habitats. The Ministry's National Strategy for Ecotourism[34] outlines the following activities to align its tourism policies with conservation goals:

"(i). Adopt low-impact wildlife tourism that protects the ecological integrity of forest and wildlife areas, secures the wildlife values of the destination and its surrounding

(ii). Highlight the biodiversity richness, their values and their ecological services to people

(iii). Highlight the heritage value of India's wilderness and protected areas

(iv). Build environmental and cultural awareness and respect

(v). Facilitate the sustainability of Ecotourism enterprises and activities" (p. 13)[34]

By responsibly and ethically integrating bats into these actions, the Ministry can help protect bat habitats while promoting responsible and sustainable tourism practices.

Ministry of Health and Family Welfare

The Ministry of Health and Family Welfare can play a potential role in bat conservation by addressing public health concerns while promoting an understanding of bats' ecological importance. Although bats are commonly associated with and can be important reservoirs for zoonoses, bats themselves are susceptible to pathogens

Uttam Saikia speaking about the importance of bats to army personnel. Photo: courtesy of Uttam Saikia and parasites transmitted by humans and domestic animals as well (Chapter 8). In addition, bats that consume vectors and reservoirs for zoonoses provide an important ecosystem service in reducing the risk of disease transmission to humans (Chapter 10). For this reason, the Ministry's projects within the National Center for Vector Borne Diseases Control and the National Centre for Disease Control's Integrated Disease Surveillance Programme overlap significantly with bat research and conservation efforts related to disease ecology and human-bat interactions.

State and union territory police departments

State and union territory police departments can play an indirect but significant role in bat conservation by enforcing laws and regulations that protect wildlife and their habitats. Their responsibilities include assisting the state and union territory forest departments in implementing the WLPA, particularly in preventing illegal activities like poaching, habitat destruction, and trafficking of bat species. State and union territory police departments also provide surveillance and security for caves, forests, and other critical bat habitats to prevent their unauthorized exploitation or vandalism.

Non-Governmental Organisations

Non-governmental organisations (NGOs) are "formal (professionalised) independent societal organisations whose primary aim is to promote common goals at the national or the international level"[35]. As such, these organisations have emerged as critical players in bat conservation efforts worldwide. Through research, education, community engagement, and advocacy, these organisations address the multifaceted challenges bats face while promoting coexistence and sustainable conservation practices. By fostering partnerships and implementing targeted actions, NGOs contribute significantly to safeguarding bats and the ecosystems they support. These organisations can act as bridges between science, policy, and the community, ensuring that bat conservation remains a priority in the broader biodiversity conservation agenda.

International NGOs (INGOs) play a pivotal role in bat conservation in India by providing resources, expertise, and global platforms to address the diverse threats to bats. Their contributions foster research, policy development, and public awareness, while supporting local research and conservation efforts. INGOs like Bat Conservation International and Global Wildlife Conservation provide technical, financial, and other support for bat research, habitat restoration, and community-based conservation projects in India. Grants and logistical support from entities like the International Union for Conservation of Nature Species Survival Commission (IUCN SSC) enable local researchers and national NGOs to conduct Red List assessments for Indian bat species and to design and implement conservation strategies. These international entities also assist and collaborate in organising workshops and training programmes to enhance the skills of researchers, forest department officials, and conservationists in bat monitoring and management. In particular, the IUCN SSC Bat Specialist Group is a collaborative and multidisciplinary network of bat biologists and conservationists supporting and promoting bat conservation activities worldwide. Several additional international networks of bat researchers and practitioners (e.g., the Global Union of Bat Diversity Networks, Global South Bats, and the Southeast Asian Bat Conservation Research Unit) also exist to unite and build the capacity of the international bat conservation community, including Indian professionals.

Within India, there are many wildlife- and environmental protection-focused NGOs; however, few have bat (or bat habitat) conservation as part of their primary working plan and mandate. Some of the national NGOs that support (or have supported) research and conservation of bats and their habitats in India include, but are not limited to:

- The Andaman Nicobar Environment Team (ANET), established by the Madras Crocodile Bank Trust (now managed by the Dakshin Foundation), facilitated surveys on bats in the Andaman and Nicobar Islands and conducted the only ecological study on the Nicobar Flying Fox (*Pteropus faunulus*) to date.
- Ashoka Trust for Research in Ecology and the Environment (ATREE), with a variety of bat projects that include epidemiological research on bats to prevent zoonotic disease transmission, studies on bats' ecosystem services, investigations of cave-dwelling bats' use of temples as critical habitats, and bat walks to engage local residents in bat conservation.
- Bat Conservation India Trust (BCIT) that partners with researchers, local communities, government agencies, and other organisations to protect bats and their habitats throughout India via advocacy, educational

outreach, surveillance and monitoring of bat roosting sites, creating digital documentation resources to support research and conservation, and other collaborative programmes.

- The Bombay Natural History Society (BNHS), one of the oldest wildlife institutions in India, which has led pioneering work on bats since the colonial period, including active advocacy for the protection of bats and their habitats, dissemination of bat education through webinars, Conservation Education Centres, and other conservation education programmes, and species-specific research and biodiversity assessments involving bat taxa.
- Centre for Wildlife Studies (CWS), with a particular interest in developing and promoting the use of the newest technologies to research and monitor bats across India.
- Kerala Forest Research Institute (KFRI), which has trained more than 80 students through annual bat workshops, engaged over 2000 students through a variety of bat education programmes, and collaborated extensively with the Kerala Forest Department (pers. comm., N. Divakar).
- Mhadei Research Center, which conducts bat diversity assessments and conservation outreach in parts of Goa, Karnataka, and the northern Western Ghats.
- National Cave Research and Protection Organization (NCRP), devoted to the study and protection of caves throughout India with research, public outreach, protection, and advocacy initiatives that incorporate and directly benefit cave-dwelling bats.
- Nature Conservation Foundation (NCF) has partnered with Bat Conservation International to conduct studies on various anthropogenic threats to Indian bats, such as wind energy, urbanisation, and conflicts between bats and archaeological site management.
- Sahyadri Nisarga Mitra, which engages in bat diversity assessments, bat habitat research and protection, and community awareness programmes focused in Maharashtra state.
- Speleological Association of India (SAI) that plans and implements a diversity of public education, advocacy, scientific research, and bat roosting and breeding site protection activities for the conservation of caves, cave ecosystems, and the bats that depend on them.
- Wildlife Conservation Society (WCS) India, the country-specific division of the INGO WCS, which, among other bat-related projects, fosters the underlying socio-cultural importance of human–bat interactions to promote coexistence with bats through their Celebrating Nature–Culture Relationships programme.
- Zoo Outreach Organisation (ZOO), which has been an active proponent of bat research by coordinating the Chiroptera Conservation and Information Network of South Asia (CCINSA), facilitating regional Red List assessments, and initiating PteroCount, a citizen science programme to monitor flying fox roosts (Chapter 11).

Community-Based Organisations

Community-based organisations (CBOs) encompass a wide range of identity- and/or place-based organisations with a variety of structures, legal statuses, funding, functions, and reach but are defined by sharing a common interest and exhibiting bottom-up efforts to influence systems in order to effect change or protect members' shared interests[36]. Examples of these organisations include Indigenous community groups, neighbourhood organisations, self-help groups, independent clubs, worker-led organisations, and rural groups that form to address environmental governance[36]. In relation to bat conservation in India, CBOs can be especially effective in:

- Conducting field research on bats and their habitats (e.g., via citizen science or co-production of information based on Indigenous science or Local Ecological Knowledge),
- Spreading awareness of bats and their ecosystem service values,
- Protecting and responsibly managing bats and their habitats, and
- Advocating for policies to conserve bats and their habitats.

Several CBOs currently benefit bats across India, the most notable of which is the community initiative to protect the critically endangered *Hipposideros hypophyllus* and its roosting site in Hanumanahalli village, Karnataka. Local residents have banded together to ensure that the bats' caves remain undamaged and unmolested by unauthorised trespassers and that the bats' water sources near the caves are not drained for irrigation[37].

Other Important Stakeholders

Community leaders

Community leaders (e.g., village elders, clan heads, religious or spiritual leaders, women's groups leaders, youth leaders) shape norms, rituals, and acceptance of change, which are all related to anthropogenic activities that directly and indirectly impact bats. For example, in Northeast India, members of the Pynurkba village in East Jaintia Hill district in the eastern most part of Meghalaya practice bat harvesting as an important component of their subsistence and cultural traditions[38]. Community leaders could collaborate with bat researchers and conservationists to ensure this tradition is practiced sustainably to protect both the bats and the tradition into the future.

In addition, community leaders have extensive local knowledge, which could play a critical role in:

- Understanding patterns of seasonal habitat use by bats,
- Identifying sacred sites shared by bats and religious devotees,
- Monitoring bat roosts and populations,
- Co-designing alternative livelihoods to reduce human behaviours that adversely affect bats and their habitats,
- Reducing the risk of zoonotic disease transmission to and from bats, and
- Co-planning and co-implementing bat conservation and habitat management strategies.

Academic institutions

Researchers at academic institutions are central to understanding the biology, ecology, and threats facing bat populations. The long-term bat research work undertaken by institutions such as Madurai Kamaraj University (MKU), Osmania University, the Kerala Forest Research Institute (KFRI), and the Indian Institute of Science has significantly advanced our understanding of Indian bat taxonomy, systematics, biology, ecology, behaviour, acoustics, and disease ecology. Moreover, academic institutions play a key role in the development of conservation strategies based on the best available science.

Cavers

Those that engage in caving (a.k.a. spelunking or potholing) either for recreation or speleology are often overlooked allies in bat research and conservation. With their technical expertise in cave exploration, frequent visitation to relatively inaccessible cave localities, and familiarity with cave ecosystems, cavers that adhere to responsible practices (i.e., with low impact on the environment and its wildlife and following all relevant safety guidelines) can assist in:

- Monitoring bats and their habitats;
- Liaising with other key stakeholders, such as local community members, private landowners, and other speleologists;
- Disseminating bat-related education and outreach;
- Co-developing and implementing field-based conservation and research projects focused on bats and their cave habitats;
- Devising best practice guidance for cave tourism ventures; and
- Providing training to chiropterologists in caving techniques and related safety and rescue protocols.

An awareness session being conducted by Shraddha Kumari K.
Photo: courtesy of Shraddha Kumari K.

Speleologists and cavers have already made substantial contributions to the research and conservation of bats in India. For example, the Caving in the Abode of the Clouds Project's long-term survey of caves in the Jaintia Hills of Meghalaya doubled the number of rare Wroughton's Giant Mastiff Bats (*Otomops wroughtoni*) known from the region when cavers discovered three new roosts[39]. By expanding their collaborations with recreational and professional cavers in the future, bat researchers and conservationists can more efficaciously map the critical habitats of cave-dwelling species, perform targeted studies of priority bat populations, and leverage the growing interest in adventure tourism for the conservation of bats and their habitats.

Traditional and social media

The role of traditional and social media content creators in wildlife conservation is more crucial than ever. Media outlets and influencers have the power to shape public perception and raise awareness about the importance of bats. By raising awareness, mobilising support, influencing behaviour, and driving real-world change, media platforms are essential in the fight to protect and conserve bats and their ecosystems. Engaging with various media and utilising their widespread influence can significantly amplify conservation efforts and lead to lasting, positive outcomes (Chapter 14).

General public

Members of the general public, especially individuals that are more directly involved in human–bat interactions (e.g., farmers, plantation owners, citizen science enthusiasts, traditional healers, households near bat roosts), have tremendous potential to support the conservation of bats and their habitats across India. Citizens can assist through direct engagement in bat conservation and research efforts (e.g., citizen science projects, changing behaviours that negatively impact bats and their habitats) and advocacy for policies that mitigate the negative impact of anthropogenic activities on bat populations (Chapter 13).

Private sector

For-profit organisations, business establishments, and multinational companies with branch locations in India can play direct and indirect roles in bat conservation. Fostering relationships with stakeholders in the private sector can promote Indian bat research and conservation through Corporate Social Responsibility (CSR) initiatives, further financial support for bat-related projects, employee–volunteer engagement programmes, promotion of bat awareness outreach campaigns, adoption of sustainable business practices, and other pro-bat activities (e.g., non-financial resource provisioning, building bat-friendly infrastructure). Since the Companies Act, 2013 requires many businesses to commit 2% or more of their 3-year net profits to CSR activities, Indian bats are likely already impacted by CSR-funded projects in the environmental sustainability, academic research, rural development, agricultural, education, health, and disaster relief sectors[40]. Linking bat research and conservation projects directly with CSR funding sources could prove especially lucrative in the future.

Opportunities for stakeholder engagement

Due to the transdisciplinary and integrated nature of bat research and conservation, chiropterologists must conscientiously and continuously identify, analyse, build relationships with, and manage the needs of a wide diversity of individuals, groups, and organisations that have an interest in, are affected by, or who can influence bat-related activities. There are numerous and constantly-evolving opportunities for improving the ethical, inclusive, and adaptive management of stakeholder relationships to benefit bat conservation and research throughout India. Below, we review several of these opportunities that we have identified as those with the broadest reach and the highest potential for fundamentally advancing bat conservation in India.

Mainstreaming bat conservation within government initiatives

Incorporating bat conservation initiatives into existing government programmes can secure financial support, eliminate implementation obstacles, and maximize the impact of these conservation efforts. This can be achieved by allocating budgets, promoting coordination across the government departments and agencies described above, and aligning conservation activities with broader development goals. It can also remove administrative and bureaucratic hurdles, enabling easier navigation of regulatory requirements and barriers. Conservation efforts can be more effectively implemented, monitored, and evaluated by leveraging the resources, infrastructure, and established networks within government agencies. This approach emphasises the interconnectedness between bat and habitat conservation initiatives, supports social development, and can lead to more comprehensive and sustainable outcomes.

Developing multi-stakeholder guidance and policies for bat-related matters

There is a tremendous need for universal, standardised protocols to define and guide best practices for a plethora of bat-related concerns, including, but not limited to:

- The responsible use of pesticides, herbicides, fungicides, fertilisers, and other chemicals in agricultural and timber production.
- The sustainable, ethical, and safe collection and use of bat guano.
- The sustainable and ethical practice of tourism, especially ecotourism, religious tourism, and archaeological tourism.
- Disease management, specifically related to outbreak response and zoonotic disease prevention and mitigation.
- Bat management within and around sites of archaeological and/or religious importance.
- Environmental Impact Assessments and other types of biodiversity conservation evaluations for mining and quarrying activities and for renewable energy projects.
- Effective, environmentally-friendly, and community-centric livelihood promotion programmes.
- Developing and implementing citizen science projects.
- Responsible media coverage of bat and other wildlife stories based on facts and the best available scientific information.

As reviewed above, each of these matters involve a wide diversity of stakeholders from the community to the global levels. Therefore, we recommend that bat-related policies and protocols should be collaboratively planned and implemented by the diverse stakeholders involved. In this way, we can ensure that these guidelines are the most effective, based on the best available information, and are supported by as many stakeholders as possible for their adoption and implementation.

Building capacity among all stakeholder groups to design and implement holistic and ethical bat conservation initiatives

A significant barrier to the planning and implementation of bat conservation is a lack of coordination and communication among stakeholder groups. By building networks and strengthening relationships across and within interested and affected parties, we can build the social capital (e.g., trust), transparency, and information exchange infrastructure that will support the effective implementation of bat conservation and research activities, policies, and relevant best practices (as described in the preceding point). As discussed in Chapter 11, law enforcement agents that are unaware of bat-related regulations cannot actively administer these protections in practice. Bat researchers, conservation NGOs, CBOs, all branches of government, and other stakeholders should collaborate with on-the-ground personnel and community members to provide training and educational outreach. This will ensure that all parties have the skills, knowledge, and tools that they need to plan, implement, monitor, and adapt bat conservation initiatives.

Co-production of education and outreach promoting human–bat coexistence and support for bat conservation

One of the most important ways that stakeholder groups can work together to improve bat research and conservation is through sharing information to promote human–bat coexistence (e.g., behaviour change messaging) and the protection of bats and their habitats (e.g., best practices related to the matters outlined in point 2 above). To this end, we strongly recommend that bat researchers, conservationists, content creators for traditional and social media, NGOs, CBOs, government agencies, nature educators, organic farmers, tourism professionals, private corporations, and other influential and knowledgeable stakeholders work together to codesign and share targeted informational outreach and education campaigns to promote bat conservation within all of the diverse social-ecological contexts of India[41] (Chapter 14). Dispelling myths and misinformation that is negative towards bats should be particularly prioritised in these outreach and education campaigns.

Constructing sustainable funding and asset management schemes to amplify bat research and conservation

Funding and other assets (e.g., human resources, innovation capacity, equipment and other physical assets) are limiting factors for most bat research and conservation projects. By fostering connections and collaborations between diverse and unique stakeholders, we can not only pursue novel fundraising opportunities but also share assets across projects and better prioritise resource use within the collective chiropterological community. As discussed above, corporations, particularly those in sectors like agriculture, tourism, or renewable energy, could provide financial support for bat conservation efforts through CSR initiatives at the local, regional, or national scale. Citizen science efforts could also exponentially increase the availability of bat distribution, behavioural, biological, and ecological data both geographically and taxonomically (Chapter 13). In addition, the private, public, and academic sectors could ethically collaborate with Indigenous and local communities to co-devise improved technology and techniques for non-lethal monitoring of bat individuals and populations. Finally, stakeholders could devise a system by which they could equitably share pooled equipment and technology to conduct collaborative bat research and conservation.

Challenges

As promising as inclusive and adaptive stakeholder management is for advancing bat conservation, it is not without its own difficulties. In fact, the greatest strength of multi-stakeholder collaboration for bat conservation is also the root of its potential obstacles: the sheer diversity of stakeholders that are involved directly or indirectly in bat-related issues across the country. The following represent some of the most significant barriers to building and maintaining equitable, adaptive, and lasting relationships among the wide variety of bat stakeholders in India.

Conflicts of interest

A diversity of interested and affected parties inevitably equates to a diversity of competing interests, many of which may be in direct opposition to one another. Disagreements between stakeholders with misaligned positions over bat-related objectives can undermine the planning and implementation of bat research and conservation strategies. These conflicts of interest can also expand to further exacerbate underlying power dynamics among stakeholders, damage future collaborative ventures, and seriously compromise pre-existing projects seeking to promote biodiversity conservation, community rights, and human livelihoods[42].

Lack of equitable and ethical representation of all stakeholders

Multi-stakeholder initiatives are frequently hindered by the inequal or unethical treatment of all parties involved, often reflecting imbalances in political, economic, social, and other forms of power. Indigenous and local communities have been historically under- or misrepresented in environmental initiatives and natural resource management policy- and decision-making in India[43][44]. Without equal and respectful representation along with concerted efforts to balance power inequities (or, in the very least, mitigate imbalances that cannot be rectified), participating stakeholders will not be able to foster trust and transparency in their relationships, exhibit ownership of the resulting products of their collaboration, share knowledge and expertise, and, ultimately, successfully implement any resulting bat conservation efforts into the future[43][44].

Absence of infrastructure to facilitate communication and collaboration among stakeholders

A significant barrier to capacity building and the free exchange of information among and between bat-relevant stakeholder groups is the absence of the infrastructure necessary to facilitate this collaboration, communication, and coordination in India. Although several networks exist to connect bat professionals globally (e.g., IUCN SSC Bat Specialist Group) and more regionally (e.g., Global South Bats), currently, no multi-stakeholder bat-related networks exist for India at the national level. The formalisation of a State of India's Bats network could be the first step towards establishing a wider association of bat-related stakeholders to address the complex issues attendant to bat research and conservation within the country (see Conclusion).

Logistical challenges

As discussed above and in other chapters within this report, effective stakeholder engagement and collaborative endeavours are typically constrained by limited resources, especially funding and trained personnel (e.g., neutral facilitators trained in conflict transformation). Other logistical challenges include those related to accessibility of information, transparent and open sharing of knowledge, and lack of incentives to motivate stakeholder participation.

Conclusion

Each stakeholder group plays a unique and important role in bat conservation. The most effective bat conservation strategies will involve collaboration among governments, local communities, NGOs, the private sector, academic institutions, the media, and other key stakeholders. By leveraging the strengths and expertise of each stakeholder group, it is possible to address the many challenges faced by bats and to ensure that India's bats continue to play their vital roles in ecosystems for generations to come.

Chapter 13
Citizen Science on Bats in India

Author: Thangsuanlian Naulak

Introduction

Bats are critical to ecosystems worldwide, providing essential services such as pollination, seed dispersal, and pest control[45]. India, with its vast biodiversity, is home to 135 species of bats (Chapter 1), many of which remain under-researched due to multiple challenges, not the least of which are logistical constraints in field studies related to bats' nocturnal behaviour and widespread geographic distribution, lack of funding, and limited research infrastructure. Understanding bat populations is crucial as habitat loss, climate change, and zoonotic disease concerns loom large.

Traditionally, the study of bats has required their capture for unambiguous species identification. This can be labour intensive as it requires using mist nets or traps, which may also expose bats to stress and potential injury. Additionally, capturing and handling bats requires specialised training that is not accessible to all citizen scientists. However, in recent years, the advancement of acoustic sampling and better tools for photographic identification has made citizen science a promising avenue for studying bats non-invasively, particularly in areas that are difficult to access and for species that are challenging to sample. Also, the participatory nature of citizen science has the capacity to democratise science by including people from all walks of life to mobilise large-scale data collection, co-produce knowledge, and foster public awareness in India.

Citizen science programmes for bats, such as the Bat Monitoring Programme in Catalonia[46], the United Kingdom's National Bat Monitoring Programme[47], and the Southern Scotland Bat Survey[48], significantly enhance our understanding of bat ecology by enabling large-scale data collection, promoting bat conservation, and overcoming logistical challenges through volunteer engagement while addressing limitations like data quality through standardised protocols. In this chapter, I use the India Biodiversity Portal (IBP) and iNaturalist as case studies to prepare a roadmap to leverage the power of citizen science for public engagement and bat research in India.

Methods

I obtained citizen science data from two sources: IBP and iNaturalist on the 3rd and 8th of October 2024, respectively. In IBP, I obtained data for bats by filtering the database using the "Taxon Browser", and then filtered the data for Chiroptera according to: "Animalia>Chordata>Mammalia>Chiroptera". I did not filter for "Location" as all observations in IBP are within the boundaries of India. I obtained a total of 828 observations. However, I decided to use "Observation with Media (n=297)" and exclude observations without media (n=531) as these observations would be challenging to independently cross-verify. In iNaturalist, I obtained observations on bats by using the "Explore" option on the top ribbon. I selected "Bats – Order Chiroptera" in the dropdown after typing "Chiroptera" in the search bar for "Species". I then restricted the geographical area by typing the keyword "India" in the search bar for "Location", which provides observations on "Chiroptera" within the Indian administrative boundary. I then used the "Filters" option and selected "Verifiable" under the title "Show". I also used shape files of the global biodiversity hotspots to identify data deficient areas for three hotspots in India ("Western Ghats and Sri Lanka", "Himalaya", and "Indo-Burma") out of the 36 biodiversity hotspots recognised by the Critical Ecosystem Partnership Fund (CEPF).

Results

Participation and representation

I obtained a total of 297 and 2,991 verifiable observations from IBP and iNaturalist, respectively. This discrepancy is expected given a much greater number of contributors to iNaturalist (n=1,317) as compared to IBP (n=86). I observed a similar representation of families across both citizen science data repositories (Table 13.1). However, the number of species documented is significantly higher on iNaturalist (n=86) in comparison to IBP (n=45). Overall, the representation of species from both platforms accounts for about two-thirds (n=86, 63.7%) of all bat species found in India.

Table 13.1 Summary statistics for citizen science data for bats available on the India Biodiversity Portal and iNaturalist. Analysed data were downloaded on the 3rd and 8th of October 2024, respectively.

	India Biodiversity Portal	iNaturalist
Total number of records	297	2,991
Total number of contributors	86	1,317
Number of states and union territories	22	34
Span of observations (in years)	19	30
Year of first bat observation upload to platform	2012	2011
Number of families documented	9	9
Number of genera documented	17	39
Number of species documented	45	86
Total number of unidentified observations	20	867

Spatial and temporal distribution

Observations from these citizen science platforms were as old as 30 years (i.e., 30 April 1994 and 25 January 2005 on iNaturalist and IBP, respectively). However, observations have been uploaded on both platforms almost a decade later (i.e., 2011 and 2012 on iNaturalist and IBP, respectively) (Table 13.1). While observations uploaded on IBP have not been consistent over the years, the number of observations uploaded on iNaturalist have grown exponentially (Figure 13.1). There is widespread spatial coverage, accounting for more than 90% (n=34) of all states and union territories (Table 13.1; Figure 13.2). On both platforms, Karnataka has the highest number of observations (n=229 for iNaturalist, and n=94 for IBP). While 14 states and union territories (Ladakh, Jammu and Kashmir, Punjab, Chandigarh, Himachal Pradesh, Haryana, Sikkim, Arunachal Pradesh, Mizoram, Jharkhand, Chhattisgarh, Daman and Diu, Dadra and Nagar Haveli, and Lakshadweep) have no data on IBP, only two (Ladakh and Lakshadweep) have no observations on iNaturalist (Figure 13.2).

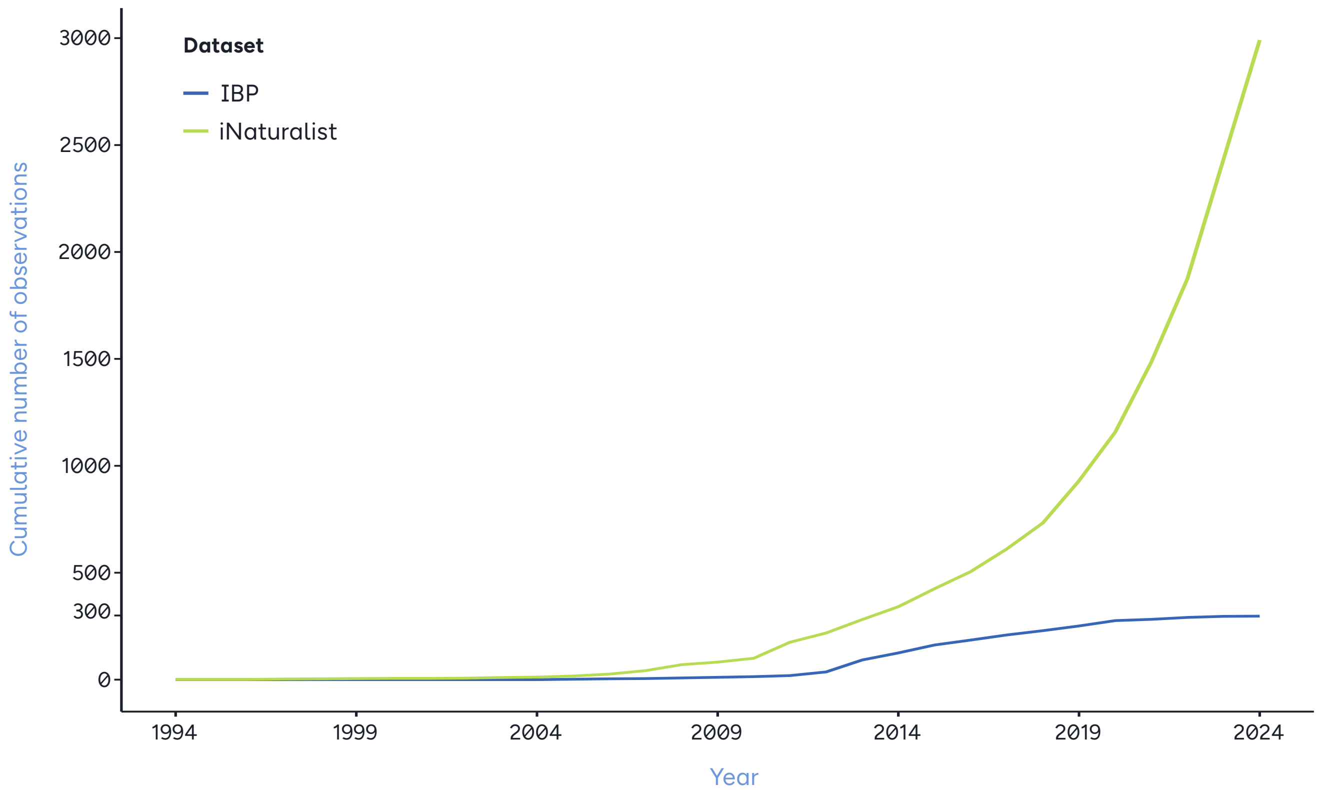
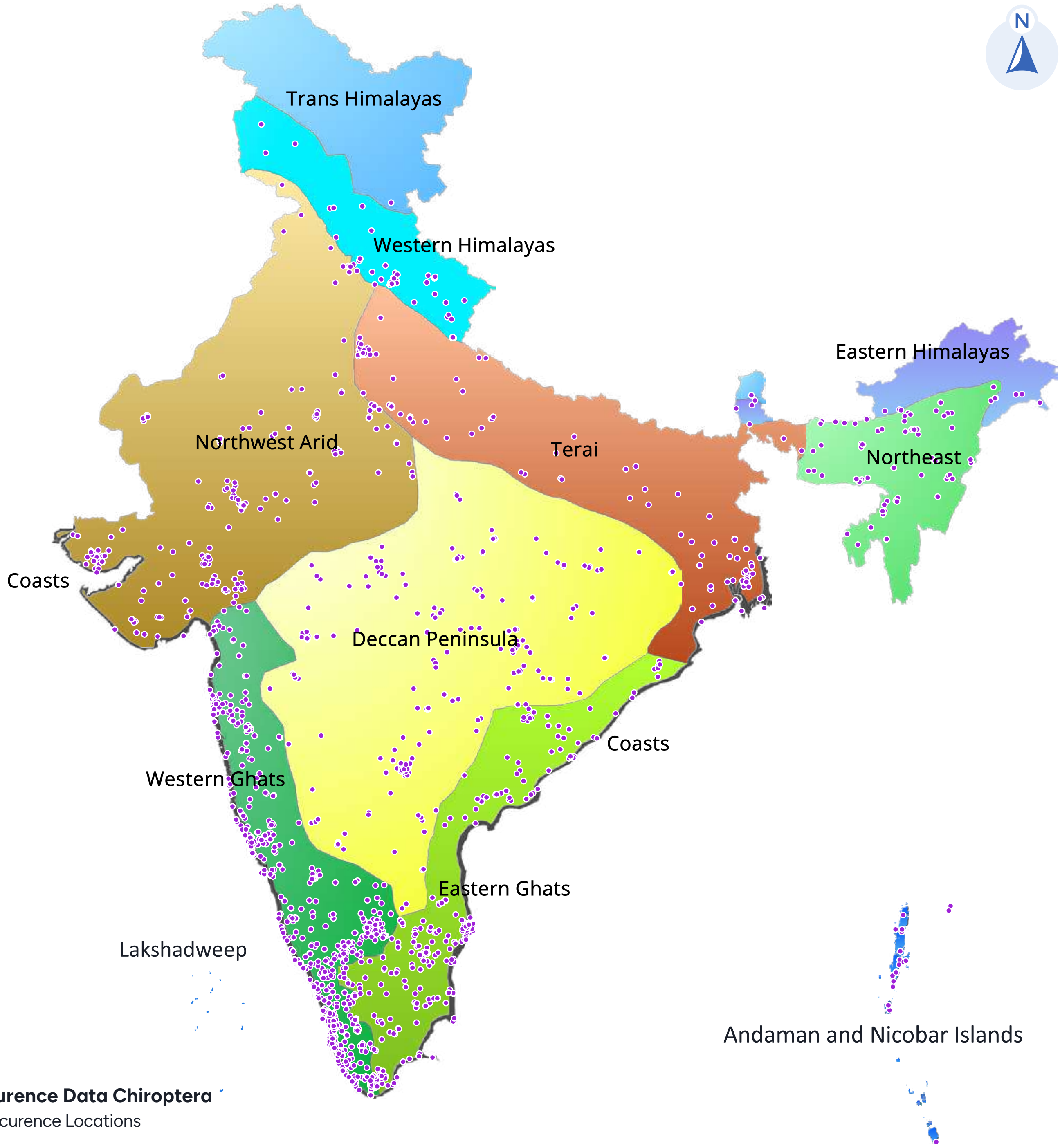


Figure 13.1 Cumulative number of bat observations uploaded to the India Biodiversity Portal (IBP) and iNaturalist over time. Analysed data were downloaded on the 3rd and 8th of October 2024, respectively.



State/Region boundaries are representative

Figure 13.2 Bat observations pooled from the India Biodiversity Portal and iNaturalist mapped onto representative outlines of the biogeographic regions of India as they were defined by the State of India's Bats (2024–2025) project (Chapter 15, Figure 15.1). Analysed data were downloaded on the 3rd and 8th of October 2024, respectively.

Biodiversity hotspots and Protected Areas

The three CEPF global biodiversity hotspots account for less than 10% (n=326) of the combined observations (n=3,288) on IBP and iNaturalist. Of these, the Western Ghats, which comprise parts of Maharashtra, Goa, Karnataka, Tamil Nadu, Gujarat, and Dadar and Nagar Haveli, account for almost two-thirds (56.4%) of all observations recorded from these biodiversity hotspots. The Indo-Burma hotspot within the states of Manipur, Mizoram, Meghalaya, Nagaland, and parts of Assam and Tripura account for approximately 25%, while the Himalaya hotspot in Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, parts of Assam and West Bengal, and the Terai area of Uttar Pradesh and Bihar accounts for almost one-fifth of the observations from all biodiversity hotspots. Meanwhile, observations located within India's Protected Area networks account for less than 10% (n=265) of the combined observations on both platforms.

Discussion

In general, citizen science platforms such as IBP and iNaturalist provide an outlet for nature enthusiasts to contribute to as well as to learn from bat professionals. At times, citizen science has even led to collaborations resulting in the addition of a new species to an area[49], the first photographic record of a species, an unusual behaviour, and other significant contributions to the field[50]. Citizen science offers numerous opportunities for advancing bat research and conservation in India. One significant advantage is its ability to scale data collection efforts: by engaging citizens across diverse regions where geographic and ecological diversity pose challenges for traditional research methods, bat researchers can scale data collection efforts that would otherwise be logistically unfeasible. Based on this analysis, I was able to elucidate some key challenges as well as future opportunities with regard to citizen science on bats in India.

Data repository

Regional platforms, such as IBP, are well-intentioned initiatives that show a promising start[49], driven by the need to decentralize natural resource management[51] and to mainstream biodiversity and ecological sciences. These platforms also serve to promote data sharing between different government agencies in India within the ambit of the National Data Sharing and Accessibility Policy[52]. However, global citizen science platforms, such as iNaturalist, have shown more potential, consistency, and greater uptake than more regional ones (Figure 13.1). By taking advantage of the strengths inherent to these platforms, such as global participation of experts and enthusiasts alike, we should utilise citizen science platforms to enhance public engagement and to inform policy in India. For instance, eBird, a global platform for birdwatchers to record their observations, has been tailored to inform conservation action and to guide future research in India[53]. Another pressing concern is the need to digitise historical records from museum specimens and other sources (e.g., published literature)[54] to act as baseline information, in line with other globally accepted databases such as the African bat database[55].

Stakeholder engagement

Data for citizen science have been used primarily for confirming species presence in specific localities or regions. Strategic engagement and collaborative participation of citizen scientists, bat researchers, institutions, and other stakeholders will be crucial to direct citizen science programmes to target achievable outcomes that are statistically sound and can further inform policy and public engagement[46][47][48]. To ensure the sustainability of these initiatives, collaborative efforts involving institutions such as universities, nongovernmental organisations (NGOs), forest departments, the Archaeological Society of India, Gram Panchayats, and Biodiversity Management Committees, among others, can help bind citizen science initiatives to broader applications, such as the protection of roosting sites, monitoring of roosts, and raising awareness (Chapter 12).

Data quality

As evidenced in this study, active participation of bat taxonomists and other experts will be required to accurately identify bat observations on these platforms and maintain robust data. Moreover, uneven participation, both geographically and demographically, can skew the data with rural and remote areas often underrepresented (e.g., mountainous localities[56]).

Indian Flying Fox (*Pteropus medius*). Photo: Gagandeep Kaur

Integration with national projects

National projects such as People's Biodiversity Registers (PBR) should also utilise global citizen science platforms such as iNaturalist to document and verify species presence[57]. While most national projects (e.g., PBRs) are time-bound and have limited means of contributing data and expertise, citizen science platforms provide a dynamic repository that is both accessible and fully participatory.

Inclusion of advanced technology

So far, citizen science efforts on bats in India have mostly been limited to photographic observations, missing out on one major aspect of citizen science: acoustic monitoring, an opportunity to contribute high-quality data with minimal training. Modern acoustic devices, such as the Echo Meter Touch 2 Bat Detector (Wildlife Acoustics, Maryland, USA), simplify the process of recording and analysing bat calls, making acoustic monitoring accessible to non-experts. This device also enables users to visualise bat calls in real-time through mobile applications, making the activity less daunting. Additionally, these recording sessions can be associated with outreach programmes, such as Bat Walks with local communities to dispel myths about bats and reduce the stigma surrounding them, promoting coexistence and local stewardship (Chapter 11). Other emerging areas of bat research, such as the integration of artificial intelligence (AI) for data validation, offer promising solutions. AI-enabled tools can automate the identification of bat calls or images, reducing errors and enhancing data quality.

Mitigating threats to bats

With rapid urbanisation in India, bat species such as the Indian Flying Fox (*Pteropus medius*) face unique challenges, including habitat fragmentation and human–wildlife conflict. PteroCount, a citizen science project started by Zoo Outreach Organisation in the early 2000s, aims to monitor flying fox roosts (Chapter 11). This project can be widely publicised and run through iNaturalist and has great potential for understanding roost selection by flying foxes and the factors contributing to their electrocution risk. This type of information is critical for the mitigation of human–bat conflict in urban and rural areas.

Logistical and ethical considerations

Funding and permit constraints often limit a researcher to a specific area or site, while a citizen scientist is unhindered by such constraints and can contribute from anywhere in India. However, ethical considerations, such as ensuring the safety of participants and addressing potential ecological disturbances caused by overenthusiastic volunteers, also require attention. Citizen scientists must be well informed to avoid disturbing bat habitats or exposing themselves and bats to zoonotic disease transmission and spillback risks.

Conclusion

Citizen science represents a transformative approach to bat conservation in India, bridging the gap between limited research infrastructure and the urgent need for ecological data. By synthesising citizen science data from IBP and iNaturalist, this study highlighted significant considerations for bat conservation and research in India. While the engagement of non-professionals poses certain difficulties, technological innovations and standardised protocols offer viable solutions. Firstly, standardised protocols for data collection and validation are essential to address concerns about scientific rigor. Secondly, methodological advancements, such as the integration of AI and bioacoustics tools, can enhance the reliability of citizen science data. Moving forward, collaborative, inclusive, and adaptive approaches will be essential to unlocking the full potential of citizen science for biodiversity conservation in India. Moreover, policymakers should recognise the value of citizen science and integrate its findings into national biodiversity frameworks.

Chapter 14
Human Dimensions of Indian Bat Conservation

Authors: Bonnie E. Gulas-Wroblewski and Rohit Chakravarty

The majority of threats impacting India's bat species are driven directly or indirectly by humans (Chapter 15). With continuing development, agricultural land use changes, and urbanisation expanding across all biogeographic regions of India, human–bat interactions and anthropogenic threats to bats will only increase. Consequently, robust social science research is critical to the success of any bat-focused conservation practice or research in India. The field of human dimensions (HD) of wildlife specifically integrates a diversity of social science disciplines (e.g., anthropology, sociology, psychology, economics, political science) to elucidate the relationships between stakeholders and wildlife issues[58][59]. Accordingly, the HD of bat management was recently highlighted as one of the top four priorities for multidisciplinary applied research, communication, and collaboration to support bat conservation worldwide[60].

Human–wildlife conflict scenarios, including human–bat conflict, are complex and often driven by underlying human–human conflicts (e.g., power imbalances between government wildlife authorities and local people[61]). Therefore, a thorough assessment of human–bat conflict requires a comprehensive evaluation of the socio-cultural, economic, and political contributors to and drivers of the conflict in addition to the ecological ones. One of the most widely employed types of HD research in respect to bat management and human–bat conflict and coexistence is conservation psychology. Conservation psychology applies psychological principles to understand and actively promote a healthy and sustainable relationship between humans and nature (including wildlife) [58]. Conservation psychology is intended to be an applied discipline, producing practical results that can guide the planning, implementation, and evaluation of conservation interventions on the ground[58]. HD research integrating conservation psychology can benefit Indian bat conservation in multiple, synergistic ways, including:

- Application of conservation psychology methodologies to assess the scope and severity of anthropogenic threats to bats (e.g., investigation of bat-related practices like hunting and persecution);
- Understanding of the root causes of anthropogenic threats to bats in order to better design ethical, feasible, and effective interventions to address these threats;
- Evaluation of the diversity of values (e.g., utilitarian, spiritual, cultural) that bats encompass for stakeholders, which can contribute to studies of bats' ecosystem services (Chapter 10) and related education and outreach campaigns;
- Promotion of behaviour change for the benefit of bats (e.g., educational initiatives motivating tolerance of bats; See Box 2 for an example);
- Provision of fundamental information for conservation marketing strategies;
- Guidance for ethical and widely-endorsed bat-related policy and management decisions (Chapter 11); and
- Co-development and implementation of monitoring and programme evaluation of bat management and conservation initiatives.

Ritualistic bat hunting festival in Nagaland.
Photo: Rajesh Puttaswamaiah

Glossary

Term	Definition
Affect	An instinctual (subconscious) and emotive response to a stimulus. Commonly referred to as "emotion"[62].
Attitude	A predisposition to respond in a favourable or unfavourable manner toward an object. Recognised to have three distinct components: the affective (how individual feels about the object), the behavioural (how individual behaves towards the object), and the cognitive (individual's conscious thoughts about the object)[63][64][65].
Behavioural control	Actual or perceived ability to perform the behaviour, including having the resources, abilities, and opportunity to perform the behaviour[66].
Behavioural intention	The formed intention of performing a specific behaviour that can lead to the actual performance of a behaviour. Most proximate determinant of behaviour but not the behaviour itself[66].
Conservation marketing	Strategic application of marketing concepts and techniques to persuade individuals, communities, and societies to advance conservation objectives[67].
Social amplification of risk	When psycho-social, institutional, and cultural processes influence how individuals perceive risk, specifically when the individual misinterprets an actual low-risk event as a high-risk event[68].
Social norms	Accepted or implied rules about how members of a social group should behave. Foundation of "culture". In the Theory of Planned Behaviour and other models, referred to as "the subjective norm"[59][64].
Tolerance (of wildlife)	Accepting wildlife and/or wildlife behaviours that one dislikes[69].
Values	An individual's fundamental, stable life goals that influence how they orient themselves to their world (e.g., guide the decisions that they make). One of the most widely-applied classification schemes for nature-related values recognises 8 possible value types: dominionistic, ecologistic, humanistic, moralistic, naturalistic, negativistic, scientific, and utilitarian[70].
Wildlife values	Wildlife-related social values[71].
Wildlife value orientations	Domination: views wildlife as subordinate to and existing for the use and benefit of humans[71]. Mutualism: views wildlife within a person's extended social network[71].

Unlike India's more charismatic wildlife species (e.g., tigers and elephants), bats face a relatively higher degree of negative attitudes, which are often intrinsically tied to social norms and may even be evolutionarily innate in humans[59][72][73]. The psychologically-rooted fear of bats, chiroptophobia, has plagued human–bat interactions and bat conservation efforts globally. Negative attitudes that vilify bats as "pests", disease vectors, or "evil" creatures have been exacerbated by their association with several zoonoses of public health importance, including the Marburg virus, SARS-CoV-2, multiple lyssaviruses, and Nipah virus[74][75]. This correlation of bats with the real risk of disease transmission can result in the social amplification of these health threats and any attendant negative perceptions of bats. The situation has been further aggravated by mass and social media's spread of misinformation and sensationalised tales of public health threats from bats, especially during the COVID-19 pandemic[60][68][76][77][78][79][80][81].

Negative attitudes towards bats not only hinder efforts to protect and conserve bats directly (e.g., by fuelling lethal persecution of bats) but also impede bat professionals' ability to conduct studies and enact conservation measures, contributing to logistical challenges in field sampling, denial of required permits and other permissions, and diminished recruitment of citizen scientists, skilled assistants, and other support personnel. Similarly, these negative attitudes can dissuade the general public's and other key stakeholders' interest in and support for government policies related to bat conservation, which can directly reduce bats' prioritisation within the agendas of relevant government agencies as well as in the conservation marketing strategies of general wildlife and environmental nongovernmental organisations (NGOs)[77] (Chapter 12). Conversely, positive attitudes towards bats can promote tolerance and protective behaviours towards bats, manifest as support for policies and regulations beneficial to bats, and be leveraged in bat-focused conservation marketing schemes[59][82][83].

Conservation interventions, especially those seeking to promote human–wildlife coexistence through education and outreach, commonly attempt to alter behaviour(s) either by fostering pro-conservation behaviours or eliminating/reducing behaviours that adversely impact conservation. Unfortunately, many of these initiatives prove ineffective (or even counterproductive) due to incorrect assumptions that were made regarding the cause-and-effect relationships underlying these behaviours[59][76][82][84][85][86]. The application of conservation psychology and its theories of behaviour change to bat conservation research and practice can better identify and interrelate the antecedents of behaviour and, therefore, provide a solid base for selecting the most effective message to motivate behaviour change within any stakeholder. Although it is beyond the scope of this chapter to thoroughly review the theories of behaviour and behaviour change along with their components, a brief overview is provided in Box 1. Those interested in exploring these topics in greater depth are directed to Kingston (2016)[59] for bat-specific information and to Clayton et al. (2015)[58] for a more general review.

Studies in India

Since the late 1990s, there have been at least six studies that have specifically focused on issues directly related to the HD of bat management and conservation in India[32][87][88][89] (Table 14.1). In addition, several other HD-related reviews and bat-related publications have provided substantial data to support our general understanding of human–bat interactions across India[74][90][91][92][93][94][95]. Below, we summarise these significant findings within a conservation psychology framework (Box 1).

Table 14.1 Summary of social science studies conducted in India on the Human Dimensions of bat management and conservation.

Citation	Research Methods	Focal topics	Geographic location	Description of study subjects
Davey et al. 1998[87]	Quantitative survey, using 4-point Likert scale to measure fear level	Fear (and disgust) reactions to 46 different animal taxa, including "bats"	India, Hong Kong, Japan, the Netherlands, South Korea, United Kingdom, and the United States	102 males, 98 females; 16-20 years old
Deshpande and Kelkar 2015[96]	Semi-structured interviews with individuals and informal focus group discussions based on questionnaire, using a quota sampling approach for "plantation-associated" and "non-associated" resource users	Knowledge and attitudes related to fruit bats and their ecosystem benefits, including perceived benefits and costs of fruit bats	Shenduruney Wildlife Sanctuary (in and adjacent to), Kerala	60 individual interviewees and 8 focus group participants (~1.2 % local population in agroforestry); males and females; 15-75 years old; included village self-government members, forest management staff, orchard owners, horticulturists, farmers, and plantation workers
Bhattacharjee et al. 2018[88]	Anonymous, close-ended questionnaire given in Bengali	Knowledge, attitudes, and behaviours related to bats; behavioural intentions related to bat conservation	Barak Valley, Assam	Standard 10-level students (~15-16 years old) from 36 rural schools randomly sampled in Barak Valley; Bengali with a diversity of other communities and tribes also represented
Debata 2021[32]*	Semi-structured interview in Odia or Hindi; direct observation of visitor number and behaviour	Knowledge of bats, attitudes towards bat conservation, and bat-related behaviour	Gupteswar cave complex, Odisha	Interviewees: 76 local villagers (71 male, 5 female) and 366 religious pilgrims (309 male, 57 female); 18-60+ years-old; occupations included non-timber forest product collector, farmer, government employee, and entrepreneur; education level varied from illiterate to post-graduate education
Kumar et al. 2021[89]	"Threats analysis" survey	Bat-related knowledge and behaviours	Lakhimpur-Kheri, Uttar Pradesh	Urban and rural residents
Deshpande et al. 2022[97]	Semi-structured interviews with questionnaires in local languages, using link tracing and quota sampling approach for respondents associated with four main fruit crops	Knowledge, attitudes, values, and cultural practices related to bats and their ecosystem services, including perceived costs and benefits	South Konkan landscape in Maharashtra and Goa, Sirsi and Mangalore landscapes in Karnataka, Shenduruney landscape in Kerala, and Ambasamudra-Tirunelveli landscape in Tamil Nadu	168 individuals with more than 10 years occupational experience of farming

*Information only provided for the social science research conducted by the author.

Attitudes

Attitudes, most notably affect, have been the focus of much of the HD work on human–bat interactions, including the studies conducted in India[59] (Table 14.1). However, experimental investigations into the degree of influence these attitudes hold for behaviour change or their ability to sway attitudes through targeted conservation interventions have yet to be explored for any stakeholder group in the country.

In rural areas of Barak Valley, Assam, proximate to sizeable bat roosts, over 3,000 teenagers (~15–16 years old) of Bengali background participated in an anonymous survey that inquired about knowledge, attitudes, practices, and behavioural intentions related to bats and their conservation[88] (Table 14.1). Most students reported a disliking of (36.5%) or an indifference to (33.9%) bats, despite more than half of the respondents (54.5%) considering bats as "good omens"[88]. This dominance of a negative affect for bats was similarly reflected in more cognitive attitudes towards bats with only 30% of the teenagers describing bats as "beneficial", while 35% of the teenagers defined bats as "harmful" due to bats' noisiness, foul odours, and destruction of trees and fruit in home gardens[88]. Despite the prominent negative attitudes expressed for bats, the study failed to find a direct correlation between these attitudes and behavioural intentions for supporting bat conservation. In fact, a slight majority (52.8%) of survey participants answered that they would actively take part in bat conservation, including students that reported negative attitudes towards bats and excluding some that reported positive attitudes towards bats[88].

Another study of young adults (16–20 years old) was conducted in India to evaluate the specific negative attitude of fear of bats[87]. Using a 4-point Likert scale, researchers surveyed the type and degree of fear elicited by 46 different animal species across young adults from seven countries (Table 14.1). Based on responses from 200 (102 males, 98 females) Indian students, generic "bats" were categorised as "disgust-relevant" (vs. fierce or fear-irrelevant) within the affect categories, despite the number of "disgust-relevant" animals classified by India respondents being the lowest number of animals in this category for any of the nations sampled. The authors' definition of "disgust" aligns with the references of bats' "foul smell" in other HD studies within India[32][88]. In terms of differences in the intensity of the response to "disgust-relevant" animals overall, female participants feared these species significantly more than did males, suggesting a gender component to the expression of disgust-based fear[87]. Although this factor was not evaluated for bats specifically within Davey et al. (1998)[72], other studies from Africa, East Asia, Europe, Latin America, and North America have reported a greater fear of and/or negative attitude towards bats in women when compared to male participants[73][76][98][99][100].

More recently, Debata (2021)[32] explored attitudes related to the conservation of bats in order to draft recommended best practices for sustainable and bat-friendly ecotourism operations in the Gupteswar cave complex tourism and pilgrimage site in Odisha (Table 14.1). Seventy-six local community members and 366 religious tourists were opportunistically interviewed at the cave sites, which are home to eight bat species (*Hipposideros ater, Hipposideros galeritus, Hipposideros speoris, Lyroderma lyra, Megaderma spasma, Rhinolophus lepidus, Rhinolophus rouxii,* and *Taphozous melanopogon*)[32]. Attitudes towards bat conservation (not bats directly) were

Adora Thabah conducting an awareness programme in Jaintia Hills, Meghalaya. Photo: Nikki Bailey categorised as aesthetic, eco-scientific, moralistic, or negative. Encouragingly, all of the local residents expressed positive attitudes in relation to bat conservation, primarily in the category of aesthetic attitudes. In juxtaposition, only 32% of the religious pilgrims visiting the cave complex reported positive attitudes towards the conservation of bats onsite with the remainder of religious tourists citing guano and foul smell as reasons for their negative attitudes for bat conservation[32]. Interestingly, neither this nor Bhattacharjee et al. (2018)'s pre-COVID-19 pandemic study[88] reported disease-related factors as contributors to the negative attitudes expressed by participants.

Questionnaire-based interviews and focus group discussions conducted with equal proportions of plantation-associated and non-associated stakeholders in an agroforestry landscape in the southern Western Ghats, Kerala revealed predominantly positive or neutral attitudes (67% of interviewees) towards fruit bats (*Cynopterus sphinx, Pteropus medius,* and *Rousettus leschenaultia*) with over half of the respondents identifying fruit bats as beneficial in at least some respect in relation to the ecosystem services that they generate for fruit production (Table 14.1). Only 10 participants (17%) perceived fruit bats to be harmful to agriculture, and the majority reported fruit bats had higher benefits from seed dispersal than costs from fruit damage in both qualitative and monetary valuations[96]. Interestingly, perceptions of the costs and benefits of fruit bats did not vary significantly between sexes and across occupations[96]. An extension of this study to four additional plantation agroforestry landscapes in the Western Ghats, which exhibited different agricultural management practices and social-ecological systems, similarly reported a majority (60.7%) of respondents that viewed fruit bats as either neutral or "useful" overall[97]. The expanded assessment of stakeholder attitudes towards fruit bats identified key variations in the perceptions of bats as well as their ecosystem services and disservices based on the type of fruit crop (including the end use of the fruit), regional variations in agroforestry management, plantation size, age of respondents, and economic factors[97]. By integrating these HD results with a comprehensive ecological analysis of fruit bat-facilitated seed dispersal in plantation landscapes, the researchers were able to describe a positive relationship between plantation-associated participants' perceptions of the benefits and costs of fruit bats with estimates for the clump-dispersal of commercially-important fruit seeds[97]. Thus, Deshpande et al. (2022) serves as a model for future studies seeking to holistically assess the dynamic links between social and ecological factors in bat management and conservation.

Social norms

Similar to attitudes, social norms (a.k.a. perceived norms, subjective norms) can have a direct effect on behavioural intentions (Box 1). These social norms are commonly classified as moral dictates (e.g., religious dogmas), taboos (socially or culturally forbidden acts), customs, and written laws or enforceable policies[59][74][82].

When aligned, social norms may reinforce or exaggerate individual attitudes towards bats and their conservation. However, social norms may also negate the effects of pre-existing attitudes on behaviour when norms are in opposition to these attitudes, especially in situations when individuals seek to fortify strong social identities. Similarly, social norms that run counter to basic utilitarian needs and/or strongly-held individual attitudes may not influence a person's ultimate behaviour[59][73][82][84]. For example, Bhattacharjee et al. (2018)[88] reported most of his survey participants exhibited negative or indifferent attitudes towards bats despite a slim majority interpreting bats as good luck. Influential social norms that are not directly connected to bats may also serve to protect (or endanger) bats through their impact on behaviours that affect bats' habitats, food supply, and/or disease risk. Therefore, although rarely considered in the management and mitigation of human–bat conflicts in India, social norms can play a crucial role in shaping behaviours towards bats and, consequently, support for bat conservation efforts.

Written regulations pertaining to bats in India are comprehensively reviewed in Chapter 11, so here we focus on a review of the current understanding of social norms related to Indian bats other than those encapsulated in policy and law. The sociocultural importance and symbolism of bats throughout most of South Asia remains poorly investigated, and most of the documentation regarding bat-related moral dictates, taboos, and customs comes from Low et al. (2021)'s thorough review of bat myths, cultural values, and symbolism across the Asia-Pacific region[74]. Bat-relevant social norms are reflected in local beliefs, myths, folktales, sayings, colloquialisms, symbolic representations, and names as much as they are in social, cultural, religious, and spiritual practices, all of which are transmitted from generation to generation[73][91][98]. These social norms can be generally categorised as those that denote positive, negative, or neutral perspectives towards bats and/or their protection. An illustration of the diversity of bat-related social norms reported in India is provided in Table 14.2.

Table 14.2 Evidence of bat-related social norms in India, excluding written legal regulations and policies. Examples are categorised as neutral, positive, and/or negative in reference to their predicted or substantiated impact on bats and bat conservation.

	Brief Description	Context	References
Neutral	Bats used as allegories for seasonal change and the evening.	2,000 year-old Tamil Sangam prose	Low et al. (2021)[74]
	A local legend of a bat being rejected by both an assembly of mammals (because the bat flies) and an assembly of birds (because the bat has teeth and sleeps upside down), reflecting the strange nature and mysterious quality of bats.	Jodhpur, Rajasthan	Frembgen (2006)[91]
Positive	Worshippers of the guardian deity Muni consider *Pteropus medius* to be sacred and protect their colonies. Divine punishment is feared in retribution for killing *P. medius*.	Madurai, Tamil Nadu	Low et al. (2021)[74]
	Worshippers of the goddess Kali consider *P. medius* to be sacred if they roost in sacred grooves, where the killing of bats for any reason is strictly forbidden. Adherents believe Kali will punish anyone who hurts or kills any bats within the sacred groves or surrounding areas (including fruit orchards). Devotees offer fruits to these *P. medius* during the Adi festivals to ensure a happy life for their family members with the bats' consumption of the fruit.	Pudukottai district, Tamil Nadu	Tangavelou et al. (2013)[92]
	Worshippers of the goddess Laxmi believe *P. medius* assist Her in bringing wealth to adherents.	Bihar	Low et al. (2021)[74]
	Festivals honouring the religious importance of bats have been held since 2001 in a bat temple at the entrance of a cave inhabited by multiple bat species.	Assam	Low et al. (2021)[74]
	Bats are considered haram in Islam. Therefore, many Muslim communities consider eating bats "forbidden", while others believe killing a bat brings bad fortune.*	Unspecified Muslim communities throughout southwest Asia, including in India.	Frembgen (2006)[91]
	Bats used as allegories for romantic or parental love.	2,000 year-old Tamil Sangam poetry	Low et al. (2021)[74]
	Bats were considered "good omens" to more than half of the respondents in a survey of over 3,000 teenagers.	Rural areas of Barak Valley, Assam	Bhattacharjee et al. (2018)[88]
Negative	Bats are considered haram in Islam. Therefore, many Muslim communities consider eating bats "forbidden", while others believe killing a bat brings bad fortune.*	Unspecified Muslim communities throughout southwest Asia, including in India.	Frembgen (2006)[94]
	A traditional bat-harvesting festival of the Longpfurii Yimchungii holds socio-political and cultural importance for the residents of Mimi village. Every mid-October for at least 7 generations, the members of the Bomrr clan harvest between 7,000-25,000 cave-dwelling bats (*Eonycteris spelaea, Hipposideros armiger*, and *Rousettus leschenaultii*), primarily for traditional medicinal use. The Bomrr are the only clan that engage in the actual harvest since they were the first clan in Mimi village to claim ownership of the three caves in which the collection is concentrated. Based on the current population numbers for some of these bat species and the other threats that they face in the region, the scale of this harvest is predicted to be unsustainable in the long term.‡	Naga subtribe of about 200 people in the clans Bomrr, Whourr, and Mer in Mimi village, Nagaland	Dovih (2015)[95]
	"Bat" described as "kān-salvār" (English translation: "dangerous for the ear") in Saraiki, which associates bats with the fear of being attacked and bitten in the ear.	Saraiki language spoken primarily in urban areas in northwestern and north central India.	Frembgen (2006)[94]
	Several Punjabi insults compare bats to nagging people or those that are "out of control". An example is the curse "Cham-charik warga, piche pae gya magron ni lehnda" (English translation: "like a bat you sit on my neck and dig your claws into me".). Also, women loudly arguing with their spouses are said to "behave like a bat" in reference to the "screeching" sound associated with bats.	Punjab and Rajasthan	Frembgen (2006)[94]; G. Kaur pers. comm.

* Depending on the specific context, the designation of bats as haram can be considered positive for bats (in terms of its protection of bats from hunting and persecution) and/or negative for bats (in relation to the negative association of bats with a "sinful" or "evil" act).

‡A more in-depth study of this social norm may uncover positive components for bats and their conservation, such as tolerance of bats or protection of their cave habitats related to intensions for sustainable use of the bats and/or a positive affect for bats related to their various values for community members.

Oftentimes, practices connected to destructive utilitarian use of bats, such as hunting for medicine, food, leather, or sale to biological institutions[74][88][89][90][94][95] (Chapter 10) are interwoven with spiritual, religious, or cultural beliefs; social identity; strengthening of social or political relationships; or other non-utilitarian valuations. In these cases, the utilitarian value of bats may have a cumulative or synergistic influence on bat-adverse behaviours, which are difficult to extricate from closely-linked social norms[74][90][94]. An illustration of the indivisibility and potential layering of these ties is provided by the bat-harvesting festival of the Longpfurii Yimchungii (Table 14.2). Thousands of bats are harvested annually by the Bomrr clan not only for medicinal use but also as an assertion of the clan's political standing and social identity. In addition, the festival holds deep cultural and historical significance for all three clans residing in the Mimi village of Nagaland[95]. Any conservation interventions seeking to end the harvest of the local cave-dwelling bats would need to address both the diversity of social norms enmeshed in this festival and the perceived utilitarian value of the bats as medicine.

More positively for bat conservation, non-bat-centric social norms serve an indirect benefit to bats and their protection across India. Approximately 14,000 sacred groves, ranging from a single large tree to several kilometres of forested land, protect pockets of biodiversity throughout the country[92]. These sacred groves are worshipped and protected by community members as the residences of local deities and important sites for related cultural, spiritual, and religious practices. As a result, critical habitat and food sources for bats are conserved along with the bats themselves[92][101]. The protection of these sacred groves, even if limited in size, can play a proportionately oversized role in the protection of bat populations, especially in regions where bats otherwise would experience significant mortality from hunting and persecution. In the Pudukottai district of Tamil Nadu, *P. medius* roosting in the sacred groves of Kali are safe from all killing, including of bats that forage in the surrounding fruit orchards that would normally bear the brunt of human–bat conflict[92]. In another region of Tamil Nadu, sacred fig trees (*Ficus benghalensis*) are regularly visited by *P. medius* despite the trees' location in areas with high levels of human disturbance[101].

Social norms can similarly offer conservation value to troglophilic bat species. Sacred cave sites protected by various belief systems can hold immense conservation value for Indian bat populations. For instance, despite religious pilgrims' abhorrence of cave bats' reportedly foul smell and deposition of guano, the eight bat species

Nithin Divakar demonstrating how to install a harp trap. Photo: courtesy of Nithin Divakar/KFRI roosting in Odisha's Gupteswar caves remain unharmed and enjoy the secure cave habitat because of the sacred beliefs associated with the caves themselves[32]. As mining operations and development expand across India (Chapter 15), the protection of these sacred cave habitats afforded by cultural, religious, and spiritual beliefs will only increase in its importance for bat conservation.

Knowledge

Knowledge about bats and bat-related information is an influential factor moderating an individual's behavioural, normative, and control beliefs, all of which shape behaviour (Box 1). In cases of human–bat conflict, knowledge can be particularly instrumental in motivating behaviour change through modifications to an individual's perceptions of risks from and/or benefits of bats, their evaluation of perceived control over any bat-related costs or risks, and their positive or negative affect for bats[82][85]. Assessments of bat-related knowledge in Indian communities have almost all reported a low level of correct information about bats, the ecosystem benefits provided by bats, and community members' impact on the bats with which they interact[32][88][89].

Despite living in close proximity to cave-roosting bats, 96.1% of interviewed community members adjacent to the Gupteswar cave complex did not know whether or not bats were mammals, and only 16.7% of religious tourists agreed that bats were mammals[32]. Half of the surveyed secondary students residing near roosting bats in Assam were also unaware of the mammalian classification of bats[88]. In contrast, an overwhelming majority (92%) of local community members interviewed in an agroforestry landscape in the Western Ghats, Kerala were able to: 1. differentiate insectivorous bats from frugivorous bats, and 2. distinguish between larger flying foxes (*P. medius*) and smaller fruit bats (*Rousettus* and *Cynopterus*)[96].

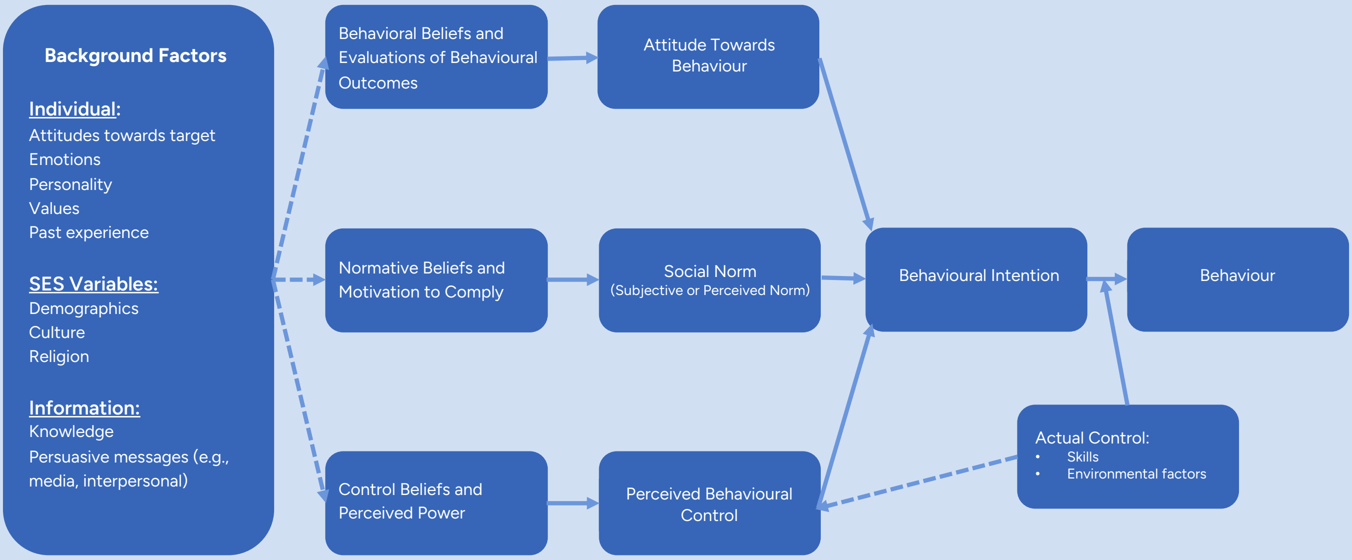
Encouragingly, a majority of both religious pilgrims and local community members recognized the Gupteswar sacred caves to be important habitats for bats[32]. However, despite this awareness of the importance of caves for bats, nearly all of the study participants incorrectly attested that human activity within the caves was not a threat to the bat species that lived there since no one physically harmed animals within the caves[32]. The deficit of knowledge regarding indirect threats to cave-roosting bats from noise and light pollution seems to be at the root of this misunderstanding[32].

Many conservation marketing campaigns and human–wildlife coexistence-promoting educational initiatives include messaging that highlights the ecosystem services provided by the wildlife species of interest. Although knowledge about ecosystem services alone is often ineffective in changing people's behaviours towards wildlife, sharing this information can elevate an individual's perceptions of the benefits of tolerating wildlife and can even subconsciously engender positive feelings towards the species[59][62][102]. Unfortunately, most studies to date indicate a poor understanding of bats' ecosystem services among the Indian populace. Only 30% of the teenagers surveyed in rural Assam considered bats to be beneficial, mostly for bats' contributions to fruit-related ecosystem services such as seed dispersal, pollination, and induction of fruiting[88]. Similarly, community members in Lakhimpur-Kheri, Uttar Pradesh were reportedly unfamiliar with any economic benefits from bats[89], and the majority (77.2%) of religious pilgrims and local residents that were interviewed at the Gupteswar caves did not know or did not think that bats were ecologically important[32].

More hopeful are the results of comprehensive social-ecological analyses of the perceived (and real) costs and benefits associated with fruit bats in multiple locations throughout the Western Ghats, which report an extensive understanding of and appreciation for the ecosystem benefits proffered by bats that support commercial fruit production[96][97]. Plantation-associated and non-associated stakeholders in agroforestry landscapes defined the beneficial attributes of multiple fruit bat species to include: 1. "seed aggregation", which facilitated easier collection of seeds by plantation workers and, therefore, lowered labour costs for plantation owners and/or a source of easily-collected seeds for sale or auction; 2. "seed transfers" that provided seeds for farmers that did not grow fruit crops; 3. identification of ripened fruit and/or mature seeds ready for collection based on fruit bat feeding evidence; 4. pollination of commercially-important species; and 5. dispersal of rare forest trees for the benefit of forest nursery managers[96][97]. Although respondents in both studies highlighted fruit bat disservices (e.g., damage to fruit crops from consumption, loss of seeds from scatter dispersal, untimely ripening from bats clawing bananas, and fouling from acidic guano), most interviewees perceived fruit bat benefits to outweigh any of these costs[96][97].

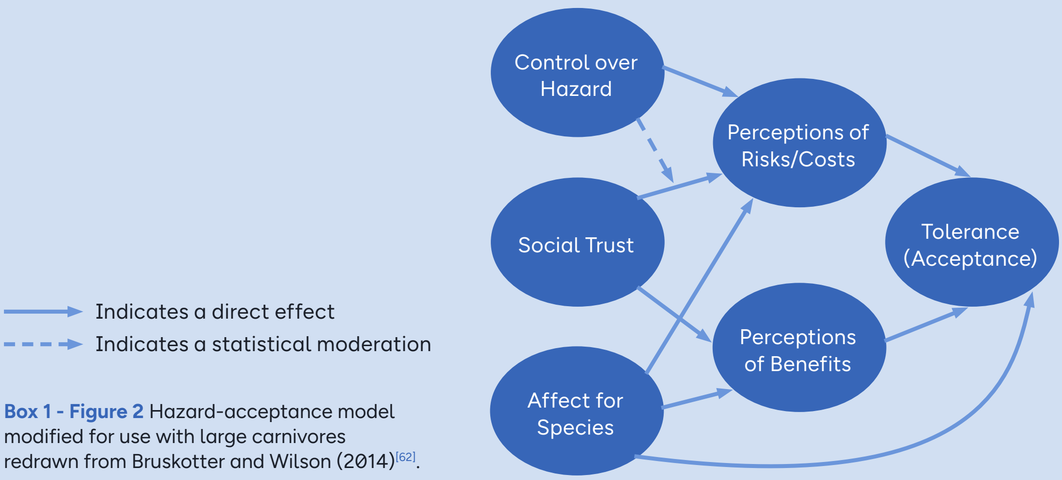
Box 1

The factors that result in human behaviours (i.e., antecedents to behaviour) are understandably of great interest in psychology and social marketing. The specific components and definitions of these antecedents to behaviour, along with their interrelationships to one another and, ultimately, how they build to the performance of behaviour, all vary based on the specific theory of behaviour change as well as on the behaviour of interest. Within conservation psychology, the most foundational of these theories of behaviour change include the theory of reasoned action[64] and the theory of planned behavior[66], with the theory of planned behaviour largely encompassing the theory of reasoned action (Box 1 - Figure 1). The factors illustrated in this model, their connections, and their moderating effects on one another are all important aspects of evaluating, modifying, and then reassessing the variety of human behaviours related to bats and their management.



Box 1 - Figure 1 Modified theory of planned behaviour model. SES = Social-Ecological System.

Of more specific interest to the field of human–wildlife conflict and conservation as it intersects with that of conservation psychology is Bruskotter and Wilson's proposed hazard-acceptance model as modified for application to large carnivores[62] (Box 1 - Figure 2). Through this model, Bruskotter and Wilson explored the psychological basis for (in)tolerance of mammalian carnivores with the use of hazard theory, risk-based judgment, and decision-formulation theory[62]. Although constructed with a focus on large, terrestrial, mammalian carnivores, the model is widely applicable to any wildlife taxon that is a real and/or perceived risk to humans. Accordingly, this hazard-acceptance model can inform applied research and guide targeted conservation interventions (e.g., education) focused on altering human behaviours for the promotion of bat tolerance, coexistence, and/or conservation.



Box 1 - Figure 2 Hazard-acceptance model modified for use with large carnivores redrawn from Bruskotter and Wilson (2014)[62].

Behavioural intentions and behaviours

Through the study of bat-related behaviours and behavioural intentions, we can gain a better understanding of the threats facing bats across India, including the severity and scope of those threats. Similarly, we can identify tolerance, coexistence, and protective behaviours directed towards bats (and/or their habitats) to ascertain the extent and manifestations of pro-bat practices in India. Understanding these behaviours can help us to establish models for promoting bat conservation behaviours in analogous contexts. In addition, evaluation of bat-related behaviours and behavioural intentions facilitates the analysis of the underlying motivations and driving factors behind these behaviours, which enables us to devise more effective interventions to modify "adverse" behaviours and to strengthen, expand, and scale up "positive" behaviours.

To date, several social science studies have evaluated what specific behaviours are posing a threat to bats in India [32][88][89][95] (Table 14.1). Several of these threats involved practices that led to the destruction and modification of bat habitats. Teenagers living in rural areas in Barak Valley, Assam reported roosting tree removal as the second leading cause of bat mortality in the region and recognised the protection of roosting trees as the most important conservation activity for local bats[88]. Kumar et al. (2021)'s threats analysis also revealed tree-felling to be the cause of lost roosting and foraging habitats for bats in Lakhimpur-Kheri, Uttar Pradesh[89]. A number of economic and social motivations underlaid the clearing of large trees within old mango orchards, specifically the creation of agricultural land, the production of more valuable wood (often used to construct furniture to earn additional income), the removal of unproductive old trees, and simplification of the partitioning of land within families[89].

Many of the direct threats that were reported by HD research in India are connected to the killing of bats with a variety of motivations. Collectively, these studies highlight the variable patterns of bat hunting and consumption behaviours within India, including people's perceptions of these behaviours in relation to the bats themselves. For instance, the "threats analysis" survey conducted among rural and urban residents of Lakhimpur-Kheri, Uttar Pradesh detailed the widespread hunting of *P. medius* in unprotected day roosts in Bhira, Jugrajpur, and Khargapur for medicine, meat, leather, oil, and museum specimens[89]. Dovih (2015) describes the large-scale annual harvest of cave-dwelling bats by the Longpfurii Yimchungii influenced by utilitarian, political, and cultural factors[95]. The survey of Standard 10-level students in rural Assam recorded 43% of participants who knew people in their neighbourhood that hunted bats, though mostly "irregularly" and "rarely" rather than "frequently" and with no explanation of the reasons behind this practice. The teenage respondents also believed tree-felling and electrocution have more significant impacts on bat populations than does hunting by local community members but that the prohibition of hunting would help to conserve bat populations[88]. The prevalence of utilitarian behaviours that involve the collection of bats for meat, medicine, leather, biological specimens, and/or spiritual, cultural, and other social reasons have been discussed above in relation to social norms and comprehensively reviewed in Chapter 10.

Although these behaviours negatively impact bats at the individual-level and, in some cases, at the population- and species-level, the use of bats may also endow these species with an important value to the human consumers, a value that would otherwise not exist[74]. Consequently, behaviours that are seemingly "adverse" for bats and their conservation may still hold benefits for the tolerance and/or protection of bats. Therefore, these behaviours should not be taken at face value and targeted for elimination (e.g., through behaviour change interventions) without a thorough vetting of the underlying antecedents for these behaviours and the behaviours' consequences for bats overall.

The detrimental disturbance of bats, independent of their collection for utilitarian use, has been assessed by several HD researchers[32][89]. Intentional disturbance of bats is a common behaviour associated with human–bat conflict-associated persecution and was recorded in the "threats analysis" survey completed by Kumar et al. (2021)[89]. Local communities regularly disturbed roosting colonies of *L. lyra, Alionoctula coromandra, Alionoctula ceylonicus*, and *P. medius*. In particular, orchard owners and village children attempted to displace flying foxes during the fruiting and harvest seasons with firecrackers and other deterrents[89]. Identification of the key actors (i.e., orchard owners and village children), specific behaviours, and timing of these behaviours (i.e., fruiting and harvest seasons) provides valuable information to design a targeted behaviour change campaign to address this specific case of human–bat conflict.

Human–bat conflicts can also arise from unintentionally harmful disturbance of bats. Debata (2021) combined a direct observation of cave visitors with semi-structured interviews of religious pilgrims and local residents to evaluate the impact of cave tourism on bats residing in the Gupteswar cave complex of Odisha[32]. The majority of visitors were drawn to the caves for cultural reasons or for leisure, participating in religious and spiritual rituals, talking, and photography within the cave systems. As a result, the cave-dwelling bats were exposed to variable levels of distressing noise and light pollution. With cave visitation rates increasing sharply during the local cultural festivals of February through July, also the breeding seasons of *H. ater, H. galeritus, L. lyra, R. lepidus*, and *T. melanopogon*, disturbance from cave tourism was predicted to have a potentially significant adverse effect on resident bat populations[32]. However, no local community members and only 12.9% of interviewed religious tourists recognised human activities in the caves were a potential threat to bats. In contrast, 80% of those interviewed attested that they never directly molested or otherwise harmed the cave-dwelling bats, indicating a desire to at least tolerate, if not outright protect, bats within the caves[32]. The discordance between the perceived pro-bat behaviours reported by interviewees and the actual bat-adverse behaviours observed by the author underscores the advantage of combining direct participant observation with survey methods in any human behavioural study.

On a more positive note, pro-bat behaviours and behavioural intentions have also been recorded in HD studies in India. Bhattacharjee et al. (2018) reported that a slight majority (52.8%) of students in rural Assam expressed a desire to actively take part in bat conservation, including those with negative attitudes towards bats and excluding some with positive attitudes towards bats[88]. Similarly, some respondents consented to paying for bat conservation despite not being interested in engaging actively in bat conservation themselves. When presented with the hypothetical scenario of being given INR 100, most students were willing to donate between INR 25 and INR 100 to bat conservation, including some students who expressed no interest in engaging in bat conservation activities directly[88].

Just over 50% of religious pilgrims visiting the Gupteswar cave complex also shared their support for the protection of bats along with their roosting sites, and an overwhelmingly majority of interviewed residents and religious tourists refrained from hurting or teasing cave-dwelling bats[32]. The local community members surveyed in Lakhimpur-Kheri, Uttar Pradesh indicated analogous protective behaviours for bats and their day roosting sites at Paraili, Biharipur and Belabojhi[89]. Although not explicitly assessed within a HD framework, the behaviours described in the Social Norms section above and in Table 14.2 further reflect the diversity of cultural, social, religious, and spiritual practices evidenced throughout India that protect bats and/or the critical habitats of bats.

Media

News and social media play a pivotal role in the dissemination of information about bats and, thus, media's framing of this information can significantly influence social norms, individual attitudes, and subsequent behaviours of the public towards bats, bat management, and bat conservation (rev. by López-Baucells et al. 2023)[80]. For this

Rajesh Puttaswamaiah speaking at Nature inFocus – a leading wildlife and nature festival. Photo: courtesy of Rajesh Puttaswamaiah/ Nature in Focus reason, media acts as a double-edged sword for bats and their conservation within India: media can generate and proliferate messages that are adverse towards bats and their protection or, conversely, can disseminate and reinforce positive conservation messaging that benefits bats and secures their protection. News and social media can also assist in social science research focused on the HD of bat management more directly. Media serve as crucial sources of data for investigations into bat-related HD issues[93][94][103][104]. Indeed, the act of reporting itself is an example of a behaviour that can influence bats and their conservation positively and/or negatively, and the study of media's influence on and interrelationship with human–wildlife conflict and coexistence is recognised as a focal topic within the field of conservation psychology[59][105].

Currently, the only published research addressing the characterisation of bats in Indian news media consists of a machine learning project that scanned news articles published on the Times of India website between 2006 and 2018 to analyse patterns in human–wildlife conflicts[93]. Although details were not provided regarding the context, "bat" was mentioned 16,575 times, a frequency only surpassed by "bee" and "lion" and significantly exceeding references to "eel", "ape", "boa", "tiger", "boar", "owl", "elephant", "bear", "leopard", "snake", "monkey", and "fox"[93]. Additional detailed analyses for "bats" were pooled with those for other wildlife taxa, so, regrettably, no specific insights on human–bat conflict can be gleaned from this study. It is not possible to determine whether the disproportionate coverage of bats is due to actual or perceived human–bat conflict, chiroptophobia, or other factors. However, the excessive amount of references to "bats" in comparison to wildlife that are more likely to cause lethal harm to humans (e.g., tiger, elephant) and that are more fierce fear-relevant to Indians (e.g., snake, bear)[87] is worth noting and examining in future bat-related media queries.

During the global COVID-19 pandemic, inaccurate and sensationalised stories about bats and their purported connection to the origin and transmission of SARS-CoV-2 spread extensively across mass and social media, galvanising negative attitudes towards bats and, in some cases, fuelling persecution of bat species[60][76][78][80]. India was not an outlier, and extensive fear-based messaging and misinformation about bats circulated widely within the country during the SARS-CoV-2 crisis. The inaccurate and negatively-hyped reporting was enough to raise alarm among Indian bat researchers and conservationists, who collaborated in designing and distributing a press release to news media in order to counter the biased coverage of bats and, in turn, to assuage any resulting adverse attitudes and/or behaviours towards bats (Box 2). This case study highlights both the dangerous effects of unethical media reporting on bats as well as the efficacy of media outlets for the distribution and amplification of educational messages that inspire bat tolerance and conservation.

Opportunities for HD Studies in India

In respect to bat management and human–bat conflict and coexistence in India, social science research is comparatively scant. Consequently, there are seemingly limitless opportunities for expanding HD studies of bats within the country. A recent comprehensive review of bat-related studies recommended ten global priorities for HD research to support bat conservation worldwide: 1. Embed studies in a conceptual framework, supported by a rigorous review of any pertinent literature to explain the constructs; 2. Explore the diversity of available methodological approaches; 3. Follow social science best practices; 4. Generate actionable recommendations grounded in the results; 5. Involve social scientists meaningfully from the design phase; 6. Work where bats are most diverse; 7. Study diverse stakeholders; 8. Move beyond mainly studying attitudes; 9. Explore the full spectrum of human–bat interactions; and 10. Conduct experimental and longitudinal studies[106]. Following the SARS-CoV-2 global pandemic and attendant persecution of bats, a more specific set of recommendations for HD researchers were proposed, namely "1. assessment of drivers of human behaviours towards bats (e.g., attitudes, emotions, values) with a focus on conservation and strategies to reduce zoonotic spill-over risk; 2. identification of human–bat conflicts (e.g., fruit crop raiding, urban roosting) and assessment of evidence based and ethically acceptable interventions to reduce such conflicts; 3. development of context-specific guidelines for communicating about bat-borne zoonoses and conservation that deliver accurate information and practical recommendations, caution against persecution of bats and promote public health" (Rocha et al. 2021, pp. 304-305)[60]. Each of these points are fully applicable to the field of bat-related HD research in India and should guide any future social science initiatives. Below, we expand on this foundation of recommendations and succinctly highlight specific priority areas for future social science investigations of bat–human interactions to promote bat coexistence, conservation, and responsible management across India.

Box 2

COVID-19 was first detected in December 2019 in China and within three months, the disease was declared a global pandemic by the World Health Organisation. Preliminary studies concluded that the SARS-CoV-2 virus responsible for COVID-19 most likely originated in horseshoe bats of the genus Rhinolophus (the exact origins of the virus continue to be debated). Following the breaking of this news, bats went viral all over the internet.

Concerned by the amount of misinformation and disinformation, bat researchers, organisations, and associations from all over the world put out articles and press releases to bust the myths that bats are responsible for spreading COVID-19 (a consolidated FAQ can be accessed via the IUCN Bat Specialist Group). Following the lead of international organisations, South Asian bat researchers also united in their efforts to conserve bats. In total, 64 researchers from six South Asian countries signed a press release that debunked myths surrounding bats and COVID-19, assuaged public concerns about living around bats, discouraged killing or causing disturbance to bats, and called for responsible reporting by the media.

As soon as the press release (written in English) was made public, it was reported in major national and regional English-language dailies (Box 2 - Figure 1). Researchers also translated the press release summary into their mother tongues, following which, the news was published and/or broadcast in some of the most widely spoken languages of the country, such as Hindi, Bengali, Tamil, Telugu, Kannada, Marathi, and Assamese (Box 2 - Figure 2). In their personal capacities, researchers also conducted webinars in English, Hindi, or their mother tongue and were interviewed by celebrity YouTubers. A compilation of all outreach output can be accessed via a special issue of *Zoo's Print*: Bat and Covid-19 outreach. Not only did the effort reach out to the Indian public, it also brought international attention to bats in India as witnessed by the production of a documentary on the Kolar Leaf-nosed Bat (*Hipposideros hypophyllus*) by Al Jazeera. Although the impact of the outreach initiative has not been conclusively measured, the collaborating researchers rejoice in the fact that for every negative article on bats, there is now a positive bat article in a major Indian language.

THE MEGHALAYA GUARDIAN

SHILLONG ■ SATURDAY ■ APRIL 25, 2020

• Scientists, conservationists bust 'myths' about bats and Covid-19

Bats do not spread COVID-19, claim researchers

Short Nosed Fruit Bat.

Box 2 - Figure 1 Example of a headline from a major Indian newspaper, "The Meghalaya Guardian", published March 25, 2020. Reprinted in *Zoo's Print Journal.*

Box 2 - Figure 2 Examples of positive bat messaging in multiple languages: (a) English; (b) Bengali, (c) Hindi, and (d) Marathi. Illustrations: Richa Kedia, published in *Zoo's Print Journal.*

Social science training and capacity building

There is a great need for truly interdisciplinary training to effectively and sustainably address the complexity of threats facing bats within the social-ecological systems of India[107][108]. In order to support this type of interdisciplinary work, social science training should be emphasised within conservation science and wildlife management education and capacity-building programmes. However, topics and skills from the fields of ecology and biology continue to dominate most curricula with little to no emphasis on the equal importance of social sciences for conservation research and practice[108]. Educational, training, and other capacity-building efforts within India should strive to integrate a social science focus equal to that placed on ecological and biological concentrations into all of their conservation science, wildlife management, and other bat-related initiatives.

Interdisciplinary and multidisciplinary collaborations

A critical analysis of bat-specific social science publications reported that, when compared to those published by unidisciplinary teams (i.e., only natural scientists or only social scientists), articles published by multidisciplinary teams (i.e., including both social and natural scientists) provided wider coverage of HD issues and better recommendations that were explicit and well-founded in the study's findings[106]. We recommend that social and natural scientists seek to foster these types of interdisciplinary and multidisciplinary collaborations[106] to improve each other's research and practice related to bats. These collaborations should also endeavour to integrate and equitably include all relevant stakeholders into the collaborative enterprise to ensure that the HD bat research conducted is: 1. appropriate to the context, 2. robust and based on the best available information, 3. useful and fit to purpose, 4. ethically-collected, synthesised, and shared, and 5. secures buy-in from key stakeholders (Chapter 12). These types of equitable and inclusive multi-stakeholder collaborations further facilitate the codesigning of bat-related conservation interventions (e.g., educational outreach). The codesigning process generates messaging that has been demonstrated to be more salient to target audiences and their needs and, thus, more effective at motivating behaviour change[41]. Some partnerships that we predict will be especially fruitful in the Indian bat context include those between social scientists and: 1. natural scientists and bat conservationists[59][106], 2. local and Indigenous communities[65], 3. public and veterinary health professionals[81][109][110][111][112], and 4. policymakers and other decision-makers[78].

Expanded research scope

One of the research priorities identified during the State of the Bats (2024–2025) in-person workshop by the Policy and Public Engagement working group was "Social studies on perception, interactions & human–bat co-existence" (Appendix 4). In line with this recognised priority, we recommend that Indian researchers pursue topics in bat-related HD that are based on the expanding body of conservation psychology literature for bats, bat management, and/or bat conservation worldwide. Attitudes, knowledge, and practices related to bats are affected to varying degrees in different contexts by demographic and other background factors (Box 1), including age, level of education, previous exposure to and experience with bats, sex/gender, residence (e.g., residence in urban vs. suburban vs. rural settings; mountainous vs. plain landscapes), occupation, religion, economic status/income, and ethnicity[73][76][98][99][100][109][110][111][113–121]. Consequently, it is imperative that any HD study account for these factors and acknowledge the limitations of its findings' applicability and transferability to other contexts.

More specifically, we suggest that research into behavioural antecedents should be prioritised for:

- Bat-related practices and behaviours,
- Salient factors for bat acceptance behaviours[82][122][123][124], specifically those outlined in the "hazard-acceptance model modified for use with large carnivores"[82],
- Evaluation and adaptation of the Bats Attitudes Standard Scale (BAtSS)[77]for the analysis of bat-related attitudes (e.g., affect) of Indian stakeholders[77][99],
- Alignment between perceived and actual behavioural control[76][82],
- The influence of wildlife value orientations on the expression of tolerance and protective behaviours for bats[125][126][127][128],
- The ethnobiological survey of as many regions, peoples, and contexts as possible, an undertaking even more urgent as Western culture supplants and dominates traditional biocultural systems of belief across India[74], and
- Information to inform conservation marketing strategies [81][83][116][119].

Diversified focal study subjects

Social science researchers exploring bat-related issues are advised to engage in thorough stakeholder mapping to identify study subjects that are the most relevant and feasible for the specific objectives, methodology, methods, and context of their study. The comprehensive stakeholder analysis of Chapter 12 provides excellent guidance for this process. We propose several stakeholder groupings that should be of interest to any study seeking not only to advance our insight into human–bat interactions but also to generate applicable data to support effective conservation interventions:

- Urban residents,
- Stakeholders related to tourism (e.g., nature-based tourism, religious tourism, and cultural tourism)[32][117][121][129][130], expanding beyond cave, religious, and archaeological sites to include other bat-related tourism ventures (e.g., the ecotours visiting *P. medius* roosts on Odisha's "Bat Island"[131][132]),
- Residents in human–bat conflict "hotspots",
- Wildlife rescuers and rehabilitators[121][133], and
- Citizen scientists[121][134] (Chapter 13).

Most of these stakeholders are also poorly-represented in global bat-related HD research, so studies of these focal subjects can benefit bat conservation from the local to global scales.

Conscientious selection of methodology and methods

The methodology (i.e., the rationale behind the approach used to research questions, related to research design, sampling, and methods) and methods (actual tools used to collect data) used by HD researchers are varied and should be chosen based on the objectives of the research, the type of research questions, the stakeholders involved in the research, and the resources available for the study[135]. Most commonly, human–wildlife conflict and coexistence researchers have relied on qualitative methods (e.g., participant observation, unstructured and semi-structured interviews, focus groups), quantitative (e.g., structured interviews, content analysis), and mixed qualitative–quantitative methods (e.g., Q-methodology, methods intended to establish consensus or support groupthink) (reviewed by Glikman et al. 2023)[135]. We advise those seeking to conduct bat-related social scientific research to carefully consider their methodology and methods in light of available resources before proceeding with their study design to ensure that they are able not only to successfully complete their research but also to generate results that appropriately and accurately address the primary objectives of their inquiry.

Bhargavi Srinivasulu conducting an awareness programme at a school in Kolar district, Karnataka. Photo: Aditya Srinivasulu

Application of social science research in bat conservation programme monitoring and evaluation

There have been few published accounts of systematic efforts to monitor and/or conduct programme evaluations for bat-focused behaviour change programmes globally. Some notable exceptions are the bat conservation workshops hosted by the Bolivian Bat Conservation Program (PCMB)[136], a public display of bats at Brookfield Zoo[137], a specially-prepared, experimental bat conservation message and bat conservation lecture for registered students and university staff from Jilin Agricultural University and Northeast Normal University[76], el Programa para la Conservación de Murciélagos de Bolivia (Bolivian Bat Conservation Program)[111], Jersey Zoo's "virtual bat experience"[138], and a bat ecosystem services awareness workshop in the El Bejucal community of Mexico[112]. There is a significant opportunity for social scientists to develop, support, and implement robust monitoring and programme evaluation studies for Indian bat conservation interventions as a model for other conservation campaigns (whether they be for bats or other wildlife species) within India and globally.

Social media-focused research

Despite the adverse effects that social media can have for bats and their conservation, these online forums hold the potential for providing enormous stores of accessible data for HD research and for serving as a very efficient, far-reaching channel of communication for disseminating positive bat messages. As of January 2024, India boasted over 462 million social media users, equating to approximately 32% of the total population[139]. As such, social media can be indispensable repositories for a large amount of bat-related social science data, which represents a wide diversity of stakeholders over a prolonged period of time with less of the challenges related to privacy, sampling sizes, and biases that hinder more direct social science collection methods[103][104]. Illustrating how bat-relevant information from Indian social media users can be effectively applied to bat-focused conservation psychological analyses, Batrice et al. (2024) evaluated Asian perspectives on bat exploitation as depicted in social media posts[107]. The authors recorded 31 social media posts on bat exploitation and persecution from India, which were collected between June 2020–May 2021. In comparison, the only other South Asian country represented (Bangladesh) only provided 22 datapoints[104]. As Natural Language Processing tools and artificial intelligence technology are further developed to facilitate mass assessments of public attitudes expressed via social media and online news outlets (e.g., Giebink et al. 2024[103]), these types of social media-based studies will become more feasible and important for HD researchers in India

Challenges

As with any scientific endeavour, there are a number of challenges both intrinsic and extrinsic to the subject matter, methodology, and methods that face any social scientist engaging in bat-related research in India. Although not an exhaustive list, herein we review some of these challenges that have not been previously discussed.

Methodology and methods challenges

Social scientists are presented with a plethora of options when it comes to defining their study methodology and choosing between effective methods[135]. However, researchers may be unable to select the ideal method for their inquiry due to logistical restrictions (e.g., limited time, resources, access to technological tools), training, and/or factors related to the study subjects.

Sampling challenges

Social scientists may be hindered by logistical, bureaucratic, or methodological hurdles in their ability to sample an adequate number and diversity of individuals, across an appropriate geographical extent, and/or for a significant period of time. Limited sampling makes it difficult to draw general, transferable conclusions, analyse results with statistical confidence, and establish a high degree of contextuality. In addition, short-term studies are likely to miss long-term trends. This shortsightedness is especially obstructive when conducting monitoring and/or programme evaluation studies that must uncover both the intended and unintended consequences of interventions as well as evaluate any changes linked to fluctuations in the external or internal environments of the project.

Cultural and other social challenges

The tremendous cultural, religious, spiritual, political, economic, ethnic, linguistic, and social diversity of India is both a strength and a challenge for its social scientists. Some of the difficulties related to these factors are relatively obvious and/or universal across contexts (e.g., communication challenges related to the diversity of languages and dialects). However, some challenges are more specific contextually or limited in scope. For example, religious ethics in some communities forbid men from interviewing women, which can limit the inclusion of critical gender perspectives in social science studies (e.g., Attaullah et al. 2022[120]). Other challenges may be more nuanced and difficult to anticipate without an intimate understanding of local community dynamics. For instance, power issues (related to caste systems, gender, age, levels of education, ethnicity, "outsider" status, residency in urban vs. rural areas, institutional associations, disparities in wealth, familial relationships, previous history of interaction, origination of funding support, etc.) often plague social science investigations and introduce biases into data collection, analysis, reporting, and co-production of information efforts[140][141].

Cultural and other social challenges can act more directly to bias social science data as well. In the case of social norms, if bats have negative associations culturally, spiritually, or socially (e.g., bats are "haram"), individuals might not be honest about their use of bats (e.g., for food or medicine)[94]. Individuals may also be dishonest for fear of retribution if their actions are illegal or socially-vilified (e.g., killing of lawfully-protected or sacred bats)[90].

Research conducted by those without social science training

Coupled with the growing recognition of HD research's utility is the limited number and capacity of social scientists (see above). This disconnect between demand and supply often leads to natural scientists embarking on social science research without adequate training, experience, and foundational understanding. As reviewed by Martin (2020), the resulting social science studies commonly: 1. lack suitable application of and reference to social science principles, concepts, and established knowledge, 2. are poorly designed with methodological flaws and misaligned methods, 3. misinterpret findings, and 4. report misguided or unsubstantiated conclusions[142].

Challenges of multidisciplinary and interdisciplinary teams

We highly recommend that any bat-related HD research conducted in India is supported by multidisciplinary and interdisciplinary collaborations. However, these types of teams face their own unique set of challenges related to: 1. obstacles to communication from dialectic differences, 2. difficulties in translating differing fields of science and co-creating research agendas due to epistemological differences, 3. conflicting agendas, 4. biases in the collected and analysed data from incompatible methodologies and methods, and 5. friction and conflicts rooted in miscommunication, pre-existing histories of interaction, competition, and lack of respect for each other's expertise or field of study[106][107][142].

Ethical challenges

The ethical challenges that face bat-focused social scientists and recommendations for navigating this minefield of conservation practice and research are comprehensively discussed by Gregg et al. (2022)[143] and Glikman et al. (2023)[135]. HD researchers in India have a responsibility to: 1. ensure the inclusive, equitable, and respectful engagement of all relevant stakeholders throughout the process, 2. reflect on their own, personal biases and intentions throughout the study, when disseminating its results, and as the findings are translated into practice, and 3. carefully consider all power dynamics, social-ecological factors, and intended and unintended consequences of their work and any subsequent conservation interventions based on their work[44][135][143].

Conclusion

These challenges are more than compensated for by the promising and limitless possibilities for bat-related HD research and practice in India. Indian social scientists have an unparalleled opportunity to build on the insightful and invaluable HD work that has already been conducted across the country to develop cutting-edge research on understudied (yet crucially important) topics, while generating important data to fuel conservation interventions for the benefit of bats, biodiversity, and human communities.

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Section V.

Research and Conservation Priorities

Kolar Leaf-nosed Bat (*Hipposideros hypophyllus*).
Photo: Rajesh Puttaswamaiah

Chapter 15
Threat Assessment for India's Bats

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From catastrophic weather events to targeted hunting and persecution, India's bats face a plethora of natural and anthropogenic threats. These threats are not only complex, due to their ever-changing and variable nature, but also rarely quantified. Therefore, a comprehensive analysis of these threats' characteristics, drivers, and impacts on India's bats is essential for identifying bat-related research priorities as well as informing decision-making related to bat management and policy. There are a limited number of studies within India that provide thorough threats assessments either for: 1. specific species (e.g., Raman et al. 2020[1]); 2. multiple species at the local to regional level (e.g., Saikia et al. 2018[2]); or 3. individual threats in detail (e.g., Murugavel et al. 2023[3]). Consequently, the State of India's Bats (2024–2025) project recognised the need to conduct a comprehensive threats assessment for all bat species across all of India. To this end, team members participated in a Threats Mapping survey and four virtual Threats Mapping workshops. The intention of this chapter is to offer insights into past, current, and future threats facing the bats of India based on the results of these participatory threats assessments (described in detail below). Consequently, it is beyond the scope of the chapter to provide an exhaustive literature review pertaining to each of these topics, and relevant citations have been incorporated to supplement the threats assessments generated by the State of India's Bats (2024–2025) participants.

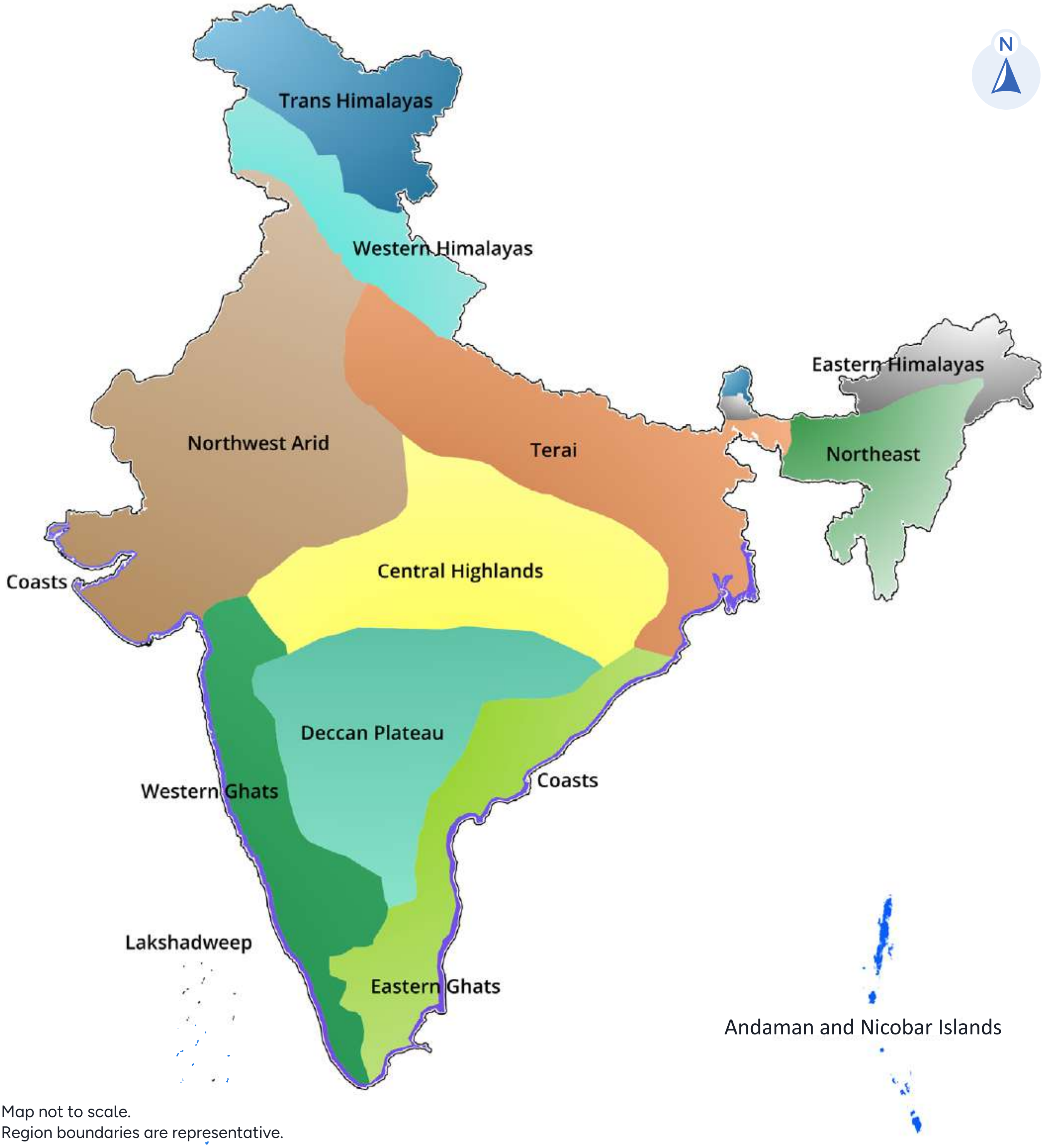
Threats Assessment Methods

Threats mapping survey

A "Threats Mapping Survey" was conducted using an online platform (Google Forms) to voluntarily elicit information from State of India's Bats project members based on their direct experience and/or with reference to credible sources (e.g., peer-reviewed literature, personal communication from trustworthy sources). Survey participants provided information about threats to bats based on biogeographic region of India (Figure 15.1) and International Union for Conservation of Nature (IUCN) Red List of Threatened Species status of bat taxa. Respondents were instructed to only complete survey sections for the geographic regions, threats, and bat taxa with which they had direct experience and/or could cite peer-reviewed, trustworthy sources to support their response. They were asked to leave any questions or sections that they did not feel confident answering blank.

Biogeographic regions were delineated based on Rodgers and Panwar (1988)[4]. We further sub-divided the Himalayas into the Western (Jammu and Kashmir, Himachal Pradesh, and Uttarakhand) and Eastern (Sikkim and Arunachal Pradesh) Himalayas to account for the vastly different nature of threats across these regions. For the same reason, we also demarcated the Central Indian Highlands in Madhya Pradesh and Chhattisgarh separately from the Deccan Peninsula (Figure 15.1). For each biogeographic region, respondents had the opportunity to assess the following:

- The relevant timescale (i.e., past, current, future) for Level 2 and Level 3 threats as classified by the IUCN Threats Classification Scheme Version 3.3;
- Each bat family in which at least one species is determined by the respondent to be experiencing a population decline as a result of any of these Level 2 and/or Level 3 threats (either directly or in combination with other threats); and



Map not to scale.
Region boundaries are representative.

Figure 15.1 A map of the biogeographic regions of India as they were defined by the State of India's Bats (2024–2025) project.

- The top five most significant Level 1 threats (as classified by the IUCN Threats Classification Scheme Version 3.3) for all bats in the region based on the threats' duration (e.g., current threats expected to increase in the future would be higher impact than those of the past that are not currently active), taxonomic impact (e.g., how many populations of how many taxa does the threat adversely impact), and geographic scope (e.g., are the threat's negative impacts significant across the entire landscape or are its significant impacts highly localized in extent). Level 1 threat "Agriculture & aquaculture" was evaluated as "Agriculture" unless otherwise indicated.

Survey participants were also guided through an evaluation of Level 2 and Level 3 threats for bats endemic to India that were assessed by the IUCN Red List of Threatened Species as "Data Deficient" or threatened (e.g., "Vulnerable", "Endangered", "Critically Endangered") (Table 15.1). Respondents were asked to mark all threats that they deduced impart a significant negative impact at the individual-, population-, and/or species-level (either directly or in combination with other threats) for each species.

Table 15.1 A list of bat species that were specifically evaluated by the State of India's Bats' "Threats Mapping" survey. Species in bold were further assessed individually during Biodiversity Hotspot Threats Mapping online workshops. These evaluated species are endemic to India and listed as "Data Deficient", "Vulnerable", "Endangered", or "Critically Endangered" on the IUCN Red List of Threatened Species. Table *does not* include *all* Indian bat species that are listed as "Data Deficient" or threatened per the IUCN Red List of Threatened Species.

IUCN Red List Assessment	Species	Common Name
Data Deficient	*Cnephaeus* (formerly *Eptesicus) tatei*[5]	Sombre Bat
	Harpiola grisea[6]	Peters's Tube-nosed Bat
	Hipposideros khasiana[7]	Khasian Leaf-nosed bat
	Murina pluvialis[8]	Rainforest Tube-nosed Bat
	Myotis peytoni[9]	Peyton's Whiskered Myotis
	Rhinolophus indorouxii[10]	None known
	Rhinolophus mitratus[11]	Mitred Horseshoe Bat
Vulnerable	*Hipposideros durgadasi*[12]	Durga Das's Leaf-nosed Bat
Endangered	***Hipposideros nicobarulae***[13]	Nicobar Leaf-nosed Bat
	Hipposideros pomona[14]	Pomona Leaf-nosed Bat
	Latidens salimalii[15]	Salim Ali's Fruit Bat
	Pteropus faunulus[16]	Nicobar Flying Fox
	Rhinolophus cognatus[17]	Andaman Horseshoe Bat
Critically Endangered	***Hipposideros hypophyllus***[18]	Kolar Leaf-nosed Bat

After each biogeographic and bat species survey section, participants were provided with additional space to freely input relevant citations, resources, links, comments, and other information related to each question. A total of 17 experts from the State of India's Bats project completed the online survey.

Biodiversity hotspot threats mapping online workshops

To supplement and expand on the threats analysis for India's bats that was conducted via the "Threats Mapping" survey described above, four 3- to 4-hour virtual workshops were hosted to investigate the cause-and-effect inter-relationships between drivers, threats, and their effects on bats in depth. These online sessions concentrated on four geographic regions and six threatened endemic bat species across India. The four geographic regions were chosen based on their high bat species richness and endemism: the Andaman and Nicobar Islands[19][20] (biogeographic region of same name), the Himalayas[21][22] (combined area of Eastern Himalayas, Western Himalayas, and Trans Himalaya biogeographic regions), Northeast India (biogeographic region of same name), and the Western Ghats (biogeographic region of same name)[23] (Figure 15.1). In alignment with their endemic ranges, the threatened species *Rhinolophus cognatus, Pteropus faunulus*, and *Hipposideros nicobarulae* were addressed during the virtual workshop for the Andaman and Nicobar Islands, while *Hipposideros pomona* and *Latidens salimalii* were assessed in the virtual workshop for the Western Ghats. The Critically Endangered status of *Hipposideros hypophyllus*[18] made the species a priority for a more targeted threats mapping exercise, so an evaluation of the threats impacting these bats was conducted with the species experts that participated in the Western Ghats Biodiversity Hotspot session. All State of India's Bats (2024–2025) project members were given the opportunity to participate in all four threats analysis workshops, and several experts attended more than one session (Appendix 1, Appendix 5).

Participants were guided through a facilitated exercise on a Miro whiteboard, where they were asked to describe the direct and indirect connections between the most significant threats to all bats in the hotspot area and: 1. the adverse effects of these threats on bats (in general and/or to specific species), and 2. the drivers, causes, or other sources of influence on these threats. These linkages were mapped on the virtual whiteboard in real-time to construct a causal flow diagram for each biogeographic hotspot. The most significant Level 1 threats to all bats in the hotspot area were delineated based on the results of the Threats Mapping survey (Appendix 5). Attendees were instructed to propose cause-and-effect (inter)relationships based on:

- Their own, direct experience,
- Reference to credible sources (e.g., peer-reviewed literature, personal communication from trustworthy sources), and
- Highly likely or highly probable connections based on logical inferences, data for other species, data for the same species in other regions/circumstances, and similar, evidence-based deductions.

In addition, participants were encouraged to provide supplementary information related to the cause-and-effect chains, including but not limited to case studies, specific examples, suggested references, feedback loops, countering positive effects of threats on bats, and explanations of any differential impacts or mitigating conditions correlated with taxonomic, behavioural, ecological, environmental, anthropogenic, or other factors.

In the cases of the Western Ghats and the Andaman and Nicobar Islands Biodiversity Hotspot workshops, an analogous process was followed to independently draft causal flow diagrams depicting the threats, causes of those threats, and detrimental effects of those threats on each threatened endemic bat species evaluated in these sessions.

Each Biodiversity Hotspot Threats Mapping virtual workshop culminated in an open discussion of the notable knowledge gaps in our current understanding of the impact of threats on bats in each region. Attendees were given free rein to reflect on any geographic, taxonomic, threat-specific, or other biases and/or unknowns in the current state of knowledge as well as the type of research required to quantify or otherwise solidify connections in the causal link diagrams.

Salim Ali's Fruit Bat (*Latidens salimalii*) with ixodid ticks. The potential impacts of vector-borne diseases on bats were discussed during the threats assessment processes. Photo: Nithin Divakar

Results

Seventeen out of 30 (56%) invited experts completed the Threats Mapping survey. At least one participant completed the questions for 11 of the 13 distinct biogeographic regions (Figure 15.1), but no responses were provided for the Trans Himalayan region or the Terai Region (including the Gangetic Plains), though Trans Himalayan regional threats to bats were broadly discussed during the online Himalayas Biodiversity Hotspot Threats Mapping workshop. Of the 17 respondents, seven were able to provide threat information related to the six endemic bat species assessed as "Data Deficient" on the IUCN Red List of Threatened Species, and 11 provided responses for questions related to the seven endemic bat species assessed as threatened on the IUCN Red List of Threatened Species.

Eighteen experts participated in at least one Biodiversity Hotspot Threats Mapping online workshop (Appendix 1). Causal flow diagrams were drafted for the threats impacting bats in each of the four biodiversity hotspot regions (Appendix 6) and for the threats specifically affecting *Rhinolophus cognatus*, *Pteropus faunulus*, *Hipposideros nicobarulae*, *Hipposideros pomona*, *Latidens salimalii*, and *Hipposideros hypophyllus* (Appendix 7).

Below is a concise summary of the key results and discussions from the evaluation of past, current, and future threats impacting bats across India as assessed by the State of India's Bats (2024–2025) project with a more detailed synthesis available in Appendix 5. These summaries are not intended to be a systematic review of the literature but rather to serve as a supplement to the current body of knowledge.

Threats to Bats by Biogeographic Region

Andaman and Nicobar Islands biodiversity hotspot

All three respondents that completed the threats survey section for the Andaman and Nicobar Islands region agreed that the Level 1 threat "Residential & commercial development" was the most significant threat facing all bat species in the region, followed by the Level 1 and 2 threats summarised in Table 15.2 (pers. obs., pers. comm. and unpublished data by R. Chakravarty, B. Srinivasulu & C. Srinivasulu). Accordingly, the online Threats Mapping workshop conducted for the Andaman and Nicobar Islands biodiversity hotspot focused on these Level 1 and 2 threats. The extensive destruction in these islands wrought by the Sumatra–Andaman earthquake and the resulting Indian Ocean tsunami of December 26, 2004 underscore the devastating effects that these disasters have had and will continue to have on the region's bat populations (Appendix 5). For this reason, attendees also addressed the cause-and-effect pathways for "Geological events" during the virtual threats mapping workshop (Table 15.2).

Table 15.2 Level 1, Level 2, and Level 3 threats discussed in relation to all bat species across the Andaman and Nicobar Islands. Definitions of threat levels and threats per the IUCN Threats Classification Scheme, version 3.3 (2022).

Level 1 Threats	Level 2 Threats	Level 3 Threats
Residential & commercial development	Tourism & recreation areas	
	Housing & urban areas	
	Commercial & industrial areas	
Human intrusions & disturbance	Recreational activities	
	Military exercises*	
Natural system modifications	Other ecosystem modifications	
Climate change & severe weather†	Temperature fluctuations	
	Natural weather disasters	
	Sea level rise	
Biological resource use	Hunting & collecting terrestrial animals	Intentional use (species being assessed is the target)
Geological events	Earthquakes‡	
	Tsunamis‡	

* War and civil unrest were not evaluated as components of this Level 2 threat.

† Participants re-defined the Level 2 threats associated with the Level 1 threat of "Climate change & severe weather" to ensure these threats were the most relevant for all bat species in this biodiversity hotspot. Attendees reported "fluctuations" rather than "extremes" as the germane temperature-related threat for bats on these islands. "Natural weather disasters" was chosen to encompass more comprehensively any potential weather event linked to anthropogenic climate change and/or natural processes that could possibly impact the Andaman and Nicobar Islands. Sea level rise was highlighted as the most important "Other impact" for the region.

‡ Due to the distinct direct and indirect effects that earthquakes and tsunamis have had and can have on bats in the Andaman and Nicobar Islands, these geological events were analysed independently as Level 2 threats.

Residential & Commercial Development. Increasing human migration has caused housing expansion and urban development, leading to habitat fragmentation. The expansion of commercial and industrial areas, particularly surrounding national security facilities, poses a present and future threat to bats' natural habitat. Additionally, the islands, being rich predominantly in natural wealth, offer limited employment opportunities for local residents apart from diving and ecotourism. Economic constraints drive residents to engage in unsustainable resource extraction such as timber collection. While the tourism industry often markets hut construction using old trees as "eco-friendly", this practice is believed to have caused deforestation of bats' habitats. Most major cave tourism sites do not contain bat roosts, and cave exploration near the coasts does not pose a significant threat at the current level. However, unregulated tourism and increased cave exploration could negatively impact bat populations in the future.

Human Intrusions & Disturbance. Military exercises across the islands disrupt local ecosystems and likely cause irreversible damage to habitats and wildlife. The usage of explosives such as RDX in testing areas within the Nicobar Islands, hold the potential of direct mortality of bats and/or elevated human–bat interactions that can increase bats' exposure to zoonotic diseases. The arrival of migrant communities for national security-related work has led to the introduction of non-native species, including domestic cats, which have been observed hunting bats emerging from caves.

Climate Change & Severe Weather. Rising sea levels are projected to lead to the loss of bat roosting habitats and to significantly impact bat populations in coastal and low-lying areas. Severe cyclones may uproot trees, likely causing a reduction in foraging and/or roosting opportunities. Sudden and unpredictable fluctuations in temperature are also harmful, potentially elevating disease risks among bat populations.

Geological Events. One workshop participant attested that many cave-dwelling bats likely perished during the cave collapses resulting from the December 2004 tsunami that was triggered by a magnitude 9.1 undersea earthquake. The tsunami completely submerged Indira Point, resulting in the loss of an entire island from the Nicobar archipelago. The status of this island's bat populations and their ultimate fate are still unknown. Earthquakes primarily cause the destruction of bats' cave habitats, while tsunamis have a greater impact on coastal habitats.

Knowledge Gaps. In considering the important knowledge gaps that exist around our understanding of threats to bats across the Andaman and Nicobar Islands, workshop participants outlined the following underexplored topics:

- **Baseline research on bats.** Although some limited research was conducted historically on both islands, there is a paucity of post-tsunami investigations of bat biology, behaviour, ecology, and population health across both island complexes, particularly the Nicobar Islands. Current government restrictions to accessibility further hinder our understanding of the bats in this biogeographic region.
- **Habitat ecology of bats.** Studies investigating the habitat requirements of most of the islands' endemic bat species are lacking. The Salim Ali Centre for Ornithology and Natural History (SACON) has documented more than 200 caves across the Andaman Islands in a project led by Dr. Manchi Shirish S. However, further research on the ecology of cave-dwelling bats is needed. Infrastructure development and the expansion of tourism have already led to the opening of two cave sites on Baratang Island, highlighting the need for research on the impact of land use changes. Engaging local communities could help gather ecological insights, as island residents may have traditional knowledge on the habitat use of specific bat taxa.
- **Human Dimensions of bats and their management.** There is a great need for community- and locally-led conservation strategies for bats on the Andaman and Nicobar Islands. Although hunting and deforesta-

Sombre Bat (*Cnephaeus tatei*). Photo: Rohit Chakravarty tion are prevalent across the islands, the degree to which these anthropogenic threats impact bats is unknown. Exploring the Human Dimensions of bats and their management, particularly local beliefs, perceptions, and interactions with bats, is essential for formulating successful conservation initiatives.

- **Taxonomy and systematics.** Significant gaps exist in species identification, resulting in taxonomic ambiguity. A comprehensive gap analysis of all bat species is necessary. Taxonomic data could be obtained from pre-existing research[19][24][25] as a baseline for future taxonomic and systematic inquiries.

Central Indian Highlands

This region represents a significant knowledge gap for our understanding of bats in India, and only one survey response for the Central Indian Highlands highlights the need for more focus on this region in future studies. The current threats impacting all bat species across the region include those classified within the Level 1 threats of "Residential & commercial development", "Energy production & mining", "Biological resource use", and "Pollution" (Appendix 5). Development of tourism and recreation areas as well as mining and quarrying activities were highlighted as the most influential on bat populations, with both threat types adversely affecting members of the Hipposideridae and Rhinolophidae (pers. obs., pers. comm. and unpublished data by T.A. Shah).

Durga Das's Leaf-nosed Bat (*Hipposideros durgadasi*).
Photo: Rajesh Puttaswamaiah

Coasts of India

Similar to the Central Indian Highlands, only one survey respondent provided a threats assessment for the coastal region of India. In order of their impact on regional bat populations (from most significant to least significant impact), the key Level 1 threats of the Coasts are: "Human intrusions & disturbance", "Natural system modifications", "Biological resource use", "Pollution", and "Climate change & severe weather". Within these threats, development of and disturbance from recreational activities such as tourism were noted as important current and future threats to bats in the families Emballonuridae, Hipposideridae, Megadermatidae, Miniopteridae, Pteropodidae, Rhinolophidae, and Vespertilionidae (pers. obs., pers. comm. and unpublished data by R. Prabhukhanolkar). Past, ongoing, and projected industrial, agricultural, air-borne, light, thermal and noise pollution were all reported to have wide-ranging detrimental impacts on bats throughout the coastal areas of India as well (pers. obs., pers. comm. and unpublished data by R. Prabhukhanolkar).

Eastern Ghats

The most significant Level 1 threats impacting all bat species within this region were reported as "Energy production & mining", "Human intrusions & disturbance", "Natural system modifications", "Residential & commercial development", and "Agriculture" (Appendix 5). Additional significant Level 1 threats include "Pollution", "Biological resource use", "Climate change & severe weather", and "Transportation & service corridors". The negative direct and indirect effects of tourism on bats was highlighted as an important conservation issue for the region, including stress from disturbance, light pollution, and the direct removal and deterrence of bat colonies from archaeological sites (e.g., temples, forts) in order to eliminate foul odours and excreta and to make them more "tourist-friendly"[3][26] (pers. obs., pers. comm. and unpublished data by B. Chattopadhyay, B. Murugavel, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu). Moreover, unchecked expansion of agro-industrial farming and residential and commercial development were projected to be major future threats to bats in the Eastern Ghats[26].

Himalayan biodiversity hotspot

When considering the Level 1 threats adversely affecting all bats in the Western Himalayan region, four survey respondents identified "Energy production & mining", "Transportation & service corridors", "Natural system modifications", "Human intrusions & disturbance", and "Climate change & severe weather" as the most significant threats (Appendix 5). Although not ranked among the top five Level 1 threats, "Residential & commercial development" and "Agriculture" were also recognised as important drivers of bat population declines in this biogeographic area.

For the Eastern Himalayas region, three survey participants determined "Energy production & mining", "Natural system modifications", "Agriculture", "Biological resource use", and "Human intrusions & disturbance" to be the most significant Level 1 threats for all bats in the region. The threats "Residential & commercial development" and "Climate change & severe weather" were also deemed significant in the Eastern Himalayas.

Based on these survey results, the online Himalayas Biodiversity Hotspot Threats Mapping workshop focused on the cause-and-effect relationships involved in the drivers and effects on bats related to the Levels 1 and 2 threats listed in Table 15.3. These threats were addressed in relation to all bat species in any area within the Western Himalayan, Eastern Himalayan, and/or Trans Himalayan biogeographic regions (Figure 15.1). The majority of discussion time was devoted to the threats "Energy production & mining", "Transportation & service corridors", and "Natural system modifications" with the key conclusions outlined below. More details are provided in the cause-and-effect linkages in Appendix 6.

Table 15.3 Level 1 and Level 2 threats discussed in relation to all bat species across the Himalayan Biodiversity Hotspot area. Definitions of threat levels and threats per the IUCN Threats Classification Scheme, version 3.3 (2022).

Level 1 Threats	Level 2 Threats
Energy production & mining	Mining & quarrying
	Renewable energy*
	Oil & gas drilling
Transportation & service corridors	Roads & railroads
	Utility & service lines
Natural system modifications	Fire & fire suppression
	Dams & water management/use
	Other ecosystem modifications
Human intrusions & disturbance	Recreational activities
	War, civil unrest & military exercises
Climate change & severe weather	Habitat shifting & alteration
	Droughts
	Temperature extremes
	Storms & flooding

*Evaluated as future threat only.

Energy Production & Mining. Local infrastructure development, particularly road construction, is driving sand mining and quarrying activities throughout the region. While abandoned mines may serve as roosting sites for some cave-dwelling bats, quarrying and other mine-related activities contribute to habitat loss for most bat species, especially in the Eastern Himalayas. In addition, land use changes associated with mining sites may impact the availability, accessibility, and quality of food items for bats. Concurrently, bats have to travel farther in search of roosting sites and food resources in degraded habitats, lowering their overall chances of survival. Although oil drilling in the Himalayas remains minimal, there are indications that such activities may increase in the future.

As renewable energy production (e.g., hydroelectricity, wind, and solar energy projects) expand, future sustainability goals must be carefully balanced with any unintended ecological consequences. For instance, blasting for dam construction will likely destroy and fragment important habitats, while also contributing to disturbance and associated health and reproductive risks. Dam-related changes to river hydrology are another concern, particularly in the Eastern Himalayas, where disturbances to riverine systems could impact water-dependent bats and their roosting sites[27]. Furthermore, large-scale damming projects have altered vegetation structure in many downstream areas, leading to habitat fragmentation and the spread of invasive species, which likely reduces overall resource availability for bats[28].

Transportation & Service Corridors. Construction of new roads and the widening of existing road networks were identified as an important contributor to bat habitat fragmentation in the Himalayan region. Geopolitical factors motivate much of this infrastructure development, such as road construction in the Eastern Himalayas for national security purposes. Enhanced connectivity from improved road networks boosts tourism, especially religious tourism, and increases the accessibility to caves, such as the Bumzuva Cave in Kashmir. Elevated visitation to cave sites could disrupt bats with population-level consequences[29][30].

The removal of roadside trees for highway expansion contributes to the loss of roosting and foraging habitat. Industrial development and hydropower projects are booming in the Himalayas and accelerating habitat degradation related to the utility and service lines as well as road construction supporting these projects. The cumulative effects of infrastructure development emphasise the need for a balanced approach that takes into account both conservation and development priorities in the Himalayas.

Natural System Modifications. Natural system modifications in the Himalayas are driven by the region's natural wealth, increasing demand for energy, tourism, and national security concerns, particularly regarding domestic insurgency. Hydropower projects have submerged vast stretches of forests, resulting in a loss of bat foraging and roosting habitats. Rising water demand for both household consumption and to support tourism activities has led to river system diversions with unknown impacts on bats and their population health. Climate change is emerging as one of the major drivers for changes to water management and the frequency and intensity of forest fires.

Forest fires, whether natural or intentional, can lead to bat mortality and the loss of foraging habitat. In agricultural areas where grasslands dominate, villagers often set fires to renew bamboo patches or to grow fresh grass for fodder, a common practice among pastoralists in North Bengal. While fires drive insects into the open, likely providing short-term feeding opportunities for bats, they ultimately disrupt the ecosystem. In the Western Himalayas, forest fires are a recurring issue, with pine forests being particularly susceptible.

In Jammu and Kashmir, agricultural landscapes have shifted significantly. Where rice paddies were traditionally cultivated, the land is now being replaced by horticulture (e.g., apple orchards). This land use shift has resulted in increased pesticide use, which may negatively impact insectivorous bats through direct and indirect exposure to contaminants and/or loss of insect prey. The widespread conversion of traditional kutcha houses to concrete structures has significantly reduced available roosting habitats for several bat species.

Knowledge Gaps. Workshop participants emphasised the high degree of uncertainty attendant to these threats, their causes, and their impact on bats in the region. Some of the key threat-relevant knowledge gaps that were discussed in the session included:

- **Baseline research on bats.** Most of the Himalayan region remains largely unsampled for bats, especially areas above 3500 metres. Consequently, major knowledge gaps persist regarding bat species' distribution in the region, habitat use, and other basic information related to bat biology and ecology.
- **Impact of various threats on bats.** There has been minimal to no documentation and/or mapping of potential hazards and their effects on bats in the region. Poorly regulated hydroelectric power projects, linear infrastructure development, and high-intensity tourism put pressure on the natural resources on which bats depend. Further study is needed to understand the long-term consequences of such developments on bat individuals, populations, and species. Attendees recommended that species with limited data available in India (e.g., *Cnephaeus tatei, Otonycteris leucophaea, Plecotus homochrous, Myotis longipes, Myotis himalaicus, Murina tubinaris,* and *Harpiola grisea*) be prioritised in any future research initiatives.

- **Prevention and mitigation options.** Even in the case of threats for which we understand the negative consequences on bats, there is a paucity of information related to effective means for preventing, mitigating, and/or eliminating the adverse effects of these threats. For instance, the electrocution of flying foxes remains a nationwide challenge. More study is needed on effective mitigation strategies and their effects on morbidity and mortality. Some promising initiatives include converting to underground rather than overhead powerlines or insulating overhead powerlines in areas with high risk of electrocution for flying foxes. Another example comes from the risk of vehicular strikes to bats attracted to the insect prey that gathers under streetlights. In some scenarios, modifying these streetlights (e.g., using smaller and more condensed highway lights or reducing the warm light spectrum) could serve as another mitigation approach. In all cases, application-based studies are crucial for understanding these techniques' feasibility and real-world impact.

Lakshadweep

The most significant Level 1 threats to bats on these islands were determined to be "Human intrusions & disturbance", "Climate change & severe weather", and "Natural system modifications", followed by "Residential & commercial development", "Energy production & mining", and "Biological resource use" (pers. obs., pers. comm. and unpublished data by R. Puttaswamaiah & S. Raman). Tourism was the only current threat indicated to have negative effects on bats with the most significant impact borne by Molossidae, and Vespertilionidae (pers. obs., pers. comm. and unpublished data by R. Puttaswamaiah & S. Raman).

Northeast Indian biodiversity hotspot

Five survey respondents delineated the threats listed in Table 15.4 as the most significant factors affecting all bats in the region (Appendix 5). In following, the online Northeast Biodiversity Hotspot Threats Mapping workshop evaluated these threats' negative effect on bats and their primary causes. Some of the main discussion points for each of these factors are reviewed below, while a more comprehensive description of the causal relationships between drivers, threats, and their effects on bats are illustrated in Appendix 6.

Table 15.4 Level 1, Level 2, and Level 3 threats discussed in relation to all bat species across the Northeast Biodiversity Hotspot area. Definitions of threat levels and threats per the IUCN Threats Classification Scheme, version 3.3 (2022).

Level 1 Threats	Level 2 Threats	Level 3 Threats
Natural system modifications	Fire & fire suppression*	
	Dams & water management/use	
	Other ecosystem modifications	
Residential & commercial development	Housing & urban areas	
	Commercial & industrial areas	
	Tourism & recreation areas	
Energy production & mining	Mining & quarrying	
	Oil & gas drilling	
Agriculture	Annual & Perennial Non-Timber Crops	Small-holder Farming
		Agro-industry Farming
	Wood & Pulp Plantations	Small-holder Plantations
		Agro-industry Plantations
	Livestock Farming & Ranching	
Human intrusions & disturbance	Recreational activities	
	War, civil unrest & military exercises	
Biological resource use	Hunting & collecting terrestrial animals	Intentional use (species being assessed is the target)
		Persecution/control
	Fishing & harvesting aquatic resources	Unintentional effects: subsistence/small scale (species being assessed is not the target) [harvest]

*Assessed as "Jhum cultivation" under "Small-holder farming" in "Agriculture" category.

Residential & Commercial Development. Unplanned urban development in Northeast India has resulted in the depletion of water sources as well as extensive bat habitat loss and fragmentation. Roosting habitat loss was highlighted as a significant risk from this type of habitat degradation. As urban sprawl expands, large-scale tree-felling even within protected areas can lead to the extirpation of sizeable bat colonies. For example, one participant recalled a case in Dulalgram, South Assam, where a colony of over one thousand *Pteropus medius* roosted on disputed land within a 100-metre buffer area around the Rukmini River. In 2019, despite the Forest Department's intervention, land conversion including tree removal caused the colony to fragment and then completely abandon the site. Bat roosting sites are also compromised when villages are modernized. Between 2017 and 2018 in Assam's Baksa district, various bat species were observed roosting in household garden trees, thatched kutcha huts, and the bamboo poles of traditionally-constructed buildings. Several years later, many of these roosting bat species were reported as absent from the area as were these historic roosting spots, which disappeared along with the removal of trees and traditional structures. Furthermore, urban encroachment along riverbanks, the filling of wetlands for construction, garbage deposited in or near water sources, and insufficient planning of green spaces within development projects predominantly threaten bats that depend directly or indirectly on wetlands and riverine habitats.


A hunted flying fox in the Andaman Islands. Photo: Rohit Chakravarty

Energy Production & Mining. The rapid expansion of energy production and mining activities in Northeast India presents a significant threat to bat diversity in this region. Sand mining contributes to overall habitat degradation, loss of roosting sites, and disruptions in food availability for bats. The use of dynamite in mining operations most likely causes direct mortality to bats as well as stress and disturbance with a host of indirect effects to the health and reproductive success of bat populations. Any pollution from oil spills and coal mine tailings can not only pollute water sources but also result in direct bat mortality and morbidity, habitat loss, and reduction in the quality and quantity of prey (Chapter 9). In regions like Assam and Meghalaya, where limestone karsts serve as critical habitat for numerous cave-dwelling species, extraction of minerals likely leads to substantial habitat destruction, which is exacerbated by the construction of linear infrastructure to support these projects.

Biological Resource Use. In many places across Northeast India, bats are hunted not only for subsistence but also for medicinal, socio-cultural, and recreational purposes. Traditional practices connected with bat hunting and consumption vary widely within the region. For example, in Nagaland, tribal members block cave entrances and light fires to smoke out large numbers of cave-roosting bats. Only men participate in this ritual, and some families have maintained this ritual for over seven generations. The limestone caves, typically whitish, turn black from the smoke built up over years of mass bat culling. In contrast, in West Siang district in Arunachal Pradesh, ritualistic mass hunting of bats is only performed by women, with some families adhering to this tradition for over nine generations. Historically, up to 50,000 bats could be killed in a single cave-bat-hunting event. More recently, local community members have observed a steep decline in the population numbers of these cave bats. Hunters now report capturing only 5,000-7,500 individuals during an average hunting event.

On a more hopeful note, in some villages, particularly in Nagaland and Arunachal Pradesh, community conserved areas help protect bats from hunting. With increased acceptance of Western medicine, local community members have also appeared to reduce their usage of bat meat as traditional medicine.

The unintended consequences of fishing can also threaten bats in the region, though the degree to which these incidents impact bat populations is unknown. Rickett's Big-footed Myotis (*Myotis pilosus*), an occasional piscivore, was reportedly impacted by the poisoning of a river that flowed through its roosting habitat within a cave system. Fishermen intoxicated river fish in order to facilitate easier fish harvests, but the subsequent secondary poisoning of bats from ingesting contaminated water and/or fish likely resulted in at least morbidity, if not mortality, among the area's resident bats.

Agriculture. Extensive and excessive use of pesticides in agricultural areas can lead to the accumulation of these toxicants in bats, reducing their overall survival rate. There is very little published data from the region on the effects of pesticides on bats, but it is highly likely that insectivorous bats accumulate pesticides through biomagnification via their insect prey, while frugivorous bats are exposed more directly while foraging. Pesticide use varies from state to state: in Assam, the use of pesticides is high in tea plantations, whereas farming in Arunachal Pradesh is largely pesticide-free.

Agricultural land-use changes, such as the growth of palm oil plantations in Assam, Nagaland, and Mizoram and the establishment of tea and coffee monocultures throughout the region, are predicted to reduce bat diversity overall. Clearing of land for agricultural production can also result in key foraging and roosting habitat loss. Around Siju Cave in Meghalaya, betel nut and rubber plantations are likely responsible for a reduction in foraging sites for local bats. Cardamom plantations result in forest clearance, posing a future threat in particular to the bats of Arunachal Pradesh and Nagaland.

Knowledge Gaps. Attendant to all of these workshop discussions was the recognition of the imposing dearth of knowledge related to the threats affecting bats in Northeast India. Among the most notable knowledge gaps acknowledged by the participants were:

- **Geographic gaps.** Among the seven sister states in Northeast India, Tripura has received the least attention with respect to wildlife conservation. The region's bat biodiversity remains unexplored, with critical gaps in understanding species' distribution in the state. A comprehensive bat species inventory is lacking for Northeast India despite the fact that the region lies in the intersection of two biodiversity hotspots.
- **Understanding effects of threats on bats.** The impact of different agricultural land use practices (e.g., jhum cultivation, palm oil plantations, monoculture production) on bat diversity and populations is an area that requires further investigation. Similarly, the consequences to bats and their populations connected to the development of industrial areas (e.g., those outside Assam) remain largely unstudied. Dams, such as Khuga Dam in Churachandpur district in Manipur, could potentially threaten bat populations. Whether seasonal submergence and other habitat alterations resulting from dam-related water management have any effect on bats needs to be determined. In addition, there is limited research on how bat populations adapt to mining-related disturbances, and a significant knowledge gap on any subsequent long-term effects on bat welfare. Systematic and long-term studies on environmental and anthropogenic threats are urgently needed. An improved understanding of bats' behavioural and physiological adaptations to disturbed habitats will provide valuable insights for conservation planning.
- **Human Dimensions of bats and their management.** The role of bats in the provision of ecosystem services requires further study. The limits of our understanding of the benefits of bats for the people of Northeast India limits our ability to effectively devise behaviour change campaigns to promote human–bat coexistence in the region. Correspondingly, a bat perception study among local communities could help guide public awareness and planning efforts to support bat conservation.

Northwest Arid Region

Among the most significant Level 1 threats impacting bats in the region identified in the survey were "Residential & commercial development", "Energy production & mining", "Climate change & severe weather", and "Human intrusions & development". "Biological resource use" and "Transportation & service corridors" were also identified as significant threats to all bat species in the Northwest Arid region. Within "Residential & Commercial development", adverse effects related to the development of "Housing & urban areas" as well as "Tourism & recreation areas" were reported to have widespread consequences for species within all bat families represented in the region (Appendix 5). Direct damage to bat roosting and breeding habitats results from unsustainable tourism, vandalism, and renovation of archaeological sites for tourism purposes[31] (pers. obs., pers. comm. and unpublished data by R. Mohan, T.A. Shah & C. Srinivasulu). In addition, light and noise pollution in tourist and urban areas alter bat activity and emergence behaviours, while air and freshwater pollution compromise the health of northwestern bat individuals and populations[31][32](pers. obs., pers. comm. and unpublished data by R. Mohan, T.A. Shah & C. Srinivasulu). Multiple threats to *Pteropus medius* (Indian Flying Foxes) were specifically reported for the region, including targeted killing related to fear and negative attitudes towards bats in general, heat waves attendant to climate change, subsistence hunting, and electrical powerline electrocutions[33][34][35] (pers. obs., pers. comm. and unpublished data by R. Mohan, T.A. Shah & C. Srinivasulu).

Peninsular India (Deccan Plateau)

Survey participants deemed the following Level 1 threats the most important for all bat species: "Residential & commercial development", "Energy production & mining", "Natural system modifications", "Human intrusions & disturbance", and "Transportation & service corridors". "Agriculture", "Biological resource use", "Pollution", and "Climate change & severe weather" were also noted as significant threats to bats throughout the Deccan Plateau (Appendix 5). More specifically, highway construction, mining of granite and coal, and urban expansion cause not only direct effects (e.g., direct morbidity and mortality, disturbance) on bats in the region but also indirect effects through habitat destruction, thermal and light pollution, and biodiversity loss[26][36][37][38][39] (pers. obs., pers. comm. and unpublished data by B.R. Ansil, R. Chakravarty, Shraddha Kumari K., R. Puttaswamaiah, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu). Tourism to caves, temples, and Archaeological Survey of India (ASI) properties further threatens bat populations through intentional and unintentional disturbance and harassment of cave-dwelling species as well as habitat destruction[26][37] (pers. obs., pers. comm. and unpublished data by B.R. Ansil, R. Chakravarty, Shraddha Kumari K., R. Puttaswamaiah, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu). Flying foxes experience additional mortality and morbidity from electrocution on electrical utility lines, heat stress, subsistence hunting, and persecution in fruit orchards[37](pers. obs., pers. comm. and unpublished data by B.R. Ansil, R. Chakravarty, Shraddha Kumari K., R. Puttaswamaiah, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

Western Ghats biodiversity hotspot

Of the many threats facing bat species across this biogeographic region, survey respondents noted the following Level 1 threats as the most impactful: "Human intrusions & disturbance," "Residential & commercial development," "Natural system modifications," "Energy production & mining," "Transportation & service corridors," "Agriculture," and "Biological resource use." In addition, "Pollution," "Diseases impacting bats," and "Climate change & severe weather" were recognised as key threats to bats in the Western Ghats (Appendix 5). In accordance with these results, the Level 1 and 2 threats in Table 15.5 were the focus of the Western Ghats Biodiversity Hotspot Threats Mapping online workshop.

Table 15.5 Level 1 and Level 2 threats discussed in relation to all bat species across the Western Ghats Biodiversity Hotspot area. Definitions of threat levels and threats per the IUCN Threats Classification Scheme, version 3.3 (2022).

Level 1 Threats	Level 2 Threats
Residential & commercial development	Housing & urban areas
	Commercial & industrial areas*
	Tourism & recreation areas
Energy production & mining	Mining & quarrying
	Renewable energy
Natural system modifications	Fire & fire suppression
	Dams & water management/use
	Other ecosystem modifications
Human intrusions & disturbance	Recreational activities
Transportation & service corridors	Roads & railroads
	Utility & service lines

*The Level 3 threats of "Agro-industry Farming" and "Agro-industry Plantations" (nested within the Level 1 threat "Agriculture" by the IUCN[5]) were partly assessed within this category.

Of the multiple Level 1 threats detrimentally affecting bats in this region, participants in the online threats assessment workshop considered "Residential & commercial development", "Energy production & mining", and "Natural system modifications" to be the most significant. Interconnections among these threats, their causes, and their effects on bats are described in Appendix 6, while summaries of some key topics addressed during the online workshop are noted below.

Residential & Commercial Development. The expansion of tourism, residential and commercial areas, and industrial development across the region poses a significant threat to bat habitats. Linear infrastructure projects, such as the upcoming six-lane Kasargod to Trivandrum highway project, has resulted in the removal of numerous *Pteropus medius* roosting trees. Expansion of railway networks through the pristine forests of the Western Ghats has caused extensive habitat fragmentation, while light pollution in cities, along highways, and within tourism-adapted cave complexes can deter bats from using their traditional roosting habitats[3][40]. The government's promotion of tourism drives the renovation of archaeological structures to be more tourist-friendly and increases tourism to cave sites, which can cause not only the direct mortality and extirpation of bats but also the loss of key roosting, breeding, and foraging sites, as well as excessive disturbance and stress to affected bats.

Fruit bats in particular face severe challenges due to habitat loss, requiring them to travel longer distances in search of food, which likely induces severe physiological stress and can increase their exposure and susceptibility to disease-causing pathogens. In Tamil Nadu and Kerala, fruit bats (e.g., *Cynopterus sphinx*) have been observed feeding in fruit shops and scavenging on fruits dropped by macaques[41], elevating the risk of human-wildlife interactions and the potential for zoonotic disease transmission (Chapter 8).

Although typically evaluated under the Level 1 threat of "Agriculture & aquaculture", commercial plantations and farming were assessed by participants in relation to the development of "commercial and industrial areas" during this workshop. Bat habitat loss and degradation were attributed to tree-felling and the complete conversion of landscapes associated with the commercial production of monocultures, such as tea and coffee. Participants underlined the example of the loss of the Pomona Leaf-nosed Bat (*Hipposideros pomona*) from its type locality in Mysore, which is now blanketed with commercial plantations. Exacerbating these direct habitat effects, the use of artificial lights and pesticides by plantations decreases prey diversity, which is expected to reduce the foraging efficiency of bats across the agricultural regions.

Energy Production & Mining. Increased demand for steel and other building materials has driven the growth of mining and the subsequent loss of bat habitats and disturbance to bats in the surrounding areas, most markedly in the foothills and coastal areas of Kerala. Such disturbances can cause stress-related immunocompromise in affected bats as well as displacement of individuals and populations, both of which have been linked to increased susceptibility and exposure to disease-causing pathogens (Chapter 8).

Energy production likely contributes to direct and indirect bat mortality and morbidity as well. Bat mortality resulting from wind farms has been well-documented in other regions worldwide, while high-tension power lines have been associated with electrocutions of *P. medius*. Accordingly, concerns were raised around several high-tension powerline electricity projects that are planned for forested areas in Kerala, which are likely to impact not only bats but also other wildlife.

Natural System Modifications. Most dams in the Western Ghats are constructed for residential use, agricultural irrigation, and hydropower. In some parts of Karnataka and Tamil Nadu, traditional bat roosting sites have been completely submerged by dam construction, including a roost occupied by Kelaart's Leaf-nosed Bats (*Hipposideros lankadiva*) in their type locality within Shivamogga district, Karnataka.

Although the sources of the majority of forest fires (i.e., natural or anthropogenic) in the region remain uninvestigated and/or unknown, fires may impact the roosting sites of local bat species to variable degrees based on their frequency and intensity. Slash and burn practices remain a major issue throughout the Western Ghats. Although the Forest Department in Annamalai has halted this agricultural practice, some hospitality professionals illegally set fires to attract wildlife and enhance tourist experiences. This could potentially lead to wildfires in and outside of protected areas. Moreover, forest fringe communities in Kerala sometimes set fires due to conflicts with Forest Department authorities and/or to claim compensation. Participants also reported that, in Tamil Nadu, garbage burning in urban and peri-urban roost sites disturbs flying foxes, forcing them to shift their roosting habitats at least temporarily.

Knowledge Gaps. Workshop participants discussed numerous knowledge gaps associated with our understanding of threats to all bats throughout the Western Ghats. Among these research priorities are:

- **Baseline research on bats.** Bat diversity in Northern Western Ghats, especially north of Pune, remains understudied. In addition, understanding population trends within colonies is crucial, especially in Kerala, where frequent Nipah outbreaks highlight the need for research on bat population dynamics and disease ecology in concert with one another. Amidst rapid land use changes, the effectiveness of protected areas in maintaining bat populations remains unclear and requires further research as well. Overall, there is a limited understanding on bat species' behaviours, morphological adaptations, and conspecific interactions. Mapping functional diversity and species composition, particularly in relation to ecosystem services, should be an area of further research. In particular, studies on insectivorous bat diets and habitat use are lacking, though this information is necessary to understand the role of bats in crop pest control and agricultural productivity.
- **Understanding effects of threats on bats.** Describing and quantifying threats to bats across the Western Ghats was discussed as a research priority. For example, the impact of forest fires, water management schemes, and solar energy development on bats, their habitat use, and their movement ecology are largely unknown and unexplored. Amidst the large-scale changes in land use across this biogeographic region, investigations into the adaptability of different bat species under varying contexts are urgently needed.
- **Human Dimensions of bats and their management.** Awareness about bat species and their roosting sites was estimated to be relatively low among the general public of the Western Ghats. Participants indicated that, at this stage, documenting people's attitudes towards bats and planning policy interventions are priorities for bat conservation in the region. Understanding species' resilience to humans and the adaptability of humans to bats in local communities was recommended as an interesting topic for future research. A local tradition of collecting sap from toddy palms (*Borassus flabellifer*) poses a drowning risk for bats, such as the endangered Salim Ali's Fruit Bat (*Latidens salimalii*), which frequently fall into and are unable to escape plastic buckets used to accumulate the liquid. Application-driven research into possible prevention and mitigation strategies for addressing bats' drowning in these sap extraction buckets was discussed at length by participants. Emphasis was placed on the importance of involving community members in this and other bat-related conservation work.

Threats to Bats by Species

Data Deficient species

The current IUCN Red List of Threatened Species recognises seven bat species that are endemic to India as "Data Deficient": *Cnephaeus* (formerly *Eptesicus*) *tatei*[5], *Harpiola grisea*[6], *Hipposideros khasiana*[7], *Murina pluvialis*[8], *Myotis peytoni*[9], *Rhinolophus indorouxii*[10], and *Rhinolophus mitratus*[11]. Seven experts contributed information to assist in expanding our understanding of threats to these poorly known species at the individual-, population-, and/or species-level (either directly or in combination with other threats). These survey data are especially instructive in the case of *C. tatei, H. khasiana*, and *R. mitratus* for which threats are undescribed in their current assessments on the IUCN Red List of Threatened Species[5][7][11].

***Cnephaeus tatei* (Sombre Bat).** The species is located near human habitations and tourist towns in Uttarakhand, and its type locality in Darjeeling is undergoing extensive tourist and residential development. Consequently, the Level 1 threat of "Residential & commercial development" was indicated as a significant risk to the species in addition to "Agro-industry farming" and "Mining & quarrying" (pers. obs., pers. comm. and unpublished data by R. Chakravarty). Threats associated with the infrastructure supporting this expansion of development, "Roads & railroads" and "Utility & service lines", were noted to have further adverse impacts on the species. Future threats to *C. tatei* are predicted to include anthropogenetic climate change based on their habitation of mid-to-high-elevations in the Himalayas (pers. obs., pers. comm. and unpublished data by R. Chakravarty). In addition, their site locality adjacent to the Char Dham High Expansion project may put the species at risk from any future dam construction and its direct and indirect ecological consequences (pers. obs., pers. comm. and unpublished data by R. Chakravarty) (Appendix 5).

***Harpiola grisea* (Peters's Tube-nosed Bat).** Similar to *C. tatei*, this species faces significant threats associated with the expansion of commercial, residential, and tourism development, particularly in Uttarakhand (pers. obs., pers. comm. and unpublished data by R. Chakravarty) (Appendix 5). "Agro-industry farming" was a key threat identified by the survey participant but not described in the current Red List assessment for *H. grisea*.

Small-scale mining in the species' type locality in Jharipani likely had detrimental effects on *H. grisea* in the past, while the bats' use of mid-to-high-elevation habitats in the Himalayas puts them at risk for adverse effects of climate change in the future (pers. obs., pers. comm. and unpublished data by R. Chakravarty).

***Hipposideros khasiana* (Khasian Leaf-nosed Bat).** In addition to persecution-fueled hunting of the species, "Mining & Quarrying" was considered a significant threat to *H. khasiana* (Appendix 5). Limestone mining is rampant throughout the Khasi Hills region, so many cave-dwelling bat species, including *H. khasiana*, are likely to be adversely affected by mining activities (pers. obs., pers. comm. and unpublished data by R. Chakravarty & U. Saikia).

***Murina pluvialis* (Rainforest Tube-nosed Bat).** Consistent with the species' IUCN Red List assessment, the survey participant identified "Mining & quarrying" as a significant threat to *M. pluvialis* (pers. obs., pers. comm. and unpublished data by R. Chakravarty). "Roads & railroads" and "Utility & service lines" were also reported as Level 2 threats of importance for *M. pluvialis* (pers. obs., pers. comm. and unpublished data by R. Chakravarty) (Appendix 5).

***Myotis peytoni* (Peyton's Whiskered Myotis).** Survey participants addressed a number of significant threats to *Myotis peytoni*, confirming the threat of human intrusion and disturbance from recreational activities as recorded in the species current Red List assessment[9] (pers. obs., pers. comm. and unpublished data by R. Chakravarty & S. Raman). The key threats identified by respondents were related to burgeoning development across the species' endemic range ("Residential & commercial development," "Roads & railroads," "Utility & service lines"), resource extraction ("Mining & quarrying"), targeted hunting of the species ("Hunting & collecting terrestrial animals: Intentional use"), proliferation of pollution ("Agricultural & forestry pollution," "Noise pollution"), and environmental risks, both natural ("Avalanches/landslides") and anthropogenically-driven ("Climate change & severe weather") (pers. obs., pers. comm. and unpublished data by R. Chakravarty & S. Raman) (Appendix 5).

***Rhinolophus indorouxii*.** *Rhinolophus indorouxii* inhabits human-dominated and forested areas in the Western Ghats and southern Eastern Ghats. The species' habitats are being destroyed by various factors, including the modification of buildings traditionally used for roosting, construction of water canals, and blasting of tunnels (pers. obs., pers. comm. and unpublished data by B. Chattopadhyay, N. Divakar, R. Puttaswamaiah & S. Raman) (Appendix 5). Tourism, especially in the high-ranges of Kerala (Wayanad), has caused large-scale land use changes and smaller-scale alterations (e.g., converting caves into tourist rooms) to *R. indorouxii*'s critical habitats (pers. obs., pers. comm. and unpublished data by B. Chattopadhyay, N. Divakar, R. Puttaswamaiah & S. Raman). It was noted that regular day trips, with an estimated 1,500 visitors per day, to sites like Edakkal Caves and other caves in Kannur further disturb these habitats and the bats that rely on them (pers. obs., pers. comm. and unpublished data by B. Chattopadhyay, N. Divakar, R. Puttaswamaiah & S. Raman). In the future, it is highly likely that the state government's Anakkampoyil-Kalladi Meppadi Tunnel Road project will pose a significant threat to all bats within this landscape, including *R. indorouxii* (pers. obs., pers. comm. and unpublished data by B. Chattopadhyay, N. Divakar, R. Puttaswamaiah & S. Raman) (Appendix 5).

***Rhinolophus mitratus* (Mitred Horseshoe Bat).** Light pollution and the expansion of housing and urban areas were identified as significant threats to *R. mitratus* (pers. obs., pers. comm. and unpublished data by A. Srinivasulu) (Appendix 5). The species was first described from Chaibasa when the town was much less developed than it is today. It was hypothesised that the city's expansion and the accompanying loss of green space may have led to the subsequent extirpation of *R. mitratus* from the area (pers. obs., pers. comm. and unpublished data by A. Srinivasulu).

Threatened species

The IUCN Red List of Threatened Species classifies species as "threatened" if they are assessed within the categories of "Critically Endangered", "Endangered", or "Vulnerable". Currently, seven bat species endemic to India are considered threatened under the IUCN Red List: *Hipposideros durgadasi*[12], *Hipposideros hypophyllus*[18], *Hipposideros nicobarulae*[13], *Hipposideros pomona*[14], *Latidens salimalii*[15], *Pteropus faunulus*[16], and *Rhinolophus cognatus*[17]. All of these threatened species were evaluated by at least one of 11 participants in the Threats Mapping survey, who selected any threat that they judged has a significant adverse effect at the individual-, population-, and/or species-level (either directly or in combination with other threats) for each species (Appendix 5). In addition, causal flow diagrams for the threats impacting *R. cognatus, P. faunulus,* and *H. nicobarulae* and *H. hypophyllus, H. pomona*, and *L. salimalii* were drafted during the virtual Biodiversity Hotspot Threats Mapping workshops for the Andaman and Nicobar Islands and for the Western Ghats, respectively (Appendix 7). Below is a summary of the key species-specific results and discussions from these structured assessments.

‹VU› ***Hipposideros durgadasi*** **(Durga Das's Leaf-nosed Bat).** Multiple threats related to burgeoning urbanisation and development, hunting, resource extraction, and agriculture were reported to detrimentally affect the species (Appendix 5, Appendix 7). Granite mining and hunting related to persecution were highlighted as key risks to *H. durgadasi* in Kolar, while former locations of the species adjacent to Jabalpur in 2013 have subsequently been engulfed by the city's expansion (pers. obs., pers. comm. and unpublished data by B.R. Ansil, R. Chakravarty, Shraddha Kumari K., R. Puttaswamaiah, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu). One expert described the felling of large trees in privately-held agricultural fields as a loss that is predicted to reduce the species' foraging habitats and potentially expose the bats to increased predation.

‹CR› ***Hipposideros hypophyllus*** **(Kolar Leaf-nosed Bat).** Although the roosting site of the species in Hanumanahalli Village has been officially protected since 2019, *H. hypophyllus* are confined to a single cave of the original three caves in which they were initially discovered. Mining is now legally prohibited within three km^2 of the protected area; however, workshop attendees noted that the accessibility resulting from previous quarrying activities has increased vehicular traffic and illegal intrusion into these cave systems, which disturb *H. hypophyllus* and likely elevates their risk of exposure to disease-causing pathogens (Appendix 5, Appendix 7). Exacerbating these risks could be the increased visitations to the roosting colony by researchers themselves, whose interest in the species has grown since the COVID-19 pandemic. Survey and workshop participants raised concerns about foraging habitat loss from tree removal on private agricultural land and from the Forest Department's misguided afforestation efforts that lack research-based planning (pers. obs., pers. comm. and unpublished data by B.R. Ansil, R. Chakravarty, Shraddha Kumari K., R. Puttaswamaiah, T.A. Shah, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

‹EN› ***Hipposideros nicobarulae*** **(Nicobar Leaf-nosed Bat).** In addition to persecution-driven hunting and disturbance from military exercises in the surrounding area, the primary threats to the species that were discussed are associated with the growth of tourism, expansion of commercial development, and impact of anthropogenic climate change on the archipelago (Appendix 5, Appendix 7). A serious concern was raised pertaining to future cave tourism, which is anticipated to destroy cave habitats, increase disturbance to bat colonies, and potentially elevate disease transmission risks as a result of increased human visitation, walkway construction, and artificial light installation inside vulnerable cave complexes[30] (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu). These effects are projected to be aggravated by the detrimental impact of climate change-induced rising temperatures, of particular risk to cave-dwelling bats (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu).

‹EN› ***Hipposideros pomona*** **(Pomona Leaf-nosed Bat).** The species is reportedly impacted by numerous threats ranging from those related to human encroachment on their critical habitats, hunting, and various forms of pollution to natural geological events and anthropogenic climate change (Appendix 5). Workshop participants identified forest loss and fragmentation as the primary threat causing population declines in *H. pomona* (pers. obs., pers. comm. and unpublished data by N. Divakar, Shraddha Kumari K., B. Murugavel, S. Raman, K. Saha, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu) (Appendix 7). Nevertheless, attendees revealed the potential for the species' adaptability and resilience in areas where forests are adjacent to certain types of agricultural plantations. A population of *H. pomona* once recorded in Coorg's coffee plantation (the species' type locality) is no longer present at this site; however, in Wayanad, *H. pomona* is found both in coffee and cardamom plantations. Interestingly, despite heavy usage of fertilisers and pesticides in Kerala's cardamom plantations, the species continues to utilise this landscape. It was hypothesised that the greater structural diversity of coffee plantations may make these agricultural habitats more attractive to *H. pomona* than less structurally-complicated monocultures, such as tea plantations (pers. obs., pers. comm. and unpublished data by N. Divakar, Shraddha Kumari K., B. Murugavel, R. Puttaswamaiah, S. Raman, K. Saha, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

‹EN› ***Latidens salimalii* (Salim Ali's Fruit Bat).** Since the majority of reported roosting sites and records of *L. salimalii* are interspersed with evergreen forest patches and plantations (from 350 m to 1400 m), human–bat interactions are moderate to high. Indigenous communities hunt this species for protein and medicine, occasionally for recreation alone[1] (pers. obs., pers. comm. and unpublished data by R. Chakravarty, B. Chattopadhyay, N. Divakar, R. Puttaswamaiah & S. Raman). However, in Kerala, though hunting persists during the monsoon season, it was not identified as a major driver of population decline. The local Indigenous community could reportedly distinguish between Leschenault's Rousette (*Rousettus leschenaultii*) and *L. salimalii*, recognise *L. salimalii* as a rarer species, and, therefore, practice sustainable hunting by preferentially targeting *R. leschenaultii* and only hunting during the monsoon season when there is a surge of individuals in the known roost sites (pers. obs., pers. comm. and unpublished data by R. Chakravarty, B. Chattopadhyay, N. Divakar, Shraddha Kumari K., B. Murugavel, R. Puttaswamaiah, S. Raman, K. Saha, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

Despite all known roosting locations occurring within or in the vicinity of protected areas, *L. salimalii* faces indirect impacts from local palm cultivation within Kerala's forested lands. Under the government's toddy palm collection process, hamlets of 20-25 palm trees are monitored and harvested by tribal communities for their sap. There have been multiple incidents of *L. salimalii* drowned in toddy sap collection pots (pers. obs., pers. comm. and unpublished data by R. Chakravarty, B. Chattopadhyay, N. Divakar, Shraddha Kumari K., B. Murugavel, R. Puttaswamaiah, S. Raman, K. Saha, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

At the landscape level, government-promoted tourism activities and plantation developments are driving large-scale land use changes and the loss of critical habitats for this species[1] (Appendix 5). Outside of the protected area, the state government has approved the construction of a 8.75 km tunnel for a road through the Anakkampoyil-Kalladi (Wayanad) region, which will significantly disrupt the landscape and likely further fragment key habitats used by *L. salimalii*[42] (pers. obs., pers. comm. and unpublished data by R. Chakravarty, B. Chattopadhyay, N. Divakar, Shraddha Kumari K., B. Murugavel, R. Puttaswamaiah, S. Raman, K. Saha, A. Srinivasulu, B. Srinivasulu & C. Srinivasulu).

‹EN› ***Pteropus faunulus* (Nicobar Flying Fox).** Endemic to the central Nicobar Islands, the species faces more hunting pressure than either *R. cognatus* or *H. nicobarulae* and are frequently hunted as a cheap source of protein. This hunting, combined with habitat destruction from national security activities and tsunamis, places the species at high risk of extirpation and/or extinction (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu) (Appendix 5). Future linear infrastructure projects are expected to result in the removal of large trees, further impacting important roosting and foraging sites for the species. Climate change is also predicted to negatively impact *P. faunulus*, such as through hyperthermia driven by warming temperatures or habitat loss from drastic changes to ecosystems across the archipelago (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu).

‹EN› ***Rhinolophus cognatus* (Andaman Horseshoe Bat).** This species' threat evaluation was particularly informative as the most recent IUCN Red List assessment for the *R. cognatus* defines threats to the species as "poorly known" and limited to disturbance from the illegal collection of edible-nest swiftlets' (*Aerodramus fuciphagus*) nests in their shared cave habitats[17]. The collection of these nests is currently better regulated and, so, was considered predominantly a threat of the past (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu). However, the growth of cave tourism, especially on Baratang Island, was identified as a significant emerging threat to *R. cognatus* (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu). Concurrently, temperature changes associated with climate change are projected to detrimentally impact all cave-dwelling bats in the region, including *R. cognatus*. Tsunamis, road construction, and disturbance from military exercises were also identified as significant current and/or future threats for the species (pers. obs., pers. comm. and unpublished data by R. Chakravarty, D. Kawalkar, Manchi Shirish S., B. Srinivasulu & C. Srinivasulu) (Appendix 5).

Conclusion

Several overarching patterns emerge in reviewing the results of this threat assessment for the bats of India:

The primary threats affecting all bat species in India are anthropogenic in origin, though natural geologic events pose significant risks to bats in several regions of high biodiversity.

Based on these expert assessments nationwide (except the Terai area), the most significant threats impacting bats (in general and more specifically at the family and species levels) were related to unchecked and poorly-planned urbanisation and development, disturbance from national security and recreational activities, resource extraction and energy production, shifts in fire and water management, various forms of pollution, and targeted hunting. Exacerbating these adverse effects, anthropogenic climate change-induced changes to future weather patterns and events, temperature fluctuations, sea level rise, and precipitation extremes are all predicted to threaten bats directly and indirectly through physiological compromise, changes in the quality and quantity of accessible food resources, and habitat loss, fragmentation, and modification. Exemplified by the 2004 Indian Ocean tsunami and periodic Himalayan landslides aggravated by climate change effects, geologic events have and will continue to detrimentally impact bats and their habitats to varying degrees, most severely in the biodiverse regions of the Himalayas, the Eastern and Western Ghats, and the Andaman and Nicobar Islands.

Improved incorporation of research and better balancing of environmental, economic, socio-cultural, and national security interests in government policies and initiatives can significantly prevent or mitigate the adverse effects of anthropogenic threats on bats in India.

When known, the drivers of most of the identified anthropogenic threats to bats across India can be causally linked to government policies and initiatives related to protecting national security, managing human population growth and movement, supporting sociocultural needs, and facilitating economic health and development. Unfortunately, even when government policies and actions are intended to benefit wildlife and ecosystems, if their planning is not guided by applicable research and the best available science, their effects may be counter to their objectives. Illustrating this point are the reported adverse consequences to *H. hypophyllus* from the well-meaning but non-scientifically-supported greening efforts led by the Forest Department in Karnataka. Future collaborations and consultations with key stakeholders (Appendix 3) by government agencies in the planning of any land use policy or program could ensure that these initiatives are: 1. based on the best available science, 2. planned using an integrated and adaptive approach, and 3. more equitably balanced in terms of the interests of all stakeholders (Chapter 14). Such systematically planned and scientifically based state policies and actions could substantially reduce or eliminate the threats outlined above and/or mitigate their various adverse effects on bats.

The impacts of anthropogenic and natural threats on Indian bats are poorly understood, rarely quantified, and largely uninvestigated.

This expert elicitation revealed how limited our understanding is regarding the threats impacting bats in India and their effects on bats from the individual- to the species-level. Gap analyses conducted for the four biodiversity hotspot regions all concluded with recommendations for research focused on the collection of baseline biological, behavioural, ecological, and taxonomic data and on Human Dimensions of bats and their management to better elucidate the current and future threats threatening the bats of India. These focal topics are echoed in both the concluding recommendations from the thematic chapters of this report as well as in the ten research priorities elected by the State of India's Bats (2024–2025) team (Chapter 16).

As the social-ecological systems in which bats, humans, and the ecosystems that they share continue to transform and shift, it will be paramount to continuously monitor the interconnections of these systems and to regularly conduct threats assessments for bat taxa. A more thorough comprehension of the risks confronting bat individuals, populations, and species is vital to develop targeted, effective, and adaptive management strategies for preventing, mitigating, and eliminating these threats and for conserving the bats of India into the future.

Chapter 16
State of India's Bats Research and Conservation Action Priorities

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Introduction

In 2002, the Status of South Asian Chiroptera: Conservation Assessment and Management Plan (CAMP) workshop was organised by Zoo Outreach Organisation (ZOO), the International Union for the Conservation of Nature (IUCN) Species Survival Commission (SSC) Conservation Breeding Specialist Group, and the former Chiroptera Conservation and Information Network of South Asia and hosted by Madurai Kamaraj University[43]. This landmark workshop set the precedent for a roadmap for bat research and conservation in India and South Asia in the coming years. During this workshop, 43 bat experts from Nepal, Sri Lanka, India, Myanmar, the United Kingdom, and the United States assessed the status of all 120 bat species known from South Asia at that time. Based on their status assessments for these species and their field experiences, the participants made recommendations for further research and conservation in the region.

The 2002 CAMP report recommendations put a strong emphasis on research priorities, including the importance of conducting surveys to ascertain the status of different bat species at a time when very little was known about the distribution of Indian bats[43]. The report emphasised the need for surveying previously unsurveyed regions and in re-surveying areas where bat species seemed to have disappeared (e.g., *Hipposideros durgadasi* in Jabalpur, Madhya Pradesh). To supplement field research, the report drew attention to the needs for building capacity in bat research and for the development of bat identification keys. Additionally, ecological research was highlighted as a high priority to document the ecological value of bats and to understand the impacts of potential threats to bat populations[43].

Report contributors voting for the top 10 research and conservation priorities at SoIBats Workshop in Bengaluru. Photo: Tikily Tayeng

Among the CAMP report's conservation recommendations, the critical need for wide-reaching public awareness campaigns and the removal of fruit bats from the vermin list in Schedule V of the Wild Life (Protection) Act, 1972 stood out[43]. The report also emphasised the need to protect roosting sites and other important habitats of threatened bat species through government policies. The Archaeological Survey of India (ASI) was identified as a key stakeholder in this regard. The report also explicitly highlighted the needs to include bat researchers in Environmental Impact Assessments (EIAs) and to identify migratory bats so that they can be protected through international agreements such as the Convention on Migratory Species (CMS)[43]. These two recommendations were remarkable considering that EIAs were heavily biased towards charismatic animals and tropical bats were seldom considered migratory species at that time.

Twenty-two years later, several of these recommendations were picked up by the CAMP workshop participants, their students, their mentees, or the next generation of bat researchers. For example, workshops on bat taxonomy and ecology have been organised in Bengaluru (2010), Goa (2015), Hyderabad (2016 & 2020), and Thrissur (2023, 2024, 2025). Chelmala Srinivasulu and colleagues' key to South Asian bats[44] has served as a gold standard for field identification in all bat surveys and ecological research in India over the past 15 years. Threatened species, such as *Hipposideros hypophyllus* and *H. durgadasi*, that faced the risk of being lost to oblivion were rediscovered and are now actively being protected[45][46]. Marking a meaningful shift in government wildlife policy, fruit bats were removed from the vermin list in 2022, and six bat species were accorded the highest protection (Schedule I) per the Indian Wild Life (Protection) Act, 1972[47] (Chapter 11).

The significant strides that the Indian bat research community has taken as a whole over the last few decades are worthy of praise. However, some key research and conservation priorities identified in the 2002 CAMP report have either not been addressed or still have large knowledge gaps. These include the continued lack of natural history or ecological knowledge for most bat species (see Section II) along with limited systematic monitoring of rare and threatened species (Chapter 4). Our meagre understanding of the ecosystem services provided by Indian bats (Chapter 10) still slows down our efforts to improve the public image of these invaluable species.

New challenges and opportunities have also emerged over the past two decades. Anthropogenic climate change and the growth of renewable energy ventures have all escalated as substantial threats to bat populations throughout India. Countering these obstacles are advances in technology to support bat research and outreach. Acoustic monitoring, which was practically unheard of in 2002, has become indispensable in bat research. Meanwhile, social media have burgeoned into important means through which to disseminate bat-related information and educational messages to promote human–bat coexistence (Chapter 14). Most encouragingly, there is a growing culture of collaboration and broad recognition of the importance of multi-stakeholder inclusion within the field of Indian chiropterology (Chapter 12).

Set in the context of these past problems, contemporary challenges, and propitious opportunities, prioritised research and conservation action recommendations were developed by participants in the State of India's Bats (2024–2025) workshop (SoIBats). Below, we not only introduce these research and conservation actions but also describe the process by which they were ranked and the means through which their impact can be amplified to support India's bats over the next twenty years.

"How-Now-Wow": Prioritisation Methods for Recommendations

During the SoIBats in-person workshop in Bengaluru in June 2024, each of four thematic working groups (Ecology and Biology; Ecosystem Services; Policy and Public Engagement; and Taxonomy, Systematics, and Monitoring) generated a list of ten research and ten conservation action priorities for the benefit of Indian bats (detailed in "State of India's Bats (2024–2025) Methods"). Consequently, a total of 40 recommendations for conservation and 40 recommendations for research were produced by all four working groups (Appendix 4). The workshop facilitation team then formed two master lists, one for research suggestions and one for conservation actions, by eliminating duplicates or merging any overlapping recommendations between the working group lists. Participants were presented with these two master lists and asked to evaluate each individual recommendation using the "How-Now-Wow" classification scheme (Box 16.1). Workshop attendees were instructed to classify each recommendation into one of the three categories (i.e., How, Now, Wow) based on a timeline within the next 10 years. Each participant was restricted to one categorising vote per recommendation and could choose to abstain from evaluating recommendations. Assessments were not anonymous, and all attendees could see each other's votes throughout the prioritisation exercise.

Following the "How-Now-Wow" assessment exercise, the workshop facilitation team compiled the categorisations for each research and conservation recommendation. The SoIBats core planning team ("State of India's Bats (2024–2025) Methods") reached the consensus that recommendations that were highly innovative and/or more likely to be implemented should be ranked higher than those that were unfeasible and/or unlikely to be implemented. Therefore, the combined scores for each recommendation's "Wow" and "Now" votes were used for the initial rankings of conservation actions and of research recommendations (i.e., those with the highest scores were considered of the greatest priority). In the case of tied rankings (i.e., when more than one recommendation within the conservation action list or within the research list received the same combined score), the recommendation with the lowest number of "How" votes was judged to be of greater priority than the other recommendation(s) sharing the same initial ranking.

Based on this ranking system, ten recommendations of the greatest priority were identified for Indian bat research (Table 16.1) and for Indian bat conservation (Table 16.2). These priorities are further detailed below, and the applicability of the conservation action priorities to ameliorate the various threats impacting Indian bats is explored in Appendix 5.

Box 16.1 The "How-Now-Wow" classification scheme uses a 2x2 matrix with originality on the X-axis and feasibility on the Y-axis. "How" ideas (● yellow in the grid) are original and innovative ideas but the resources or the tools to pursue them may not currently be available. "Now" ideas (● blue in the grid) are low-hanging fruits: ideas that may not be innovative but are low risk and easy to implement. "Wow" ideas (● green in the grid) are innovative, breakthrough ideas that are feasible and have the potential to make a huge impact.

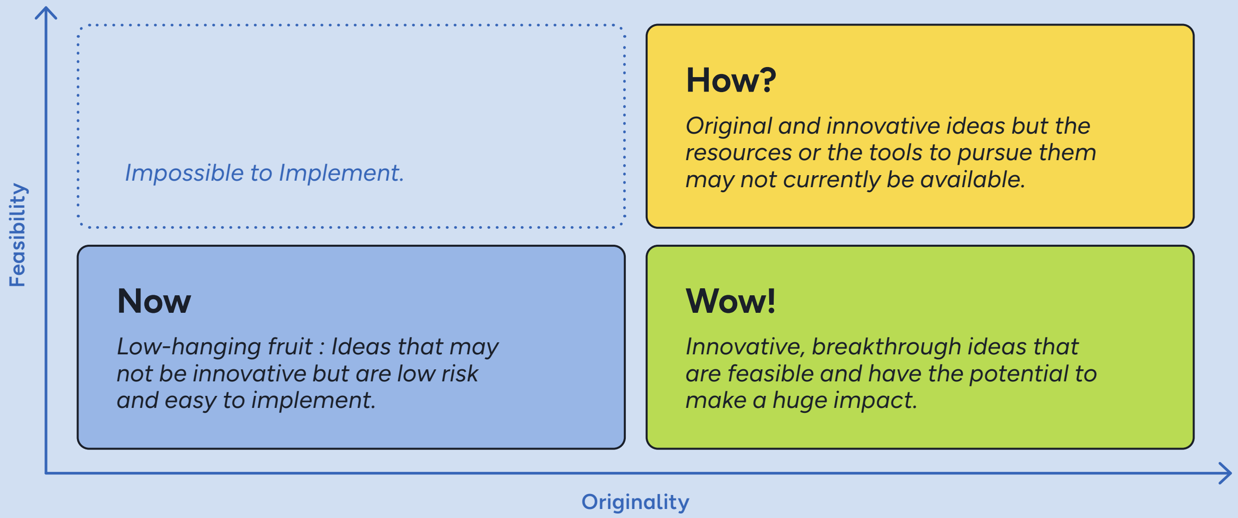

Table 16.1 The top ten priorities for future bat research in India. Participant categorisations of each recommendation according to the "How-Now-Wow" system (Box 16.1) are also provided. Priorities with more "Wow" votes are highlighted in green, and those with more "Now" votes are highlighted in blue. None of these priorities received any "How" votes.

Top 10 Research Priorities	"Wow" votes	"Now" votes
Identifying "bat hotspots"	11	4
Building comprehensive call libraries	12	2
Long-term monitoring to understand the effects of climate change on bats	3	10
Identifying home ranges and critical habitat of threatened bat species	6	5
Conducting detailed studies on bat diets (for priority species)	10	1
Investigating the pathogen diversity in Indian bats and potential disease interfaces	5	6
Enhancing taxonomic knowledge of data deficient species	9	2
Characterising the impact of urbanisation and light pollution on bats	3	8
Identifying "high priority" bat species	10	0
Establishing molecular resources for studying bat ecology	4	5

Table 16.2 The top ten priorities for future bat conservation in India. Participant categorisations of each recommendation according to the "How-Now-Wow" system (Box 16.1) are also provided. Priorities with more "Wow" votes are highlighted in green, and those with more "Now" votes are highlighted in blue. None of these priorities received any "How" votes.

Top 10 Conservation Action Priorities	"Wow" votes	"Now" votes
Building a network of stakeholders for engagement in conservation	10	6
Increasing public awareness through targeted outreach activities and via social media	12	4
Conserving bat habitats through protected areas	4	11
Conducting Red List assessments for India's endemic bats	4	10
Developing best practices guidance for bat research, human–bat interactions, and bat rescue, rehabilitation, and release	7	4
Incorporating bats as integral parts of national and state biodiversity strategy action plans	9	2
Protecting historical bat roosts	6	5
Identifying key bat diversity areas	8	2
Drafting management action plans for "bat hotspots"	8	2
Including bats and bat experts in EIAs	5	4

SoIBats Research and Conservation Action Priorities

Top ten research priorities for Indian bats

1. Identifying "bat hotspots". "Bat hotspot" here (and below) may be loosely defined as an area that contains:

- High species diversity,
- Important habitats for endemic species,
- Populations of globally threatened species or species of national importance, and/or
- Large roosting or nursing colonies that may be under immediate threat.

Identifying bat hotspots will require targeted surveys combining trapping and acoustic sampling. Certain areas may be prioritised based on prior biodiversity and biogeographic knowledge. The support of state forest departments and funding sources is crucial for facilitating biodiversity documentation.

2. Building comprehensive call libraries. Bat acoustic detectors have become an indispensable tool in surveying and monitoring bat communities. However, interpretation of the recordings to the species level is often limited by the lack of comprehensive reference libraries for echolocation calls. At present, bat echolocation calls have been documented for only about three-quarters of Indian bat species[19][21][48][49][50]. Whenever possible, field researchers should include the collection of acoustic data to augment our reference material for the echolocation calls of different bat species and/or regional species pools. Increasing the number of sample recordings for species in different habitats and geographical locations will also help to develop robust call classifiers for different bat species and biogeographic regions within India.

3. Long-term monitoring to understand the effects of climate change on bats. To date, studies on the impacts of climate change on bats are biased towards the Global North, where long-term data on bat distribution, population trends, and demographics are more available. Even in these cases, research has been primarily focused on predictive modelling of species distributions under varying climate scenarios rather than on empirical investigations of bats' genetic, physiological, or behavioural responses to climate change effects[51]. To fill these knowledge gaps, we recommend initiating long-term monitoring of bats, targeting areas where bat research has already been, or is being, conducted to assess shifts in range, habitat use, or other behavioural or physiological factors in adaptation to climate changes. In the longer term, we encourage researchers to collaboratively scale up these types of case studies to other biogeographic regions, ideally with the support of sustainable funding.

4. Identifying home ranges and critical habitat of threatened bat species. Seven bat species endemic to India are considered threatened under the IUCN Red List (*Hipposideros durgadasi, H. hypophyllus, H. nicobarulae, H. pomona, Latidens salimalii, Pteropus faunulus*, and *Rhinolophus cognatus*)[12]-[18], and six bat species (*Hipposideros hypophyllus, Latidens salimalii, Otomops wroughtoni, Pteropus faunulus, P. melanotus*, and *Rhinolophus cognatus*) are recognised as threatened by the Government of India in their listing as Schedule I protected species under the Indian Wild Life (Protection) Act, 1972[47]. Historically, the conservation of threatened bat species has often been restricted to measures protecting their roosting habitat. Expanding conservation efforts to include protection of threatened species' foraging, breeding, and other critical habitats is hindered by the absence of data on their home ranges, habitat use, and habitat preferences. Therefore, we recommend that researchers focus on home range and habitat ecology studies of threatened species through means such as radio telemetry, Global Positioning System (GPS) transmitters, or acoustic sampling (as applicable based on the species of interest) (Chapter 6, Chapter 7).

5. Conducting detailed studies on bat diets (for priority species). In addition to identifying home ranges and crucial habitats for threatened species, we also recommend studying their diet, preferably through DNA metabarcoding (Chapter 5). Identification of important dietary items across seasons will enable more holistic habitat conservation and restoration efforts that take into account threatened bats' requirements and those of the species on which they feed. We also recommend that researchers conduct dietary studies on priority species (not necessarily threatened species) that have the potential to offer significant benefits to humans through their dietary habits. For example, bat species that are common and widespread in distribution, abundant in certain regions, involved in human–bat interactions, and/or frequently use human-dominated habitats may provide disproportionately salient ecosystem services to various stakeholder groups (Chapter 10). In studying the diets of these priority species, we can better quantify the contributions of bats to human and ecosystem well-being, which will provide additional fodder for bat awareness and conservation outreach campaigns.

6. Investigating the pathogen diversity in Indian bats and potential disease interfaces. In the wake of consecutive Nipah virus outbreaks in India (specifically in Kerala) and the COVID-19 pandemic, we recommend that virologists, epidemiologists, and bat researchers collaborate to investigate the disease ecology of bats within a One Health framework. Epidemiological investigations into the potential causes of disease outbreaks can be hampered by a lack of understanding of bats and their disease ecology. Working collaboratively across disciplines can help mitigate this impediment and facilitate the design of more effective, disease-specific prevention measures to reduce future outbreaks for human and bat health (Chapter 8).

Fly eggs on a bat. Investigating bat ectoparasites (such as these flies), endoparasites, and pathogens is among the top research priorities identified by the State of India's Bats team. Photo: Nithin Divakar

7. Enhancing taxonomic knowledge of data deficient species. Despite the great importance of taxonomic and systematics research to understanding and, thus, conserving India's diversity of bat species, there continues to be a paucity of these types of data for many regions and bat taxa in the country (Chapter 2). We recommend that researchers adopt a transdisciplinary approach and employ the most advanced technology to address gaps in our taxonomic knowledge of India's bats. For instance, areas with data deficient species should be resurveyed, more specimens should be collected and analysed to resolve indeterminate taxonomy, and taxonomists and systematists should collaborate with museums at home and abroad to critically evaluate type specimens of questionable taxonomic assignment (Section I).

8. Characterising the impact of urbanisation and light pollution on bats. Currently, 36% of India's population lives in cities[52]. The country's urban population is steadily rising, and unsustainable urban development is projected to expand[53]. Acknowledging this growth of urban areas and their associated infrastructure combined with our limited understanding of the impacts of urbanisation and light pollution on bats (Chapter 15), we recommend that researchers expand on the work of Murugavel et al. (2021, 2023)[3][40] to empirically evaluate the effects of these threats on bat individuals, populations, and species across India.

9. Identifying "high-priority" bat species. The mention of "high-priority" bat species automatically makes one imagine threatened species. However, as discussed above in Research Priority 5, "high-priority" bat species can refer to non-threatened taxa as well. In addition to bat species that offer valued ecosystem services, several non-threatened bat species may be vulnerable to emerging threats such that they might soon become threatened. This recommendation, not entirely independent of the ones above, acknowledges this knowledge gap and urges researchers to quantify threats and their population-level impacts. This recommendation may also be seen as a precedent towards identifying model bat species for studying the impacts of different threats.

10. Establishing molecular resources for studying bat ecology. This research recommendation leverages the increasing capacity and expertise for conducting molecular research in the country. We recommend that researchers focus on collecting baseline molecular data applicable in population ecological, demographic, and conservation genetic research. Some examples of the benefits of this type of data compilation are:

- Quantifying genetic diversity (or lack thereof) within and between populations to critically evaluate the effects of various threats and/or management actions on bats.
- Sequencing genomes of different bat species for application in understanding gene flow and identifying species adaptations.
- DNA barcoding of vouchered and carefully identified bat specimens so that future studies can rely on genetic identification of individuals sampled in the field.
- Collaborating with entomologists and DNA barcoding insect prey species to enable the identification of prey remains through DNA metabarcoding.

Top ten conservation action priorities for Indian bats

1. Building a network of stakeholders for engagement in conservation. Bat conservation is inherently interdisciplinary in nature. As comprehensively examined in Chapter 12, a wide diversity of stakeholders from the public, private, and non-profit sectors are interested in, affected by, or significantly influence bat management and conservation in India. Inclusive engagement with these stakeholders can benefit bat conservation at the community, regional, and national levels by improving the quality and effectiveness of conservation interventions and ensuring the buy-in of key stakeholders to support their successful implementation. We strongly encourage bat researchers and practitioners to create a formal network of collaborators to plan, implement, assess, and adapt bat conservation strategies across all relevant contexts and scales throughout India.

2. Increasing public awareness through targeted outreach activities and via social media. The majority of India's bat species are primarily threatened by human-driven factors (Chapter 15). The solutions to these threats equally lie with humans, such as through the development, support, and implementation of policies and conservation interventions to protect bats and their habitats. To promote human–bat coexistence and generate public support for bat conservation measures, we recommend that educational outreach and behaviour-change initiatives be used to target key stakeholders and communities across India (Chapter 14). Direct engagement with communities through bat walks and school programs can be organised to increase positive attitudes towards bats. Concurrently, educational outreach to wildlife law enforcement personnel, natural resource managers, policymakers, and other agents responsible for overseeing bats and their habitats can improve the planning and implementation of bat protective measures (Chapter 11). We further recommend that bat conservationists rely on conservation marketing and psychological principles to design persuasive, bat-positive messaging that can be shared widely via traditional and social media outlets.

3. Conserving bat habitats through protected areas. Although approximately 187,163 km^2 of India is managed as legally protected national parks, wildlife sanctuaries, community reserves, or conservation reserves, this protected area only represents a small percentage of the estimated 827,356.95 km^2 of forested lands and a fraction of the cave habitats that support the country's diversity of bats[54]. We advocate for identifying and prioritising "bat hotspots" (Research Priority 1) and critical habitats for threatened species that are currently outside the boundaries of India's protected area system. Bat researchers should collaborate with government agencies, policymakers, local and Indigenous communities, and private landholders to safeguard these important landscapes either as legal protected areas, Indigenous and Community Conserved Areas, conservation trusts (e.g., for privately-owned land), and other binding mechanisms for habitat protection.

4. Conducting Red List assessments for India's endemic bats. We encourage India's bat experts to work with the IUCN Red List Authority for the IUCN SSC Bat Specialist Group to regularly coordinate IUCN Red List assessments for all 135 species of Indian bats. Furthermore, we suggest that bat species endemic to India that are currently threatened, at elevated risk for becoming threatened in the near future, and/or previously listed as "Data Deficient" be prioritised for reassessments (Chapter 15). Bat researchers should also consider regional, national, and state- or union territory-level Red List assessments to initiate bat conservation across geographical scales.

5. Developing best practices guidance for bat research, human–bat interactions, and bat rescue, rehabilitation, and release. We recognise the need for developing Standard Operating Procedures (SOP) and guidelines to ensure that human–bat interactions (e.g., use of bats in research and education; captive care of bats; general public's direct and indirect contact with wild bats) are as humane, safe (for both bats and humans), and ethical as possible. We encourage bat researchers to draft and accept bat-specific guidelines for minimising stress, safeguarding animal welfare, and protecting the health and safety of all parties during the capture, handling, care, euthanasia, and other activities involved in the use of bats for research and/or educational purposes (e.g., those provided by the American Society of Mammalogists[55]). Most bat researchers receive questions from the general public on how to deal with bat situations, such as how to evict bats from their private properties or how to manage flying foxes in spaces that are used by people. In view of this, we recommend that researchers work together to craft advice (e.g., in the form of Frequently Asked Questions) for problems that the general public frequently faces with bats. Additionally, wildlife rescuers and rehabilitators frequently seek suggestions on rehabilitating bats from field researchers. We recommend that bat researchers and conservationists collaborate with wildlife caregivers and veterinarians to draft evidence-based best practices for the rescue, rehabilitation, husbandry, release, and post-release monitoring of all species of Indian bats (sensu the captive and veterinary care reference for insectivorous bats published by Bat World[56]).

6. Incorporating bats as integral parts of national and state biodiversity strategy action plans. In a country where conservation is typically centred on charismatic, large mammals[57], we push for greater acknowledgement of the fact that bats are the most species-rich order of mammals. Given their vast diversity and cosmopolitan distribution across India, we recommend pushing for their inclusion in all relevant local to national level biodiversity conservation plans.

7. Protecting historical bat roosts. Bats and humans having been living together for millenia in India, so it comes as no surprise that bats have adapted to use human structures as roosting and breeding sites. However, as historical buildings are renovated or replaced with modern architecture and as religious, historic, and archaeological sites are managed to boost tourism, bats are losing critical habitats with adverse effects on bat populations and species throughout India (Chapter 15). The Archaeological Survey of India (ASI) manages sites for heritage conservation that are often inhabited by bats (Chapter 11, Chapter 12). Unfortunately, bats are usually seen as a nuisance in these properties. We recommend working closely with the ASI to frame plans for bat conservation under the umbrella of heritage conservation.

8. Identifying key bat diversity areas. Chiropterologists cannot efficaciously conserve bats or protect and restore crucial bat habitats without knowing where these bats and habitats are geographically (and temporally, in the case of migratory species) located. We recommend that bat researchers and conservationists prioritise the identification of "bat hotspots" as defined in Research Priority 1 to inform integrated and adaptive strategies to protect and expand key areas of high bat diversity.

9. Drafting management action plans for "bat hotspots". The scope of this report is limited to reviewing the current state of bat research and conservation in India and presenting opportunities for the future. As a next step, we recommend that researchers use this knowledge to liaise with key bat conservation stakeholders (Chapter 12) and prepare holistic management and conservation action plans for "bat hotspots" and "high priority" bat species (see Research Priorities 1 and 9). Initiation of these types of multi-stakeholder, multifaceted plans will realise the SoIBats report's full potential.

10. Including bats and bat experts in Environmental Impact Assessments. To date, negative impacts on bats remain largely unexplored in Environmental Impact Assessments (EIAs) mandated for developmental projects. This is often due to the lack of expertise in bats among those conducting these EIAs. We recommend including bat experts in EIAs wherever applicable. This recommendation is particularly relevant for wind energy projects and road-widening projects that are known to threaten bat populations globally (Chapter 15).

Leveraging Connections to Amplify Impact

Most of the research and conservation action priorities described above are interconnected or interdependent such that when combined, their impact is synergistic rather than simply additive (Figure 16.1). By collectively acting upon these priorities in tandem, researchers, conservationists, and other key stakeholders can maximise the holistic bat conservation achieved through their cumulative efforts.

For example, the enhancement of taxonomic knowledge (Research Priority 7), the compilation of echolocation reference libraries (Research Priority 2), and the development of genomic resources for population studies (Research Priority 10) are foundational for achieving broader research and conservation objectives. Developing comprehensive acoustic reference libraries plays a critical role in advancing the effectiveness of acoustic monitoring. Identification of acoustic recording to the species level enables us to know when and where species occur, which is vital to identifying important sites and habitats for protection (Research Priority 4). If a species is not threatened, acoustic monitoring may still aid in identifying population declines, thereby addressing the objective of identifying "high-priority species" for conservation (Research Priority 9). Acoustic sampling can also be used to understand the impacts of anthropogenic stressors such as urbanisation (Research Priority 8) and to identify disease interfaces through data on habitat use (Research Priority 6). When repeated over years, the results of acoustic monitoring can assist in understanding the impacts of climate change on bats (Research Priority 3). When combined, all the pieces of information gathered through acoustic monitoring can contribute data needed for Red List assessments of Indian bats (Conservation Priority 4).

Building echolocation reference libraries rests heavily on researchers' taxonomic knowledge (Research Priority 7). It is recommended that voucher recordings from an individual bat are substantiated with morphological and genetic identification. Additionally, taxonomic splits through the identification of cryptic species help delineate "bat hotspots" (Research Priority 1) as when an erstwhile wide-ranging species is suddenly found to occur in a narrow geographic range. However, identifying cryptic species greatly relies on the quality of molecular samples and databases (Research Priority 10). Moreover, genomic tools can be used to predict bats' responses to climate change (Research Priority 3).

The fruitful pursuit of these bat research priorities and the successful implementation of these bat conservation priorities rests soundly on collaboration, communication, and coordination among a network of diverse stakeholders (Conservation Priority 1). As reviewed in Chapter 12, these interested and affected parties range from nature educators to staff in different governmental and non-governmental bodies to community members to funders to content creators for media outlets to academics and citizen scientists. Although a daunting task, the creation of a formal network of such bat stakeholders has the potential to support and greatly advance bat conservation through a united front for the benefit of India's people, bats, and thriving ecosystems.

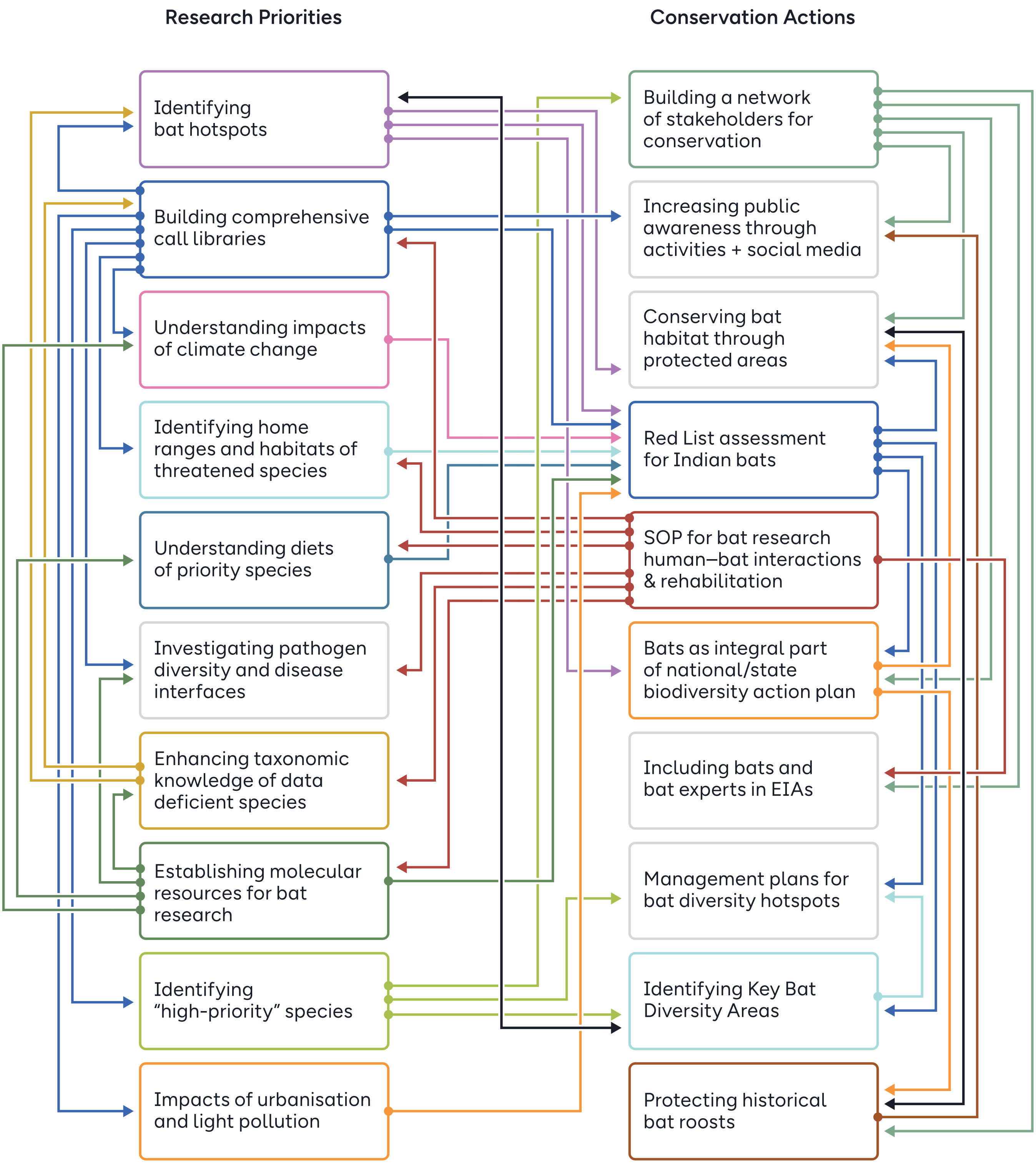

Figure 16.1 Links between the top ten conservation action and research priorities defined by the State of India's Bats (2024–2025) project.

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Conclusion

Taking Flight: The Future of India's Bats

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The State of India's Bats (SoIBats) report is an all-encompassing treatise intended to guide research and conservation on bats in India into the foreseeable future. It is a product of, and a testament to, India's growing bat research community. Over the next decade, we envision that the following accomplishments will realise the opportunities highlighted in this report to maximise its on-ground impact for bat conservation:

1. Students of the natural and social sciences will engage in multidisciplinary research projects to address the research priorities listed in this report, filling priority knowledge gaps that currently hinder the advancement of both bat research and conservation practice in India.
2. Bat conservationists will cultivate and expand their collaborative relationships with a diverse array of stakeholders to design, implement, and continuously-adapt integrated and sustainable conservation initiatives for bat conservation across India.
3. Funding agencies and policy-makers will rely on the research and conservation priorities (Chapter 16), challenges, and opportunities identified in this report to inform their decision-making in relation to and in support of Indian chiropterology and responsible bat management.
4. The SoIBats project will set a precedent for the development of multi-stakeholder conservation action plans for bats and their habitats across all contexts (e.g., human–bat conflict, ecotourism, renewable energy and development projects, sustainable agriculture) and geographic regions in India.
5. The SoIBats project has unified the contemporary bat research community like no other initiative. This unity must culminate in the founding of a structured network that can conduct collaborative projects and outreach, offer student mentorship, organise local conferences, and build the capacity of stakeholders in bat conservation.

Even prior to its publication, this report had already spurred game-changing research and unique collaborations. When we reconvene in 2034 to reassess and update this report, we are confident that an inclusive, transdisciplinary, and forceful group of bat researchers and practitioners will be celebrating the transformative work that has germinated from this report and the partnerships it has fostered.

Appendix 1
Participants in the State of India's Bats (2024–2025) Process

This table summarises the active participation of expert chiropterologists and speleologists in the facilitated in-person and online events that supported the development of the State of India's Bats (2024–2025) report (for more details, refer to "State of India's Bats (2024–2025) Methods" in Introduction). List of names in no particular order.

Participant	Affiliation	Pre-Meeting Online Workshops				State of India's Bats (2024–2025) Workshop Bengaluru, India		Biodiversity Hotspot Threats Mapping Online Workshops			
		Ecology and Biology Working Group (May 18, 2024)	Ecosystem Services Working Group (May 17, 2024)	Policy and Public Engagement Working Group (May 14, 2024)	Taxonomy, Systematics, and Monitoring Working Group (May 18, 2024)	June 17, 2024	June 18, 2024	Andaman and Nicobar Islands Biodiversity Hotspot (January 25, 2025)	Himalayas Biodiversity Hotspot (January 26, 2025)	Northeast India Biodiversity Hotspot (February 24, 2025)	Western Ghats Biodiversity Hotspot (February 26, 2025)
Aditya Srinivasulu	University of Reading, Reading, Berkshire, United Kingdom										X
Adora Thabah	Independent, Shillong, Meghalaya, India	X	X	X	X	X	X				
B.R. Ansil	School of Biological Sciences, University of Oklahoma, Norman, Oklahoma, USA; National Centre for Biological Sciences, Tata Institute of Fundamental Research, Bangalore, Karnataka, India	X				X	X			X	
Baheerathan Murugavel	Indian Institute of Science Education and Research Mohali; (IISER Mohali), Sahibzada Ajit Singh Nagar (Mohali), Punjab, India; Kerala Forest Research Institute (KFRI), Peechi, Kerala, India; VAAVAL-Centre for Indian Bat Research on Ecosystem Sustainability, Coimbatore, India	X	X			X	X				X
Balaji Chattopadhyay	Ashoka University, Sonipat, Haryana, India					X			X		
Bhargavi Srinivasulu	Osmania University, Hyderabad, Telangana, India; Zoo Outreach Organisation, Coimbatore, Tamil Nadu, India					X	X	X	X		X
D. Pilot Dovih	Ashoka University, Sonipat, Haryana, India					X	X			X	
Dhanusha Kawalkar	Speleological Association of India (SAI), Coimbatore, Tamil Nadu, India; Sálim Ali Centre for Ornithology and Natural History (South India Centre of Wildlife Institute of India), Coimbatore, Tamil Nadu, India			X		X	X	X			
Gagandeep Kaur	Sálim Ali Centre for Ornithology and Natural History (South India Centre of Wildlife Institute of India), Coimbatore, Tamil Nadu, India					X	X				
Harish Prakash	Gandhi Institute of Technology and Management (deemed to be) University (GITAM), Visakhapatnam, Andhra Pradesh, India			X		X	X				
Kadambari Deshpande	Indian Institute for Human Settlements (IIHS), Bengaluru, Karnataka, India					X	X				
Kalu Ram Senacha	Indian Bat Conservation Foundation, Mumbai, Maharashtra, India					X	X				

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Participant	Affiliation	Pre-Meeting Online Workshops				State of India's Bats (2024–2025) Workshop Bengaluru, India		Biodiversity Hotspot Threats Mapping Online Workshops			
		Ecology and Biology Working Group (May 18, 2024)	Ecosystem Services Working Group (May 17, 2024)	Policy and Public Engagement Working Group (May 14, 2024)	Taxonomy, Systematics, and Monitoring Working Group (May 18, 2024)	June 17, 2024	June 18, 2024	Andaman and Nicobar Islands Biodiversity Hotspot (January 25, 2025)	Himalayas Biodiversity Hotspot (January 26, 2025)	Northeast India Biodiversity Hotspot (February 24, 2025)	Western Ghats Biodiversity Hotspot (February 26, 2025)
Kasturi Saha	Independent, Kolkata, West Bengal, India					X	X				X
M. Mathivanan	Ashoka Trust for Research in Ecology and the Environment (ATREE), Bengaluru, Karnataka, India			X		X	X				
Nithin Divakar	Kerala Forest Research Institute (KFRI), Thrissur, Kerala, India			X	X	X	X				X
Pratik Das	Indian Institute of Science (IISc), Bengaluru, Karnataka, India					X	X		X	X	
Rahul Prabhukhanolkar	Govindram Seksaria Science College (Autonomous), Belagavi, Karnataka, India	X			X	X	X				
Rajesh Puttaswamaiah	Bat Conservation India Trust (BCIT), Bengaluru, Karnataka, India	X			X	X	X				
Ram Mohan	Western Sydney University (WSU), Hawkesbury, New South Wales, Australia	X		X		X*	X*				
Rohit Chakravarty	Nature Conservation Foundation, Mysuru, Karnataka, India; Bat Conservation International, Austin, Texas, USA	X	X		X	X	X	X	X		
Sanjay Molur	Zoo Outreach Organisation, Coimbatore, Tamil Nadu, India					X	X				
Manchi Shirish S.	Sálim Ali Centre for Ornithology and Natural History (South India Centre of Wildlife Institute of India), Coimbatore, Tamil Nadu, India		X			X	X	X			
Shraddha Kumari K	Jain University, Bengaluru, Karnataka, India		X		X	X	X				X
Sreehari Raman	Kerala Agricultural University (KAU), Vellanikkara, Kerala, India; Kerala Forest Research Institute (KFRI), Peechi, Kerala, India	X		X	X	X	X				X
Chelmala Srinivasulu	Osmania University, Hyderabad, Telangana, India					X	X	X	X		X
Tariq Ahmed Shah	Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Srinagar, Jammu and Kashmir, India				X	X*	X*		X		
Thangsuanlian Naulak	Wildlife Institute of India; Forest Research Institute (deemed to be) University, Dehradun, Uttarakhand, India			X	X	X	X		X	X	
Trisa Bhattacharjee	Zoo Outreach Organisation, Coimbatore, Tamil Nadu, India					X	X				
Uttam Saikia	Zoological Survey of India (ZSI)-North Eastern Regional Centre, Shillong, Meghalaya, India					X	X			X	

X* = Unable to attend in-person, but participated online.

Appendix 2
Synonyms for Indian Bat Species' Names

The following list of synonyms for bat species recorded in India was compiled by Bhargavi Srinivasulu.

Pteropodidae

1. *Cynopterus sphinx*	*Vespertilio sphinx* Vahl, 1797 *Vespertilio fibulatus* Vahl, 1797 *Pteropus pusillus* Geoffroy, E., 1803 *Pteropus marginatus* Geoffroy, E., 1810 *Pachysoma brevicaudatum* Temminck, 1837 (not *Pachysoma brevicaudatum* Geoffroy, I., 1828) *Cynopterus marginatus* var. (*Pachysoma scherzeri*) Zelebor, 1869 *Cynopterus brachyotis scherzeri* Zelebor, 1869 *Cynopterus marginatus* var. *ellioti* Gray, 1870 *Cynopterus sphinx gangeticus* Andersen, 1910
2. *Cynopterus brachyotis*	*Pachysoma brachyotis* Müller, 1838 *Cynopterus marginatus* var. *andamanensis* Dobson, 1873
3. *Eonycteris spelaea*	*Macroglossus spelaeus* Dobson, 1871
4. *Latidens salimalii*	None.
5. *Macroglossus sobrinus*	*Macroglossus minimus sobrinus* Andersen, 1911
6. *Megaerops niphanae*	None.
7. *Pteropus medius*	*Vespertilio gigantea* Brünnich, 1782 *Pteropus giganteus* (Brünnich, 1782) *Pteropus edwardsi* I. Geoffroy, 1828 *Pteropus assamensis* McClelland, 1839 Nomen nudum *Pteropus ruvicollis* (misspelt *rubricollis* or *rubicollis*) Ogilby, 1840
8. *Pteropus hypomelanus*	None.
9. *Pteropus melanotus*	*Pteropus nicobaricus* Fitzinger, 1861 (nomen nudum) *Pteropus nicobaricus* Zelebor, 1869
10. *Pteropus faunulus*	None.
11. *Rousettus leschenaultii*	*Pteropus leschenaultii* Desmarest, 1820 *Cynopterus affinis* Gray, 1843 *Eleutherura fusca* Gray, 1870 *Cynonycteris infuscata* Peters, 1873
12. *Sphaerias blanfordi*	None.

Rhinolophidae

13. *Rhinolophus ferrumequinum*	*Vespertilio ferrum-equinum* Schreber, 1774 *Rhinolophus brevitarsus* Blyth, 1863 (nomen nudum) *Rhinolophus ferrum-equinum regulus* Andersen, 1905 *Rhinolophus ferrumequinum regulus* Andersen, 1905
14. *Rhinolophus hipposideros*	*Vespertilio hipposideros* Bechstein, 1800
15. *Rhinolophus affinis*	None.
16. *Rhinolophus pusillus*	*Rhinolophus minor* Horsfield, 1823 (preoccupied by *Vespertilio ferrumequinum minor* Kerr, 1792)
17. *Rhinolophus trifoliatus*	None.
18. *Rhinolophus perniger*	*Rhinolophus luctus perniger* Hodgson, 1843
19. *Rhinolophus nippon*	*Rhinolophus ferrumequinum nippon* Temminck, 1835
20. *Rhinolophus rouxii*	*Rhinolophus petersii* Dobson, 1872
21. *Rhinolophus lepidus*	None.
22. *Rhinolophus macrotis*	None.

Rhinolophidae, continued

23. *Rhinolophus mitratus*	None.
24. *Rhinolophus subbadius*	*Rhinolophus garoensis* Dobson, 1872
25. *Rhinolophus pearsonii*	None.
26. *Rhinolophus andamanensis*	*Rhinolophus affinis andamanensis* (Dobson, 1872)
27. *Rhinolophus yunanensis*	None.
28. *Rhinolophus beddomei*	*Rhinolophus luctus beddomei* Andersen, 1905
29. *Rhinolophus sinicus*	*Rhinolophus rouxii sinicus* Andersen, 1905
30. *Rhinolophus cognatus*	None.
31. *Rhinolophus shortridgei*	*Rhinolophus lepidus shortridgei* K. Andersen, 1918

Hipposideridae

32. *Asellia tridens*	*Rhinolophus tridens* E. Geoffroy, 1813
33. *Coelops frithii*	None.
34. *Hipposideros speoris*	*Vespertilio speoris* Schneider, 1800 *Rhinolophus dukhunensis* Sykes, 1831 *Hipposideros apiculatus* Gray, 1838 *Hipposideros penicillatus* Gray, 1838 *Hipposideros speoris pulchellus* Andersen, 1918
35. *Hipposideros diadema*	*Rhinolophus diadema* E. Geoffroy, 1813 *Phyllorhina nicobarensis* Dobson, 1871 *Hipposideros nicobarensis* (Dobson, 1871)
36. *Hipposideros armiger*	*Rhinolophus armiger* Hodgson, 1835
37. *Hipposideros fulvus*	*Hipposideros bicolor fulvus* Gray, 1838 *Rhinolophus fulgens* Elliot, 1839 *Hipposideros murinus* Gray, 1838 *Phyllorhina aurita* Tomes, 1859
38. *Hipposideros galeritus*	*Phyllorhina brachyota* Dobson, 1874 *Phyllorhina galerita* Dobson, 1876
39. *Hipposideros ater*	*Hipposideros bicolor ater* Templeton, 1848
40. *Hipposideros lankadiva*	*Hipposideros lankadiva mixtus* Andersen, 1918 *Hipposideros lankadiva unitus* Andersen, 1918 *Hipposideros schistaceus* Andersen, 1918
41. *Hipposideros cineraceus*	*Phyllorhina micropus* Peters, 1872 *Hipposideros cineraceus micropus* (Peters, 1872)
42. *Hipposideros nicobarulae*	*Hipposideros ater nicobarulae* Miller, 1902 *Hipposideros bicolor nicobarulae* Miller, 1902
43. *Hipposideros gentilis*	*Hipposideros pomona gentilis* (Andersen, 1918)
44. *Hipposideros pomona*	None.
45. *Hipposideros larvatus*	*Rhinolophus larvatus* Horsfield, 1823 *Phyllorhina leptophylla* Dobson, 1874
46. *Hipposideros durgadasi*	*Hipposideros cineraceus durgadasi* Khajuria, 1970
47. *Hipposideros hypophyllus*	None.

Megadermatidae

48. *Lyroderma lyra*	*Vespertilio (Megaderma) carnatica* Elliot, 1839 *Megaderma spectrum* Wagner, 1844 *Megaderma schistacea* Hodgson, 1847 *Encheira lyra caurina* Andersen and Wroughton, 1907 *Megaderma lyra caurina* (Andersen and Wroughton, 1907) *Megaderma lyra* E. Geoffroy, 1810
49. *Megaderma spasma*	*Vespertilio spasma* Linnaeus, 175

Rhinopomatidae

50. *Rhinopoma hardwickii*	None.
51. *Rhinopoma microphyllum*	*Vespertilio microphyllus* Brünnich, 1872 *Rhinopoma kinneari* Wroughton, 1912

Emballonuridae

52. *Saccolaimus saccolaimus*	*Taphozous saccolaimus* Temminck, 1838 *Taphozous pulcher* Blyth, 1844
53. *Taphozous perforatus*	None.
54. *Taphozous longimanus*	*Taphozous fulvidus* Blyth, 1841 *Taphozous brevicaudus* Blyth, 1841 *Taphozous cantori* Blyth, 1842
55. *Taphozous nudiventris*	*Taphozous nudiventer* Temminck, 1838 [unjustified emendation]
56. *Taphozous melanopogon*	None.
57. *Taphozous theobaldi*	None.

Molossidae

58. *Mops plicatus*	*Vespertilio plicatus* Buchanan, 1800 *Nyctinomus bengalensis* Desmarest, 1820 *Dysopes murinus* Gray, 1830 *Chaerephon plicatus* (Buchanan, 1800)
59. *Otomops wroughtoni*	*Nyctinomus wroughtoni* Thomas, 1913
60. *Tadarida insignis*	*Cephalotes teniotis* Rafinesque, 1814
61. *Nyctinomus aegyptiacus*	*Nyctinomus aegyptiacus* Geoffroy, E. 1818 *Dysopes geoffroyi* Temminck, 1826 *Nyctinomus tragata* Dobson, 1874 *Tadarida tragata* (Dobson, 1874) *Tadarida thomasi* Wroughton, 1919 *Tadarida gossei* Wroughton, 1919 *Tadarida aegyptiaca gossei* Wroughton, 1919

Vespertilionidae

62. *Arielulus circumdatus*	*Vespertilio circumdatus* Temminck, 1840 *Pipistrellus circumdatus* (Temminck, 1840)
63. *Cnephaeus pachyomus*	*Eptesicus pachyomus* (Tomes, 1857) *Scotophilus pachyomus* Tomes, 1857 *Eptesicus serotinus pachyomus* (Tomes, 1857)
64. *Cnephaeus pachyotis*	*Eptesicus pachyotis* (Dobson, 1871) *Vesperugo pachyotis* Dobson, 1871
65. *Cnephaeus ognevi*	*Eptesicus ognevi* Bobrinskii, 1918 *Eptesicus sodalis ognevi* Bobrinskii, 1918 *Eptesicus bottae ognevi* Bobrinskii, 1918
66. *Cnephaeus gobiensis*	*Eptesicus gobiensis* Bobrinskii, 1926 *Eptesicus nilssonii gobiensis* Bobrinskii, 1926 *Eptesicus nilssonii centrasiaticus* Bobrinskii, 1926 *Eptesicus nilssonii kashgaricus* Bobrinskii, 1926
67. *Cnephaeus tatei*	*Eptesicus tatei* Ellerman & Morisson-Scott, 1951) *Nycticeius atratus* Blyth, 1863 (not Kolenati, 1858)
68. *Hesperoptenus tickelli*	*Nycticejus tickelli* Blyth, 1851 *Nycticejus isabellinus* Horsfield, 1851
69. *Scotoecus pallidus*	*Vespertilio noctulinus* I. Geoffroy, 1831 *Nycticeius pallidus* (Dobson, 1876)

Vespertilionidae, continued

70. *Scotomanes ornatus*	*Nycticejus ornatus* Blyth, 1851
	Nycticejus nivicolus Hodgson, 1855
	Nycticejus emarginatus Dobson, 1871
	Scotomanes ornatus emarginatus (Dobson, 1871)
	Scotomanes ornatus imbrensis Thomas, 1921
71. *Scotophilus kuhlii*	*Scotophilus fulvus* Gray, 1843
	Scotophilus wroughtoni Thomas, 1897
	Scotophilus temmincki wroughtoni Thomas, 1897
	Scotophilus kuhlii wroughtoni Thomas, 1897
72. *Scotophilus heathii*	*Nycticejus heathii* Horsfield, 1831
	Vespertilio belangeri Geoffroy, 1834
	Scotophilus heathi belangeri (Geoffroy, 1834)
	Nycticejus luteus Blyth, 1851
	Scotophilus flaveolous Horsfield, 1851
73. *Nyctalus plancyi*	*Vesperugo (Noctula) plancyi* Gerbe, 1880
	Nyctalus noctula plancyi (Grebe, 1880)
74. *Nyctalus leisleri*	*Vespertilio leisleri* Kuhl, 1817
75. *Nyctalus montanus*	*Pterygistes montanus* Barrett-Hamilton, 1906
	Nyctalus leisleri montanus (Barret-Hamilton, 1906)
76. *Pipistrellus pipistrellus*	*Vespertilio pipistrellus* Schreber, 1774
77. *Alionoctula coromandra*	*Scotophilus coromandra* Gray, 1838
	Vespertilio coromandelicus Blyth, 1851
	Myotis parvipes Blyth, 1853
	?Vesperugo nicobaricus Fitzinger, 1861
	Scotophilus coromandelianus Blyth, 1863
	?Vesperugo micropus Peters, 1872
78. *Alionoctula babu*	*Scotophilus javanicus* Gray, 1838
79. *Alionoctula abramus*	*Vespertilio abramus* Temminck, 1840
	Pipistrellus javanicus abramus (Temminck, 1840)
80. *Alionoctula tenuis*	*Vespertilio tenuis* Temminck, 1840
	Pipistrellus principulus Thomas, 1915
81. *Alionoctula ceylonicus*	*Scotophilus ceylonicus* Kelaart, 1852
	Vesperugo indicus Dobson, 1878
	Pipistrellus chrysothrix Wroughton, 1899
	Pipistrellus ceylonicus chrysothrix (Wroughton, 1899)
	Pipistrellus ceylonicus subcanus Thomas, 1915
82. *Alionoctula paterculus*	*Pipistrellus abramus paterculus* Thomas, 1915
	Pipistrellus javanicus paterculus (Thomas, 1915)
83. *Scotozous dormeri*	*Pipistrellus dormeri* (Dobson, 1875)
	Scotozous dormeri caurinus Thomas, 1915
	Pipistrellus dormeri caurinus (Thomas, 1915)
84. *Barbastella darjelingensis*	*Plecotus darjelingensis* Hodgson, 1855 in Horsfield, 1855
	Synotus darjelingsis (Hodgson, 1855)
	Barbastellus darjelinensis Dobson, 1875 (sometimes as *dargelinensis*)
	Barbastella blanfordi Bianchi, 1916
85. *Otonycteris leucophaea*	*Plecotus leucophaeus* Severtzov, 1873
	Otonycteris hemprichii leucophaea (Severtzov, 1873)
86. *Plecotus homochrous*	*Plecotus homochrous* Hodgson, 1847
	Plecotus puck Barrett-Hamilton, 1907
	Plecotus auritus puck Barret-Hamilton, 1907

Vespertilionidae, continued

87. *Plecotus wardi*	*Plecotus auritus wardi* Thomas, 1911
88. *Hypsugo affinis*	*Vesperugo* (*Pipistrellus*) *affinis* Dobson, 1871 *Pipistrellus affinis* (Dobson, 1871) *Falsistrellus affinis* (Dobson, 1871)
89. *Hypsugo savii*	*Vespertilio savii* Bonaparte, 1837 *Pipistrellus savii* (Bonaparte, 1837)
90. *Hypsugo cadornae*	*Pipistrellus cadornae* Thomas, 1916 *Pipistrellus savii cadornae* Thomas, 1916
91. *Mirostrellus joffrei*	*Nyctalus joffrei* Thomas, 1915 *Hypsugo joffrei* (Thomas, 1915)
92. *Ia io*	*Pipistrellus io* (Thomas, 1902)
93. *Glischropus meghalayanus*	None.
94. *Eudiscopus denticulus*	*Discopus denticulus* Osgood, 1932
95. *Tylonycteris fulvida*	*Vespertilio pachypus* Temminck, 1840 *Scotophilus fulvidus* Blyth, 1859 *Tylonycteris rubidus* Thomas, 1915
96. *Tylonycteris malayana*	*Tylonycteris robustula malayana* (Chasen, 1940)
97. *Myotis formosus*	*Vespertilio formosa* Hodgson, 1835 *Kerivoula pallida* Blyth, 1863 *Vespertilio auratus* Dobson, 1871 *Vespertilio dobsoni* Andersen, 1881 *Vespertilio andersoni* Trouessart, 1897 (nomen novum for *Vespertilio dobsoni* Andersen, 1881) *Myotis formosus auratus* (Dobson, 1871) *Myotis formosus andersoni* (Trouessart, 1897)
98. *Myotis hasseltii*	*Vespertilio hasseltii* Temminck, 1840 *Leuconoe hasselti* Wroughton, 1918 (not Temminck, 1840)
99. *Myotis horsfieldii*	*Vespertilio horsfieldi* Temminck, 1840 *Myotis adversus horsfieldi* (Temminck, 1840)
100. *Myotis muricola*	*Vespertilio muricola* Hodgson, 1841 (nomen nudum) *Vespertilio muricola* Gray, 1846 *Myotis mystacinus muricola* (Gray, 1846) *Vespertilio blanfordi* Dobson, 1871
101. *Myotis siligorensis*	*Vespertilio siligorensis* Horsfield, 1855 *Vespertilio darjilingensis* Horsfield, 1855
102. *Myotis blythii*	*Vespertilio blythii* Tomes, 1857 *Vespertilio murinoides* Dobson, 1873 *Vespertilio dobsoni* Trouessart, 1878
103. *Myotis pilosus*	*Vespertilio* (*Leuconoe*) *pilosus* Peters, 1869 *Myotis ricketti* (Thomas, 1894)
104. *Myotis nipalensis*	*Vespertilio pallidiventris* Hodgson, 1844 (nomen nudum) *Vespertilio nipalensis* Dobson, 1871 *Myotis mystacinus nipalensis* (Dobson, 1871) *Myotis meinertzhageni* Thomas, 1926
105. *Myotis annectans*	*Pipistrellus annectans* Dobson, 1871 *Vesperugo anectens* Dobson, 1876 *Myotis primula* Thomas, 1920 *Myotis annectans primula* Thomas, 1920
106. *Myotis laniger*	*Vespertilio laniger* Peters, 1871 *Myotis daubentonii laniger* (Peters, 1871)

Vespertilionidae, continued

107. *Myotis longipes*	?*Myotis theobaldi* Blyth, 1855
	Vespertilio macropus Dobson, 1872 (not of Gould, 1854)
	Vespertilio longipes Dobson, 1873 (renaming of preoccupied nomen *macropus*)
	Vespertilio megalopus Dobson, 1875
108. *Myotis montivagus*	*Vespertilio montivagus* Dobson, 1874
	Myotis mystacinus montivagus (Dobson, 1874)
109. *Myotis altarium*	None.
110. *Myotis peytoni*	*Myotis montivagus peytoni* Wroughton and Ryley, 1913
111. *Myotis sicarius*	None.
112. *Myotis himalaicus*	*Myotis frater* Aellen, 1923
113. *Submyotodon caliginosus*	*Vespertilio caliginosus* Tomes, 1859
	Myotis mystacinus caliginosus (Tomes, 1859)
	Myotis muricola caliginosus (Tomes, 1859)
114. *Harpiocephalus harpia*	*Vespertilio harpia* Temminck, 1840
	Harpiocephalus rufus Gray, 1842
	Vespertilio pearsonii Tomes, 1858
	Harpiocephalus mordax Thomas, 1923
	Harpiocephalus harpia mordax Thomas, 1923
115. *Murina aurata*	None.
116. *Murina cyclotis*	None.
117. *Murina huttoni*	None.
118. *Murina leucogaster*	*Murina leucogastra* Thomas, 1899
119. *Murina tubinaris*	*Harpyiocephalus tubinaris* Scully, 1881
	Murina huttoni tubinaris (Scully, 1881)
120. *Murina pluvialis*	None.
121. *Murina jaintiana*	None.
122. *Murina guilleni*	None.
123. *Harpiola grisea*	*Murina grisea* Peters, 1872
124. *Harpiola isodon*	None.
125. *Phoniscus jagorii*	None.
126. *Kerivoula picta*	*Vespertilio pictus* Pallas, 1767
	Vespertilio kirivoula Cuvier, 1832
127. *Kerivoula crypta*	*Kerivoula hardwickii crypta* Wroughton and Ryley, 1913
128. *Kerivoula lenis*	*Kerivoula papillosa lenis* Thomas, 1916
129. *Kerivoula kachinensis*	*Kerivoula hardwickii kachinensis* (Bates *et al.*, 2004)
130. *Kerivoula furva*	None.

Miniopteridae

131. *Miniopterus fuliginosus*	*Vespertilio fuliginosa* Hodgson, 1835
	Miniopterus schreibersii fuliginosus (Hodgson, 1835)
132. *Miniopterus pusillus*	*Miniopterus australis pusillus* Dobson, 1876
133. *Miniopterus phillipsi*	None.
134. *Miniopterus magnater*	*Miniopterus schreibersii magnater* Sanborn, 1931
135. *Miniopterus srinii*	None.

Appendix 3
Stakeholder Map

This figure was drafted by Rahul Prabhukhanolkar and Dhanusha Kawalkar to depict the governmental and non-governmental actors that are important stakeholders for advancing bat research and conservation in India. State of India's Bats (2024–2025) participants were given the opportunity to refine the diagram based on their personal experience, and all feedback was incorporated into this final figure. A detailed conceptual description of the diagram is provided in Chapter 12.

Appendix 3 figure can be accessed at the following link: https://miro.com/app/board/uXjVIoI2BHc=/?share_link_id=887023591835

Go to Appendix 3 figure

Scan to access Appendix 3 figure

Appendix 4
Research and Conservation Action Priorities

During the State of India's Bats (2024–2025) meeting in Bengaluru in June 2024, all four working groups generated a list of ten research and ten conservation priorities. The workshop facilitation team then parsed through the lists to eliminate duplicates and merge overlapping recommendations. The following are the resulting master lists that were presented for "How-Now-Wow" assessment by the whole group (for more details, refer to "State of India's Bats (2024–2025) Methods" in Introduction). Priorities mentioned in green feature in the priority lists in Chapter 16. Please note that there are differences in the way the priorities are worded here and in Chapter 16 because the priorities have been rephrased for a broader audience in Chapter 16.

List of Research Priorities

1. Identifying home ranges & habitat (foraging, breeding) of threatened bat species
2. Detailed studies on bat diets (for priority species)
3. Impact of pollutants & pesticides on bats
4. Building comprehensive call libraries
5. Genomic resources for bat population genetics - DNA barcoding
6. Understanding bat assemblages across different habitats (gradient)
7. Pathogen diversity in Indian bats and potential disease interfaces
8. Long-term monitoring to understand effects of climate change
9. Studies on migration
10. Impact of wind farms on mortality & behaviour
11. Quantification of ecosystem services (seed dispersal, pollination, guano, pests)
12. Assessing economic value of ecosystem services
13. Ectoparasite diversity
14. Ecological studies on endemic bats
15. Species inventories in understudied areas
16. Correcting taxonomic errors/data of cryptic, lost and data deficient species
17. Social studies on perception, interactions & human-bat co-existence
18. Spatio-temporal variations in populations & survivorship
19. Impact of urbanisation & light pollution
20. Standardising methods for abundance studies
21. Impacts of invasive species and monoculture on bats
22. Identifying "high-priority" species
23. Impact of solar installations & mining on bats
24. Identifying "bat hotspots"

List of Conservation Action Priorities

1. Conserving bat habitat through protected areas
2. Formulating cave tourism guidelines
3. Building a network of stakeholders for engagement in conservation
4. Including bats and bat experts in EIA
5. Preserving/allocating space for bats in anthropogenic infrastructure
6. Increasing public awareness through targeted outreach activities (bat walks, schools, forest dept.) + social media
7. SOP for bat research, human–bat interactions & rehabilitations
8. Artificial bat roosts (urban & other)
9. Conservation efforts targeting threatened, endemic, unprotected species
10. Identifying Key Bat Diversity Areas
11. Eco-Certification of crops pollinated/dispersed by bats
12. Bats as integral part of national/state biodiversity strategy action plan
13. Integrating scientific data into policy & outreach
14. Mapping & identification of roosts targeted for auction to preserve them
15. Developing guidelines for planned infrastructure (mitigation measures)
16. Inclusion of bats as priority species at the government level
17. Renovation of protection of historical roosts (ASI)
18. Red List assessments of India's bats
19. Management action plans of bat hotspots

Appendix 5
Threats to Indian Bats and Conservation Solutions

This table provides a comprehensive summary of the results from the State of India's Bats Threats Mapping online survey (Chapter 15) with reference to the conservation action priorities identified during the State of India's Bats (2024–2025) workshop in Bengaluru, India (Chapter 16). References for the survey results reviewed in the table are listed below the table grouped by: 1. biogeographic region and 2. general category of bat species.

Threats section

Threats were evaluated by 17 survey participants based on their direct experience and/or with reference to credible sources (e.g., peer-reviewed literature, personal communication from trustworthy sources) (Chapter 15). All but one of the threats are Level 2 and Level 3 threats per the definitions of the IUCN Threats Classification Scheme, version 3.3 (2022). The final threat "Other: Loss of roosting sites in traditionally constructed huts and shades" was suggested by a survey participant under the general category of "Other" and was not clearly attributable to any distinct threat classification per the IUCN scheme. Consequently, this specific threat was only assessed by a single respondent across all of the categories.

Biogeographic Region section

The biogeographic regions represent the 11 of 13 biogeographic regions of India (Figure 15.1) for which participants provided survey responses. The abbreviations for each biogeographic region are noted within parentheses below the full spelling of each region. These abbreviations are used to indicate the geographic area of relevance for each threat category within the "Bat Family" section of the table.

All threats were evaluated for their adverse effects on any bat species within each biogeographic region as well as its temporal relevance (Chapter 15). If at least one respondent noted the impact of the threat on bats in the region, this is indicated by a P ("past threat"), C ("current threat"), and/or F ("future threat") accordingly. If no respondents indicated the threat was a past, current, or future threat and at least one respondent noted the threat was "not a threat" to bats in the region, this was delineated by "NT." If no respondents indicated the threat was a past, current, or future threat or "not a threat," the effects of the threat on bats in the region was considered "unknown" and is indicated by a "U." "C*" delineates a threat was originally mapped as a future threat, not a threat, or unknown. However, subsequent survey responses unequivocally established this as a current threat in the biogeographic region.

Bat Family section

All threats were evaluated for their adverse effects on bat families within each biogeographic region. If one or more survey participant responded that at least one bat species within a family is experiencing a population decline as a result of the threat (either directly or in combination with other threats) in a region, this is indicated by the abbreviation for that biogeographic region (see above) in the appropriate space. A blank space indicates that no survey respondent reported the threat as causing at least one bat species within any family to experience a population decline in any biogeographic region. In this case, absence of evidence is not evidence of absence, and blank spaces in this section may indicate a lack of understanding of the effects of threats rather than the absence of these threats' detrimental impact on bats within these families in these biogeographic regions.

Data Deficient Species and Threatened Species sections

Currently, the IUCN Red List of Threatened Species recognises six bat species endemic to India as "Data Deficient" and seven endemic bat species as "threatened" (Vulnerable, Endangered, Critically Endangered). Survey participants identified any threats that had significant negative impacts at the individual-, population-, and/or species-level (either directly or in combination with other threats) for each data deficient and threatened species, which are marked with a "X" within the table. As noted above, blank spaces in these sections may indicate a lack of understanding of the effects of these threats rather than the absence of these threats' detrimental impact on bat species.

Conservation Action Priorities section

Within this section, the top ten conservation action priorities defined during the Bengaluru workshop (Chapter 16) are compared to the threats assessed within the online survey. An "X" indicates that the implementation of the conservation action is predicted to prevent, mitigate, eliminate, or otherwise ameliorate the threat and/or its adverse impact(s) on bats in India. This may be through direct or indirect means, and the conservation action may operate independently or synergistically with other interventions.

Threats	Biogeographic Region											Bat Family								
	Western Himalayan (WH)	Eastern Himalayan (EH)	Northwest Arid (NWA)	Northeast (NE)	Central Indian Highlands (CIH)	Eastern Ghats (EG)	Western Ghats (WG)	Peninsular India/Deccan Plateau (PI)	Coasts (C)	Andaman and Nicobar Islands (AN)	Lakshadweep (L)	Emballonuridae	Hipposideridae	Megadermatidae	Miniopteridae	Molossidae	Pteropodidae	Rhinolophidae	Rhinopomatidae	Vespertilionidae
Housing & urban areas	C	CF	CF	CF	C	CF	PCF	PCF	C	CF	NT	NWA, WG, PI	EH, NWA, NE, EG, WG, PI, AN	NWA, NE, WG, PI, C, AN	WH, NE, WG	NWA, PI	WH, NWA, NE, EG, WG, PI, C	WH, EH, NWA, NE, EG, WG, PI, AN	NWA, EG, PI	NWA, EG, WG, PI, C, AN, L
Commercial & industrial areas	NT	F	C	CF	F	F	PCF	CF	C*	CF	F	NWA, WG, PI, AN	NE, WG, AN	NE, WG, C, AN	NE, WG, AN	NE	WG, AN	NE, WG, AN	NE, WG	WG, AN
Tourism & recreation areas	PCF	C	CF	CF	CF	CF	CF	CF	CF	PCF	CF	NWA, NE, CIH, EG, WG, PI, C, AN	WH, EH, NWA, NE, CIH, EG, WG, PI, C, AN	NWA, NE, CIH, EG, WG, PI, C, AN	WH, NE, WG, C, AN	NWA, NE, CIH, EG, WG, PI, L	WH, EH, NWA, NE, EG, WG, PI, C, AN	WH, EH, NWA, NE, CIH, EG, WG, PI, C, AN	NWA, NE, EG, WG, PI	WH, NWA, NE, CIH, EG, WG, PI, C, AN, L
Small-holder farming	NT	C	NT	CF	U	C	PCF	NT	U	U	NT		EH, NE, EG				EH, NE, EG, WG	NE, EG		WG
Agro-industry farming	C	CF	NT	CF	U	C	PCF	CF	C*	CF	NT	WG, PI	WH, EH, NE, EG, WG, PI, AN	WG, AN	WH, WG, C, AN	WG	WH, NE, EG, WG, C, AN	WH, EH, NE, EG, WG, PI, C, AN	WG, PI	WH, WG, PI, C, AN
Small-holder timber plantations	NT	C	NT	CF	U	C	PC	NT	U	U	NT		EH, NE, EG				NE, EG, WG	EH, NE, EG		
Agro-industry timber plantations	PCF	C	NT	CF	U	C	PCF	C	U	P	NT		WH, NE, PI	NE, PI	WH, NE		WH, NE, WG	WH, NE, PI		WH, NE, WG, PI
Livestock farming & ranching	NT	C	NT	CF	U	U	PC	U	U	NT	NT		NE				NE	NE		
Oil & gas drilling	NT	C	NT	C*F	U	U	NT	F	U	U	NT		NE	NE	NE			NE		NE
Mining & quarrying	PCF	CF	CF	PCF	CF	CF	PCF	PCF	CF	NT	NT	EG, WG, PI, C	WH, NWA, NE, CIH, EG, WG, PI, C	WH, NWA, EG, WG, PI, C	WH, NE, WG, C	WH, EG, WG, PI	WH, EH, NWA, NE, EG, WG, PI, C	WH, NWA, NE, CIH, EG, WG, PI, C	NE, EG, WG, PI	WH, NE, EG, WG, PI, C
Renewable energy	F	NT	CF	C*	CF	F	CF	CF	U	NT	C*F	NWA, NE, WG, PI	WG			NE, PI, L	NE, WG		NWA, NE, PI	NE, WG, PI, L
Roads & railroads	CF	C	C	CF	F	CF	PCF	CF	U	C*	NT	WG	WH, EH, NE, WG, PI, AN	WH, WG, AN	WH, WG	WH	WH, NE, WG	WH, EH, NE, WG, PI, AN	WG	WH, EH, WG, PI, AN
Utility & service lines	C	NT	C	C*	U	F	PCF	C	U	CF	NT	NWA	NWA				WH, NWA, NE, WG, PI, AN			
Hunting: intentional use (species being assessed is the target)	NT	CF	CF	PCF	CF	PC	PCF	PC	U	PCF	NT	AN	EH, NE, AN				EH, NWA, NE, EG, WG, PI, AN	EH, NE, WG, AN	WG	EH, NE, WG
Hunting: persecution/control	NT	CF	CF	C	CF	C	PCF	PCF	U	PCF	F	NE, EG, WG	EH, NE, EG, WG, PI	NE, WG	NE, WG	WG	EH, NE, EG, WG, PI	EH, NWA, NE, EG, WG, AN	WG	WG
Human intrusions & disturbance: Recreational activities	PCF	C	C	CF	U	C	PCF	CF	CF	CF	C*F	NE, EG, WG, PI, C	WH, EH, NE, EG, WG, PI, C, AN	WH, EG, WG, PI, C	WH, NE, WG	WH, WG, L	EH, NE, EG, WG, PI, C	WH, EH, NWA, NE, EG, WG, PI, C, AN	NWA, WG, PI	WH, NE, WG, PI, C, L
Human intrusions & disturbance: war, civil unrest, and military exercises	CF	NT	C*	C	U	U	NT	NT	U	C*	NT	NWA, AN	NWA, AN	AN	AN		AN	AN		WH, AN
Fire & fire suppression	CF	F	NT	CF	U	U	PCF	C*	U	NT	NT	WG	WH, WG	WH, WG	WG	WG	WH, NE, WG	WH, WG	WG	WH, NE, WG, PI
Dams and water management/use	PCF	CF	F	CF	U	P	PCF	CF	U	NT	NT		WH		WH		WH	WH		WH
Invasive non-native/alien species	CF	NT	NT	U	U	U	F	CF	U	U	NT		WH	WH	WH		WH	WH		WH
Diseases impacting bats	CF	NT	F	C*F	U	U	C*F	NT	U	NT	U					WH	NE, WG	WH		WH
Domestic & urban waste water pollution	CF	F	C	U	U	U	CF	CF	U	CF	NT						WH, NWA, AN	WH		WH, NWA, PI, AN
Industrial pollution (e.g., oil spills, mining tailings)	PCF	F	NT	F	U	CF	CF	CF	PF	NT	NT	WG	WG	WG	WH, WG	WG	WH, WG	WG	WG	WH, WG, PI
Agricultural & forestry pollution (e.g., herbicides, pesticides, soil erosion)	PCF	F	CF	CF	CF	CF	PCF	CF	CF	C*	C*F	WG, PI, C	WH, NE, WG, PI, C, AN	NWA, NE, WG, PI, C	WH, WG, C	WH, NWA, WG, L	WH, NE, WG, PI, C, AN	WH, NE, WG, PI, C, AN	NWA, WG, PI	WH, NWA, NE, WG, PI, C, AN, L
Garbage & solid waste	C	F	F	F	CF	CF	PCF	CF	U	NT	NT	WG							WG	WG
Airborne pollutants	NT	F	C	F	U	U	CF	U	CF	NT	NT						NWA		NWA	NWA
Light pollution	CF	F	CF	F	CF	CF	CF	CF	CF	U	NT	WG, PI	WH, WG, PI	PI, C	WH, C	WG, PI	EG, WG, C	WH, WG, PI, C	WG, PI	WH, NWA, WG, PI, C
Thermal pollution	C*	F	NT	F	U	U	CF	CF	CF	NT	NT						WG, C	WH		WH
Noise pollution	C	F	C	F	CF	CF	CF	C*	CF	NT	NT			PI			NWA			
Earthquakes/tsunamis	C*F	F	CF	NT	U	U	NT	NT	U	PF	C*F	NWA, AN	WH, NWA, AN	WH, NWA, AN	WH, AN	WH, L	WH, AN	WH, NWA, AN	NWA	WH, AN, L
Avalanches/landslides	CF	C	NT	C	F	CF	PCF	NT	U	NT	NT	NE, WG	WH, WG	WH, WG	WH, WG	WH, WG	WH, NE, WG	WH, NE, WG	WG	WH, WG
Climate change & severe weather	CF	CF	CF	CF	F	CF	PCF	CF	F	CF	C*F	NE, WG, PI, AN	WH, NE, WG, PI, AN	WH, WG, PI, AN	WH, NE, WG, AN	WH, NE, WG, PI, L	WH, EH, NWA, NE, WG, PI, AN	WH, NE, WG, PI, AN	NE, WG, PI	WH, NE, WG, PI, AN, L
Other: Loss of roosting sites in traditionally constructed huts and shades		CF		CF													NE			EH, NE

Threats	Data Deficient Species							Threatened Species							Conservation Priorities									
	Cnephaeus tatei	*Harpiola grisea*	*Hipposideros khasiana*	*Murina pluvialis*	*Myotis peytoni*	*Rhinolophus rouxii*	*Rhinolophus mitratus*	*Hipposideros durgadasi*	*Hipposideros hypophyllus*	*Hipposideros nicobarulae*	*Hipposideros pomona*	*Latidens salimalii*	*Pteropus faunulus*	*Rhinolophus cognatus*	Building a network of stakeholders for engagement in conservation.	Increasing public awareness through targeted outreach activities and via social media	Conserving bat habitats through protected areas.	Conducting Red List assessments for India's endemic bats.	Developing best practices guidance for bat research, human-bat interactions, and bat rescue, rehabilitation, and release.	Incorporating bats as integral parts of national and state biodiversity strategy action plans.	Protecting historical bat roosts.	Identifying key bat diversity areas.	Drafting management action plans for "bat hotspots".	Including bats and bat experts in EIAs.
Housing & urban areas		x			x	x	x	x			x				x	x	x			x		x	x	x
Commercial & industrial areas	x	x				x		x							x	x	x			x		x	x	x
Tourism & recreation areas	x	x			x	x		x			x	x		x	x	x	x			x	x	x	x	x
Small-holder farming						x						x			x	x	x			x		x	x	
Agro-industry farming	x	x				x					x	x			x	x	x			x		x	x	
Small-holder timber plantations						x						x			x	x	x			x		x	x	
Agro-industry timber plantations						x						x			x	x	x			x		x	x	x
Livestock farming & ranching															x	x	x			x		x	x	
Oil & gas drilling															x	x	x			x		x	x	x
Mining & quarrying	x	x	x	x	x	x		x	x		x	x			x	x	x			x		x	x	x
Renewable energy															x	x				x		x	x	x
Roads & railroads	x	x		x	x	x		x	x		x	x		x	x		x			x		x	x	x
Utility & service lines	x	x		x	x							x			x		x			x		x	x	x
Hunting: intentional use (species being assessed is the target)					x	x		x	x		x	x	x		x	x			x	x		x	x	
Hunting: persecution/control			x			x		x	x	x	x	x	x		x	x			x	x	x	x	x	
Human intrusions & disturbance: Recreational activities					x	x		x	x		x	x		x	x	x	x		x	x	x	x	x	
Human intrusions & disturbance: war, civil unrest, and military exercises										x			x	x	x		x			x				
Fire & fire suppression						x					x	x			x		x			x		x	x	
Dams and water management/use	x											x			x		x			x		x	x	x
Invasive non-native/alien species															x	x	x			x		x	x	
Diseases impacting bats												x			x	x			x	x			x	
Domestic & urban waste water pollution															x	x	x			x		x	x	
Industrial pollution (e.g., oil spills, mining tailings)															x		x			x		x	x	
Agricultural & forestry pollution (e.g., herbicides, pesticides, soil erosion)					x	x		x	x		x	x			x	x	x			x		x	x	
Garbage & solid waste															x	x	x			x		x	x	
Airborne pollutants															x									
Light pollution		x				x	x								x	x	x		x	x		x	x	
Thermal pollution						x					x	x			x									
Noise pollution					x	x					x				x	x	x		x	x		x	x	
Earthquakes/tsunamis						x							x	x										
Avalanches/landslides					x	x					x	x												
Climate change & severe weather	x	x			x	x				x	x	x	x	x										
Other: Loss of roosting sites in traditionally constructed huts and shades															x	x				x	x	x	x	

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Appendix 6

Causal Diagrams of the Primary Threats to Indian Bats for Four Biogeographic Regions Identified as Biodiversity Hotspots

These figures depict the causal flow diagrams that were constructed by participants (Appendix 1) in the Biodiversity Hotspot Threats Mapping online workshops for the Andaman and Nicobar Islands, the Himalayas, Northeast India, and the Western Ghats. For more details on these virtual workshops and the processes followed during each, please refer to Chapter 15. Each diagram illustrates the direct and indirect causal linkages between: 1. Level 1 and Level 2 threats to bats in India (per the IUCN Threats Classification Scheme, version 3.3 [2022]), 2. significant drivers or root causes of these threats, and 3. adverse effects of these threats on bat individuals, populations, or species. When relevant, feedback loops and notable positive effects from Level 1 and Level 2 threats are also clearly represented in these causal flow diagrams.

Appendix 6 figures can be accessed at the following link: https://miro.com/app/board/uXjVIuHzyt4=/?share_link_id=132518797168

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Appendix 7

Causal Diagrams of the Primary Threats to Six Threatened Bat Species Endemic to India

These figures depict the causal flow diagrams that were constructed by participants (Appendix 1) in the Biodiversity Hotspot Threats Mapping online workshops for the Andaman and Nicobar Islands and the Western Ghats. The threatened bat species that were collectively assessed during these virtual workshops were *Hipposideros hypophyllus*, *Hipposideros nicobarulae*, *Hipposideros pomona*, *Latidens salimalii*, *Pteropus faunulus*, and *Rhinolophus cognatus*. For more details on these virtual workshops and the processes followed during each, please refer to Chapter 15. Each diagram illustrates the direct and indirect causal linkages between: 1. Level 1 and Level 2 threats affecting these bat species (per the IUCN Threats Classification Scheme, version 3.3 [2022]), 2. significant drivers or root causes of these threats, and 3. adverse effects of these threats on bat individuals, populations, or the species.

Appendix 7 figures can be accessed at the following link: https://miro.com/app/board/uXjVIuHzyt4=/?share_link_id=132518797168

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