Journal of

Wildlife Science

Crossref

DIAMOND OPEN ACCESS

VOLUME 1, ISSUE 2, JULY 2024

Journal of Wildlife Science

Published By: Wildlife Institute of India https://wii.gov.in/

Contact Information: For inquiries regarding submissions, editorial policies, or other matters related to JWLS, please contact:
Journal of Wildlife Science, Wildlife Institute of India,
PO Box # 18, Chandrabani, Dehradun – 248001 INDIA
Email: info@jwls.in

DOI (Volume 1, Issue 2): https://doi.org/10.63033/JWLS.WGOE9780

Cover Image: *Nanorana vicina* in Binog Wildlife Sanctuary. © Abhijit Das.

About the Journal

The Journal of Wildlife Science (JWLS) is dedicated to advancing wildlife science and conservation through rigorous, evidence-based research across taxa and ecosystems. The journal operates on a diamond open-access model, meaning neither authors nor readers incur fees for accessing or publishing in JWLS. In a departure from the traditional pay-to-publish or pay-to-read models, our mission is to foster open and free access to high-quality, peer-reviewed interdisciplinary research in wildlife science, conservation, and management. We provide an inclusive, author-friendly platform welcoming original articles, reviews, commentaries, policy briefs, and novel paper types like Methods Papers, Natural History Notes, and Academic Practices in Wildlife Science. Our unique peer review approach emphasises constructive mentorship between authors and reviewers to elevate quality while fostering a collaborative research community.

JWLS is a quarterly publication with an online-first feature (publishing online as soon as the article is accepted). Therefore, the authors can submit their latest findings, insights, and perspectives for publishing in JWLS at any time.

Aim and Scope

JWLS does not categorise research into taxonomic classes. Authors working on any wildlife taxa, community or ecosystems can submit their work under a theme of JWLS. See the list of themes at https://jwls.in/author-guidelines.

Submission Guidelines

Authors interested in submitting their work to JWLS are encouraged to review the updated submission guidelines at https://jwls.in/author-guidelines.

Manuscripts should be submitted online through our submission system (https://www.editorialmanager.com/jwls/), and all submissions will undergo rigorous peer review.

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Content

Commentary

Review Article

Research Articles

Short Communication

Short Note

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Commentary

Connectivity conservation through linear infrastructure mitigation: Taking small steps for a giant conservation effort

Bilal Habib[1*], Akanksha Saxena[1]

[1]Department of Animal Ecology & Conservation Biology, Wildlife Institute of India, Chandrabani, Dehradun.

DIAMOND OPEN ACCESS Crossref

EDITED BY
Vishnupriya Kolipakam
Wildlife Institute of India

*CORRESPONDENCE
Bilal Habib
bh@wii.gov.in

RECEIVED 30 July 2024
ACCEPTED 15 August 2024

CITATION
Habib, B. & Saxena, A. (2024). Connectivity conservation through linear infrastructure mitigation: Taking small steps for a giant conservation effort. *Journal of Wildlife Science,* 1 (2), 62-68. https://doi.org/10.63033/JWLS.BZOG7974

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Social and economic growth imperatives have been the driving force behind the large-scale and rapid spurt in linear infrastructure (LI) projects in India, particularly roads and railway lines. However, while these projects aim to improve the transportation connectivity of the country, their ecological impacts on the natural ecosystems of the country are becoming increasingly evident. We delve into the prerogatives of both infrastructure development and conservation scenarios in India as they relate to one another. We also trace the country's journey in the realm of mitigating the impacts that these vital infrastructure projects exert on natural systems. We also outline future research directions for ecologists and the course of actions for LI development agencies and other stakeholders to harmonise the conflict between development and conservation. In conclusion, we aim to provide a blueprint for concerted efforts from both conservation and development proponents to ensure that the path to India's economic growth is sustainable.

Keywords: Linear infrastructure, landscape conservation, developing country, sustainable development.

Introduction

In the past few decades, the Indian growth story has become one to reckon with. Counted among the fastest growing developing nations of the world, the country's efforts to achieve economic and social development are accelerating at a fast pace. The surge in economic development in the past few decades after the economic liberalisation in the early 90s has been partly fuelled by an aggressive push for infrastructure growth. Transportation linear infrastructure (LI), particularly roads and railway lines, figures among the top focal areas of the government to achieve this growth. Having overtaken Japan as the world's third largest automotive market with more than a 500% jump in vehicle registrations in the past two decades (Balasubramanian, 2023), the road transport sector in India is showing no sign of slowing down. Additionally, railway line electrification and rail network expansion are being primed as lifelines to connect people, as well as help transport goods and key resources such as minerals and metals important for industry. Ambitious government projects such as those that seek to enhance accessibility and the Bharatmala project that seeks to optimize the efficiency of the movement of goods and people across the country (PIB, 2024), seem to be at the centre of the Indian growth story.

However, while these plans are working to transport India to greater economic self-sufficiency, the natural wealth of the country is at the receiving end. The country is rife with examples of busy roads and railway lines cutting through prime wildlife habitats and corridors, aggravating the impacts of human-presence on wildlife in these regions and hampering connectivity between habitats. While consolidated estimates of wildlife mortality on roads and railway lines in India are lacking, it is well established that such mortalities are highest in well-connected landscapes and Protected Areas (PAs) (Grilo *et al.*, 2011). Further, such mortality in wildlife corridors can lead to the loss of 'fit' individuals of a population (Bujoczek *et al.*, 2011) - a huge loss for the genetic pool of already endangered species. The problem is compounded by the prevalent LI planning framework that puts conservation concerns on the backburner while deciding LI design and alignments. Here, we delve into the present scenario of LI development in India as it pertains to its repercussions for long-term wildlife and landscape conservation. We also analyse the growth of transportation ecology and the science of mitigation planning worldwide and in India, concluding with future directions in the areas of research, developer initiatives and policy. Thus, our analysis aims to be a starting point for a concerted effort to achieve LI growth that is wildlife-friendly and sustainable.

Biodiversity conservation in India: beyond Protected Areas

Counted among the world's most biodiverse regions, India boasts a rich array of natural landscapes, ecosystems and habitats. Despite being the most populous country in the world today, India is home to the highest number of large terrestrial carnivores (average body weight > 15 kg) in the world (Johnsingh, 1986), in addition to highly diverse aquatic, herpetofaunal, avian, mammalian, floral and invertebrate assemblages. The wildlife in the country majorly survives within a vast network of PAs, harbouring rich tropical, marine, montane and grassland ecosystems in almost pristine conditions. For example, the one-horned rhinoceros *Rhinoceros unicornis* is known to thrive in protected spaces like the Kaziranga, Dudhwa and Manas National Parks. On the other hand, some wildlife species have historically thrived in landscapes with low level of human activity or have adapted to life in multi-use landscapes. For example, about 30% of tigers *Panthera tigris* and 80% of Asian elephants *Elephas maximus*, live outside PAs (Jhala *et al.*, 2021; Kshettry *et al.*, 2020) Leopards *Panthera pardus* are famously known to be adaptable to living near human settlements (Surve *et al.*, 2022), and the great Indian bustard *Ardeotis nigriceps* and the Indian wolf *Canis lupus pallipes* have co-evolved to live alongside low intensity agriculture and pastoralism (Dutta & Jhala, 2021; Jhala & Giles, 1991).

Spaces outside PAs have another pivotal role - to keep PAs and habitat networks connected. Currently about 5.43% of the country's geographical area is legally protected under 1022 PAs (https://wiienvis.nic.in/Database/Protected_Area_854.aspx) with different levels of protection. However, only a few of these PAs are large enough to sustain wildlife populations and ecosystems for the long term by themselves. For example, a majority (32) of the 55 tiger reserves in the country have inviolate core areas smaller than the minimum 800 km^2 required to sustain a tiger population of 80-100 individuals that is viable in the long-term (https://ntca.gov.in/tiger-reserves/#-tiger-reserves-2). Similarly, elephant reserves are declared for Asian elephant conservation in India (https://wiienvis.nic.in/Database/eri_8226.aspx); however, these account for a mere 40% of the total elephant range and are not sufficient to contain the Indian elephant population.

Migratory and dispersal pathways, also called corridors, are important for facilitating wildlife movement across PAs, but often lie outside the PA network and are already under immense anthropogenic pressures. The few studies on species-specific corridors mapped for certain landscapes or across the country, including those for tigers and elephants (Habib *et al.*, 2021a; Qureshi *et al.*, 2014; WTI, 2017), have revealed rapid shrinkage of these corridors. Despite this shrinkage, certain non-forest and moderately-modified landscapes facilitate wildlife movement between habitat patches, regularly used by species such as tigers, leopards and wolves (Habib *et al.*, 2021b; Hussain *et al.*, 2022), and as such form connecting links between populations. Such land uses also account for 40.67% of the elephant range in India (Padalia *et al.*, 2019). Rapid development that does not take into account the role of corridors and such land use matrices in maintaining ecological connectivity will have repercussions for the long term viability of increasingly isolated wildlife populations, and may threaten species persistence in the face of climate change. Thus, it is not only the legally protected wilderness areas, but also these unique spaces outside PAs and the mosaics of natural-human modified spaces that require conservation action to maintain their ecosystem function.

Corridors at crossroads

The ongoing threats to India's biodiversity are compounded by the intrusion of LI networks in sensitive wildlife habitats as well as designated ecological corridors. Fast-moving vehicular and train traffic on a road or railway track passing through a wildlife habitat or corridor is like a death trap for unsuspecting animals. Depending on the behavioural and cognitive abilities of wildlife species (Jacobson *et al.*, 2016), animals may continue to collide with vehicles and trains over time, or learn to avoid these areas at certain times of the day or entirely. Unfortunately, both responses can lead to population declines (Fahrig and Rytwinski, 2009). Such declines can be caused by the loss of individuals in a population by collision-related mortality. While high animal mortality is expected inside protected habitats because of high local animal abundances (Grilo *et al.*, 2011), the mortality of the occasional 'fit' disperser on a road or railway line passing through a corridor can be extremely detrimental to the local gene pool (Bujoczek *et al.*, 2011). Secondly, LI can cause the separation of once contiguous regional wildlife populations because of the avoidance of habitats adjacent to road and railway line clearings. This can happen through multiple pathways, such as by avoidance of the physical road surface, avoidance of traffic emissions such as noise, and avoidance of cars and vehicular traffic (D'Amico *et al.*, 2015). Roads and railway lines also decrease the quality of the habitat through which they pass, the effects percolating a few kilometres inside the habitat (Forman, 2000). Light, sound and air pollutants can leach into natural systems, cause disturbance to wildlife, interfere with inter- and intra-species communication, and add to the barrier already created by the physical road and railway track (Silva Lucas *et al.*, 2017; van der Ree *et al.*, 2015). The situation is compounded by the creation of smaller habitat fragments by road networks, more than half of which are <1 km^2 in size (Ibisch *et al.*, 2016) that are unsuitable for sustaining wildlife populations. Further, secondary development such as human settlements and establishments following the construction of a road or railway track can create more disturbances and reinforce the barrier to animal movement.

Nature, and the complex web of ecological interactions within it, relies on a delicate balance. Imbalances in these processes introduced through human activities can have adverse fallouts. For example, the unnatural removal of top predators from an ecosystem can lead to the proliferation of herbivores that would lead to unregulated grazing and trophic cascades (Kuijper *et al.*, 2016). Excessive unnatural removal of herbivores or prey species can lead predators to switch to domestic prey for survival, which would, in turn, increase conflict with human communities living near wildlife habitats. Tipping the scale towards natural imbalance would also deprive us of ecosystem services originating from wilderness areas, such as the provision of water, carbon sequestration, maintenance of mineral and hydrological cycles, and provision of valuable resources to forest-dependent communities. There are several other repercussions of human intrusion in natural spaces that we do not yet fully comprehend, but anticipate that it would be to the detriment of natural and human well-being in the long run.

The development of transportation LI sectors in sensitive landscapes is one such activity that is in direct conflict with wildlife and nature conservation through its myriad direct, indirect

 DOI: https://doi.org/10.63033/JWLS.BZOG7974

and cumulative effects. It would be unfortunate if the path to India's development was paved with severe repercussions for India's wildlife and ecosystems. Thus, maintaining the current Indian growth trajectory with India's place in the world as one of the most biodiverse regions is a humongous yet responsible task that requires small steps in ingenuity and innovation, backed by rigorous science.

Balancing infrastructure growth and conservation: inspirations and pathways

The mitigation hierarchy is a four-step framework that aims to manage biodiversity and ecosystems while balancing conservation with developmental needs (CEQ, 2000). The four steps are: Avoidance, Minimisation, Restoration, and Offsetting. With regard to the primary and foremost action in the hierarchy i.e., 'Avoidance', the Indian government has taken active steps to regulate any new infrastructure development within legally protected areas and designated wildlife and ecological corridors (MoRTH, 2019). However, most of this infrastructure development is expected to occur in rural areas where many development schemes of the government are focused. These are also the regions where humans and wildlife live in close proximity, in very elastic and open interfaces. Human activities and land uses like agriculture and settlements are often used equally if not more by some wildlife species that reside in fragmented but useful forest patches, largely cohabiting with each other in shared spaces (Jhala & Giles, 1991; Mahajan *et al.*, 2021). It is in these areas that the construction of infrastructure such as roads and railway lines pose a threat to the delicate balance of coexistence, and threaten the role of these rural landscapes as habitats and permeable corridors (Hussain *et al.*, 2022).

Experiences from other parts of the world have shown that building bridge-like structures (underpasses, overpasses, culverts, via-ducts, canopy bridges) under and over the 'grade' of the road or railway line (Smith *et al.*, 2015), and fencing to deter wild animals from accessing the road or railway line (Donaldson & Elliott, 2021) can help reduce the impacts of roads and railway lines. These measures can help save human lives as well since collisions with large animals such as elephants, deer like sambar and spotted deer, and wild pigs can be fatal for motorists and passengers. Further, technological solutions available today, including animal detection and early warning systems that alarm and alert wild animals near the road or railway line, and motorists, respectively, can be useful in averting possibly fatal collisions. Mitigation measures for other species groups, such as herpetofauna and birds, are specific to their ecological needs. The applicability of each of these measures can vary with the road or railway line project, landscape and target animal communities. Given the long life of transportation infrastructure and the large ecological footprint they have, the choice of mitigation measures requires careful research and understanding of the ecosystem, animal community and species most likely affected.

The field of road, railway and general LI ecology that forms the basis of wildlife mitigation measures gained traction prominently in the 1990s, with recognition of impacts and contemplation of solutions to this fast-growing problem (Forman & Deblinger, 1998; Forman *et al.*, 1997; Forman & Alexander, 1998). Around the same time, Canada became a world leader in mitigating the impacts of roads on wildlife by constructing 38 wildlife underpasses, 6 overpasses and exclusion fencing when the Trans-Canada Highway (TCH) passing through the Banff National Park was being widened between 1981 and 1996. Over 20 years old today, the wildlife crossing structures along the TCH are the highest in number along a single highway in the world, and the most diverse in terms of crossing structure types (Parks Canada Agency, 2022). The crossing structures are also the subject of the world's longest running wildlife mitigation monitoring programme, making the passages the most studied crossing structures in the world. Long-term monitoring of the crossing structures have revealed that these measures reduced wildlife-vehicle collisions by up to 80% (Clevenger *et al.*, 2001), and that the crossings allowed sufficient gene flow to prevent genetic isolation (Sawaya *et al.*, 2014). The research also shed light on the structural preferences of different species and species guilds (Clevenger and Waltho, 2005), that informed mitigation measures in other parts of the world.

These findings have also helped convince decision-makers that crossing structures work for wildlife, and have inspired the construction of several crossing structures around the world. For example, Malaysia took the lead on green highways in Southeast Asia by incorporating wildlife passages into highway construction and upgradation projects. Crossing structures and viaducts on highways in Malaysia today range from 80 – 900 m in width, and have even been constructed on an existing highway where no upgradation was planned (Wan Nordin *et al.*, 2020).

The beginning of the road for LI ecology in India

In India, while the recognition of the impacts of the increasing network of LI was still growing in the past decade, we were still in the infancy of understanding the direct impacts of LI on wildlife species found in the subcontinent (Rajvanshi *et al.*, 2001), and policy aspects of LI in ecologically-sensitive areas (Raman, 2011). The general understanding was that wide roads with fast-moving and heavy traffic would deter wildlife movement and cause wildlife mortality. Faced with a rampage of projects that threatened severe wildlife connectivity in the past few decades, we turned to the vast knowledge of road and railway ecology in the developed world. Images of the great animal crossing structures on the Trans-Canada Highway on the Banff National Park and eco-ducts on highways in Peninsular Malaysia inspired strategies to mitigate LI impacts in our country.

One of the landmark projects that paved the way for mandatory wildlife mitigation measures on LI in India was the improvement of the National Highway 44 (NH 44, earlier called NH 7). NH 44 is the longest highway in India, connecting 11 Indian states and several important urban and agricultural centres. On its way north from Nagpur (Maharashtra) towards Seoni (Madhya Pradesh) in central India, the highway passes through the Pench Tiger Reserves in Maharashtra and Madhya Pradesh states (together called Pench hereafter), and surrounding forests. Pench is a fabled tiger haven, and currently holds one of the most important source populations of tigers in the Central Indian Landscape (Qureshi *et al.*, 2014). Dispersing tigers from the reserve make their way across the majorly agrarian landscape with forest tracts towards other tiger habitats, and help revive wildlife and forests there. Such forest tracts originating from the eastern Pench form part of the corridors connecting Pench to other tiger habitats, most importantly Kanha Tiger Reserve in Madhya Pradesh and Navegaon Nagzira Tiger Reserve in Maharashtra. The erstwhile 2-lane NH 44 with rapidly increasing traffic, was also aligned along the eastern boundary of Pench, threatening the links between Pench and other tiger habitats in the landscape.

In view of the grave danger to the permeability of the corridors originating at Pench because of the expansion of NH 44 and the possible rise in animal mortality because of a further increase in

 DOI: https://doi.org/10.63033/JWLS.BZOG7974

traffic, the project gained extensive public and legal attention during the mid-2010s. Multiple civil society organisations and conservation NGOs came together to demand mitigation measures for the highway through litigation. Initially, the Central Empowered Committee (CEC) of the Supreme Court of India recommended using an alternate route, that would impair a different tiger corridor (Habib *et al.*, 2015). However, in a *fait accompli* situation on the existing NH 7 resulting from the prevalent piecemeal approach to LI development, following this approach would funnel traffic from already upgraded sections into a narrower space (alignment inside the forest) creating a greater barrier to animal movement (Habib *et al.*, 2016). Consequently, the National Highway Authority of India (NHAI) which was incharge of the upgradation project, was required to construct mitigation measures on the highway section passing through the tiger reserves and corridors. Finally, the crossing structures on NH 44 were ready to be used by the wildlife of Pench after multiple field visits, site assessments, technical reports, and deliberations involving an army of conservationists, decision-makers and highway officials. The 60 km stretch of the 4-laned highway now has 13 dedicated wildlife crossing structures between Chorbahuli village in Maharashtra and Mohgaon village in Madhya Pradesh, including the 1400 m long underpass on NH 44 passing through the Pench Tiger Reserve in Madhya Pradesh, the longest operational animal underpass in the world today.

The construction of the crossing structures has not only been a conservation milestone for India, but has also contributed to our knowledge of what works best for the Indian wildlife in terms of mitigation strategies on LI. The set of 9 crossing structures on the Maharashtra section of NH 44 are now the subject of a long-term monitoring programme that seeks to answer some basic questions regarding crossing structure design and use by wildlife of the Indian subcontinent (Saxena and Habib, 2022). Regular monitoring and camera traps set up under the crossing structures since early 2019 have revealed that the structures are currently being used by at least 23 wild mammals. While the learning curve varied for different species, a 240% increase in use of the structures during the first three years was observed (Habib *et al.*, 2020). The monitoring has also helped understand why group-living prey species prefer using underpasses at sites with vegetation cover nearby, and how larger structures make it possible for different tiger individuals to use the same structure without confronting one another. The study has also indicated how constructing larger structures can help buffer the effects of humans using the crossing structures as well, a situation that is typical of and omnipresent in India.

A roadmap for the present and future

As we await more interesting and novel insights from the crossing structure monitoring exercise at Pench, mitigation measures on several road and railway line projects across the country are under construction or nearing completion. Notable among these are the 1797 crossing structures comprising underpasses and overpasses on the 700 km long Mumbai-Nagpur Samruddhi Mahamarg (Mumbai-Nagpur Expressway), including the world's widest wildlife overpass measuring 60 m. Much earlier, crossing structures for elephants were constructed under the NH 54E passing through the Lumding Elephant Reserve, Assam (Singh *et al.*, 2010). The Delhi-Dehradun expressway connecting the capital cities of Delhi and Uttarakhand states would soon be ready with multiple large elevated sections totalling 21 km (Pandav and Habib, 2020), that would help clear the historic bottleneck between the Rajaji Tiger Reserve and the north-western limit of the Terai Arc Landscape that extends till Haryana. It is indeed a matter of pride for India to have begun the journey of mitigating the impacts of LI quite late as compared to the rest of the world, and yet have some of the world's largest wildlife-friendly structures on LI today.

These crossing structures offer us a unique opportunity to gather more information on the design and implementation of mitigation strategies through monitoring. This is because these are much larger than the mitigation measures present in other parts of the world (Denneboom *et al.*, 2021). The varied geographic spread of these projects, and variability in structure types, landscapes and target faunal communities also make these projects apt for a country-wide monitoring exercise.

Moving forward, it is essential to invest in rigorous research in an adaptive management framework to keep up the momentum of LI development that proactively integrates biodiversity conservation concerns into their plans. In this direction, ecologists must build on the wealth of global road and railway line ecology research, and supplement it with the diversity of unique problems and solutions applicable to wildlife in the Indian subcontinent. Further, solutions must move towards ecosystem and multi-species-focussed strategies from those focussing on single species, considering the varied ecological needs of different ecosystems and species groups. Novel solutions require relying on traditional wildlife management techniques combined with innovative and technological approaches. We need to enhance our current understanding of the natural world with how species ecology and behaviour are changing in the 'Anthropocene' in response to infrastructure development. Fostering transboundary cooperation for natural landscapes traversing nation-states is also vital for the immensely biodiverse Indian subcontinent. Close coordination and consultation with LI development agencies to understand engineering perspectives while designing viable mitigation structures would help put us in good stead, and achieve realistic biodiversity conservation targets.

In this direction, we outline a few guiding research elements and areas of research required to take LI ecology research in India forward. The outputs of the research should have direct practical influence on LI and mitigation planning decisions. These include basic questions that need to be answered for such ecological research to be applicable (Roedenbeck *et al.*, 2007; van der Ree *et al.*, 2015), as well as questions that we think are specific to and typical of developing economies, like India. These questions may require a synthesis of different studies and preferably field-based experimental (as opposed to observational) studies.

1. What are the wildlife population-level consequences of LI-related impacts?
2. What is the relative importance of LI-related impacts on wildlife as compared to that of other human activities?
3. Under which scenarios and within which biodiverse landscapes/regions areas should LI development be avoided completely, and what are the compelling arguments for the same?
4. How do species behaviour, ecology, energetics and interspecific interactions change in the vicinity of human infrastructure, and what consequences can it have for LI impacts (e.g., increase/decrease in roadkill rates), human-wildlife interactions, and mitigation measure effectiveness?
5. How effective are elements of existing infrastructure and mitigation structures, and how can they be modified or retrofit to be more effective?
6. With respect to mitigation measures, which impacts demand priority as a consequence of the weight of their influence on wildlife?
7. In terms of mitigation measure design and planning, can combinations and designs of mitigation measures reduce more than one impact, and for more than one species or taxa (focus on community-level instead of focal species approach)?

 DOI: https://doi.org/10.63033/JWLS.BZOG7974

8. How can interactions between species and physical infrastructure be explained through a trans-disciplinary lens (e.g., ecology, engineering, design), and how can these findings influence mitigation measure design?
9. In terms of monitoring, what statistics (crossing frequency, roadkill rate) of crossing structure/mitigation measure certify its effectiveness in context of the impact it was envisioned to mitigate?
10. How can existing LI segments passing through ecologically-sensitive habitats be identified, prioritised and mitigated, including options such as rerouting existing infrastructure, if objectively necessary?
11. What are the economics of LI development through areas that are ecologically fragile in terms of socio-economic benefit, environmental and ecological cost, cost of mitigative actions, and long-term costs/benefits of incorporating (or not) ecological concerns into infrastructure planning?

We expect that focussed research with strong inferences regarding impacts and viable working solutions would help provide weightage to the conservation vs. development argument in favour of considering ecological concerns into infrastructure development and planning, which currently tips in favour of socio-economic considerations.

At the same time, we provide a blueprint for action by LI development agencies to streamline the process of integrating of biodiversity conservation into development plans. These actions would not only ensure timely integration of conservation concerns into development plans, but would also reduce risks of litigation, monetary loss and delayed project implementation.

1. Initiate SEA or sectoral assessments including regional environmental impact assessments that consider the cumulative impacts of multiple infrastructure on a landscape (Saxena *et al.*, 2016),
2. Align multiple infrastructures in the same corridor through inter-agency cooperation, for example between road agencies that work at different levels (NHAI, PWD) but may have projects aligned nearby,
3. Include mitigation and biodiversity offset costs into overall project costs to avoid cost overruns later on,
4. Provide well thought-out and equally viable alignment alternatives to forest and conservation agencies at the planning stage, before the process of obtaining statutory forest, wildlife or environmental clearances, and land acquisition have been initiated, and
5. Invest in research on the effectiveness of mitigation measures and structural components of mitigation measures like fences, crossing structure construction material, road lighting, automated animal detection and collision avoidance systems.

Further, collective action from multiple stakeholders can also help maintain the momentum of achieving sustainable transportation infrastructure. Some areas of action by these stakeholders can be concerted outreach efforts by non-governmental organisations (NGOs) and the media. NGOs working at national and local levels can help collate wildlife mortality data from roads and railway lines in collaboration with the relevant forest departments. Greater awareness and recognition of the impacts of LI on wildlife can help garner public support. This can also be achieved by widening the scope of environmental and wildlife science studies in educational institutes to include thematic areas addressing conservation challenges in the Anthropocene, including that of LI impacts.

More importantly, it is vital to make concerted efforts to realise policy imperatives to achieve sustainable LI development. It is important to suitably advance and adapt our environmental protection policies and frameworks to keep up with the challenge of the rapidly expanding transportation sector. Development of LI-specific guidelines within the framework of existing environmental assessment laws through intersectional research in environmental, social and wildlife policy is imperative, given the uniqueness of the problem. A step towards this direction could be the use of tools such as strategic environmental assessments of LI development plans at the sectoral and regional levels (Saxena *et al.*, 2016).

Considering the vital link between an efficient transportation system and economic progress, the coming decade is expected to be crucial for India. The efforts we make in this decade will also dictate how we are able to sustain a thriving natural world in the face of accelerated human development. If we are to maintain the aspired quality of infrastructure, and overall human and environmental well-being, solving this crisis is imminent and would require inventive and often simple solutions. By investing in green infrastructure to reduce wildlife-vehicle collisions and maintain the continuity of natural processes like wildlife movement, the nation can ensure road and rail safety, and secure resilient natural landscapes. In other words, investing in green LI that connects habitats maintains and/or facilitates habitat connectivity can help reduce conservation costs by reducing the costs of translocating wild animals and enhancing wildlife in smaller habitats. Thus, a strong commitment to biodiversity-inclusive growth that is sensitive to both economic development as well as nature conservation will truly help us achieve development that is sustainable in the long term and demonstrate the nation's will towards responsible ecological stewardship.

Acknowledgements

The authors would like to acknowledge the support from Director, Dean and Registrar Wildlife Institute of India. Authors also acknowledge the support and guidance of former Director Dr. V. B. Mathur and Dr. Asha Rajvanshi Former Sc – G and EIA Nodal Officer, Wildlife Institute of India. Authors also acknowledge the support from other linear infrastructure agencies especially NHAI, MoRTH, MoR, CEA, Ministry of Power and other for support and relevant information. The authors would like to acknowledge the anonymous reviewers whose comments helped improve the manuscript substantially.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY

No data was used in this research.

AUTHOR CONTRIBUTIONS

BH conceived the idea, AS wrote the first draft of the paper. Both BH and AS revised the initial draft and approved the final draft for submission.

References

Balasubramanian, A., (2023). Roads and Road Transport in India: Towards a History of the Present [WWW Document]. *Vis.* Clim. Loss. URL https://histecon.fas.harvard.edu/climate-loss/roads/index.html (accessed 6.26.24).

Bujoczek, M., Ciach, M. & Yosef, R., (2011.) Road-kills affect avian population quality. Biol. Conserv. 144, 1036–1039. https://doi.org/10.1016/j.biocon.2010.12.022

CEQ, (2000). Protection of the environment (under the National Environment Policy Act). (No. 40 CFR 1500-1517). Council on Environmental Quality, Washington, DC: Council on Environmental Quality.

Clevenger, A.P., Chruszcz, B. & Gunson, K.E., (2001). Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions. *Wildl. Soc. Bull*. 29, 646–653.

Clevenger, A.P. & Waltho, N., (2005). Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. *Biol. Conserv.* 121, 453–464. https://doi.org/10.1016/j.biocon.2004.04.025

D'Amico, M., Périquet, S., Román, J. & Revilla, E., (2015). Road avoidance responses determine the impact of heterogeneous road networks at a regional scale. J. Appl. *Ecol.* 53, 181–190. https://doi.org/10.1111/1365-2664.12572

Denneboom, D., Bar-Massada, A. & Shwartz, A., (2021). Factors affecting usage of crossing structures by wildlife – A systematic review and meta-analysis. *Sci. Total Environ.* 777, 146061. https://doi.org/10.1016/j.scitotenv.2021.146061

Donaldson, B.M. & Elliott K.E.M., (2021). Enhancing existing isolated underpasses with fencing reduces wildlife crashes and connects habitat. Hum.-Wildl. *Interact*. 15, 148–161.

Dutta, S. & Jhala, Y., (2021). Devil is in the detail: behaviorally explicit habitat selection by the Critically Endangered great Indian bustard. Endanger. *Species Res.* 45, 55–69. https://doi.org/10.3354/esr01126

Fahrig, L. & Rytwinski, T., (2009). Effects of roads on animal abundance: An empirical review and synthesis. *Ecol. Soc.* 14. https://doi.org/10.5751/ES-02815-140121

Forman, R. & Deblinger, R.D., (1998). THE ECOLOGICAL ROAD-EFFECT ZONE FOR TRANSPORTATION PLANNING AND MASSACHUSETTS HIGHWAY EXAMPLE.

Forman, R.T.T., (2000.) Estimate of the Area Affected Ecologically by the Road System in the United States. Conserv. Biol. 14, 31–35.

Forman, R.T.T., Alexander, L.E., 1998. Roads and their major ecological effects. *Annu. Rev. Ecol. Syst.* 29, 207–231. https://doi.org/10.1146/annurev.ecolsys.29.1.207

Forman, R.T.T., Friedman, D.S., Fitzhenry, D., Martin, J.D., Chen, A.S., & Alexander, L.E., (1997). Ecological effects of roads: toward three summary indices and an overview for North America, in: Canters, K. (Ed.), Habitat Fragmentation and Infrastructure. Ministry of Transport, Public Works and Water Management, The Netherlands, pp. 40–54.

Grilo, C., Ascensão, F., Santos-Reis, M. & Bissonette, J.A., (2011). Do well-connected landscapes promote road-related mortality? *Eur. J. Wildl. Res.* 57, 707–716. https://doi.org/10.1007/s10344-010-0478-6

Habib, B., Nigam, P., Mondal, I., Hussain, Z., Ghaskadbi, P., Govekar, R.S., Praveen, N., Banerjee, R., Ramanujam, R.M. & Ramgaonkar, J., (2021a). Telemetry Based Tiger Corridors of Vidarbha Landscape, Maharashtra, India. Wildlife Institute of India, Dehradun.

Habib, B., Ghaskadbi, P., Khan, S., Hussain, Z. & Nigam, P., (2021b). Not a cakewalk: Insights into movement of large carnivores in human-dominated landscapes in India. *Ecol. Evol.* 11, 1653–1666. https://doi.org/10.1002/ece3.7156

Habib, B., Rajvanshi, A., Mathur, V.B. & Saxena, A., (2016). Corridors at Crossroads: Linear Development-Induced Ecological Triage As a Conservation Opportunity. Front. *Ecol. Evol.* 4, 132. https://doi.org/10.3389/fevo.2016.00132

Habib, B., Saxena, A., Jhala, Y.V. & Rajvanshi, A., (2020). Monitoring of Animal Underpasses on National Highway 44 (earlier 7) passing through Pench Tiger Reserve, Maharashtra, India (No. 2020/09). Wildlife Institute of India, Dehradun, Dehradun.

Habib, B., Saxena, A., Mondal, I., Rajvanshi, A., Mathur, V.B. & Negi, H.S., (2015). Proposed mitigation measures fov maintaining habitat contiguity and reducing wildlife mortality on NH6 & 7 in the Central Indian Landscape. Wildlife Institute of India, National Tiger Conservation Authority.

Hussain, Z., Ghaskadbi, P., Panchbhai, P., Govekar, R., Nigam, P., & Habib, B., (2022). Long-distance dispersal by a male sub-adult tiger in a human-dominated landscape. *Ecol. Evol*. 12, e9307. https://doi.org/10.1002/ece3.9307

Ibisch, P.L., Hoffmann, M.T., Kreft, S., Pe'er, G., Kati, V., Biber-Freudenberger, L., DellaSala, D.A., Vale, M.M., Hobson, P.R. & Selva, N., (2016). A global map of roadless areas and their conservation status. *Science* 354, 1423–1427.

Jacobson, S.L., Bliss-Ketchum, L.L., De Rivera, C.E. & Smith, W.P., (2016). A behavior-based framework for assessing barrier effects to wildlife from vehicle traffic volume. *Ecosphere* 7, 1–15. https://doi.org/10.1002/ecs2.1345

Jhala, Y., Gopal, R., Mathur, V., Ghosh, P., Negi, H.S., Narain, S., Yadav, S.P., Malik, A., Garawad, R. & Qureshi, Q., (2021). Recovery of tigers in India: Critical introspection and potential lessons. *People Nat.* 3, 281–293. https://doi.org/10.1002/PAN3.10177/SUPPINFO

Jhala, Y.V. & Giles, R.H., (1991). The Status and Conservation of the Wolf in Gujarat and Rajasthan, India. *Conserv. Biol.* 5, 476–483. https://doi.org/10.1111/j.1523-1739.1991.tb00354.x

Johnsingh, A.J.T., (1986). Diversity and conservation of carnivorous mammals in India. Proc. Indian Acad. Sci.

Kshettry, A., Vaidyanathan, S., Sukumar, R. & Athreya, V., (2020). Looking beyond protected areas: Identifying conservation compatible landscapes in agro-forest mosaics in north-eastern India. Glob. *Ecol. Conserv.* 22, e00905. https://doi.org/10.1016/j.gecco.2020.e00905

Kuijper, D.P.J., Sahlén, E., Elmhagen, B., Chamaillé-Jammes, S., Sand, H., Lone, K. & Cromsigt, J.P.G.M., (2016). Paws without claws? Ecological effects of large carnivores in anthropogenic landscapes. *Proc. R. Soc. B Biol. Sci.* 283. https://doi.org/10.1098/rspb.2016.1625

Mahajan, P., Khandal, D. & Chandrawal, K., (2021). Factors Influencing Habitat-Use of Indian Grey Wolf in the Semiarid Landscape of Western India. *Mammal Study* 47, 23–37. https://doi.org/10.3106/ms2021-0029

MoRTH, 2019. Principles to be adopted while considering the highway near or within wildlife sanctuaries/National Parks/Animal Corridor. https://morth.nic.in/print/5937

Padalia, H., Ghosh, S., Reddy, C.S., Nandy, S., Singh, S. & Kumar, A.S., (2019). Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. Environ. *Monit. Assess.* 191, 802. https://doi.org/10.1007/s10661-019-7696-5

Pandav, B. & Habib, B., (2020). Rapid assessment of wildlife and suggested mitigation measures for development of Delhi Dehradun highway in the Shivalik hills. Wildlife Institute of India, Dehradun.

Parks Canada Agency, Govt. of Canada, (2022). Wildlife crossing structures - Wildlife crossing structures and research [WWW Document]. URL https://parks.canada.ca/pn-np/ab/banff/nature/conservation/transport/tch-rtc/passages-crossings (accessed 6.23.24).

PIB, 2024. Building India: 10 years of Infrastructure Development (No. RU-56-01-369-140324/EXPLAINER). Press Information Bureau, Ministry of Information & Broadcasting.

Qureshi, Q., Saini, S., Basu, P., Gopal, R., Raza, R. & Jhala, Y.V., (2014). Connecting Tiger Populations for Long-term Conservation. National Tiger Conservation Authority & Wildlife Institute of India, Dehradun. https://doi.org/Tr2014-02

Rajvanshi, A., Mathur, V., Teleki, G. & Mukherjee, S., (2001). Roads, Sensitive Habitats and Wildlife Roads, Sensitive Habitats and Wildlife Environmental Guideline for India and South Asia.

Raman, T.R.S., (2011). Framing ecologically sound policy on linear intrusions affecting wildlife habitats - Background paper for the National Board for Wildlife 20, 51.

 DOI: https://doi.org/10.63033/JWLS.BZOG7974

Roedenbeck, I.A., Fahrig, L., Findlay, C.S., Houlahan, J.E., Jaeger, J.A.G., Klar, N., Kramer-Schadt, S. & van der Grift, E.A., (2007). The Rauischholzhausen agenda for road ecology. Ecol. Soc. 12. https://doi.org/10.5751/ES-02011-120111

Sawaya, M.A., Kalinowski, S.T. & Clevenger, A.P., (2014). Genetic connectivity for two bear species at wildlife crossing structures in Banff National Park. *Proc. R. Soc. B Biol. Sci.* 281, 20131705. https://doi.org/10.1098/rspb.2013.1705

Saxena, A. & Habib, B., (2022). Crossing Structure Use in a Tiger Landscape, and Implications For Multi-Species Mitigation. Transp. Res. *Part Transp. Environ.* 109, 103380. https://doi.org/10.2139/ssrn.4032623

Saxena, A., Rajvanshi, A. & Mathur, V.B., (2016). Progressive Trends in the Uptake of SEA in South Asia. http://dx.doi.org/10.1142/S1464333216500186 18. https://doi.org/10.1142/S1464333216500186

Silva Lucas, P., Gomes de Carvalho, R. & Grilo, C., (2017). Railway Disturbances on Wildlife: Types, Effects, and Mitigation Measures, in: *Railway Ecology. Springer, Portugal,* pp. 81–99.

Singh, A.P., Singh, A.K., Mishra, D.K., Bora, D.P.J., Sharma, A., (2010). Ensuring safe access to wildlife in Lumding Reserve Forest, India, Mitigating the impacts of up-gradation of Doboka-Silchar National Highway (NH54E). WWF-India.

Smith, D.J., van der Ree, R. & Rossel, C., (2015). Wildlife crossing structures: an effective strategy to restore or maintain wildlife connectivity across roads, in: van der Ree, R., Smith, D.J., Grilo, C. (Eds.), Handbook of Road Ecology. John Wiley & Sons, Ltd.

Surve, N.S., Sathyakumar, S., Sankar, K., Jathanna, D., Gupta, V. & Athreya, V., (2022). Leopards in the City: The Tale of Sanjay Gandhi National Park and Tungareshwar Wildlife Sanctuary, Two Protected Areas in and Adjacent to Mumbai, India. Front. *Conserv. Sci*. 3. https://doi.org/10.3389/fcosc.2022.787031

van der Ree, R., Jaeger, J. a. G., Rytwinski, T. & Van Der Grift, E., (2015). Good science and experimentation are needed in road ecology, in: Handbook of Road Ecology. *Wiley*, pp. 71–81. https://doi.org/10.1002/9781118568170.ch10

van der Ree, R., Smith, D.J. & Grilo, C., (2015). The ecological effects of linear infrastructure and traffic: challenges and opportunities of rapid global growth, in: van der Ree, R., Smith, D.J., Grilo, C. (Eds.), Handbook of Road Ecology. John Wiley & Sons, Ltd.

Wan Nordin, W.S., Ibrahim, S. N., Elagupillay, S. T. & Gopalakrishnan L. (2020). Guidelines for Development of Smart Green Linear Infrastructure for Safe Movement of Large Wild Mammals in Peninsular Malaysia: Underpasses & Overpasses for Roads. Department of Wildlife and National Parks, Peninsular Malaysia, Kuala Lumpur.

WTI (2017). Right of Passage: Elephant Corridors of India [2nd Edition], Conservation Reference Series No. 3. Wildlife Trust of India, New Delhi.

 DOI: https://doi.org/10.63033/JWLS.BZOG7974

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Review Article

Current Perspectives in the Forensic Analysis of Timbers using Vibrational Spectroscopy: A Review

Arti Yadav[1], Sweety Sharma[2], Lovlish Gupta[2], Vaibhav Singh[2], Rajinder Singh[1*]

[1]Department of Forensic Science, Punjabi University, Patiala, Punjab, India, 147002.
[2]LNJN National Institute of Criminology and Forensic Science, National Forensic Science University, Delhi Campus, Ministry of Home Affairs, Government of India.

DIAMOND OPEN ACCESS Crossref

EDITED BY
Ajay Gaur
Centre for Cellular & Molecular Biology, Hyderabad, India

*CORRESPONDENCE
Rajinder Singh
rajinder_forensic@pbi.ac.in

RECEIVED 19 April 2024
ACCEPTED 02 August 2024
ONLINE EARLY 06 August 2024

CITATION
Yadav, A., Sharma, S., Gupta, L., Singh, V., Singh, R. (2024). Current Perspectives in the Forensic Analysis of Timbers using Vibrational Spectroscopy: A Review. *Journal of Wildlife Science,* 1 (2), 69-80.
https://doi.org/10.63033/JWLS.KRNG5178

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Wildlife crime has increased significantly with respect to timbers such as illegal timber trading, logging, harvesting, and counterfeiting. It has tremendously drained the economy of different countries since timber trafficking at the global level has an average annual net worth of US$ 50-150 billion. Moreover, timbers can act as important forensic evidence as they can be found at the crime scenes revealing the relationships between the crime scene and corpus delicti. Since ancient times, various traditional techniques have been used for timber identification such as anatomical investigation by visual method at the macroscopic and microscopic levels. However, morphological and anatomical techniques have some advantages, such as cost effectiveness, and limitations as they require experienced personnel. Vibrational spectroscopic tools such as infrared and Raman spectroscopy help in discriminating various species of timber as different timber species have unique phytochemicals. By examining the concentrations of cellulose, lignin, and hemicelluloses, the chemical composition can also be estimated. Herein, this review is carried out using vibrational spectroscopic methods for timber identification to combat criminal activities related to timbers for the dissemination of justice. Recent advancements and prospects are also emphasized in this review paper.

Keywords: Timbers, FTIR, NIR, Spectroscopy, Chemometrics, Forensic.

Introduction

Timbers are utilized in our day-to-day life owing to their multifarious applications such as paper production, fuel source, carpentry, furniture, musical instruments, railway foundations, and flooring. Some timber species are valuable for their medicinal and aromatic properties. It is also used as a biodegradable composite and a significant source of energy. Timber as a fuel has an advantage over other fossil fuels as the emission of carbon dioxide is 90% lower. It is used in many forms such as trusses, piles, beams, girders, and columns. Due to its magnificent properties, it is being used at a large scale resulting in the overexploitation of some precious timber species such asagarwood (*Aquilaria* spp.), mahogany (*Swietenia macrophylla*), monkey puzzle (*Araucaria araucana*), red sandalwood (*Pterocarpus santalinus*), *etc.* that are now on the verge of extinction or being endangered. These valuable timbers are illegally traded at the global level and have a market worth billions. Global timber trafficking accounts for 15-30 % of the total timber trade, estimated to be around US$50-150 billion per year (Wallen, 2018). The smuggling of timber strips can severely impact a large economy, especially if it has been generated through illegal logging. It has not only deeply affected the forest by depleting the lands but has also threatened the livelihood of the indigenous tribes and destroyed the habitat of flora and fauna.

International measures to mitigate the problem often include the implementation of legislation intended to discourage illicit timber trade and restrict the trafficking of particular species from specific areas. These are listed in the various plant-protecting organizations at the global level such as the International Union for Conservation of Nature (IUCN) Red List and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which includes three appendices based on the degree of protection required (Dormontt *et al.*, 2015; Schloenhardt, 2008). Appendix I includes species that are threatened with extinction. Therefore, the trade of such species is strictly forbidden, and can only be permitted in exceptional circumstances. Appendix II includes species not yet on the verge of extinction, although the trade of these species must be controlled and monitored to avoid their complete extinction. In Appendix III, the species of least concern have been listed and these species can be exported or imported with an appropriate document for clearance at entry or exit on the port as mentioned in the United Nations Environmental Programme (UNEP), 2019.

Forensic science is a vast field with its root spread into nearly all domains. One of the subfields of forensic science is forensic botany which involves the application of the theory and the principles of botany to seek justice in criminal investigation (Solinge *et al*., 2016). Another important aspect of forensic botany is controlling illegal logging and harvesting timber species. A major issue in the identification process is that most of the timber products lack the diagnostic characteristics essential for plant identification (fruit, pollen, flowers, and leaves), and therefore, it becomes very difficult to identify a specific timber species (Dormontt *et al.*, 2015; Wiedenhoeft, 2016). Timbers are mainly composed of cellulose, hemicellulose, and lignin. However, the concentrations are not only species-dependent but also affected by environmental conditions, geographical locations, ageing, and fossilization. The level of precision of timber identification varies significantly through physical, chemical, and genetic methods. The summary of the research conducted so far to identify timbers is represented in Figure 1.

In addition to investigating timber involved in illicit timber logging, adulteration (Kannangara *et al.*, 2020), and harvesting, forensic agencies are also interested in knowing: What is the age of the specimen procured? To what geographical location does the specimen belong? The prior question becomes important to find out whether the timber was harvested before the implementation of legislation or not. Determining the geographical area is crucial as some species are restricted to specific areas within their distributional range.

Most traditional morphological traits cannot identify and classify plant material (timber) at the species level, especially when the specimens are collected in a decayed form and lack physical features (Dormontt *et al.*, 2015; Kannangara *et al.*, 2020). Traditionally, timber species were identified using time-consuming and laborious methods such as physical, visual, and anatomical inspections (Yang *et al.*, 2015). Nowadays, quick approaches are preferred over traditional methods such as Fourier Transfer Infrared (FTIR) spectroscopy, DNA barcoding, and stable isotopes (Dormontt *et al.*, 2015). All techniques have some advantages and limitations. Certain studies also show that Raman and NIR spectroscopic methods have evolved to analyze particularly non-structural extractive substances from timbers. These characteristics were examined for decades using traditional techniques, whereas due to expensiveness, and time consumption, alternative spectroscopic methods such as Near-Infrared Spectroscopy (NIRS) and Raman spectroscopy are more frequently utilized at current times (Schimleck & Workman, 2004). Various characteristics of timber have been studied for a long time and are analyzed by specific spectroscopic methods. For example, surface and chemical characteristics are widely analyzed using FTIR spectroscopic methods, whereas biological components and origin in terms of geographical region of timber species can be easily identified using NIR Spectroscopy. These characteristics are summarized and represented in Figure 2.

The era of IR spectroscopy started with Borga *et al.* (1992), who were the pioneers in the field of applying FTIR spectroscopy for timber identification. It was followed by Schimleck (2004) by classifying species of *Eucalypts* using NIRS in conjunction with principal component analysis (PCA). There is a wide applicability of NIRS for the analysis of timbers, such as discriminating similar-looking timber species (Flæte *et al.*, 2006; Haartveit & Flæte, 2008), discriminating same timber species belonging to different geographical origins (Rana *et al.*, 2008), analyzing the structure of photodegraded wood (Colom *et al.*, 2003), and studies on timbers subjecting to physical and chemical treatments (Hinterstoisser *et al.*, 2003; Schwanninger *et al*., 2004). A detailed list of the spectroscopy methods applied in timber forensics so far is given in Table 1.

Fourier Transform Infrared (FTIR) Spectroscopic

FTIR spectroscopy is a very useful method for characterizing the structural chemistry of timber with minimum sample preparation (Popescu *et al.*, 2007). Primarily, FTIR spectroscopy along with multivariate data analysis chemometric tools such as PCA, Linear Discriminant Analysis (LDA), Partial Least Square Regression (PLSR), and Soft Independent Modelling of Class Analogies (SIMCA) are used for the qualitative and quantitative analysis of timbers. Spectroscopic analysis is a handy tool over conventional methods, as the latter may often destroy the timber sample and require a large sample size for the time-consuming analysis procedure (Soest, 1963).

Analysis of surface characteristics of timbers is one of the major advantages of FTIR spectroscopic analysis; this was indicated by similar research where the surface texture and other characteristics of a corn stalk were analyzed using FTIR spectroscopy and X-ray diffraction techniques (Zhao *et al.*, 2013). Timber biomass is one of the most valuable, renewable and abundant biomasses present on the earth. However, the analysis of these timber samples using FTIR spectroscopy needs certain physical modifications, such as a reduction in the size of biomass to increase its bulk density, new surface area, pore size, *etc.* Hence, a superfine grinding technology is used nowadays for analysis in FTIR spectroscopy (Zhao *et al.*, 2013).

FTIR spectroscopy along with a chemometric approach is one of the best options to analyze timber samples without requiring time-consuming sample preparation. This has helped in the qualitative and quantitative analysis of timbers and has made the highly complex procedure easier compared to procedures that involve the isolation of timber components and degradation of the monomeric fragment. FTIR coupled with multivariate analysis is the most straightforward spectroscopic analysis used for rapid analysis of the structural components of timber. When compared to traditional chemical analytic methods, this technique is non-destructive and also utilizes a very small sample size (Chen *et al.*, 2010). Colom *et al.* (2003) showed that the photodegraded timbers can also be subjected to structural analysis using FTIR spectrometry. The degradation in the timber samples indicates the chemical and structural strength of particular timber samples. FTIR not only determines the potency and extent of degradation of timber but also identifies the cause of the deterioration such as natural ageing, oxidation, thermochemical degradation, artificial ageing, *etc.*

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

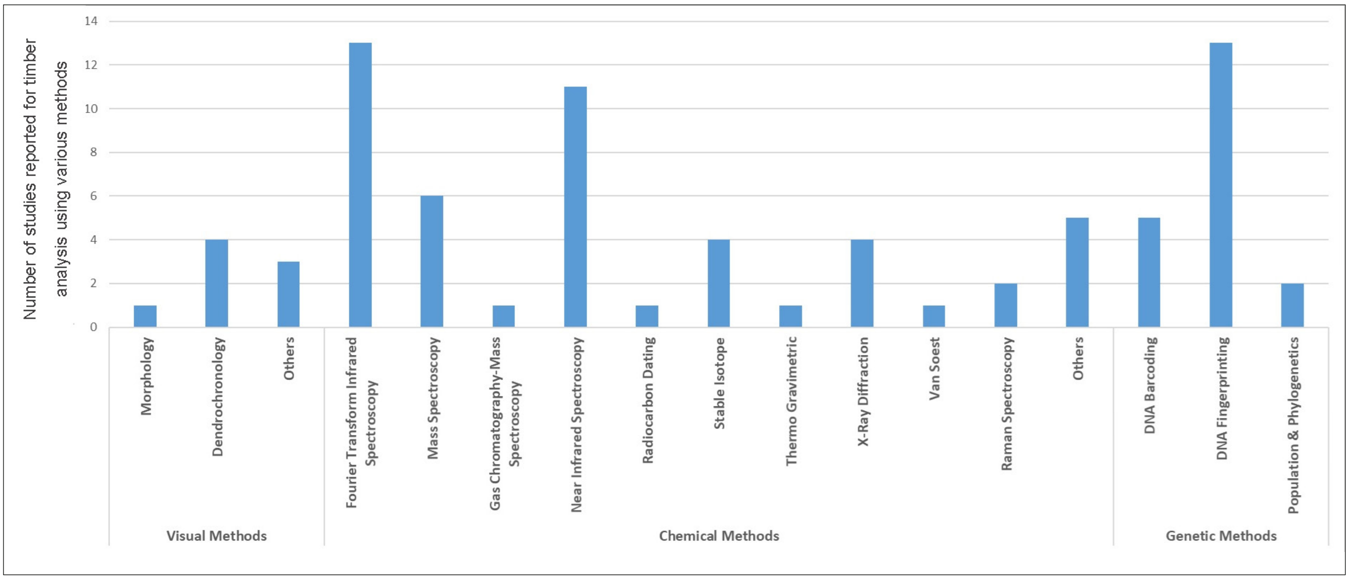

Figure 1: Methods used for the analysis of timber.

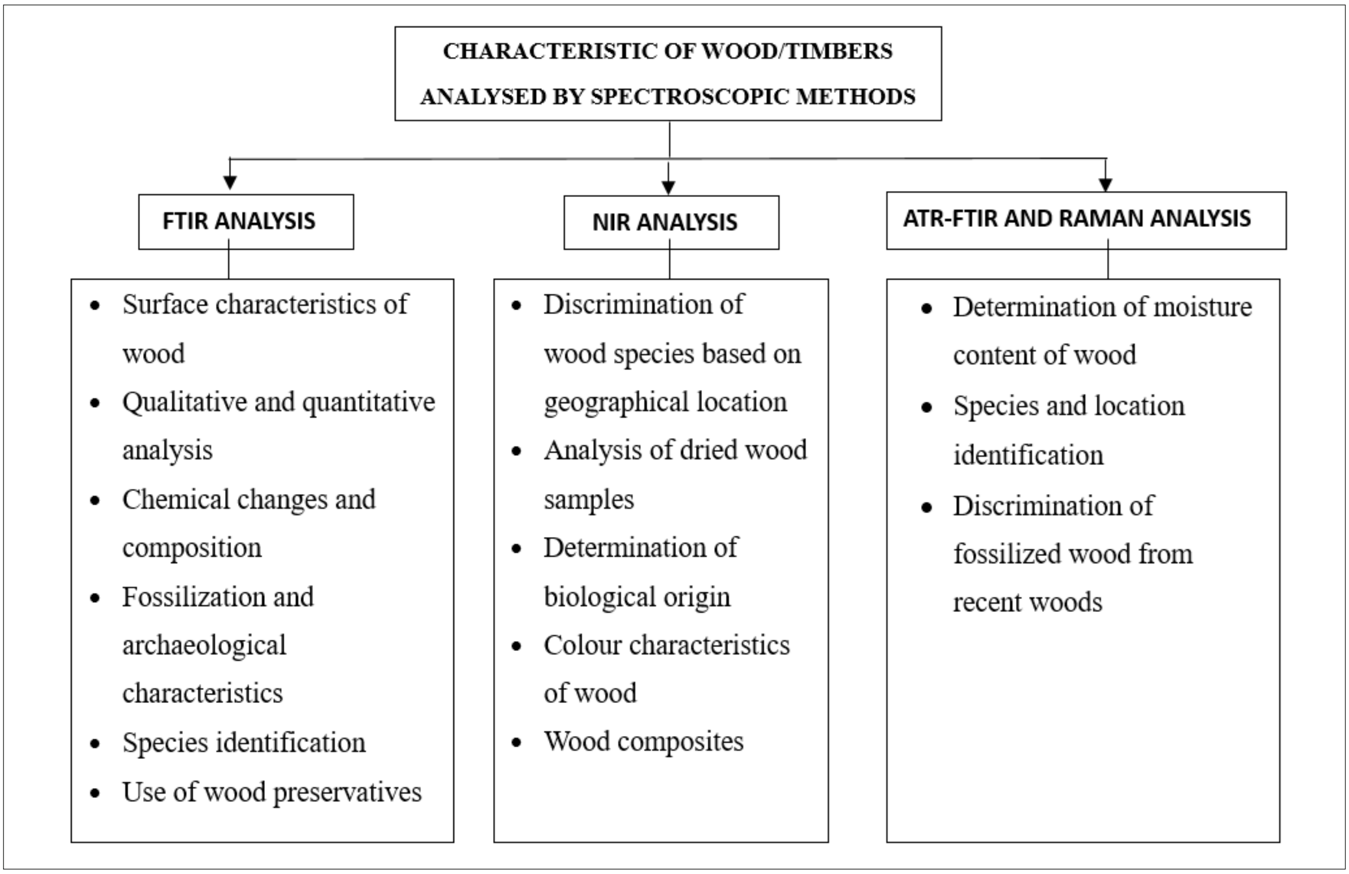

Figure 2: Spectroscopic techniques and analysis of individual characteristics of timber.

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

Table 1. Analysis of timbers using various spectroscopic methods coupled with statistical or chemometric approaches.

Aim	Results	Statistical tool	Accuracy	Conclusion	References
		Near Infrared Spectroscopy (NIRS)			
Analysis of hardwood species in chip form using reflectance NIR spectroscopy, seven species were encountered including beech, acacia, hornbeam, ash-tree, aspen, birch, and cherry.	NIR regions of timber have established overtone regions of stretching or other vibrations of functional groups such as O-H, C-H, and N-H, extensive drying (105°C) has resulted in new peaks in regions where water contents were absent. The regression coefficient was 0.8054.	Partial Least Squares Regression (PLSR)	R^2 0.8054	Wet wood chips were successfully identified in comparison to dried chips. All the wood species were accurately identified except cherry, and ash trees which were identified with low accuracy.	Russ *et al.*, 2009
Analysis of solid timber species has been performed using NIR spectrometry to identify and differentiate specimens of Swietenia macrophylla from other timber species.	Intact wood samples were analysed instead of analysing it in powdered form to observe the efficiency of NIRS to identify and discriminate it from the other three timber species. It was observed that the anatomical surface affected the spectra obtained with a small error rate.	Partial Least Squares Discriminant Analysis (PLS-DA)		NIRS along with PLS-DA was an exclusive tool to analyse and separate different timber species such as mahogany from similar types of timbers by using the intact wood sample.	Braga *et al.*, 2011
Establishment of geographical provenance of timber *i.e.*, to geolocate the timber samples to a specific geographical area using NIR spectrometry.	Different peaks in the region of IR spectroscopy were obtained using FT-NIR Spectroscopy as follows: • amorphous region, OH stretching at 7000 cm^{-1} • semi-crystalline region, OH stretching at 6718 cm^{-1} • crystalline region, OH stretching at 6287 cm^{-1} • 5883 cm^{-1} region is for CH stretching having CH_3 group. • 5800cm^{-1} for the first overtone of furanose or pyranose rings of hemicellulose.	Cluster Analysis (CA), Identify Test (IT), Principal Component Analysis (PCA)	-	FT-NIR is non-destructive, cost-effective, highly sensitive, detects very minute chemical composition differences, and can determine the origins of unknown timbers.	Sandak *et al.*, 2011
NIRS along with chemometric models were used for the discrimination of specific timber species such as true mahogany, cedar, andiroba, and curupixa.	The Root Mean Square Error (RMSE) for curupixa, andiroba, cedar, and mahogany were 0.06, 0.12, 0.09, and 0.14 respectively. The misclassification rate was much less in the build chemometric models.	PLS-R	RMSE: curupixa, andiroba, cedar, and mahogany were 0.06, 0.12, 0.09, and 0.14, respectively.	NIRS with a chemometric approach such as PLS R is very helpful for the conservation of endangered species of timber such as mahogany.	Pastore *et al.*, 2011
Timber species and location identification using NIR Spectroscopy.	• NIR spectra have shown maximum overtone at O–H stretching of cellulose at 1473nm peak. • At 2092 nm, O-H and C-H deformation was indicated (for cellulose and xylem). • The variance level in chemical composition obtained from PCA was 76%, 11% for the spectra. PLS-DA models have shown 400-2500nm region of different and separate spectra for three timber species with 100% accuracy.	PCA PLS-DA	90 % accuracy for PLS-DA	• Case 1. NIR Spectroscopy models showed 100% correctness in demonstrating different timber species. • Case 2. Three models with three trees from different locations showed the accuracy of 67%, 94%, and 99%. Hence, NIR has the potential for the identification of different timber species, location-wise. However, an accurate result may need better identification techniques.	Yang *et al.*, 2015

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

Significant analysis of the origin of the country of true mahogany timber species using NIR spectrometry and multivariate analysis.	SIMCA analysis produced was significant and reliable results with 67-100% and 70-98% efficiency, in the range of 1595-2396 and 950-1650 nm, respectively. The PLS-DA approach was significant with 90-100% accuracy, 1470 nm wavelength in NIR spectra represented OH stretching of cellulose, water, and hemicellulose.	Soft Independent Modelling of Class Analogies (SIMCA), PLS-DA	SIMCA and PLS-DA up to 100% accuracy	Well-defined analytical details were analysed discriminating the heterogeneity of timber species.	Silva *et al.*, 2018
Quality control and quality assurance of pellet markets by discriminating various timber residues using NIR or FT-NIR in timber processing units.	PCA plotted scores clustered in various timber residues; various separation trends differentiated major ply timber and OSB timber samples along with virgin timbers. However, glue-laminated timbers were not plotted in comparison to virgin timbers. Hardwood showed negative values of PCA, whereas positive scores were indicative of softwood. PLS-DA was used to separate virgin and treated timbers, which were not easily discriminated by PCA.	PCA, PLS-DA	100 % accuracy from PLS-DA	Sensitivity, specifically rated higher in the PLS-DA approach, when used with NIR Spectroscopy. However, variable selection methods have been allocated for better classification performance. NIR spectroscopy was a great tool used in pellet industries for various screening purposes, and the results obtained were fast. The technique is non-destructive, has high traceability, and is cost-effective.	Mancini *et al.*, 2018
Discrimination of timber species procured from their natural forest from plantations by using NIRS and various chemometric models.	NIR along with chemometrics efficiently discriminated natural forest timber and commercially planted timber species. NIR with PCA was able to differentiate 98.08% of the variance between different species of timber, whereas PLS-DA efficiently discriminated with 86-100 % accuracy.	PLS-DA, PCA, RMSE, Range Error Rate (RER), Ratio of Performance to Deviation (RPD), Standard Normal Variate (SNV)	PCA: 98.08% accuracy PLS-DA: 86-100% accuracy	Timber samples such as *Jacaranda, Aspidosperma, Apuleia,* and *Cedrela* species were successfully differentiated based on their origin.	Ramalho *et al.*, 2018
To differentiate soft and hardwood in historical wooden statues of the Nazenji-temple in Japan by using NIR spectroscopy.	NIRS combined with PCA efficiently separated archaeological or historical wood.	PCA performed with the second derivative of the NIR spectra	-	NIRS along with chemometric methods such as PCA can efficiently differentiate between hardwood and softwood.	Abe *et al.*, 2020
		Fourier Transform Infrared Spectroscopy (FTIR)			
Analysis of concentration of lignin in kraft pulps using PAS-FTIR.	Characteristic bands of lignin were obtained majorly at 1605-1593 cm^{-1}, 1515-1505 cm^{-1} and 1430-1422 cm^{-1}. Vibrations for aromatic compounds of lignin were seen at 1507 cm^{-1}.	PLSR	R^2 value of 0.97 with a moving mirror velocity of 1 cm/s	PAS-FTIR was found as a reliable alternative to other FTIR methods.	Dang *et al.*, 2007
Analysis and differentiation of various timber samples and establishment of their biological origin.	Headspace coupled with FTIR produced more reluctant spectra for dry and fresh timber samples, the absorption peaks were in the range of 3600-3000 cm^{-1}. However, the IR region profoundly indicated CH stretching at 3550-2900 cm^{-1} region, whereas peaks for cyclic and aromatic compounds having OH groups of alcohol, phenol, and other acidic constituents were falling in the region 1700-600 cm^{-1}.	Hierarchical Cluster Analysis (HCA), PCA	-	Headspace fingerprinting of timber species can be easily done with vapor phasic FTIR spectroscopy, which was recognised by various pattern recognition techniques. Hence, headspace FTIR analysis offers a significant, simple, and high throughput alternative to headspace analysis.	Kalaw & Sevilla, 2019

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

Identification of different species of timber, and their source of origin for forensic analysis by using ATR-FTIR spectroscopy and chemometric tools.	ATR- FTIR analysis showed the difference in the organic and inorganic composition of various timbers. Chemical compositions were significant and different with various forms of lignin, cellulose, hemicellulose, mannose contents, *etc.*	PCS, HCA, Linear Discrimination Analysis (LDA)	HCA: 81% LDA: 87.5% accuracy	PCA, HCA, and LDA add to ATR-FTIR for the analysis and identification of origin of timbers at a faster pace, providing a proof of concept and discriminative and non-destructive analysis. This analysis provided a formative and formulating approach for analysing the discriminating power of timber samples.	Sharma *et al.*, 2020
			Hyphenated techniques		
Analysis of chemical compositions of archaeological wood (oak and pine) by using ATR-FTIR, and Pyrolysis gas chromatography mass spectrometry (PY-GC-MS).	Results have indicated that archaeological timbers contained higher contents of carbohydrates, whereas lignin was present in very low amounts.	PCA, one way ANOVA	-	PCA, along with FTIR data matrices, very peculiarly examined the chemical composition of different archaeological timbers. These results were also supported by PY-GC-MS analysis.	Traore *et al.*, 2016
Examination of the physiochemical composition of timber samples after heat treatment.	This study analysed the chemical modifications that took place in cellulosic, hemicellulosic, and lignin contents of timbers like Scots pine, oriental beech, and oriental spruce after heat treatment. Bands obtained between 1730-1732cm^{-1} were reported for C-O vibrations (mainly stretching) of acetyl groups of carboxyl, aldehydes, aromatic or conjugated aldehydes and esters.	--	-	ATR-FTIR and FT-Raman spectra provided better explanatory differences in the chemical composition of heat-treated timber. FT Raman analysis produced significant differences in the lignin band.	Ozgenc *et al.*, 2017
Characteristic analysis of fossil Sequoioxylon timber species using FTIR and FT-Raman spectroscopy.	FT-Raman analysed various alkyl chains in the fossilized timber, and in the presence of moisture C–O and C–H were significantly highlighted. Chemical changes between fossil and new timber species were observed at the 1800-800cm^{-1} region.	--	-	FT-Raman was able to analyse the chemical composition of the timber samples, whereas Laser-Induced Breakdown Spectroscopy (LIBS) was able to determine the significant change in the chemical contents, revealing the degradation intensity of timbers.	Ozgenc *et al.*, 2018

Photoacoustic spectroscopic method (PAS) is one of the most valuable tools as it is equipped with specialized high-sensitivity microphones, low-noise electronics, computerized data handling, *etc.* PAS associated with FTIR is more practical and has various advantages as it does not require the transmission of samples and can be probed upon a range of sample sizes, multiple depths, *etc.* (Dang *et al.* 2007). Another remarkable IR spectroscopy is headspace FTIR analysis, this technique helps in timber headspace analysis and is the best alternative for timber species identification. Although the spectra can only be generated through FTIR, indicating the presence of several organic or inorganic functional groups. However, the visual discrimination becomes complicated by the use of spectra alone. Therefore, PCA (resulting in 89.57% accuracy) and Hierarchal Cluster Analysis (HCA) were used to discriminate timber species by their taxonomic categories at the species level (Kalaw & Sevilla, 2019).

Attenuated Total Reflectance Fourier Transform Infrared (ATR-FTIR) spectrometry is another method for the characterization of timber. A moderate amount of work has been done using ATR-FTIR spectroscopy. Traore *et al.* (2016) differentiated two archaeological timbers using Pyrolysis Gas Chromatography Mass Spectrometry (PY-GC-MS) and ATR-FTIR spectroscopy along with multivariate analysis. The timber samples were collected from different regions of the old Nave Cathedral of Segovia, Central Spain, and the shipwreck in Ribadeo Bay in northwest Spain. The results showed a low amount of lignin in the shipwreck, whereas the beam wood had abundant amounts of carbohydrates present in it. The lower contents of lignin were indicative of enhanced oxidation in oxygenated conditions. The obtained spectra reflected similarities between oak in the case of the shipwreck and pine in the case of the beam. ATR-FTIR spectroscopy can provide appropriate information on the chemical composition along with analytical tools such as PY-GC-MS for timber discrimination and the retained state of the lignin in archaeological timber.

DOI: https://doi.org/10.63033/JWLS.KRNG5178

Sharma *et al.* (2020) performed a study in which 24 different timber species were procured from the Timber Science Department, Brno, Czech Republic to discriminate between softwood and hardwood using ATR-FTIR spectroscopy along with multivariate statistical analysis, which became a boon to analysts as PCA-LDA resulted in about 87.5% of correct classification between timber samples from unknown origin. Whereas HCA was able to distinguish samples with 81% accuracy. The technique not only identified and distinguished timber species, but also helped in locating the samples geographically and determining its classification in the hierarchical system up to species and genus level. Also, ATR-FTIR spectrometric analysis is a non-destructive and quick approach. Hence, samples can be easily preserved and reused. Moreover, this method can be employed to build a large database of timbers for future studies and references. Several studies have used FTIR for timber samples such as investigating the effect of photodegradation in softwood, and hardwood by observing the chemical changes of cellulose and lignin (Colom *et al.*, 2003). Popescu *et al.* (2009) used FTIR in addition to X-ray diffraction techniques for the differentiation of softwood (Norway spruce *Picea abies*) and hardwood (*Eucalyptus* sp.) from pulp fibers. A total of 12 timber samples including a mixture of seven softwoods and four hardwoods, were identified and characterized by using FTIR along with chemometric models such as PCA, PLS, and LDA (Popescu *et al.*, 2009).

Recently, Traore & Cortizas, (2023) compared four timber species belonging to southern Mali, West Africa using FTIR spectroscopy in conjunction with chemometric approaches. The study was aimed at determining the chemistry and molecular structure of the species of *Pterocarpus erinaceus, Daniellia oliveri,* and *Khaya senegalensis*. The FTIR results showed that the characterization of the timber species was possible with the help of the molecules and functional groups of lignin and carbohydrates.

Fourier Transform Raman Spectrometry

Ozgenc *et al.* (2017) used Fourier Transform Raman (FT-Raman) and ATR-FTIR spectrometry to determine the structural and chemical changes occurring in the timber samples caused by heat treatments. Three different timber species were analyzed, including oriental spruce (*Picea orientalis*), oriental beech (*Fagus orientalis*), and scot pine (*Pinus sylvestris*). Both techniques indicated changes at the chemical level caused by heat treatment. The results showed that the organic acid content of the timber, mainly formic and acetic acid accumulated as these acids are responsible for the degradation of polysaccharides and reduction in the degree of polymerization. Analysis of the lignin formation through FT Raman showed that the lignin band changed at 1600 cm^{-1}. The content of lignin increased, whereas the relative cellulose and hemicellulose content decreased. The changes observed after the heat treatment varied with the timber species.

Identification of Fossil and Present-Day Timber

NIR spectrometry is one of the reliable spectroscopic techniques for qualitative and quantitative estimation of timber samples, and fossilized timbers (Tsuchikawa, 2007; Adedipe *et al.*, 2008; Braga *et al.*, 2011). Recent advances in vibrational spectroscopic methods such as FTIR and FT Raman have also helped in differentiating the characteristics of fossil timbers from present-day timbers. One such study was conducted by Ozgenc *et al.* (2018) for timber analysis by procuring two timber samples, *viz., Sequoioxylon* sp*.,* a fossil timber & *Sequoiadendron giganteum,* a present-day timber. The fossilized timber was collected from Istanbul, Turkey and it belonged to the Oligocene- Miocene period. The analysis using FT Raman revealed that the fossilized timber cell wall generally has more deteriorated lignin content than the carbohydrates. FT Raman analysis also estimated that fossilized timber has lower contents of cellulose and hemicellulose, with more detailed results compared to FTIR spectrometry. Another spectroscopic technique, Laser Induced Breakdown Spectroscopy (LIBS) estimated the oxygen and hydrogen contents in the fossilized timber samples, which is the main reason for the decrease in molecular mass and total body weight.

Fuchtner & Thygesen (2023) used confocal Raman spectroscopy along with chemometric methods to study the effect of heartwood extractives on brown rot decay in Norway spruce. The authors concluded that the rate of degradation was slower in Norway spruce due to the effect of extractives which delayed lignin degradation in the cell wall enriched with lignin.

Near Infrared (NIR) Spectrometry

The past ten years of analysis of timber species using NIR indicate that NIR spectrometry, along with various chemometric tools such as PCA, LDA, SIMCA, and Partial Least Squares – Discriminant Analysis (PLS-DA), is an efficient technique for the identification and differentiation of various timber species. NIR spectrometry can determine the chemical composition of timber such as lignin, cellulose, water, and phenolic substances. It can provide additional information on the physical and chemical properties of timber samples. Physical properties such as moisture content, surface texture, grain angle, density, and other anatomical as well as mechanical parameters can be analyzed by NIR spectrometry. Information related to various engineered timbers was also reviewed such as laminated veneer lumber, particleboard, medium-density fibreboard, and urea-formaldehyde resin. NIR spectroscopy can give good spectra for various timber samples, such as wet stored timbers, and also, it gives indicative results for the analysis of decay resistance offered by a heartwood. The technique is also efficient in characterizing raw materials of timber such as pulp, used for paper manufacturing. Hence, examination of a paper via NIR spectrometry coupled with multivariate analysis or chemometric analysis helps in its constituent analysis and can correlate it to specific timber. Adedipe *et al.* (2008) conducted a study on different timber samples, including white oak (*Quercus alba*) and red oak (*Quercus alba*) that were collected from five different counties of the USA, *viz*., Randolph County, Mason County, Preston County, *etc.* The two timber samples were subsequently analyzed using NIR spectrometry coupled with SIMCA. The wavelength ranges between 800-2500 nm were used to obtain spectra of 150 timber samples. However, the calibration models in the ranges of 1100-2200 nm, 100-2500 nm, and 1400-1900 nm were developed by SIMCA using standard normal variate (SNV) transformation. NIR spectra in the wavelength range from 800-2500 nm provided useful information for the discrimination of the above-mentioned species.

Timbers are composed of complex organic and inorganic materials; therefore, NIR spectral analysis hence becomes complicated at this point. However, it can analyze the contributions of different cellulosic contents in two spectral domains (Schubert *et al.*, 2022). Scientists have evaluated that a combination of UV-visible and NIR spectrometry was efficient in studying the chemical composition of the timber. NIR spectroscopic analysis gives better spectra through transverse and radial surfaces instead of tangential surfaces, indicating, that surface analysis is an important aspect. Root mean squares are generally used to evaluate moisture content however, it was

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

well measured in timber samples using the multilayer PLS method. NIR spectrometry is a boon for botanists and forensic scientists in estimating the origin and source of timber samples and industrially processed timber pellets (Mancini *et al.*, 2018).

The literature has accounts of the analysis of seven timber chip samples with a controlled amount of moisture, which were acacia (*Robinia pseudoacacia*), ash-tree (*Fraxinus silvatica*), aspen (*Populus tremula*), beech (*Fagus silvatica*), birch (*Betul alba*), cherry (*Cerasus avium*) and hornbeam (*Carpinus betulus*) (Adedipe *et al.*, 2008; Chen *et al.*, 2010; Gigac & Fišerová, 2010; Ramalho *et al.*, 2018; Teodorescu *et al.*, 2021). The spectra were obtained using NIR and the variation in moisture content in various timbers significantly affected the results. Timber chips with a higher water content were easily and better analyzed by NIR spectrometry. However, the timber chips with lower moisture content were not differentiated easily. Hence, a high identification accuracy (90%) was observed in acacia, aspen, birch, and hornbeam whereas, ash-tree and cherry were identified with low accuracy. The actual versus predicted relationship for all the studied timber sample was linear with a coefficient of determination (R^2) of 0.8054 (Russ *et al.*, 2009). This indicated that most of the timber species have similar chemical composition but different moisture content. The change in the moisture content of the wooden components affects their density, volume, exterior features, biological and mechanical properties. These changes can affect the integrity of the results of timber analysis.

NIR spectroscopy is also efficient in discriminating softwood and hardwood. A study conducted by Abe *et al.* (2020), differentiated softwood and hardwood statues in the Nazenji temple, Japan using NIR spectroscopy. The results showed that NIRS combined with PCA efficiently separated archeological wood. Similarly, Silva *et al.*, (2018) analysed the origin of the country of true mahogany timber species using NIR spectroscopy and multivariate data analytical tools such as SIMCA and PLS-DA. It was observed that SIMCA resulted in 67-100 % and 70-98 % accuracy in the NIR range of 1595-2396 nm and 950-1650 nm wavelengths respectively. Similarly, the PLS-DA approach was significant with 90-100 % accuracy.

Subsequent studies using FT-NIR spectroscopic techniques have also been carried out to identify and link timber species with their geographical location. One study conducted by Bachle *et al.* (2012) classified thermally modified wood using FT-NIR spectrometry and chemometric tools such as SIMCA. Sandak *et al.* (2011) determined the geographical provenance of timber using FT-NIR. Various timber samples of spruce (*Picea abies*) were collected from four different regions, *viz*., Finland, Italy, northern and southern Poland. Depending on the geographical provenance, the timbers were collected as two different sample types. In the first sample type, timbers were collected from different regions of Europe, whereas in the second type, it was collected from different localities in Italy. FT-NIR helped in the analysis of chemical compositions that vary in timber samples of different locations. The results showed that for methods 1 and 2, the accuracy of 100% and 99.5% were obtained respectively. The separation among the timber was more prominent in the samples collected from a different region of Europe compared to the samples from a narrow region of Italy, although the separation within Italy was also significant. Therefore, the method is applicable in deciphering geographical provenance and to curb illicit timber harvesting from protected areas.

Studies have revealed that NIR coupled with chemometrics can determine the age of various timber species. The reliability of spectroscopic methods in determining the chemical constituents, age, moisture content, and differentiation of fossilized timber is already high. NIR coupled with PLS-DA has helped differentiate virgin timber and glue laminated timbers with 100% accuracy. An alternative to PLS-DA is multivariate analysis, which rapidly determines the the origin of timber and biomass when used with NIR spectrometry (Mancini *et al.*, 2018; Colom *et al.*, 2003; Sandak *et al.*, 2011). Ramalho *et al.* (2018) reported that NIR spectrometry determined the timber species from plantation and native forests. Timbers were taken from several tropical trees in Brazil. The sample timber obtained from planted forests were *Eucalyptus* clones which were commercially produced, whereas specimens from natural forests were of genera A*spidosperma, Apuleia,* and *Jacaranda.* PLS-DA coupled with NIR clearly distinguished *Aspidosperna, Apuleia,* and *Jacaranda* from *Eucalyptus* species. However, this differentiation can also be done using PCA based on NIR spectra. About 86% of the correct results were obtained using PLS-DA models from untreated NIR spectra. However, treated NIR along with the PLS-DA models are robust in determining and classifying timber specimens from planted and natural forests.

Pastore *et al.* (2011) analyzed solid timber specimens of *Swietenia macrophylla* and three other timber samples namely andiroba (*Carapa guianensis*), curupixá (*Mecropholis melinoniana*), and cedar (*Cedrela odorata*). Samples of mahogany, andiroba, curupixá, and cedar were collected from 29, 25, 31, and 26 trees, respectively. Analysis from different faces also revealed that the spectra had differences. Therefore, the analyses must be carried out in a repeatable protocol. Yang *et al.*, (2015) used NIR spectroscopy along with chemometric models such as PCA (Case I), and PLS-DA (Case II) to identify three timber species including *Pometia* sp, *Couratari* sp., and *Instia* sp. which were collected from Dongba in Beijing, China. A total of 315 timber samples were prepared. In Case I, PCA was applied to the NIR spectra which resulted in 100% accuracy. In Case II, PCA along with PLS DA was used to identify the three species resulting in the construction of three different identification models based on locations. The results obtained after calibration correctness were 67%, 99%, and 94% for *Pometia* sp*.*, *Couratari* sp., and *Instia* sp., respectively. A comparison of the IR and Raman spectroscopy for timber analysis is given in Table 2.

Hyphenated Techniques

Ebner *et al.* (2023) compared two different charring treatments employed on the surface of fir wood samples, which is used to enhance its aesthetic appearance and weather protection capacity. The authors compared the gas-burning charring method with the traditional Japanese technique using ultraviolet resonance Raman and FTIR spectroscopy along with X-ray-computed micro-tomography analysis. The results of FTIR spectroscopy showed major changes in the bands indicating lignin and carbohydrates when compared with the spectra of reference samples. Moreover, the results indicate the degradation of carbohydrates due to pyrolysis. The ultraviolet resonance Raman spectroscopy helped to estimate the differences in the chemical composition of the samples using these charring methods. Whereas the X-ray-computed micro-tomography techniques estimated the morphological changes in the wood samples after the charring process.

Similarly, Tuncer *et al.* (2024) studied the changes in the wood chemistry after the contact charring and submersion in linseed oil in the wood of *Eucalyptus bosistoana*, and *Pinus taeda* by using FTIR, Raman spectroscopy, and Scanning Electron Microscope (SEM). The Raman spectroscopy showed that as a result of charring, the total lignin content increased, whereas the carbohydrate content decreased. The

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

charring of the wood samples had resulted in elevated contact angles due to raised hydrophobicity in addition to the homogeneity, and sensitivity in the cell walls. The FTIR analysis showed a decrease in the content of carbohydrates, and the building of aromatic compounds due to charring. A detailed list of the chemometric methods and hyphenated modifications used in spectroscopic techniques is given in Table 3.

Table 2: Comparison of Infrared (IR) and Raman spectroscopy for the analysis of timbers.

	IR Spectroscopy	Raman Spectroscopy
Determination of genus	Yes	Yes
Determination of species	Yes	Yes
Determination of age	No	No
Determination of geography	Yes	Yes
Sample size	Less	Less
Cost per run	≤₹100	≤₹100
Process speed	Seconds to Minutes	Few minutes
Equipment needed	NIR machinery and its database	Raman Spectrometer equipment
Requirements of reference material	Reference spectra of timber specimen and regional database	Raman database of timber
Principle	Near-infrared ray interacts with the molecule of timber and changes its vibrational energy (stretch and bent vibration) on absorption	The incident light interacts with vibrating particles and scatters, which results in a change in the vibrational energy of the molecule
Pre-treatment stage	Not required	No
Destruction of samples	No	No (Rarely if the intensity is high)

Table 3. Summarised chemometric models and hyphenated modifications used with spectroscopic techniques.

Spectroscopic Analysis	Major Chemometric (statistical) tools	Associated Hyphenated Techniques
FTIR Spectroscopy	• Partial size distribution • Multivariate analysis • Principle component Analysis • Hierarchal Cluster Analysis • Partial Least Square Discriminant Analysis • Total crystallinity Index • Lateral Order Index • Linear Discriminant Analysis	• Superfine grinding • X-ray Diffraction • Xenon test chamber • Photoacoustic Rapid Scan • Headspace Fingerprinting • Pyrolysis gas chromatography mass spectrometry (PY-GC-MS) • Fourier Transform • Attenuated Total Reflectance • Laser-induced breakdown Spectroscopy • Light Microscopy
NIR Spectroscopy	• Multivariate analysis • Partial Least Square Regression • Cluster Analysis • Partial Least Square Discriminant Analysis • Principle Component Analysis Discriminant Analysis • LS-Support Vector Machine • Artificial Neural Networks • Root Mean Square Error of Calibration • Soft Independent modelling of class Analogy • Range Error Rate • Ratio of Performance to Deviation • Artificial Neural Networks • Standard Normal Variate	• Fourier Transform • Reflectance Spectroscopy • FT-Raman Spectroscopy

DOI: https://doi.org/10.63033/JWLS.KRNG5178

Conclusion

Several wildlife crimes concerning timbers have significantly and rapidly increased in past decades. It has led to a major economic loss when considering its illegal trade to the extent that it has caused recession in countries such as the Central African Republic (Hellwig-Botte, 2014). Another major issue concerning timber is that construction buildings and furniture can be made with substandard timber species, claiming to be a superior material. Besides the identification of timber by morphological studies (macroscopic), chemical methods are also useful for determining timber up to the genus level. Vibrational spectroscopic methods are described in this review article with their significant advantages. There is a growing need to examine timber in a rapid way where illegal timber logging is routinely escalating. Various spectroscopic approaches discussed in this review can provide a thorough analysis of species of timbers. Methods such as IR spectroscopy, Raman spectroscopy with chemometric tools such as Least-squares Support Vector Machine models (LS-SVM), Artificial Neural Networks (ANN), PLSR, PCA, *etc.*, as well as other technical methods such as photoacoustic rapid scan, Fourier transform, attenuated total reflectance, *etc.*, have been proven crucial in the identification of timber species, estimation of the age of timber, and fossilization of ancient timber samples recovered from crime scenes. Hyphenated techniques such as ATR-FTIR coupled with FT-Raman, and ATR-FTIR coupled with Pyrolysis GC-MS had more significant results. These techniques successfully measured the chemical and physical differences in timber samples, as well as substantial measurements of environmental impacts such as oxidation, degradation, and any other measurable physiochemical or biological changes. These methods provide tools to link suspects, victims, and the crime scene. This review also discussed various significant chemometric tools, which are of equal importance when analysing any biological material.

Acknowledgements

The authors would like to express their sincere gratitude to the University Grants Commission (UGC), Ministry of Human Resource Development, Government of India for providing financial assistance to the first author (UGC Ref. No. 200510156051).

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY

No data was used in this research.

AUTHOR CONTRIBUTIONS

Arti Yadav: Writing- Original draft, review & editing.
Sweety Sharma: Writing- review & editing.
Lovlish Gupta: Writing- review & editing. Vaibhav Singh: Writing- review & editing.
Rajinder Singh: Conceptualization, Supervision, Writing-review & editing.

References

Abe, H., Kurata, Y., Watanabe, K., Ishikawa, A., Noshiro, S., Fujii, T., Iwasa, M., Kaneko, H. & Wada, H., (2020). The separation of softwood and hardwood in historical wooden statues of the Nazenji-temple in Japan using NIR spectroscopy. *IAWA Journal*, 41(4), 740-750. https://doi.org/10.1163/22941932-bja10038

Adedipe, O.E., Dawson-Andoh, B., Slahor, J. & Osborn, L., (2008). Classification of red oak (*Quercus rubra*) and white oak (*Quercus alba*) wood using a near-infrared spectrometer and soft independent modelling of class analogies. *Journal of Near Infrared Spectroscopy*, 16(1), 49-57. https://doi.org/10.1255/jnirs.760

Bächle, H., Zimmer, B. & Wegener, G., (2012). Classification of thermally modified wood by FT-NIR spectroscopy and SIMCA. *Wood Science and Technology*, 46, 1181-1192. https://doi.org/10.1007/s00226-012-0481-z

Borga, P., Hämäläinen, M. & Theander, O., (1992). Correlations between near-infrared spectra of wet-stored timber and the storage time in relation to the water quality. *Holzforschung*, 46, 299-303. https://doi.org/10.1515/hfsg.1992.46.4.299

Braga, J.W.B., Pastore, T.C.M., Coradin, V.T.R., Camargos, J.A.A. & da Silva, A.R., (2011). The use of near infrared spectroscopy to identify solid wood specimens of *swietenia macrophylla* (Cites Appendix II). *Iawa Journal*, 32(2), 285-296. https://doi.org/10.1163/22941932-90000058

Chen, H., Ferrari, C., Angiuli, M., Yao, J., Raspi, C. & Bramanti, E., (2010). Qualitative and quantitative analysis of wood samples by Fourier transform infrared spectroscopy and multivariate analysis. *Carbohydrate polymers*, 82(3), 772-778. https://doi.org/10.1016/j.carbpol.2010.05.052

Colom, X., Carrillo, F., Nogués, F. & Garriga, P., (2003). Structural analysis of photodegraded wood by means of FTIR spectroscopy. *Polymer degradation and stability,* 80(3), 543-549. https://doi.org/10.1016/S0141-3910(03)00051-X

Dang, V.Q., Bhardwaj, N.K., Hoang, V. & Nguyen, K.L., (2007). Determination of lignin content in high-yield kraft pulps using photoacoustic rapid scan Fourier transform infrared spectroscopy. *Carbohydrate polymers*, 68(3), 489-494. https://doi.org/10.1016/j.carbpol.2006.11.005

Dormontt, E.E., Boner, M., Braun, B., Breulmann, G., Degen, B., Espinoza, E., Gardner, S., Guillery, P., Hermanson, J.C., Koch, G. & Lee, S.L., (2015). Forensic timber identification: It's time to integrate disciplines to combat illegal logging. *Biological Conservation*, 191, 790-798. https://doi.org/10.1016/j.biocon.2015.06.038

Haartveit, E.Y. & Flæte, P.O., (2008). Near infrared spectroscopy (NIRS) as a tool for effective classification of wood. In Proceedings of the 51st International Convention of Society of Wood Science and Technology (CHILE) 1-9.

Ebner, D.H., Tortora, M., Bedolla, D.E., Saccomano, G., Vaccari, L., Barbu, M.C., Grzybek, J. & Schnabel, T., (2023). Comparative investigation of chemical and structural properties of charred firewood samples by Raman and FTIR spectroscopy as well as X-ray-micro-CT technology. *Holzforschung*, 77(9), 734-742. https://doi.org/10.1515/hf-2023-0024

Flæte, P.O., Haartveit, E.Y. & Vadla, K., (2006). Near-infrared spectroscopy with multivariate statistical modelling as a tool for differentiation of wood from tree species with similar appearance. *New Zealand Journal of Forestry Science*, 36(2/3), 382.

Füchtner, S. & Thygesen, L.G., (2023). Subcellular level impact of extractives on brown rot decay of Norway spruce elucidated by confocal Raman microscopy and multivariate data analysis. *Wood Science and Technology*, 1-33. https://doi.org/10.1007/s00226-023-01476-4.

Gigac, J. & Fišerová, M., (2010). Identification of wood species by application of visible spectral reflectance. *Wood Research*, 55(1), 79-86.

Hellwig-Bötte, M., (2014). Wildlife crime in Africa global challenge: successful countermeasures must involve local populations (No. 12/2014). SWP Comments.

Hinterstoisser, B., Schwanninger, M., Stefke, B., Stingl, R. & Patzelt, M., (2003), April. Surface analyses of chemically and thermally modified wood by FT-NIR. In Acker, VJ, Hill, C. The 1st European conference on wood modification. Proceeding of the first international conference of the European society for wood mechanics,15-20.

Kalaw, J.M. & Sevilla, I.I.I.F., (2019). Differentiation of wood species using headspace fingerprinting through fourier-transform infrared spectroscopy. *Acta Manilana*, 67, 31-38.

Kannangara, S., Karunarathne, S., Ranaweera, L., Ananda, K., Ranathunga, D., Jayarathne, H., Weebadde, C. & Sooriyapathirana, S., (2020). Assessment of the applicability of wood anatomy and DNA barcoding to detect the timber adulterations in Sri Lanka. *Scientific Reports*, 10(1), 4352. https://doi.org/10.1038/s41598-020-61415-2

Mancini, M., Rinnan, Å., Pizzi, A., Mengarelli, C., Rossini, G., Duca, D. & Toscano, G., (2018). Near infrared spectroscopy for the discrimination between different residues of the wood processing industry in the pellet sector. *Fuel*, 217, 650-655.

Özgenç, Ö., Durmaz, S., Boyaci, I.H. & Eksi-Kocak, H., (2017). Determination of chemical changes in heat-treated wood using ATR-FTIR and FT Raman spectrometry. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 171, 395-400. https://doi.org/10.1016/j.saa.2016.08.026

Ozgenc, O., Durmaz, S., Serdar, B., Boyaci, I.H., Eksi-Kocak, H. & Öztürk, M., (2018). Characterization of fossil Sequoioxylon wood using analytical instrumental techniques. *Vibrational Spectroscopy*, 96, 10-18. https://doi.org/10.1016/j.vibspec.2018.02.006

Pastore, T.C.M., Braga, J.W.B., Coradin, V.T.R., Magalhães, W.L.E., Okino, E.Y.A., Camargos, J.A.A., de Muñiz, G.I.B., Bressan, O.A. & Davrieux, F., (2011). Near infrared spectroscopy (NIRS) as a potential tool for monitoring trade of similar woods: Discrimination of true mahogany, cedar, andiroba, and curupixá. *Holzforschung*, 65(1), 73-80. https://doi.org/10.1515/hf.2011.010

Popescu, C.M., Popescu, M.C., Singurel, G., Vasile, C., Argyropoulos, D.S. & Willfor, S., (2007). Spectral characterization of eucalyptus wood. *Applied spectroscopy*, 61(11), 1168-1177. https://doi.org/10.1366/000370207782597076

Popescu, C.M., Singurel, G., Popescu, M.C., Vasile, C., Argyropoulos, D.S. & Willför, S., (2009). Vibrational spectroscopy and X-ray diffraction methods to establish the differences between hardwood and softwood. *Carbohydrate Polymers*, 77(4), 851-857. https://doi.org/10.1016/j.carbpol.2009.03.011

Rana, R., Müller, G., Naumann, A.& Polle, A., (2008). FTIR spectroscopy in combination with principal component analysis or cluster analysis as a tool to distinguish beech (*Fagus sylvatica L.*) trees grown at different sites. *Holzforschung*, 62(5) 530-538. https://doi.org/10.1515/HF.2008.104

Ramalho, F.M., Andrade, J.M. & Hein, P.R., (2018). Rapid discrimination of wood species from native forest and p lantations using near infrared spectroscopy. *Forest Systems*, 27(2), e008-e008. https://doi.org/10.5424/fs/2018272-12075

Russ, A., Fišerová, M. & Gigac, J., (2009). Preliminary study of wood species identification by NIR spectroscopy. *Wood Research*, 54(4), 23-32.

Sandak, A., Sandak, J. & Negri, M., (2011). Relationship between near-infrared (NIR) spectra and the geographical provenance of timber. *Wood science and technology*, 45, 35-48. https://doi.org/10.1007/s00226-010-0313-y

Schimleck, L. & Workman Jr, J., (2004). Analysis of timber and paper. *Near-Infrared Spectroscopy in Agriculture*, 44, 633-646.. https://doi.org/10.2134/agronmonogr44.c22

Schubert, M., Panzarasa, G. & Burgert, I., (2022). Sustainability in wood products: a new perspective for handling natural diversity. *Chemical Reviews*, 123(5), 1889-1924. https://doi.org/10.1021/acs.chemrev.2c00360.

Schloenhardt, A. & Schloenhardt, A., (2008). The illegal trade in timber and timber products in the Asia-Pacific region (No. 89). Canberra: Australian Institute of Criminology.

Schwanninger, M., Hinterstoisser, B., Gierlinger, N., Wimmer, R. & Hanger, J., (2004). Application of Fourier transform near infrared spectroscopy (FT-NIR) to thermally modified wood. *Holz als Roh-und Werkstoff*, 62, 483-485.

Sharma, V., Yadav, J., Kumar, R., Tesarova, D., Ekielski, A. & Mishra, P.K., (2020). On the rapid and non-destructive approach for wood identification using ATR-FTIR spectroscopy and chemometric methods. *Vibrational Spectroscopy*, 110, 103097. https://doi.org/10.1016/j.vibspec.2020.103097

Silva, D.C., Pastore, T.C., Soares, L.F., de Barros, F.A., Bergo, M.C., Coradin, V.T., Gontijo, A.B., Sosa, M.H., Chacón, C.B. & Braga, J.W., (2018). Determination of the country of origin of true mahogany (Swietenia macrophylla King) wood in five Latin American countries using handheld NIR devices and multivariate data analysis. *Holzforschung*, 72(7), 521-530. https://doi.org/10.1515/hf-2017-0160

Soest, P.V., (1963). Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. *Journal of the Association of official Agricultural Chemists*, 46(5), 829-835. https://doi.org/10.1093/jaoac/46.5.829

Solinge, T.V., Zuidema, P., Vlam, M., Cerutti, P.O. and Yemelin, V., (2016). Organized forest crime: a criminological analysis with suggestions from timber forensics.n*IUFRO World Series*, 35, 81-96.

Teodorescu, I., Erbasu, R.I., Branco, J.M. & Tapusi, D., (2021). Study in the changes of the moisture content in wood. *IOP Conference Series: Earth and Environmental Science*, 664, 012017. https://doi.org/10.1088/1755-1315/664/1/012017.

Traoré, M. & Martínez Cortizas, A., (2023). Comparative study of four timber wood species in southern Mali (West Africa) by combining FTIR spectroscopy and multivariate analysis. European Journal of Wood and Wood Products, 81(6), 1513-1524. https://doi.org/10.1007/s00107-023-01979-8.

Traoré, M., Kaal, J. & Cortizas, A.M., (2016). Application of FTIR spectroscopy to the characterization of archeological wood. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 153, 63-70. https://doi.org/10.1016/j.saa.2015.07.108

Tsuchikawa, S., (2007). A review of recent near infrared research for wood and paper. *Applied Spectroscopy Reviews*, 42(1), 43-71. https://doi.org/10.1080/05704920601036707

Tuncer, F.D., Kartal, S.N., Soytürk, E.E., Arango, R.A., Ohno, K.M., Önses, M.S., Çelik, N. & Ibanez, C.M., (2024). Changes in chemical properties and microstructure of Pinus taeda and Eucalyptus bosistoana woods modified by contact charring. *European Journal of Wood and Wood Products*, 82(1), 107-121.

Wiedenhoeft, A., (2016). Best practice guide for forensic timber identification. In: United Nations Office on Drugs and Crime: International Consortium on Combating Wildlife Crime. Vienna, Austria: Laboratory and Scientific Section, Global P rogramme for Combating Wildlife and Forest Crime: 1-226.

Wallen, K.E., (2018). Global timber trafficking harms forests and costs billions of dollars–here's how to curb it. *The Conversation*, 24.

Yang, Z., Liu, Y., Pang, X. & Li, K, (2015). Preliminary investigation into the identification of wood species from different locations by near infrared spectroscopy. *BioResources*, 10(4), pp.8505-8517.

Zhao, X., Chen, J., Chen, F., Wang, X., Zhu, Q. & Ao, Q., (2013). Surface characterization of corn stalk superfine powder studied by FTIR and XRD. Colloids and Surfaces B: *Biointerfaces,* 104, 207-212., https://doi.org/10.1016/j.colsurfb.2012.12.003

 DOI: https://doi.org/10.63033/JWLS.KRNG5178

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Research Article

Home range and seasonal movement of *Nanorana vicina* (Stoliczka, 1872) (Anura: Dicroglossidae) in Himalayan streams, India

Swati Nawani[1], Deb Shankha Goswami[2], Arup Das[3], Krishnendu Banerjee[1], Abhijit Das[1]*

[1]Wildlife Institute of India, Dehradun, Chandrabani, Uttarakhand, 248001, India.
[2]34, Talpukur south, Naihati, 24 Parganas(N), West Bengal, 743165, India.
[3]Aaranyak, 13 Tayab Ali Bylane, Beltola Tiniali, PO: Beltola, Guwahati – 781028, Assam, India

DIAMOND OPEN ACCESS Crossref

EDITED BY
Mewa Singh
Institution of Excellence, University of Mysore

*CORRESPONDENCE
Abhijit Das
abhijit@wii.gov.in

RECEIVED 18 March 2024
ACCEPTED 26 July 2024
ONLINE EARLY 29 July 2024

CITATION
Nawani, S., Goswami, D.S., Das, A., Banerjee, K., Das, A. (2024). Home range and seasonal movement of *Nanorana vicina* (Stoliczka, 1872) (Anura: Dicroglossidae) in Himalayan streams, India. *Journal of Wildlife Science,* 1 (2), 81-86. https://doi.org/10.63033/JWLS.JJAP3927

FUNDING
Funding was supported under the Grant in Aid scheme from the Wildlife Institute of India (WII), Dehradun and the Ministry of Environment, Forest and Climate Change, Government of India.

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

The spatial movement pattern is a poorly known aspect of amphibian ecology, especially in the Indian Himalayan region. Thus, we studied the home range and movement of *Nanorana vicina*, an obligate stream frog endemic to the Western Himalayas. We radio-tagged 16 individuals and tracked their movement for an average of 63 days in two streams of Binog Wildlife Sanctuary, Uttarakhand. Our results showed that the highest mean movement of a tagged frog was 5.9 ± 3.26 meters (m) in 13 days during monsoon. Most of the movements (90 %) were restricted within the stream. Movement varied significantly across seasons, with the highest movement during the monsoon (2.71 ± 0.46 m) and the lowest during the post-monsoon (0.78 ± 0.14 m). The Dunn's Test revealed that post-monsoon movement was significantly lower than in both pre-monsoon and monsoon periods. The minimum convex polygon showed a range of 1.61 m^2 to 43.16 m^2 and 15.78 m^2 to 684.99 m^2 for 50% and 90% MCP, respectively. No significant difference was found in the weights of frogs before tagging and after removing tags ($n = 10$, $p > 0.05$). Himalayan streams are subjected to rapid anthropogenic and climate-induced changes. Less vagile and highly philopatric species, such as *N. vicina*, might be much more vulnerable to such changes. Thus, the study highlights the importance of the stream and the riparian zone for the conservation of this stream frog.

Keywords: Radio telemetry, stream anuran, spatial ecology, stream morphology, Indian Himalayan region, Uttarakhand.

Introduction

Stream amphibians, such as frogs, are valuable indicators of ecosystem health (Welsh & Ollivier, 1998). Nevertheless, they are vulnerable to climate change, deforestation, pollution, and habitat degradation (Kim *et al.* 2019; Panwar 2020). Frogs often exhibit site fidelity and limited home ranges, moving primarily within a small, defined area to access resources, avoid predators, and maintain body moisture and temperature (Sinsch 2014). Moreover, stream frogs inhabiting mountains at high elevations are more prone to habitat alteration and degradation than terrestrial species (Saeed *et al.* 2022). Thus, knowledge of how frogs use and move among habitats is crucial for effective management plans and strategies concerning the species and habitat (Groff *et al.* 2017). In recent years, radio telemetry has been used globally to study the movement, habitat use and home range of terrestrial and aquatic frogs (Daugherty & Sheldon, 1982; Tessier *et al.* 1991; Kam & Chen, 2000; Sinch *et al.* 2012; Akram *et al.* 2022). However, studies focused on the movement or home range of stream frogs in the Indian Himalayan region are unfortunately lacking, where biodiverse freshwater habitats are under threat (Johal & Rawal, 2005).

Herein, we investigated movement and home range of *Nanorana vicina* using radio telemetry in India. This study aimed to address three questions, 1). Is there a seasonal difference in the movement of tagged frogs? 2). Are there differences in the movement pattern between a natural stream and another stream affected by anthropogenic disturbances? 3). What is the home range size of tagged frogs? We also assessed whether tags led to weight loss in frogs.

Material and Methods

The study was conducted in Binog Wildlife Sanctuary (BWLS) (28° 60´ - 31°28´ N, 70°49´ - 80°60´ E), Uttarakhand, India (Figure 1). We selected two perennial streams and classified those as 'Disturbed stream' and 'Undisturbed stream' based on the degree of anthropological modifications such as check dams and artificial pools. Streams at the locality are spring-fed and approximately 5 meters wide with moderate flow, primarily rocky with intermittent gravel and pools with detritus, fallen logs and leaf litter. We used very high frequency external transmitters (Model SOPR- 2070, battery life 135 days; Wildlife Material, US), keeping in view the constrains in shape and size of the anuran body. Following global standards (Goldberg *et al.* 2002), a transmitter weighing less than 3% of the frog's bodyweight was tied in the groin region. The frogs were kept overnight under controlled conditions before being released in the same area of capture. We tracked 16 individuals of *N. vicina* for an average span of 63 days (Minimum= 13 days; Maximum= 92 days) from May to October 2019 (Table 1). Bodyweight of individuals ranged from 115–190 gm (Mean± SD = 150.9 ± 24.58 gm, n = 16). In the initial month of the study, tagged frogs were located thrice at 7-8 AM, 12-1 PM, and 8-9 PM to assess diurnal and nocturnal movements. Subsequently, given the species' nocturnal activity patterns, tracking frequency shifted to nightly readings between 8 PM and 12 AM, conducted near-daily to monitor potential movement. The surveys were mostly continuous, apart from a few sessions being abrupt by harsh weather conditions. Depending on the nature of the terrain the maximum range of the signal was 50 – 100 meters. We have used seven tags on seven individuals while four tags were reused on nine different individuals, which is explained in Nawani *et al.* (2022). Individuals were given identification *Nanorana vicina* disturbed (NVD) and *Nanorana vicina* undisturbed (NVU) followed by an individual identifying number. We used meter tape to calculate the daily distance moved by individuals after each relocation. We measured straight-line distances (from the previous location to the next location) between an individual's movements. We collected location data with a focus on maintaining a five-meter range of accuracy. When a frog moved less than 10 meters, we decided not to record the location as GPS errors could potentially compromise the reliability of such data. However, when we could achieve accuracy levels better than the individual's movement range, we recorded GPS locations (average = 13 locations per individual, n = 6). Consequently, individuals (n = 10) with very less movement or location data were excluded from home range estimation. We discontinued tracking in case of transmitter signal failure or a situation where the transmitter began to abrade any frogs.

Data Analysis:

Since the sex of the individuals (male and female) could not be ascertained based on their morphological characteristics in the field, we refrained from including any tests or analyses related to this aspect. Using the movement data, we calculated the mean distance moved by all individuals over the study period. To determine whether there were differences in the seasonal movement, we performed Kruskal-Wallis test with pre-monsoon (May-June), monsoon (July–August) and post-monsoon (September–October) movement data, followed by Dunn's test with Benjamini-Hochberg adjustment. We also calculated the percentage of total movement made in streams and land. We performed the Mann-Whitney U test to compare movements made in two streams. Our sample size was low; therefore, we calculated home range using minimum convex polygon (MCP) at 50% and 90% isopleths. We also assessed the change in the weight of frogs before tagging and after the final removal of tags using the Wilcoxon's signed rank test. The values given are mean with standard error and the significance for all tests was compared at p-value = 0.05. We performed statistical analysis using Microsoft Excel and R version 3.4.1 (R core team ,2021). All maps were created using Arc GIS version 10.1 (ESRI, Redlands, USA).

Results

During the study period, the majority of frog movement (90.60%) was confined to the wetted width of the stream, with only 9.39% occurring on land. The mean movement distance varied among individuals, ranging from 0.49 ± 0.14 meters to 5.9 ± 3.26 meters (Table 1). Individual home ranges, estimated using the MCP method, exhibited substantial variation. At the 50% utilization level, home ranges spanned 1.61 m^2 to 43.16 m^2, while at the 90% utilization level, they encompassed a much wider area of 15.78 m^2 to 684.99 m^2 (Table 2).

Frog movement exhibited significant seasonal differences (df = 2, $p << 0.05$). Movement was the highest during the monsoon season (2.71 ± 0.46 m), followed by the pre-monsoon (1.41 ± 0.12 m) and post-monsoon seasons (0.78 ± 0.14 m). Post-hoc analysis using Dunn's test revealed that while pre-monsoon and monsoon movement did not differ significantly ($p > 0.05$), post-monsoon movement was significantly lower than both pre-monsoon ($p << 0.05$) and monsoon ($p << 0.05$). No significant differences were observed in movement distances between frogs tagged in the two different streams ($p > 0.05$).

Furthermore, no significant differences were found in the body weight of the individuals before tagging and after removing the tags (n = 10, $p > 0.05$)

Discussion

Previous studies on *N. vicina* movement patterns have yielded valuable insights, albeit with certain limitations. Akram *et al.* (2022) observed restricted movements of less than 3 meters during a short-term, post-monsoon survey (8 days), while Batool *et al.* (2023) reported movement within a 120 m^2 area along stream banks. These studies, while providing valuable insights, primarily focus on short duration observations and do not offer a comprehensive assessment of home range. Our study, employing the MCP method, offers a broader understanding of the home range of *N. vicina.* Furthermore, our study covers three distinct seasons (pre-monsoon, monsoon, and post-monsoon), capturing potential seasonal variations in movement.

MCP analysis revealed that the majority of movements by tagged individuals in our study were concentrated along the stream course, with occasional movement towards land (Figure 2). This pattern aligns with previous studies and highlights the species' close association with stream habitats. The use of MCP in our study is justified, as it is the standard method in studying home range in frogs (Luger *et al.* 2009; Neu *et al.* 2016) and can be used when the sample size is low (Boyle *et al.* 2009). While the sample size may limit the generalizability of our findings, our results, combined with those of Akram *et al.* (2022) and Batool *et al.* (2023), collectively suggest that *N. vicina* exhibits a restricted movement pattern, particularly in association with stream environments. This understanding is crucial for conservation efforts, as it highlights the species' vulnerability to habitat alterations, particularly those affecting stream ecosystems.

DOI: https://doi.org/10.63033/JWLS.JJAP3927

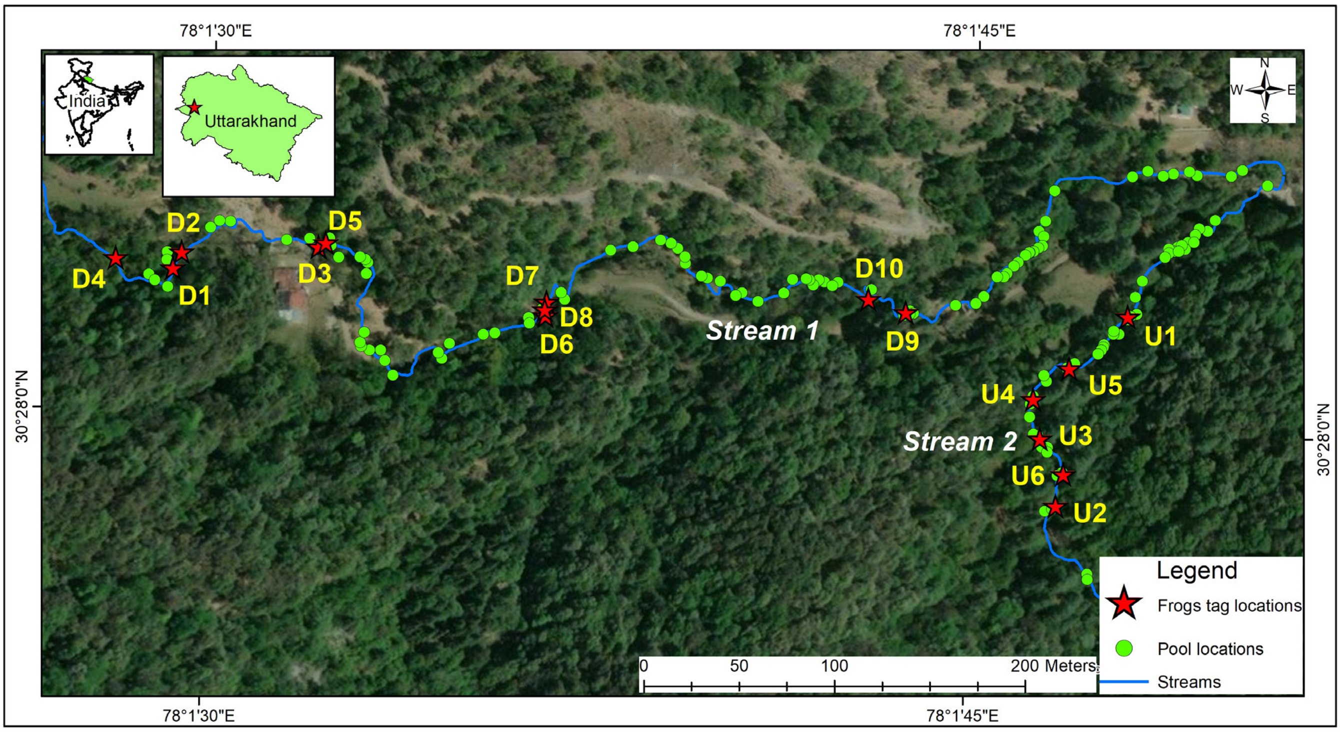

Figure 1: Locations of the tagged *Nanorana vicina* movements in Binog Wildlife Sanctuary, Uttarakhand, India. (D1 to D10 are the individuals in the disturbed stream (n=10), and U1 to U6 are the individuals in the undisturbed stream (n=6).

Table 1. Movement and tracking history of 16 radio tagged frogs.

Individual ID	Mean movement (m)	Standard error	No. of tagging days	Tag Removed/shed by animal/ recover/lost
NVU1	2.06	0.17	91	Removed/Recovered
NVU2	0.98	0.34	86	Shed by animal/Recovered
NVU3	2.28	0.59	84	Removed/Recovered
NVU4	0.68	0.16	68	Removed/Recovered
NVU5	1.79	0.48	92	Removed/Recovered
NVU6	5.07	2.61	26	Shed by animal/Recovered
NVD1	1.95	0.32	45	Removed/Recovered
NVD2	1.85	0.34	86	Removed/Recovered
NVD3	2.33	0.13	68	Removed/Recovered
NVD4	2.57	0.82	49	Removed/Recovered
NVD5	5.93*	3.26	13	Removed/Recovered
NVD6	0.49**	0.14	78	Removed/Recovered
NVD7	0.76	0.62	78	Lost
NVD8	0.59	0.32	52	Lost
NVD9	0.93	0.51	51	Lost
NVD10	1.21	0.52	51	Lost

Note: NVD = *Nanorana vicina* disturbed, NVU = *Nanorana vicina* undisturbed (* = highest, **= lowest)

 DOI: https://doi.org/10.63033/JWLS.JJAP3927

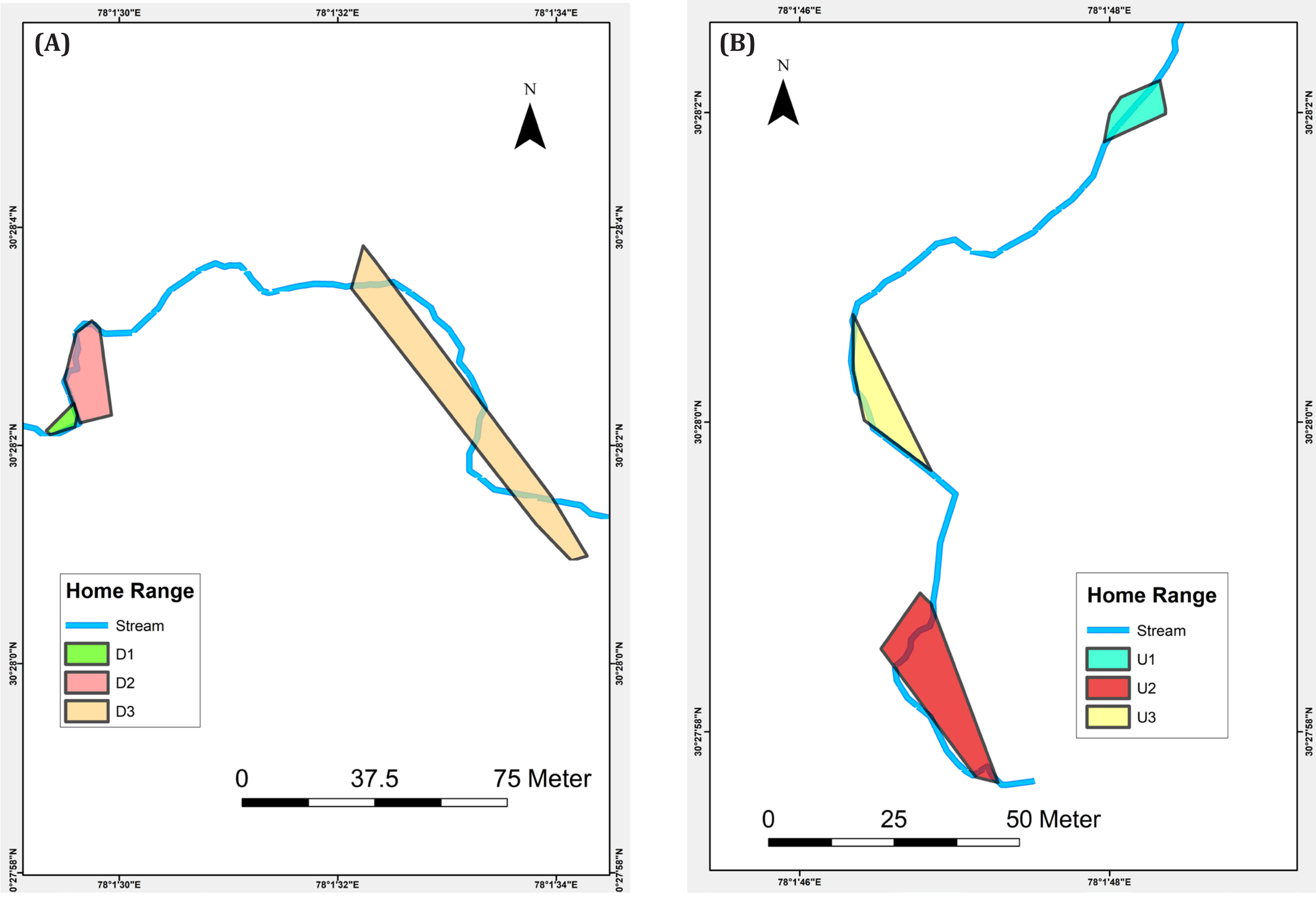

Figure 2. The home ranges (MCP) of six radio- tagged *Nanorana vicina* individuals along the streams and riparian area. The width of the streams is approximately 5 m. (A) The home ranges in the disturbed stream, (B) the home ranges in the undisturbed stream.

Table 2. Home range at 50% and 90% of six individuals using Minimum convex polygon.

Individual ID	MCP(m^2)	
	50%	90%
NVD1	8.59	15.78
NVD2	43.16	170.48
NVD3	12.01	684.99
NVU1	10.11	39.48
NVU2	31.94	200.78
NVU3	1.61	20.78

Although frogs exhibited less vagility, tagged frogs moved slightly more during the monsoon. In one case, a single individual (NVD3) moved approximately 100 m in a day during the monsoon (July), which was the highest movement throughout the study period. This movement resulted in the largest home range for NVD3 individual (Figure 2, A). Studies have shown that such movements by species may be undertaken to avoid areas that could flood during rain (Bosman *et al.* 1996).

While our study results do not provide an explanation for factors influencing movement and philopatry in *N. vicina*, the species' affinity for pool habitats with rocky boulders, as noted by Ahmed *et al.* (2020) and Rais *et al.* (2014), may offer a partial explanation. The abundance of such habitats in both streams could explain the lack of significant differences in the observed movement patterns between them. Additionally, the larval morphology of *N. vicina*, characterized by an anteroventral oral disc, dorsoventrally flattened body, and low tail fins, suggests adaptation to shallow, flowing water environments (Banerjee *et al.* 2020; Gill *et al.* 2020). A similar pattern has also been reported in some tropical and temperate stream-dwelling anurans that exhibited philopatry with limited movement (Inger 1969; Daugherty & Sheldon, 1982; Tessier *et al.* 1991). The limited movement by individuals is probably due to easy accessibility of necessary resources in their nearby

DOI: https://doi.org/10.63033/JWLS.JJAP3927

surroundings, such as riparian zones. These areas probably provide sufficient ecological resources, therefore long-distance movements are not required (Kam & Chen 2000) and amphibians tend to move less during their lifetime compared to the other vertebrates (Zug *et al.* 2001). While our study did not find significant differences in overall movement between disturbed and undisturbed streams, previous work in the same study area has documented the impact of check dams and stream channel modification on tadpoles of the genus *Nanorana* (Jithin *et al.* 2022a, b; Jithin & Das 2022).

Additionally, the tag attachment did not significantly impact the body weight of the frog. Tags were immediately removed if any lesions on the body of the frogs were observed, ensuring animal welfare. Furthermore, two frogs with attached nonfunctional tags were recovered after a span of 21 months;, however, no weight loss was detected. Throughout the course of study, we successfully recovered seven tags from the individuals while the rest four tags were lost (Nawani *et al.* 2022).

Our results provide valuable insights into the movement and home range of this sedentary, stream-dwelling frog. Thus, serving as a foundational platform for future research on this specific species and other Himalayan stream frogs. However, further studies are required to answer the factors influencing the movement, habitat use and home range of stream frogs. Additionally, to comprehend the impacts of habitat degradation on these less mobile and sedentary species, a long-term monitoring study is required.

Study Limitations:

While our study add new information about the movement patterns and home range of *N. vicina*, certain limitations need to be acknowledged. The species' limited movement, particularly if less than 5 meters, coupled with the GPS device's location error of 5 meters, may have compromised exact home range estimation. To mitigate this potential bias, we recorded GPS locations only when frogs moved more than 10 meters and supplemented these data with manual measurements using a meter tape.

Additionally, our home range analysis was based on six individuals. Thus, low sample size may limit the generalizability of our findings to the broader population of *N. vicina.* Further studies incorporating larger sample sizes and potentially more precise tracking technologies would be worthwhile to refine our understanding of *N. vicina* home range dynamics.

Acknowledgements

We sincerely acknowledge - Uttarakhand Forest Department providing research permission (permit letter no 1236/5-6 [WII] dated 16 November 2017). We also acknowledge Director, Dean and Research Coordinator of WII and Indraneil Das (Malaysia) for supporting our research. We are extremely grateful to Mrs. Kehkashan Naseem (Former DFO) and Dr. Shipra Sharma (Former FRO) for their immense support during field work. We would also like to extend our thanks to Forest guards of Binog wildlife sanctuary. Authors are thankful to Nilanjan Chatterjee, Jithin Vijayan, Siddhart Rajmohan, Shruti Arora, Aastha Saini, Naitik Patel, Bitupan Boruah, Anukul Nath, Bhawna Dhawan, Surojit Moitra, Devendra Ji and his family, Kuldeep Rawat and his family. We would like to express our sincere gratitude to Mr. Varun S Kher, Scientist C, WII and the anonymous reviewer for their time and expertise in reviewing our manuscript.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY

The data that supports the findings of this study are available in this article.

AUTHOR CONTRIBUTIONS

Conceptualization, fundraising and editing: Ab.D,
Field Work and data collection: S.N, D.S.G, K.B, Ab.D,
Data analysis: S.N, Ar.D, K.B.,
Original draft writing: S.N, K.B.

References

Ahmed W., Rais M., Saeed M., Gill S. & Akram S. (2020). Site occupancy of two endemic stream frogs in different forest types in Pakistan. *Herpetological Conservation and Biology*, 15(3), 506-511.

Akram A., Rais M., Saeed M., Ahmed W., Gill S. & Haider J. (2022). Movement Paradigm for Hazara Torrent Frog *Allopaa hazarensis* and Murree Hills Frog *Nanorana vicina* (Anura: Dicroglossidae). *Biodiversity Data Journal* 10: e84365. https://doi.org/10.3897/BDJ.10.e84365

Banerjee K., Boruah B. & Das A. (2020). First record of carrion feeding by tadpoles of *Duttaphrynus himalayanus* and *Nanorana vicina* from western Himalaya, India. *Tropical Natural History*, 20(3), 268-271.

Batool A., Rais M., Saeed,M., Akram A., Ahmed J., Ahmed W., Batool A. & Kyle KJ. (2023). New survey data on abundance and movements for two poorly known Asian Spiny Frogs. *Herpetozoa*, 36, 113-121.

Bosman W., Van Gelder JJ. & Strijbosch H. (1996). Hibernation sites of the toads *Bufo bufo* and *Bufo calamita* in a river floodplain. *Herpetological Journal*, 6(3), 83-86.

Boyle SA., Lourenço WC., Da Silva LR. & Smith AT. (2009). Home range estimates vary with sample size and methods. *Folia Primatologica*, 80(1), 33-42.

Daugherty CH & Sheldon AL. (1982). Age-specific movement patterns of the frog *Ascaphus truei*. *Herpetologica*, 468-474.

Gill S., Rais M., Saeed M., Ahmed W. & Akram A. (2020). The tadpoles of Murree hills frog *Nanorana vicina* (Anura: Dicroglossidae). *Zootaxa*, 4759(3), zootaxa.4759.3.11.

Goldberg CS., Goode MJ., Schwalbe CR. & Jarchow JL. (2002). External and implanted methods of radiotransmitter attachment to a terrestrial anuran (*Eleutherodactylus augusti*). *Herpetological Review*, 33(3), 191-193.

Groff LA., Calhoun AJ. & Loftin CS. (2017). Amphibian terrestrial habitat selection and movement patterns vary with annual life-history period. *Canadian Journal of Zoology*, 95(6), 433-442.

Inger RF. 1969. Organization of communities of frogs along small rain forest streams in Sarawak. *The Journal of Animal Ecology*, 123-148.

Jithin V., Johnson JA. & Das A. (2022a). Understanding the influence of check dam and season on habitat use to develop habitat suitability criteria for overwintering tadpoles of *Nanorana* spp. *River Research and Applications* 38(9) 1629-1641

Jithin V., Johnson JA. & Das A. (2022b). Influence of check dams on the activity pattern and morphometric traits of overwintering tadpoles in the Western Himalaya. *Limnologica* 95:125992

Jithin V. & Das A .(2022). Deaths of overwintering *Nanorana* sp tadpole due to desiccation during check dam maintenance in a Western Himalayan Stream, India. *Herpetological Bulletin*. 162: 23-25.

Johal MS. & Rawal YK. (2005). Key to the management of the western Himalayan hill streams in relation to fish species richness and diversity. *Hydrobiologia*, 532(1), 225-232.

Kam YC. & Chen TC. (2000). Abundance and movement of a riparian frog (*Rana swinhoana*) in a subtropical forest of Guandau stream, Taiwan. *Zoological Studies-Taipei-*, 39(1), 67-75.

Kim JJ., Atique U. & An KG. (2019). Long-term ecological health assessment of a restored urban stream based on chemical water quality, physical habitat conditions and biological integrity. *Water*, 11(1), 114.

Luger M., Hödl W. & Lötters S. (2009). Site fidelity, home range behaviour and habitat utilization of male harlequin toads (Amphibia: *Atelopus hoogmoedi*) from Suriname: relevant aspects for conservation breeding. *Salamandra* 45:211–218.

Nawani S., Banerjee K. & Das A. (2022). A case of radiotag recovery from *Nanorana vicina* (Anura: Dicroglossidae) (Stoliczka, 1872). Hamadryad.

Neu CP., Bisanz SS., Nothacker JA., Mayer M. & Lötters S. (2016). Male and female home range behavior in the Neotropical Poison Frog *Ameerega trivittata* (Anura, Dendrobatidae) over two consecutive years. *South american journal of herpetology*, 11(3), 212-219.

Panwar S. (2020). Vulnerability of Himalayan springs to climate change and anthropogenic impact: A review. *Journal of Mountain Science*, 17(1), 117-132.

R Core Team. (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/December21,2021.

Rais M., Abbassi S., Batool T., Jilani MJ., Assadi MA., Mubarak H. & Baloch S. (2014). A note on recapture of *Nanorana vicina* (Anura: Amphibia) from Murree, Pakistan. *Journal of Animal and Plant Sciences*, 24, 455-458.

Saeed M., Rais M., Akram A., Williams MR., Kellner KF., Hashsham SA. & Davis DR. (2022). Development and validation of an eDNA protocol for monitoring endemic Asian spiny frogs in the Himalayan region of Pakistan. *Scientific reports*, 12(1), 1-13.

Sinsch U., Oromi N., Miaud C., Denton J. & Sanuy D. (2012). Connectivity of local amphibian populations: modelling the migratory capacity of radio-tracked natterjack toads. *Animal Conservation,* 15(4): 388-396.

Sinsch U. (2014). Movement ecology of amphibians: From individual migratory behavior to spatially structured populations in heterogeneous landscapes. *Canadian Journal of Zoology* 92:491–502.

Tessier C., Slaven D. & Green DM. (1991). Population density and daily movement patterns of Hochstetter's frogs, *Leiopelma hochstetteri*, in a New Zealand mountain stream. *Journal of Herpetology*, 25(2), 213-214.

Welsh Jr, H. H., & Ollivier, L. M. (1998). Stream amphibians as indicators of ecosystem stress: a case study from California's redwoods. *Ecological applications,* 8(4), 1118-1132.

Zug GR, Vitt LJ & Caldwell JP. (2001). Herpetology: An Introductory Biology of Amphibians and Reptiles. *Academic Press*, USA.

 DOI: https://doi.org/10.63033/JWLS.JJAP3927

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Research Article

EDITED BY
Vishnupriya Kolipakam
Wildlife Institute of India

*CORRESPONDENCE
Mewa Singh
mewasinghltm@gmail.com

RECEIVED 25 June 2024
ACCEPTED 09 August 2024
ONLINE EARLY 11 August 2024

CITATION
Velankar, A. D., Kumara, H. N., Sheethal, V. R., Pal, A., Mishra, P. S., Singh, M.(2024). Activity budget and habitat use in the Nicobar long-tailed macaque *Macaca fascicularis umbrosus. Journal of Wildlife Science,* 1 (2), 87-95.
https://doi.org/10.63033/JWLS.RUPT1872

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Activity budget and habitat use in the Nicobar long-tailed macaque *Macaca fascicularis umbrosus*

Avadhoot D. Velankar[1,2], Honnavalli N. Kumara[1], Vepur Ramamurthy Sheethal[1], Arijit Pal[1,3], Partha Sarathi Mishra[1,4], Mewa Singh[5*]

[1]Salim Ali Centre for Ornithology and Natural History, South India Centre of Wildlife Institute of India, Anaikatty Post, Coimbatore 641108, Tamil Nadu, India
[2]Wildlife Conservation Society India, 551, 7th Main Road Rajiv Gandhi Nagar, 2nd Phase Bengaluru - 560097 Karnataka, India
[3]The Food and Land Use Coalition India, WRI India, AADI, Hauz Khas, New Delhi 110016, India
[4]Srishti Manipal Institute of Arts, Design and Technology, MAHE Bengaluru Campus, Govindapura, Bengaluru – 560064, Karnataka, India
[5]Biopsychology Laboratory, Institution of Excellence, Vijnana Bhavan, University of Mysore, Manasagangotry, Mysore-570006, Karnataka, India

Abstract

Time-activity budget and pattern of habitat use are basic tools to understand an animal's interaction with its environment. We studied a primarily commensal group of long-tailed macaques (*Macaca fascicularis umbrosus*) with 22 individuals in the Great Nicobar Island of India at Campbell Bay. Data on the frequency and duration of different activities were collected through scan sampling and *ad libitum* notes. We recorded the geo-coordinates of the visually approximated group center using a handheld GPS receiver (Garmin GPS Map 76csx) every 30 min to assess the ranging patterns. The group spent more time resting, followed by feeding/foraging, social behaviours, movement, and scouting. The time spent on various activities did not vary at different times of the day and showed no seasonal variations. The macaques fed mostly on the cultivated fruits. Although the total home range size was 66ha, the most frequently used area was only 6 ha. The macaques ranged over a larger area in the dry season than in the wet season. All these patterns show that the behaviour of the study group was typical of that of the commensal macaques of other species.

Keywords: Feeding, foraging, habitat use, long-tailed macaque, movement, Nicobar Island, ranging, social behaviour, time-activity budget.

Introduction

Two aspects of an organism's behavioural profile that are essential for its overall adaptation are the way an organism allots its time to various activities and the pattern of its habitat use. Unlike resources such as food, mate, and space, time is constant and finite throughout the lifecycle of the organism. Animals budget their time and energy for different activities in an adaptive manner. Wilson (1975) made two generalizations about time-activity-energy budgets: the principle of stringency stating that these budgets evolve to fit the times of greatest stringency, and the principle of allocation that time and energy are allocated to activities in terms of priorities that usually descend as food, antipredation, and reproduction. Monitoring the activity budget of an animal is the easiest way to understand the interdependence of the animal and its environment. Hence, spatio-temporal changes in environment, physiology, and social organization of a species are directly reflected in changes in time invested in various activities. For example, barbary macaques (*Macaca sylvanus*) spent more time feeding during snowfall days than during no snowfall (Majolo *et al.*, 2013). Urban commensal rhesus macaque (*M. mulatta*) groups spent more time resting than rural groups (Jaman & Huffman, 2013). Similarly, the diet pattern of a species dictates its activity budget. A frugivorous and habitat specialist species such as the lion-tailed macaque (*M. silenus*) was found to move farther in search of food during the resource crunch period than during the resource-rich period (Santosh *et al.*, 2015). On the other hand, folivorous species such as Guereza (*Colobus guereza*) and the snub-nosed monkey

(*Rhinopithecus roxellana*) were found to spend more time resting than moving (Fashing, 2001; Guo *et al.*, 2007). The social organization of a species also influences the time spent on different activities. Species that are involved in scramble competition over limited food resources tend to spend more time moving (van Schaik *et al.*, 1983) than species without scramble competition (Fashing, 2001).

Changes in diurnal activity due to environmental, physiological, or social factors manifest as variations in ranging patterns within and between species. Lion-tailed macaques were reported to use regions with high fruit availability and shifted their home range accordingly during the wet and dry seasons (Santosh *et al.*, 2015). Similar results were reported in red colobus (*Colobus badius*), where time spent in the area correlated with availability of food resources (Clutton-Brock, 1975). Habitat use is also observed to vary seasonally. Seasonal shrinkage in home range size was observed in Japanese macaques (*M. fuscata*) due to the availability of supplemental food during the tourist season (Koganezawa & Imaki, 1999). In lion-tailed macaques, ranging varied seasonally, which was influenced by the availability of *Artocarpus heterophyllus* and *Ficus amplissima* in summer, *Artocarpus heterophyllus* in monsoon, and *Cullenia exarillata* and *Toona ciliata* in post-monsoon (Erinejery *et al.*, 2015). Just like the within-group scramble competition affects ranging patterns (van Schaik *et al.*, 1983), the between-group competition has also been observed to play an important role. Nilgiri langurs (*Semnopithecus johnii*) were observed to shift their home range to avoid between-group encounters (Kavana *et al.*, 2014). The availability of food also influences tolerance between neighbouring groups. Japanese macaque was reported to have more overlapping home ranges in resource-rich areas than in resource-poor areas (Maruhashi *et al.*, 1998).

The long-tailed macaque (*M. fascicularis*) is a primarily frugivorous species that exploits various resources indicating its generalist nature (Yeager, 1996). They exhibit scramble competition and tend to have larger home ranges for larger group sizes (van Schaik *et al.*, 1983). The Nicobar Islands in India harbour a unique subspecies of long-tailed macaques (*M. f. umbrosus*). The 2004 tsunami destroyed large parts of the habitat of these macaques and drastically reduced their population (Sivakumar, 2010). However, over the next decade or so, the population recovered with a very high rate of turnover (Velankar *et al.*, 2016). Whereas several studies on demography (Pal *et al.*, 2018a), foraging (Pal *et al.*, 2018b; Das *et al.*, 2020; Venlankar *et al.*, 2023) and social behaviour (Pal *et al.*, 2019; Mishra *et al.*, 2020a,b) of this island population are reported, there is no study on their basic activity patterns and habitat use. Here, we report the activity budget and habitat use by these long-tailed macaques inhabiting an area populated by humans at Campbell Bay in the Nicobar Islands and discuss the effect of such habitat on the activity patterns.

Methods

Study Site:

The study was conducted at Campbell Bay, Great Nicobar Island, lying between 7° 1' 30" – 7° 0' 0" N and 93° 4' 30" – 93° 57' 0" E (Figure 1). The study site includes a mosaic of natural as well as human-altered land cover types. The coastal region of the study area is dominated by *Pandanus* spp. and a littoral forest consisting of *Ficus rumphii, Alstonia* spp., *Garcinia nervosa, Terminalia* spp., and *Semecarpus* spp., while the inland region is dominated by human habitation and plantations of coconut (*Cocos nucifera*) and beetle nut (*Areca catechu*) (Sinha *et al.*, 1999). Human habitation consists primarily of small single-story households with kitchen gardens intermittent with open and dense secondary scrub vegetation. The area inhabited by humans is dominated by introduced vegetation consisting of bananas (*Musa paradisiaca*), guava (*Psidium guajava*), and mangoes (*Mangifera indica*). The altitude of the study area ranges from 0 m asl to 218 m asl. Study area receives an annual rainfall of about 3200 mm. A major portion of the rainfall is received from May to November, whereas December to April remains relatively dry.

Study Group:

We selected a group of 22 individuals of long-tailed macaques located at Campbell Bay for the current study. The group had three adult males, seven adult females, two subadult males, seven juveniles, and three infants. The group was habituated for observer presence from April 2013 to October 2013.

Data collection:

The group was followed from dawn (0600 hrs) to dusk (1800 hrs). We recorded the major activities using instantaneous scan sampling (Altmann, 1974) for five minutes at intervals of 30 minutes as per the ethogram provided in Table 1. All individuals in the group were scanned. Though the number of scans for the adults was about equal, it varied among younger individuals due to the age differences and birth intervals. The average number of scans per individual was 5.11 ± 1.9SD. In addition to the major activities, we recorded data on the strata used, feeding, and proximity to the nearest and farthest individuals of the focal animal. For feeding activity during continuous feeding bouts as well as during foraging, details of plant species along with parts consumed and processing and handling by a macaque were documented using *Ad-libitum* notes. We recorded the geo-coordinates of the visually approximated group centre using a handheld GPS receiver (Garmin GPS Map 76csx) every 30 min.

Analysis

Activity budgets:

We sorted the scan data season-wise, and prepared contingency tables as activity vs month and time of the day for dry and wet seasons. The proportion of each activity was calculated using the aggregated activity budget method (Marsh, 1981). Similarly, information on feeding habits was prepared in contingency tables for the wet and dry seasons. We classified the food items based on the source as plantation and forest species. Food items were further divided into origins of the source *i.e.* animal, plant, and human waste. The resources of the plant species were subdivided into various parts, such as fruit, leaf, stem, flower, and roots. The proportion of major behavioural states (Table 1) was calculated for a day by dividing the day into 6 classes. We performed the Kruskal-Wallis nonparametric test (Quinn & Keough, 2002) to compare the proportions of the various activities between seasons. We employed the G-test to check for differences within behavioural and feeding classes, and the Z-test of proportions for the difference between seasons.

Habitat Use:

We converted the group locations as shape files. The study area was overlaid with a vector grid of 100 m x 100 m cell dimensions (Grueter *et al.*, 2009; Santosh *et al.*, 2015). We kept a one-

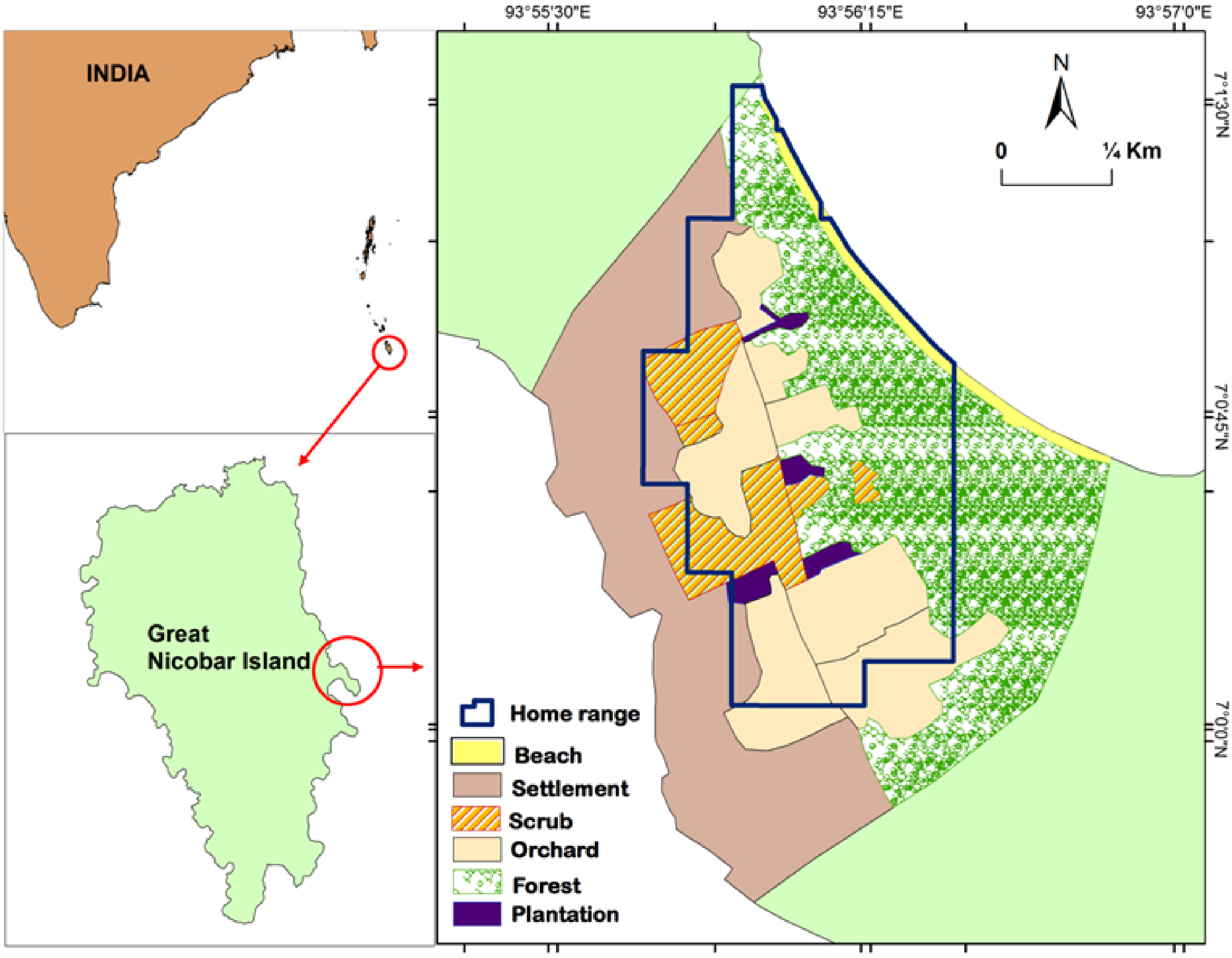

Figure 1: Map of the study site in Campbell Bay region with home range of the study group

Table 1: Ethogram of the major behavioural states of the Nicobar long-tailed macaques recorded during the study period along with a brief description

Activity	Description
Movement	Locomotion to spatially different locations; vertical movement on the same tree and movement within group spread was not considered as movement
Feeding/Foraging	Feeding on plant or animal resources. This involves food acquisition, processing and consuming. Also included moving exploration with intermittent feeding
Resting	This comprises of states such as mastication, self-grooming, sleeping or sitting.
Social	Behaviours comprising grooming, play, courtship, mating and agonistic interactions with other group members
Scouting	Individuals giving alarm calls to potential threats or being vigilant after noticing other group in vicinity including behaviours directed towards other groups or organisms

 DOI: https://doi.org/10.63033/JWLS.RUPT1872

hectare area as an appropriate unit to understand the habitat used by the group, considering the home ranges of a few groups (see Pal *et al.*, 2018). The frequency of grid cell use was computed by counting the number of point locations within a grid cell for wet and dry seasons. The frequencies were converted into proportions by dividing the count of points within a grid cell by the total number of points recorded during each season. The study area was classified into six broad land cover types as habitats *viz.*, Beach, Household, Orchards, Primary Forest, Open scrub, and Plantation. Since the study area was small, land-use and landcover classes were mapped accurately by digitizing them using high-resolution google earth imagery (Figure 1). Ground control points to determine boundaries were taken using handheld GPS. The spatial availability of each habitat type was estimated as a proportion of habitat type within the area of each grid cell. While following the study group, we recorded the geocoordinate of the group location every 30 minutes. Connecting those consecutive points of a day with the nearest distance was considered the daily path length.

Variation in intensity of grid use and variation in day activity budget between seasons was compared using non-parametric Wilcoxon's Signed Rank test. We employed McNemar's chi-square test (Quinn & Keough, 2002) to determine whether the group used the same grids during different seasons. We employed one-way ANOVA to assess variations in the spatial availability of habitat types within each grid cell. The comparisons between classes were done by Tukey's post-hoc test of Honest Significant Difference (HSD). We used Pearson's correlation to check for the association between the intensity of grid use and the proportion of available habitat type. Tree density and food species density were also calculated for each grid. Proximity from human settlements, home range overlap with other groups, and the number of between-group encounters observed in each grid were taken as explanatory variables. We used a Generalised Linear Model to test the influence of these seven covariates on the grid-use pattern by the macaques. All statistical analyses were carried out using R statistical language v3.02 (R Development Core Team, 2008) with R Studio IDE for R v0.98.953 with a p-value set at 0.05. We used QGIS v2.13, to prepare land use and land cover maps, as well as to extract information on ranging.

Results

Activity budgets: We collected a total of 4628 individual scans from October 2013 to December 2015 (Table 2). Macaques spent more time resting, which was followed by feeding/foraging, social, and movement, while the time spent on scouting was much shorter (Figure 2) (Kruskal – Wallis $\chi2$ = 53.84, df = 4, P <0.001). Time spent on each activity was almost similar at different times of the day during the dry (Figure 2a) and the wet (Figure 2b) seasons as indicated by the flatness of the curves. There were no significant difference in activities within each daytime class between seasons (Movement: W = 17, P = 0.17, Feed/forage: W = 10, P = 0.50, , Social: W = 14, P = 0.07, Rest: W = 12, P = 0.75, Scout: W = 17, P = 1.70) (Table 2) (Figure5).

Feeding/foraging: The macaques were observed to forage and feed on 26 major food items, of which 12 were introduced by humans and 14 were of native origin (Table 3). The relative frequency of feeding on introduced species was significantly higher (Z = 27.93, P < 0.01) than on native species (Figure 3). Macaques relied significantly more on plant resources than on animal or human waste resources (Z = 19.78, P < 0.01) (Figure 4). Among plant resources, macaques fed on fruits (N = 675) significantly more than flowers (N = 6), stems (N = 32) and leaves (N = 50) (Figure 5) (Z = 15.38,P < 0.01). Coconut (27.0 - 27.0%), banana (11.9 - 9.3%), guava(18.6 - 19.0%), and *Pandanus* spp.(10.2 - 8.6%) were the most commonly consumed fruits.

Habitat use: A total of 803 group locations (Dry N = 330, Wet N = 473) were spread over 66 grid cells. Although the total home range size was 66 ha (66 grid cells), the group used only about 6 ha (six grid cells; 9.09%) for most of their movement (Figure 6a). The number of grid cells entered in the dry season (Figure 6b) was more than in the wet season (McNemar's $\chi2$ = 16.36, p < .01) (Figure 6c). However, the number of intensively used grid cells between the two seasons was almost the same. The group did not use many grids in the western, northern, and southern parts during the wet season. The daily path length was longer in the wet season than in the dry season (t = 2.35, df = 55, p < 0.05) (Table 4).

The GLM was run with seven predictors keeping the grid use as the response variable. The model was significantly explanatory when compared with a null model (residual deviance = 913.19, null deviance = 1642.58, DF = 65, residual DF = 61, p < 0.001). The model showed the affinity of the group to grids with overlapping home ranges of adjacent groups. The group also did not avoid the area with frequent between-group encounters (Table 5).

The spatial availability of all habitat types within each grid cell differed significantly ($F_{5, 390}$ = 19.11, P < 0.001). The mean spatial availability of Primary Forest (0.39 ± 0.40) and Orchards (0.32 ± 0.38) was significantly higher than that of other habitat types (Figure 7). Overall proportion of each habitat type within the home range was 2.90 % for beach, 7.70 % for households, 14.00 % for open scrub, 33.70 % for orchards, 38.50 % for primary forest and 3.10 % for plantation. However, Pearson's correlation between habitats and the proportion of grid use did not show significant association between all habitats and the intensity of use, except for the plantation which showed weak but significant association (Table 6).

Discussion

The study group spent most of its time on resting which was followed by feeding/foraging, social, and movement. Diurnal activity patterns did not vary among different time slots of the day and between seasons. Although the macaque diet included several food components, its primary diet was fruits. No seasonal variation in dietary patterns was observed. The home range of the study group was 66 ha, while only 6 ha of that was used most frequently. The area used in the wet season was less than the area used in the dry season. The group showed no tendency to avoid overlapping ranges with other groups or areas of greater between-group encounters.

The study group, being partially commensal, largely fed on food resources from orchards and plantations, spending little time in the acquisition of low-cost high-energy foods with ample spare time for resting. Similar observations were reported in rhesus macaque (*M. mulatta*), where an urban commensal group spent 46% of its time resting alone (Jaman & Huffman, 2013). Similarly, provisioned groups of *Macaca fascicularis* in Vietnam were observed to spend 31.60% to 36.83% of time resting, which again was the most common activity (Son, 2003). Likewise, a provisioned group of Tibetan macaques (*M. thibetana*) spent 59.72% of its time resting (Wang *et al.*, 2007). The time spent on different activities remained almost constant throughout the day. Unlike many other primate species, especially in their natural habitats, which generally show two foraging peaks during a day (Qihai *et al.*, 2014; Zhou *et al.*, 2022) and seasonal variations in their time-activity budgets (Zhou *et al.*, 2007, 2022), the present study group showed no such patterns due to the constant year-round food supply in the human-dominated habitat.

DOI: https://doi.org/10.63033/JWLS.RUPT1872

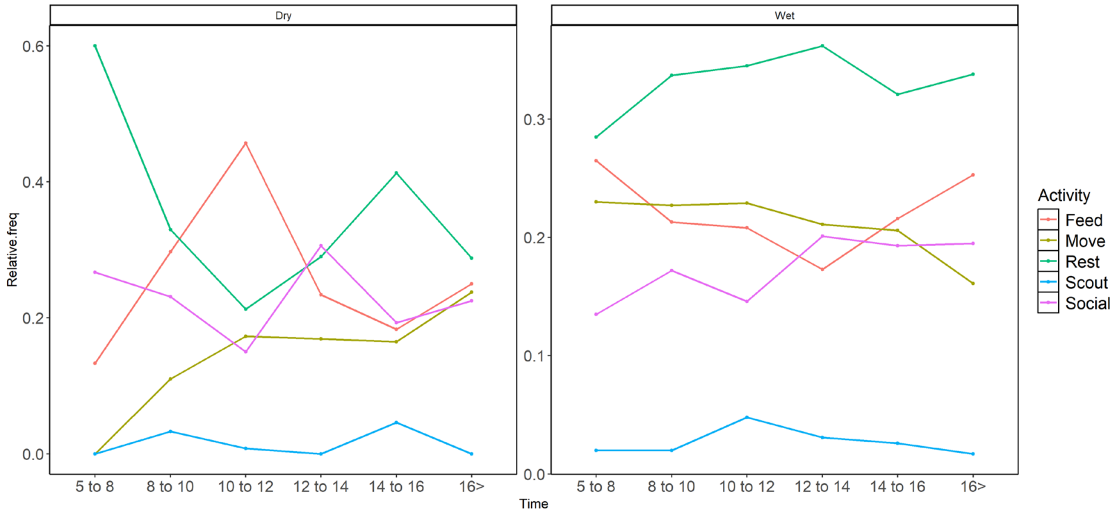

Figure 2: Activities at different times of the day. Left. Dry Season, Right. Wet Season

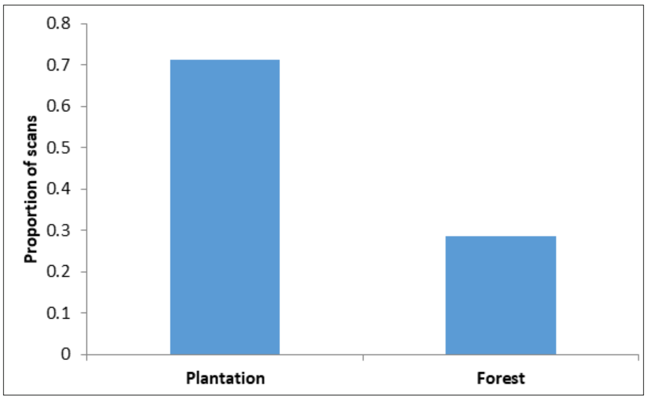

Figure 3: Proportion of food items consumed by Nicobar long tailed macaques

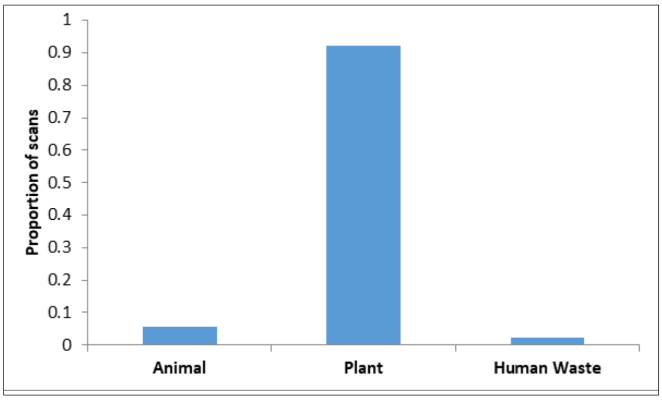

Figure 4: Proportion of food items of animal, plant or human origin consumed by Nicobar long tailed macaques

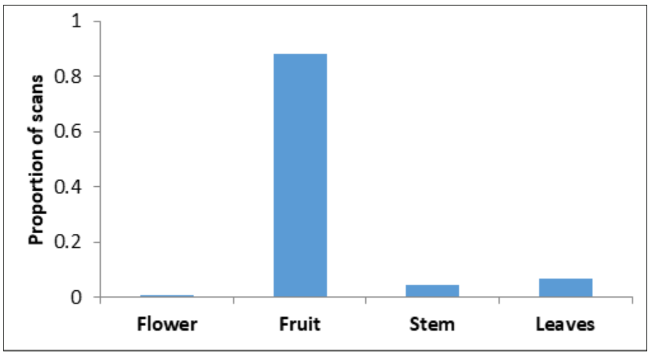

Figure 5: Proportion of different plant parts eaten by Nicobar long-tailed macaques

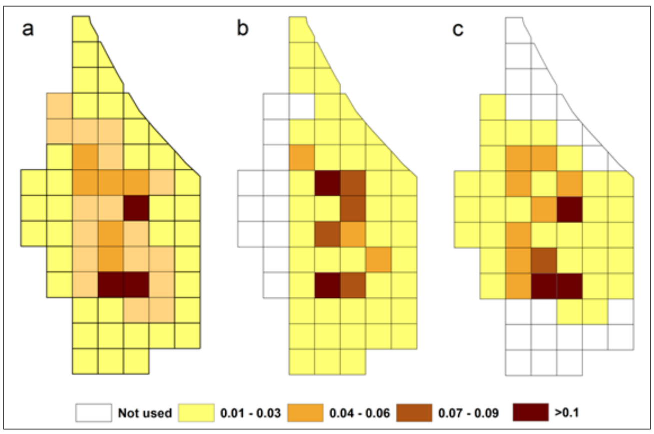

Figure 6: Proportion of grid cells used by Nicobar long tailed macaques in, a. Overall study period, b. Dry season, c. Wet season

DOI: https://doi.org/10.63033/JWLS.RUPT1872

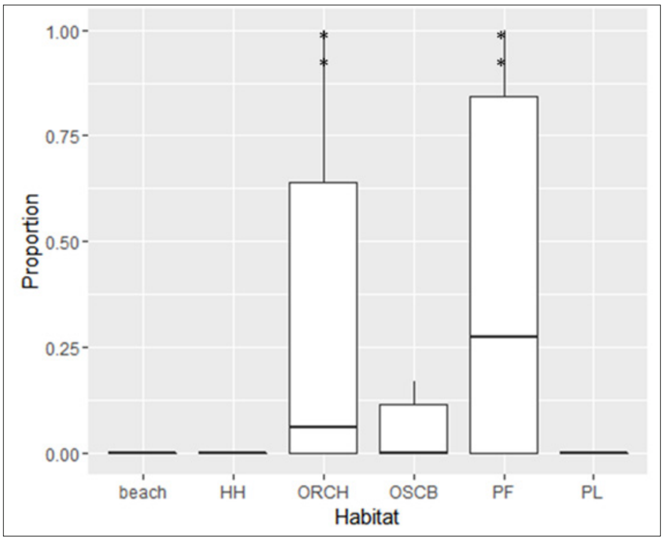

Figure 7: Proportion of habitat type in the grid cells within the home range of study group Nicobar long-tailed macaque. HH = Households, ORCH = Orchards, OSCB = Open Scrub, PF = Primary Forest, PL = Plantation. ** Tukey HSD test $P_{adj}<0.001$

Table 2: Number and proportion of scans recorded for each activity in each season (total scans 4628)

Activity	Total	Dry	Wet	G test of proportions
Move	21.37 (N = 989)	16.48 (N = 90)	22.02 (N = 899)	G = 4.10, df = 2 NS
Feed/Forage	22.64 (N = 1048)	28.58 (N =156)	21.92 (N =892)	G = 2.74, df = 3, NS
Social	18.58 (N = 860)	22.16 (N = 121)	18.10 (N = 739)	G = 3.71, df = 2 NS
Rest	34.44 (N = 1594)	31.14 (N = 170)	34.88 (N = 1424)	G = 2.20, df = 2 NS
Scout	2.96 (N = 137)	1.65 (N = 9)	3.14 (N = 128)	G = 1.60, df = 2 NS

NS – Non significant

Table 3: Relative frequency and source of major food items consumed by Nicobar long tailed macaques.

Common name	Species	Dry season		Wet season		Overall Percent scans
		N (scans)	Percent scans	N (scans)	Percent scans	
		Food items of cultivated or human origin				
Australian acacia	*Acacia auriculiformis*	11	6.2	42	6.7	6.60
Custard apple	*Annona reticulata*	4	2.3	12	1.9	1.99
Papaya	*Carica papaya*	4	2.3	12	1.9	1.99
Coconut	*Cocos nucifera*	38	21.5	169	27.0	25.78
Hibiscus	*Hibiscus rosa-sinensis*	0	0.0	3	0.5	0.37
Banana	*Musa paradisiaca*	21	11.9	58	9.3	9.84
Guava	*Psidium guajava*	33	18.6	119	19.0	18.93
Sugarcane	*Saccharum* spp.	3	1.7	9	1.4	1.49
Tomato	*Solenum lycopersicum*	2	1.1	6	1.0	1.00
Egg plant	*Solenum melongena*	2	1.1	6	1.0	1.00
Tamarind	*Tamarindus indica*	3	1.7	9	1.4	1.49
-	Egg	0	0.0	3	0.5	0.37
-	Urban waste	0	0.0	3	0.5	0.37

 DOI: https://doi.org/10.63033/JWLS.RUPT1872

Species in forests and secondary growth on fallow land						
Jackfruit,	*Artocarpus* spp.	1	0.6	3	0.5	0.50
Australian pine	*Casurina equisetifolia*	4	2.3	4	0.6	1.00
Wild musk melon	*Cucumis* spp.	6	3.4	18	2.9	2.99
Banyan	*Ficus bengalensis*	2	1.1	6	1.0	1.00
-	*Ficus* spp.	2	1.1	6	1.0	1.00
Infane	*Garcinia* spp.	2	1.1	6	1.0	1.00
	Invertebrate	10	5.6	34	5.4	5.48
Mango	*Mangifera* spp.	8	4.5	33	5.3	5.11
Kevda	*Pandanus odoratissimus*	18	10.2	54	8.6	8.97
-	*Semecarpus* spp.	1	0.6	6	1.0	0.87
-	Soil	2	1.1	2	0.3	0.50
-	unknown sp. A	0	0.0	3	0.5	0.37
-	Urban waste	0	0.0	3	0.5	0.37

Table 4: Seasonal variation in daily path length in metres by Nicobar long-tailed macaques

Season	N	Range (Metres)	Mean (± SD)
Dry	27	712.82 - 1280.41	916.13 (±121.79)
Wet	30	704.18 - 1336.76	1025.40 (±219.35)
Overall	57	704.18 - 1336.76	973.64 (±186.63)

Table 5: Influence of covariates on the intensity of grid use by Nicobar long-tailed macaques

Grid Use ~ HR Overlap + BGE + Tree Cover + Food Tree Density				
Predictor	**B**	**SE**	**Walds Z**	**P**
Intercept	1.462	0.104	13.965	<0.0001
Home range overlap	0.724	0.120	6.050	<0.0001
Between-group encounters	0.240	0.010	23.724	<0.0001
Tree cover (%)	0.034	0.166	0.027	NS
Food tree density	-0.903	1.078	-0.837	NS

NS – Non significant

Table 6: Pearson's product-moment correlation between the intensity of grid use and available habitat types.

	Beach	Household	Open scrub	Orchards	Primary forest	Plantation
Correlation coefficient	0.161	- 0.164	- 0.140	- 0.10	- 0.12	0.334
p	0.192	0.186	0.263	0.931	0.923	0.005

DOI: https://doi.org/10.63033/JWLS.RUPT1872

The group was observed to feed on 25 food resources, of which four were most common, *viz.*, coconut, banana, guava and *Pandanus* spp. Among them, three resources were from orchards and plantations in human habitation, and those were available throughout the year. Primary forests and orchards spatially cover the majority of the study area (72.2%). Yeager (1996) reported similar findings from Kalimantan Tengah, Indonesia, where the long-tailed macaque exploited 33 plant resources of which five were most frequent in their diet. This indicates the generalist nature of the species; as in both studies, macaques utilized the most abundant, and thus, low-cost resource first. Due to this high dependency on perennially available food sources, the group did not exhibit seasonality, and the most heavily used grids, or core home ranges, remained unchanged between the seasons. However, they were observed to utilize a few more grids, especially littoral patches, to feed on Pandanus, available during the dry season. Significantly longer daily path length in the wet season than in the dry season indicated a more intensive search of the area in the wet season.

The ranging pattern of a species is highly dependent on food availability, and seasonal changes in food availability (Clutton-Brock, 1975, Maruhashi *et al.*, 1998; Santosh *et al.*, 2015,). Human-influenced land cover types (orchards, plantations, households, and open scrub) constituted 58.6% of the home range of the present study group. This may have resulted in the constant availability of food resources in all seasons in the home range. Thus, the extent of intensively used grids by the study group did not differ significantly. However, the group used a larger portion of the home range in the dry season compared to the wet season. Such patterns have been observed in other macaque species also. In the toque macaques (*M. sinica*), the dry season home range of 3.98 ha was larger than the wet season range of 2.8 ha (Jayapali *et al.*, 2023). As in the case of the present study group which did not use many grids in the northern, western and southern parts of its range during the wet season, the Japanese macaques shifted their home ranges between the eastern and western parts and modified their travel rates seasonally (Hanya *et al.*, 2020). van Schaik *et al.* (1983) demonstrated that larger groups travel farther due to the 'pushing forward effect' where group members try to go to newer unexploited patches sooner. The resource competition was very low in our study group, as it was a small unimale group. In a human-dominated landscape, the study group adapted to food resources available in human habitation, which has resulted in increased human-macaque conflict in the region. Coconut, banana, and guava are cultivated by local people for economic gains, and the resulting loss has increased human-macaque conflict (Mishra *et al.* 2020c).

The between-group competition instead of food availability was the most influencing factor on grid-use by the study macaques. The study group was among the smallest compared to the two neighbouring groups of 79 and 37 individuals, having massive handicap during aggressive encounters (Pal *et al.*, 2018a). Hence, affinity of the study group towards home range overlap and areas with high between-group encounters seems apparently counter-intuitive. However, it can be explained due to the following reasons: van Schaik *et al.* (1983) showed that daily path length increases with group size because individuals in a group attempt to reach intact foraging patches, and larger groups move often and spend less time in a patch. Conversely, a smaller group will exhaust the patch at a much slower rate and will not be influenced by 'the pushing forward effect'. This may have allowed the present small group to utilize the smaller patches within the home range overlap more efficiently. Also, the resource requirement of a smaller group is lesser, enabling it to exploit smaller patches that larger groups cannot exploit. All these pattern show that the behaviour of the study group was typical of that of the commensal macaques of other species.

Acknowledgements

We thank the Department of Science and Technology, Government of India, for the financial assistance to HNK (Grant No.SR/SO/AS-49/2011 to carry out the project. We are grateful to the Principal Chief Conservator of Forests, Port Blair, Andaman and Nicobar Islands, for granting permission to carry out the study (Permit No. CWLW/WL/134/566), and the Assistant Commissioner, Andaman and Nicobar Administration, for providing the necessary permits to access the tribal areas. We express our gratitude to the Andaman and Nicobar Forest Department, especially the Nicobar division along with the Nicobar Administration, for logistical support. We thank the Directors, SACON, Coimbatore, for their valuable support. Mewa Singh thanks the Indian National Science Academy for the Distinguished Professor award (N0. SP/DP/2023/656) during which this article was prepared.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY

Data and codes are available from the corresponding author on request.

AUTHOR CONTRIBUTIONS

HNK and ADV conceived the study. ADV, SVR, AP, and PSM carried out the fieldwork and data analysis. HNK and MS procured funding and supervised the study. All authors contributed to the article preparation.

References

Altmann, J. (1974). Observational study of behavior: sampling methods. *Behaviour*. 49(3), 227-266.

Clutton-Brock, T. H. (1975). Ranging behaviour of red colobus (*Colobus badius tephrosceles*) in the Gombe National Park. *Animal Behaviour*, 23, 706-722.

Das, S., Harpalani, M., Chaudhuri, B., Negi, R., Ali, T.H. & Singh, M. (2020). Use of an embedded fruit by the Nicobar long-tailed macaque (*Macaca fascicularis umbrosus*): I. Familiarity to coconuts (*Cocos nuciferus L.*) and temporal patterns of coconut foraging. *Primate Conservation*, 34, 195-216.

Erinjery, J.J., Kavana, T.S. & Singh, M. (2015). Food resources, distribution and seasonal variations in ranging in lion-tailed macaques, *Macaca silenus* in the Western Ghats, India. *Primates*, 56, 45–54.

Fashing, P. J. (2001). Activity and ranging patterns of guerezas in the Kakamega Forest: intergroup variation and implications for intragroup feeding competition. International Journal of *Primatology*, 22(4), 549-577.

Grueter, C. C., Li, D., Ren, B., & Wei, F. (2009). Choice of analytical method can have dramatic effects on primate home range estimates. *Primates*, 50(1), 81-84.

Guo, S., Li, B., & Watanabe, K. (2007). Diet and activity budget of *Rhinopithecus roxellana* in the Qinling Mountains, China. *Primates*, 48(4), 268-276.

Hanya, G., Yoshihiro, S., Hayaishi, S. & Takahata, Y. (2020). Ranging patterns of Japanese macaques in the coniferous forest of Yakushima: Home range shift and travel rate. *American Journal of Primatology*, 82(10), e23185.

Jaman, M. F. & Huffman, M. A. (2013). The effect of urban and rural habitats and resource type on activity budgets of commensal rhesus macaques (*Macaca mulatta*) in Bangladesh. *Primates*, 54(1), 49-59.

Jayapali, U., Perera, P., Cresswell, J. & Dayawansa, N. (2023). Does Anthropogenic Influence on Habitats Alter the Activity Budget and Home Range Size of Toque Macaques (*M. sinica*)? Insight into the Human-Macaque Conflict. *Trees, Forests and People*, 13, 100412.

Kavana, T. S., Erinjery, J. J. & Singh, M. (2014). Male takeover and infanticide in Nilgiri langurs *Semnopithecus johnii* in the Western Ghats, India. *Folia Primatologica*, 85(3), 164-177.

Koganezawa, M., & Imaki, H. (1999). The effects of food sources on Japanese monkey home range size and location, and population dynamics. *Primates*, 40(1), 177-185.

Majolo, B., McFarland, R., Young, C., & Qarro, M. (2013). The effect of climatic factors on the activity budgets of Barbary macaques (*Macaca sylvanus*). *International Journal of Primatology*, 34(3), 500-514.

Marsh, C. W. (1981). Time budget of Tana River red colobus. *Folia Primatologica*, 35(1), 30-50.

Maruhashi, T., Saito, C., & Agetsuma, N. (1998). Home range structure and inter-group competition for land of Japanese macaques in evergreen and deciduous forests. *Primates*, 39(3), 291-301.

Mishra, P.S., Pal, A., Velankar, A.D., Kumara, H.N. and Singh, M. (2020a). Do males bond? A study of male-male relationships in Nicobar long-tailed macaque *Macaca fascicularis umbrosus*. *Journal of Biosciences*, 45,22

Mishra, P.S., Pal, A., Velankar, A., Kumara, H.N., Singh, M. & Cooper, M. (2020b). Does rank rule? Rank-related grooming patterns in Nicobar long-tailed macaques *Macaca fascicularis umbrosus*. *Primates*, 61, 443-453.

Mishra, P. S., Kumara, H. N., Thiyagesan, K., Singh, M., Velankar, A. D., & Pal, A. (2020c). Chaos in coexistence: perceptions of farmers towards long-tailed macaques (*Macaca fascicularis umbrosus*) related to crop loss on Great Nicobar Island. *Primate Conservation* 34, 175-183.

Pal, A., Kumara, H.N., Velankar, A., Mishra, P.S. & Singh, M. (2018a). Demography and birth seasonality in the Nicobar long-tailed macaque (*Macaca fascicularis umbrosus*). *Current Science*, 114, 1732-1737.

Pal, A., Kumara, H.N., Mishra, P.S., Velankar, A. & Singh, M. (2018b). Extractive foraging and tool-aided behaviors in the wild Nicobar Long-tailed Macaque (*Macaca fascicularis umbrosus*). *Primates*, 59, 173-183.

Pal, A., Kumara, H.N., Velankar, A.D., Mishra, P.S. & Singh, M. (2019). Changes in behavior following a 'rank changeover by challenge' in the Nicobar long-tailed macaque (*Macaca fascicularis umbrosus*). *Current Science*, 117, 672-682.

Qihai Z., Hua W., Huaxing T., Zhonghao H., Ali K., & Chengming H. (2014). Niche separation of sympatric macaques, *Macaca assamensis* & *M. mulatta*, in limestone habitats of Nonggang, China. *Primates*, 55(1), 125–137.

Quinn, G. P., & Keough, M. J. (2002). Experimental design and data analysis for biologists. Cambridge University Press.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL https://www.R-project.org.

Santhosh, K., Kumara, H. N., Velankar, A. D., & Sinha, A. (2015). Ranging behavior and resource use by lion-tailed macaques (*Macaca Silenus*) in selectively logged forests. *International Journal of Primatology*, 36(2), 288-310.

Sinha, B. K. (1999). Flora of Great Nicobar Island. Botanical Survey of India, Dehradun.

Sivakumar, K (2010). Impact of the tsunami (December, 2004) on the long tailed macaque of Nicobar Islands, India. *Hystrix, the Italian Journal of Mammology*, 21, 35–42.

Son, V. D. (2003). Diet of *Macaca fascicularis* in a mangrove forest, Vietnam. Laboratory Primate Newsletters, 42(4), 1-5.

van Schaik, C. P., Van Noordwijk, M. A., de Boer, R. J., & den Tonkelaar, I. (1983). The effect of group size on time budgets and social behaviour in wild long-tailed macaques (*Macaca fascicularis*). *Behavioral Ecology and Sociobiology*, 13(3), 173-181.

Velankar, A.D., Kumara, H.N., Pal, A., Mishra, P.S. & Singh, M. (2016) Population Recovery of Nicobar Long-Tailed Macaque *Macaca fascicularis umbrosus* following a Tsunami in the Nicobar Islands, India. *PLoS ONE*, 11(2), e0148205.
doi:10.1371/journal. pone.0148205

Velankar, A.D., Kumara, H.N., Pal, A., Mishra, P.S. & Singh, M. (2023). Tough nut to crack? Proficiency in coconut processing of the Nicobar long-tailed macaque *Macaca fascicularis umbrosus*. *Journal of Biosciences*, 28,1-10.

Wang, G., Yin, H., Yu, G. & Wu, M. (2007). Time budget of adult Tibetan macaques in a day in spring. *Chinese Journal of Wildlife*, 29, 6–10.

Wilson, E.O. (1975). Sociobiology: The new synthesis. The Belkna Press of Harvard University.

Yeager, C. P. (1996). Feeding ecology of the long-tailed macaque (*Macaca fascicularis*) in Kalimantan Tengah, Indonesia. *International Journal of Primatology.* 17(1), 51-62.

Zhou, J., Li, Wen-Bo., Wang, Xi., & Li, Jin-Hua. (2022). Seasonal change in activity rhythms and time budgets of Tibetan macaques. *Biology*, 11(9), 1260.

Zhou Q., Wei F., Huang C., Li M., Ren B., & Luo B. (2007). Seasonal variation in the activity patterns and Time Budgets of *Trachypithecus francoisi* in the Nonggang Nature Reserve, China. *International Journal of Primatology*, 28, 657–671.

 DOI: https://doi.org/10.63033/JWLS.RUPT1872

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Short Communication

Addressing Human-Elephant Conflict in Sarpang, Bhutan: Challenges and Practices

Ugyen Tshering[1], Rupali Thakur[2], Sonali Ghosh[3], Anukul Nath[2*]

[1]Jomotsangkha Wildlife Sanctuary, Department of Forests and Park Services, Bhutan
[2]Wildlife Institute of India, India
[3]Assam Forest Department, Assam, India

DIAMOND OPEN ACCESS Crossref

EDITED BY
Vishnupriya Kolipakam
Wildlife Institute of India

*CORRESPONDENCE
Anukul Nath
anukul@wii.gov.in

RECEIVED 7 March 2024
ACCEPTED 14 August 2024

CITATION
Tshering, U., Thakur, R., Ghosh, S., Nath, A. (2024) Addressing Human-Elephant Conflict in Sarpang, Bhutan: Challenges and Practices. *Journal of Wildlife Science*, 1 (2), 96-101.
https://doi.org/10.63033/JWLS.FTLB3638

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Abstract

Asian elephants face threats from human-elephant conflict (HEC), driven by habitat encroachment and fragmentation. In the foothills of the Himalayas, HEC affects a large number of people, causing significant damage to property and crops. Bhutan, sharing elephant habitats with India, faces similar challenges, particularly in the southern regions in Sarpang. We studied the HEC pattern and mitigation strategies adopted by people through a questionnaire survey. Our primary data from the Sarpang division showed that more than 40 % of households experienced HEC. The elephant largely affected maize and paddy along with cash crops such as areca nut, orange, ginger, and cardamom. The study revealed a strong association between crop-raiding incidents and cultivated areas, with most depredations occurring at night. The majority of respondents indicated that crop depredation has increased over the years, which could be linked to the degradation and fragmentation of forest habitat in the landscape. Mitigation measures, such as electric fencing, are preferred but underutilized due to financial constraints. The study emphasizes the need for transboundary cooperation between India and Bhutan, integrating traditional and advanced mitigation strategies, and community involvement. Effective communication, joint patrolling, and habitat restoration are the keys to managing HEC. Transboundary governance should include political and legal support, regional diplomacy, and innovative land use policies.

Keywords: Conservation policy; Conservation strategies; Landscape management; Questionnaire survey; Wildlife Management.

Introduction

Human-elephant conflict (henceforth HEC) is recognized as one of the key threats to the survival of Asian elephants (*Elephas maximus*). Due to their requirements for large home ranges, elephants increasingly come into conflict with humans, especially where human populations and associated activities have significantly increased (Desai & Riddle, 2015). The Indian subcontinent, comprising India, Bangladesh, Bhutan, Nepal, and Sri Lanka, hosts a substantial wild elephant population exceeding 27,312 individuals (MoEFCC, 2017), representing 66.4% of the total Asian population (Kemf & Santiapillai, 2000). The continual encroachment and fragmentation of elephant habitats caused by increasing populations in South Asia has resulted in an increase in human-elephant interactions and conflicts (Fernando *et al.*, 2005). Crop depredation is a prevalent and foremost issue in South Asia as 20% of the human population lives inside and adjacent to elephant habitat areas (Bandara & Tisdell, 2002). Numerous studies highlight the complexity and severity of HEC in South Asia empirically (Sukumar 2006; Desai & Riddle, 2015; Nath *et al.* 2015; Rai & Karthik, 2021; Thant *et al.* 2021; Pandey *et al.* 2022).

Human-wildlife conflict is a significant concern on the national agenda in Bhutan (Nature Conservation Division, 2008), with conflicts developing in many regions of the country. Particularly, the recurring encounters between humans and elephants have been a longstanding issue, inflicting economic burdens and sociocultural strains on farmers inhabiting the southern regions of Bhutan. These confrontations often lead to significant losses in agricultural yield and property damage (Jigme & Williams, 2011). Bhutan shares a contiguous elephant habitat with India, primarily in the southern region of the country. These habitats encompass administrative divisions such as Samtse, Gedu (Chhukha), Sarpang, and Samdrup Jongkhar (comprising Samdrup Jongkhar and Pemagatshel), in addition to protected areas including Phibsoo

Wildlife Sanctuary, Royal Manas National Park, and Jomotshangkha Wildlife Sanctuary (Nature Conservation Division, 2018). A national elephant survey was conducted in Bhutan in 2016 that estimated about 678 elephants confined to the southern foothills adjoining Assam and West Bengal states of India (Nature Conservation Division, 2018).

The Government of Bhutan has consistently recognized local communities as essential collaborators in conservation efforts (Rinzin *et al.*, 2009). Bhutanese people have also been guided by the Buddhist principles of compassion towards all living beings. However, because of frequent conflicts with wildlife, communities now see them as an impediment to their livelihoods and survival. A survey by Wang *et al.* (2006) on the attitudes of farmers towards livestock loss in Jigme Singye Wangchuck National Park in south-central Bhutan showed that 68% of the respondents wanted to exterminate problem animals. Addressing human-wildlife conflict has become a challenging task for the Ministry of Agriculture and Forests, and particularly the Department of Forests and Park Services, which has administrative control over forested areas in Bhutan. Agriculture is the primary focus in the southern region of Bhutan, characterized by its higher human population density. However, farmers in this area face economic losses and significant challenges due to the presence of elephants (Jigme & Williams, 2011; Nagdrel, 2008). Conflicts primarily occur in buffer zones since only a few people live within Protected Areas (Jigme & Williams, 2011). Sarpang is one of the *dzongkhags* (districts) in southern Bhutan impacted by this issue. A similar pattern was also seen in the neighbouring state of Assam (Nath *et al.*, 2009, 2015) in India bordering Bhutan. Legally, the Asian elephant is protected under Schedule I (assigning highest protection) of national legislation in India and Bhutan (as in the Forest and Nature Conservation Act, 1995 of Bhutan and Wildlife (Protection) Act, 1972 of India), but challenges remain in enforcement and implementation (Menon *et al.*, 1997). Hence, to implement species conservation measures and protect livelihoods, baseline information on the status and difficulties of HEC in the region is necessary. Here, we present the results obtained from a baseline study that was conducted to assess the extent of HEC in Sarpang, Bhutan. Additionally, we also discuss the implications for mitigation and governance to address these complex issues associated with HEC.

Study Area

The present study was carried out in the Sarpang forest division (SFD; 26.8632° N, 90.2675° E) of Bhutan. It is located at the southernmost region of Bhutan with Tsirang division and Phibsoo Wildlife Sanctuary in the west, Royal Manas National Park in the east, Jigme Singye Wangchuck National Park in the north and India in the south (Figure 1). It is one of the earliest divisions to be formed (in 1959) under the Department of Forests and Park Services of Bhutan. Currently, the division covers two districts, namely Sarpang and Dagana, comprising 12 *gewogs* (blocks) of a total area of about 1200 km^2. Broadleaf forest constitutes ~82% of the total land area of SFD (Table 1). The elevation ranges from 100 to 3600 m with annual precipitation of 3,500–5,500 mm (Department of Agriculture, 2012). Biological corridor number 3, which connects Royal Manas National Park, Jigme Singye Wangchuck National Park, and Phibsoo Wildlife Sanctuary, also falls within the administrative jurisdiction of the Division, provisioning better connectivity among protected areas (Tenzin *et al.*, 2021). The divisional headquarter is located at Sarpang-Tar, Shompangkha *gewog* of Sarpang *dzongkhag*.

Methods

We conducted interviews with residents in the Sarpang forest division in the spring of 2016, following a stratified random sampling approach (Anoop *et al.*, 2023; Thant *et al.*, 2021). We used a structured close-ended questionnaire (Appendix 1). All *chewogs* (sub-blocks) (n = 48) in a *gewog* under the SFD were included in the survey, and 10% of all households from each of the *chewog* were selected for interview. The questionnaire was pre-tested with ten households to assess its relevance and efficiency. The questionnaire collected comprehensive data on respondents' demographics, education, livelihood, crop cultivation patterns, attitudes towards elephants, and the mitigation measures they adopted (Sampson *et al.*, 2019; Milda *et al.*, 2020). Data collection focused on incidents from the past two years. The choice of selecting 10% of households per *chewog* was made to balance the representativeness and manageability of the sample size, ensuring a statistically significant representation of the study population.

Only the households reporting conflict with elephants were included in the HEC analyses. We quantified conflict incidents by calculating the percentage of households reporting HEC incidents relative to the total number of households interviewed in each gewog. Temporal patterns of crop damage were categorized into four periods – morning, midday, evening, and night – as it was difficult for respondents to pinpoint the exact timing of crop damage. We used Pearson's correlation in SPSS v.16.0 to explore the relationship between crop raiding incidents and the cultivation area of different crops. This approach allowed us to identify associations and better understand the factors relating to HEC. We used ArcGIS v10.3 to create maps illustrating the spatial distribution of HEC incidents.

Results

Characteristics of respondents

Among 249 respondents, 64.43% (n = 160) were male, and 35.57% (n = 89) were female. The age distribution was classified into three categories: 18–35 years (18.3%), 36–59 years (56%), and 60 years and above (25.7%). Approximately 27.1% of the respondents had completed primary education, 4% had completed junior schooling, 2.6% had completed secondary education, and only 0.9% had completed graduation. Notably, 65.4% of the respondents had no formal education. The ethnic composition included 59.7% Lhotsam, 23.4% Sharchop, 14.3% Khengpa, and 2.6% Ngalop tribes. Among these, 42% were relocated from other regions of Bhutan under a resettlement program. The primary sources of household income were agriculture (76.9%), livestock (10.6%), business (7.7%), and wages/salary (4.8%). The main agricultural crops cultivated were maize, followed by areca nut (Table 2).

Conflict Analysis

Out of 249 households interviewed, 104 households (41.8%) reported conflict with elephants. The respondents who reported conflict with elephants mostly cultivated maize and paddy, along with cash crops such as areca nut, orange, ginger, and cardamom (Table 2). An average of 1.45 ± 1.05 ha land per household was also left fallow. The three most important reasons for leaving the land fallow were- 1) crop damage by wildlife (35.21%), 2) irrigation/water shortage (22.54%), and 3) shortage of man power (21.13%), followed by less productivity, landslides, rocky fields, and fodder cultivation (Table 3).

 DOI: https://doi.org/10.63033/JWLS.FTLB3638

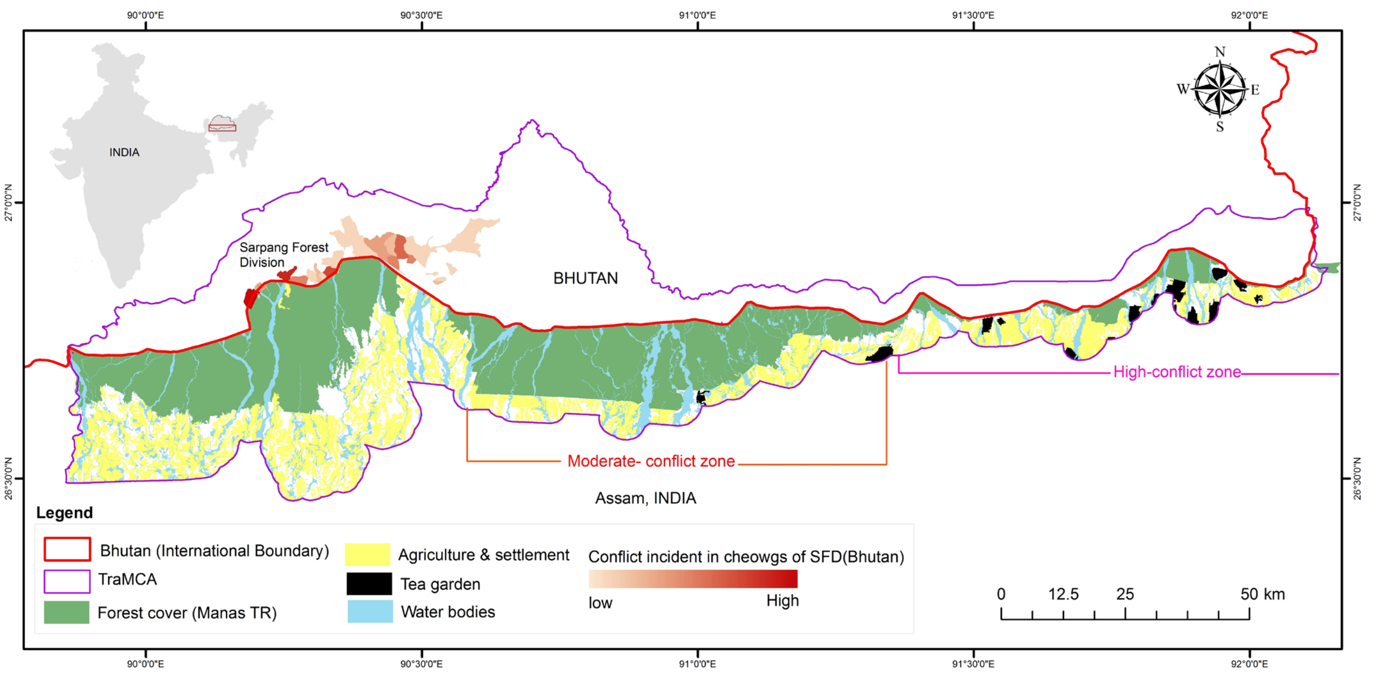

Figure 1. Map showing the conflict incidents in different *chewogs* of Sarpang forest division (SFD), Bhutan, and conflict zone (based on the number of elephant and human death reports) in the Transboundary Manas Conservation Area (TraMCA) region of India

Table 1. Area coverage of land use types in Sarpang Forest Division, Bhutan

Land-use types	Area (km^2)
Agriculture	75.80
Built up areas	3.23
Landslide	6.12
Broadleaf Forest	993.13
Mixed Conifer Forest	11.07
Meadows	1.72
Rock outcrop	3.473
Shrub	75.15
Lakes	0.006
Rivers	36.35
Reservoirs	0.053

Table 2. Cultivated crops in the Sarpang Forest Division and correlation between incidence of conflict and area of crops cultivated

Crop Type	Respondents (%)	Area in ha (mean ± SE)	Correlation of crop area with incidents of conflict (Pearson's r)
Maize	27	0.62 ± 0.04	.559**
Paddy	17	0.70 ± 0.06	.527**
Mustard	1	0.26 ± 0.03	.426*
Areca nut	24	0.28 ± 0.03	.374*
Millet	15	0.30 ± 0.02	.333
Cardamom	1	0.77 ± 0.48	-.271
Orange	8	0.54 ± 0.19	.122
Ginger	7	0.12 ± 0.01	.019

*p<.05, **p=<.01

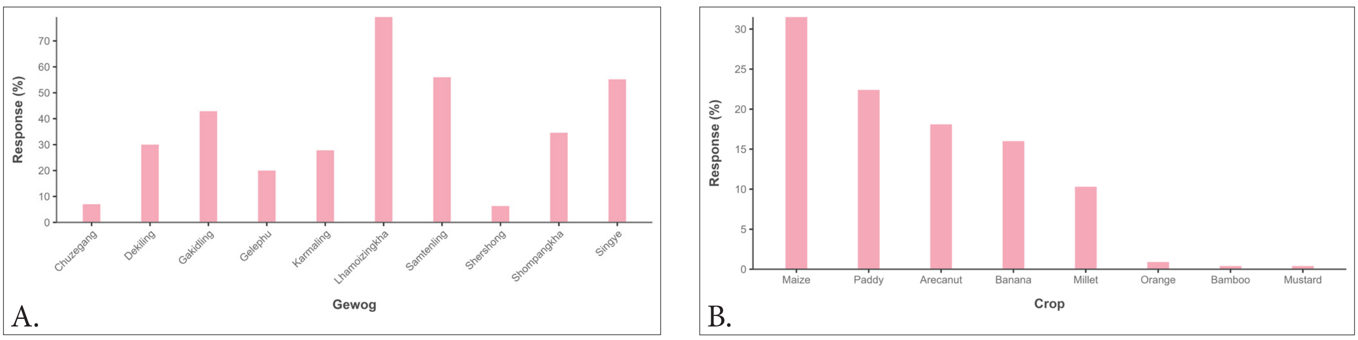

Figure 2. Responses of people about human-elephant conflict status in Sarpang forest division, Bhutan. **A)** Percent of respondents reporting a conflict incident in each gewog (block), **B)** Types of cross raided by elephants in Sarpang forest division.

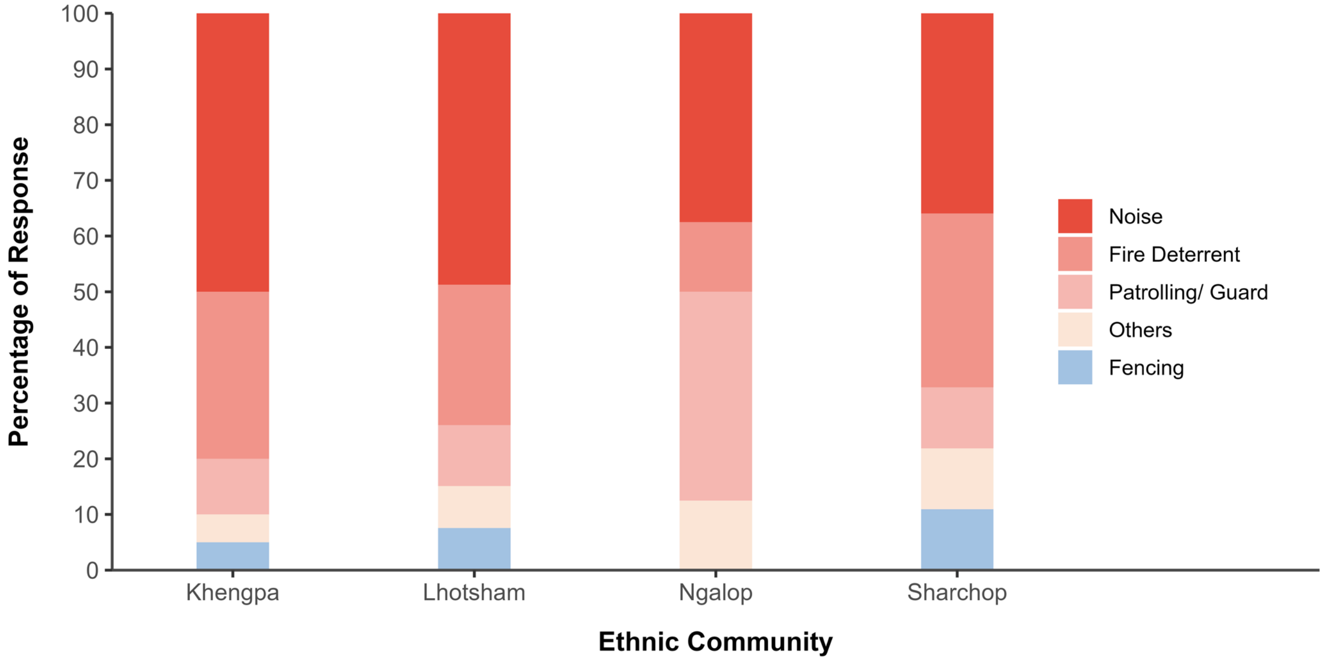

Figure 3 Mitigation measures practiced by different ethnic communities in Sarpang Forest Division, Bhutan.

Table 3. Reasons reported by farmers for keeping land fallow in Sarpang Forest Division, Bhutan

Reason for keeping land fallow	% respondent
Crop depredation by wildlife	35.21
Irrigation/water shortage	22.54
Shortage of manpower	21.13
Low production	8.45
Landslide	5.63
Rugged terrain	2.82
For fodder plantation	1.41
Land adjacent to the international border	1.41
Isolated settlement	1.41

Out of 12 *gewogs* studied, 10 reported conflicts with elephants and the remaining two with wild pigs. The most affected *gewog* was Lhamoizingkha under Dagana *dzongkhag*, followed by Samtenling in Sarpang *dzongkhag* (Figure 2A). Two *gewogs* located at higher elevations from the foothills did not report conflict with elephants.

Our findings reveal a strong association between the occurrence of crop-raiding incidents by elephants and the extent of cultivated crop areas (Table 2). Maize (32%) was the most raided crop by wild elephants, followed by Paddy (22%), as well as other crops including areca nut (18%), banana (16%), and millet (10%) (Figure 2B). Both maize (r= 0.559) and paddy (r = 0.527) cultivation showed strong positive correlations with crop raiding (Table 2).

About 80.3% of the respondents stated that elephants raided crops during the night, followed by evening (16%), morning (2.2%) and afternoon (1.5%). Subsequently, 51.46% of respondents stated that crop depredation has increased. According to them, the most common reasons for such an increase were the degradation of the forest habitat, an increase in elephant populations, an increase in settlements near the forest, and a decrease in hunting due to strict law enforcement. However, 33.98% of the respondents stated that crop depredation has decreased due to mitigation measures such as electric fencing. The rest stated there was no change in the conflict pattern.

Mitigation Measures

Reports of crop and wildlife depredation are important in order to undertake mitigation interventions. However, 36% of the respondents did not report crop depredation incidents to the agencies because i) they were unaware of the reporting system, ii) the damage caused by elephants was minimal, and iii) they were tolerant towards such damage due to their Buddhist faith. Respondents reported incidents to the *gewog* civic administration and the forest department. Local communities have predominantly relied on traditional mitigation. The measures adopted by ethnic communities included keeping night vigils, making fire, and beating drums (Figure 3). Besides, communities expressed demand for electric fences due to their perceived effectiveness.

Discussion

Increasing cases of HEC is a major issue for the communities living in and around the Sarpang division of Bhutan. Agriculture is the main source of income for the people of Sarpang, with maize and paddy being the primary crops cultivated. Subsequently, the frequency of crop raiding incidence was also high for these two crops. This pattern is consistent with observations from both Asia and Africa, where elephants are known to primarily feed on mature staple crops (such as rice, maize, and wheat). Apart from high nutritional value, palatability and ease of handling during foraging have made these crops highly attractive for consumption, especially to adult males (Biru & Bekele 2012; Gross *et al.*, 2018). Moreover, the high proportion

 DOI: https://doi.org/10.63033/JWLS.FTLB3638

of respondents involved in agriculture (76.9%) reflects the limited diversification of livelihoods, making households highly vulnerable to crop depredation. This is compounded by the fact that a significant portion of the population relies on subsistence farming, with minimal access to alternative income sources (Barua *et al.*, 2013; Ogra, 2008; Woodroffe, 2005). In Sarpang, elephants often raid crops because of their close proximity to the forest boundary. Desai & Riddle (2015) mentioned that HEC occurs because people live and practice agriculture adjacent to elephant habitats. Therefore, crop protection will continue to have high labour and financial costs (Gross *et al.*, 2018). The present study and studies carried out elsewhere clearly showed that the elephants raid or damage mature crops compared to other stages of growth, but there are multiple other factors that can influence the movement and behaviour of the species (Chiyo & Cochrane, 2005; Desai & Riddle, 2015; Songhurst *et al.*, 2015; Gross *et al.*, 2018). These can broadly be grouped into four factors – habitat quality, elephant population, individual elephant behaviour, and people's tolerance level – that contribute to initiating and escalating HEC in Asia (Desai & Riddle, 2015).

The occurrence of HEC was more during the cropping season (summer). This substantiated the previous studies (Jigme & Williams, 2011) that during the non-growing season of a gricultural crops, elephants would migrate to India and remain there until the next cropping season. Similarly, a study in Manas National Park, India, revealed that elephant density was high during the dry season as compared to the wet season (Das, 2020), which in several ways supports the local movement pattern of elephants in the region. The observation that elephants predominantly raid crops at night in Sarpang is consistent with findings from various studies across different regions, including Bhutan and India (Jigme & Williams, 2011; Sukumar, 2003).

Mitigation strategies employed in Sarpang include traditional methods, which, while helpful, often fall short of providing long-term solutions (Kochprapa *et al.*, 2023; Pandey *et al.*, 2022). The community's preference for electric fencing reflects a shift towards more effective, albeit costlier, measures. Thus, addressing HEC in Sarpang necessitates a multifaceted approach incorporating both traditional and modern strategies. The forest department of Bhutan is taking several steps to mitigate the HEC in this region. Severely affected communities have been equipped with solar/electric fencing, with a total of 153 km of electric fencing established across the entire division. Habitat restoration efforts are also ongoing, including the construction of waterholes, fodder enrichment, removal of invasive Lantana camara, and corridor management. The Forest Department conducts education programs, and awareness initiatives are conducted in schools and communities to promote elephant conservation. In severely affected communities, Quick Response Teams (QRTs) have been established, comprising local members ranging from five to eleven individuals. In gewogs with a high number of HEC incidences, five Elephant Conservation Committees (ECC) have been formed, and crop insurance schemes have been initiated in these ECCs.

While solar-powered electric fencing is the preferred mitigation measure in the TraMCA (Transboundary Manas Conservation Area) landscape, fewer than 1 % of affected farmers in Bhutan have been able to install such systems due to financial limitations. Consequently, there is a pressing need to enhance transboundary coordination between India and Bhutan, particularly concerning governance and conflict management policies. However, conservation and management in the transboundary region present significant complexities and challenges, requiring socio-political consent and approval (Selier *et al.*, 2016). Therefore, it is crucial to develop a transboundary policy framework that aligns legal and policy adjustments with the landscape-scale movements of megaherbivores.

Lastly, a multi-pronged approach is recommended, to effectively tackle transboundary governance issues as follows- institutional arrangements: establish political and legal support, develop management plans, and implement conflict mitigation strategies, alerts, and penalties; regional diplomacy: foster multi-stakeholder groups and promote regional collaboration; community participation: encourage community-based protection measures, including cooperative crop guarding and fencing; awareness and education: increase community understanding of elephant conservation through initiatives led by Protected Areas and educational agencies; capacity building and law enforcement: provide joint training for officials and local teams on either side of the border to enforce laws and manage relevant data.

TO DOWNLOAD APPENDIX 1 CLICK **HERE**

Acknowledgements

The authors would like to thank the Department of Forests and Park Services, Govt of Bhutan and Forest Department, BTAD, Govt. of Assam for providing relevant permissions to carry out field research and for sharing published data records respectively. Indira Gandhi National Forest Academy and Wildlife Institute of India are thanked for providing the requisite support and academic platform for conducting the study.

CONFLICT OF INTEREST

The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY

Data and codes are available from the corresponding author on request.

AUTHOR CONTRIBUTIONS

UT, SG, AN conceived and designed the study. UT carried out field sampling. UT, RT & AN analysed the dataset. UT & SG write the first draft of the MS. RT & AN reviewed and edited the final draft.

References

Anoop, N. R., Krishnan, S., & Ganesh, T. (2023). Elephants in the farm–changing temporal and seasonal patterns of human-elephant interactions in a forest-agriculture matrix in the Western Ghats, India. Frontiers in Conservation Science, 4, 1142325.

Bandara, R., & Tisdell, C. (2002). Asian elephants as agricultural pests: Economics of control and compensation in Sri Lanka. Natural Resource Journal, 42(3), 491–519.

Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of human–wildlife conflict: Health impacts, opportunity and transaction costs. Biological Conservation, 157, 309-316.

Biru, Y., & Bekele, A. (2012). Food habits of African elephant (*Loxodonta africana*) in Babile Elephant Sanctuary, Ethiopia. Tropical Ecology, 53(1), 43-52.

Chiyo, P. I., & Cochrane, E. P. (2005). Population structure and behaviour of crop-raiding elephants in Kibale National Park, Uganda. African Journal of Ecology, 43(3), 233-241.

Das, J. P., Lahkar, B. P., Sahu, H. K., & Singha, H. (2020). Population Estimation of Asian Elephants in a Tropical Forest of Northeast India. Gajah, (52).

Desai, A.A., & Riddle, H.S. (2015). Human-elephant conflict in Asia. US Fish and Wildlife Service, Washington, DC, USA, and Asian Elephant Conservation Fund, St. Louis, MO, USA.

Department of Agriculture (2012). Data collection survey on strategic Agricultural water supply and management in southern Bhutan (Final report of Japan International Cooperation Agency (JICA) Sanyu Consultants INC., Department of Agriculture, Thimphu, Bhutan.

Fernando, P., Wikramanayake, E., Weerakoon, D., Jayasinghe, L.K.A., Gunawardene, M., & Janaka, H.K. (2005). Perceptions and patterns of human–elephant conflict in old and new settlements in Sri Lanka: Insights for mitigation and management. Biodiversity & Conservation, 14, 2465-2481.

Gross, E.M., Lahkar, B.P., Subedi, N., Nyirenda, V.R., Lichtenfeld, L.L., & Jakoby, O. (2018). Seasonality, crop type and crop phenology influence crop damage by wildlife herbivores in Africa and Asia. Biodiversity and Conservation, 27, 2029-2050.

Jigme, K., & Williams, A.C. (2011). Current status of Asian elephants in Bhutan. Gajah, 35, 25-28.

Kemf, E., & Santiapillai, C. (2000). Asian Elephants in the wild. 2000—A WWF Species Status Report. Gland, Switzerland.

Kochprapa, P., Savini, C., Ngoprasert, D., Savini, T., & Gale, G. A. (2023). Spatio-temporal dynamics of human– elephant conflict in a valley of pineapple plantations. Integrative Conservation, 2(2), 95-107.

Menon, V. (1997). A god in distress: threats of poaching and the ivory trade to the Asian elephant in India (No. 3). Asian Elephant Conservation Centre, Indian Institute of Science.

Milda, D., Ramesh, T., Kalle, R., Gayathri, V., & Thanikodi, M. (2020). Ranger survey reveals conservation issues across Protected and outside Protected Areas in southern India. Global Ecology and Conservation, 24, e01256. doi: https://doi.org/10.1016/j.gecco.2020.e01256

MoEFCC (2017). Synchronized elephant population estimation: India (2017). Project Elephant Division, Ministry of Environment, Forest and Climate Change, Government of India.

Nagdrel (2008) Extent of Human-Elephant Conflicts and the Threat to Elephant Populations in Southern Bhutan. M.Sc. thesis, University of Natural Resources and Applied Life Sciences.

Nath, N.K., Lahkar, B.P., Brahma, N., Dey, S., Das, J.P., Sarma, P.K., & Talukdar, B.K. (2009). An assessment of human-elephant conflict in Manas N ational Park, Assam, India. Journal of Threatened Taxa, 309-316.

Nath, N.K., Lahkar, B.P., Dutta, S.K., & Das, J.P. (2015). Human-elephant conflict around Manas National Park, India: Local people's attitudes, expectations and perceptions. Gajah, 42, 15-21.

Nature Conservation of Bhutan (2008). Bhutan National Human-Wildlife Conflict Management Strategy. Thimphu: Department of Forests.

Nature Conservation of Bhutan (2018). National Elephant Survey Report. Nature Conservation Division, Department of Forests and Park Services, Ministry of Agriculture and Forests, Thimphu, Bhutan.

Ogra, M. V. (2008). Human–wildlife conflict and gender in protected area borderlands: A case study of costs, perceptions, and vulnerabilities from Uttarakhand (Uttaranchal), India. Geoforum, 39(3), 1408-1422.

Pandey, N., Lurz, P., Hopker, A., Anderson, N., Goswami, J., Kumar, S., & Rather, T. A. (2022). Impact and Mitigation of Human-Elephant Conflict around Kaziranga National Park, Assam, India. International Journal of Ecology and Environmental Sciences, 48(6), 703-714.

Rinzin, C., Vermeulen, W. J., Wassen, M. J., & Glasbergen, P. (2009). Nature conservation and human well-being in Bhutan: An assessment of local community perceptions. The journal of environment & development, 18(2), 177-202.

Sampson, C., Leimgruber, P., Rodriguez, S., McEvoy, J., Sotherden, E., & Tonkyn, D. (2019). Perception of human–elephant conflict and conservation attitudes of affected communities in Myanmar. Tropical Conservation Science, 12, 1940082919831242.

Selier, S. J., Slotow, R., Blackmore, A., & Trouwborst, A. (2016). The legal challenges of transboundary wildlife management at the population level: The case of a trilateral elephant population in southern Africa. Journal of International Wildlife Law & Policy, 19(2), 101-135.

Songhurst, A., McCulloch, G., & Coulson, T. (2016). Finding pathways to human–elephant coexistence: a risky business. Oryx, 50(4), 713-720.

Sukumar, R. (2003). The Asian elephant: Ecology and management. Cambridge University Press.

Tenzin, J., Dhendup, P., Dorji, D., Nidup, S., & Thinley, P. (2021). Annotated checklist and conservation status of mammal species in Sarpang District, Bhutan. Indonesian Journal of Social and Environmental Issues (IJSEI), 2(3), 258-270.

Thant, Z. M., May, R., & Røskaft, E. (2021). Pattern and distribution of human-elephant conflicts in three conflict-prone landscapes in Myanmar. Global Ecology and Conservation, 25, e01411.

Wang, S. W., Lassoie, J. P., & Curtis, P. D. (2006). Farmer attitudes towards conservation in Jigme Singye Wangchuck National Park, Bhutan. Environmental Conservation, 33(2), 148-156.

Woodroffe, R., Thirgood, S., & Rabinowitz, A. (Eds.). (2005). People and wildlife, conflict or co-existence? (Vol. 9). Cambridge University Press.

JWLS
Volume 1, Issue 2 (July 2024)

TYPE Short Note

Free-ranging Spotted Deer (*Axis axis*) in Chennai, India

Rosella Daniels[1*], Sarangan Prabakaran[1]

[1]Marine Biology Regional Center, Zoological Survey of India, Santhome High Road, Chennai 600 028

DIAMOND OPEN ACCESS Crossref

EDITED BY
Mewa Singh
Institution of Excellence, University of Mysore

*CORRESPONDENCE
Rosella Daniels
danielsrosella@gmail.com

RECEIVED 29 May 2024
ACCEPTED 25 June 2024
ONLINE EARLY 1 July 2024

CITATION
Daniels, R., Prabakaran, S. (2024)
Free-ranging Spotted Deer (*Axis axis*) in Chennai. *Journal of Wildlife Science,* 1 (2), 102-103.
https://doi.org/10.63033/JWLS.GGKV4784

PUBLISHED BY
Wildlife Institute of India, Dehradun, 248 001 INDIA

Keywords: Spotted Deer, Chennai, Meta-population

Spotted Deer or Chital (*Axis axis*) is a medium-sized cervid endemic to South Asia. The largest population of spotted deer is found in India, where it can be seen in suitable habitats across the country, except in the northwestern arid plains and the higher reaches of the Himalayas (Schaller, 1967; Raman, 2015).

The history of spotted deer presence in Chennai city is somewhat murky. There are unpublished reports of spotted deer straying into parts of Tambaram from the forests of Vandalur during the early years of the twentieth century (Anandhapriyan, 2016). Well-known naturalist and wildlife photographer M. Krishnan has, however, stated that the spotted deer is an 'introduced' species (Krishnan, 1972). According to him, there was a small herd of spotted deer held captive within a paddock in the Government House of erstwhile Madras. Around the time of India's independence in 1947, these deer were released inside the 'Guindy Lodge', a wilderness area that surrounded the Raj Bhavan (Shanker, 2014). It was here that the well-known Guindy Deer Park was first established and years later, in 1978, the Guindy National Park came into existence (Raman *et al.*, 1996).

Although M. Krishnan's views have been generally accepted, another little-known book has provided some interesting, if not contradicting, insights. According to the author, Isabel Savory, a British hunter who travelled in India towards the end of the 19th century, the 'Guindy Park' was already 'overstocked' with spotted deer (Savory, 1900). It appears that the spotted deer has had a much longer history in Chennai than previously thought. Only further research can reveal whether all the deer found in the city have descended from an introduced stock.

Spotted deer continue to thrive in Chennai. However, there is little authentic information on its population size. One of the earliest studies undertaken on the deer was in 1968. According to this study there were 825 deer inside the Guindy Deer Park (Barnard *et al.*, 1969). The population size inside the Guindy National Park as estimated in 1991, was 482, and in 1992, it was 622 (Raman *et al.*, 1996). Today the spotted deer is found in many other localities inside the city. Outside the Guindy National Park, the deer number is the largest within the adjoining Indian Institute of Technology Madras (Care Earth, 2006). Smaller sub-populations exist within a few institutional areas in the vicinity and are also somewhat far removed in Tambaram at a distance of nearly 20 km south of the Guindy National Park. Other than these, there are small free-ranging herds locally especially in Vandalur and Urapakkam (pers. obs.).

Free-ranging herds were very common in the residential areas of Velachery about a decade ago (Daniels, 2013). However, there are hardly any free-ranging deer that can be seen at present. The first author of this paper, who lives in Velachery, closely monitored free-ranging herds over a period of six years between July 2006 and June 2012. Herds that foraged locally used to enter an open, unused park right in front of her apartment to rest. This occured on a daily basis and it was possible to get close to the deer and directly count every individual without disturbing them. Herds were small and nearly 60% of the herds encountered were of three or fewer deer. Only once a herd of 12 deer was observed (Daniels, 2013). When the six years' data was scrutinized, a steady decline in the number of herds became evident (Figure 1).

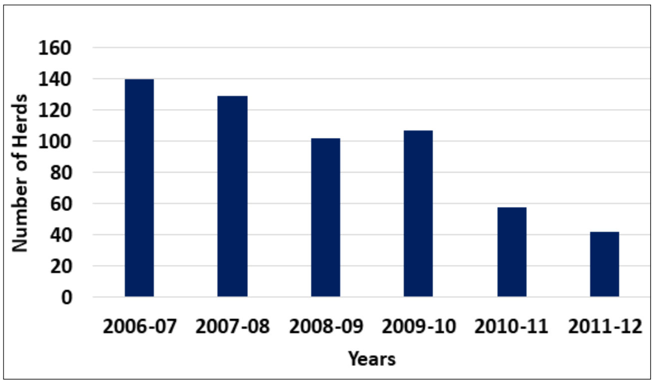

Figure 1: Declining trend in the number of free-ranging herds of spotted deer encountered in Velachery (Source: Daniels, 2013).

What exactly triggered the decline in the number of free-ranging herds between 2006 and 2012 is not fully clear. It is possible that free-ranging spotted deer constantly seek better sources of food and safer habitats and are, therefore, prone to dispersion. The availability of food is known to induce dispersion (Raman, 2015). Movement of free-ranging herds has also been reported elsewhere. In a recent article published in *The Hindu*, it was reported that spotted deer regularly move back and forth through a 'corridor' between the Vandalur reserve forest and Selaiyur in East Tambaram (The Hindu Bureau, 2024). It is possible that there are a few more corridors.

Spotted deer in Chennai has apparently survived in the form of a dynamic 'meta-population'. Periodic dispersion of small herds may have played a role in keeping the sub-populations inter-connected. It is therefore important to manage the spotted deer in Chennai in a way that sub-populations do not get totally isolated and there is scope for continuous exchange of animals between them. The Chennai Metropolitan Area covers more than 5000km^2. Priority should be to map the distribution of the spotted deer within this vast area and identify the various sub-populations and important corridors that keep them connected. Such an exercise will immensely help in the long-term management of the deer in Chennai.

Acknowledgements

Authors are grateful to the anonymous reviewers for their critical review and comments on a previous version of the manuscript.

CONFLICT OF INTEREST
The authors have no competing interests to declare that are relevant to the content of this article.

DATA AVAILABILITY

Data will be made available on request from the first author Rosella Daniels.

AUTHOR CONTRIBUTIONS

Rosella Daniels: Design the study, data collection, curation and analysis, and drafting the manuscript.
Sarangan Prabakaran: Scrutinizing data, vetting the analysis and interpretation of results, editing and finalizing the manuscript.

References

Anandhapriyan, M. (2016) Madras Christian College Biodiversity: A Compilation. https://www.researchgate.net/publication/327746145_Madras_Christian_College_Biodiversity_A_Compilation

Barnard, E., Mohammed Basheer, P. R., Eidsvik, H. K. & Ruhle, G. C. (1969) Guindy National Park, Madras, Tamil Nadu: Report. In: IUCN Eleventh Technical Meeting, New Delhi, India. IUCN Publications, New Series No 19: 80-85.

Care Earth (2006) Rapid Assessment of Biodiversity on the Campus of Indian Institute of Technology – Madras. Report Submitted to Indian Institute of Technology Madras, Chennai.

Daniels, R (2013) Declining Trends in a Local Population of Free-ranging Chital (*Axis axis*) in Chennai. In: Proceedings of the National Conference on Biodiversity: Greening Strategies for Sustainable Development. Women's Christian College, Chennai.

Krishnan, M. (1972) An ecological survey of the larger mammals of peninsular India: Part I. Journal of Bombay Natural History Society 69: 469-501.

Raman, T. R. S. (2015) Chital *Axis axis*. In: Mammals of South Asia Volume Two. Johnsingh, A. J. T. & Manjrekar, N. (eds). Universities Press, Hyderabad, 192-222.

Raman, T. R. S., Menon, R. K. G. & Sukumar, R. (1996) Ecology and Management of Chital and Blackbuck in Guindy National Park, Madras. Journal of Bombay Natural History Society 93: 178-192.

Savory, I. (1900) A Sportswoman in India: Personal Adventures and Experiences of Travel in Known and Unknown India. Hutchinson & Co., London.

Schaller, G. B. (1967) The Deer and the Tiger. University of Chicago Press, Chicago.

Shanker, K. (2014) The Wildlife of Madras City – featuring M. Krishnan. Current Conservation 8(1): 6-12.

The Hindu Bureau (2024) NGT calls for report on dumping of solid waste in Vandalur reserve forest. The Hindu (Chennai edition) 147 (119): 3.

JWLS

JOURNAL OF WILDLIFE SCIENCE

Interdisciplinary Journal of Wildlife Research, Conservation and Management

Contact Information:

Journal of Wildlife Science
Wildlife Institute of India,
PO Box # 18, Chandrabani,
Dehradun – 248001 INDIA
Email: info@jwls.in

https://jwls.in

Crossref
DIAMOND OPEN ACCESS
भारतीय वन्यजीव संस्थान
Wildlife Institute of India