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Cover Image: A Caracal (*Caracal caracal*), a rare and elusive small cat found in arid regions of India, captured in Ranthambore Tiger Reserve, Rajasthan.
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Content

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TYPE Commentary

From afterthought to blueprint: Making wildlife-friendly linear infrastructure a design requirement, not post-hoc mitigation measures

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Abstract

Developing economies like India are pushing for aggressive linear transportation infrastructure (LTI) growth as a means to achieve economic and social development. Among LTI, roads and railway lines are the prime focus of infrastructure growth plans. Often, the focal project implementation areas, especially remote and rural reaches of the country, are near biodiversity-rich forests and wildlife corridors, and are impacted in various ways during the construction and operation of these projects. In its present form, LTI development planning in India occurs in isolation, with biodiversity and environmental protection measures considered much later in the planning stage. This process leaves little scope for incorporating appropriate environment and wildlife-friendly measures into LTI projects passing through ecologically sensitive habitats, with scarce options to mitigate the impacts of such projects. Further, considering the lack of inclusion of mitigation costs at the planning stage, delayed imposition of such costs on developers leads to inflation of budgets and delayed project implementation. Overall, the present model of LTI planning in India does not satisfy either financial viability, sustainability, or conservation objectives.

We assert that LTI planning through sensitive landscapes should include wildlife-friendly measures as a design requirement, rather than mitigation measures. These measures ought to be part of LTI planning and costing at the inceptive stages as a standard procedure. This can be made possible through early engagement with conservation agencies to pre-emptively evaluate alternatives, and, if unavoidable, integrate environment and wildlife-friendly measures into infrastructure design and costs. Such a framework would be beneficial from the project developers' perspective as it would lead to easier environmental clearances, realistic project budgets, and completion timelines. More importantly, it would ensure that all possible options have been explored to avoid and minimise impacts to biodiversity. Consequently, all unavoidable infrastructure projects in biodiversity-rich or sensitive landscapes must include provisions for environment and wildlife-friendly components in their design, which are built into project costs.

Keywords: Infrastructure planning, mitigation hierarchy, road ecology, sustainable development, wildlife crossing

Introduction

The growth in linear transportation infrastructure (LTI) in India over the past few decades has not only improved connectivity, but also the quality of life of its citizens (Pradhan & Bagchi, 2013). India has achieved the milestone of having the second largest road network (66.71 lakh km) and the fourth largest railway network in the world (68,584 route km), concurrent with its position as one of the world's fastest growing economies (PIB, 2024). Some of the drivers of this growth are rapid urbanisation, industrial, agricultural and economic growth, and the recognition of LTI's role in achieving socio-economic aspirations. Yielding a 60% growth in India's national highway network in the last 10 years, connecting 99% of rural habitations through the Pradhan Mantri Gram Sadak Yojana (rural connectivity scheme), and unifying goods and passenger movement through the Bharatmala Pariyojana are key initiatives by the government in the road transportation sector. Further, modernisation of rail travel and rail infrastructure through augmentation of trains, improvement in railway stations, rapid electrification of railways, and expansion of urban metro systems have been key milestones in the development of railways in India (PIB, 2024).

While these schemes have systematically propelled infrastructure growth in the country, planners often fail to recognise the impacts of these large-scale projects on biodiversity that can have long-term repercussions for ecological security. LTIs passing through ecologically-sensitive areas exert a range of impacts on biodiversity. These impacts include, and are not limited to, wildlife mortality and injury through collisions with vehicles and trains, impediments to wildlife movement, avoidance by wildlife of habitats near these infrastructure, exploitation of natural resources by humans through increased access, and overall loss of ecological integrity through fragmentation of once contiguous natural landscapes (Forman & Alexander, 1998; van der Ree *et al.,* 2015). However, the prevalent framework of LTI development leaves little scope for early integration of biodiversity concerns into development plans. The impacts of LTI on wildlife are considered much later in the LTI project development phase, and often lead to sub-optimal biodiversity mitigation strategies.

While the current progress in developing LTI across the nation is an important step in achieving economic self-sufficiency and social well-being, such growth at the cost of our natural wealth would impair ecosystem functions and, consequently, national ecological security. Thus, along with fulfilling economic aspirations of the country through development, safeguarding India's natural wealth should also be a priority and a long-term goal for the nation. Here, we aim to make the case for the integration of biodiversity concerns into LTI project design at the inceptive stages of development planning, instead of as post-hoc mitigation measures. Further, we assert that institutionalisation of such a framework is vital to ensure ecological security for a nation that relies heavily on nature and natural resources.

Is nature a speed-bump to economic prosperity?

There are direct benefits to the well-being of India's people and economy by safeguarding nature. In addition to the intrinsic values of preserving nature and wildlife as co-habitants of this planet, safeguarding nature will ensure the flow of the multitude of ecological services that benefit humans like the provision of water, carbon sequestration, and regulation of local climate, hydrological, and mineral cycles (Wood *et al.,* 2018). Further, ecosystem services provided by largely intact natural landscapes act to boost agricultural productivity (Reed *et al.,* 2017), bolster the resilience of human communities against climate change (Hisano *et al.,* 2018), and provide alternate sources of livelihood and economic security to local communities.

Thus, India's largely agrarian economy, socio-economic upliftment of India's populace, and important economic activities such as nature-based tourism are directly dependent on the well-being and integrity of natural resources of the country. Protecting the interests of nature and wildlife while planning and implementing LTI would not only benefit conservation but also secure the lives and livelihoods of the people who are the target beneficiaries of these development plans. From the conservation viewpoint, maintaining the integrity of wildlife corridors and habitat patches against fragmentation and species loss because of LTI reduces downstream costs of conservation actions such as habitat restoration, population augmentation, and wildlife relocation. However, while sustainable development has been flagged to be a key component of India's futuristic LTI development plans, multiple prospects of proactively integrating nature-friendly designs into this realm remain unexplored.

Mitigation or integration?

At present, the loss of human lives and financial losses from road accidents, wastage of fuel, time, and excessive pollution because of traffic congestion are seen as major costs to the environment and society. To resolve these issues, road safety and traffic management strategies like road widening, roundabouts on high traffic junctions, speed control, and guardrails are incorporated into road design. Flyovers and underpasses in cities to handle congestion, bypasses through densely populated settlements, and high-speed trains and metros to transport more passengers in less time are all requirement-based transportation designs. These strategies, for which guidelines are diligently followed by LTI development agencies, involve proactively altering the design of the infrastructure to accommodate requirements that have been anticipated.

Construction of transportation corridors in pristine, intact, and biodiversity-rich areas fragments once contiguous habitat patches (Nayak *et al.,* 2020) and cause wild animal mortality (Silva Lucas *et al.,* 2017). Further, emissions from LTI construction and operation can leach into the surrounding natural landscapes, causing pollution (Ahmed *et al.,* 2020; Ramachandra & Shwetmala, 2009). These, among other impacts, can also lead to significant ecological losses to the nation, adding to ecological restoration and conservation costs to the government. Vehicular collisions with large-bodied wildlife species can also cause significant damage to vehicles and can often be fatal for passengers. Thus, in anticipation of these costs, it is prudent to incorporate biodiversity concerns into LTI planning and design. Consequently, measures to plan alignments of LTI in biodiversity-rich and sensitive landscapes, and structural measures to enable wildlife crossing and reduce mortality, should be treated as integral designs for constructing roads and railway lines through sensitive habitats, and not mitigation measures. Inclusion of these measures in the initial stages of LTI planning and design would ensure that mitigation costs are included in project budgets. Given the sustainability aspirations of the government, seamless integration of biodiversity conservation in development cannot occur till such time that such measures are formally recognised among LTI development agencies as a design necessity, rather than an afterthought.

The prevalent framework

The prevalent system of Environmental Impact Assessment (EIA) in India begins at the screening stage, where projects are assessed for whether an EIA is required or not. At this stage, LTI project proposal costs and alignments have been finalised, and mitigation measures recommended through the EIA process (including avoidance of critical habitats or realignment) are either implausible or add to the pre-approved project costs. Further, formulation of LTI development plans, policies, and schemes does not involve strategic environmental assessments or SEAs, and sectoral or regional environmental assessments (Saxena *et al.,* 2016). As a consequence of this and isolated sectoral development planning, most large-scale development plans fail to adequately integrate biodiversity and environmental protection measures.

The mitigation hierarchy is a framework that aims to avoid, reduce, and compensate for adverse environmental impacts of developmental projects by avoiding critical habitats, altering project design and construction methods to reduce impacts, and restoring the natural state and function of alternate sites through the steps of Avoidance, Minimization or Mitigation, Remediation, and Compensation (CEQ, 2000). The hierarchy is ideally followed in that order, *i.e.*, first, avoid development and consequent impacts, second, include measures to minimize and mitigate most impacts for unavoidable projects, and lastly, compensate for residual impacts.

Contrasted against this framework, the prevalent LTI planning and assessment paradigm in India leaves out ecology from the initial phases, which is why 'mitigation' at later stages is required. Mitigation, *i.e.*, the act of taking measures to reduce the severity or harmfulness of some activity, is thus seen as a band-aid for the impacts that could have been avoided. Some characteristics of the present LTI planning framework that have caused mitigation measures to gain a bad reputation are as under:

- In addition to a disconnect with environmental and natural resource managers, and stakeholders at planning stages, different transportation agencies belonging to the same sector have separate plans for LTI in the same geographical region, leading to multiple transportation corridors in the vicinity of each other, fragmenting landscapes multiple times.

- Consideration of alternative alignments is done primarily from the point of view of project finances and ease of land acquisition.

- Simultaneous land acquisition and environmental clearance application by user agencies for different segments of the same alignment leads to a *fait accompli* situation (Habib *et al.,* 2016). This results in non-feasibility of considering alternate alignments because of pre-emptive land acquisition and construction in land outside of protected areas.

- Non-inclusion of mitigation costs in the initial project budget dilutes mitigation efforts downstream.

Institutionalising integration of biodiversity in development plans

India's efforts in mitigating the impacts of LTI in the past decade have included construction of some of the world's largest wildlife crossing structures on highways (such as those on the National Highway 44 passing through the Pench Tiger Reserves, Maharashtra and Madhya Pradesh), and working towards retrofitting existing LTI. In addition to prohibiting the construction of new LTIs in protected areas (MoRTH, 2019), several road and railway line projects today have mitigation measures in the form of animal crossing structures integrated into the project design. With a few exceptions, these were mostly post-hoc measures that were thought of much after the technical project designs had been approved by authorities, and limited project budgets restricted the consideration of the whole range of mitigation measures. Until procedures to integrate biodiversity concerns into development plans from the initial stages are proactively institutionalised, such endeavours would remain knee-jerk reactions or subject to the prerogatives of decision-makers.

A framework for all stages of the mitigation hierarchy in planning LTI in ecologically sensitive areas

We present here a framework based on the mitigation hierarchy that enables early consideration of biodiversity concerns in LTI planning. Here, delineation of ecologically-sensitive areas where no infrastructure development should take place or 'no-go zones', using a range of criteria can be done during the project planning stage. This information and/or criteria should be further used to plan the optimum LTI alignments on a regional scale. Integration of wildlife-friendly road or railway line design, habitat restoration, and offset costs into project plans and budgets is central to our proposed framework.

Avoidance:

To earmark areas as no-go zones for LTI development, the formulation of appropriate biodiversity criteria is an essential first step to 'conservation planning' as it pertains to LTI development. These criteria may include biodiversity values of the region, such as importance in maintaining species and landscape connectivity, landscape uniqueness and composition, species diversity and endemism, unique ecosystem services, socio-cultural importance, and species and landscape conservation priority. Some of these areas may fall outside the purview of protected areas.

Development of such criteria would be subject to the availability of information denoting the fragility or sensitivity of a region for biodiversity. To this end, ecologists and conservationists must make concerted efforts to generate a readily available database of landscapes and regions at different spatial scales where LTI development should be avoided. This database should be easily accessible to LTI development agencies. In the absence of such information, LTI planners should initiate consultation with conservation agencies and researchers to generate this information. Further, rerouting of LTI alignments to avoid critical habitats would require mechanisms such as cost-benefit analyses to determine the best alternative alignments that would help achieve socio-economic benefits while reducing costs to nature and wildlife (Fyumagwa *et al.,* 2013). Alternative alignments should be designed accordingly, in consultation with all stakeholders, *viz.*, local communities, social scientists, and conservation agencies.

Avoidance of LTI alignments through ecologically-sensitive areas can also be achieved through inter-sectoral coordination and integrated planning, which has been highlighted as a critical strategy under the 'six pillars' of Gati Shakti, India's ambitious transportation plan for economic and sustainable development (PMGS-NMP, n.d.).

Wildlife-friendly LTI design and habitat restoration:

Wildlife-friendly strategies such as crossing structures and fencing, and site restoration measures for LTI should be integrated during the designing stage, as opposed to the prevalent practice of revising the approved project design at later stages to accommodate biodiversity concerns. Incorporation of wildlife-friendly designs are especially important for upgradation plans of existing LTI alignments, where implementing such measures can greatly reduce barrier and mortality effects. The design of such measures, as prescribed in best practice guidelines, should be done in consultation with biodiversity experts and infrastructure specialists.

Offsetting:

In India, the compensatory afforestation (CA) scheme is akin to biodiversity offsets, wherein user agencies are required to fund land acquisition and afforestation activities in non-forest land in lieu of forest land diverted for non-forestry purposes. The scheme allows for the reclamation and restoration of degraded lands, and in case of LTI projects, CA funds can be used for restoring degraded wildlife corridors, potentially leading to a measurable improvement in corridor functionality (Dutta *et al.,* 2018). This activity should go beyond mere afforestation, and can include corridor management, removal of invasives, strengthening of protection, and human-wildlife conflict mitigation in corridor areas. A description and timeline of activities should be included in the project plan too.

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Conclusion

In India, we have made significant strides in terms of mitigating the impacts of LTI on wildlife. These include some of the world's largest wildlife crossing structures on roads and railway lines in vital wildlife landscapes, and proactive efforts by LTI agencies to mitigate the impacts of new and existing infrastructure. Systematic efforts are now required to keep up the momentum of development that is in sync with nature conservation. These efforts must build on the lacunae of the prevalent LTI planning paradigm, which presently lead to downstream losses for both LTI projects and biodiversity.

Considering the importance of maintaining connected landscapes for long-term viable conservation, it is pertinent that LTI, which is a major threat to achieving this connectivity, also approaches planning in a similar way. In other words, strategic and sectoral planning, *i.e.*, LTI planning at a broader scale, and integration of wildlife-friendly measures into LTI design are central to ensuring the compatibility of India's development and conservation goals.

The need to inculcate LTI planning practices that safeguard nature and avoid critical intact landscapes is imminent, considering the accelerated increase in the Indian road and railway infrastructure, and the simultaneous recognition of the role of maintaining intact natural landscapes for human well-being. The framework proposed here aims to integrate these two national priorities, both of which have repercussions for socio-economic development and long-term ecological and economic security. Adoption of such a framework would help achieve overall socio-economic benefits from LTI development as well as the availability of ecosystem services from intact natural landscapes, particularly in rural India where most of the LTI projects are envisioned.

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CONFLICT OF INTEREST

Dr. Bilal Habib is the Managing Editor, and Dr. Akanksha Saxena is an Academic Editor at the Journal of Wildlife Science. However, they did not participate in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

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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. Both authors contributed equally to the paper.

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TYPE Review Article

Wild animals in zoos: A new paradigm is needed for zoos in the future

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Abstract

This review describes the main approaches used for working with wild animals in zoos, and briefly traces the history and theoretical background of these approaches. The theoretical background should be considered when current approaches are discussed for the improvement and design of future zoos. Hediger's individual-based concept of 'Zoo biology' is introduced, followed by a (small) population-oriented approach. Further approaches are presented focusing on animal welfare and behavioural/environmental enrichment concepts. We found that for all approaches, there is a lack of consideration of concepts of evolutionary theory. Lacking these concepts and the divergent backgrounds of the approaches might account for the management and resulting sustainability problems. Recent management concepts that are based on evolutionary theory, particularly life-history theory, are proposed. The use of these concepts requires a change in paradigm in terms of focusing management and husbandry on the individual phenotypes (the units of natural selection) that constitute a population, instead of focusing on populations as assemblies of genotypes. It is proposed that a paradigm change can support the development of a comprehensive and integrated management approach that would be more compatible with all critical aspects of the biology of the animals and treat them on the same level of importance. Since reproduction is central to evolutionary theory, the new paradigm would particularly emphasise the management of the reproductive biology of the species, and thus support breeding.

Keywords: *Ex-situ* conservation, future zoos, individual-based, management concepts, phenotype-oriented, zoo animals

Introduction

Keeping wild animals in zoos has a long tradition. After an early period, in which wild animals were kept for entertainment and out of interest for foreign worlds (see Gray, 2017), a 'science-based' and more animal- and conservation-centred period followed. In the earlier period, the quality of the living conditions and welfare aspects were not considered systematically. Discrepancies between natural habitats and the altered conditions in zoos, as well as the resulting suffering of the animals and mismatches, were perhaps not considered, or even understood. During the science–based period that started in the 1950s, new approaches to working with wild animals in zoos were propagated, which resulted in better living conditions, higher survival rates, and more successful breeding. Scientific standards with biology-based husbandry techniques and guidelines were developed. Starting from 1980s, an orientation emerged towards regarding individual animals as parts of a population, with the aim to establish captive populations of a species as a reserve for its threatened wild populations. This development brought zoo biology closer to conservation biology. As a consequence, many captive populations were managed under breeding programmes. The potential for long-term persistence and sustainability of these populations, however, turned out to be low in many of the cases (see Lees & Wilcken, 2009; Lacy, 2013; Powell *et al.*, 2019a) – possibly due to prevailing suboptimal husbandry and population management and a lack of integrated management involving conservation planning (Lacy, 2013). The need for improvements in husbandry and management was discussed subsequently by several authors (see the special issue of *Zoo Biology*, Vol. 38, Issue 1- Powell *et al.*, 2019b).

Our study emphasises that management approaches are influenced by various considerations and 'philosophies' that emerged in the history of zoos. These philosophies influence the approaches currently used and, therefore, must be considered when these approaches are discussed critically. It is the aim of this paper to describe the main approaches used for the work in zoos, and to consider their potential to establish an integrated management approach sensu Lacy (2013), for the viability of captive and all populations that are interactively managed or affected.

Hediger's 'Zoo Biology'

The first comprehensive and influential concepts about the work in zoos were developed by Hediger (Hediger 1942, 1950, 1954, 1968, 1965, 1969, 1982, 1984). According to him, concepts as available at the beginning of the 20th century did not consider the *principal* aspects of keeping wild animals but only consisted of *individual recipes* and recommendations. As a general principle, he proposed to consider keeping wild animals in zoos with reference to the seemingly trivial fact that the natural living conditions of an animal differ from those in a zoo. The differences should be identified and bridged. Husbandry should be designed by using information about the biology of the species and should focus on the individuals. The work in zoos, overall, should be science-based. To achieve this, he proposed to establish a special biological discipline called 'Zoo biology'. Within the zoo biology framework, various disciplines should function interactively towards dealing with three main clusters of problems: space, nutrition, and the animal-man relationship (see Hodges *et al.*, 1995). Hediger proposed that zoo biology covers anything that is of biological relevance in a zoo (Hediger, 1965, 1969). According to Chrulew (2020), Hediger's theoretical position is established from the perception of the world from the animal's point of view. The concept of a 'self-world of the animal', as used by Hediger, was elaborated earlier by a theoretical biologist Jakob von Uexküll (von Uexküll, 1920, 1926, 1957; Uexküll & Kriszat 1934). Chrulew (2020, p. 137) notes that Hediger 'operationalised' Uexküll's approach to animal worlds in order to optimise the design of zoo enclosures. The enclosures are considered as both physical and psychological habitats in which captive animals could live appropriately. For instance, enclosures that could function as a 'territory' and allow critical 'flight distances' would be ethically and biologically acceptable. Properly equipped enclosures in zoos would support the animals' well-being and allow a long life and successful reproduction, an indicator of the appropriateness of the keeping system. As an important means to facilitate coping after the transfer of an animal from the wild to captive conditions, appropriate habituation and training procedures to achieve 'tameness' are suggested. Continuous training would furthermore keep the animals busy and prevent behavioural disturbances and boredom. Hediger's recommendations were derived from personal observations and experiences. They are based on knowledge of the biology of the species involved, as available in the 1960s. These recommendations are still applied and cited as founding elements for welfare and enrichment concepts (Shepherdson, 1998; Maple & Perdue 2013; Powell & Watters 2017). His later publications, especially his book '*Beobachtungen zur Tierpsychologie im Zoo und im Zirkus*' (Hediger, 1961), however, indicate that he was not aware of, or was reluctant to integrate some developments from animal behaviour studies (comparative ethology, sociobiology) into his concepts of the work in zoos. He rather cultivated an approach that neglected standards of scientific work and ignored the theory-based, experimentally oriented, and quantitative approach of some relevant disciplines. Under the umbrella of a '*Tierpsychologie*' (animal psychology) that intends to 'understand' ('*Verstehen*') an animal's behaviour, he made use of anthropomorphic and speculative explanations, *e.g.* concerning animal-man relationships (see Hediger, 1961). The evolutionary theory was not considered sufficiently. Hediger rather regarded the discrepancies between the living conditions in the wild and in captivity as a key aspect of the work in zoos, but did not consider them in (theoretical) terms of the adaptive potential of a species, thus neglecting an important concept of evolutionary theory (see Hediger, 1982).

After Hediger's publications, Kleiman *et al.* (1996), for the first time, provided a comprehensive description of key topics and approaches used for the work in zoos in their book 'Wild Mammals in Captivity'. Kleiman *et al.*'s approach was based on Crandall's (1964) work, which itself was appreciated by Hediger (1965) as the first "*Lehrbuch der Wildtierhaltung*" (Textbook for Keeping Wild Animals). Crandall's approach was strictly organised along the taxonomic units of mammals, whereas the contributions of Kleiman *et al.* (1996) are organised with reference to various functional clusters like 'basic husbandry', 'nutrition', 'exhibitory', and 'population management for conservation'. A more recent comprehensive overview of research activities and key topics carried out with reference to zoos is provided in Kaufman *et al.* (2019). Many of the studies cited there are published in 'Zoo Biology', a journal that covers a large spectrum of topics following Hedger's eclecticist approach. It was regarded by Hediger (1982) as a visualisation of his concept of zoo biology. Wemmer *et al.* (1997), Anderson *et al.* (2008), and Lindburg (2008) provided analyses of the topics covered in Zoo Biology, and their studies indicate a bias towards dealing with mammals, and especially primates, and their beha viour.

Change in paradigm: Populations matter for conservation!

The topic 'population management' in Kleiman *et al.* (1996, 2010) refers to an important paradigmatic change in the role of zoos and work emerging in the 1980s. The *wild* populations of zoo conspecifics were increasingly perceived as endangered, and the zoos were supposed to think beyond individual institutions and support the species' survival by establishing *reserve populations*. They were also supposed to support relevant research, field studies, and conservation projects in the countries of origin. The national and international breeding programmes taken up in the 1980s enriched the work in zoos by introducing coordinated management between individual zoos and advanced, science-based husbandry standards, especially in terms of genetic management. In the breeding programmes, the individuals of a species kept in different zoos were 'virtually combined' into a population that was supposed to serve as a reserve, a model, and an ambassador for the wild population. The programmes introduced concepts of population biology and, referring to the usually small size of zoo populations, preferably used concepts of the genetics of small populations (see Ballou *et al.*, 2010). The long-term persistence of captive populations of a species and the realisation of its function as a reserve were believed to depend mainly on management aimed at the preservation of genetic diversity. The members of a population were expected to transfer the 'genetic raw material' to further generations (Ballou *et al.*, 2010). The number of species covered by breeding programmes has grown rapidly in the last decades, but many of these captive populations so far have not been productive enough to develop the potential for sustainability (Leus *et al.*, 2011; McCann & Powell 2019).

Back to individuals: Focus on animal welfare

Parallel to, and rather independent of, the establishment of captive populations with its focus on the genetic management, the issues about the quality of life of individuals and their captive environments generated renewed discussions

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(Shepherdson, 1998; Melfi, 2009). As elaborated by Powell & Watters (2017), these discussions were forwarded by animal welfare movements in Europe and the USA, referring to the wellbeing (and suffering) of animals in a variety of contexts and institutions in which wild or domesticated animals were kept under suboptimal conditions. According to the authors, the zoos, and especially the zookeepers, gave consideration to the welfare matters. Aspects of the life of individual animals and their traits got back into the focus of management, thus turning back to Hediger's approach. This was also possibly induced by the widespread breeding problems in many programmes (see Powell *et al.*, 2019a). As means of choice to improve welfare since the 1990s, 'environmental' or 'behavioural enrichment' measures and programmes were propagated (for definitions see Shepherdson, 1998). Many publications and projects related to the above issues were launched (see Young, 2003; Kleiman *et al.*, 2010; Maple & Perdue, 2013; Binding *et al.*, 2020). Some authors have even 'upgraded' and treated these fields of work, especially the topic of animal welfare, as independent 'sciences' (see Maple, 2007; Powell & Watters 2017). It seems that this approach tended to 'displace' the function, scope, and importance of 'ordinary' husbandry and management. A few authors (Schulte-Hostedde & Mastromonaco, 2015; Bacon, 2018), however, emphasise the need to integrate enrichment measures into general husbandry and management.

Current welfare, as well as enrichment concepts and projects, differ in terms of their 'philosophical background'. According to Mellen & MacPhee (2001), they have been influenced by different 'schools of thinking' resulting in 'behavioural engineering' (Markowitz, 1979, 1982) and a 'naturalistic' approach (Hancocks, 1980; Hutchins *et al.*, 1984). Mellen & MacPhee (2001) proposed a 'holistic approach' based on the assessment of the animal's natural history and exhibit constraint, and providing species-appropriate opportunities.

Enrichment and animal welfare concepts have been influenced by concepts of early comparative psychology and behaviourism, respectively, as represented by, for example, Watson (1928), Skinner (1974), and Erwin *et al.*, (1979). Guided by a rigid research paradigm, these researchers carried out experimental studies (*e.g.* on learning) using animals kept under strongly controlled and therefore often 'barren' conditions that explicitly ignored species-typical traits, corresponding adaptations and welfare considerations (see also Shepherdson, 1998). One of the proximate consequences of this approach was that the experimental animals developed behavioural disturbances and bizarre behaviours (*e.g.*, Skinner, 1948; see also Novak *et al.*, 2006). They sometimes could be 'treated' and 'healed' by providing a richer spectrum of environmental and/or social stimuli. These studies influenced the establishment of the currently used 'enrichment' concept with its focus on specific critical stimuli and limited consideration of the overall living conditions.

The critical phenomena that are addressed to develop 'enrichment' measures and to assess their effects are aspects of an individual animal's behaviour, but also of its physiology, and more recently, of the cognitive and emotional system. 'Stress' is regarded as one of the key management and research problems in this context. According to the 'behavioural engineering' approach influenced by Markowitz (1979, 1982), the animals are predominantly considered in their *artificial* environment with regard to potential mismatches to the internal status of animals (*e.g.* resulting from a need or drive to migrate, to hunt for food or to lead a social life). A *naturalistic* approach (see Hancocks, 1980) aiming at animal welfare considers the animal predominantly in its natural environment. Captive conditions should allow the realisation of species-typical behaviour. This approach comes close to Hediger's concepts and seems to fully realise 'animal welfare' considerations. Living conditions of animals in their natural habitat, however, usually cannot be perfectly replicated in a zoo due to space limitations and other constraints. Naturalistic approaches, therefore, also may have to consider whether the 'naturalistic' conditions offered in a zoo really meet the needs of animals and their adaptive potential (see Poole, 1992).

Studies emerging from a comparative/behaviouristic background typically use terminology and concepts of behaviourism. The lack of concepts of evolutionary biology and the concept of species *adapted* to special environmental conditions and life history patterns in the behaviouristic approach can limit the potential of this approach for the development of appropriate husbandry and management programmes.

The various approaches and concepts as outlined above have divergent theoretical and methodological origins. Hediger (1954, 1968, 1984) saw his work in the context of biology, animal psychology, and veterinary medicine. His '*Tierpsychologie*', however, had a very personal and anthropocentric perspective and was not close to the 'Comparative Psychology' with its behaviouristic background as used in the American science community. Further, it was not compatible with the quantitative and hypothesis-oriented comparative ethology that substituted '*Tierpsychologie*' in Europe.

The population-oriented work in zoos that emerged in the 1980s was not derived from Hediger's concepts. It emerged from thinking in terms of (threatened) populations, as emphasised in conservation biology. It, however, does not consider the full spectrum of concepts of population ecology. It is rather guided by concepts of the 'genetics of small populations', focusing on the individuals of a population in their existence as genotypes and is mainly organised in the frame of the 'small population paradigm' (see Caughley, 1994). It led to a reduced consideration of the nature of the individuals and of the captive populations, and its foundation in evolutionary theory. The individuals are managed mainly with reference to their existence as gene carriers - although the genotype of an individual represents *only one of the levels* of the individual phenotype. To achieve defined genetic structures in breeding units and populations, the 'small population paradigm' propagates demographic management with a strong focus on the genotype of individuals - as derived from pedigrees – ignoring or overruling (adaptive) traits of the reproductive system of a species including 'non-genetic traits' that are critical for successful reproduction (see Hildebrandt *et al.*, 2000; Hermes *et al.*, 2004; Wachter *et al.*, 2011; Ludwig *et al.*, 2019).

The animal welfare and enrichment movement contributed to the establishment of programmes and husbandry schedules that improved the quality of life of animals in zoos. Its origin in behaviouristic concepts, which ignore species-typical traits, however, can hinder an integration of aspects of biology of an animal, like adaptations as evolved in the past and acting as constraints and factors that determine a species' potential for dealing with altered living conditions.

Recommendations for husbandry and management derived from diverging approaches may not sufficiently support each other and lead to unbalanced keeping and management systems. Discrepancies, for instance, may occur between recommendations concerning aspects of genetics and behaviour. Sustainability problems in many captive populations, as currently described (Kaumanns *et al.*, 2008; Lees & Wilcken, 2009; Leus *et al.*, 2011; Long *et al.*, 2011; Che-Castaldo *et al.*, 2019), may be a consequence of such discrepancies. It is assumed that a comprehensive and integrated approach requires the consideration of the key traits of the species involved along with relevant concepts of evolutionary theory,

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especially those that concern with the persistence and adaptability of populations. Lacy's (2013) proposal of a management that integrates the various levels of husbandry and other parts of the work in zoos under the umbrella of pedigree-based genetic management is critically regarded. It is rather assumed that the various areas of husbandry and management of captive populations can only be integrated by referring to their common background as provided by evolutionary-based biology. Evolutionary theory does not support the dominance of one area (*e.g.* genetics) as a guiding discipline for husbandry and management. Its appropriate consideration would rather promote a balanced approach covering all aspects of an animal's life on the same level of importance.

Elements of a broader approach: Individual-based and phenotype-oriented

The 'classical' approaches are not fully based on evolutionary theory, or inadequately consider relevant concepts. Some authors, however, propagate the integration of evolution in the management of captive zoo populations (*e.g.*, Seidensticker & Forthman, 1998; Schulte-Hostedde & Mastromonaco, 2015). They demonstrate how this can enhance reproductive success and health for sustainability by using, for example, the integration of the natural mating system in the management of a captive population.

Based on the assumption that breeding and managing animals in zoos must incorporate all basic aspects of their biology, an integrated approach to husbandry and management requires a common foundation in evolutionary theory. Therefore, we propose a new approach by using the relevant concepts of evolutionary theory, especially life history theory, as a basic and guiding framework. For the practical work in zoos, this would require a change in paradigm in terms of regarding the individual phenotype as the key unit of management, and not the population to begin with. It would lead to a more appropriate consideration of an animal's complex biology and resulting needs. It especially should lead to more emphasis on the management of the reproduction – the core biological system in evolutionary theory.

In a series of papers, Kaumanns *et al.*, (2013, 2020) and Kaumanns & Singh (2015) propose the basic elements of an approach with regard to the prevailing approaches. With reference to life history theory, they argue that populations are constituted by individual phenotypes and not just by the latter's genotypes. A key component of life-history theory is that individual phenotypes are the constituents of a population and are therefore under selection (see Ricklefs, 1991; Stearns, 2000; Hendry *et al.*, 2011). According to Ricklefs (1991), the transformation processes in life histories from genotype to phenotype to ethotype (behaviour, physiological processes), demotype (age-specific fecundity), and fitness are inseparable from each other and have no existence apart from their environmental context. This complexity and interrelatedness among the different structures within a phenotype and its fitness must be considered and reflected in individual-based population management (see Kaumanns & Singh, 2015). Such an approach must regard the individual phenotypes as the units of management. The individual phenotypes in a population and the population are interrelated. 'Individual phenotype' refers to the total of an organism's appearance resulting from the interaction of the genotype and the environment, including all of its traits on all organismic levels like morphology, development, physiology, and behaviour (Kaumanns & Singh, 2015). Regarding individuals as the units of management with all their fitness-related properties that contribute to individual variation in survival and reproductive success requires the establishment of a management approach that considers their various properties (genotype, ethotype, demotype) at the same level of importance (see Kaumanns *et al.*, 2020). The various fields of practical management and husbandry should be organised accordingly. The management of behavioural traits, for example, is as important as the management of genetic systems. It is evident, however, that under the limited captive conditions, it can be difficult to outbalance, for instance, the requirements reulting from these systems (see Ballou *et al.*, 2010; Kaumanns & Singh 2015). Compromises must be developed that allow coping within the frame of the adaptive potential of the species and within the coping potential of an individual on the level of modifications (*e.g.* learning) (see Kummer, 1971). Watters *et al.*, (2003, 2017) propagate and elaborate a phenotype–oriented approach to population management. They, however, do not explain how this would be compatible with the widely used 'classical' demographic approach as emerging from the small population paradigm.

In addition to emphasising the need for phenotype-oriented management, Kaumanns *et al.*, (2020) point to a greater consideration of the reproductive system of a species. This is indicated by the life history theory, which states that the adaptiveness of a population is realised *via* the successful reproduction of its individuals and via transferring the determinants of adaptive phenotypes to the next generations. Whatever happens in a population and influences breeding is relevant for the adaptiveness of a population. A basic assumption of evolutionary theory and life history theory is that 'animals are designed for breeding' (Stearns, 1976, 2000). This, therefore, must provide the conceptual frame in which management and husbandry of wild animals in zoos are executed (see Kaumanns *et al.*, 2020).

Adaptations and traits in the reproductive system of a species are an essential part of its '*bauplan*' (body plan). The latter also includes other traits and adaptations, for example, feeding ecology and predator avoidance. Mismatches between the 'Bauplan', and, especially, its adaptations referring to the reproductive system and living conditions, can result in breeding problems that can lead to sustainability problems and low adaptiveness of the population. With the studies on the long-term development of the historical global captive population of the lion-tailed macaque, Begum *et al.*, (2021, 2022, 2023) provide an example of a captive primate population that suffered from similar management deficiencies. Over about a hundred years of existence, lion-tailed macaques were kept in (too) small groups that did not allow the establishment of the species-typical social structures, especially the female-bonded system. Overall, the productivity of the population was low: only 60% of the adult females bred at all, individual differences in reproduction were large, and infant mortality was high. The authors pointed to a probable loss of large phenotypic and genetic diversity and discussed the development of the population, its overall poor status and conservation potential with reference to management systems that did not fully consider species typical adaptations – especially the female-bonded social system, as typical for macaques. The female-bonded social system is regarded as a key trait of the species. The key traits are primary determinants of fitness in terms of breeding conditions in each environment (see Kaumanns *et al.*, 2020).

Conclusions

The currently used approaches in the work in zoos primarily refer to essential aspects of the biology of the captive animals. However, our study reveals that Hediger's individual-based

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contributions to 'Zoo biology', as well as concepts of (small) population management and of enrichment, do not fully support each other, and do not have components that facilitate their integration. This is proposed to be due to a lack of consideration of the underlying concepts of evolutionary theory and the resulting consequences for management and husbandry.

Firstly, a management plan for a population should consider and optimise the status of the individual members and their breeding units (Kaumanns & Singh, 2015; Kaumanns *et al.*, 2020). Population management should not be realised without an integrated management of its individual members and especially their breeding performance. The total of the individual members of a population constitutes the breeding potential of the population. Management and husbandry of individuals must be oriented at the '*Bauplan*' and at individual-specific (acquired) traits. An essential part would be the preservation of behavioural competence (sensu Seidensticker & Doherty, 1996). 'Behavioural competence' refers to the various behavioural skills essential for survival and reproduction, for example, food searching, foraging, locomotion, predator avoidance, inter- and intraspecific social interactions, mating, and infant rearing. The skills and experience of a primate female in the context of infant rearing are as relevant as her genetic status to reproductive success and recruitment for population management. Management has to provide the appropriate conditions for acquiring these skills. To manage a phenotype, the status of the genotypes needs to be assessed and considered with special importance regarding a captive population's long-term persistence and function as a reserve. Since the establishment of breeding programmes, it has been propagated to preserve genetic diversity as a key goal (see Ballou *et al.*, 2010). Contrary to the approach as propagated traditionally by mainly using demographic management with reference to genetic aspects (see Ballou *et al.*, 2010), we propose achieving diversity by supporting species' typical life-history patterns as much as possible. The reproductive system should be allowed to function in a species-typical pattern. The study by Penfold *et al.*, (2014) indicates that management of population size and thus reproduction in a population predominantly via birth control and other 'artificial' means can reduce the reproductive potential of a population. In the lion-tailed macaque captive population, for instance, the reproductive biology of the species was ignored by, *e.g.* transferring individual females to non-natal groups for genetic reasons (see Begum *et al.*, 2023). In the wild, females remain in their natal groups throughout their lives (Kumar, 1987) and only the males disperse (Kumar *et al.*, 2001). The study by Begum *et al.*, (2023) revealed that most zoos in the global historical captive population kept lion-tailed macaques in groups that deviated demographically from those typical in the wild. The majority of the captive groups were too small, had less than five members, few adult females, and did not cover several generations. Many males were removed at a (too) young age as juveniles, and adult male tenures were long. Groups in wild contiguous forests typically consist of 16-21 individuals, usually with one adult male (with short tenure), several adult females and immature animals (*e.g.*, Kumar, 1987; Kumara & Singh, 2004; Kumara *et al.*, 2014; Singh, 2019). Groups comprise members of varying age-sex classes and generations, allowing socialisation conditions relevant for the development of species-typical behavioural patterns (see Kaumanns *et al.*, 2006). The core of the group is constituted by clans of related females that have individualised permanent relationships and strong bonds with each other (see Kumar, 1987; Thierry *et al.*, 2004; Singh, 2019).

A realisation of the concepts elaborated above and their integration in the design of future zoos would require reconsidering some of the basic goals and approaches of the current work in zoos. This especially matters with regard to the conservation of nature and to the establishment of captive populations in zoos as reserves. Evidently, a stronger focus on the individuals of a population must consider the large differences between species and must identify what an adaptive phenotype in a given population under given living conditions should look like. A key message of our study is that management programmes should consider that the management of genetic aspects, behavioural aspects, and physiological aspects are regarded on the same level of importance.

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CONFLICT OF INTEREST

Werner Kaumanns & Mewa Singh hold editorial positions at the Journal of Wildlife Science. However, they did not participate in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

No additional data was used in this research.

AUTHOR CONTRIBUTIONS

WK and NB conceptualised the idea and wrote the initial draft; NB and MS reviewed the draft and assisted in preparing the final version. All authors have read and approved the final manuscript.

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Unveiling the Elusive: Density, Activity Patterns, and Human-Interactions of Striped Hyenas in Kappathagudda Wildlife Sanctuary

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Abstract

The striped hyena is a nocturnal and elusive carnivore, making population assessments challenging. We estimated its density, activity patterns, and interactions with wildlife and humans using camera-trap surveys and community interviews. Multi-session spatially explicit capture–recapture (SECR) models with a hazard rate detection function yielded a pooled density of 1.24 individuals/100 km^2 (SE = 0.27, 95% CI: 0.81–1.90) across 1,488 summer and 2,656 winter trap nights. Kernel density estimation confirmed predominantly crepuscular and nocturnal activity, with temporal overlap detected with Indian hare, wild pig, blackbuck, and porcupine. Spatial co-occurrence analyses indicated largely random associations, though some positive associations with langur, leopard, and grey mongoose likely reflected shared habitat use rather than ecological interactions. Interviews with 141 residents revealed frequent encounters but minimal conflict, with livestock predation limited mainly to young goats. Overall, results highlight the hyena's adaptability and scavenging ecology, emphasising the importance of community-based strategies for coexistence and landscape-level conservation planning.

Keywords: Camera-trapping, coexistence, landscape conservation, scavenging ecology, spatially explicit capture–recapture, temporal activity overlap

Introduction

The striped hyena (*Hyaena hyaena*) belongs to one of the smallest families within the order of mammalian carnivores- Hyaenidae (Bothma, 1998; Hadad *et al.*, 2023a; Kruuk, 2008; Solari & Baker, 2007). This family currently comprises only four extant species: striped hyena (*Hyaena hyaena*), aardwolf (*Proteles cristata*), brown hyena (*Hyaena brunnea*), and spotted hyena (*Crocuta crocuta*) (Bhandari *et al.*, 2021a; Koepfli *et al.*, 2006; Mills & Hofer, 1998). The striped hyena is smaller and less aggressive than its more well-known relative, the spotted hyena. It is a medium-sized predator characterised by pointed ears, a prominent dorsal crest of long dark hair, a sloping back, and a coat that varies from buff to grey with black transverse stripes (Neupane *et al.*, 2021). Striped hyenas can be individually identified by their unique patterns of stripes and spots found on various body parts, including the shoulders, flanks, hips, and limbs (Spagnuolo *et al.*, 2022). These distinctive patterns, along with physical markers such as scars or ear notches, facilitate identification. However, the lack of sexual dimorphism makes determining the sex of striped hyenas challenging. The Sstriped hyena is nocturnal and a solitary forager (Singh *et al.*, 2014; Wagner *et al.*, 2008). It is also a facultative scavenger (Leslie, 2016; Mohamed Ahmed *et al.*, 2012; Panda *et al.*, 2022, 2023a), and occasionally predates on small animals (Leakey *et al.*, 1999). As an omnivore (Alam & Khan, 2015; Kruuk, 2008), its diet includes small vertebrates, invertebrates, carcasses, vegetables, fruits, and organic waste, making it highly adaptable to diverse environments.

Globally, striped hyenas are found across a range extending from Africa (as far south as Central Tanzania) to the Arabian Peninsula, Turkey, Central Asia, and the Indian subcontinent, including Nepal (Mills & Hofer, 1998). They are widely found in open habitats (Rieger, 1979), sparse thorny bushes (Mills & Hofer, 1998), riverbeds (Bhandari *et al.*, 2015), grasslands (Bhandari *et al.*, 2021b), deserts, semi-deserts, rocky areas (Qarqaz *et al.*, 2004), dry deciduous forests (Gajera *et al.*, 2009), and arid and semi-arid environments (Panda *et al.*, 2023a). The global population of striped hyenas has suffered a significant decline and is currently listed as Near Threatened on the IUCN Red List (AbiSaid & Dloniak, 2014), with an estimated 5,000 to 9,999 mature individuals remaining. Throughout the species' range, striped hyenas occur at low densities (Wagner, 2006). This study aims to estimate the density of the lesser-known striped hyena using the photographic capture–recapture method (Cutler, 1999) through the SECR method (Harihar *et al.*, 2010; Gupta *et al.*, 2009; Singh *et al.*, 2014), given the species' elusive and shy nature (Hadad *et al.*, 2023b).

The persistence of carnivores in human-dominated landscapes has emerged as one of the greatest conservation challenges of our time (Lamb *et al.*, 2020). The rapid proliferation of human populations and widespread land-use changes are major drivers of wildlife population declines. These factors contribute to habitat fragmentation, alterations in natural landscapes, and restrictions on animal movement, all of which are prevalent concerns in the present study area (Ellis *et al.*, 2013; Tucker *et al.*, 2018). Across much of their range in India, striped hyenas coexist with human populations (Bhandari *et al.*, 2021b; Das, 2022; Panda *et al.*, 2022; Singh *et al.*, 2014; Young *et al.*, 2020), though conflicts have been reported in certain human-dominated landscapes (Akash *et al.*, 2021; Selvaraj & Sha, 2018; Tal, 2024) and in other parts of the world (Dadashi-Jourdehi *et al.*, 2020; Derouiche *et al.*, 2020; Moures-Nouri *et al.*, 2023; Mwebi *et al.*, 2024; Rieger, 1979). This study also aims to examine the interactions of striped hyenas with other wildlife species and human communities. Understanding hyena populations is crucial for assessing their ecological roles, mitigating human–wildlife conflicts, and developing effective conservation strategies.

Material and Methods

Study area

Kappatagudda Wildlife Sanctuary (244.5 km^2), located in Gadag District, Karnataka, comprises hilly and rocky terrain interspersed with dry deciduous forests, scrublands, and grasslands (Figure 1). Elevation ranges from 300 to 1,000 m, with a semi-arid climate and annual rainfall of 450–650 mm. The Tungabhadra River forms its southern boundary. Initially notified as a Conservation Reserve in 2015 and upgraded to a Wildlife Sanctuary in 2019, the area was historically affected by gold and iron ore mining, which left ecological scars despite the absence of current mining activity (Koppar, 2024). The sanctuary also contains human settlements along its periphery, where agriculture and livestock grazing are major livelihoods. These factors shape prey availability, scavenging opportunities, and potential human–hyena interactions.

Data Collection

Camera Trap Survey: A two-phase camera trap survey was conducted in Kappatagudda Wildlife Sanctuary (Maurya *et al.*, 2018; Regmi *et al.*, 2022) . Phase I (01 June – 01 July, 2023) used a 1.4 × 1.4 km grid from a prior sign survey by the Karnataka Forest Department, with 48 stations (96 Cuddeback C1 cameras, two per station) operating for 31 days, yielding 1,488 trap nights and ~94 km^2 coverage. Phase II (15 January – 16 February, 2024) expanded coverage to the entire sanctuary using a 2 × 2 km grid, with 121 Cuddeback and Browning cameras at 83 locations for 32 days, totalling 2,656 trap nights and ~272 km^2 coverage. While the larger grid reduced resolution, adaptive camera placement optimised detection probability and effort distribution; some Phase I sites were resampled and new ones added, reflecting logistical and seasonal considerations of the broader project design. Camera trap effort was calculated based on individual camera locations rather than per grid cell, as deployments were influenced by terrain, accessibility, and signs of animal activity.

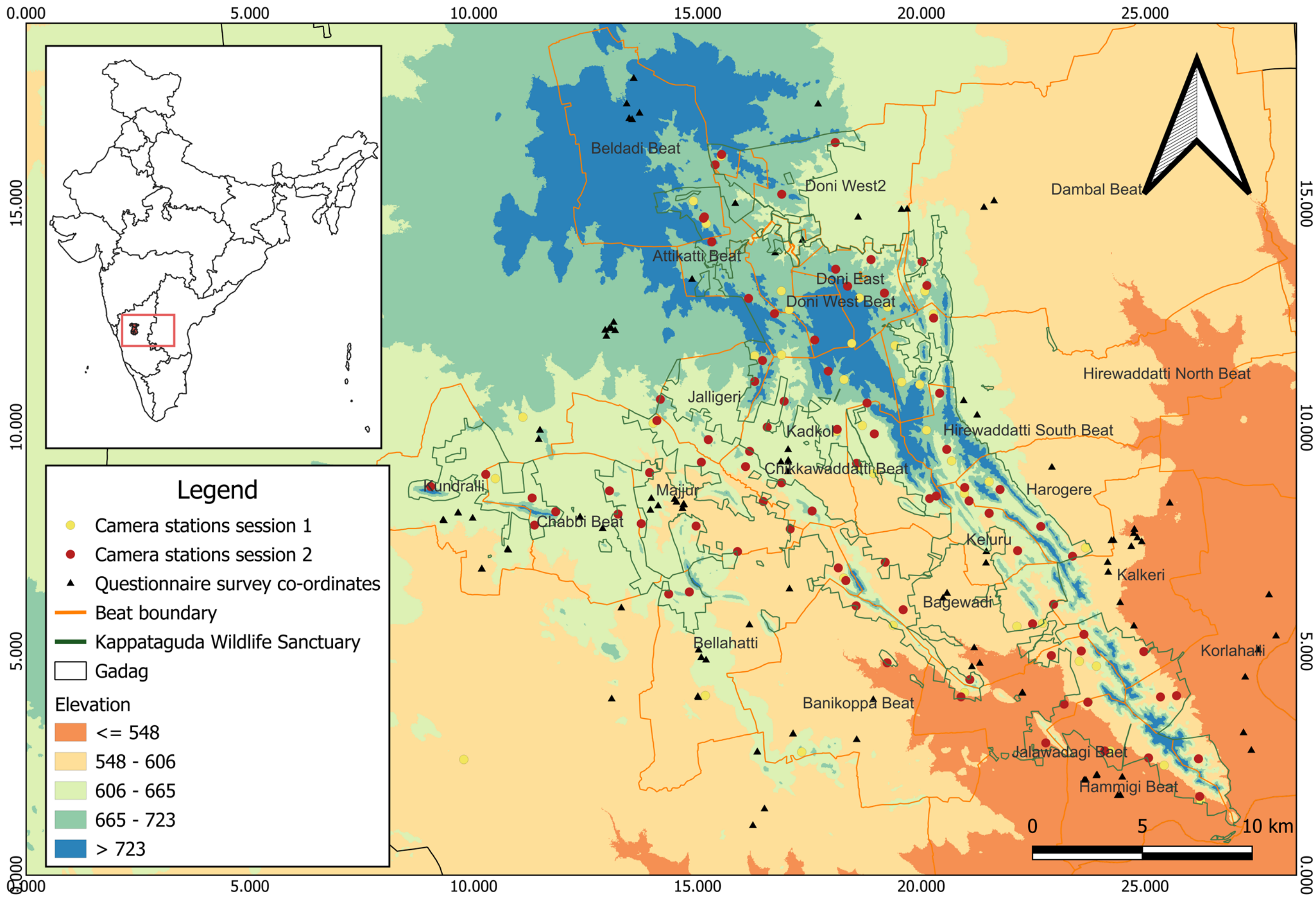

Figure 1. Map of Kappatagudda Wildlife Sanctuary showing research locations, including camera trap stations and questionnaire survey points.

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Human-Hyena Interaction: Human-hyena interactions were assessed through a field-based survey conducted between February and March 2024 in villages surrounding the Kappatagudda Wildlife Sanctuary. A total of 141 semi-structured interviews were conducted across 41 villages located in close proximity to the sanctuary. Village selection was purposive, based on proximity to the sanctuary and likelihood of hyena interactions. The survey targeted a diverse group of respondents, including shepherds, farmers, and labourers, with a particular focus on individuals who had potential hyena encounters. The number of interviews per village varied and was determined based on the availability and willingness of suitable respondents, who were often seasonally mobile and carried the risk of sampling bias. The questionnaire covered a broad range of topics, including demographic information, knowledge and perceptions of striped hyenas, conflict experiences, livestock predation, and economic impacts. A local field assistant familiar with the villages and residents accompanied the surveyor, helping to engage individuals who might otherwise have been reluctant to participate, and facilitating the collection of more inclusive and representative information.

Data analysis

We used multi-session spatially explicit capture–recapture (SECR) models to estimate the density of striped hyenas across both phases of the camera-trap survey. The SECR models were implemented in R using the secr package (Efford, 2010), employing a hazard-rate detection function to estimate hyena density within the study area. Individual identification was based on unique stripe patterns (Figure 2). Two investigators independently identified individuals, and discrepancies were resolved by consensus, and cross-checking ensured consistency. In Phase I, 48 stations were equipped with paired cameras, yielding 17 identified individuals based on higher-quality left-flank images. In Phase II, 83 stations operated with 121 cameras, from which 21 individuals were identified using right-flank images. The two phases were analysed jointly as a multi-session SECR model, with detection probability at the activity centre (g0) and spatial scale of detection (σ) allowed to vary by session, and keeping the mask (buffer = 20km, spacing = 200m) the same for both sessions. We compared models with and without a session effect on density (D ~ session *vs.* D ~ 1), and we fitted three alternative detection functions (Half-normal (HN), Hazard-rate (HR), and Exponential (EX)).Model support was assessed using Akaike's Information Criterion corrected for small sample sizes (AICc). Models were fitted using maximum likelihood with the "secr.fit" function, specifying a count detector type. Diel activity patterns of all species were analysed using the camtrapR package in R (Niedballa *et al.*, 2016). Independent detection records were generated with the "recordTable" function using a ≥30-min threshold, and "activityDensity" to compute smoothed activity curves with kernel density methods (Wang *et al.*, 2015). Temporal overlap between striped hyenas, other carnivores, and potential prey was quantified using overlap coefficients, with uncertainty assessed through bootstrap resampling (999 iterations; "resample" and "bootEst" functions). We assessed spatial relationships between striped hyenas and other species using probabilistic co-occurrence models implemented through the cooccur package in R (Griffith *et al.*, 2016). Habitat overlap was quantified using Pianka's niche overlap index (Tsafack *et al.*, 2021), calculated from species-specific capture histories derived from species-specific capture histories. For this, presence–absence matrices were constructed across camera trap stations (1 = detected, 0 = not detected), treating detections as indicators of site use (Carbone *et al.*, 2002). For data on human-hyena interactions, collected through questionnaire surveys, we used Microsoft Excel for summarisation and analysis. Data were summarised through descriptive statistics (frequencies, percentages, and means) to capture trends in local perceptions and experiences with hyenas. Given the low frequency of conflict incidents and the generally positive perceptions, the analysis was primarily descriptive.

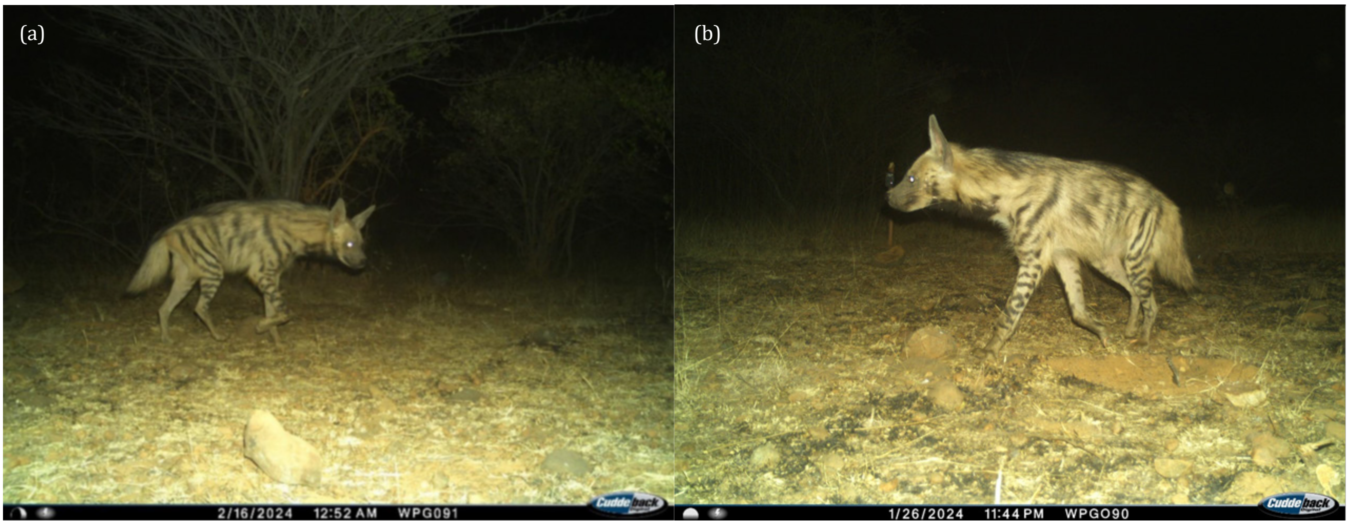

Figure 2. Right (a) and Left (b) Flank of Striped Hyena (Individual No. 10) in Kappatagudda Wildlife Sanctuary, Gadag.

Results

Density estimation

In the first session, 48 trap stations were deployed, resulting in the identification of 17 individual hyenas based on left-flank profiles. Among these, individual SH6S1 recorded the highest number of recaptures (n = 32). In the second session, 83 trap stations were used, and 21 individuals were identified from right-flank profiles, with SH10S2 showing the highest number of recaptures (n = 16). Capture–recapture data were analysed using multi-session spatially explicit capture–recapture (SECR) models with a hazard rate detection function. Model comparisons indicated strong support for the hazard rate model

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over exponential and half-normal alternatives (Table 1). The hazard rate model with session effects on density, $g0$, and σ had the lowest AICc (938.79) and highest support (AIC weight = 0.94). The exponential model received limited support (ΔAICc = 5.45, AICwt = 0.06), while the half-normal was clearly unsupported (ΔAICc = 46.88, AICwt ≈ 0). A subsequent comparison of hazard rate models with either session-specific or constant density showed that the constant density model ($D\sim1$, $g0\sim$ session, $\sigma\sim$session) had slightly greater support (AICc = 937.08, AICwt = 0.58) than the session-specific density model ($D\sim$session, AICc = 938.79, AICwt = 0.42) (Table 2). Under the session-specific model, density was estimated at 1.57 individuals/100 km^2 (SE = 0.40; 95% CI: 0.90–2.73) in Session 1 and 1.03 individuals/100 km^2 (SE = 0.29; 95% CI: 0.60–1.76) in Session 2 (Table 3). When density was held constant across sessions, the pooled estimate was 1.24 individuals/100 km^2 (SE = 0.27) (Table 4). The hazard rate shape parameter (z) was consistent across sessions, estimated at 2.77 (95% CI: 2.25–3.43).

Activity patterns of striped hyena

Striped hyenas exhibited crepuscular and nocturnal activity across both sessions. In Session 1 (n = 160), activity peaked during dawn (05:00–07:00) and dusk (18:00–20:00), while in Session 2 (n = 97), activity was more evenly spread throughout the night with a clear increase between 20:00 and midnight. These results indicate flexible nocturnal foraging behaviour, with consistent reliance on crepuscular hours. It is important to note that activity patterns reflect detections at camera sites rather than complete individual activity cycles. (Figure 3)

Temporal and spatial interaction between striped hyena and other animals

Striped hyenas showed high temporal overlap ($\hat{\Delta}$ > 0.8) with several nocturnal and crepuscular species, including wild pig (n = 196, $\hat{\Delta}$ = 0.83 ± 0.03; 95% CI: 0.77–0.89), black-naped hare (n = 879, $\hat{\Delta}$ = 0.86 ± 0.03; 95% CI: 0.81–0.91), porcupine (n = 825, $\hat{\Delta}$ = 0.80 ± 0.02; 95% CI: 0.76–0.86), and the cathemeral blackbuck (n = 211, $\hat{\Delta}$ = 0.86 ± 0.03; 95% CI: 0.81–0.91). These overlaps likely reflect temporal synchrony rather than direct predation, given the species' scavenging ecology and photographic evidence of carrion feeding. Overlap with diurnal species was low, e.g., grey mongoose (n = 16, $\hat{\Delta}$ = 0.13 ± 0.04; 95% CI: 0.06–0.22), consistent with contrasting diel niches. Among carnivores, overlaps were high with Asian palm civet (n = 12, $\hat{\Delta}$ = 0.75 ± 0.09; 95% CI: 0.56–0.90) and small Indian civet (n = 117, $\hat{\Delta}$ = 0.84 ± 0.03; 95% CI: 0.77–0.90), indicating concurrent nocturnal activity. Overlap estimates may be affected by unequal detections across species. Spatial co-occurrence (Pianka's index) was mostly random, with only langur (n = 46; 0.5045), leopard (n = 11; 0.4385), and grey mongoose (n = 16; 0.7457) showing moderate spatial overlap. Overall, striped hyenas shared space and time with multiple species, but patterns reflect habitat-level overlap and nocturnality rather than niche partitioning or trophic interactions. (Figure 4)

Table 1: Model selection results comparing hazard rate, exponential, and half-normal detection functions for striped hyena multi-session SECR models (Model: D ~ session, g0 ~ session, σ ~ session, z ~ 1).

Detection function	Parameters (npar)	LogLik	AIC	AICc	ΔAICc	AIC weight
Hazard rate	7	-460.53	935.06	938.79	0.00	0.94
Exponential	6	-464.25	940.51	943.22	5.45	0.06
Half-normal	6	-484.97	981.94	984.65	46.88	0.00

Table 2: Comparison of hazard rate SECR models with constant versus session-specific density for striped hyenas.

Model	Parameters (npar)	LogLik	AIC	AICc	ΔAICc	AIC weight
D ~ 1, g0 ~ session, σ ~ session, z ~ 1	6	-461.19	934.37	937.08	0.00	0.5849
D ~ session, g0 ~ session, σ ~ session, z ~ 1	7	-460.53	935.06	938.79	0.69	0.4151

Table 3: Density estimates of Striped Hyena in Kappatagudda Wildlife Sanctuary, Gadag
(Model: D ~ session, g0 ~ session, σ ~ session, z ~ 1, detection function: Hazard rate)

Session	Trap nights	Encounter rate	Number of individual striped hyena	Occasion (days)	Density(D)±SE individuals/ 100 sq. km	95% Confidence limit (individuals /100 sq. km	Detection probability (g0±SE)	Sigma (σ)±SE (in Km)
S1	1488	0.064	17	31	1.57±0.4	0.90±2.7	0.22±0.18	1.2±0.5
S2	2656	0.031	21	32	1.03±0.3	0.60±1.76	0.02±0.007	3.8±0.7

Table 4: Density estimates of Striped Hyena in Kappatagudda Wildlife Sanctuary, Gadag
(Model: D ~ 1, g0 ~ session, σ ~ session, z ~ 1, detection function: Hazard rate)

Session	Density(D)±SE individuals/ 100 sq. km	95% Confidence limit (individuals /100 sq. km	Detection probability (g0±SE)	Sigma (σ)±SE (in Km)
S1	1.24±0.2	0.8±1.9	0.21±0.22	1.3±0.71
S2	1.24±0.2	0.60±1.76	0.02±0.007	3.7±0.77

https://doi.org/10.63033/JWLS.DOWL1544

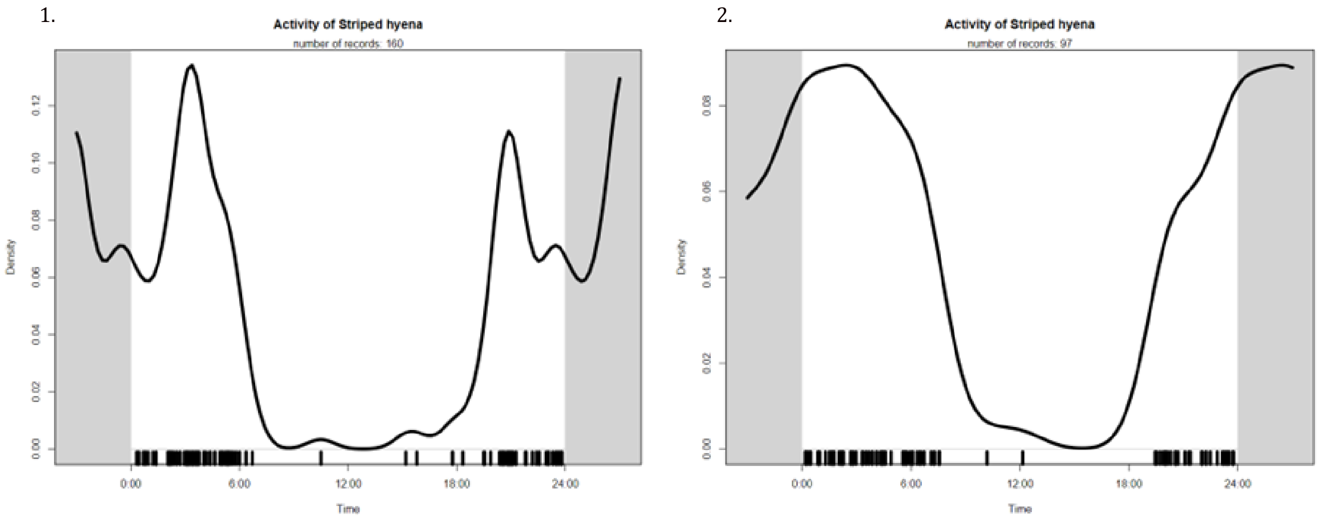

Figure 3. Seasonal Activity Patterns of Striped Hyena in Kappatagudda Wildlife Sanctuary. 1. Summer and 2. Winter.

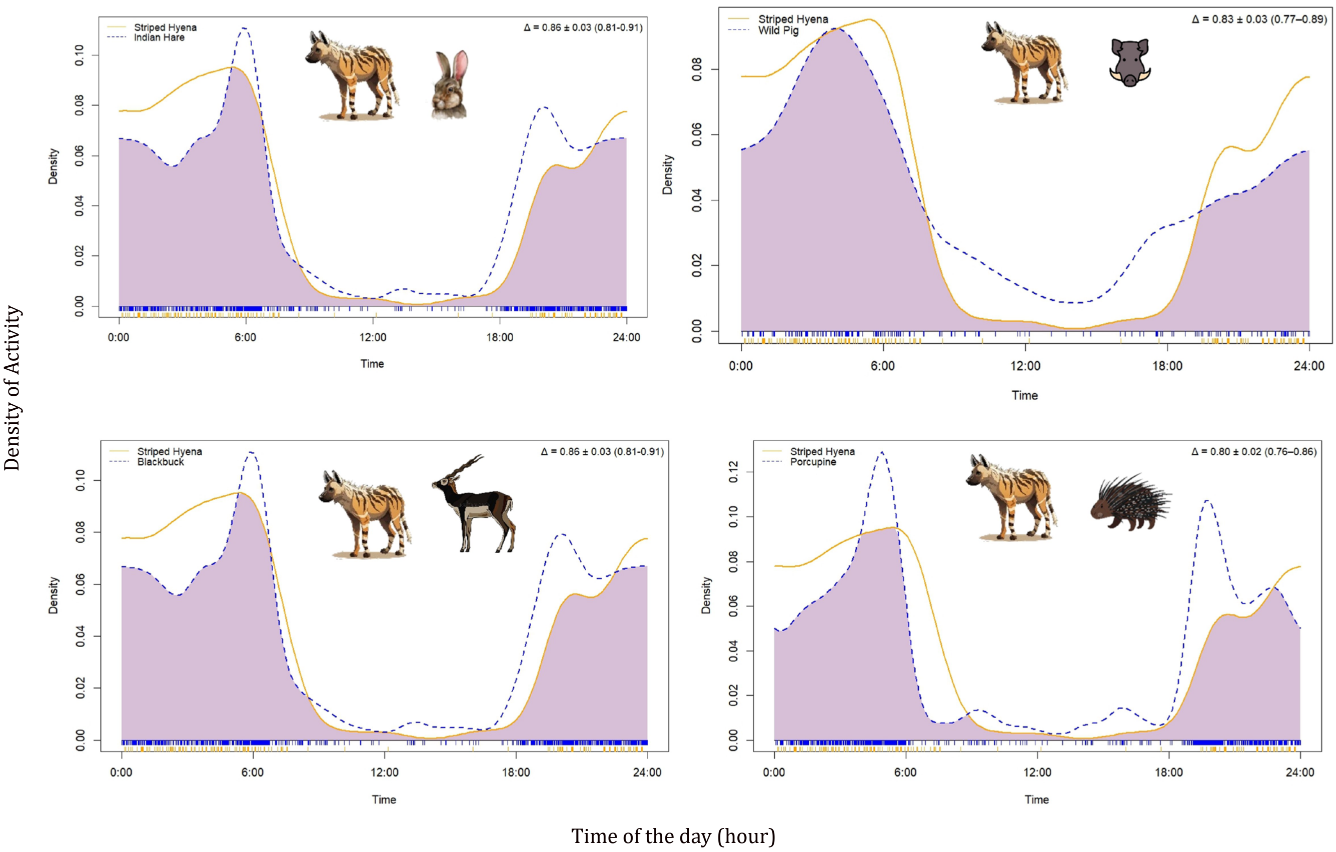

Figure 4. Pairwise temporal overlap between the striped hyena with their potential prey species in Kappatagudda Wildlife Sanctuary, Gadag.

Human-striped hyena interaction

A total of 141 respondents, primarily Kuruba shepherds engaged in livestock rearing and small-scale agriculture, reported frequent encounters with striped hyenas, most often during livestock grazing near forest edges. Households comprised an average of six members, earned on average approximately 1 lakh INR annually, and maintained large herds (≈111 animals/household) grazing about 6.4 km per day. While encounters occurred mainly in forested areas, hyenas were occasionally observed entering villages in search of food. Most encounters took place at night (18:00–06:00), with seasonal peaks in winter (35%) and summer (28%). Reported behaviours included commuting (52%), hunting/feeding (36%), resting (9%), and rare territorial displays (2%). Scavenging, although likely, was not explicitly described in local accounts. Livestock depredation was reported by 35 households, totalling 44 incidents, primarily involving young sheep and goats in Bagewadi and Kalkeri. Losses ranged from 3,000 to 40,000 INR, yet no respondents accessed government compensation schemes. Importantly, 92% of participants could identify hyenas, and misidentification with wolves was considered unlikely, supporting the reliability of reported predation incidents. Community perceptions of hyenas were divided. Approximately half (55.4%) believed populations were increasing, while the rest perceived declines. Views on threat status were mixed, 36% disagreed that hyenas are dangerous, whereas 46% agreed or strongly agreed. Similarly, 39% considered hyenas a livestock threat, while 42% disagreed. Nearly half opposed strict population control, and 48% were neutral regarding hyenas' ecological role, though 30% acknowledged their importance in maintaining ecosystem balance. Overall, respondents expressed low to moderate concern about human–hyena conflict, indicating that while hyenas are a visible component of daily life and occasionally cause livestock losses, they are not perceived as an urgent threat by the majority of the community.

Discussion

Assessing the status of solitary, nocturnal, and elusive species such as the striped hyena presents inherent challenges. We estimated hyena density across two sessions (July and January), with values ranging from 1.03 to 1.57 individuals/100 km^2 and a pooled mean estimate of 1.24 individuals/100 km^2. The hazard rate model for the detection function was strongly supported over exponential and half-normal alternatives, reflecting its flexibility in capturing steep declines in detection with distance and accommodating heterogeneity through the shape parameter (z). Within hazard rate models, the constant-density formulation was marginally favoured over session-specific density, suggesting that true population density remained stable across sessions, with apparent differences more likely driven by variation in detectability and ranging behaviour rather than demographic change over the short interval. The pooled results indicate moderate detectability. and movement ranges are consistent with a wide-ranging carnivore in a semi-arid landscape. Although session-specific models showed variability in detection parameters, we interpret these differences cautiously, as they are likely influenced by a combination of seasonal shifts in ranging behaviour, prey distribution, vegetation cover, reproductive cycles (e.g., post-littering movements), and survey effort (48 traps in Session 1 *vs.* 83 in Session 2). Striped hyena densities across their distribution show considerable regional variation. In Africa and Central Asia, estimates are generally low (0.1–3 individuals/100 km^2) (Hadad *et al.*, 2023c; Hadad *et al.*, 2023d), whereas densities in Israel and India are higher, often exceeding 2–12 individuals/100 km^2 (Athreya *et al.*, 2013; Harihar *et al.*, 2010; Mandal *et al.*, 2017; Gupta *et al.*, 2009; Singh *et al.*, 2010; Singh *et al.*, 2014; Tichon *et al.*, 2016). Within India, densities range from 0.07 individuals/km^2 in Gir (Alam *et al.*, 2015) to 15.1 individuals/100 km^2 in Sariska (Gupta *et al.*, 2009) and 12 individuals/100 km^2 in Sawai Mansingh (Panda *et al.*, 2022), reflecting differences in prey availability, habitat, anthropogenic pressures, and survey effort. Our pooled estimate of 1.24 individuals/100 km^2 falls below most Indian reports, suggesting the study landscape supports a comparatively smaller population, likely constrained by agricultural expansion, livestock grazing, mining, and other human disturbances. Since our study did not focus on collecting detailed environmental data like NDVI, rainfall, or temperature, we were unable to quantitatively assess the influence of seasonal resource variability on hyena detectability or density. Future research integrating environmental variables and individual movement data would be essential to disentangle these effects and improve the understanding of hyena ecology across seasons. Kernel density plots of activity indicate that striped hyenas are primarily nocturnal and crepuscular, though patterns may be influenced by camera placement and reflect activity along foraging routes rather than initial emergence from dens or refuge sites. Activity was largely consistent across sessions, with slight temporal shifts likely reflecting responses to temperature, prey availability, water, and avoidance of human disturbances such as agriculture and livestock movement. High temporal overlap with species such as the Indian hare, wild pig, blackbuck, and porcupine indicates shared nocturnal activity rhythms but does not imply predation. Striped hyenas are primarily scavengers (Panda *et al.*, 2023b), though opportunistic predation on small, vulnerable species such as hares has been documented. In contrast, consumption of porcupines and wild pigs is more often linked to scavenging (Bopanna, 2013; Mandal *et al.*, 2018). In our study, camera traps recorded hyenas feeding on hare, domestic dog, and carrion (Supplementary Figure S1), but without scat or kill-site data, the relative roles of predation and scavenging cannot be distinguished. Accordingly, we view activity overlap as temporal synchrony rather than ecological interaction. Spatial co-occurrence analysis supports this interpretation, with most species showing random associations, with the hyena's role as a facultative scavenger with opportunistic foraging, consistent with its well-established ecology. Future work incorporating dietary or movement data would be required to clarify predation versus scavenging dynamics.

The striped hyena population in Kappatagudda Wildlife Sanctuary (WLS) faces multiple conservation challenges, including historical mining, agricultural expansion, livestock grazing, and human encroachment (~20–25 km^2). More than 20 villages occur within the sanctuary boundary, and additional settlements lie in the surrounding landscape, making human–wildlife interactions inevitable. Before its designation as a sanctuary, 37 villages were located inside the reserve (Sawkar & Hegde, 2013); till now, encroachments for agriculture, livestock grazing, and firewood collection remain extensive. Local livelihoods are primarily dependent on farming and pastoralism, with the Kuruba and Scheduled Tribe (ST) communities forming a large proportion of respondents. High livestock numbers (goats, sheep, cattle, buffalo) graze regularly along the sanctuary edges and sometimes inside, despite the absence of formal grazing permissions. Importantly, carcass dumping within the sanctuary provides a consistent food source for scavengers such as striped hyenas. These socio-economic factors are key drivers of hyena movement, scavenging behaviour, and the nature of human–hyena interactions in the region. Our socio-ecological survey, covering 41 villages, revealed that 35 of 141 respondents (24.8%) reported conflicts with striped hyenas. Most incidents involved livestock depredation (44 cases), with young goats being the most vulnerable, alongside nine domestic dogs and one calf. Some households reported multiple losses. While these conflicts highlight the economic risk to local communities, the frequency of hyena-related incidents was lower than in other regions (Selvaraj & Sha, 2018; Bhandari & Bhusal, 2017), likely reflecting the species' elusive nocturnal habits, reliance on scavenging, and the presence of natural prey. No cases of human injury or fatality were reported, though a few respondents noted opportunistic crop-raiding during the watermelon season.

Despite occasional livestock depredation, retaliation against hyenas appeared minimal. Local attitudes were largely neutral to positive, with many respondents favouring coexistence over lethal responses. This tolerance is rare in many other conflict-prone landscapes, which may be shaped by long-standing traditions of coexistence, non-lethal conflict mitigation practices (torchlights, guard dogs, makeshift fencing), pastoralist lifestyles, and cultural perceptions of hyenas as scavengers rather than dangerous predators. In contrast, hyenas are persecuted in parts of Iran, Nepal, and northern India due to fear, superstition, or perceived threats (Selvaraj & Sha, 2018; Moures- Nouri *et al.*, 2023; Bhandari & Bhusal, 2017). The relative tolerance observed in Kappatagudda is therefore notable and highlights the potential for coexistence. However, mitigation practices remain rudimentary, and there is little awareness among communities about the ecological role of hyenas, underscoring the need for outreach and education. Community reports and camera trap data confirmed the solitary nature of hyenas, with occasional sightings of cubs and dens suggesting the presence of resident, breeding populations. Taken together, frequent sightings, relatively few conflicts, and local tolerance suggest opportunities for sustainable coexistence. Strengthening conflict-reporting systems, revising compensation frameworks to include depredation events inside the sanctuary, and promoting innovative deterrent strategies could reduce economic losses and support conservation goals. Future studies should also integrate genetic sampling, prey availability assessments, and inter-carnivore interactions to build a deeper understanding of hyena ecology in this multi-use landscape. Finally, we note that conflict data were based on respondent recall, which may be subject to memory bias or misattribution. This limitation highlights the importance of long-term, systematic monitoring of both conflict incidents and hyena ecology. Our study provides the first systematic baseline for striped hyenas in Kappatagudda, offering a foundation for future ecological and socio-cultural research, and informing strategies to strengthen human–wildlife coexistence in semi-arid protected areas.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DATA AVAILABILITY

The data will be provided upon request from the corresponding author

AUTHOR CONTRIBUTIONS

SL conceptualised the study. AA collected data. AA, SL curated data. SL, AA developed the methodology. AA and SL analysed data. AA wrote the original manuscript. SL and AA reviewed and edited the manuscript. SL procured funding, provided resources, and supervised the work.

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TYPE Short Communication

New larval host plant records for wild silkmoths from Arunachal Pradesh in the Indian Eastern Himalaya

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Abstract

Silkmoths are both ecologically significant and economically valuable insects, with larval host plant associations playing a crucial role in shaping their development, survival, and silk yield. Arunachal Pradesh, a biodiversity hotspot in the Eastern Himalayas, harbours diverse silk moth species. However, comprehensive documentation of their host plants remains limited. Through extensive field surveys conducted in various parts of Arunachal Pradesh, we recorded 14 species of wild silkworms, and documented seven species of new host plant associations for three wild silkmoth species in addition to the previous records. The new records include *Gunda ochracea* Walker (Bombycidae) on *Ficus rumphii* Blume (Moraceae), *Antheraea frithi* Moore on *Terminalia chebula* Retz, *Terminalia myriocarpa* Van Heurck & Müll. Arg, *Combretum pilosum* Roxb. ex G.Don (Combretaceae), *Lagerstroemia speciosa* (L.) Martyn (Lythraceae), *Castanopsis lanceifolia* (Oerst.) Hickel & A.Camus (Fagaceae) and *Samia canningii* (Hutton, 1859) on *Litsea monopetala* (Roxb.) Pers. (Lauraceae). These results fill a major gap in the ecological knowledge of wild silkmoths in the Eastern Himalayas. Additionally, it supports sericultural applications of the documented larval host plants.

Keywords: Arunachal Pradesh, Bombycidae, host plant associations, Saturniidae, sericulture, wild silkmoths

Introduction

Silk is one of the most ancient and highly valuable, prized biomaterials, appreciated for its protein-based composition, tensile strength and lustre (Ki *et al.,* 2009). While many arthropods produce silk, it is primarily the cocoons of lepidopteran larvae — especially those from Bombycidae and Saturniidae — that are utilised in sericulture. Both families belong to the superfamily Bombycoidea, noted for its capacity to produce robust silk-fibres during pupation (Zwick, 2008; Sutherland *et al.,* 2010; Zwick *et al.,* 2011).

The Bombycidae includes about 202 species across 27 genera, with *Bombyx mori* being the most domesticated and studied for mulberry silk production. Whereas Saturniidae is a highly diverse family with over 3,400 species and approximately 180 genera globally, known for wild silk varieties like tasar, muga and eri (Kitching *et al.,* 2018). India, particularly the northeastern region, including Arunachal Pradesh, is a centre of silkmoth diversity. Arunachal Pradesh alone had a record of 27 saturniid and 10 bombycid species (Gogoi *et al.,* 2014; Kumar *et al.,* 2016), before the present survey.

Despite rich taxonomic data, larval host plant associations — critical for silkmoth development and silk yield — are, however, inadequately recorded in this region. Host plant selection influences not only larval survival but also cocoon quality (Vijayan, 2013; Das *et al.,* 2020). Therefore, the introduction of new host plants could be beneficial to the sericulture sector. Furthermore, the relationship between herbivorous insects and host plants conveys the tale of coevolution and evolutionary radiation (Farrell & Mitter, 1990; Fordyce, 2010). Thus, understanding these associations can pave the way for further studies on ecological specialiszation and co-evolutionary dynamics among wild silkmoths and native host plants.

Materials and Methods

Field surveys were undertaken in different locations of Arunachal Pradesh between 2023 and 2024, covering elevations ranging from 150 to over 3,000 m above mean sea level (Figure 1). The survey locations included both planted and natural forest covers. The natural forest cover in the studied area was comprised of tropical evergreen, semi-evergreen, moist deciduous, pine, or subalpine forests.

Host plants were identified based on three key observations:

1. Presence of larval excreta under host trees,
2. Evidence of partial leaf consumption,
3. Direct visual confirmation of larvae feeding in the wild.
4. Search for cocoons, followed by a search for larvae in the same host plant

Only those host plant records with active larval feeding were considered valid. Some of the areas were visited multiple times to monitor the cocoon formation of the larvae. Some larvae were also raised in both outdoor and indoor conditions to validate the identification of the moths that developed from the larvae.

Plant voucher specimens were collected and pressed to prepare a herbarium. Plants were identified based on local floras (Kanjilal *et al.,* 1934-1940; Hajra *et al.,* 1996; Giri *et al.,* 2008), and the present status of nomenclature was verified from www.plantsoftheworldonline.org (POWO, 2025). Moth identification was carried out when adult moths developed from the corresponding larva and cocoon (Peigler & Naumann 2003, Gogoi *et al.,* 2014, Sondhi & Kunte 2014; Sondhi *et al.,* 2025).

Results and Discussion

During the survey, the following 14 species of wild silkmoths were recorded:

(A) Saturniidae: *Tasar* silkworm *Antheraea frithi* Moore, 1859 and *Antheraea mylitta* (Drury, 1773); wild race of *muga* silkworm *Antheraea assamensis* Helfer, 1837, wild *eri* silkworm *Samia canningii* (Hutton, 1859), Emperor moth *Rinaca cidosa* (Moore, 1865) (=*Saturnia cidosa*), *Rinaca thibeta* (Westwood, 1854) (=*Saturnia thibeta*), moon moths *Actias selene* (Hübner, 1807), *Actias maenas* Doubleday, 1847, *Actias parasinensis* Brechlin, 2009, atlas moth *Attacus atlas* (Linnaeus,1758) and *Archaeoattacus edwardsii* (White 1859), *plain golden* emperor moth *Loepa katinka* (Westwood, 1848), Cricula moth *Cricula trifenestrata* (Helfer, 1837)

(B) Bombycidae: *Gunda ochracea* Walker, 1862

Out of these, *Rinaca cidosa* was recorded from West Siang district and Eaglenest Wildlife Sanctuary (West Kameng district), *Rinaca thibeta* from West Siang district, *Cricula trifenestrata* and *Antheraea mylitta* from Lower Siang district and all others from Papum Pare district. All larval stages, cocoons and moths were recorded for *Antheraea frithi* and the wild race of *Antheraea assamensis*. Only the fifth instar larva, cocoon and adult stages were recorded for the wild race of *Samia canningii* and the *Rinaca cidosa*. Only moth stages were recorded for the rest. Therefore, in this investigation, host plants were not assigned to these silkworms.

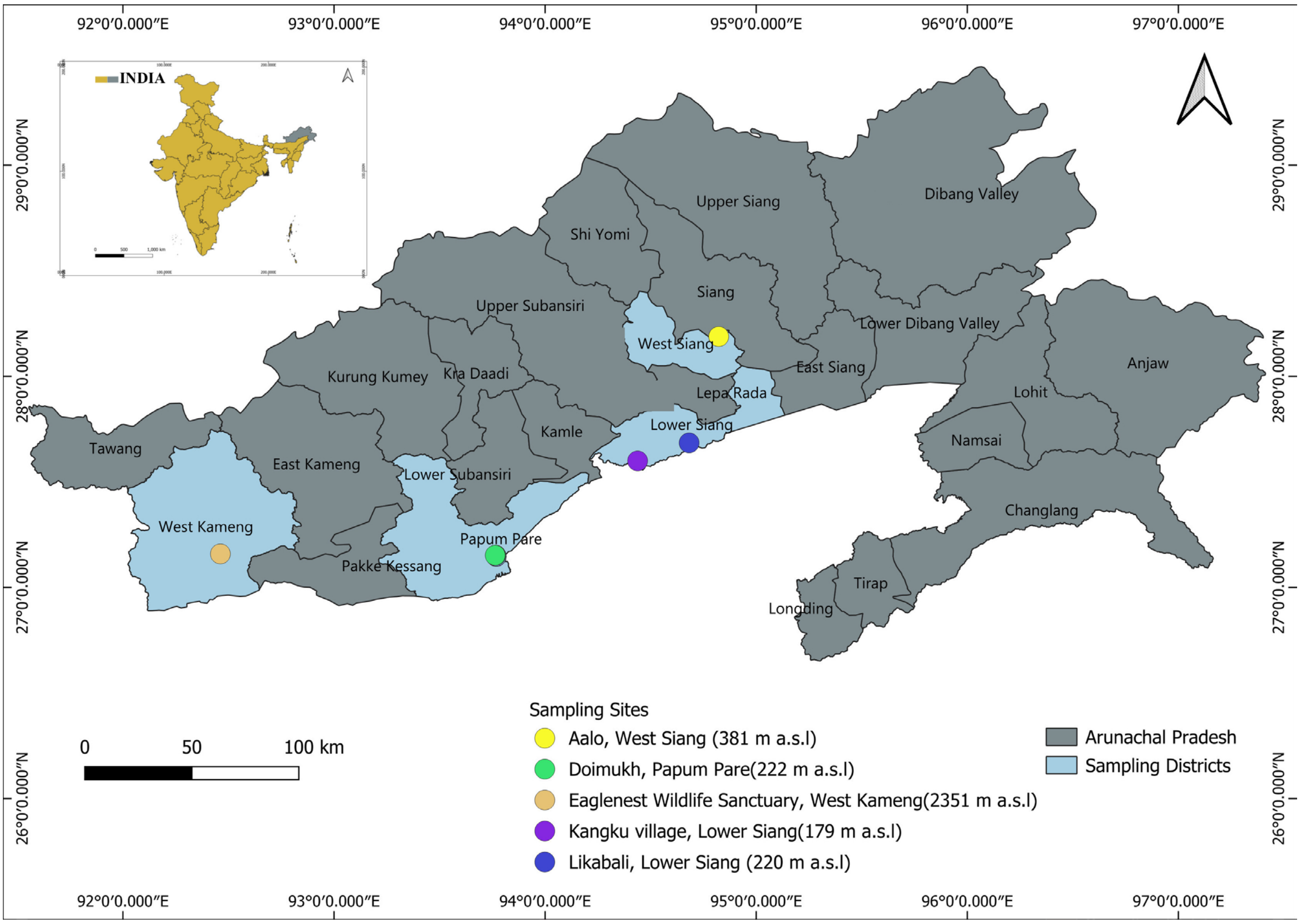

Fig. 1: A map of Arunachal Pradesh, India showing the locations where the silkworms and host plants are recorded.

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We report new host plant for the species as follow (Figure 2):

(A) *Gunda ochracea* on *Ficus rumphii* Blume (Rosales: Moraceae)

(B) *Antheraea frithi* on *Terminalia chebula* Retz., *Terminalia myriocarpa* Van Heurck & Müll. Arg, *Combretum pilosum* Roxb. ex G. Don (Myrtales: Combretaceae), *Lagerstroemia speciosa* (L.) Martyn (Myrtales: Lythraceae), and *Castanopsis lanceifolia* (Oerst.) Hickel & A.Camus (Fagales: Fagaceae)

(C) *Samia canningii* on *Litsea monopetala* (Roxb.) Pers. (Laurales: Lauraceae)

We also observed previously recorded and known host plants (Figure 2):

(A) Wild race of *Antheraea assamensis* on *Litsea monopetala* (Roxb.) Pers. and *Machilus gamblei* King ex Hook.f. (=*Machilus bombycina* King ex Hook.f.) (Laurales: Lauraceae)

(B) *Antheraea frithi* on *Terminalia arjuna* (Roxb. ex DC.) Wight & Arn., (Combretaceae)

(C) *Antheraea mylitta* on *Ziziphus mauritiana* Lam. (Rosales: Rhamnaceae)

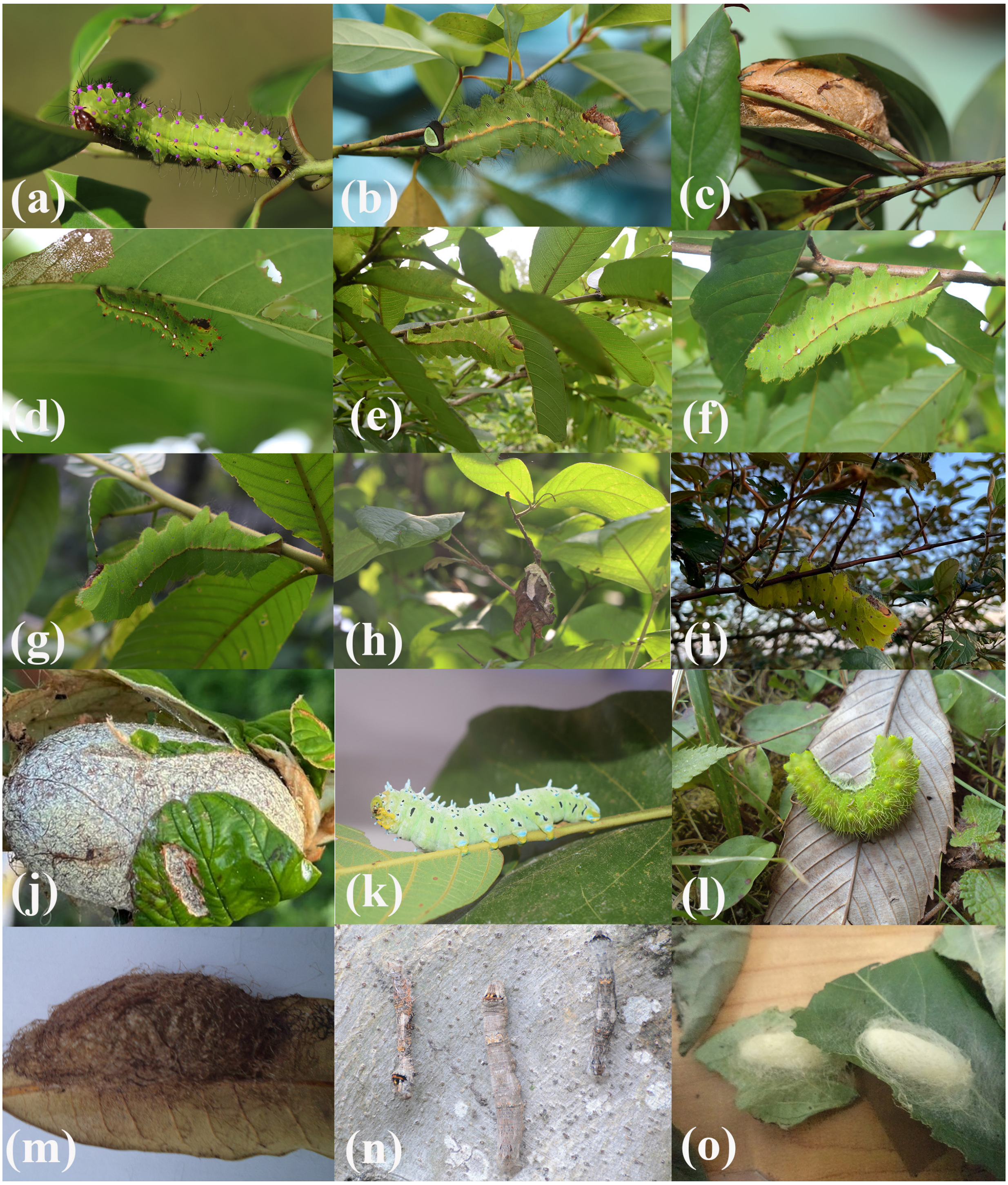

Fig. 2: (a-c) Wild race of (a) third and (b) fifth instar larva of muga silkworm, *Antheraea assamensis* and (c) its cocoon on Som tree, *Machilus gamblei*; (d-h) Larva of *tasar* silkworm *Antheraea frithi* on (d) Indian crape myrtle, *Lagerstroemia speciosa*, (e) Arjun tree, *Terminalia arjuna*, (f) Myrobalan tree, *Terminalia chebula*, (g) Hollock tree, *Terminalia myriocarpa*, (h) its cocoon on *Combretum pilosum*; (i, j) Tasar silkworm, *Antheraea mylitta* and its cocoon on Ber tree, *Zizyphus mauritiana*; (k) Wild *eri* silkworm, *Samia canningii* on Soalu plant, *Litsea monopetala*; (l, m) Larva of *Rinaca* moth and its cocoon; (n) Larvae of wild bombycid moth, *Gunda ochracea* on banyan fig tree *Ficus rumphii*; (o) Cocoon of *Gunda ochracea.*

Further, we documented the cocoon properties of selected wild silkworm species raised on particular host plants (Table 1).

Table 1. Cocoon morphometric parameters of selected wild silkworms reared on various host plants.

Sl. No.	Host plant used for rearing	No. of cocoon measured (N)	Cocoon weight with pupa (g) ± SD	Cocoon length (mm) ± SD	Cocoon breadth (mm) ± SD
A. *Antheraea frithi*					
1.	*Terminalia chebula*	3	4.18 ± 1.43	42.91 ± 1.44	20.11 ± 0.81
2.	*Terminalia arjuna*	4	7.19 ± 1.32	43.20 ± 1.92	21.90 ± 1.10
3.	*Terminalia myriocarpa*	3	10.91 ± 2.48	48.05 ± 5.06	21.64 ± 3.34
4.	*Lager-stroemia speciosa*	3	7.95 ± 1.73	45.37 ± 3.53	22.34 ± 1.55
B. *Antheraea assamenseis* (wild race)					
5.	*Machilus gamblei*	3	9.20 ± 0.29	51.79 ± 1.15	23.49 ± 0.70
C. *Samia canningii*					
6.	*Litsea monopetala*	3	3.03 ± 0.39	42.51 ± 1.24	17.09 ± 3.36
D. *Gunda ochracea*					
7.	*Ficus rumphii*	5	0.55 ± 0.12	25.25 ± 1.71	12.39 ± 2.54

Prior reports showed that *Antheraea frithi* primarily feeds on species of *Terminalia* and members of Dipterocarpaceae and Fagaceae (Chutia *et al.,* 2016; Singh *et al.,* 2022). The inclusion of *Lagerstroemia speciosa* is a novel observation in this study. Similarly, *Litsea monopetala*, known as a host of semi-domesticated *Antheraea assamensis*, was here reported as a natural host for *Samia canningii*, expanding its ecological associations. As per a previous study, *Samia canningii* can be reared on *Ricinus communis* L. (Malpighiales: Euphorbiaceae) and *Heteropanax fragrans* (Roxb.) Seem. (Apiales: Araliaceae) — host plants it shares with the domesticated *Samia cynthia* (Taba & Gogoi, 2019). The current record from Lauraceae introduces a new host family for this species. The present study also shows that the larvae of *Samia canningii* that feed on *Litsea monopetala* are larger in diameter (length: ca. 58.60 mm, breadth: ca. 17.75 mm) and cocoons are larger in length and breadth (length 42.51, breadth 17.09 mm) compared to those reared on *Ricinus communis* and *Heteropanax fragrans* (length 62–65 mm, width 9–10 mm; Cocoon length 27–33 mm, breadth 12–14 mm) (Taba & Gogoi 2019). Therefore, it may be hypothesised that *Litsea monopetala* could be a better host plants for the purpose of the sericulture industry compared to other plants known for hosting *Samia canningii*. Phylogenetic proximity exists among Rosales, Fagales, Malpighiales and Myrtales, which are associated with *Bombyx mori*, *Gunda ochracea*, *Antheraea frithi*, *Antheraea mylitta* and *Samia cynthia*. In contrast, Laurales (host to *Antheraea assamensis* and *Samia canningii*) and Apiales (host to *Samia cynthia*) are more distantly related (Figure. 3) (Li *et al.,* 2021). This divergence in host plant phylogeny may reflect adaptations of silkworms driven by domestication and ecological specialisation. These patterns suggest that *Antheraea assamensis* and *Samia canningii* may share evolutionary host plant lineages adapted to Lauraceae, diverging from other Saturniids and Bombycids whose host plants (in the family such as Lythraceae, Combretaceae, Moraceae, Fabaceae, Euphorbiaceae) are more closely related phylogenetically (Li *et al.,* 2021).

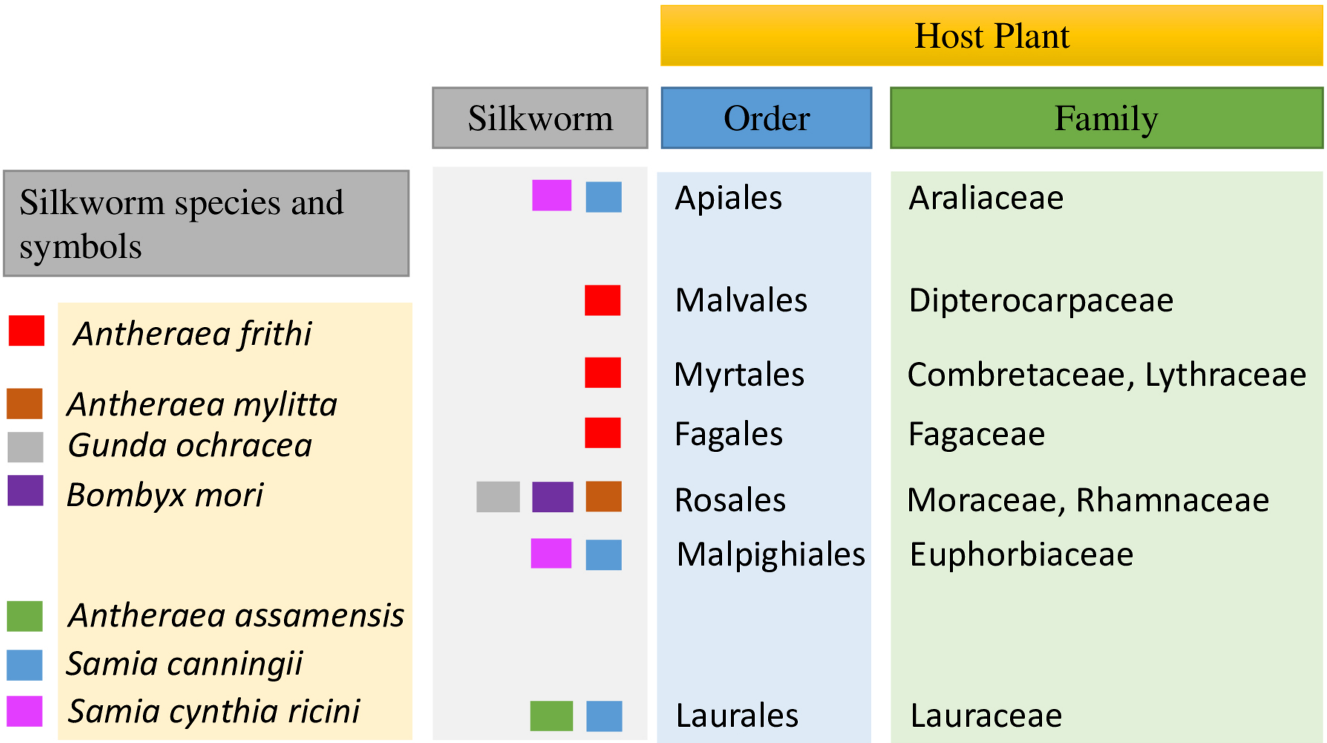

Fig. 3: Hypothetical grouping of the silkworms based on larval host plant phylogeny (Li *et al.,* 2021).

Conclusion

This study expands our knowledge of silkmoth – host plant interactions, revealing new larval host associations for key wild silkmoth species. These findings have broad implications for evolutionary biology, conservation ecology and the development of sustainable sericultural practices in the Indian East Himalayan regions. Protecting both the moths and their host plants is essential for conserving the intricate ecological web and supporting rural livelihoods dependent on wild silk.

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CONFLICT OF INTEREST
There is no actual or potential conflict of interest.

DATA AVAILABILITY
Data are available with the corresponding author on request.

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HG, TD, SS- Survey and manuscript writing. APD-Identification of plants and manuscript writing.

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Records of Total Albinism in *Heteropneustes fossilis* (Bloch, 1794) from Upper Brahmaputra Valley, Assam, India

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Abstract

The phenomenon of total albinism in fishes is rare, and very few cases of albinism are reported across the globe. In this study, we report total albinism in two wild specimens of stinging catfish *Heteropneustes fossilis*, collected from the Lesia river in the Dhemaji district of Assam, Northeast India. There are only two more such reports of total albinism in this epigean fish from India, one published in 1966 from Assam and the other in 2023 from West Bengal.

Keywords: Heteropneustidae, Indo-Burma biodiversity hotspot, Lesia river, Siluriformes, stinging catfish

In fishes, albinism is a rare phenomenon, and is caused due to an autosomal recessive allele (Uieda *et al.*, 2007) or due to heavy metal pollution (Oliveira & Foresti, 1996). In total albinism, the entire body of the animal is whitish with reddish eyes (Sazima & Pombal Jr., 1986). Of the 14 recorded cases of albinism in Neotropical fishes, 11 belong to Siluriformes (Nobile *et al.*, 2016), indicating a higher prevalence of the phenomenon in this taxon. A few cases of albinism have been reported from India, including Magur *Clarias batrachus* (Hora, 1926) and freshwater eel *Anguilla bengalensis* (Jones & Pantulu, 1952). Albinism has also been reported in the cave fish *Indoreonectes evezardi* from the Kotumsar Cave, Chhattisgarh (Biswas, 2010), and in different cave fishes from Meghalaya, which includes *Schistura larketensis*, *Schistura papulifera* and *Neolissochilus pnar* (Kosygin *et al.*, 2023). Total albinism in *Heteropneustes fossilis* has previously been reported from Assam (Baruah, 1966), and West Bengal (Das *et al.*, 2023). Here we report on two observations of total albino *H. fossilis* individuals from the Dhemaji district of Assam, India. In cave fishes, albinism or de-pigmentation is a type of adaptation (Barr, 1968), while the present report is from an epigean environment (river) sans any subterranean selection pressure.

H. fossilis, commonly known as stinging catfish, belongs to the order Siluriformes and family Heteropneustidae. It is locally called *Singee* in Assamese and *Shing* in Bengali. The species is distributed across South and Southeast Asia, including India (Jayaram, 1999; Fernado *et al.*, 2019). Although the species was considered 'Least Concerned' by the IUCN with a '*stable*' population trend in 2019, a '*continuing decline in area, extent and/or quality of habitat*' has also been noted (Fernado *et al.*, 2019). Its population is declining in the wild largely due to anthropogenic disturbances, habitat loss and over exploitation (Haniffa *et al.*, 2008). The catfish commonly inhabits ponds, wetlands, marshes, ditches and small rivers. The species survives well in wetlands with heavy infestation of water hyacinth and in hypoxic conditions, thanks to its accessory air-breathing organ (Munshi, 1961; Samad *et al.*, 2017; Saha *et al.*, 2022).

The Dhemaji district (Assam, Northeast India) is bordered by the Brahmaputra river in the east and south, the Subansiri river in the west, and the Himalayan foothills of Arunachal Pradesh in the north. The district is criss-crossed by several smaller rivers, including Lesia, Na-Nadi, Gai-Nadi, Sissi, Jiadhal, Boginadi, *etc.* (Fig. 1). Most of these smaller rivers, including the Lesia river, don't retain flow during the lean season (January to March). This also facilitates the growth of aquatic macrophytes, including water hyacinth. The climate of the area is humid (70 – 90%) with high annual rainfall (2600 – 3200 mm). Rainfall generally starts in April and continues until September, July being the rainiest month. The temperature ranges between 5.9°C in winter and 39.9°C in summer. Seasonal floods are common throughout the low-lying areas of the district.

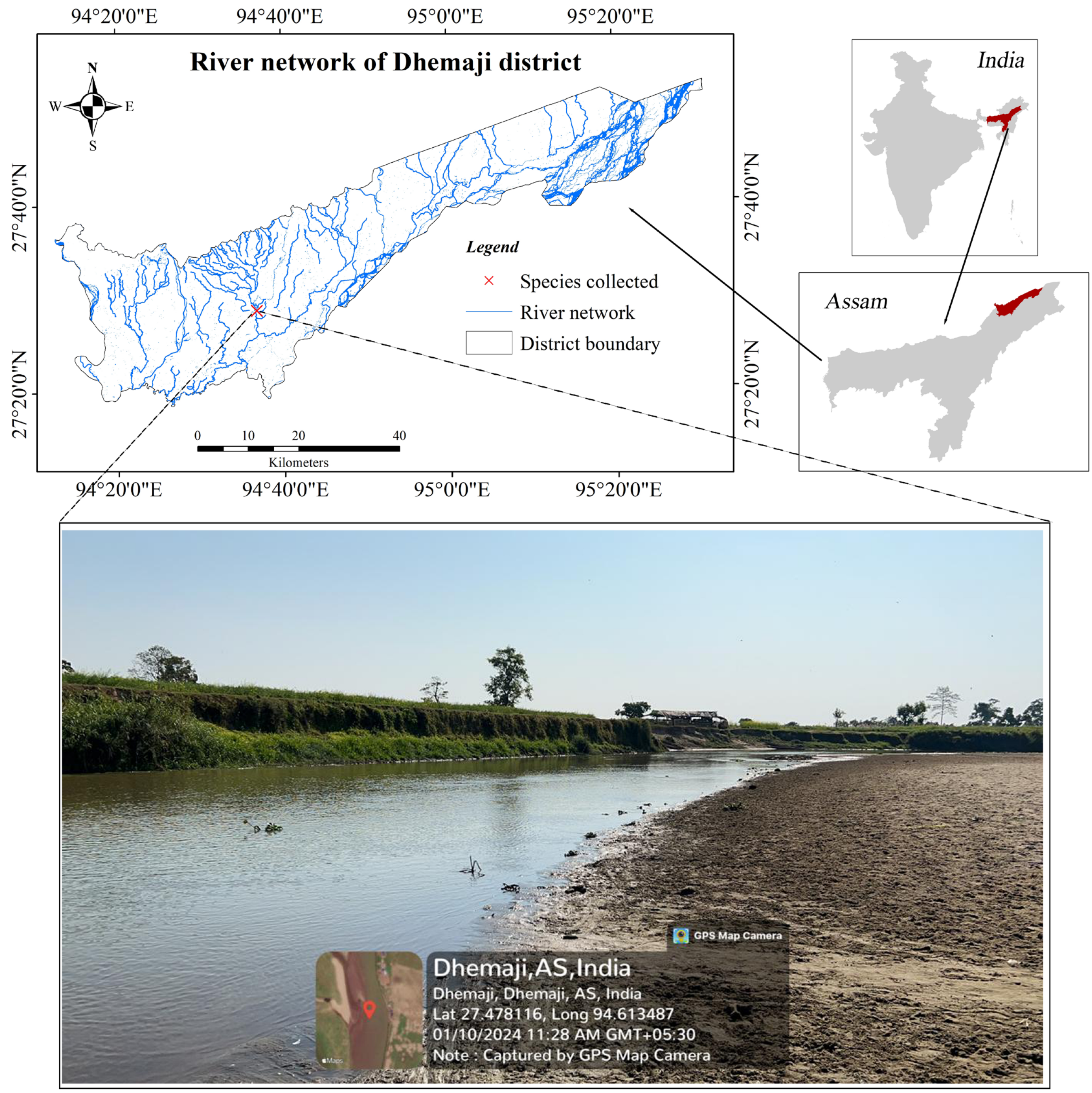

Figure 1. Location and photograph of the river section where the albino specimen of *Heteropneustes fossilis* were collected, Lesia river, Dhemaji district, Assam, India.

Both the albino *H. fossilis* individuals were collected from the Lesia river, a tributary of the Brahmaputra river, within the Amguri area of Dhemaji district, Assam, India (Figure 1). The individuals were caught by the local fishermen during their routine net fishing bouts on 10th January, 2024 at 1100 hrs. The fish were caught in a seine net of dimensions 20 m × 2 m (length × breadth), having a mesh size of 5 mm. The specimens were collected at 27.478°N and 94.613°E, where the depth of the river section ranged from 0.5 m to 2 m. Both individuals were of the same age and length (c. 13 cm). The eyes were devoid of pigmentation, reddish with a white ring. The fins and head were more reddish, and both specimens were totally albino (Figure 2). Since we intended to perform further genetic and behavioural studies, the specimens were not preserved, and other morphometrics were not performed (Figure 3).

Before the presented observations, there are two reports of total albinism in *H. fossilis* from India. Baruah (1966) reported albinism in the *H. fossilis* from a pond in a fish farm of Assam. Another specimen was reported by Das *et al.* (2023) from West Bengal, India, who termed their specimen as 'Golden Stinging Catfish'; the term 'golden' appears to be a misnomer. Genetic variation in pigmentation is common under domestic conditions and in selective breeding. Albinism has also been attributed to environmental toxins such as heavy metal pollution (Oliveira & Foresti, 1996). It is reported that albino fish exhibit behavioural differences, such as lesser aggressiveness and poor shoaling behaviour, compared to normally pigmented individuals (Slavík *et al.*, 2016). The present report may encourage further research on the albino variant, focusing on genetics, behavioural and reproductive ecology *vis-à-vis* the normally pigmented individuals.

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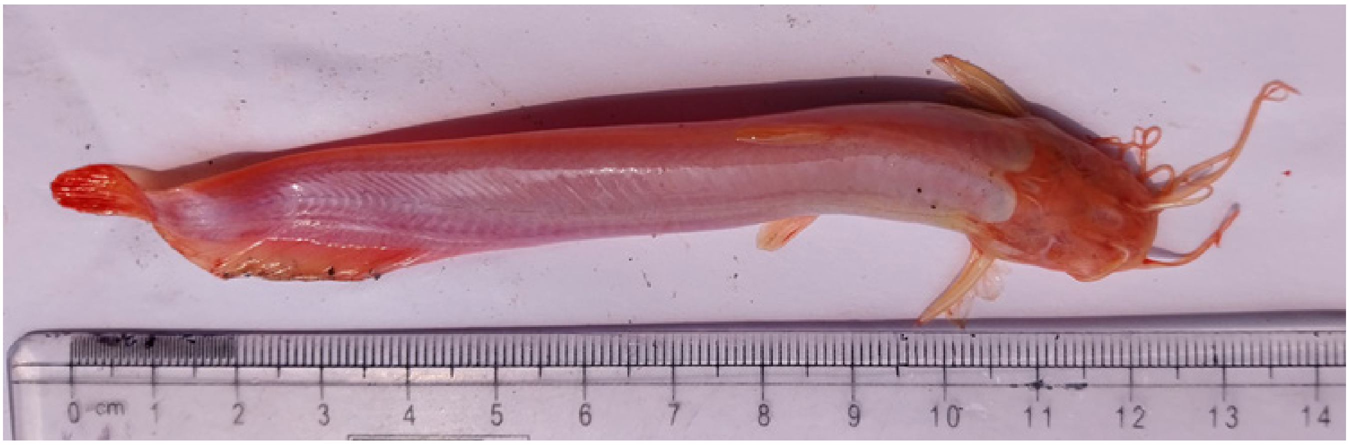

Figure 2. Photograph of the total albino *Heteropneustes fossilis* individual from the Lesia river, Dhemaji, Assam, India.

Figure 3. The two total albino *Heteropneustes fossilis* individuals were kept in an aquarium along with normally pigmented individuals in the Department of Zoology, Dhemaji College, Dhemaji, Assam, India.

The state of Assam has over 1,00,000 ha of floodplain wetlands, including ox-bow lakes, marshes, fens, *etc.* There are over 79 such wetlands in Dhemaji district covering an area of over 119 ha (CICFRI, 2000). Local fishermen look for the catfish in wetlands and smaller rivers. With the beginning of monsoon showers in April, mature individuals start migrating in search of new suitable habitats for spawning, thereby becoming vulnerable to capture. During the monsoon, passive gears, including gill nets, are commonly used for the catch, while dewatering is common in winter months. Extensive and excess catch for food, gradual decline in habitat quality and area, building dams on rivers, *etc.* are some of the major threats to the wild populations of the species (Haniffa *et al.*, 2008; Fernado *et al.*, 2019). The catfish is a delicacy for the local communities and tribes, including *Mising, Sonowal-Kachari*, *Deori* and others, and is highly priced (between INR 500 – INR 1000 per kg). Being a good source of protein, iron and calcium (Hasan *et al.*, 2022), the fish has ethnomedicinal importance. The indigenous people of Assam believe that consumption of the catfish is beneficial for pregnant and lactating women, and for the treatment of anaemia and general weakness.

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CONFLICT OF INTEREST

The authors declare no conflict of interests.

DATA AVAILABILITY

Data will be made available upon reasonable request.

AUTHORS' CONTRIBUTION

PS and DH conducted the field study, and collected the specimens. ASC prepared the maps (Figure 1). PS, JC, SP and MKM maintained and studied the specimen. PS and MKM wrote the manuscript; MKM revised the submission. All authors read and approved the manuscript.

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TYPE Natural History Note

Caracal's Comeback – First photographic record of Caracal in the Ramgarh Visdhari and Mukundara Hills Tiger Reserve, India

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Abstract

Caracals (*Caracal caracal*) were once widely distributed in India's semi-arid regions but lost more than 90% of their range due to habitat loss in the past century. Herein, we present the first photographic evidence of caracal in Rajasthan's Ramgarh Visdhari and Mukundara Hills Tiger Reserves, beyond the two known caracal populations in Kachchh (Gujarat) and Ranthambhore landscape (Ranthambhore, Kailadevi, Dholpur in Rajasthan). This finding indicates return of caracal in Ramgarh and Mukundara, and revived the hope for the species' conservation in the semi-arid western Indian landscape. The record also highlighted the importance of rigorous scientific monitoring through camera traps in order to record the presence of rare and elusive species in the landscape. Dedicated surveys for caracals, focusing on their ecology, behaviour, and conservation needs, are crucial for ensuring the long-term survival of India's most endangered cat.

Keywords: Camera trapping, distribution, new records, Rajasthan, semi-arid landscape, small cats

Carnivores, across the trophic pyramids, are experiencing widespread population declines and range contractions due to unchecked rise in anthropogenic pressures leading to habitat loss, fragmentation, poaching, and prey depletion, *etc.* (Ripple *et al.* 2014). Under these circumstances, documenting the distribution of an endangered species and understanding its ecology is crucial in making informed conservation decisions.

The caracal (*Caracal caracal* Schreber, 1776), is a medium-sized, elusive wild cat known for its distinctive black ears adorned with tufts of sensitive hair. The presence of caracal in the Indian subcontinent dates back to the Harappan civilization (Ghosh, 1982). Although widespread and relatively common in its overall range (Nowell & Jackson, 1996), it has witnessed a drastic range loss and population decline over the past few decades (Farhadinia *et al.*, 2007; Avgan *et al.*, 2016). In India, the caracal has lost more than 90% of its historical range, mostly due to habitat loss (Khandal *et al.*, 2020), and its population status is perilous. Without safeguarding the existing caracal habitat, it is likely to follow the fate of the cheetah in India (Pocock, 1939; Sharma & Sankhala, 1984; Divyabhanusinh, 1995; Ranjitsinh & Jhala, 2010). The present distribution of the caracal in India is limited to two known regions: the Kachchh landscape in Gujarat, and the Ranthambhore landscape, which includes - Ranthambhore, Kailadevi, and Dholpur in Rajasthan (Jhala *et al.* 2021). However, these two populations have plausibly been isolated for generations now, as no recent record of the species has been reported from anywhere else (Khandal *et al.* 2020). Camera trapping is a cost-effective and technically reliable method, widely used for the documentation of species presence, distribution, and monitoring their movement as well as population trends (Sanderson & Trolle 2005). Bycatch information generated from camera traps proves eventful in describing records of rare and elusive species and gaining new ecological insights (Tanwar *et al.* 2021; Burton *et al.* 2022).

Ramgarh Visdhari Tiger Reserve (hereafter RVTR, area 1501.88 Km², 25°59'N, 75°19'E to 25°53'N, 76°49'E) and Mukundara Hills Tiger Reserve (hereafter MHTR, area 1135.78 Km² ,24°38′ to 25° 7' N to 75°26' to 76°12′ E) are situated in the Hadoti plateau of Rajasthan, India (Figure 1). RVTR and MHTR form part of the 'semi-arid' biogeographic region (Rodgers & Panwar, 1988), and are characterized by Northern Tropical Dry Deciduous Forests (Champion & Seth, 1968). The terrain in these Vidhya-Aravalli Mountain ranges mainly consists of narrow valleys, hills, and plateau top plains with narrow water drainages and rivulets crossing the landscape. Both the tiger reserves, MHTR and RVTR, are extended habitats of the greater Ranthambore landscape (Figure 1), and serves as a crucial sink habitat for tigers (Sadhu *et al.*, 2017). Despite protection under the Tiger Reserve status, these habitats are exposed to various forms of anthropogenic interferences. Considering their importance, the Wildlife Institute of India initiated the long-term ecological monitoring of these two tiger reserves, and the present survey was part of it.

We deployed double-sided camera traps in a systematic grid-based (2 km²) manner in RVTR (n=89) and MHTR (n=273). These cameras were deployed on forest roads and animal trails, tied to tree trunks at 30-45 cm height above the ground, to maximize captures of carnivore species. During the survey session of winter 2024-25, photographs of caracal were obtained from nine camera trap stations in RVTR between 19th December 2024 and 21st January 2025 (Figure 2a, b), spanning across a minimum area of ~60 km² (Figure 1). In MHTR, caracal photographs were obtained between 16th February 2025 and 25th February 2025 (Figure 2c, d), at two different locations (~8 km apart, straight line distance). All the caracal records in our study area were nocturnal, with captures between 18:00 hrs and 06:00 hrs. These events recorded the first photographic evidence of the caracal in RVTR and MHTR, from where it was considered locally extinct (Khandal *et al.*, 2020). The camera traps, where the caracals were captured, also had the presence of other carnivores, including tiger, leopard, hyena, golden jackal, jungle cat, Asiatic wildcat, and rusty-spotted cat. In one of the pictures, the caracal was carrying a small prey (most likely a lagomorph). However, the image was not clear enough to ascertain the prey species (Figure 2b).

In RVTR, the caracal was captured in valleys and plateau top forests, while in MHTR, the species were captured on plateau tops adjacent to riverine habitats (of Chambal and Eru rivers). These valleys are characterized by sparse to moderate vegetation and low canopy cover, dominated by *Terminalia pendula* and *Neltuma juliflora*. The forest roads in these areas are also frequently used by the villagers for fuelwood collection and travelling across the forest. The hill and plateau consist of relatively open forests, are less disturbed, and are dominated by patches of *Terminalia pendula*, *Acacia catechu* and *Boswellia serrata*. Including Caracal (*Caracal caracal schmitzi*), the area now is inhabited by six different wildcat species, *i.e.*, tiger (*Panthera tigris*), leopard (*Panthera pardus*), jungle cat (*Felis chaus*), Asiatic wildcat or desert cat (*Felis lybica*), and rusty-spotted cat (*Prionailurus rubiginosus*).

Caracal sightings were in fair numbers in the Bundi district (RVTR) in the last century (Pocock, 1939; Prakash, 1960) as reported in recorded gazettes from the royal states of imperial India, while no confirmed capture or sighting was reported in and around MHTR apart from displayed taxidermy hunted specimens in museums, given the rare status of the species in the region (Khandal & Dhar 2024). The last confirmed evidence of the species was in 1987 in RVTR (then Ramgarh Visdhari Wildlife Sanctuary), when a road kill specimen of a caracal was recorded in forest department catalogs (Khandal *et al.*, 2020). Although the habitats of both MHTR and RVTR are found suitable for caracal, no photographic evidence was recorded of the species during the past surveys (Jhala *et al.* 2015, Jhala et al, 2021; Latafat *et al.* 2023, Qureshi *et al.* 2023). The nearest known sighting of a caracal was near the Phalodi region (aerial distance 64 km) of Ranthambhore Tiger Reserve (Jhala

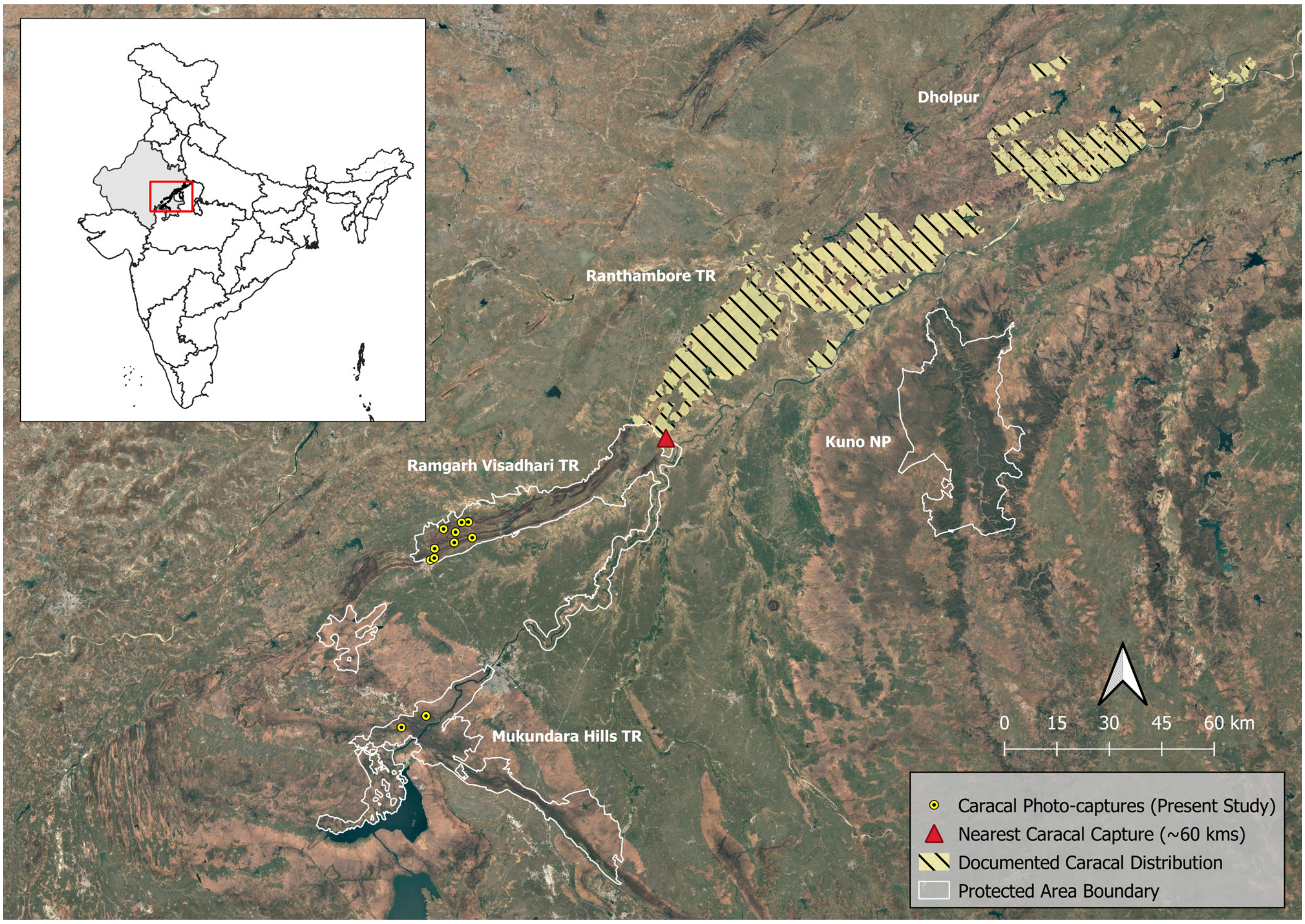

Figure 1. Map showing documented caracal distribution (Jhala *et al.*, 2021, Khandal & Dhar, 2024) with camera trap capture locations from the present study.

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Figure 2. Photo-captures of the caracal from the present study. a) First photo-capture in RVTR. b) Caracal carrying a lagomorph in RVTR. c) First photo-capture of caracal in MHTR. d) Last Photo-capture of caracal in MHTR during current study.

et al., 2021). It is possible that the individual photo-captured in the present study might be dispersing from Ranthambhore (Phalodi region). Caracals are large ranging species, and are known to cover larger distances in resource sparse areas (Norton & Lawson, 1985; Bothma & Riche, 1994; Avenant & Nel, 1998; van Heezik & Saddon, 1998; Marker & Dickman, 2005). The probability of RVTR and MHTR harboring sizable caracal populations currently is low (given no photographic captures in the recent surveys). These recent photo-captures of caracal have revived the hope for caracal conservation in the semi-arid western Indian landscape and highlighted the importance of rigorous scientific monitoring to record rare and elusive species, such as caracal. Dedicated species-specific studies focused on population status, habitat use, ranging pattern, and genetic assessment are required for developing effective conservation strategies to safeguard the species' long-term viability (Jhala *et al.* 2021; Khandal & Dhar 2024).

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CONFLICT OF INTEREST

Qamar Qureshi, Vishnupriya Kolipakam and Bilal Habib hold editorial positions at the Journal of Wildlife Science. However, they did not participate in the peer review process of this article except as authors. The authors declare no other conflict of interest.

DATA AVAILABILITY

All data are presented in the paper.

AUTHORS' CONTRIBUTION

RT, MP, and AS conceived and designed the study. RT, MP, and DS carried out the field study. QQ, BH, VK, AS, SS, MS, RK and SJ secured necessary permission and resources to carry out the study. AS, VK, BH and QQ supervised the research work. RT, MP and AS wrote the original draft. All the authors contributed for the final version of the manuscript.

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