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Addressing Human–Monkey Conflict in Nepal: An Evidence-Based Argument for an Integrated Ecosystem Approach

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Human–monkey conflict (HMC) represents an increasing socioecological challenge in Nepal's midhill regions, where agricultural systems and community-managed forests coexist within highly fragmented landscapes. This study reinterprets HMC as an emergent property of a coupled socioecological system shaped by the interaction of habitat degradation, altered resource availability, primate behavioral adaptation, and human land-use dynamics. Drawing on a structured narrative review and concept-mapping approach, we synthesize heterogeneous ecological, behavioral, and socioeconomic evidence into an integrated analytical framework. Findings indicate that current mitigation strategies, including deterrence, physical barriers, and population control interventions (currently at the pre-implementation phase) are largely reactive, labor-intensive, and insufficient to address the structural drivers of conflict. In particular, forest regeneration processes, while increasing overall tree cover, often fail to restore trophic functionality, contributing to a dual-resource system in which anthropogenic food sources remain highly attractive to primates. This dynamics is reinforced by behavioral plasticity, habituation, and social learning in monkey populations, leading to persistent and self-reinforcing conflict patterns. To address these limitations, the study proposes an integrated ecosystem approach (IEA) as a conceptual and operational framework for HMC mitigation. The IEA integrates ecological restoration, behavioral ecology, and governance mechanisms through coordinated interventions targeting habitat functionality, spatial configuration of resources, reduction of anthropogenic food subsidies, adaptive monitoring, and community-based management. By shifting the focus from symptom-oriented mitigation to the modification of the underlying ecological incentives, the IEA aims to provide a more sustainable and scalable pathway for conflict reduction. Although developed within the context of Nepal, the framework has broader applicability to other human–wildlife conflict systems, provided that interventions are adapted to local ecological, agricultural, and institutional conditions. The study contributes to advancing both the theoretical understanding and practical management of HMC by bridging the gap between socioecological systems theory and applied conservation strategies.

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Background

Human–wildlife conflict (HWC) represents one of the main challenges at the interface between biodiversity conservation and human livelihoods, particularly in contexts characterized by rapid changes in land use and profound ecological shifts [1,2]. These conflicts arise from the spatial and functional overlap between human activities and the ecological needs of wildlife, manifesting as expressions of complex socioecological systems in which competition for limited resources, trade-offs between conservation and production, and institutional dynamics interact in nonlinear ways [3,4]. In South Asia and the Himalayan region, these dynamics are particularly pronounced due to the combination of high human population density, biological richness, and increasing landscape fragmentation [5,6].

Among the various wildlife taxa, nonhuman primates exhibit a particular propensity for conflict with human populations, owing to their high cognitive abilities, marked dietary flexibility, and capacity to adapt to anthropized environments [7–9]. Nonhuman primates belonging to the genus *Macaca* exhibit high ecological plasticity, allowing them to exploit fragmented habitats, agricultural landscapes, and urbanized environments. While this adaptability facilitates their survival in rapidly changing

contexts, it also contributes to increasing the frequency and intensity of direct human–primate interactions [10].

In Nepal, human–monkey conflict (HMC) is a substantial and increasingly reported socioecological problem, particularly in the intermediate hill regions, where small-scale agriculture is closely integrated with community-managed forest systems [11]. Crop raiding by rhesus monkeys (*Macaca mulatta*), Assamese monkeys (*Macaca assamensis*), and langurs (*Semnopithecus hector* and *Semnopithecus schistaceus*) represents the primary form of interaction, with measurable impacts on household economies and food security [12]. Empirical evidence documents not only direct crop losses but also broader indirect effects, including changes in land-use practices and, in some cases, the abandonment of cultivated land [13]. Despite growing attention, interpreting the temporal dynamics of HMC remains methodologically complex. Much of the available evidence is based on observational data or short-term studies, limiting the ability to reconstruct long-term trajectories [14]. However, existing studies indicate that key drivers, including habitat degradation, food scarcity, and expanding human settlements, are associated with increased HMC [15]. These processes may contribute to conflict dynamics in which wildlife increasingly depends on anthropogenic resources, potentially intensifying the problem over time. The mitigation strategies adopted to date include traditional deterrence methods (such as slingshots, stones, and loud sounds), physical barriers, and, in neighboring countries, sterilization programs [16]. Many of these approaches are predominantly reactive and focused on managing the immediate symptoms of conflict. Community surveys indicate that physical barriers are often ineffective, while traditional deterrents are rated as only moderately effective. Existing mitigation efforts have not proven effective against the notorious crop raiders.

In this context, HMC can be more appropriately understood as an emergent property of a coupled socioecological system in which ecological processes, primate behavioral responses, land-use dynamics, and institutional frameworks interact through multiple, nonlinear feedback mechanisms. Landscape transformations, including habitat fragmentation, agricultural expansion, and structural but functionally incomplete forest regeneration, alter the balance between natural and anthropogenic resources, thereby reshaping primates' movement ecology, foraging strategies, and degree of habituation to human presence. These behavioral adaptations increase the frequency and intensity of crop incursions, amplifying socioeconomic impacts and eliciting predominantly localized and reactive human responses, which in turn contribute to the reinforcement of self-sustaining feedback dynamics. In light of these considerations, there is a clear need for integrated approaches capable of simultaneously addressing the ecological, behavioral, and institutional dimensions of the system. To this end, we propose the integrated ecosystem approach (IEA) as an analytical and operational framework designed to identify recurrent mechanisms, conceptual gaps, and underexplored interactions. The IEA is structured around 4 interlinked components, i.e., ecological drivers, behavioral responses, socioeconomic impacts, and governance and mitigation structures, which are not treated as discrete analytical categories but as functionally interdependent subsystems embedded within a coupled socioecological system, where feedback processes, cross-scale interactions, and nonlinear dynamics govern the emergence and persistence of conflict patterns.

This work aims to reinterpret HMC in Nepal as a coupled socioecological system shaped by the interaction between habitat quality, resource availability, and monkey population dynamics and to develop an explicit, operational conceptual framework that integrates ecological restoration, behavioral ecology, and community governance. In doing so, the study seeks to contribute both to advancing the scientific understanding of HMC and to informing more effective and sustainable management strategies. Specifically, it contributes by (a) synthesizing fragmented evidence into a unified conceptual structure, (b) explicitly linking ecological and behavioral mechanisms with governance processes, and (c) proposing an operational framework that can guide future empirical validation and applied management interventions.

Materials and Methods

Search strategy and selection criteria

The present study adopts a structured conceptual review with framework development rather than a systematic review or meta-analysis. Its primary output is the integration of heterogeneous evidence into an operational socioecological model aimed at hypothesis generation and policy interpretation rather than quantitative synthesis. Accordingly, the synthesis follows a structured narrative review design with an explicitly analytical and conceptual orientation, consistent with Grant and Booth [17] and subsequent refinements on integrative synthesis approaches [18]. Unlike systematic reviews and meta-analyses, which emphasize exhaustive retrieval and quantitative aggregation of evidence, structured narrative approaches are particularly suited to complex socioecological systems characterized by heterogeneous and multidisciplinary evidence, where the primary objective is conceptual integration rather than statistical inference. To ensure transparency and reduce interpretative ambiguity, the synthesis was guided by an iterative concept-mapping procedure through which key concepts were extracted, compared, and organized into a relational hierarchical structure linking ecological drivers, behavioral responses, socioeconomic impacts, and governance and mitigation processes. This procedure enabled a transition from descriptive narrative synthesis to a structured conceptual architecture in which empirical evidence is embedded within explicit causal and feedback relationships, ensuring traceability between the literature base and the resulting framework.

The literature base was developed through a comprehensive and iterative search strategy across major bibliographic databases, including PubMed, Web of Science, Scopus, and Google Scholar, complemented by gray literature from governmental agencies, international organizations, and nongovernmental organizations, in line with established best practices in conservation science synthesis [19]. The search strategy combined keywords and Boolean operators across 4 thematic domains: conflict-related terms (e.g., "human–wildlife conflict" and "human–monkey conflict"), taxonomic terms (e.g., "macaque" and "nonhuman primates"), geographic terms (e.g., "Nepal" and "South Asia"), and driver- and response-related terms (e.g., "crop raiding", "habitat fragmentation", "community forestry", and "mitigation strategies"). Study selection followed a purposive, relevance-based inclusion strategy rather than rigid eligibility criteria, consistent with narrative and integrative synthesis methodologies [20], prioritizing conceptual contribution over methodological homogeneity. Included studies provided empirical evidence or theoretical insight on ecological drivers (habitat degradation, resource availability, and landscape fragmentation),

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behavioral responses (foraging flexibility, habituation, and spatial adjustment), socioeconomic impacts (crop loss, economic burden, and livelihood implications), mitigation strategies (deterrents, land-use interventions, and community-based management), and governance structures (community forestry systems and institutional arrangements shaping human–wildlife interactions). A snowballing strategy through reference list screening of key publications further ensured iterative refinement and thematic saturation. Despite its comprehensiveness, the evidence base remains highly heterogeneous in methodological design, spatial coverage, and reporting standards, limiting direct comparability and precluding quantitative synthesis.

Results of Conceptual Synthesis

Concept mapping and framework development

The analytical framework underpinning the synthesis was thematic and mechanism oriented, aimed at identifying recurrent patterns, causal pathways, and feedback structures across socioecological dimensions of human–nonhuman primate conflict. Conflict is conceptualized as an emergent property of interactions between ecological processes, primate behavioral adaptation, and human decision-making systems. Ecological processes include habitat quality, spatial configuration of resources, landscape structure, and anthropogenic food provisioning; behavioral responses encompass foraging strategies, habituation, movement ecology, and spatial plasticity in nonhuman primates, while human dimensions include agricultural practices, land-use change trajectories, and mitigation behaviors operating across spatial and temporal scales. Particular emphasis is placed on the interaction between natural and anthropogenic food resources, conceptualized as a dual-resource environment shaping primate movement ecology, population dynamics, and conflict intensity. Rather than quantitative aggregation, the objective is the construction of an integrated explanatory framework linking structural ecological drivers to observed conflict patterns through explicit causal and feedback relationships, thereby extending the analysis toward a hypothesis-generating model suitable for future empirical validation and comparative socioecological research.

Figure 1 summarizes this conceptual framework, representing HMC as a socioecological system composed of 7 interconnected components describing mechanisms of emergence, persistence, and mitigation. At the base (components 1 and 2), landscape-scale ecological drivers, including forest fragmentation, habitat degradation, agricultural expansion, and structurally incomplete forest regeneration lacking trophic recovery, reshape resource availability by reducing access to natural food

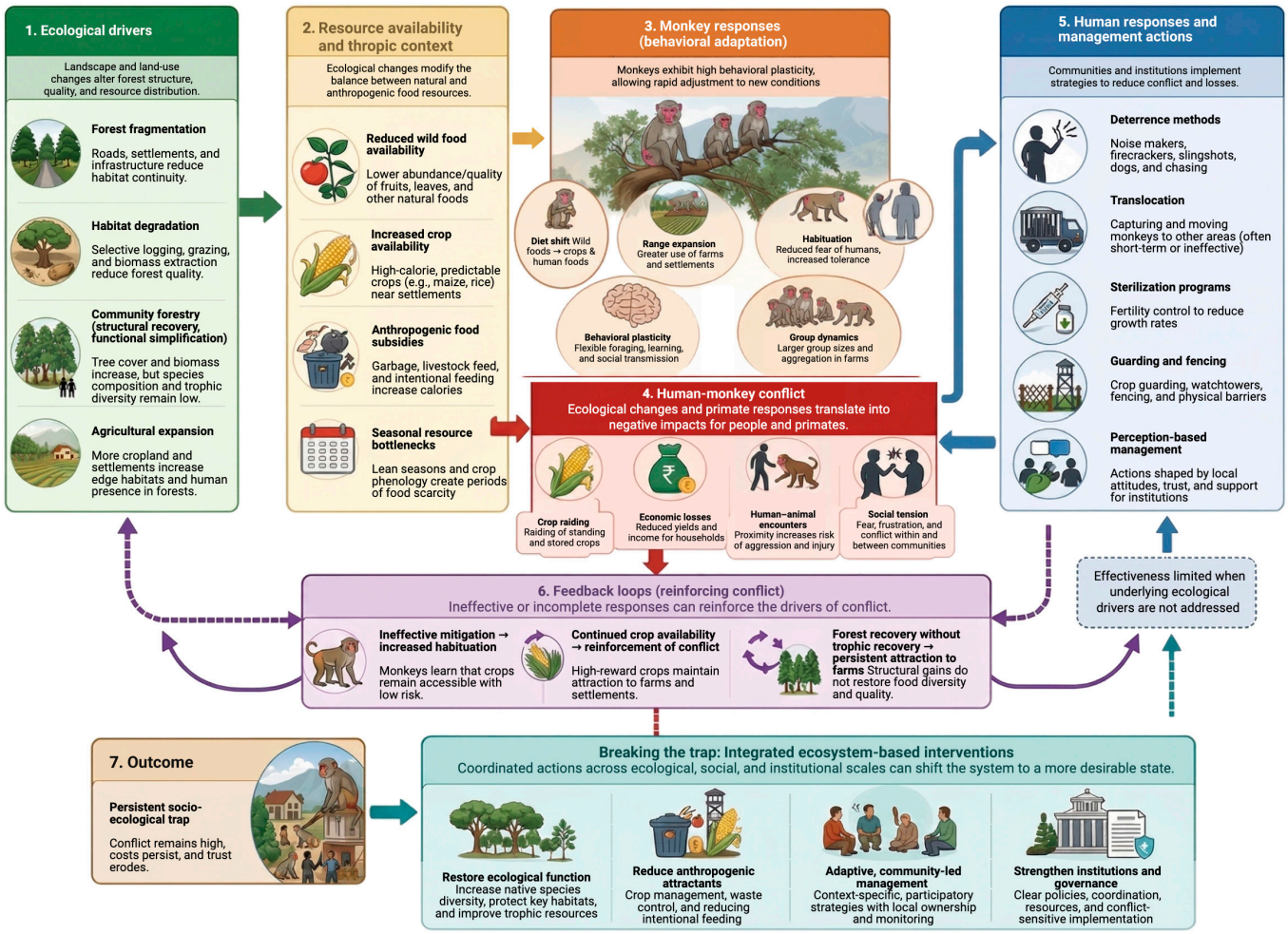


Fig. 1. Conceptual framework representing human–monkey conflict as a socioecological system composed of interconnected components. The figure was prepared using the software BioRender.

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sources while increasing the predictability of anthropogenic resources. Within this context, primate populations (component 3), particularly rhesus monkeys and Assamese monkeys, respond through high behavioral plasticity, including dietary shifts toward crops, range expansion, and increased habituation to human presence. These dynamics drive conflict emergence (component 4), primarily in the form of crop raiding, with substantial socioeconomic consequences. Human responses (component 5), generally reactive and localized, fail to address structural drivers and generate reinforcing feedback mechanisms (component 6), including increased habituation due to ineffective deterrence, persistent attractiveness of high-yield crops, and insufficient regeneration of natural forest food resources. Collectively, these processes lead to the formation of a socioecological trap (component 7), characterized by a self-reinforcing and persistent state of conflict.

Thematic patterns emerging from the literature

The synthesis of the included studies revealed 3 overarching thematic patterns that recur consistently across geographic contexts, taxa, and methodological approaches and that collectively informed the conceptual architecture of the IEA framework.

The first and most pervasive pattern concerns the primacy of ecological drivers in shaping conflict dynamics. Across the evidence base, habitat degradation, landscape fragmentation, and the progressive depletion of natural food resources in structurally simplified forests emerge as the dominant structural conditions enabling and intensifying HMC. Importantly, the literature consistently distinguishes between tree cover expansion, which has increased across Nepal's midhill regions due to community forestry programs, and functional trophic recovery, which remains largely absent from regenerating landscapes. This distinction is fundamental: increasing forest cover does not translate into adequate food resource availability for frugivorous and omnivorous primates, thereby sustaining the attractiveness of anthropogenic food sources. This pattern directly informed the emphasis placed within the IEA on functional forest restoration rather than mere afforestation.

The second recurrent pattern concerns the role of behavioral plasticity and social learning as amplifying mechanisms of conflict. Studies across South and Southeast Asian macaque systems converge on the finding that crop-raiding behavior is not simply an opportunistic response to food scarcity but a socially transmitted and cognitively reinforced strategy that can persist across generations even when ecological conditions change. In rhesus macaques (*M. mulatta*), the primary conflict species in Nepal, learned foraging traditions and rapid habituation to deterrence measures generate a form of behavioral inertia that conventional mitigation strategies are structurally unable to address. This pattern highlighted the need for the IEA to explicitly incorporate behavioral ecology as an operational domain, rather than treating primate behavior as a fixed background variable.

The third pattern relates to the structural inadequacy of existing mitigation approaches. Across all geographic contexts examined, current strategies, including guarding, noise deterrents, sterilization, and translocation, are consistently described as reactive, labor-intensive, and effective only in the short term. The literature reveals a persistent disconnect between the systemic, multidriver nature of HMC and the localized, symptom-focused character of management interventions. This pattern identified a structural gap that the IEA is explicitly designed to address, by shifting the intervention logic from conflict suppression to modification of the underlying ecological and behavioral incentives.

Evidence gaps identified through concept mapping

The iterative concept-mapping procedure applied during the synthesis identified 10 substantive evidence gaps across the 5 thematic domains (see Table S1). These gaps represent areas where the existing literature either lacks empirical grounding in the Nepalese context, relies on extrapolation from other geographic or taxonomic systems, or documents a phenomenon without providing a mechanistic explanation or management-relevant insight.

The most critical gaps cluster around 2 domains. In the domain of ecological drivers, the near-complete absence of quantitative data on the trophic quality of community-managed forests in Nepal represents a major constraint on management design. While the qualitative argument for functional restoration is well supported theoretically, the species-specific dietary requirements of *M. mulatta*, *M. assamensis*, and *S. schistaceus* in relation to available forest food resources have not been empirically characterized in Nepal's midhill landscapes. In the domain of governance and institutions, the absence of a coordinated national monitoring framework means that conflict data remain fragmented, locally collected, and methodologically inconsistent, severely limiting spatial and temporal inference at the landscape scale.

These gaps are not merely academic limitations: they represent the operational uncertainties that any management framework must acknowledge and address through adaptive mechanisms.

Recurrent causal mechanisms and construction of the IEA

Beyond thematic patterns and evidence gaps, the synthesis identified 3 recurrent causal mechanisms that operate across geographic contexts and taxa and that collectively explain the emergence, persistence, and self-reinforcing nature of HMC as a socioecological phenomenon. These mechanisms constitute the structural logic underpinning the IEA.

The first mechanism is the dual-resource system. In all documented contexts, HMC intensifies when anthropogenic food sources, i.e., crops, waste, and intentional provisioning, become energetically competitive with or superior to natural forest resources. This is not simply a consequence of forest loss but of a shift in the relative predictability, energy density, and spatial accessibility of food sources available to primates. When crops offer higher energy returns per unit foraging effort than degraded forest patches, the ecological incentive structure fundamentally favors conflict behavior, regardless of deterrence efforts. The dual-resource framing is not novel in isolation, but its explicit integration as a driver of population-level foraging decisions, rather than an incidental background factor, is a conceptual contribution of the present synthesis.

The second mechanism is the feedback loop between cropland abandonment and habitat expansion. Multiple studies document that persistent crop raiding drives progressive abandonment of agricultural parcels, particularly those located near forest edges. Abandoned fields undergo secondary forest regeneration, which increases structurally available habitat for macaques and other synanthropic wildlife, potentially intensifying conflict at a spatial scale that extends beyond the originally affected parcels. This positive feedback loop, i.e., conflict → abandonment → regeneration → expanded macaque habitat → intensified conflict, represents self-reinforcing dynamics that is invisible to single-site, short-term management approaches and that can be

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addressed only through landscape-scale intervention frameworks such as the IEA.

The third mechanism concerns reactive management reinforcing habituation. The literature consistently shows that ineffective or inconsistently applied deterrents, including noise devices, guarding, and projectile-based scaring, contribute to accelerated habituation in macaque populations, paradoxically reducing the effectiveness of subsequent interventions. Because management responses are typically reactive and localized, they are rarely sustained long enough or applied at a sufficient intensity to modify behavior durably. This creates a ratchet effect in which each round of deterrence produces diminishing returns while simultaneously selecting for bolder, less deterrable individuals within conflict-prone troops. This mechanism highlights the behavioral and evolutionary dimensions of management failure and directly informs the IEA's emphasis on reducing the ecological incentives for crop raiding rather than relying on direct behavioral suppression.

These 3 mechanisms, i.e., the dual-resource system, the abandonment–regeneration feedback loop, and the habituation ratchet, define the structural logic of HMC as a socioecological trap. Their explicit identification through the concept-mapping synthesis provided the empirical and theoretical basis for the construction of the IEA, whose 6 operational domains are each designed to interrupt or modify one or more of these mechanisms.

Quantifiable impacts on livelihoods

HMC in South Asian agroecosystems represents a multiscalar socioeconomic stressor that affects rural livelihoods through direct crop losses, indirect management costs, and long-term land-use restructuring, as shown in Fig. 2.

Across the Himalayan foothills and midhill landscapes of Nepal, India, and Sri Lanka, rhesus monkeys and other commensal primates have been consistently identified as key agents of agricultural damage, particularly in maize-, rice-, wheat-, and vegetable-based subsistence systems.

At the household level in Nepal, Koirala et al. [21] provided a precise monetary estimate of crop-raiding impacts in the Kavrepalanchok District, reporting an average direct loss of approximately US$14.9 per household, corresponding to 4.2% of income derived from maize and rice production. Similar household-level quantification has been reported in India, where studies on rhesus monkeys in Himachal Pradesh and Uttarakhand document historically variable but often severe crop losses. Saraswat et al. [22] reported that farmers in Bilaspur District, Himachal Pradesh, experience substantial yield losses from crop raiding by monkeys, with prior accounts from Uttarakhand indicating that losses that were approximately 10% in earlier decades had escalated to 50% to 90% in some localities over the following 5 to 10 years, particularly in villages adjacent to forest corridors or near pilgrimage routes that increase food provisioning and animal habituation. Although

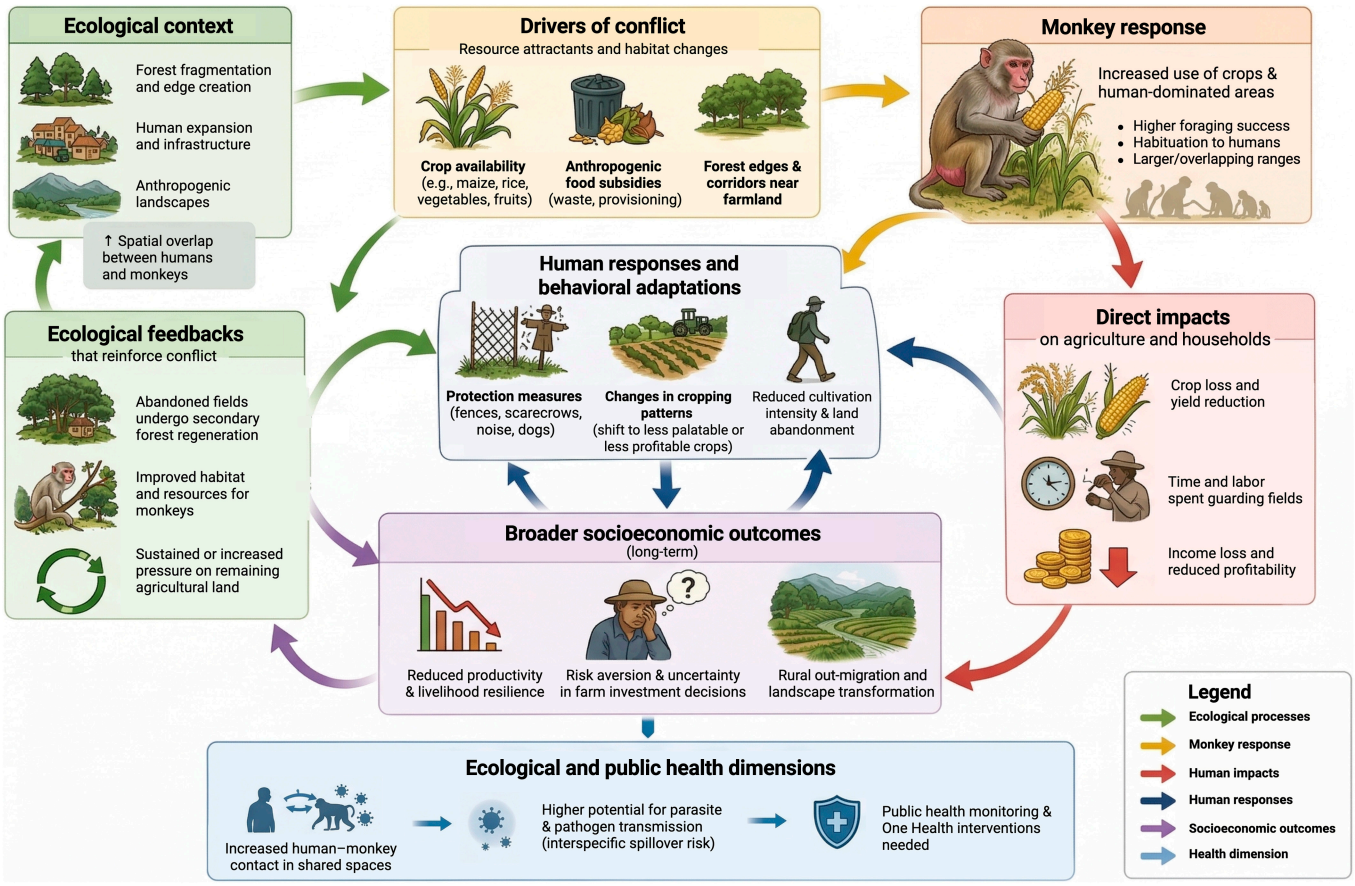


Fig. 2. Summary of the socioecological drivers, responses, and feedbacks in human–monkey conflict (HMC) across South Asian agroecosystems. Forest fragmentation and anthropogenic landscapes increase human–monkey overlap; crop availability drives monkey habituation and crop use; and direct agricultural losses generate labor costs, income reduction, and cropland abandonment. Abandoned fields undergo forest regeneration, creating a positive feedback loop that sustains or intensifies conflict. Health dimensions arise from increased interspecific contact. The figure was prepared using the software BioRender.

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exact monetary conversions vary depending on market price fluctuations, these yield-loss ranges confirm that economic impacts can be considerably higher than those observed in less fragmented Nepalese landscapes. Crop depredation by monkeys is eroding public support for their conservation and, in some areas, provoking retaliatory killings [23–25].

Beyond direct crop loss, indirect economic burdens significantly increase the total cost of HMC. In multiple Himalayan case studies, households report allocating substantial daily labor time during peak cropping seasons to guarding fields, representing a substantial opportunity cost in labor-constrained agrarian systems. These labor costs are rarely monetized but are consistently identified as a major determinant of perceived conflict severity and agricultural decision-making, including reduced cultivation intensity and abandonment of agricultural parcels. Regmi et al. [26] documented this pattern specifically for Nepal's midhill communities, noting that crop guarding constitutes one of the primary household responses to monkeys' incursions in Langtang National Park and surrounding areas. Baral et al. [27] further demonstrated that HMC in Nepal's community forestry landscapes is strongly shaped by landscape configuration, with higher crop loss rates observed in villages located closer to regenerating forest mosaics and forest edges. In these systems, rhesus monkeys represent a major crop-raiding species, contributing substantially to reported agricultural damage and reinforcing spatial heterogeneity in conflict intensity across sites. Multi-site comparisons consistently confirm that proximity to forest edges is a key predictor of crop-raiding frequency and associated yield reductions relative to more interior settlements.

One of the most consequential outcomes of chronic crop raiding is cropland abandonment. Bista et al. [28] examined cropland abandonment in Nepal's midhill community forestry landscapes and demonstrated that parcels located near forest edges are markedly more likely to be abandoned, with HWC identified as an important contributing factor alongside outmigration and agricultural labor shortages. Other studies in Nepal's hill regions similarly report substantial variability in abandonment rates across districts and elevations, with land being progressively withdrawn from cultivation in areas experiencing persistent wildlife pressure [29]. Once abandoned, agricultural plots frequently undergo secondary forest regeneration, which may increase habitat suitability for monkeys and other synanthropic wildlife, thereby reinforcing spatial feedback mechanisms that can contribute to sustained or recurrent HWC risk over time.

In Sri Lanka, long-term studies on toque monkeys (*Macaca sinica*) consistently document substantial agricultural losses across both perennial and annual crops, with toque monkeys frequently identified as the principal crop-raiding primate species and a major source of agricultural damage [30]. A broad range of crops is affected, including coconuts, paddy, vegetables, maize, and bananas. Recent quantitative survey-based evidence from rural agricultural settings in the Kurunegala District confirms the economic relevance of this conflict, reporting substantial household crop losses and deterrence costs attributable to monkeys' crop raiding [31]. Although ecological conditions differ from Himalayan systems, these findings reinforce the broader pattern that commensal monkeys can impose high localized economic burdens in fragmented agricultural mosaics. At a broader South Asian scale, assessments of primate crop raiding indicate that conflict is not only economically damaging but also behaviorally transformative, contributing to changes in cropping patterns and landscape-level management strategies [32,33]. Koirala et al. [34] further showed that nearly 15% of Nepal's land area where human settlements are permitted is characterized by moderate or high rates of human–rhesus monkey conflict and that the ongoing fragmentation of forests is the primary ecological driver of this intensification. These adaptations often reduce long-term agricultural efficiency even when short-term losses are partially mitigated.

From a systems perspective, the socioeconomic burden of HMC extends beyond agriculture into risk perception and livelihood insecurity. Households in high-conflict zones report increased uncertainty regarding farm investment decisions and a tendency toward risk-averse cropping strategies, which can reduce the overall productivity and resilience of rural economies [34]. While these effects are not always quantified in monetary terms, their recurrence across studies suggests a consistent structural impact of wildlife pressure on rural decision-making. Increasing spatial overlap between humans and monkeys in anthropogenic landscapes introduces additional ecological and public health dimensions. Studies on primate infectious disease ecology at human–monkey interfaces demonstrate that greater contact in human-modified environments alters space use and increases the potential for interspecific transmission of parasites and other infectious agents [35–37].

Drivers of Human–Monkey Conflict in Nepal

Species-specific ecology and conflict drivers

Three monkey species, i.e., rhesus monkeys, Assamese monkeys, and Nepal gray langurs, account for the majority of crop-raiding incidents in Nepal, and their differing ecological and behavioral traits are fundamental to understanding variation in HWC intensity across landscapes. HWC is increasingly conceptualized as a coupled socioecological system shaped by interacting ecological processes, wildlife behavioral responses, land-use transformation, and human decision-making, rather than as a phenomenon driven solely by wildlife behavior [38–40]. Within this framework, primate crop raiding represents a particularly dynamic case because primates possess high cognitive abilities, behavioral plasticity, and complex social learning systems, which facilitate rapid adaptation to anthropogenic environments and novel food sources [8,41,42].

Rhesus monkeys are the dominant conflict species in Nepal, largely due to their extreme behavioral plasticity and synanthropic tendencies [34]. Across South and Southeast Asia, rhesus monkeys are widely documented as highly adaptable generalist primates capable of exploiting a wide spectrum of anthropogenic resources, including crops, refuse, and direct provisioning by humans [43,44]. Their ecological success in disturbed landscapes is driven by several interacting traits: an omnivorous and opportunistic diet, large multimale multifemale social groups, flexible ranging behavior, and high levels of social learning. Importantly, crop-raiding behavior is often socially transmitted within groups, with experienced individuals facilitating the spread of innovative foraging strategies among troop members. Such socially mediated behavioral diffusion can generate persistent foraging traditions that persist across generations and may prove resistant to conventional deterrence strategies [45].

Assamese monkeys exhibit a more forest-dependent ecological profile, with comparatively lower synanthropy and stronger reliance on forest interior habitats [46]. Studies on their feeding ecology indicate a stronger dependence on seasonal fruit and

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forest plant resources and relatively smaller troop sizes compared to those of rhesus monkeys [47]. These ecological characteristics reduce their capacity to exploit highly fragmented agricultural mosaics. Consequently, crop-raiding behavior tends to occur primarily along forest–agriculture edges where forest patches directly adjoin cultivated land. This edge-dependent spatial pattern suggests that Assamese monkeys are more sensitive to habitat configuration and forest connectivity than to agricultural expansion alone, reinforcing the importance of landscape structure in mediating conflict intensity.

Nepal gray langurs display yet another ecological strategy. Langurs are predominantly folivorous colobines with digestive adaptations enabling them to process fibrous plant material, and their foraging ecology is closely tied to forest canopy structure and plant species composition [24]. Compared with monkeys, they generally exhibit lower behavioral plasticity in anthropogenic environments. Although crop consumption can occur, particularly during periods of seasonal food scarcity, their involvement in crop-raiding events tends to be more opportunistic and less systematically destructive than that of monkeys. Because langurs rely heavily on arboreal travel routes and canopy continuity, habitat fragmentation that disrupts canopy connectivity may strongly constrain their movement patterns and reduce the frequency with which they access agricultural landscapes.

Across all 3 taxa, variation in home-range size, dietary breadth, and social learning capacity strongly mediates both the frequency and intensity of crop-raiding behavior. Rhesus monkeys typically exhibit flexible and relatively large home ranges in fragmented landscapes, enabling frequent incursions into agricultural matrices, while Assamese monkeys and langurs tend to show movement patterns more tightly linked to forest habitat structure. These interspecific differences align with broader theoretical perspectives in ethnoprimatology and conflict ecology, which emphasize that primate crop-raiding behavior is best understood as a behavioral adaptation emerging from interactions between primate ecology and anthropogenic landscapes, rather than as a fixed species-level trait.

Biogeographical context of HMC in Nepal

Nepal occupies a unique biogeographical position within the Himalayan region, characterized by extreme environmental heterogeneity generated by steep altitudinal gradients, complex topography, and strong climatic variation over relatively short spatial scales. Within a geographic area of approximately 147,181 km^2, elevation ranges from less than 60 m above sea level in the southern Terai plains to 8,848 m at Mount Everest, producing a mosaic of ecological zones that include tropical lowland forests, subtropical and temperate broadleaf forests, montane conifer forests, and alpine ecosystems. This extraordinary environmental variability has positioned the Himalayan region as a major center of biodiversity and endemism, where species distributions are strongly structured along climatic and altitudinal gradients [48]. Such landscape heterogeneity has important implications for the spatial ecology of wildlife populations. In mountainous systems like the Himalaya, topographic barriers, river systems, and fragmented habitat patches often restrict dispersal and gene flow, shaping population structure and movement patterns across the landscape. Recent genetic and landscape ecological studies suggest that Himalayan species frequently exhibit patterns of isolation by distance and isolation by landscape resistance, where physical barriers and habitat discontinuities influence connectivity among populations [49]. Within this complex ecological context, Nepal supports several species of nonhuman primates whose distributions are strongly associated with forest habitats across midhill and lower montane regions. Conflict-causing monkey species exhibit partially overlapping but ecologically differentiated distributions across the Himalayan landscape. Rhesus monkeys are among the most geographically widespread primates in Asia and display exceptional ecological flexibility. Across Nepal, they occur in a wide range of habitats including subtropical forests, temperate woodlands, scrubland, and human-dominated environments such as agricultural landscapes, urban areas, and religious sites. Their distribution extends across a broad altitudinal range, from the lowland Terai to elevations approaching 3,000 m, making them one of the most adaptable primate species in the region [50].

Spatial modeling studies further indicate that a large proportion of Nepal provides environmentally suitable habitat for rhesus monkeys. Species distribution modeling suggests that approximately 44% of the country's land area contains suitable habitat, with monkey populations occurring across both protected areas and human-dominated landscapes. Notably, less than 10% of suitable habitat falls within protected areas, meaning that the majority of monkey populations occur within multiuse landscapes where agricultural activities and human settlements are widespread [34]. In contrast, Assamese monkeys display a more restricted ecological distribution. Surveys across Nepal indicate that this species primarily occupies midhill forest ecosystems, typically ranging between approximately 130 and 2,650 m in elevation. Their populations are concentrated along major river systems and forested hillslopes, particularly in eastern and central Nepal. Compared with rhesus monkeys, Assamese monkeys show stronger dependence on relatively intact forest habitats and are less frequently observed in highly urbanized environments [46].

Nepal gray langurs exhibit yet another ecological pattern. These colobine primates are primarily associated with midaltitude and montane forest ecosystems, including subtropical broadleaf forests, mixed conifer–broadleaf forests, and temperate woodlands typically below 4,000 m [51]. Their arboreal lifestyle and folivorous diet make them particularly sensitive to changes in forest structure and canopy continuity. As a result, landscape fragmentation and forest degradation can markedly influence their movement patterns and population connectivity across the Himalayan terrain [52]. The distribution of these 3 primate taxa across Nepal reflects broader patterns of habitat specialization and ecological niche partitioning within Himalayan landscapes. Field studies conducted in areas where rhesus and Assamese monkeys occur sympatrically suggest that the 2 species partition habitat use along gradients of human disturbance. Assamese monkeys tend to occupy forest interiors and protected areas, whereas rhesus monkeys frequently exploit disturbed habitats, temple forests, and agricultural mosaics where anthropogenic food resources are available [53]. This spatial segregation highlights the importance of landscape context in shaping patterns of HMC. In particular, the midhill regions of Nepal, where forest patches, agricultural land, and rural settlements occur in close proximity, represent key zones where primate ecological ranges overlap with human land-use systems. The resulting interface between monkey habitats and agricultural landscapes creates favorable conditions for crop-raiding behavior and repeated interactions between monkeys and

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farming communities. Consequently, understanding the biogeographical distribution of conflict-causing monkeys within the Himalayan landscape is essential for interpreting the spatial patterns of HMC observed across Nepal. The interaction between altitudinal gradients, habitat fragmentation, and expanding human land use generates a dynamic socioecological environment in which primates with high ecological flexibility, particularly rhesus monkeys, are able to exploit anthropogenic resources and persist in close proximity to human populations.

Habitat degradation and food resource depletion

Habitat degradation and the associated depletion of natural food resources represent one of the primary ecological drivers underlying HMC in Nepal. However, as highlighted by a recent study [21], the relationship between habitat change and primate crop-raiding behavior is neither linear nor deterministic but mediated by a complex interplay of resource distribution, landscape configuration, and species-specific foraging strategies.

Across the midhill regions of Nepal, forest cover has increased over recent decades, largely due to the success of community forestry programs [54]. Nevertheless, increasing forest cover does not necessarily equate to functional ecological restoration. A growing body of evidence indicates that many regenerating forests in South Asia are structurally simplified and often dominated by fast-growing or economically valuable species with limited trophic value for wildlife, particularly for frugivorous and omnivorous primates. As Estrada et al. [55] emphasized, such forests may exhibit reduced plant diversity, lower fruiting-tree density, and diminished seasonal availability of key nutritional resources, effectively functioning as "trophic bottlenecks" despite their apparent structural recovery. This pattern is consistent with the broader finding that primary forests remain irreplaceable for sustaining tropical biodiversity, whereas secondary and degraded forests often lack the ecological complexity required to support viable primate populations [56].

For primates, food availability is a critical determinant of ranging behavior and habitat use. Studies on primate feeding ecology consistently show that reduced availability of preferred natural foods, particularly fruits and young leaves, can lead to increased reliance on fallback foods and expansion of foraging ranges [57,58]. In fragmented landscapes, this process is further amplified by the spatial juxtaposition of nutritionally rich agricultural crops, which often provide higher energy returns per unit effort compared to wild food resources. Crops such as maize, rice, and fruits are typically more predictable, energy dense, and temporally synchronized, making them highly attractive to generalist feeders like rhesus monkeys [59,60]. Recent research on human-modified landscapes provides further insight into this dynamic. Studies have shown that primate populations can reach unusually high densities in degraded or edge habitats when supplemented by anthropogenic food sources, including crops and food waste [9,61]. This "ecological release" from natural constraints can lead to elevated population densities that further intensify pressure on adjacent agricultural systems, reinforcing conflict dynamics. However, the assumption that restoring natural food resources will automatically reduce crop raiding is overly simplistic. Empirical studies from South Asia and other primate systems demonstrate that anthropogenic foods may remain preferential even when natural resources are available, particularly in species characterized by high behavioral plasticity and social learning [7,8]. In rhesus monkeys, for instance, learned crop-raiding behaviors can persist across generations, creating culturally transmitted foraging strategies that are not easily reversed by ecological restoration alone. This highlights the importance of considering behavioral inertia and cognitive adaptation in addition to ecological drivers. Moreover, unregulated human provisioning, whether intentional (e.g., religious feeding) or incidental (e.g., poorly managed waste), has been shown to alter primate behavior, demography, and social dynamics, often leading to increased group sizes and intensified human–primate interactions [62].

Seasonality further complicates the relationship between habitat quality and conflict intensity. Natural food availability in Himalayan forests is highly seasonal, with pronounced fluctuations in fruiting phenology. During periods of natural food scarcity, particularly in premonsoon months, primates may increase their dependence on agricultural resources regardless of baseline habitat quality [58]. This seasonal mismatch between forest food availability and crop cycles creates predictable temporal peaks in conflict intensity, especially when high-value crops reach maturation stages.

Landscape structure also plays a critical role in mediating the effects of habitat degradation. Fragmented forest–agriculture mosaics create a high edge density, facilitating frequent primate incursions into cultivated areas. Edge habitats often provide both refuge and access, allowing primates to exploit crops while maintaining proximity to forest cover. Studies have shown that crop-raiding frequency is strongly correlated with distance to forest edges and patch configuration rather than simply with overall forest cover [32,59]. Additionally, structurally simplified plantations and monodominant reforestation efforts often provide limited trophic resources, reinforcing the conclusion that habitat quality and floristic composition are more critical than tree cover per se [56].

Taken together, these findings suggest that habitat degradation contributes to HMC not only through absolute reductions in food availability but also through qualitative changes in resource distribution, temporal variability, and spatial accessibility. From a systems perspective, the problem is best conceptualized as a shift from a forest-dominated resource landscape to a dual-resource system in which anthropogenic foods become increasingly competitive or even dominant drivers of primate foraging decisions.

Population dynamics, reproductive ecology, and density-dependent regulation

Understanding population dynamics is essential for explaining both the persistence and the temporal variability of HMC. In primates, population size and growth are determined by the interaction between natality, mortality, and density-dependent regulation, all of which can be substantially altered in human-modified environments.

In natural systems, primate populations are typically regulated through a combination of resource limitation, predation, disease, and social factors. However, in Nepal's midhill landscapes, several of these regulatory mechanisms have been weakened or disrupted. In particular, the near extirpation of large predators has reduced top-down control on primate populations, while increasing availability of anthropogenic food sources has relaxed bottom-up constraints related to resource limitation.

Anthropogenic food subsidies play a central role in this process. A substantial body of literature demonstrates that access to high-energy, predictable food sources can markedly enhance

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reproductive output in primates. Improved female nutritional condition is associated with earlier age at first reproduction, shorter interbirth intervals, and increased infant survival [63]. In rhesus monkeys and other monkeys species, provisioning, whether intentional or incidental, has been consistently linked to changed diurnal activity budget and higher population densities compared to nonprovisioned populations [43,50]. This decoupling of population growth from natural carrying capacity can lead to locally elevated primate densities in anthropogenic landscapes. Importantly, such density increases do not necessarily stabilize quickly, particularly in the absence of strong density-dependent feedback mechanisms. Instead, populations may temporarily exceed the ecological carrying capacity of surrounding forest habitats, increasing pressure on agricultural systems as alternative food sources.

At the same time, density-dependent processes are not entirely absent but may operate in altered forms. In primates, density dependence can manifest through increased intragroup competition, reduced juvenile survival, delayed dispersal, and social stress, all of which may eventually limit population growth [64]. However, when anthropogenic food sources buffer resource scarcity, these feedbacks may be weakened or delayed, allowing populations to remain at elevated densities for extended periods.

Reproductive ecology also contributes to the temporal dynamics of conflict. In rhesus monkeys, reproductive cycles are typically seasonal, with mating occurring in autumn and births peaking between late winter and early spring (approximately October to February for mating and January to April for births, depending on latitude) [65]. This results in periods of increased energetic demand associated with gestation, lactation, and juvenile growth.

These physiological demands often coincide with critical agricultural periods. In Nepal, the growth and maturation of key crops such as maize and rice overlap with periods of increased nutritional requirements in primate populations, particularly during lactation and juvenile development (March to June). This temporal overlap provides a mechanistic explanation for seasonal peaks in crop-raiding intensity, as high-energy crops become especially valuable during periods of elevated energetic demand.

Juvenile recruitment further amplifies this effect. Following birth peaks, the increase in group size due to dependent offspring can elevate total food requirements at the troop level. Juveniles also play a role in behavioral dynamics, as they learn foraging strategies, including crop raiding, through social observation and participation, contributing to the intergenerational persistence of conflict behaviors [45].

From a spatial perspective, population pressure interacts with habitat fragmentation to influence movement patterns. Larger or denser troops may expand their ranging areas or increase the frequency of incursions into agricultural land when local resources are insufficient. Empirical studies on primate ranging ecology show that increased population density is associated with expanded home ranges and greater use of anthropogenic habitats in fragmented landscapes [63].

These dynamics highlight a critical tension within ecosystem-based management (EBM) approaches. Habitat enrichment, while potentially increasing natural food availability, may also lead to short- to medium-term increases in primate carrying capacity and population size, particularly if not accompanied by effective regulatory mechanisms. This underscores the importance of integrating population monitoring and adaptive management. Rather than viewing population control measures as contradictory to ecosystem-based approaches, they should be understood as conditional tools within a broader adaptive system. Continuous monitoring of population trends, reproductive parameters, and intensity of conflict is essential to detect situations in which ecological interventions alone are insufficient. In such cases, ethically regulated fertility control or other population management strategies may be required to restore balance between population size, resource availability, and acceptable levels of human–wildlife interaction [66].

Overall, HMC dynamics in Nepal cannot be fully understood without considering the interplay between altered population regulation, enhanced reproductive output, and anthropogenic resource availability. These factors jointly contribute to a system in which primate populations may remain persistently above natural equilibrium levels, reinforcing the need for integrated, feedback-driven management strategies.

Evaluation of Current Mitigation Strategies

HMC in Nepal's midhill regions is currently addressed through a heterogeneous set of mitigation strategies that primarily aim to reduce immediate crop losses rather than resolve the underlying ecological and socioeconomic drivers of conflict. Although these approaches provide short-term relief in specific contexts, they are largely reactive, labor-intensive, and insufficiently integrated within a broader landscape-scale management framework.

At the local level, mitigation relies predominantly on direct human deterrence strategies, including guarding, noise-based scaring, visual deterrents, and active chasing [31,67]. Guarding remains the most widely used method, particularly during peak crop vulnerability periods, but its effectiveness is increasingly constrained by labor shortages and rural out-migration. Additional measures such as dogs, firecrackers, scare devices, and projectile-based deterrence are commonly employed [68,69], yet their impact is generally short-lived due to rapid behavioral habituation in monkeys [70].

More intensive interventions, including sterilization and translocation, represent attempts to manage population size or redistribute conflict individuals. Fertility control approaches have been increasingly explored as nonlethal population management tools; however, their effectiveness in free-ranging monkey populations remains variable and context dependent, with significant limitations related to delivery methods, long-term efficacy, and economic feasibility [71]. In addition, sterilization may produce complex and not fully predictable behavioral and social effects within primate groups, further complicating its application at scale [72]. Translocation, although frequently proposed as a mitigation strategy, is widely recognized in the conservation literature as a high-risk and often unreliable intervention. Its success depends on highly specific ecological and social conditions, and outcomes are rarely generalizable across contexts [73]. Empirical studies indicate that while translocation can succeed under controlled conditions, it requires intensive monitoring and favorable habitat characteristics that are seldom met in human-dominated landscapes [74]. Collectively, existing mitigation strategies reflect a broader pattern described in the literature as symptom-focused wildlife conflict management, where interventions target immediate conflict outcomes rather than the ecological processes that generate them [75]. This highlights a persistent gap between behavioral ecology theory and applied management practice.

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IEA: A Framework for HMC Management

We propose the IEA as a multilevel mitigation strategy integrating ecological, behavioral, socioeconomic, and governance dimensions within a coupled socioecological system (Fig. 3). It is important to position the IEA accurately: it does not constitute a genuinely novel theoretical framework, but rather a context-specific operationalization of established principles drawn from adaptive management, ecosystem-based governance, and socio-ecological systems theory. The added value of the present formulation lies not in conceptual originality per se but in the systematic application of these principles to the specific problem space of HMC in Nepal's midhill community forestry landscapes, where such integration has not previously been attempted in an explicit and structured form. While ecosystem-based frameworks are increasingly applied in conservation science, they often remain conceptually broad and insufficiently operationalized. The present formulation addresses this gap by linking system-level theory with actionable interventions tailored to Nepal's midhill socioecological context. The IEA is defined as a multilevel conflict mitigation framework targeting the ecological root causes of HMC through coordinated interventions across habitat structure, resource distribution, primate behavior, and governance systems, structured around 6 interdependent operational domains: (a) functional forest restoration and species-specific habitat enrichment using native fruit- and leaf-bearing taxa (e.g., *Ficus* spp. and *Artocarpus* spp.) while avoiding concentration of attractant species near agricultural edges; (b) spatially differentiated buffer zones with graded vegetation composition to reduce abrupt forest–agriculture transitions and limit crop-raiding corridors, adapted to local topography, slope, and land-use intensity; (c) reduction of anthropogenic food subsidies through waste management; regulation of direct feeding in religious, touristic, and peri-urban contexts; and crop selection strategies reducing edge palatability; (d) behavioral and population monitoring with adaptive feedback systems tracking movement patterns, habitat use, and population trends, including ethically governed fertility control when necessary as a conditional regulatory tool; (e) integration of wildlife nutritional ecology into community forestry planning, shifting from timber- or carbon-centered approaches toward multifunctional forest systems; and (f) participatory governance and socioeconomic alignment through co-management, compensation systems, participatory land-use planning, and alternative livelihood strategies such as community-based ecotourism.

Unlike conventional mitigation strategies focused on immediate conflict suppression, the IEA targets structural ecological conditions generating conflict by reshaping landscape-scale trade-offs between natural and anthropogenic resources that drive primate foraging decisions. Its contribution is 3-fold: first, it incorporates primate-specific behavioral mechanisms, including cognitive flexibility, social learning, and rapid adaptation in monkey troops; second, it integrates forest trophic quality as a key driver of conflict dynamics; and third, it unifies population regulation and habitat management within an adaptive feedback framework enabling ethically calibrated, data-driven interventions rather than predefined responses. Collectively, these elements position the IEA as an operational and context-specific framework for addressing human–primate conflict in South Asian community forestry landscapes. To translate this from

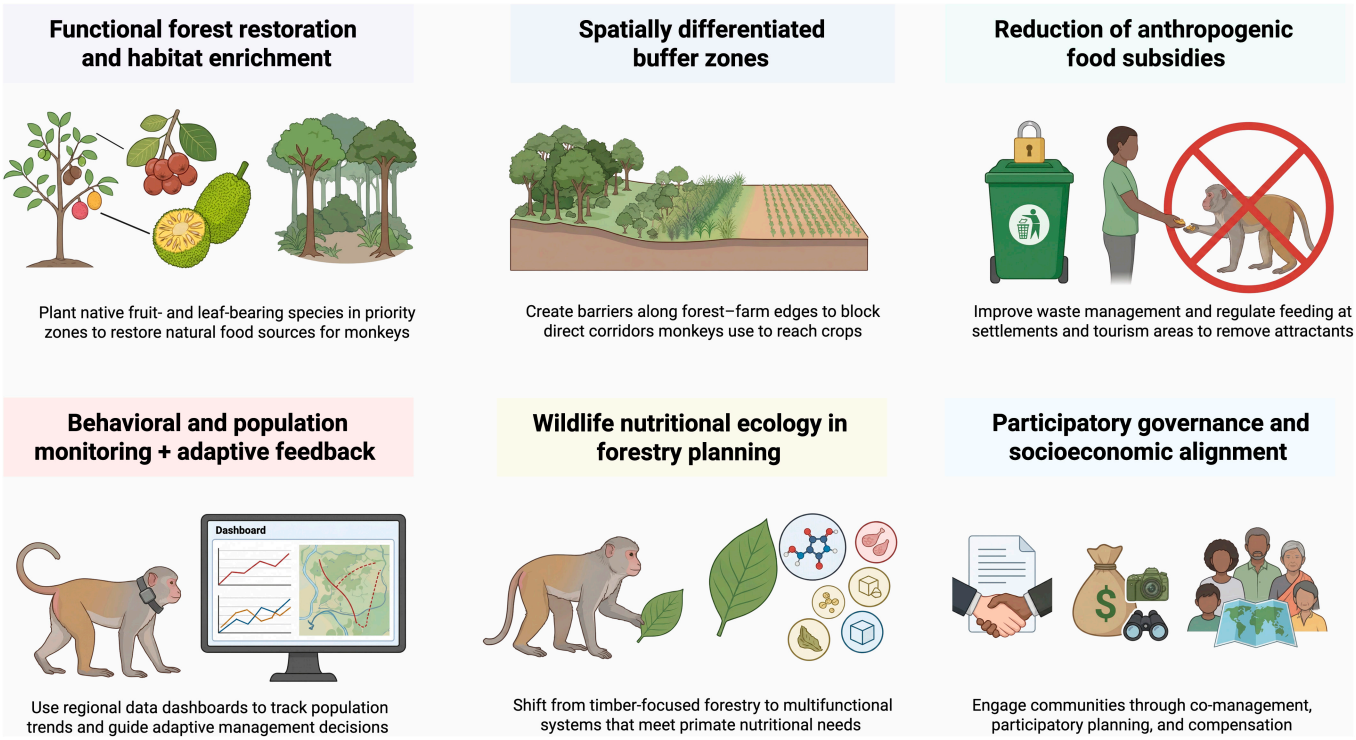


Fig. 3. Operational domains of the integrated ecosystem approach (IEA) for human–monkey conflict mitigation in Nepal's midhill socioecological system. The framework integrates 6 interdependent strategies: functional forest restoration and habitat enrichment, spatially differentiated buffer zones, reduction of anthropogenic food subsidies, behavioral and population monitoring with adaptive feedback, integration of wildlife nutritional ecology into forestry planning, and participatory governance with socioeconomic alignment. These components collectively target the ecological and behavioral drivers of crop-raiding behavior while strengthening institutional and community-based management capacity. The figure was prepared using the software BioRender.

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principle to practice, each of the 6 domains requires specific operational content. The thresholds proposed below represent initial operational benchmarks derived from analogous wildlife management contexts and the existing literature on primate ecology and community forestry governance; they are not empirically validated for Nepal's midhill systems specifically and should be calibrated through site-specific baseline surveys prior to full implementation.

For domain 1 (functional forest restoration), operational indicators include fruiting-tree density (target: a regionally calibrated minimum density, with indicative targets of 10 to 20 trees per hectare depending on forest type and species composition, consistent with dietary requirements documented for rhesus macaques in South Asian forest systems), seasonal food availability index (at least one fruiting species available in each calendar month), and distance of high-palatability planting from agricultural edges (minimum 200-m buffer). The 200-m buffer distance is consistent with crop-raiding literature showing that incursion frequency declines rapidly beyond 150 to 200 m from the forest edge [59,60]. Decision criterion: restoration plans should be revised if monthly botanical surveys detect a seasonal gap exceeding a predefined threshold (e.g., >6 weeks without ripe fruit in forest interior plots), drawing on the fallback food literature documenting seasonal nutritional stress periods in primate systems [57,58].

For domain 2 (buffer zones), operational indicators include edge permeability score derived from Global Positioning System (GPS)-collar tracking data (target: reduction of crop-raiding incursion frequency by a minimum meaningful effect size, with 30% within 2 years proposed as consistent with effect sizes reported in comparable wildlife management interventions), buffer width (minimum 50 m of mixed native vegetation at forest–agriculture interfaces, applicable on slopes <30° for practical manageability, following agroforestry buffer guidelines), and proportion of high-palatability crops within 100 m of forest edge (target: <20% of edge-adjacent agricultural area, derived indirectly from studies linking crop type to raiding frequency [32]). Decision criterion: buffer zone design should be modified if troop incursion rates remain above baseline after 18 months.

For domain 3 (reduction of anthropogenic subsidies), operational indicators include waste management compliance rate at the settlement level (target: >90% of households using covered bins or compost enclosures near forest edges, consistent with minimum standards for anthropogenic attractant reduction in HWC programs), number of unauthorized feeding events per month at monitored religious and tourist sites (target: zero, enforced through local ordinance), and crop palatability index (prioritizing maize variety substitution with low-palatability cultivars in edge-adjacent plots). Decision criterion: if village-level conflict incident reports do not decline by a meaningful margin (e.g., ≥25%) within 12 months of waste management implementation, investigate supplementary attractant sources, drawing on studies documenting food subsidy reduction effects on human–primate conflict.

For domain 4 (behavioral and population monitoring), operational indicators include troop size and composition surveyed biannually, crop-raiding incident frequency logged monthly at the village level through standardized community reporting forms, and population growth rate estimated annually. Decision criterion: if the population growth rate substantially exceeds the estimated natural carrying capacity of the surrounding forest habitat, as determined by site-specific baseline surveys, trigger review of fertility control options under ethical governance protocols. Monitoring should use a combination of line-transect surveys, GPS-collar tracking on representative individuals, and community-reported conflict logs validated against field checks.

For domain 5 (integration of nutritional ecology into forestry planning), operational indicators include proportion of community forest operational plans that include species-specific dietary requirements (target: 100% of revised plans within 5 years) and trophic functionality score—a composite index measuring fruiting-tree species richness, seasonal coverage, and food accessibility for target species. Decision criterion: community forestry operational plans should be rated inadequate and flagged for revision if the trophic functionality score falls below a regionally calibrated threshold determined during baseline surveys.

For domain 6 (participatory governance and socioeconomic alignment), operational indicators include proportion of households enrolled in compensation schemes (target: ≥80% coverage in high-conflict wards, following community-based conservation guidelines), time from conflict event to compensation payment (target: ≤30 d, consistent with best practice from compensation programs in analogous contexts), co-management committee meeting frequency (minimum quarterly), and alternative livelihood uptake rate (target: ≥20% of households in pilot zones within 3 years). Decision criterion: if community satisfaction scores (assessed by annual participatory survey) fall below a positive threshold (e.g., 60% positive), governance structures should be reviewed for equity and procedural fairness, drawing on International Union for Conservation of Nature guidelines for community-based conservation and documented experiences from Nepal's community forestry user groups [27].

Within the IEA, this implies that habitat restoration must move beyond tree cover expansion toward functional trophic restoration, explicitly incorporating species-specific dietary preferences, seasonal resource continuity, and spatial configuration. At the same time, the effectiveness of such interventions is inherently conditional and must be evaluated in conjunction with behavioral and anthropogenic factors, rather than assumed as a standalone solution.

In contrast, the IEA proposed in this study offers a structured framework for operationalizing a system-level understanding of HMC. Rather than focusing solely on preventing primates from accessing agricultural crops, the approach emphasizes the restoration of ecological functionality within forest habitats, reduction of anthropogenic attractants, and strengthening of institutional governance mechanisms. The central premise of the IEA is that sustainable conflict mitigation requires addressing the ecological incentives that drive crop-raiding behavior while simultaneously improving management capacity at the landscape scale.

To translate this conceptual framework into practical management actions, the IEA can be operationalized through a set of integrated interventions. First, community forestry systems should undergo functional ecological redesign. Existing operational plans should be revised to incorporate spatially explicit planting schemes that prioritize native fruiting and folivorous species aligned with documented dietary preferences of local primate populations. Forest restoration should differentiate between interior enrichment zones and edge-buffer areas, ensuring that highly attractive food resources are located away from agricultural boundaries. Second, ecological buffer zones should be established at forest–agriculture interfaces. These

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buffers should consist of mixed native vegetation designed to reduce edge permeability and disrupt direct movement corridors between forest habitats and cultivated fields. Buffer design must be context specific, taking into account topography, crop type, and known primate movement routes. Third, anthropogenic food attractants must be systematically reduced. Local governance institutions should strengthen waste management systems, regulate intentional feeding practices, and discourage informal provisioning around settlements, religious sites, and tourism areas. Unmanaged organic waste and tourism-driven feeding represent persistent artificial subsidies that reinforce crop-raiding behavior. Fourth, adaptive monitoring systems should be established to track primate populations and conflict dynamics. A coordinated regional or national framework should collect data on population trends, troop movement patterns, and spatial distribution of conflict events. These data would enable evidence-based adaptive management and support ethically regulated interventions when the ecological carrying capacity is exceeded. Fifth, policy alignment across forestry, agriculture, and conservation sectors is essential. Land-use planning and reforestation initiatives should integrate biodiversity functionality alongside traditional objectives such as timber production and carbon sequestration. Incorporating wildlife food-web dynamics into community forestry guidelines would ensure that reforestation contributes to both forest cover expansion and ecosystem functionality. Finally, community-based co-management and incentive structures are critical for long-term success. Local communities must remain central actors in conflict mitigation through participatory governance, strengthened compensation mechanisms, and alternative livelihood opportunities. Ecotourism and ecosystem-service-based incentives may further align conservation and economic objectives.

It is important to recognize that implementation of the IEA should be gradual and context sensitive. In the short term, habitat enrichment interventions may initially increase local primate carrying capacity before stabilizing through density-dependent processes and adaptive management. Continuous monitoring and long-term institutional commitment are therefore essential.

Although developed within Nepal's midhill socioecological context, the IEA has broader conceptual applicability to other HWC systems. However, transferability requires careful ecological and institutional adaptation. For instance, conflict dynamics involving Sri Lankan toque monkeys (*M. sinica*), which rely heavily on tropical fruit resources, differ substantially from grain-dominated systems in Nepal. Similarly, governance structures such as Nepal's community forestry model may not exist elsewhere, requiring analogous institutional arrangements before implementation.

Discussion

The structured conceptual review of literature indicates that HMC in Nepal cannot be interpreted as a simple consequence of opportunistic wildlife behavior, but rather represents the emergent outcome of a complex socioecological system. Within this system, environmental changes, resource availability, behavioral adaptations by primates, and human responses influence one another through feedback mechanisms that tend to stabilize and, in some cases, amplify the conflict over time.

A key factor concerns the role of habitat quality. Although the expansion of forest cover in Nepal represents an important success of community forestry policies, this expansion has not been accompanied by an equivalent recovery of ecological functionality. In particular, the reduced availability of adequate food resources for frugivorous and omnivorous species appears to contribute to a shift in foraging strategies toward anthropogenic resources, which are more predictable and energy dense. This transition from a system based on natural resources to a dual system, in which agricultural resources compete with or replace forest resources, represents a key mechanism in the intensification of conflict. At the same time, the high behavioral plasticity of monkeys, particularly rhesus monkeys, plays a decisive role. The capacity for social learning and the intergenerational transmission of crop-raiding strategies contribute to the persistence of the conflict even in the presence of mitigation measures. This aspect highlights how purely deterrent approaches are inherently limited, as they do not address the behavioral mechanisms underpinning the phenomenon.

From a management perspective, an analysis of currently adopted strategies confirms the prevalence of reactive interventions, focused on the immediate reduction of damage rather than on modifying the structural conditions that generate it. Deterrent measures, while widespread, are often ineffective in the medium to long term due to habituation; more intensive interventions, such as sterilization and relocation, have limitations related to costs, scalability, and ethical implications. Similarly, compensation systems, while essential for maintaining social tolerance, do not address the ecological drivers of the conflict.

In this context, the IEA proposed in this study offers a substantial contribution, as it allows for the integration of fragmented evidence within a coherent and operational conceptual framework. The value of the IEA lies in its ability to directly link ecological mechanisms (habitat quality and resource distribution), behavioral mechanisms (plasticity and social learning), and institutional mechanisms (governance and land management), overcoming the traditional separation between ecology and conflict management. It is worth noting, however, that the IEA's 6 domains are each individually well established in the conservation and wildlife management literature; what is less common is their simultaneous operationalization within a single management architecture tailored to the community forestry context. Researchers should therefore be transparent when applying this framework that its strength lies in integration and contextual specificity, not in the novelty of its constituent elements.

A central aspect emerging from the review is that the effectiveness of mitigation strategies depends on their ability to act simultaneously across multiple levels of the system. Isolated interventions, even if technically effective, tend to be neutralized by feedback from the system itself. In contrast, integrated approaches that combine habitat management, reduction of anthropogenic resources, and adaptation of land-use practices have the potential to more durably alter the ecological and behavioral incentives driving crop raiding.

Finally, it is important to emphasize that the implementation of integrated approaches introduces new complexities. In particular, habitat enrichment interventions could, in the short term, increase the local carrying capacity and influence population dynamics, requiring continuous monitoring and adaptation systems. This highlights the need to view conflict management as a dynamic and iterative process, rather than as a set of static solutions.

A critical question that the present study does not fully resolve is whether the IEA offers substantive advantages over

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existing governance frameworks, particularly adaptive management and EBM. Adaptive management, as formalized by Holling [76] and subsequently elaborated in conservation contexts, already prescribes iterative cycles of planning, implementation, monitoring, and adjustment in response to ecological feedback, precisely the logic that underpins the IEA's monitoring domain. Similarly, EBM frameworks have long emphasized the integration of ecological, social, and institutional dimensions in the governance of natural resources. The IEA's genuine contribution relative to these antecedents lies not in the underlying logic, which is broadly shared, but in the explicit incorporation of behavioral ecology and trophic functionality as design parameters for habitat restoration and in the application of these principles specifically to the human–primate conflict context in South Asian community forestry systems. This distinction should be made explicit in future applications of the framework, and researchers should be cautious not to overstate the novelty of the IEA relative to the substantial body of integrated management literature already available.

The institutional feasibility of the IEA must also be assessed honestly. Nepal's community forestry system is widely recognized as one of the most developed decentralized natural resource governance frameworks in Asia, and this institutional foundation is a genuine asset for IEA implementation. However, several structural barriers remain. First, the operational plans of community forest user groups are typically prepared by underresourced district forest offices with limited technical capacity in wildlife nutrition or behavioral ecology; revising these plans to incorporate trophic functionality criteria would require substantial investment in technical training and extension support. Second, intersectoral coordination between the Department of Forests and Soil Conservation, the Department of National Parks and Wildlife Conservation, and the Ministry of Agriculture and Livestock Development remains weak in practice, meaning that policy alignment across the IEA's domains would require explicit institutional mandates rather than voluntary coordination. Third, compensation mechanisms for crop losses in Nepal's midhill regions remain inconsistent in coverage and often inadequate in timeliness and payout levels, creating persistent grievances that can undermine community engagement with any management framework. These institutional constraints do not invalidate the IEA as a conceptual framework, but they underscore that successful implementation is contingent on prior or parallel institutional reform that the framework itself cannot deliver.

The political economy of HMC management in Nepal presents additional challenges that any realistic appraisal of the IEA must acknowledge. Rhesus monkeys hold significant religious and cultural status in Nepali society, and their protection is embedded in national wildlife legislation. This status complicates the application of population regulatory tools such as fertility control, even when justified by monitoring data, and can generate public opposition to management interventions perceived as targeting a protected species. At the same time, the rural households most severely affected by crop raiding are typically among the economically marginalized, with limited political voice relative to urban conservation constituencies. This asymmetry in political representation can result in management priorities that are ecologically suboptimal for conflict reduction. Furthermore, community-based ecotourism, proposed as an alternative livelihood strategy under domain 6, remains viable only in areas with sufficient wildlife viewing potential and access infrastructure; in the majority of Nepal's midhill districts, where HMC is most intense, these conditions are not currently met. The IEA should therefore be implemented with a clear-eyed recognition that the political and economic conditions enabling its full operationalization may take years or decades to materialize and that interim strategies—including improved compensation mechanisms, community capacity building, and targeted deterrence co-designed with affected communities—remain necessary and legitimate components of a pragmatic management portfolio.

Conclusion and Recommendations

HMC in the hilly regions of Nepal results from the interaction of ecological and socioeconomic factors, including habitat degradation, forest fragmentation, fluctuations in the availability of natural resources, and increasing access to anthropogenic food sources. The strategies currently in place are largely reactive and inadequate for addressing the structural causes of the problem. In light of this evidence, a shift in perspective is needed, moving the focus from damage management to system management. The IEA provides a useful framework in this regard, as it allows for interventions targeting the ecological and behavioral factors that drive the conflict.

In operational terms, several priorities emerge clearly. Forest planning should incorporate ecological functionality criteria, promoting the availability of adequate food resources within natural habitats. The interfaces between forests and agricultural areas require targeted management through solutions that reduce direct access to crops. At the same time, it is essential to limit anthropogenic food sources by improving waste management and regulating intentional feeding practices.

Another key element is the strengthening of monitoring systems, which are necessary to support evidence-based adaptive strategies. The systematic collection of data on populations, movements, and conflict dynamics can significantly improve the capacity for intervention. At the same time, it is crucial to promote greater coordination between forestry, agricultural, and conservation policies. Involvement of local communities remains an indispensable condition. Participatory mechanisms, economic incentives, and alternative livelihood strategies are essential to ensure the long-term sustainability of interventions.

Overall, lasting conflict reduction requires integrated, adaptive, and context-specific approaches capable of addressing the ecological and social dynamics that generate it. Although the proposed framework was developed in the context of Nepal, the underlying principles can be applied to other HWC systems, provided that they are adequately adapted to local specificities.

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Supplementary Materials

Table S1

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Addressing Human–Monkey Conflict in Nepal: An Evidence-Based Argument for an Integrated Ecosystem Approach

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Human–monkey conflict (HMC) represents an increasing socioecological challenge in Nepal's midhill regions, where agricultural systems and community-managed forests coexist within highly fragmented landscapes. This study reinterprets HMC as an emergent property of a coupled socioecological system shaped by the interaction of habitat degradation, altered resource availability, primate behavioral adaptation, and human land-use dynamics. Drawing on a structured narrative review and concept-mapping approach, we synthesize heterogeneous ecological, behavioral, and socioeconomic evidence into an integrated analytical framework. Findings indicate that current mitigation strategies, including deterrence, physical barriers, and population control interventions (currently at the pre-implementation phase) are largely reactive, labor-intensive, and insufficient to address the structural drivers of conflict. In particular, forest regeneration processes, while increasing overall tree cover, often fail to restore trophic functionality, contributing to a dual-resource system in which anthropogenic food sources remain highly attractive to primates. This dynamics is reinforced by behavioral plasticity, habituation, and social learning in monkey populations, leading to persistent and self-reinforcing conflict patterns. To address these limitations, the study proposes an integrated ecosystem approach (IEA) as a conceptual and operational framework for HMC mitigation. The IEA integrates ecological restoration, behavioral ecology, and governance mechanisms through coordinated interventions targeting habitat functionality, spatial configuration of resources, reduction of anthropogenic food subsidies, adaptive monitoring, and community-based management. By shifting the focus from symptom-oriented mitigation to the modification of the underlying ecological incentives, the IEA aims to provide a more sustainable and scalable pathway for conflict reduction. Although developed within the context of Nepal, the framework has broader applicability to other human–wildlife conflict systems, provided that interventions are adapted to local ecological, agricultural, and institutional conditions. The study contributes to advancing both the theoretical understanding and practical management of HMC by bridging the gap between socioecological systems theory and applied conservation strategies.
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