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Towards Policy Strategies for Managing Vertebrate Pests in Arid and Semi-arid Regions of India

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Abstract: Vertebrate pest conflict has become a significant production constraint in India's arid and semi-arid agro-ecosystems, where small and rainfed farms are highly vulnerable to crop depredation and resource competition with wildlife. Species such as wild boar, nilgai, Indian peafowl, and rodents frequently cause severe yield losses ranging from 15% to 50% in drought-prone farming areas. Habitat fragmentation, expansion of irrigated pockets in drylands, and climate-driven scarcity of forage and water have intensified wildlife movement into cultivated fields, particularly in states like Rajasthan, Gujarat, and dry zones of Karnataka and Madhya Pradesh. Despite increasing damage reports, mitigation remains limited due to procedural delays, fragmented responsibilities between forest and agriculture institutions, and inadequate access to validated non-lethal deterrents. This review synthesizes emerging ecological trends, regional vulnerability patterns, and socioeconomic impacts of vertebrate pests within arid and semi-arid regions. The paper outlines a farmer-supportive Vertebrate Pest Management Policy Framework that emphasizes rapid-response legal mechanisms, insurance-linked compensation, commercialization of eco-friendly repellents and bio-fencing technologies, and community-managed deterrent systems. Enhancing institutional coordination, field-level adoption of proven technologies, and dryland-specific planning approaches is crucial for safeguarding livelihoods and strengthening climate-resilient agriculture in India's arid landscapes.

Key words: Vertebrate pest management, human–wildlife conflict, policy framework, technological interventions, governance challenges

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India's agricultural landscape, long celebrated for its biodiversity and productivity, is now facing an escalating crisis: the unchecked rise of vertebrate pest infestations. Unlike invertebrate pests such as insects and nematodes, which have been extensively researched and routinely managed through integrated pest management (IPM) frameworks, vertebrate

pests present a distinct set of ecological, legal, and socio-political challenges (Anwar *et al*., 2015). These animals, which include rodents, monkeys, nilgai, wild boars, peafowls, and elephants, inflict widespread crop losses in various crops through direct consumption, trampling, and disturbance of agricultural fields. The impacts are not just economic but also deeply emotional and psychological for farmers who often invest their entire seasonal livelihood in these vulnerable crops. The intensification of vertebrate pest issues is not a random phenomenon but the outcome of a rapidly transforming rural-forest interface (Sathyakumar *et al*., 2016). Accelerated urban expansion, infrastructure development, mining, and deforestation have fragmented natural habitats and obliterated traditional wildlife corridors. Consequently, wild herbivores once contained within forests are now frequently entering farmland in search of food. This breakdown of ecological boundaries has transformed sporadic crop raids into persistent and geographically widespread conflicts. Moreover, climate change is compounding the issue, altering migration patterns and food availability in forest ecosystems. Erratic rainfall, prolonged droughts, and shifts in vegetation patterns are pushing wildlife to adapt in ways that bring them into closer and more frequent contact with human settlements. The problem is further magnified in India due to its extraordinary agro-ecological diversity and high human population density. Agricultural fields often lie adjacent to protected forests, making them vulnerable frontline zones of human-wildlife conflict. For small and marginal farmers who comprise more than 80% of India's farming population, even partial damage to a standing crop can result in financial ruin, food insecurity, and long-term indebtedness. Beyond crop and income loss, vertebrate pest conflicts impose chronic psychological stress and social disruption. Farmers endure sleepless nights guarding fields under unsafe conditions and often face debt, delayed compensation, and eroding trust in institutions (Ogra, 2008; Barua *et al*., 2013). These pressures sometimes push affected communities toward risky or illegal copying measures, undermining both livelihoods and conservation goals.

What complicates the issue further is the legal and institutional paradox inherent in India's wildlife governance system. Many of the animals responsible for damaging crops, such as peafowls and monkeys, are protected under the Wildlife Protection Act, 1972, a landmark conservation law enacted to safeguard India's threatened fauna. This legal shield means that farmers, even when severely impacted, cannot legally harm or repel these animals without prior permission from forest authorities, as an approval process often riddled with delays and inconsistencies (MoEFCC, 2024). This creates a policy deadlock: the same animals that destroy livelihoods are protected as national assets, leading to growing resentment among farming communities. This paradox not only fuels frustration and illegal retaliation but also challenges the legitimacy of conservation efforts in rural India. Therefore, addressing vertebrate pests in Indian agriculture involves not only biological management but also navigating legal and administrative complexities. These themes are explored in depth later in this paper. It calls for a balanced and context-specific policy response, one that recognizes the need to protect wildlife while also safeguarding the economic and psychological well-being of India's farmers.

Human-wildlife conflict involving vertebrate pests continues to inflict substantial economic damage across Indian agriculture. Recent studies estimate yield losses in conflict-prone regions range from 15% to 50%, with particularly severe impacts on crops like rice, sugarcane, maize, and fruits (MoEFCC, 2023). However, these figures primarily reflect direct crop loss. The true socio-economic toll is much higher when hidden and indirect costs such as mental stress, sleep deprivation, school dropouts, and household labour diverted to guarding fields are factored in. Such burdens are rarely acknowledged in formal compensation schemes, leading to substantial underestimation of actual losses (Barua *et al*., 2013).

Case studies illustrate the scale of the issue. In Kangra district of Himachal Pradesh, economic losses from animal conflict average Rs. 25,358 per farm annually. Production losses account for ~53.63% of this figure, while increased cultivation costs especially fencing and watch duties make up ~46.37% (Thakur *et al*., 2022). State-level losses are estimated at Rs. 300–Rs. 4500 m yr^{-1}, escalating to Rs. 1,5000 m yr^{-1} when including preventive costs. Key

Table 1. Vertebrate herbivores in agricultural landscape

Pest species	Scientific name	Affected crops	Regions affected	Notable impacts	References
Indian Field Mouse	*Mus booduga*	Rice, wheat, and stored grains	Widespread across agricultural landscapes in India	Crop damage, disease transmission	Singh and Singla (2020)
House Rat	*Rattus rattus*	Rice, wheat, and stored grains	Nationwide in agricultural and peri-urban zones	Crop damage, disease transmission	Garg *et al*. (2017)
Bandicoot Rat	*Bandicota bengalensis*	Rice, wheat, and stored grains	Throughout major rice-wheat systems of India	Crop damage, disease transmission	Singh and Singla (2020).
Depredatory bird	*Psittacula spp., Corvus spp., Columba livia, Pavo cristatus.*	Sunflower, sorghum, maize, various crops, grains, vegetables	Widely distributed in agro-ecosystems across India	Pre-harvest losses, pre- and post-harvest losses, seedling destruction, yield reduction	Thakur *et al*. (2022)
Wild boar	*Sus scrofa*	Maize, groundnut, and vegetables	Human–wildlife interface zones, plains and hill agriculture across India	Crop destruction, human-wildlife conflict	Rai (2023)
Nilgai	*Boselaphus tragocamelus*	Wheat, sugarcane, maize, pulses, and poplar	Northern and Central India (U.P., Haryana, Rajasthan, M.P., Bihar)	Crop destruction, human-wildlife conflict	Chandel *et al*. (2025)
Rhesus Macaque	*Macaca mulatta*	Fruits, vegetables, and cereals	Forest-fringe & peri-urban zones of North and Central India; expanding range	Crop damage, socio-economic stress	Thakur et al. (2022)
Porcupine	Hystrix indica	Roots, tubers, vegetables, cereals	Agricultural–forest borders in India	Root crop damage, burrowing issues, conflict with farmers	Chauhan (1990)
Asian Elephant	*Elephas maximus*	Paddy, banana, and coconut	Forest-adjacent agricultural belts (Western Ghats, NE India)	Large-scale crop destruction, human fatalities	Rathi *et al*. (2020)

impacted crops include wheat (Rs. 8,237 farm^{-1}), paddy (Rs. 3,363 farm^{-1}), and maize (Rs. 3,100 farm^{-1}), with monkeys and wild boars being the most destructive species. In Thrissur district, Kerala, wild elephants, boars, and monkeys have caused extensive crop raiding, often forcing farmers to abandon fields or switch to non-palatable crops. Though specific economic figures are unavailable, farmers report chronic income loss, land-use changes, and mounting expenses on mitigation (Govind and Jayson, 2018).

Nationally, the Indian Ecological Society reports crop losses between 10 to 30% in conflict zones, alongside secondary burdens such as labour loss, healthcare, forced migration, and long-term livelihood disruptions. Wild pig depredation alone has led to 5 to 36% yield loss in several states including Tamil Nadu and Odisha (WII Report, 2022). Karnataka and Maharashtra continue to see rising fatalities from leopard and tiger attacks, with 22 deaths reported in Chandrapur district alone (Times of India, 2024). Based on Kangra's per-farm data, extrapolated to 10 similarly impacted regions, India's national-level annual losses from vertebrate pest conflicts are conservatively estimated at Rs. 15,0000 m excluding livestock loss, forest department expenditure, and injury/death compensations. Recent aggregated analyses now place this figure at Rs. 22,0000 to Rs. 26,0000 m yr^{-1}, or approximately 0.6 to 0.8% of India's agricultural GDP. This study aims to analyse the rising vertebrate pest conflicts in India, focusing on their causes, economic

consequences, and the governance barriers that constrain effective management.

*Economic losses and agricultural damage***:** Variety of vertebrate species including wild boar, nilgai, monkeys, peafowl, and rodents frequently share space with agricultural landscapes leading to loss of standing crops and damage to stored produce and infrastructure, affecting local livelihoods.

Rodents: Species such as the Indian field mouse (*Mus booduga*), house rat (*Rattus rattus*), and bandicoot rat (*Bandicota bengalensis*) are known for extensive damage to rice, wheat, and stored grains (Chaudhary, 2024). Rodents are highly prolific breeders, which makes their populations hard to control once established. In many agro-ecosystems, rodents contribute to around 15% of total crop and stored-grain loss. In addition to crop damage, they are vectors of several diseases like leptospirosis, plague, hymenolepiasis, capillariasis etc. (Brar *et al*., 2021). Porcupines (*Hystrix indica*) also feed on commercial crops and grasses, leading to significant agricultural losses. They are particularly destructive to crops like maize and various vegetables (Nair and Jayson, 2020).

Wild boar (Sus scrofa): A widespread pest in paddy and vegetable fields, wild boars are known for uprooting crops, feeding on tubers, and trampling young plants. Their populations have surged in fragmented forest areas where natural predators are scarce (Singh and Kumar, 2018). In affected agricultural regions, wild boars can cause 25-35% damage to major crops, and are considered the dominant vertebrate pest in many zones.

Nilgai (*Boselaphus tragocamelus*): Often termed as the 'Blue Bull,' Nilgai is a significant pest in northern and central India. Its feeding habits include grazing on wheat, sugarcane, maize, pulses, and poplar, causing substantial economic losses (**Singla** *et al*., 2025). Crop loss due to nilgai is generally reported in the 10 to 30% range in depredation-affected areas.

Monkey (*Macaca* spp.): Species like the Rhesus macaque (*Macaca mulatta*) and Bonnet macaque (*Macaca radiata*) frequently raid fruit orchards and vegetable farms, leading to massive crop losses. Their increasing adaptation to urban and semi-urban areas has intensified conflict with farmers (Time of India, 2025). Surveys indicate 10-30% yield loss in orchards and vegetable fields affected by macaque raids.

Peafowl (*Pavo cristatus*): India's national bird, though protected, is a common pest in grain crops and vegetable gardens. Their feeding and scratching behaviour can destroy seedlings and affect yields (Govind and Jayson, 2018).

These species, while ecologically vital, inflict direct yield losses, infrastructure damage, and elevate production costs for farmers, most of whom lack the financial capacity to absorb such repeated shocks.

Regional Variability and Data-Driven Loss Estimates

While the issue of vertebrate herbivore conflict is national in scale, its manifestations vary significantly across regions, shaped by the local ecology, cropping patterns, forest proximity, and species composition. This diversity demands location-specific responses rather than uniform policy measures. The conflict is no longer a series of isolated incidents, it is a systemic, evolving crisis, deeply embedded in regional contexts.

Further, primates such as the Bonnet macaque (*Macaca radiata)* and Nilgiri langur (*Semnopithecus johnii*) exhibit high levels of adaptability and opportunism, targeting both subsistence crops and commercial fruit plantations in peri-forest and semi-urban landscapes. Wild boars (*Sus scrofa*), for instance, are known to uproot tubers, damage paddy fields, and trample standing crops, often in large groups. Indian peafowl (*Pavo cristatus*), although culturally revered, have become increasingly problematic in some regions, damaging tender shoots, grains, and vegetable crops. Rodents like porcupine, rats and even certain bird species further compound the situation, especially in areas with fragmented forest-agriculture interfaces. The impact is disproportionately borne by tribal and marginal farmers, who typically rely on small landholdings without insurance coverage, irrigation facilities, or access to alternative livelihoods. Their dependence on seasonal crops and limited ability to recover from repeated losses intensifies food insecurity and economic hardship. Moreover, bureaucratic hurdles such as complex paperwork, delayed verification, and lack of field-level assistance often prevent affected farmers from successfully

Table 2. State-wise crop loss estimates due to vertebrate herbivores

State	Pest species	Affected crops	Estimated loss	Reference
Madhya Pradesh	Wild boars, Nilgai	Maize, Groundnut	>15-20% during peak season	Chandel *et al.* (2024)
Kerala	Monkeys, Elephants, Wild boar Porcupine	Banana, Areca nut, Paddy	30-40% in tribal areas	Kerala Forest Dept. Annual Report (2023); Shaharban and Hanna (2024)
Rajasthan	Nilgai	Bajra, Wheat, Mustard	10-15% annually	Krishi Jagran (2022)
Assam	Elephants, Rodents	Paddy	20-50% yield loss	Dutta, N. (2021). Applied Ecology and Environmental Sciences; Media reports (2022–2024))
Himachal Pradesh	Rhesus Monkeys	Apples, Vegetables	Rs. 1,500-2,000 crore/ year	Thakur *et al*., 2022
Odisha	Elephants, Deer	Paddy, Oilseeds, Pulses	>Rs. 40 crore/year in compensation	OUAT (2021), Odisha Forest and Revenue Dept.

reporting wildlife-related crop damage. As a result, many cases go unreported, leading to widespread exclusion from state-supported compensation and relief schemes.

In the hill state of Himachal Pradesh, monkeys (especially Rhesus macaques) have emerged as a dominant vertebrate pest, severely disrupting horticultural and vegetable-based economies. The apple industry, a cornerstone of Himachal's rural economy, faces annual damages exceeding INR1,500 to 2,000 crore, according to state wildlife and agriculture reports. Monkeys not only consume fruits and damage orchards, but also exhibit behaviours like stripping bark, uprooting saplings, and intimidating farm labourers, making entire tracts of land inaccessible or economically unviable. The government has attempted sterilization drives, with mixed results due to low coverage, religious opposition, and high adaptability of the species. Farmers have started abandoning traditional orchards in some belts, signalling a slow shift in cropping patterns due to pest pressure (Gopalan and Radhakrishna, 2022).

In Odisha, particularly in districts like Angul, Keonjhar, and Sundargarh, the human-elephant conflict has reached chronic levels, with a combination of crop raids, property damage, and human fatalities. The state reports annual compensation payouts of over INR 40 crore, primarily for paddy, pulses, and oilseed crop losses, as well as damaged houses and death-related compensation. However, these figures do not reflect the full scale of the economic and emotional trauma, as many farmers do not report losses due to bureaucratic complexity or fear of harassment, receive only partial payments, or are excluded due to documentation issues. This underestimation results in a false perception of conflict scale and inadequate policy responses. Additionally, elephant movement patterns are becoming less predictable due to habitat degradation and fragmentation, increasing the spatial footprint of conflict zones.

In arid and semi-arid states such as Rajasthan, Gujarat, and the dry zones of Karnataka and Madhya Pradesh, conflict is largely driven by ungulates like nilgai, blackbuck, wild boar, and Indian peafowl, which take advantage of vast rainfed agricultural landscapes and damaging crops such as pearl millet, groundnut, pulses, and cotton especially during periods of drought, when natural forage becomes severely limited. The problem has intensified with the expansion of irrigated agriculture around canal systems, creating resource-rich pockets that attract wildlife from adjoining scrub forests. Marginal farmers with small holdings, minimal irrigation, and no crop insurance are often forced to bear repeated damages without adequate compensation. The dual regulatory challenge conserving protected species like blackbuck while safeguarding farmer livelihoods further complicates management. In some traditional farming belts, persistent wildlife pressure has led to cropping pattern shifts and farmland abandonment, signalling a long-term threat to the sustainability of dryland agriculture.

Mitigation challenges

Despite greater policy attention and scientific recognition, effective on-ground responses to vertebrate pest conflict remain limited. The difficulty lies not just in the absence of tools or laws, but in a complex intersection of legal rigidity, bureaucratic delays, cultural sensitivities, and underfunded systems. These constraints often result in delayed interventions, eroded public trust, and retaliatory behaviors that harm both livelihoods and wildlife (Manral *et al*., 2016).

Legal and socio-cultural constraints to vertebrate pest management: Addressing wildlife-induced crop loss remains heavily constrained by administrative inertia and unreliable economic relief. The Forest Department retains exclusive authority over conflict mitigation, creating a multilayered approval system involving officers from RFO to CCF ranks, and in some cases, state-level clearance. Although designed to regulate conservation, this structure often delays even basic non-lethal interventions like solar fencing or bioacoustic deterrents (Vidhi Centre for Legal Policy, 2020). The absence of digital tracking and defined timelines leaves farmers waiting during critical crop stages when deterrence must be immediate. These procedural delays, combined with fear of accountability among field staff in tribal and remote regions, lead to inaction and frustration, increasing the likelihood of illegal, risky responses such as poisoning or mobbing of wildlife (Nair *et al*., 2020; Shillim Institute, 2023). Poor coordination between forest, agriculture, and revenue agencies further widens mistrust and reduces community cooperation with conservation efforts.

Compensation mechanisms, intended as economic safeguards, are similarly viewed as inconsistent and inequitable. Manual and subjective damage assessments often undervalue losses, particularly in scattered or short-duration crops, and delays in disbursal render compensation ineffective as timely relief. Structural gaps are evident in species recognition: protected species like peafowls are commonly excluded despite significant crop damage; rodents and depredatory birds also receive limited policy attention. These shortcomings result in crop shifts away from vulnerable varieties, heightened demand for lethal control, and retaliatory actions in several conflict-prone areas (Sampath, 2018). Without reliable access to legal mitigation support or fair compensation, sustainable coexistence becomes increasingly difficult.

Inadequate alternatives: Although India has developed a range of non-lethal, eco-friendly wildlife deterrents, their deployment at the farm level remains minimal due to economic, logistical, and institutional hurdles. ICAR's AINP-VPM has supported innovations such as BoRep and DeeRep developed by Kerala Agricultural University, proven effective and environmentally safe, yet not widely accessible due to lack of subsidy inclusion and commercialization pathways. Similar advancements like bioacoustic devices and solar fencing from Professor Jayashankar Telangana University, repellents and community-based deterrent models from PAU, chili-garlic formulations from TNAU, ultrasonic deterrents from MPKV, and elephant-focused strategies through OUAT and Assam Agricultural University which demonstrate strong national research capacity. However, weak extension linkages, absence of PPP-driven supply chains, and limited availability through KVKs restrict adoption in high-conflict regions. Without policy support for scaling production, distribution, and farmer training, these scientifically validated alternatives risk remaining underutilized despite urgent field demand.

Governance complexity: legal ambiguity, ethical constraints, and financing gaps: Managing vertebrate pest conflicts in India remains hindered by fragmented governance structures, unresolved legal questions, and cultural sensitivities surrounding protected species. While wildlife falls under MoEFCC and agriculture under the Ministry of Agriculture and State departments, coordination between these agencies is weak, especially during crisis situations such as elephant or nilgai incursions (MOEFCC, 2022). Forest departments act as the primary enforcement authorities but often lack clear protocols with agriculture and revenue departments, resulting in delays, duplicated effort, or complete inaction when rapid field decisions are required. Although some states have introduced Standard Operating Procedures, these remain inconsistent and often reactive to media or political pressure rather

than rooted in ecological assessments, leaving frontline officers reluctant to make decisions without explicit authorization for fear of legal repercussions or scrutiny (Vidhi Centre, 2020).

Layered onto this institutional ambiguity is a profound ethical and governance dilemma. Species like elephants and monkeys hold sacred cultural significance linked to widely worshipped deities such as Ganesha and Hanuman, while the peafowl is not only protected but recognized as India's national bird. Consequently, scientifically recommended measures including sterilization, relocation, or deterrents frequently face emotional opposition, legal challenges, and political hesitance, generating policy paralysis until conflicts escalate (ToI, 2024; Rangarajan *et al.,* 2006). Farmers, caught between economic vulnerability and cultural restraint, either endure repeated losses or resort to hidden and illegal actions such as electrocution and poisoning, which escalate ecological risks and fuel mistrust between communities and state institutions.

Effective conflict mitigation therefore requires stronger financial instruments that align conservation priorities with livelihood security. Current compensation programs are slow, limited in coverage, and insufficient during peak agricultural stress, pushing the need for improved mechanisms. Expanding PMFBY through optional add-on coverage for wildlife-related damage, as recommended by the National Board for Wildlife and piloted in some states, offers one viable pathway (Hindustan Times, 2021; IFMR LEAD, 2024). Decentralized relief funding through CAMPA, district mineral funds, and CSR can accelerate localized support, consistent with Parliamentary recommendations (Parliament of India, 2023). Public-private partnerships can scale tested non-lethal technologies such as repellents, solar fencing, and bioacoustic devices currently underutilized despite ICAR and state university innovations (IGBP, 2020). Incentive-based models like PES, demonstrated in Karnataka's beehive fencing initiatives, further show potential for community-led coexistence (The Guardian, 2020). Only through legally aligned responsibilities, culturally aware decision-making, and sustainable financing can vertebrate pest management transition from reactive crisis response to proactive, locally trusted governance.

International models and their adaptability to Indian conditions: Countries across Asia and Africa, facing similar challenges of human–wildlife conflict (HWC), have pioneered localized and cost-effective interventions that balance ecological and community needs. Several of these models, rooted in participatory governance and livelihood-sensitive frameworks, present viable templates for adaptation in India.

The United Nations Development Programme's BIOFIN initiative, in partnership with Nepal's Ministry of Forests and Environment, has piloted an innovative Human–Wildlife Coexistence Insurance Scheme. This model is operational in biodiversity-rich buffer zones surrounding Chitwan and Bardia National Parks. The scheme integrates compensation for wildlife-induced crop and livestock losses into mainstream agricultural insurance. Key enablers include government-backed subsidies and locally-calibrated premium contributions, thereby ensuring affordability and community ownership. According to BIOFIN (2024), this mechanism has enhanced household resilience while reinforcing positive attitudes toward conservation, creating a scalable model for other South Asian nations.

In Kenya, the Northern Rangelands Trust (NRT) has pioneered a system of Blockchain-Enabled community conservancies that integrate habitat protection with tangible economic incentives. These conservancies function under legally recognized land-use agreements and are governed by participatory boards composed of local stakeholders. Communities are actively involved in wildlife protection and in return, receive benefits from eco-tourism revenues, wildlife photography rights, and regulated hunting concessions. In recent years (2024-2025), NRT has piloted blockchain-based smart contract systems that automate and verify conservation-linked payments using satellite imagery and crowd-sourced data. These digital mechanisms ensure transparency, reduce leakage, and enhance trust in conservation finance. Studies have shown that this model improves human-wildlife tolerance and incentivizes long-term sustainable land use, particularly among pastoralist populations.

In Sri Lanka, community-centric approaches to human–elephant conflict (HEC) have been particularly successful. Locally managed deterrents such as electric fencing and beehive fences have demonstrated strong outcomes in reducing crop raids, as documented in the studies by WWF (2024). These barriers are constructed and maintained by local villagers, offering higher maintenance quality and seasonal flexibility aligned with agricultural cycles. The innovation of beehive fencing not only serves as an effective natural deterrent (elephants avoid bees), but also generates supplementary income from honey production, thus enhancing economic resilience and incentivizing conservation behavior. Compared to centrally administered mitigation systems, these community-managed structures have shown greater adaptability, accountability, and ecological sustainability.

Chen *et al.* (2025) study trialled an AI (YOLOv5)-based computer vision system powered by solar microcontrollers to detect bears and trigger visual deterrents. Achieved 91.3% detection accuracy, offering real-time, non-lethal prevention in remote, off-grid regions. Adaptability to India: Deployable in Uttarakhand and Himachal Pradesh for Himalayan black bear conflict mitigation.

The blockchain-based corridor model demonstrates strong adaptability for India, particularly in tribal and buffer-zone regions where community participation is central to conservation success. Integrated with national initiatives such as CAMPA and the Green India Mission, this model can create transparent eco-financing systems that directly link habitat restoration with community incentives. Similarly, the Sri Lankan human–elephant conflict framework offers high relevance for Indian conflict-prone landscapes including Wayanad, Hassan, Kodagu, and North Bengal. Its structured approach to early warning, community engagement, and livelihood support can be effectively aligned with programs like the National Mission for Sustainable Agriculture and the Green India Mission, strengthening both conservation outcomes and rural resilience. In addition, the Smart IoT-based Bear Deterrent System developed in **Tibet** (2025) provides a promising technology-driven solution for Indian regions experiencing frequent bear–human interactions, offering real-time monitoring and non-lethal deterrence that can be integrated into broader wildlife management strategies.

Integrating farmer voices and field surveys: Despite being the most directly affected stakeholders, farmers' experiences and perspectives are often underrepresented in the discourse on vertebrate pest management. Most policy responses are based on forest department reports or satellite-based damage assessments, which fail to capture the emotional, economic, and socio-cultural dimensions of conflict at the village level. Participatory studies from India and other South Asian contexts consistently show that field-based ethnographic and survey data provide critical insights into how communities perceive wildlife, how they adapt to recurring crop losses, and why certain mitigation efforts succeed or fail. For instance, Ogra (2008) documented in Uttarakhand that women bear disproportionate labor and psychological burdens from guarding crops against wild boars and monkeys, which is rarely acknowledged in compensation schemes.

Similarly, Barua *et al* (2013) highlighted that conflict mitigation policies often focus only on quantifiable crop loss, ignoring opportunity costs, such as time spent guarding fields, disrupted education for children, and changes in cropping patterns. These costs are better captured through Participatory Rural Appraisal (PRA), oral histories, and village-level conflict mapping tools rarely used in official wildlife assessments. In a recent study from Assam, Naha *et al*. (2020) conducted field surveys in elephant conflict zones and found that local farmers preferred rapid, in-kind support (e.g., grain or fencing supplies) over delayed cash compensation. This reflects the broader sentiment among rural households that existing bureaucratic processes are neither timely nor culturally aligned.

For India to develop a truly equitable vertebrate pest policy, it must institutionalize farmer participation in both design and evaluation. Tools like community biodiversity registers, social audits for compensation delivery, and citizen science apps for conflict tracking can bridge the gap between official data and lived reality. These approaches not only improve policy accuracy but also rebuild trust in conservation governance.

Possible solutions and the way forward

Solutions must respond to the specific institutional, legal, and socio-cultural challenges outlined in Section 3. This section outlines policy tools and models to address those challenges. Below are integrated, actionable solutions for transforming conflict into coexistence.

Revision of the Wildlife Protection Act / Policy Flexibility

Effectively managing human-wildlife conflict in India demands a more adaptive and decentralized legal framework, particularly a revision of the Wildlife Protection Act (WPA), 1972. While the WPA has played a vital role in protecting endangered species and curbing habitat loss, its rigid structure offers little scope for timely, localized interventions, especially when dealing with species like nilgai, monkeys, and wild boars that frequently damage crops but remain fully protected under the law. Currently, forest officials and local communities face legal constraints that prevent swift action during wildlife incursions. To address this, the Act must allow controlled, region-specific flexibility without undermining its conservation principles. A key reform would be the regulated use of Section 62, which permits temporary reclassification of specific species as 'vermin.' This process must be science-led, time-bound, and subject to public consultation and annual ecological reviews to prevent misuse. The intent is not blanket culling but enabling evidence-based management where conflict is chronic and damaging.

Equally important is the establishment of rapid-response protocols that legally empower officers to deploy non-lethal deterrents such as electric or bio-fencing, sonic devices, and community patrols during peak conflict situations. These actions must be backed by legal clarity to prevent delays and ensure accountability. To maintain ecological integrity, any exemptions or reclassifications must be transparently reviewed and publicly reported based on data such as population trends, conflict frequency, and mitigation outcomes. This approach balances wildlife protection with farmers' right to livelihood, providing a legal middle path that supports coexistence and restores public trust in conservation governance. International examples offer valuable guidance. Kenya's community-run conservancies, Nepal's insurance-backed compensation for crop losses, and Sri Lanka's integration of fencing with local vigilance all emphasize decentralization, shared responsibility, and proactive planning principles that can be adapted to India's diverse agro-ecological contexts.

Integrated management and technological innovations: Modern technology holds transformative potential in addressing the long-standing challenges of vertebrate pest management in India. Traditionally, conflict mitigation has been reactive, often triggered by damage already done, whether in the form of crop destruction, human injury, or retaliatory harm to wildlife. However, the integration of technological tools into conflict management systems can shift the approach from reaction to prevention, from manual to automated, and from fragmented responses to data-driven strategies. This evolution is not only timely but essential, given the increasing intensity and frequency of wildlife incursions into agricultural landscapes. Community night guarding, lighting systems, and coordinated patrolling continue to be widely practiced in elephant and wild boar conflict zones, yet these interventions require constant human presence and offer only temporary deterrence. Physical protection measures such as solar-powered electric fencing, nylon netting, chain-link installations, GI wire fencing, and trench systems have demonstrated success in minimizing wild boar access when maintained collectively and positioned strategically at forest–farm interfaces. Rodent suppression through integrated field sanitation, burrow fumigation, Trap Barrier Systems, and predator resurgence via barn owl nest box installation has further improved crop protection outcomes and reduced chemical dependence. For peafowl-prone farmlands, seedling net enclosures, reflective visual deterrents, and bio-based seed repellents support early-growth-stage crop survival but require more structured extension delivery for consistent farmer adoption.

One of the most promising frontiers is the use of AI-powered monitoring systems and drone-based surveillance. These technologies are already being piloted in conflict-prone areas such as Wayanad in Kerala and parts of Rajasthan, where forests and farms lie in close proximity (Kerala Forest Department, 2023; ToI, 2024). Drones equipped with thermal cameras

and AI algorithms can track the movement patterns of large animals like elephants or wild boars in real time. When integrated with early warning systems, these tools can send alerts to farmers via SMS or mobile apps, allowing them to take pre-emptive measures to protect their fields. This not only minimizes damage but also reduces panic and overreaction, which often lead to illegal or harmful interventions. Another promising innovation is the use of bioacoustic deterrents (Katidhan, 2023). These devices emit sounds that mimic predator calls or distress signals, effectively dissuading species like nilgai or certain birds from entering cultivated areas. When paired with solar-powered systems and motion sensors, these deterrents can be automated to provide round-the-clock protection without the need for constant human supervision. Though not foolproof, they offer a non-lethal, ethical, and scalable alternative to conventional methods, complementing field-validated sound-based devices and cracker stations that have already shown sustained performance in wild boar mitigation. Likewise, GIS-based conflict mapping is emerging as a vital planning tool. By analyzing spatial patterns of wildlife movement and crop damage, such mapping can highlight hotspot zones that require urgent attention, enabling more targeted deployment of resources, including mitigation infrastructure and community awareness programs, thereby improving the efficiency and impact of intervention strategies (Wildlife Institute of India, 2022). The development of mobile applications for real-time conflict reporting, such as those under the All-India Network Project on Vertebrate Pest Management (AINP-VPM, 2023), complements these efforts by ensuring that ground-level observations flow directly into policy pipelines and decision-support systems. These apps enhance transparency and community participation while building a feedback loop for evidence-based policymaking. The real significance of these technologies lies in how they democratize conflict control and empower farmers; instead of waiting for slow-moving bureaucracies to respond, farmers equipped with predictive tools and instant alerts can take proactive action to safeguard their livelihoods, while authorities gain continuous, granular datasets that support long-term ecological zoning, resource prioritization, and adaptive policy interventions. Collectively, the convergence of conventional deterrents, ecological strategies, and cutting-edge technologies represents a critical transition from isolated, reactive measures to intelligent, preventive, and scalable conflict mitigation capable of addressing India's rapidly evolving human–wildlife interface.

Community-based mitigation: A sustainable and socially just approach to human-wildlife conflict mitigation must place local communities at the center of both planning and implementation. India's rural landscape is dotted with institutions such as Gram Panchayats, Joint Forest Management Committees (JFMCs), and Self-Help Groups (SHGs) that already have deep social roots and operational familiarity with local landscapes (Indo-German Biodiversity Program, 2023). Leveraging these bodies through decentralized governance not only enhances the relevance and reach of mitigation efforts but also builds a sense of ownership and accountability that is crucial for long-term success.

One critical strategy is to provide microgrants or targeted subsidies to local groups for implementing mitigation infrastructure. These funds can be used to install and maintain bio-fencing, solar-powered lights, natural repellents, or crop protection nets. Because these solutions often require continuous upkeep and adaptive modifications, entrusting communities with financial autonomy ensures more responsive and context-specific management. Rather than waiting for external interventions, communities can act quickly and collaboratively to prevent damage before it escalates. Regular training workshops, facilitated by officials from the Forest or Agriculture departments, can equip communities with practical skills in non-lethal deterrent use, conflict reporting protocols, and basic ecological literacy. Such training not only enhances technical know-how but also fosters a more empathetic understanding of wildlife behavior, helping reduce fear and misinformation that often lead to hostile or illegal actions against animals.

Moreover, the formation and support of community vigilance groups has shown significant promise in regions like Wayanad (Kerala), Odisha, and Chhattisgarh. These groups often made up of local youth, farmers, and forest-edge dwellers organize night patrols,

monitor crop damage, and disseminate early warnings about wildlife movement (Times of India, 2025). When formalized and backed by modest stipends, training, and communication tools (such as walkie-talkies or mobile apps), these groups become vital links in the larger mitigation ecosystem. Their presence not only deters wildlife incursions but also boosts community morale and cooperation. The underlying rationale is simple yet powerful: when people are owners, not passive observers, of conflict mitigation systems, they are more likely to maintain infrastructure, follow protocols, and hold each other accountable. This peer accountability fosters a culture of collective responsibility and reduces the dependence on overstretched state machinery. Also, it promotes social cohesion, local innovation, and a bottom-up flow of information that can inform district- and state-level policies.

Compensation and insurance: A fair, efficient, and transparent compensation and insurance system is a cornerstone of any successful human-wildlife conflict management strategy. At present, India's compensation mechanisms administered primarily by forest departments are often plagued by procedural delays, limited outreach, subjective assessments, and inadequate payouts (Centre for Wildlife Studies, 2021). These shortcomings erode farmer trust, intensify grievances, and in some cases, lead to retaliatory actions against wildlife. To restore credibility and provide meaningful support to affected communities, there is an urgent need to modernize the system through technology, expand coverage through insurance, and simplify processes through policy reform.

One of the most impactful reforms would be the use of satellite imagery, drone mapping, and AI-based analytics to objectively assess crop damage caused by wild animals (Wildlife Institute of India, 2023). These tools can replace subjective field inspections, which are often delayed, inconsistent, or manipulated. By leveraging remote sensing technologies, assessments can be made faster, more accurately, and with verifiable proof, thereby reducing corruption and disputes. In parallel, the rollout of user-friendly mobile applications can revolutionize the claims process. Such apps would allow farmers to lodge damage complaints, upload geo-tagged photographic evidence, and track the status of their applications in real time. This level of transparency not only reduces frustration but also enhances accountability within the bureaucracy.

A more sustainable and scalable solution, however, lies in expanding agricultural insurance coverage to explicitly include wildlife-related losses. While the Pradhan Mantri Fasal Bima Yojana (PMFBY) currently provides coverage for climatic and pest-related crop failures, it does not account for damage from animals such as elephants, wild boars, or nilgai. Integrating a wildlife damage rider into the PMFBY, especially in high-risk districts bordering forests, can offer institutional protection against recurring losses. Alternatively, a standalone wildlife crop insurance scheme, jointly subsidized by the central and state governments, can be developed for conflict-prone zones. Complementing these reforms should be the introduction of interim relief payments for verified claims, which would ease the financial burden during the typically long processing period. States such as Madhya Pradesh and Karnataka have experimented with such interim payouts, which serve as a vital buffer for small and marginal farmers who cannot afford long waits for compensation.

In addition to PMFBY, other relevant schemes such as the Restructured Weather-Based Crop Insurance Scheme (RWBCIS) and the Kisan Credit Card (KCC) scheme can be aligned with wildlife conflict mitigation through enhanced coverage options and emergency credit provisions. Similarly, the National Disaster Response Fund (NDRF), currently used for natural calamities, can be explored for exceptional wildlife-related crises, particularly in areas facing repeated and large-scale damage from migratory or territorial species. Eventually, predictable, timely, and equitable compensation is not merely an economic transaction; it is a moral and institutional acknowledgment of the risks borne by farmers in supporting coexistence with wildlife. By building a responsive compensation framework, the state sends a clear message: that it values its food producers as much as its biodiversity, and that coexistence will not come at the cost of justice and dignity for rural communities.

Ecological buffer zones: Addressing human-wildlife friction in a durable way necessitates landscape-level foresight. Establishing transition zones, spatial buffers between forested regions and cultivated lands, serves as a cushioning mechanism, absorbing potential wildlife movement before it translates into agricultural damage. Rather than relying entirely on reactive measures, these zones embrace preventive spatial design, integrating ecological logic with rural land use. One effective approach is the introduction of unpalatable or repellent vegetation along farm boundaries. Plants such as citronella, lemongrass, and Mexican marigold are typically avoided by herbivores and have the added benefit of being commercially viable for use in fragrances and natural repellents. These botanical barriers form a natural deterrent line, both functional and economically beneficial, minimizing wildlife intrusion without the need for aggressive deterrents (JMAPS, 2025).

Another useful tactic involves sacrificial perimeter planting, also known as decoy cropping. This strategy entails sowing vegetation that is preferable to wildlife along the outer fringes of farms, effectively luring animals away from core crop areas. For instance, high-yield fodder grasses can divert browsing species like nilgai or wild boar preserving sensitive crops such as pulses or tubers deeper within the field. These decoy rows act as ecological traps, offering a compromise between conservation and cultivation. Beyond agricultural tactics, a systems-level intervention is required within forest boundaries (BioHavoc, 2025). Collaborating with biodiversity experts, land-use planners, and watershed specialists, efforts should focus on revitalizing forest corridors and rehabilitating water catchments. Animals often venture into croplands due to habitat depletion, food shortages, or drying springs. Enhancing the quality of forest interiors can reduce their dependence on human-managed landscapes and re-anchor them to their natural ranges.

Furthermore, economic diversification within transition belts can significantly lower reliance on conventional crops. Introducing income streams like nature-based tourism, aromatic plant harvesting, or medicinal herb cultivation can support both ecological health and rural stability. Financial assistance and technical support for such ventures can be mobilized under national initiatives like the National Mission on Sustainable Agriculture (NMSA) or the Green India Mission (GIM). At their core, ecological transition zones do more than merely restricting wildlife; they rechannel movement and harmonize rural activities with natural rhythms. These zones symbolize a shift from conflict to collaboration, where shared territory becomes a space for intelligent coexistence, not constant confrontation. By realigning land use with ecological understanding, we can pave the way for durable, humane, and adaptive solutions that benefit both biodiversity and agricultural livelihoods (NMSA, 2025; GIM, 2025).

Public Awareness and Coexistence Models: Fostering peaceful human-wildlife interactions requires more than policy shifts or technological fixes; it demands a transformative change in public mindset. The current perception of wildlife as a threat must be gradually replaced with a deeper understanding of ecological interdependence. To achieve this, a comprehensive and culturally sensitive communication framework must be established, designed to engage people across generations and social contexts. One powerful tool in this endeavor is curriculum integration, embedding conflict-related ecological education within school programs. By introducing wildlife behavior, conservation ethics, and simple coexistence strategies into classrooms, we nurture empathy and ecological literacy from a young age. Children, in turn, become agents of change in their households and communities (Wildlife SOS, 2024).

In rural and tribal belts, where digital access may be limited, community radio and folk art forms serve as trusted channels. These media can be used to broadcast timely warnings, share locally tailored mitigation tips, and highlight success stories of human-wildlife coexistence. Formats like storytelling, puppet theatre, or village songs can deliver messages in a relatable, memorable manner, bridging the gap between scientific knowledge and cultural context. Simultaneously, digital platforms can be harnessed to amplify local voices and innovations. Social media campaigns, especially those using vernacular languages and local influencers, can help normalize coexistence strategies, counter misinformation, and build a sense of solidarity among farming

communities across the country. Sharing short videos of farmers using non-lethal deterrents or celebrating elephant-safe harvests can reshape public discourse from fear to resilience.

Another key component is the institutionalization of recognition programs. Acknowledging and rewarding communities that implement humane and effective conflict mitigation through titles like "Conflict-Resilient Village" or financial incentives for eco-friendly innovation encourages a culture of proactive problem-solving. These acknowledgments validate grassroots efforts and shift the focus from portraying communities as passive victims of wildlife conflict to recognizing their ability to act, organize, and lead local solutions. Finally, raising awareness is not an optional supplement; it is a strategic necessity. When citizens are informed, engaged, and empowered, they become collaborators in conservation, not adversaries. Public engagement reduces friction, builds trust between authorities and communities, and helps lay the foundation for a shared, sustainable future where both people and wildlife can thrive (Wildlife Trust of India, 2023).

Conclusions

The challenge of vertebrate pest management in India is no longer a peripheral concern it as a critical agrarian, ecological, and governance issue that demands urgent, coordinated, and compassionate action. As this document demonstrates, vertebrate species such as elephants, monkeys, wild boars, nilgai, peafowls, and rodents are causing significant and recurring losses across India's agricultural heartlands. These losses are not merely economic but deeply social, psychological, and political in nature. The prevailing policy framework where shaped by conservation-era legislation, fragmented governance, inadequate compensation, and outdated deterrent systems which is no longer equipped to handle the dynamic realities of a landscape where human and wildlife territories increasingly intersect. What is needed is not a choice between conservation and cultivation, but a reimagined model of coexistence grounded in science, community partnership, legal reform, and technological innovation. Region-specific flexibility within the Wildlife Protection Act, community-based mitigation systems, technology-enabled early warning and compensation tools, and ethical governance that respects both cultural reverence and livelihood rights are essential pillars of this new paradigm. India must recognize that the farmers safeguarding our food systems are also frontline stakeholders in wildlife conservation. A just, responsive, and participatory policy in which one that protects biodiversity while enabling agricultural resilience is not just an ecological necessity, but a national imperative. Only through such an integrated approach can we transform a narrative of conflict into one of coexistence, equity, and shared stewardship of our landscapes.

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