Mitigating Human-Elephant Conflict: A Comprehensive Strategy of Crop Replanting, Compensation, Acoustic Deterrents, and Community Education

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Abstract

This paper presents a comprehensive meta-analysis of human-elephant conflict (HEC), focusing on the interactions between expanding human habitats and shrinking elephant ranges. The study reveals that habitat loss due to agricultural expansion and urbanization has drastically reduced elephant habitats—by 94% in China and over 50% in other Asian countries between 1700 and 2015 (Silva, 2023). This habitat loss has also resulted in significant crop losses. Various mitigation strategies are evaluated, including compensation programs, education programs, agricultural deterrents, early detection systems, and acoustic deterrents. However, each strategy has its limitations. The paper proposes a novel, multi-faceted approach that includes government-supported financial aid for farmers to plant less attractive crops, conditional compensation for crop losses only when law-mandated crops are damaged, and educational initiatives to foster empathy for elephants. This integrated strategy aims to balance human needs with ecological preservation and offers a scalable model for mitigating HEC globally.

Keywords: Elephants, Human-animal conflict, Mitigation Strategies

Introduction

Human habitat expansion, driven by inefficient land-use practices such as expanding agricultural fields and the need for more land due to overpopulation, results in overlapping territories and increased competition for resources between humans and wildlife. This overlap often results in what is known as human-animal conflict (Nyhus, 2016). Human-animal conflict is a critical global issue, defined as negative interactions between humans and wildlife that result in adverse outcomes for both parties (World Wildlife Fund, 2023). This conflict is most pronounced with large mammals due to their extensive home ranges and resource needs (Nyhus, 2016). Large mammals are vulnerable due to low reproductive rates, high value in the illegal wildlife trade, and slow adaptation to environmental changes, pushing them closer to extinction (WWF, 2020). For instance, the African elephant is already threatened by poaching and habitat loss faces further decline from retaliatory killings stemming from human-elephant conflicts such as invasion of croplands, property damage, and human casualties (WWF, 2020). Other global examples of human-animal conflict include baboons attacking young cattle in Namibia and one-horned rhinos destroying crops in Nepal (Human-Wildlife Conflict, 2020). In Europe, bears and wolves prey on livestock (Human-Wildlife Conflict, 2020). All these examples involve relatively large mammals and result in financial losses for farmers or residents, property damage, and injury or death for both humans and animals.

Human-animal conflict is a long-term issue that has yet to find a universally effective solution, but this does not mean that solutions are unattainable. This paper will examine the case study of human-elephant conflict (HEC) and assess potential mitigation strategies, aiming to identify a relatively comprehensive approach that could effectively address and manage HEC.

Background on Elephants

Elephants are beloved and iconic megafauna, comprising two species: the African elephant (*Loxodonta africana*) and the Asian elephant (*Elephas maximus*), which includes the subspecies *Elephas maximus indicus* and *Elephas maximus borneensis* (World Wildlife Fund, 2012 & 2018). According to the World Wildlife Fund (2020a), there are approximately 415,000 African elephants and 48,323 Asian elephants left in the world. The International Union for Conservation of Nature (IUCN) classifies African elephants as “vulnerable” and Asian elephants

as “endangered” on the red list, highlighting the critical need for conservation action. According to IUCN standards, “vulnerable” species face a high risk of extinction in the wild in the medium term, while “endangered” species are at an even greater risk, with a higher likelihood of becoming extinct in the wild in the near future. African elephants inhabit 37 countries across sub-Saharan Africa, while Asian elephants are found in 13 countries in South and Southeast Asia. Their home ranges vary significantly, from 200 to 2,000 km², depending on habitat and resource availability (Sukumar, 2006).

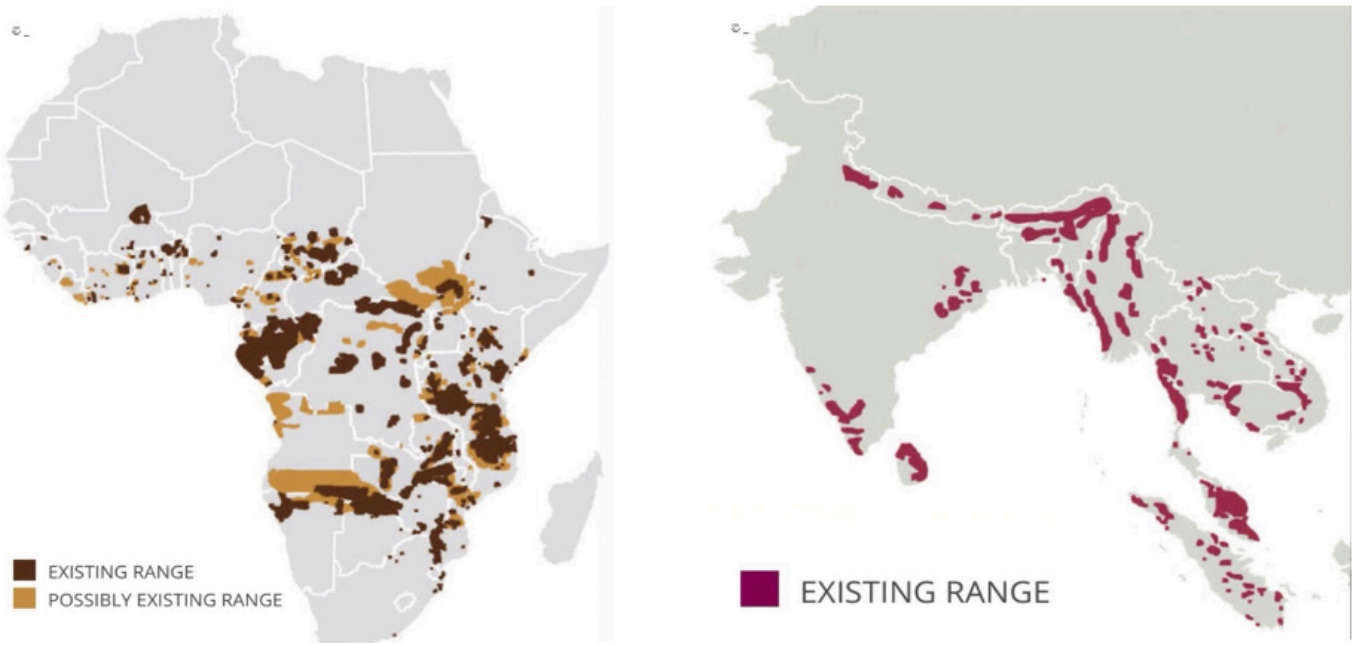

Figure 1: Geographical Distribution of Elephants (World Wildlife Fund, 2018)
- *Left:* Map illustrating the geographical distribution of African elephants, which inhabit 37 countries across sub-Saharan Africa. The species is currently classified as vulnerable.
- *Right:* Map illustrating the geographical distribution of Asian elephants, primarily found in 13 countries across South and Southeast Asia. The species is classified as endangered.

African elephants are notably larger than their Asian counterparts. Males of the African species can reach up to 3.3 m in height at the shoulder and weigh up to 6,000 kg, whereas Asian elephants are smaller with males typically 2.7 m tall and weighing to 5,400 kg (World Wildlife Fund, 2012 & World Wildlife Fund, 2018). In both species, reproduction has a lengthy gestation period of approximately 22 months, usually resulting in the birth of a single calf that has a lactation period of approximately 2-3 years (Sukumar, 2006). Family groups generally consist of 5-20 individuals, with males often solitary or in small, temporary groups (Sukumar, 2006). Elephants primarily consume grasses, leaves, bark, and fruits (mostly tropical fruits), with daily vegetation intake reaching up to 150 kg (Sukumar, 2006). They spend 12–18 hours each day feeding (Sukumar, 2006).

Elephants serve an important ecological role as ecosystem engineers and seed dispersers. They uproot trees and create water holes, facilitating habitats for various species enhancing biodiversity and supporting ecosystem resilience. Tan et al. (2020) quantified and identified seeds in Asian elephant dung at two salt licks over six years in the dipterocarp forests

of northern Peninsular Malaysia. They found seeds in 19.1% of 1,284 dung piles and in 57.1% of the 63 months monitored, representing over 48 morphospecies from 25 plant families. This high frequency and taxonomic diversity of seeds demonstrate the importance of Asian elephants in maintaining plant biodiversity. The loss of other large herbivores, like Sumatran rhinos, has already compromised seed dispersal, making elephants the sole effective seed dispersers in this region (Tan, 2020).

Asian elephants have a closer association with humans than African elephants. In Hindu mythology, they are linked to celestial beings and epic narratives, such as the divine elephant Airavata, the revered mount of Indra, the king of the gods (Airavata: The Majestic Elephant of Mythology | Hindu Temple Talk, n.d.). Airavata symbolizes purity and grace, protects Indra's realm, and battles demons. The profound cultural reverence for Asian elephants, combined with their endangered status that indicates more frequent and severe conflicts near human settlements, accentuates a more pronounced love-hate relationship between Asian elephants and humans compared to that with African elephants. This review will focus on the case study of the human-elephant conflict of Asian elephants.

Human-Asian Elephant Conflict

Habitat loss due to overlapping habitats is a primary cause of human-wildlife conflict and is particularly significant in the context of human-elephant conflicts in Asia. Habitat loss occurs as forests are cleared for agriculture, urbanization, and infrastructure development, shrinking elephant habitats and reducing the availability of food and water (Menon & Tiwari, 2019). Silva et al. (2023) examined archival records and found that in 1700, 100% of the area within 100 km of the current Asian elephant range was classified as suitable habitat. By 2015, however, elephants had lost 94% of their habitat in China, which held most of the Asian elephants' population. Habitat loss was also significant in India, Thailand, Vietnam, and Indonesia, with reductions exceeding 50%, while Laos and Malaysia saw some restoration (see FIGURE 2). This represents a decline of approximately 51.4% in the amount of suitable habitat over this period. This loss forces elephants to venture into "new" human territories, leading to substantial human impact. In response to habitat loss, elephants often raid farms and destroy crops.

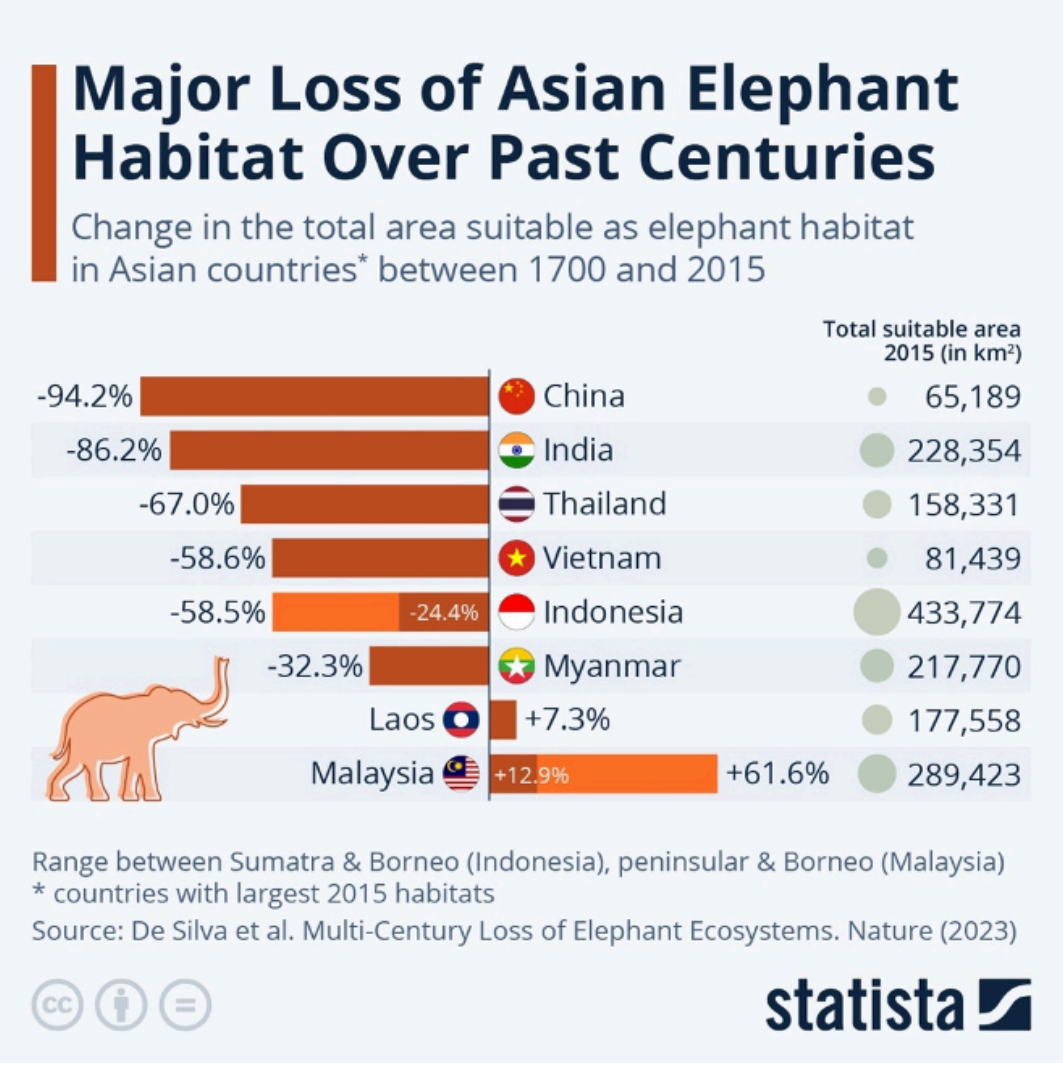

Figure 2: Major Loss of Asian Elephant Habitat Over the Past Centuries (Silva, 2023)

- This figure illustrates that three-quarters of Asian countries have experienced a decrease in the total area suitable for elephants between 1700 and 2015, with most countries showing reductions greater than 50%. Only two countries have seen an increase in the area of suitable habitat.

Overlapping human and elephant habitats has led to significant crop loss for rural farmers in Asia. Neupane et al. (2013) interviewed 1,182 households in southern Nepal to evaluate the human perception of the impact of land-use practices on human-elephant conflict. Between 2012 and 2017, 99% of households reported elephant damage, with increased attacks associated with traditional crop cultivation (rice and large maize fields), banana tree maintenance, and home alcohol production. Similarly, Nyhus et al. (2009) conducted an 18-month study in Kambas National Park, Sumatra, Indonesia, using 20 local informants from 13 villages along the park boundary to record data such as the number of elephants and types of damage on standardized forms. Nyhus et al. (2009)'s study found that although only 20% of the estimated 2,400 elephants (about 480) were involved in crop raiding, they raided all (100%) of the villages along the 1,300 sq-km park boundary. Both studies demonstrate that elephants

can cause significant agricultural damage, leading to substantial economic losses for farmers. Frustrated by repeated crop losses and potential threats to their safety, farmers may resort to retaliatory killings, involving poisoning, electrocution, or direct confrontation.

Elephants do not raid crops intentionally; rather, human activities in overlapping territories alter elephant behavior, leading to increased crop raiding. As agricultural developments encroach on wild elephant habitats, farms growing olfactorily attractive crops like pineapples, bananas, sugarcane, papayas, coffee, and spices become high-value targets (Wettasin, 2023). These mixed crop plantations create a pseudo-habitat—an environment that superficially resembles a natural habitat but is actually a result of human agricultural practices. The nutritionally rich crops with higher water content attract elephants because these crops provide a significant source of hydration and energy, which is particularly appealing to them (Ball, 2022). Coincidentally, these crops are frequently grown by tropical villagers. The problem arises from humans' choice of crops; if less attractive options like ginger or spicy fruits were chosen, elephants might not raid these farms as often.

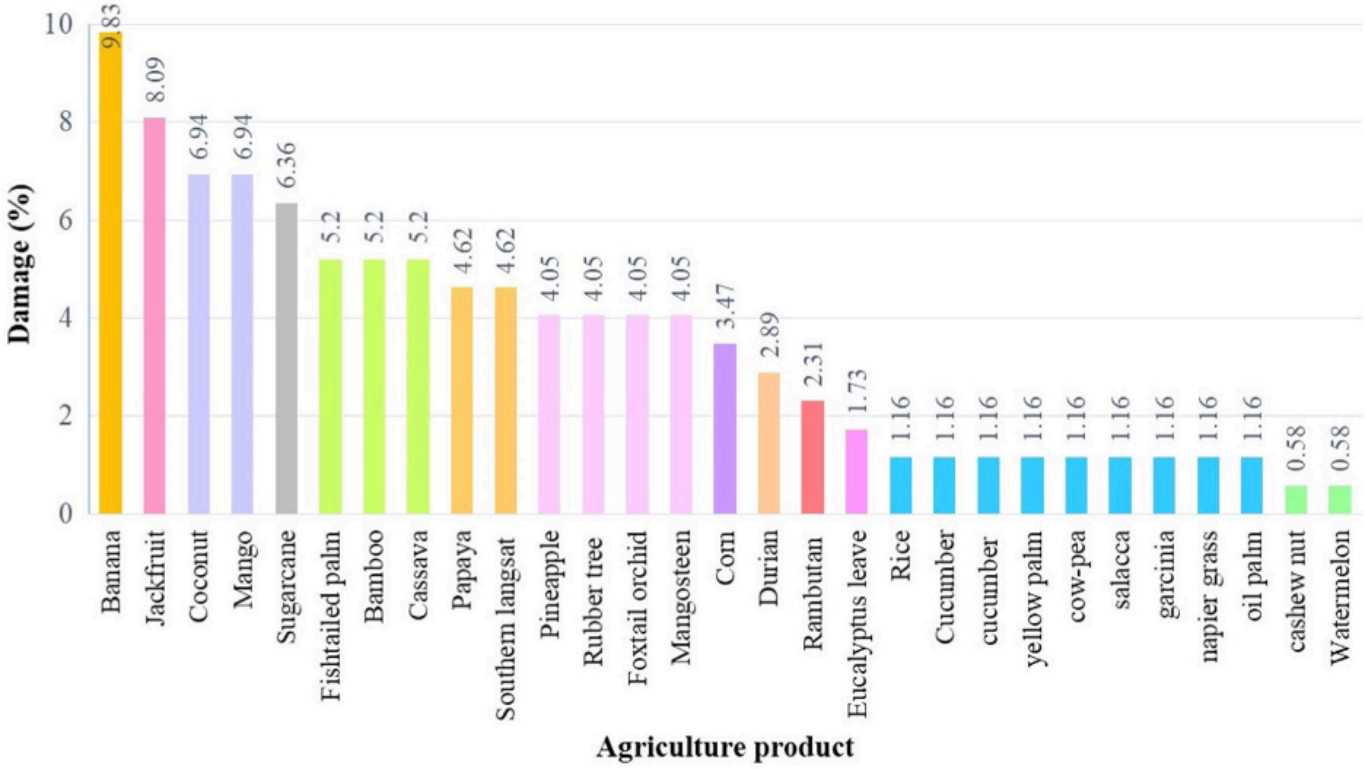

Figure 3: Consequences of crop raiding by wild Asian elephants in the eastern part of Thailand in the last 10 years (n = 183 households), (Wettasin, 2023).

- The crops most likely to be raided are those with high water and sugar content, such as bananas, jackfruit, and coconuts.

In addition to crop selection, Ball et al. (2022) emphasize that human activities such as pollution and industrialization interfere with elephants' sense of smell and hearing. Noise from construction and development affects their behavior by disrupting their communication and navigation. Loud noises can cause elephants to flee or become disoriented, leading them to inadvertently enter human territories and farms, often resulting in crop raids (Ball, 2022). For

example, elephants exposed to constant noise pollution may avoid their usual pathways and wander into agricultural areas, especially at night when the noise levels decrease (Ball, 2022). This disruption can lead to increased nighttime crop raids, as elephants are drawn to quieter environments where they may encounter farms. Ball et al. (2022)'s study suggests volume affects elephants' activeness and behavior in foraging.

Figure 4: Impact of Anthropogenic Cues on Elephant Behavior (Ball, 2022)
A camera trap image from a Thai crop field shows a bull elephant breaking through a fence to forage at night. This illustrates how human-induced olfactory and auditory distractions can mislead elephants' navigation and foraging behavior.

Evaluation of Current Mitigation Strategies

Common human-animal conflict mitigation strategies include compensation payments, education and outreach, early detection systems, agricultural deterrents, and acoustic deterrents. Each strategy has its own mechanisms, advantages, and limitations.

- **Compensation Programs**: Compensation programs reimburse farmers for losses caused by wildlife, potentially reducing retaliatory killings and fostering coexistence. Ravenelle et al. (2017) reviewed 288 publications on 138 unique compensation programs across 50 countries and found that $222 million has been paid out since 1980 to farmers affected by wildlife-induced losses. The study revealed that 75% of criticism was centered on administrative inefficiencies, while 75% of positive feedback highlighted

reductions in retaliatory killings and improvements in coexistence. Despite the high rate of positive feedback, the success of these programs depends heavily on prompt payment administration. Inefficiencies in processing payments can undermine their effectiveness. Because not all governments are sufficiently resourced, the effectiveness of compensation programs is limited to regions with the capacity for timely administration and does not extend globally.

- **Education and Outreach Programs:** Education and outreach programs aim to modify perceptions of wildlife damage and reduce conflict through awareness training. By informing communities about the actual versus perceived costs of wildlife damage, these programs seek to mitigate antagonism. Wetering et al. (2022) reviewed 169 studies from 43 countries, involving 176,007 participants aged 3 to 19, and found that the most effective program improved students‘ environmental knowledge by 95.3%. This means that, on average, students’ understanding of environmental issues increased by 95.3% compared to their initial knowledge. Although such educational initiatives can significantly enhance environmental awareness among children and teenagers, they are not always the most direct approach. Additionally, if these programs do not address underlying issues or are implemented in isolated areas, they may inadvertently increase tensions and cause conflicts to shift to neighboring regions (Dickman, 2010). Deeply rooted cultural or religious beliefs about wildlife can also be resistant to change (Dickman, 2010). The overall effectiveness of education is often limited by its inability to fully address all aspects of wildlife damage and retaliation and may encounter resistance in communities with pre-existing tensions toward conservation efforts.

- **Agricultural Deterrents:** Agricultural deterrents like chili-coated fences involve applying chili oil to cloths and placing them around crops. The strong, unpleasant odor of the chili repels elephants, making the crops less attractive to them. Karidozo et al. (2015) evaluated the effectiveness of chili-based deterrents, specifically chili fences, in reducing human-elephant conflicts in Southern Zambia. Through a combination of field trials and control plots, they found that chili fences reduced crop damage by elephants by approximately 80% compared to control plots without any deterrents, indicating significant effectiveness in mitigating conflicts. Chili fences are considered one of the most optimal methods, as they do not harm elephants, are easy to apply, and are relatively inexpensive. However, the adoption of such methods largely depends on whether villagers are willing to change their crop selection if the government does not mandate it.

Figure 5: Farmer Applying Chilli Oil to Fences (Bolles, 2017)

This image shows a farmer applying chili oil to ropes and cloths used as fences around crops.

- **Early Detection and Warning Systems:** Early detection and warning systems use technologies such as GPS tracking, motion sensors, and camera traps to alert people to the presence of animals. This allows them to take preventive measures, like moving livestock or using deterrents, to avoid conflicts. Dertien et al. (2023) deployed 12 TrailGuard AI camera-alert systems in the Kanha-Pench corridor to detect tigers and other species prone to causing conflicts. The cameras successfully detected tigers 98.83% of the time when triggered, and sent notifications within 30 to 42 seconds, giving villagers enough time to protect their livestock. This highlights the potential of these systems to reduce human-wildlife conflicts and poaching threats. However, the technology requires significant

investment and technical expertise and is susceptible to malfunctions. Additionally, if villagers cannot check notifications promptly, the system's effectiveness in protecting crops and livestock is compromised (Shaffer, 2019).

- **Acoustic Deterrents:** Acoustic deterrents use sound to scare away animals or discourage them from entering specific areas, employing loud noises, alarms, or unpleasant sound frequencies. The aim is to create a negative experience for the animals, causing them to avoid the area. Thuppil et al. (2016) investigated the effectiveness of acoustic deterrents in reducing crop-raiding by elephants in southern India, using passive infrared sensor systems that automatically played recorded predator sounds when motion was detected. They found that tiger growls deterred 100% of crop-raiding attempts on the first encounter and 50% on subsequent encounters, while leopard growls deterred 100% of attempts on both first and subsequent encounters. This study demonstrates that acoustic deterrents, particularly tiger growls, can effectively reduce human-elephant conflicts when used alongside other deterrents, such as chili fences (Thuppil, 2016). However, acoustic deterrents may become less effective over time as elephants adapt, potentially causing conflicts to shift to other regions (Shaffer, 2019).

Each of these strategies works well individually, but combining them could provide even greater effectiveness.

Proposed Strategy for Mitigating Human-Asian Elephant Conflict

The root cause of human-elephant conflict (HEC) often lies in inefficient land use practices. Ideally, addressing HEC would involve changing land use plans at the source. However, in Asia, such changes may not be practical due to pressing socioeconomic issues. For example, in India, about 70% of the population depends on agriculture for their livelihood (FAO, 2023). Additionally, India's population has surged by around 16.7%, growing from about 1.2 billion in 2010 to over 1.4 billion in 2023. This growth rate is considerably higher than that of many other developing countries, such as China, where the population increased by only 5.2% during the same period (Mogul, 2023). These factors—high population growth, widespread poverty, land scarcity, and a heavy reliance on agriculture for economy—often take precedence over conservation priorities. As a result, implementing changes in land use planning becomes challenging and prohibitively expensive in such contexts.

Aside from inefficiencies in land use practices, the primary cause of human-elephant conflict (HEC) is often the selection of crops. Changing crop selection is easier than changing land use plans because it involves fewer structural and economic adjustments, allowing for more immediate and flexible implementation. The proposed strategy centers on government-supported financial aid for farmers to replant crops that are less attractive to elephants. This agricultural deterrent method aims to minimize crop raiding by altering the landscape to discourage elephants from entering farms. Implementing laws that mandate the cultivation of non-appealing crops ensures uniform adoption among farmers, thereby reducing the likelihood of attracting elephants to specific areas. For example, while mangoes are highly attractive to elephants, crops like chili peppers or ginger, which elephants typically avoid, could be promoted as alternatives. Neupane et al. (2017) support this approach, recommending that

growing less attractive crops and moving fruit trees away from homes can significantly reduce human-elephant conflicts.

In addition, this plan incorporates acoustic deterrents, which, while effective, may not provide a long-term solution as elephants could eventually adapt to them. Acoustic deterrents should be used initially but removed once they become ineffective, and can later be sold or repurposed for other uses. If these deterrents become weathered or damaged, farmers should replace them promptly to prevent elephants from resuming their crop-raiding habits. Deterrents should be installed around farms rather than between them, allowing elephants to navigate around the barriers and still travel for breeding, foraging, and connecting with other populations.

If crop damage persists despite these changes, the government should provide compensation to farmers for verified losses rather than arbitrary claims. Compensation will be conditional upon compliance with new crop regulations and on replacing deterrents when weathered, such as those with low sound quality. Conversely, penalties will be imposed on farmers who cultivate prohibited crops or fail to replace weathered deterrents. To ensure accuracy, a verification process should include regular field inspections by trained agents and the use of remote sensing technology to document and assess crop damage and compliance. This approach is different from traditional compensation methods because it ties compensation directly to whether crop regulations are followed. Payments are made only if elephants continue to raid crops despite the use of deterrent crops and well-designed acoustic deterrents. As crop losses decrease, the amount of compensation payments the government has to make also decreases. This reduces the financial burden on the government, allowing them to conserve their funds and be better prepared to compensate for accidental raids on new crops. The system aims to cut down on administrative inefficiencies, ensure that financial aid is conditional, and encourage farmers to take proactive measures, ultimately improving effectiveness and sustainability.

The proposed strategy also emphasizes educating villagers about the ecological importance of elephants by having local teachers train students of all ages on the significance of elephants, encouraging them to promote their protection across generations. Elephants are vital for biodiversity, serving as the primary seed dispersers and ecosystem engineers in Southeast Asian forests. For those motivated by self-interest, this can be framed as a practical reason for protection: conserving elephants is linked to preserving essential resources for human survival. This understanding can foster a sense of urgency when conserving elephants. Additionally, educating villagers that elephants do not intentionally invade farms but are often misled by olfactory or auditory disturbances created by humans can shift the blame from elephants to these human-induced disturbances. This perspective helps villagers understand that elephants are acting out of instinct rather than malice, and encourages them to recognize their own actions as contributing to the problem. By fostering empathy and tolerance through education about elephants' biological systems and ecological roles, villagers may not only reduce their negative perceptions of elephants but also decrease the incidence of elephant killings.

Overall, the proposed multi-faceted method addresses both the root causes of conflict and the need for practical, enforceable solutions.

Conclusion

Resolving human-animal conflicts remains a significant challenge, but the proposed strategies offer promising avenues for progress. The hope lies in creating sustainable solutions that balance ecological preservation with human needs. This case study is invaluable as it

provides practical insights and innovative methods for mitigating conflicts, offering a model that can be adapted and scaled to other regions facing similar issues.

As the saying goes, addressing poverty is fundamental. By solving poverty, we can address human-elephant conflicts and other human-wildlife conflicts.

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