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Mitigating Human-Elephant Conflict in Southeast Asia

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ABSTRACT. – Human-elephant conflict (HEC) poses serious threats to humans and to elephants, and while HEC in Southeast Asia is increasing, mitigation effectiveness data are lacking. Previous assessments of available mitigation options have not compared relative benefits and impacts of each on a practical level to identify which factors should be considered by local agricultural communities and/or other stakeholders when choosing among mitigation options. Understanding which mitigation approach to apply in a given context is crucial for effective mitigation planning and can aid in the development of more holistic methods. We reviewed the literature regarding the strengths and weaknesses of 14 currently applied HEC mitigation methods in Southeast Asia, considering five key factors for each mitigation option: 1) effectiveness at reducing crop damage, 2) initial start-up costs, 3) maintenance/long-term costs, 4) potential impacts on humans and 5) potential impacts on elephants. Our results suggest there are considerable tradeoffs among these five factors for any given mitigation option and that none of the available mitigation methods are simultaneously highly effective in preventing crop damage and low cost while presenting minimal impact to people and elephants. Although our metric of comparison is not comprehensive, it may offer an initial set of guidelines for decision making.

KEYWORDS: crop damage, decision making, human-elephant conflict, mitigation measures, Southeast Asia

INTRODUCTION

Human-wildlife conflict poses a significant threat to the survival of many wildlife species globally and multiple countries have been affected. Human-wildlife conflict occurs when wildlife habitat and other resource needs compete with those of people. This overlap often results in wildlife entering into human-dominated areas, causing damage to property and infrastructure, particularly agricultural crops and livestock. These interactions not only lead to economic losses but also compromise human safety and well-being. In response, people seek to protect their assets often leading to retaliation which causes injury and death to wildlife and such confrontations increases the risk human injury and death as well (Gubbi et al., 2014).

Among the numerous occurrences of human-wildlife conflict, human-elephant conflict (HEC) stands as an especially serious conservation challenge, posing substantial threats to both human livelihoods and the survival of elephant populations (Hoare, 2015; Shaffer et al., 2019). HEC occurs throughout the ranges of both African and Asian elephants. As human populations expand, these harmful trends have consequently driven elephants and people into closer and more regular contact, escalating HEC (Chartier et al., 2011). HEC has become a key threat to biodiversity conservation (Redpath et al., 2013), and the management of the conflict is now a main goal for elephant conservation efforts.

In Asia, the home of the Asian elephant (*Elephas maximus*), HEC occurs in all countries within their range, including Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos PDR, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand, and Vietnam. The remaining population of Asian elephant is estimated at between 41410 to 52345 individuals living in fragmented habitats across these range countries (Shaffer, 2019). HEC in Southeast Asia, like elsewhere in Asia poses significant challenges to both local livelihoods and conservation of elephants (Kiratporn et al., 2019; Sampson et al., 2021). The effectiveness of elephant conservation efforts has been reduced by extensive habitat conversion and fragmentation and HEC. For example, elephant populations in Cambodia, Indonesia, Laos, Myanmar, Thailand, and Vietnam have been reduced to an estimated 9700 individuals (Martin and Stiles, 2003, Menon and Tiwari, 2019). Elephants in the region have been known to damage various crop types including banana, cashew, jackfruit, pineapple, and several others (Wettasin et al., 2023). In addition to crop damage, HEC sometimes also leads to damaged property causing further economic hardship, further limiting local livelihoods. Local perceptions toward elephants vary considerably depending on the context of an area particularly economic conditions, cultural practices and local beliefs (Thekaekara et al., 2021). Various mitigation methods have been applied ranging from traditional and low cost to expensive and innovative (Silva and Srinivasan, 2019) but there is a strong site-specific component suggesting that some mitigation methods are not suitable for every HEC site (van de Water et al., 2018; Nguyen et al., 2021; Sinha et al., 2021). Understanding the tradeoffs among available mitigation strategies and understanding which mitigations should be applied in a given context in the region may facilitate human-elephant coexistence.

Efforts to mitigate human-elephant conflict and promote coexistence in Southeast Asia include a variety of strategies, from ecological approaches to community-based initiatives and technological interventions. This review compares HEC mitigation measures focusing on those previously implemented in the region and their relative effectiveness in Southeast Asia. Furthermore, identifying the inherent tradeoffs among the currently available mitigation strategies in Southeast Asia could help further our understanding of HEC in general and highlight the pros and cons of the strategies currently available in the region and their potential for improvement.

MATERIALS AND METHODS

Study area

The study area covers Cambodia, Indonesia, Laos PDR, Malaysia, Myanmar, Thailand, and Vietnam. These countries are home to Asian elephants (*Elephas maximus indicus*) while Indonesia is home to Sumatran elephants (*Elephas maximus sumatranus*) and Bornean elephants (*Elephas maximus borneensis*). These seven countries are the only ones in Southeast Asia that have wild elephants and have reported HEC.

Literature review

The review draws upon a comprehensive literature search conducted using academic databases, reports, and academic publications related to HEC across Southeast Asia. Google Scholar was used and searches included keywords "human-elephant conflict", "elephant conservation", "conflict mitigation", “Southeast Asia” and related terms. Studies were selected based on their relevance to understanding the crops damaged, mitigations used and their effectiveness. Both primary research studies and review articles were considered.

Performance rating scale of mitigation methods

We initially developed this method based on what we considered the main issues for comparing HEC mitigation methods, although later after we had finalized our methods, we discovered that there was a previous smaller study from Sumatra that used somewhat similar metrics (Sugiyo et al., 2016), potentially lending further support to our approach here. For our study, each mitigation method was evaluated using five mostly qualitative metrics, 1) effectiveness, 2) initial (startup) costs, 3) maintenance costs, 4) impact to humans and 5) impact to elephants. Each of these five metrics were scaled from 1 to 5. Effectiveness was measured from least effective to most effective, using a score from 1 to 5, with 1 defined as least effective and 5 most effective. The effectiveness score was evaluated based on the level of crop damaging by elephants after a given mitigation implementation, this included consideration of how quickly elephants adapted (i.e., accessed the target crops) over time based on the literature accounts and our own field observations in Thailand and considered in relation to the other available methods. The difficulty here was that based on our review, effectiveness remains largely unquantified, thus our ranking was necessarily coarse. The initial costs and maintenance costs were calculated from the reported budgets found in the literature and our previous observations (C. Savini, unpublished data). Here the focus was on assessing the likelihood that local farmers could afford to implement a given mitigation strategy and thereafter maintain such a system. Our assumption was that given the general lack of government financial support within Southeast Asia, individual farmers or small local communities are mostly on their own in terms of implementing and maintaining mitigation systems. The rating was from the most expensive to the cheapest, which we scaled from 1 to 5. For example, using local materials with initial costs under USD$50, such methods were rated as a 5. When the start-up costs reached over USD$30000, costs of such methods were rated as having a low score (level 1). When the methods required maintenance regularly and needed a large budget to keep the system in working condition, the maintenance costs were considered relatively high (lower scores), while methods that required relatively limited financial inputs over time were given higher scores. With our methods, costs were included twice (initial and maintenance) because we assumed cost would be a major driver in the willingness of local people to implement a given mitigation method (Fernando et al., 2008). Because human and elephant safety should be key factors in the decision process, we gave separate scores for human and elephant safety. Impact levels of mitigations on humans and elephants were evaluated based on the relative possibility of human (or elephant) injury or death when using such methods based on the literature and our previous field observations and personal communications (C. Savini, unpublished data). The rating ranged from highest to lowest impact scaled from 1 to 5. Finally, we then summed these five metric scores to provide an overall score to assess how each mitigation method performed relative to each other, with 25 being the possible maximum and five the possible minimum for a given mitigation method. The lead author estimated the initial scores for each of the five factors for each of the 14 mitigation methods compared, and then the co-authors discussed the scores and occasionally re-estimated them depending on the outcome of our discussions.

RESULTS

Management/Mitigation Strategies

The mitigations methods were classified into nine rough groupings following Perera (2009): 1) Physical barriers, 2) Vigilance methods, 3) Deterrence methods, 4) Repulsion methods, 5) Elephant drives, 6) Capture (followed by translocation or taming), 7) Culling, 8) Compensation schemes, 9) Land-use planning, and 10) Alternative crops (see Table 1 for an overview of available mitigation methods, their key strengths and weaknesses, and the literature used and Fig. 1 to show the number of publications in SEA for each mitigation methods).

1. Physical barriers — protecting crops by preventing elephants from entering.

a) Beehive fences

Beehive fences have shown potential to reduce crop destruction in Africa (King et al., 2017, Scheijen et al., 2018, Branco et al., 2019). The evidence in SEA is not as strong or clear partly because there have been far fewer studies (van de Water et al., 2020, Dror et al., 2020). Such fences have been used globally in countries with HEC including countries in SE Asia (Indonesia and Thailand). Based on our analysis, the effectiveness of beehive fences was considered moderate (score = 3) because there was some reported success in lowering the potential impact of elephant crop damage in Thailand (van de Water et al., 2020). The key to the method is the presence and behavior of bees and how this affects the behavior of elephants, potentially lowering the chance of elephants entering an area. However, one study reported that such fences may be mostly ineffective because Asian bees were less aggressive compared to African bees (Dror et al., 2020). Furthermore, poor management of beehives could lead to low bee survival which can greatly reduce the effectiveness of the method (Enukwa et al., 2017). Ecological conditions can also greatly affect beehive conditions, particularly the availability nectar sources. This method has a wide range of setup costs for implementation and maintenance but has the potential to be introduced widely (initial cost score of 2). The construction costs were estimated at USD$300 to USD$400 per 100m of fence (Scheijen et al., 2018; Branco et al., 2019). The maintenance cost was rated as relatively high although the maintenance costs also varied depending on the context. Roughly, USD$200 is estimated for colony establishment and colony maintenance (Butler et al., 2019). Regular maintenance and local training in the technique as well as people's enthusiasm play significant roles in the overall effectiveness of this method (van de Water et al., 2020). In addition, beehives can serve as a possible alternative income source for local communities from honey production, potentially lowering the maintenance costs. While beehive fences are a promising protective strategy, it also has the added benefit of being of relatively low impact to humans and elephants. This method was rated as very low impact level (5) to both human and elephants. Beehive fences typically pose no harm to elephants and as they often avoid getting close to the fence (King et al., 2011). Local people who applied the methods also interact less with elephants (compared to active guarding for example) which could lower the potential injury from elephants. The overall score of this method was 17 (Table 2).

b) Electric fences

Electric fences are barriers used to prevent elephants from entering an area using electric current through wire fencing. This method has the potential to protect an entire area or community depending on the funds available for construction and maintenance, as well as the quality and complexity of the fencing depending on the materials and design. Electric fences have been introduced to many HEC sites in SE Asia, including Cambodia, Indonesia, Malaysia and Thailand to reduce crop damage and have shown to be moderately effective (score of 3) (Webber et al., 2011, Asimoupoulos et al., 2016, Gunaryadi et al., 2017, van de Water et al., 2018). This method has the advantage of scalability, making it suitable to apply over large as well as small farms. However, the main challenge of implementing this method is the high cost of construction and maintenance (rating score were 2 for both). The initial costs are estimated to range from USD$250-900 per 100m (Gunaryadi et al., 2017; Nguyen et al., 2021). This method requires high maintenance costs to work effectively especially at larger scales or highly fragmented lands. Studies also show that elephants adapt to the electric fences by

TABLE 1. Strengths and weaknesses of assessed mitigation methods and their use in Southeast Asia.

Mitigation		Where this method has been studied	Strengths for people/elephant	Weaknesses for people/elephant	References
Physical barriers	Beehive fences	Indonesia Thailand	- Honey could benefit local people // -Lower risk to elephants	-High setup costs -Condition of environment for suitability for bees -Need training for bee keeping	1 - 8
	Electric fences	Cambodia, Indonesia, Malaysia, Thailand	-Can be applied in large areas (>1km) -Potentially prevent damage when well maintained	-High costs -Need proper maintenance // -Higher risk to elephants -Elephants can adapt over time	1, 2, 4, 5, 9, 10, 11, 12
	Trenches	Indonesia Thailand Malaysia	-Can be implemented in wide areas	-High construction and maintenance costs -Highly susceptible to rain damage	1, 4, 8, 9, 13
Vigilance methods	Monitoring and surveillance	Cambodia, Malaysia, Thailand	-Early detection -Potentially reduce the damage risk from elephants	-Labor intensive -Requires connectivity among local people -Ineffective if not combined with other methods such as guarding	4, 5, 11, 14, 15
	Trip alarm fences	Indonesia Thailand	-Low costs -Can be used in medium-sized areas (farm scale) -Lower risk to humans	-Easily broken by elephants -High maintenance costs -Ineffective if standalone	1, 4, 8, 9
Deterrent methods	Chili fences	Cambodia, Indonesia, Myanmar	-Easy to implement -Can be used in medium-sized areas // -Lower risk to elephants	-High maintenance costs -Labor intensive -Variability in efficacy	1, 2, 4, 5, 8, 14, 16
Repulsion methods	Crop guarding by locals	Cambodia, Vietnam, Indonesia, Lao PDR, Malaysia, Myanmar, Thailand	-Low costs -Can be implemented across large areas	-Labor intensive -Need commitment and dedication of local people -Potential risk to humans and elephants	4, 5, 7, 8, 9, 11, 12, 13, 16, 17
	Patrol (response units)	Indonesia Thailand	-Increase effectiveness of existing methods -Trained patrol team could lead to lower risks to people and elephants	-Labor intensive -Need accessibility to farm areas -Logistically difficult in a large areas -Need training and collaboration among stakeholders	18, 19, 20
Elephant drives		Cambodia, Indonesia		-High risk to humans and elephants -Need training -Temporary solution	1, 12, 17, 21, 22
Capture		Malaysia, Indonesia		-Problem remains -High costs -High risk for humans and elephants -May shift HEC to other areas	1, 4, 5, 8, 9, 12, 23, 24, 25
Culling				-Problem remains in the area after culling // -Reduced elephant gene pool	1, 4, 9, 26, 27
Compensation		Vietnam	-Enhance tolerance of locals to elephant damage	-Funds can be delayed -Unfairly distributed -If insufficient, can lead to low satisfaction -Require reliable funding	4, 5, 7, 9, 11, 13, 28
Land-use planning		Indonesia, Lao, Thailand	-Can potentially reduce the frequency of crop damage // -Connectivity could lead to promote biodiversity	-Resources and budget constraints	4, 8, 9, 29
Alternative crops		Thailand	- Reduced crop damage -Another income to supplement loss from crop damage	-Need market research for appropriate measures -High start-up costs	4, 5, 29

Enukwa et al., 2017[1], Gunaryadi et al., 2017[2], Branco et al., 2019[3], Shaffer et al., 2019[4], Snyder et al., 2020[5], Van de Water et al., 2020[6], Nguyen et al., 2022[7], Kuswanda et al., 2022[8], Khounboline et al., 2003[9], Asimopoulos et al., 2016[10] , Water et al., 2018[11], Silva et al., 2019[12], Li et al., 2018[13], Webber et al., 2011[14], HUTAN, 2020[15] ,Allendorf et al., 2015[16] ,English et al., 2022[17] ,Oelrichs et al., 2016[18] ,Ghani et al., 2019[19], Kochprapa et al., 2023[20], Fernando et al., 2008[21], Andyono et al., 2018[22] ,Saaban et al., 2020[23], IUCN, 2023[24], Zaini et al., 2023[25], Chiyo et al., 2011[26] , Fernando et al., 2019[27], Jarungrattanapong et al., 2012[28] , Maifaey et al., 2018[29]

finding ways around, over, under or by pushing them down (Mutinda et al., 2014). However, when electric fences are properly deployed, the risk of human encounters with elephants could be reduced leading to lower impact levels to people (score of 5). Despite the promising effectiveness, this method presents a potential impact to elephants from the electrocution (Kalam et al., 2018). Also, if such fencing is employed over very large areas, such barriers may negatively affect elephant population dynamics potentially

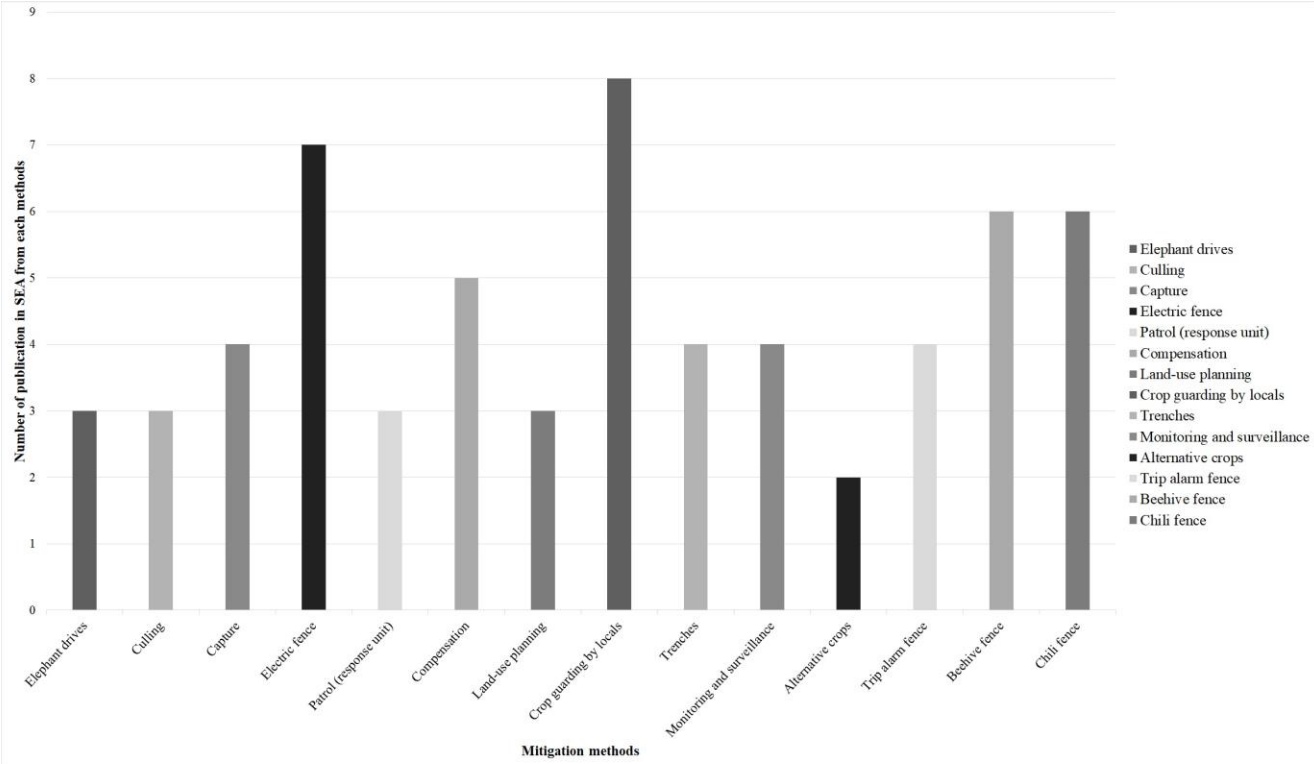

FIGURE 1. Number of publications in Southeast Asia for each mitigation methods. The order was based on the ranking of the overall score of the given mitigation method.

impacting their movements for breeding and foraging (Gunaryadi et al., 2017). Thus, the level of impact on elephants was rated as mostly negative (score of 1). In addition, such barriers may lead to elephants moving to other places, simply shifting the problem to other locations. The overall performance score of this method was 13 (Table 2).

c) Trenches

Trenches are typically dug around agricultural fields, or villages to prevent crop damage. From our review, this method has been used in Indonesia (Borneo), Thailand, and Myanmar in Southeast Asia. Based on our review, the effectiveness of trenches we also rated as moderate (3) in reducing crop damage. During the initial period shortly after trenches are constructed, there appears to be a noticeable reduction in crop damage frequency (Das et al., 2022). However, without proper maintenance, the trenches naturally erode, and therefore elephants are eventually able to get past such barriers. Elephants have also learned to adapt by manipulating the soil around these trenches so that they become less steep and therefore become passable over time. Overall trenches are useful in areas with resources to construct and maintain them properly, however trenches can be labor-intensive to create and maintain, and such costs can be a limitation in some areas. The construction cost is varied but perhaps USD$160 per 100m (C. Savini, unpublished data). Thus, the construction and maintenance costs were above average (score of 2) to implement this method. In addition, trenches may not be suitable in areas with especially heavy rains. While this method is less hazardous for farmers (score of 5) compared with guarding and chasing elephants, trenches can be a danger to elephants as they can become trapped, which can cause injuries or even death as they struggle to climb out (Nyhus et al., 2000). Hence, this method was rated as higher impact to elephants (score of 2). The overall score of this method was 14 (Table 2).

2. Vigilance methods — alert local people to the presence of elephants before they enter an area.

a) Monitoring and surveillance

These methods involve the monitoring and observation of elephants and their behavior in areas vulnerable to crop damage, serving as a reactive method to mitigate HEC. CCTV (closed circuit television), camera trap systems, watch towers, and community networks play a critical role in this mitigation by helping with detection of elephants before they damage crops. It has been used in Cambodia (Webber at al., 2011), Indonesia (Gunaryadi and Hedges, 2017), Malaysia (HUTAN, 2020) and Thailand (Van de Water et al., 2018). This method alone probably cannot effectively prevent/reduce crop

TABLE 2. Strengths and weaknesses of assessed mitigation methods and their use in Southeast Asia.

Mitigation	Eff. score	Int. cost score	Mtn. cost score	IH level	IE level	Total score	Primary Stakeholders
	1-5	1-5	1-5	1-5	1-5		
Chili fences	2	3	3	5	5	18	Locals, Gov, NGO
Trip alarm fences	3	4	3	3	4	17	Locals, NGO
Beehive fences	3	2	2	5	5	17	Locals, Gov.
Monitoring and surveillance	2	2	3	4	5	16	Gov., Locals
Alternative crops	2	2	2	5	5	16	Locals, Gov., NGO
Trenches	3	2	2	5	2	14	Locals, Gov.
Crop guarding by locals	4	5	2	1	2	14	Locals
Patrol (response units)	3	3	2	2	3	13	Gov., Locals
Land-use planning	1	1	1	5	5	13	Gov.
Compensation	1	1	1	5	5	13	Gov., Public/Private liability, insurance
Electric fences	3	2	2	5	1	13	Locals, Gov., Private sector
Capture	1	2	2	1	1	7	Gov., NGO
Culling	1	1	1	2	1	6	Gov., NGO
Elephant drives	1	1	1	1	1	5	Gov., Private sector

Effective scores (Eff.) for a range of Human-Elephant Conflict (HEC) mitigation methods, Level of initial costs (Int. cost) and maintenance cost (Mtn.), risk level to humans and elephants. Effective score was ranked from least effective – most effective at reducing crop damage from elephants (1-5). Level of initial and maintenance cost was ranked by most expensive to cheapest (1-5). Impact level of humans (IH) and elephants (IE) was ranked from highest risk to lowest risk (1-5). Primary stakeholders who contribute to the given mitigation method and suitable context for the particular mitigation.

damage frequency but can alert guarding teams to prevent elephant damage (score of 2). There were some initial costs required such as, construction of watch towers, setting camera systems or radio networks in the community. The cost varies depending on the context and primary stakeholders who implement the method. For example, the construction cost of a watch tower was about USD$7500 (Sapkota et al., 2014). Overall, the cost to setup a monitoring system to cover an area was typically high, so the initial cost was considered higher than many of the other methods available (score of 2). Maintenance costs to cover the equipment and human resources to monitor surveillance points, can cost a moderate amount of money to maintain (score of 3). However, by detecting elephants early, it can be used to plan how to guard an area more effectively and potentially reduce the negative impact to guarding team when driving elephants. It could lead to lower risk to people (score of 4 for human impact) from early detection but some encounters are still likely to occur. Usually, this method was done by trained participants so the risk to elephants was considered low (score of 5 on elephant impact). The extensive training and the use of strict protocol of individuals is key to increasing the effectiveness and reducing the impact to people and elephants. The overall score of this method was 16.

b) Trip alarm fences

Tripwires are connected to devices that make loud noises remains, such as sirens, or flashing lights when triggered by an animal's movement. There are reports of using such methods in Indonesia and Thailand. The effectiveness of such a system depends on the speed of the community's response to the alarm. Trip alarm fences alone are helpful in providing warning of an elephant incursion which allows local people to potentially drive elephants before they enter an area. The noises and flashing lights produced by the alarm often startle elephants, encouraging them to turn away from the area. However, it is likely that elephants adapt to this method leading them to pass through such fences and/or including the destruction of these fences. Overall, the effectiveness of this method was considered moderate (score of 3). The initial cost for this method is quite low (~USD$19 per 100m). The cost including batteries, local materials, and fence construction which make the initial cost quite cheap (score of 4). Regular maintenance is needed to ensure it works correctly, including checking on the alarm and replacing batteries which are not considered expensive (score of 3). This method provided lower potential impact to humans from the warning (score of 3 for human impact). Still, the chance of injuries from an unexpected encounter remains (score of 4 for impact to elephants). The overall score using trip alarm fences was estimated at 17.

3. Deterrent methods — discourage the movement of elephants into an area.

a) Chili fences

Chili-based crop protection methods uses ground chili mixed with oil, covered over ropes, and/or clothes hung on fences. The method has been studied in many HEC sites including Cambodia, Indonesia, and Myanmar (Webber et al., 2011; Allendorf et al., 2015; Gunaryadi et al., 2017). When compared to other methods, this method's effectiveness appeared to show less potential in crop damage prevention. Some studies have shown that this method has a wide range of deterrent effects, with reports ranging from elephants avoided touching (or getting close to) chili fences to no deterrent effect (Webber et al., 2011, Enukwa et al., 2017 Gunaryadi et al., 2017). However, during rainy seasons the chili is often washed away (Von Hagen et al., 2023). Hence, the effectiveness of the method overall was considered relatively low (score of 2). Nevertheless, this method is easy to implement, requiring mainly the mixing of ground chili with grease and applying it on fences. However, this method requires some initial costs (~USD$86 per hectare; Chang'a et al., 2016) and has relatively higher maintenance costs although still moderate although potentially higher during rainy seasons (score of 3). Locals need to regularly reapply the chili-mixture on the fences which make its labor intensive (again especially during rainy seasons). Still, this method poses no harm to humans and elephants and chili has the potential of being grown in HEC areas as it appears to be unpalatable to elephants which may help with maintenance costs associated with chili fences (Webber et al., 2011). The impact level to humans and elephants were considered very low (5). The overall score of chili fence was 18.

4. Repulsion methods — drive elephants away from croplands

a) Crop guarding by local people

Crop guarding by locals depends on the active involvement of farmers and community members who live in an area. Guarding has been used in almost every country facing HEC including Cambodia (English et al., 2022), Lao PDR (Khounboline et al., 2003), Thailand (Kochprapa et al., 2023) and elsewhere. When the guarding in the area is intense (people actively protecting their crops regularly), the effectiveness in preventing crop damage is high (score of 4). The use of traditional knowledge and locally-sourced materials (such as utilizing loud noises, firecrackers, flashlights etc.) can be cost-effective making the initial cost for this method low (score of 4). Although effective, the success of guarding requires dedication and cooperation of locals as the guarding team may need to actively protect their crops nearly every night of the year depending on the location (maintenance score of 2). Thus, using this method has significant labor costs and quality of life issues, such as a lack of sleep from guarding all night and the risk of injury or death from elephants. Guarding thus can have high impacts on people and elephants. People guarding are at higher risk of having close encounters with elephants increasing the likelihood of injuries and death (Human impact level was 1). Accordingly, when locals need to protect themselves, it can lead to more lethal methods against elephants which potentially lead to injuries or deaths of elephants (score of 2). The summary score for this method was 14.

b) Patrolling (Response units)

Response units involve a trained group of local community members and park rangers patrolling and driving elephants out of an area. Based on our review only Indonesia, Malaysia (Borneo), and Thailand (Oelrisch et al., 2016; Ghani, A., N., 2019, Kochprapa et al., 2023) were found using this method. There is limited data on its effectiveness, but our previous study comparing various methods at one site, patrolling was at least partly effective in preventing crop damage but still lower when compared to guarding by locals (Kochprapa et al. 2023). This relatively lower level of effectiveness compared to guarding could be due to how efficiently patrols can cover an area, which may be problematic if large areas need patrolling and such areas also need accessibility so that patrols can travel to incident locations quickly. Still, relative to available methods, patrols can be reasonably effective (score of 3). However, this method needs some establishment costs such as trained patrol teams, vehicles, and networking which could cost a moderate amount (initial cost score of 3). Moreover, this method is labor intensive and can be relatively expensive (Kochprapa et al., 2023). In addition, there needs to be strict protocols and trained patrol teams to help in lowering the risks to people and elephants as there is usually more coordination among the groups and such teams have more training in how to safely drive away elephants compared to farmers guarding individually (impact level to humans and elephants were 2 and 3 respectively). The total score of this method was 13 (Table 2).

5. Elephant drives

Elephant drives involve a coordinated effort by trained experts, such as mahouts or elephant handlers, using captive elephants to guide wild elephants away from human settlements, agricultural fields, or other areas where HEC occurs. Overall, studies have shown that such methods were ineffective in reducing conflicts (Effectiveness score was 1). Currently, the method is used in Indonesia (Andyono et al, 2018) and previously in Cambodia (English et al., 2022). It only provides a temporary solution whereby elephants relatively quickly return to the same areas. Elephant drives also require experienced mahouts and captive elephants, which may not be available in all regions. This method can be resource-intensive in terms of personnel and time (initial and maintenance costs of 1). Although no economic data was available for Southeast Asia, there is a report of a drive in Sri Lanka which cost over USD$1 million for driving 250-300 elephants from an area (Fernando, 2008) (Initial and maintenance cost of 1). Furthermore, elephant drives still involve close proximity to wild elephants and can pose risks to handlers and elephants (impact level to humans and elephants of 1). The overall score of this method was 5.

6. Capture — capture problem animals and translocate them

Capturing problem elephants that damage crops and move them from the conflict areas which has been used in Malaysia and Indonesia (Fernando et al., 2012, Kuswanda et al., 2022; Zaini et al., 2023). The method has shown to be ineffective as the problem remains and/or has the potential to simply shift the conflict to another area or community (Effective score was 1). Such problem elephants may still damage the crops after translocation (Shaffer et al., 2019). Furthermore, translocating elephants is relatively expensive including the capture, logistics, and expertise estimated at USD$8800 for a single elephant (Initial costs and maintenance costs scores were rated at 1). The process also has a significant risk to people and elephants during capturing and transporting (Human and elephant potential impact levels were both 1). Capture received a total performance score of 5.

7. Culling – killing or lethal control

Culling involves the removal or killing of individual elephants that are considered problematic due to their repeated involvement in conflicts with humans, particularly when they pose a severe threat to human livelihoods. There is no record of using this method in SE Asia thus we used studies from Africa to evaluate this method (Slotow et al., 2021). This HEC mitigation method was found to be ineffective and does not provide a long-term solution (Effective score was 1). We could not find published estimates of the costs of culling, however based on the costs of capturing and translocating elephants in Malaysia which potentially have at least some of the similar procedures (Zaini et al, 2023), the estimated cost was USD$7,000 (score of 2 on the cost scale). The remaining elephants may still engage in crop damage after culling (Enukwa et al., 2017; Shaffer et al., 2019). Also, killing elephants may also potentially affect the genetic diversity of elephant populations (Chiyo et al., 2011; Fernando and Matsuda, 2019; Shaffer et al., 2019) (impact level of 1). Due to ethical, ecological, and long-term conservation goals, non-lethal methods we considered more sustainable. The total performance score of culling was 7.

8. Compensation schemes

This method provides financial compensation for local people who suffer from crop damage by elephants. The method has been used in many HEC sites but in SE Asia, the only published records were found in Malaysia, Thailand, and Vietnam (Jarungrattanapong et al., 2012, Sinha et al., 2021, Nguyen et al., 2022). Effectiveness was difficult to evaluate; however, it may help to increase tolerance of local people towards elephants (Desai and Riddle, 2015), but some studies have shown that locals often have a negative attitude towards elephants even if compensation schemes are applied (Ladkood and Kullachai, 2018, Sinha et al., 2021). Thus, the effectiveness in using compensation was generally considered low (score of 1). In addition, management of compensation schemes can be problematic. Compensation can be unfairly distributed (however, costs and benefits of living with elephants are unfairly distributed (Anthony et al., 2010), insufficient, furthermore, delayed processes can lower the satisfaction with such a program in a community (Sinha et al., 2021). Moreover, it needs reliable funding to cover most of the local people who may be affected by the conflict long-term. Thus, good governance is particularly important in mitigating HEC. There was little data on the exact amounts spent on compensation schemes, but in Thailand, a government insurance program in 2019 to cover costs from crop damage by elephants was estimated at USD$50 million (Thai PBS, 2019). Thus, the cost for the method is high (cost score of 1 for both implementation and maintenance). From these points, the total performance score of this method was 13.

9. Land-use planning

Land-use planning involves elephant habitat management and uses methods to conserve, restore, and/or improve natural elephant habitats in human-dominated areas or changing over farms to a different form of agriculture, especially cattle farming, to reduce the attractiveness of farms for elephants. Elephant habitat improvement focuses on maintaining resources such as water and saltlicks, in theory reducing the potential incentives for elephants to enter human-dominated areas. Furthermore, increasing connectivity of habitats such as creating ecological corridors could support elephants in accessing more resources and reduce habitat fragmentation, thus promoting biodiversity and could be effective in the longer-term (IUCN, 2020). The effectiveness of land use planning to reduce crop damage frequency was difficult to evaluate but probably depends on the context and the scale of the land-use enhancements. For example, our recent study in Thailand suggested that the availability of resources for elephants did not appear to reduce crop damage by elephants (Kochprapa et al. 2023). We found that elephants still fed on crops if there were crops elephants preferred available in the same general vicinity, even if they were far from the forest edge and with enhanced forage and water supplies available. Furthermore, according to Maifaey (2018), changing from crop agriculture to dairy farming for example could potentially reduce HEC at the individual farm level, but elephants still forage over wide areas and were therefore nevertheless able to find preferred crops on other nearby farms. Overall, we thus rated this method as less effective (score of 1) assuming small-scale land-use change as was typically discussed in the literature. However, presumably large-scale land-use change would have a larger impact on HEC, but we found no regional data to test this. For example, the cost of one cow is about USD$1,000 in Thailand (as of 2024), which suggests that such transitions or similar wholesale changes in farming practice would be extremely challenging for most farmers (Maifaey, 2018) (score of cost of initial investment and maintenance were rated as 1). However, such changes could provide long-term and sustainable strategies that address the root causes of HEC. This strategy requires collaboration between stakeholders (including financial support from governments and conservation organizations). The overall performance score of this method was 13.

10. Alternative crops

Alternative crop cultivation involves the cultivation of crops that are less preferred by elephants. The effectiveness of alternative crops depends on the crop selection, local context, and the willingness of farmers to adopt these practices (Effectiveness score of 2). Furthermore, to reduce the incidents by planting unpalatable crops, typically large-scale adoption is needed for a few basic reasons (Snyder et al., 2020). To implement on a large-scale, local communities need to cooperate with governments or conservation organizations or organize themselves as a community enterprise to develop suitable measures such as finding markets for such alternative crops, funding for changing crops, and conducting market research (Score for cost were 2 for initial and maintenance costs). Moreover, elephants may travel through unpalatable crop areas to access preferred crops if they are available nearby causing damage via trampling (Kochprapa et al., 2023). The unpalatable crops probably need to be a few kilometers in width and length to have practical levels of effectiveness if conventional crops as still available in an area. Nevertheless, local people can benefit from alternative incomes through diversified agricultural practices (Shaffer et al.,2019). The overall score was 16.

DISCUSSION

Overall, despite the limited data available from Southeast Asia, our results have suggested that different mitigation methods have been applied and their effectiveness likely vary considerably along with substantial tradeoffs among methods in terms of costs and impacts to people and elephants. In summary, when looking at the total performance score for each mitigation method (Table 2, Fig. 2), it was possible to group the results into three rough categories, with the top five mitigation strategies having similar scores (16-18 total points), followed by a second group of 6 methods which scored similarly but a few points lower than the top 5 (13-14 points), and then finally the bottom 3 methods which we rated as notably lower overall (5-7 points) in terms of overall performance (Fig. 3).

Using our criteria, the top 5 mitigation methods in terms of total performance scores were chili fences, trip alarm fences, beehive fences, monitoring and surveillance, and alternative crops. The top scoring methods were ranked as having only moderate effectiveness in terms of preventing crop damage by elephants, but these methods were relatively cheap (with some exceptions, see below) compared to other methods and thus likely more realistic for most farmers in Southeast Asia to implement. Typically monitoring/surveillance and alternative crop costs were relatively higher because they require implementation more at the community-scale (greater levels of

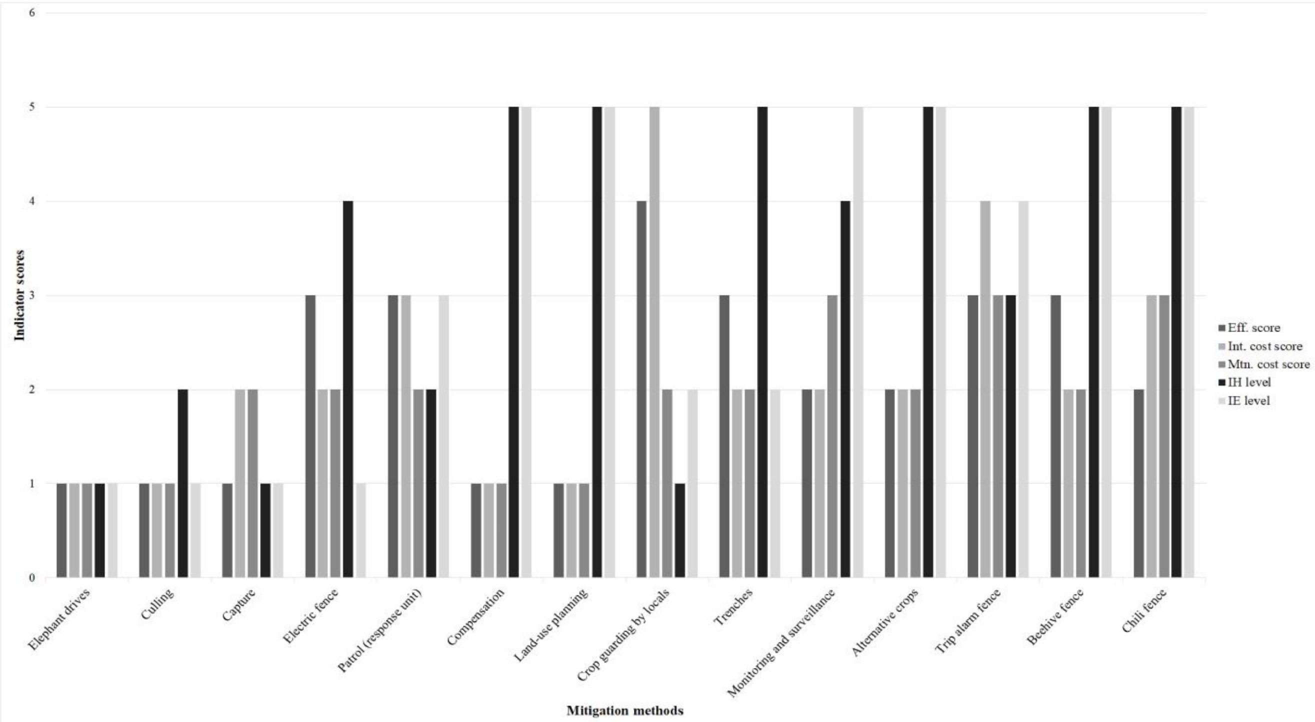

FIGURE 2. Mitigation methods based on scores per indicator. Eff. for Effectiveness scores of mitigation methods, Int. cost for Level of initial costs and Mtn. for maintenance cost, IH for Impact level to humans and IE for impact level to elephants. Effective score was ranked from least effective – most effective at reducing crop damage from elephants (1-5). Level of initial and maintenance cost was ranked by most expensive to cheapest (1-5). Impact to human and elephants were ranked from most negative to most positive impact (1-5).

cooperation among farmers and other stakeholders), rather than at the farm scale. Nevertheless, one of the major advantages of these top-scoring methods was that they pose relatively lower impacts to humans and elephants. The rough scoring heuristic we describe here in effect gave higher scores to mitigation techniques that pose lower impacts to humans and elephants and were overall considered better because they provide modest deterrence and are relatively easier and cheaper for farmers to implement. Still, these methods require some maintenance which could affect their performance, particularly local enthusiasm is needed for implementation or need to be implemented in combination with other lower-impact methods (such as in some monitoring programs) to provide more effective protection.

The six moderately ranked methods included trenches, crop guarding, patrolling, land-use planning, compensation, and electric fences. Although some of these mitigation methods provide potentially greater effectiveness in lower crop damage by elephants, they tended to be expensive or pose higher impacts to humans and/or to elephants. For example, electric fences are frequently used in Southeast Asia and many consider them relatively high in terms of effectiveness, however, due to the high cost of construction and maintenance, this method may be difficult to apply in areas where financial resources are particularly limited. Similarly, while crop guarding by individual farmers might rank higher in terms of effectiveness against crop damage as well as its simplicity and lower financial costs, this method often poses particularly high impacts to humans and elephants. Of particular concern is the quality-of-life issues if farmers need to guard their crops essentially every night of the year such as we observed in Kuiburi, Thailand, where the crop damage occurs almost every night (Kochprapa et al., 2023). Though, according to Gross et al., 2019, higher efforts in guarding did not reduce the crop damage costs if the guarding was applied without a clear strategy. Therefore, a communal strategy or action plan should be considered when guarding. Patrolling on the other hand, was shown as moderate in effectiveness in our ranking system but poses notably lower impacts to humans and elephants compared to guarding by individual farmers. The current limitations for patrolling appear to be related to available human resources and accessibility to effectively cover areas where there is frequent HEC. Government support for more patrol teams, greater accessibility and more guarding stations could potentially increase the ranking/value of this strategy. In addition, joint local and park ranger patrol teams could serve as a key mechanism to reduce tensions between local farmers and protected area managers regarding HEC.

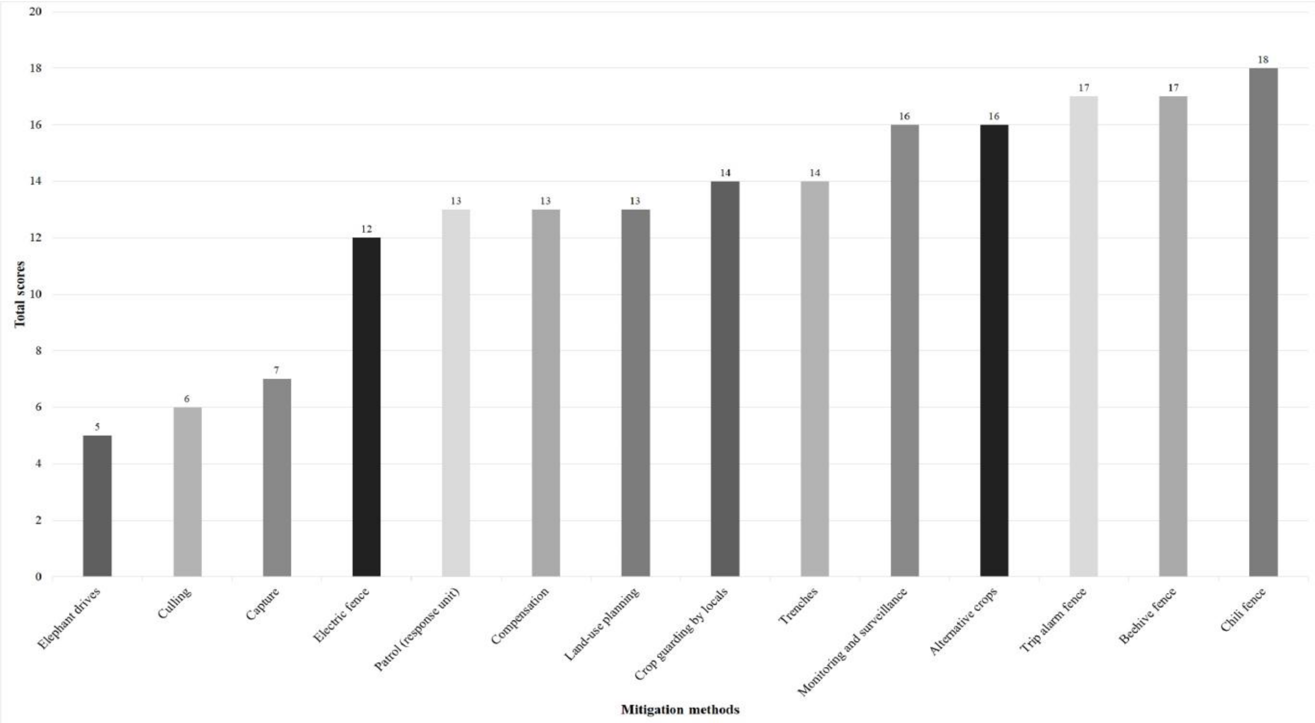

FIGURE 3. Ranking of mitigation methods based on total scores

The final group of methods, capture, culling, and elephant drives scored at the bottom of our ranking system. These three methods have been shown to be relatively ineffective in lowering crop damage and were also considered very expensive. Furthermore, elephant drives, culling, and capture of problematic elephants pose higher impacts to humans and elephants. Culling is employed in some African countries with the purpose of controlling the overpopulation of elephants (Gallagher et al., 2012). However, culling is less likely to be accepted for management of a protected species in Southeast Asian countries due to ethical-cultural considerations (Rubio et al., 2020, Thekaekara et al., 2021). Overall, these three methods held the least promise in terms of their practicality in managing HEC based on our analysis.

In summary, we found that no single mitigation method was a clear winner or was clearly better overall which aligns with previous studies indicating that no method works in isolation and a combination of measures are probably needed (Nelson et al., 2003, Gross et al., 2022). Elephants also become habituated easily, and therefore applying different mitigation methods alternately could be useful in reducing habituation (Perera, 2009). Our results also suggested that the relative performance of a given mitigation method probably strongly depends on the local context in terms of resources available (human and financial), history/culture, and the local landscape ecology. The trade-offs will also greatly depend on the costs of the crop damage caused by elephants, in which farms suffering from extensive damage may require the most expensive, but low impact mitigation options, which would also require extensive financial support from governments and/or wildlife non-governmental organizations. We encourage managers and communities to consider multiple factors when choosing mitigation methods: 1) resources (human and financial), 2) scale (time and spatial scale), 3) potential impacts (to people and elephants), and 4) potential for community engagement. Our study used simple methods to assess the potential as well as limitations and the trade-offs inherent in choosing among the currently available mitigation methods important for management planning. Understanding the cost-effective-impact ratio could assist locals in making decisions about current and future use of their resources. Communities may need assistance to consolidate their resources, organize themselves, and find the most suitable methods to implement (Sugiyo et al., 2016). More detailed assessments of mitigation methods will require more data and more complex calculations for detailed decision making, however the heuristic we have outlined here may offer a first step in the process. As HEC is highly affected by site-specific variables, stakeholders can begin to at least assess the overall benefits, costs, and trade-offs involved. Additionally, we did consider the impacts to the environment from mitigation methods but there was not enough data available to make an informed assessment. Further studies of potential ecological or environmental impacts of mitigation methods should be considered. Likewise, further studies of mitigation methods in Southeast Asia could provide more useful evidence for evaluation of these methods.

Finally, at the individual farm scale, community collaboration methods are likely to be key, potentially used in combination with less risky methods such as trip alarm fences, beehive fences and/or monitoring and surveillance to reduce burdens on patrol teams. Then, at the community level, plans toward the development of alternative crops and further to land-use planning including increased connectivity and creation of corridors to reduce forest fragmentation will be needed for longer-term coexistence.

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