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Beehive fences as a sustainable local solution to human-elephant conflict in Thailand

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Abstract

As human-elephant conflict (HEC) increases, a better understanding of the human dimensions of these conflicts and non-violent mitigation methods are needed to foster long-term coexistence. In this study, we conducted household questionnaires ($n = 296$) to assess the prevalence of HEC and attitudes towards elephants in four rural villages in Thailand. In addition, we evaluated a pilot beehive fence as a sustainable solution for HEC. The majority of the households reported seeing or hearing elephants near their property at least once a week (84.9%) and experienced negative impacts from elephants in the last 5 years, (81.0%). The beehive fence deterred 88.4% of individual elephants ($n = 155$) and 64.3% of elephant groups ($n = 28$) that approached the fence. Most elephants (70.7%) exhibited behaviors suggesting heightened attentiveness or alarm. The farm owner reported economic and social benefits of the beehive fence. By contributing to farmer income and reducing crop damage caused by wild elephants, beehive fencing may provide an important locally-managed complement to regional HEC mitigation methods.

KEYWORDS

asian elephants, beehive fence, camera-traps, citizen science, coexistence, crop raiding, human dimensions, human-elephant conflict, sustainability

1 | INTRODUCTION

The Asian elephant (*Elephas maximus*) is categorized as endangered on the IUCN Red List (Choudhury et al., 2008) with an estimated population of fewer than 50,000 individuals (Fernando & Pastorini, 2011). Habitat loss has been a major cause of population decline (Calabrese et al., 2017), forcing elephants to find food and water outside protected areas (PAs), resulting in crop loss, property damage, injuries, and death of both humans and elephants (Shaffer, Khadka, Van Den Hoek, & Naithani, 2019 and references therein). Hence, human-elephant conflict (HEC) represents a significant challenge for the long-term coexistence of humans and elephants (Fernando et al., 2008; Shaffer et al., 2019; Sukumar, 2006; Van de Water & Matteson, 2018).

Since people are an integral part of HEC, understanding the social fabric of communities that live with elephants is fundamental to developing effective solutions (Shaffer et al., 2019). People's attitudes and tolerance towards wildlife are influenced by cultural, religious and economic values and socio-economic factors, including gender, age, education, and source of livelihood (Jhala et al., 2019; Western, Nightingale, Mose, Sipitiek, & Kimiti, 2019). Importantly, negative interactions with elephants have been shown to be related to feelings of resentment (Van de Water & Matteson, 2018). For these reasons, solutions for HEC must be grounded in the context of the people that live in direct contact with elephants.

In several African countries, fences outfitted with African honey bee (*Apis mellifera scutellata*) have been proven to successfully deter African elephants (*Loxodonta africana*) from farms while providing additional income (Branco et al., 2020; King, Lala, Nzumu, Mwambingu, & Douglas-Hamilton, 2017). African honey bees also have been useful in deterring elephants from bark stripping large trees (Cook, Parrini, King, Witkowski, & Henley, 2018). In Sri Lanka, Asian elephants have been shown to move away from the buzzing sound produced by Asian honey bees (*Apis cerana indica*) (King et al., 2018). Beehive fences may be particularly effective because bee stings inflict short-term pain to which elephants do not habituate, just like chili or electric fences (Vollrath & Douglas-Hamilton, 2002). In Thailand, Italian honey bees (*Apis mellifera ligustica*) have been used for honey production for over 70 years (Phankaew, 2016) and thus are widely managed in the region. As compared with the Asian honey bee, the Italian honey bee is considered more desirable for beekeeping because of its higher honey production and less tendency to swarm (Schneider, 1990). However, unlike African honey bees, Italian and Asian honey bees are less aggressive and relatively inactive at night (Hoare, 2012) when most crop damage occurs, which might affect their capability to deter elephants. A recent experiment with captive elephants using Italian honey bees in Thailand showed that 51.0% of the elephants did not cross the beehive fence, a success rate that decreased to 34.0% during the second trial (Dror et al., 2020).

The aim of this study is to gain more insight into the potential of beehive fencing with Italian honey bees to mitigate crop damage by Asian elephants in Kaeng Hang Maeo district, a HEC hotspot in Eastern Thailand (Kitratporn & Takeuchi, 2020). Specifically, the research has the following objectives: (a) to evaluate the prevalence of HEC and attitudes towards elephants in the HEC hotspot using questionnaire data, and (b) to pilot test the effectiveness of a fence outfitted with Italian honey bees for deterring elephants on a farm using motion-sensing camera traps and qualitative interview data. Camera traps are a suitable technique for observing elephant responses to beehive fences because they can capture fence break attempts as well as behavioral responses and variables such as elephant group size, age, and sex, which may influence the likelihood of fence-breaking. Previous research showed, for example, that fence-breaking more often occurs in small groups of elephants (King et al., 2017), and that male elephants tend to take more risks than cows and calves (Hoare, 1999; Kioko, Kiringe, & Oduor, 2006). Moreover, to avoid confrontations with people and reduce visibility, some elephants may prefer to feed on crops after dark and on nights with less moonlight (Gunn et al., 2014). Therefore, we also evaluated the effect of group size, sex, and full moon on elephant behaviors. We hypothesized that small groups, all-male groups, and dark nights would increase the likelihood of fence-breaking. To verify evaluations of the potential of the beehive fence based on camera trap data, and to gain more in-depth insight into important aspects that influence the perceived effectiveness and socio-economic benefits of the beehive fence, we conducted post-study interviews with the farm owner.

2 | METHODS

2.1 | Study area

The study was conducted in Pawa sub-district in Kaeng Hang Maeo district of Chanthaburi province in Eastern Thailand, an area defined as HEC hotspot (Kitratporn & Takeuchi, 2020). Kaeng Hang Maeo district has a population of 37,698 and population density of 30.1/km^2 (National Statistical Office, 2010). The district is dominated by agricultural land (mostly cassava, rubber, and oil palm) and is surrounded by the PAs Khao Ang Rue Nai Wildlife Sanctuary, Khao Soi Dao Wildlife Sanctuary, Khao Sip Ha Chan National Park, and Khao Chamao-

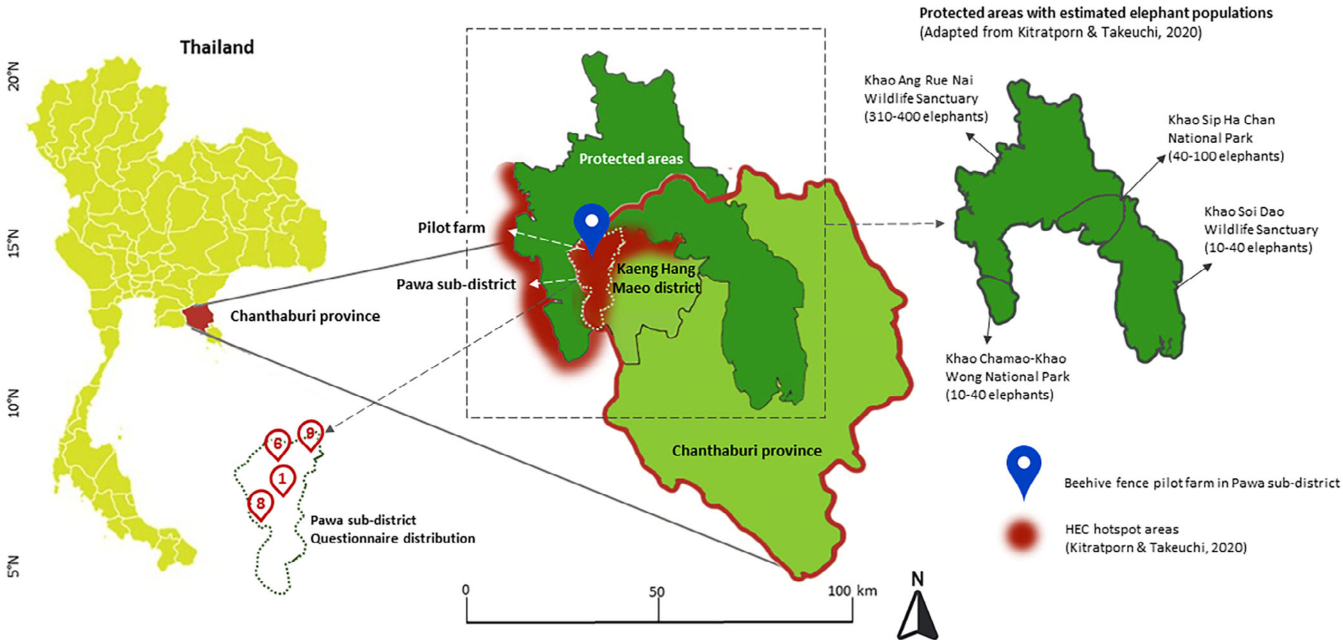

FIGURE 1 Map of Thailand indicating Chanthaburi province in Eastern Thailand (left). The pilot farm is located in the Pawa sub-district, in Kaeng Hang Maeo district, which is surrounded by protected areas. The HEC hotspot areas in Kaeng Hang Maeo district are indicated as transparent red (center) (adapted from Kitratporn & Takeuchi, 2020). The questionnaires were distributed in Villages 1, 6, 8, and 9 of Pawa sub-district

Khao Wong National Park (Figure 1). The PAs serve as a habitat for a growing population of several hundred wild elephants (Jarungrattanapong & Sajjanand, 2012; Menkham et al., 2019), with some PAs reaching a population density of 0.2 elephants/km^2 (Kitratporn & Takeuchi, 2020). Elephants often exit the PAs and individuals can wander as far as 30 km from the boundaries (Suksavatea, Duengkaeb, & Chaiyes, 2019). In 2012, approximately 70–80 elephants lived in the area between the PAs and agricultural land (Jarungrattanapong & Sajjanand, 2012).

2.2 | Study procedures and instruments

2.2.1 | Household questionnaire

In October 2017, we surveyed 296 households in four villages in Pawa sub-district including Village 1 ($n = 146$), Village 6 ($n = 25$), Village 8 ($n = 100$), and Village 9 ($n = 25$), representing 33.8% of the total number of households. The household questionnaire (Supporting Information 1) was adapted from a previous study we conducted in Western Thailand (Van de Water & Matteson, 2018) and addressed the prevalence of HEC. The content of the questionnaire was discussed with representatives from the Phuluang Wildlife Research Station, who, in turn, explained it to the village leaders. The village leaders facilitated the distribution of the translated and printed questionnaires. The village leaders approached houses evenly distributed through the HEC area. All community members above 18 years old that were present at the moment were eligible to participate in the study. For this study, we focused on six questions: (a) How often do you see or hear elephants near your property?; (b) Over the last 5 years, did you or your family members gain any benefit from living near wild elephants? (e.g., financial benefits through ecotourism, conservation jobs or from beehive fences, feelings of pride to live near wild elephants or feelings of satisfaction/pride to participate in conservation work); (c) Over the last 5 years, did you or any of your family members experience a negative impact from elephants? (e.g., crop damage, property damage, human injuries or death, fear, lack of sleep, or stress); (d) Have you ever tried any methods to deter the elephants?; (e) Do you feel it is important to invest in elephant conservation?; and (f) Which statement describes your future plans regarding crop damage most accurately?

2.2.2 | Beehive fence pilot study

In July 2016, we started a beehive fence pilot study in one subsistence farm in Pawa sub-district. The farm is located at about 10 km distance from the PAs on a migration route of wild elephants. The 0.4 ha farm was surrounded with a 250 m bamboo fence that included

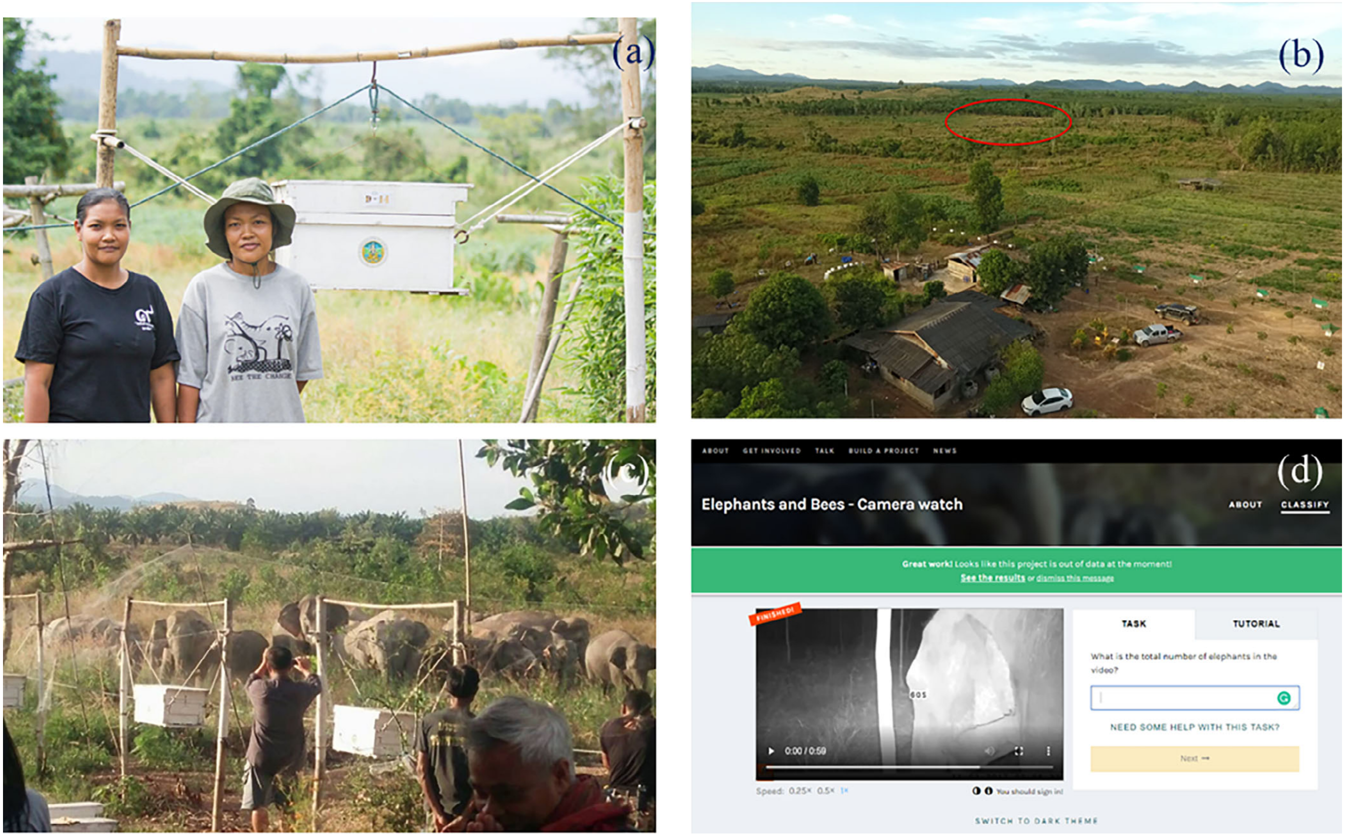

FIGURE 2 (a) The owner of the beehive fence and her sister, showing the trigger mechanism which opens the hive during a fence-breaking attempt, (b) the farm and part of the beehive fence, with a herd of elephants (circled in red) and the PA in the background, (c) herd of wild elephants behind the beehive fence, (d) a screenshot of the Zooniverse citizen science interface which was launched in January 2019

40 Langstroth beehives affixed to the fence with ropes (Figure 2a–c) (King, 2019). All hives were occupied by large and healthy Italian honey bee populations at the start of the study. To adapt the fence to the smaller Asian elephants and increase the number of bees, the distance between the hives was reduced to 6 m (10 m is common for African elephants) and no "dummy hives" were used (hive look-alikes used to reduce costs). Beehives were outfitted with a low-cost trigger mechanism developed by the Phuluang Wildlife Research Station, which opens the hives to activate dormant bees during fence-breaking attempts occurring at night (Figure 2a). The hive opens when an elephant pushes the rope and closes again when the rope is released. The trigger mechanism is only implemented when a strong bee colony has been established. We never observed any indication that bees were disturbed to the point that they would abscond. At the time of the study, the farm included mango, tamarind, starfruit, banana, and papaya trees and had water tanks, making the property attractive to elephants.

To observe elephant reactions to the beehive fence, 12 motion sensor-triggered Bushnell Trophy Cam HD camera traps were installed on trees near the fence at 1.5 m above the ground. The camera traps were programmed to record 30 or 59 s with an interval time of 3 s between each video clip. The pilot study continued for 17 months, from August 1, 2016 to December 31, 2017. We initially considered monitoring a nearby control farm, but farmers could not be refrained from using additional deterrent measures such as firecrackers and noise. Respecting the farmers' methods for protecting their livelihood, and due to a resulting lack of standardization with the experimental plot, we did not continue data collection in the control farm.

2.2.3 | Post-study farm-owner interviews

After the pilot study, we conducted two semi-structured interviews with the farm owner. The first interview took place at the end of the study period in January 2018. As the owner kept the beehive fence after the study, we conducted a second interview in September 2019 in order to provide a longer-term perspective on the benefits of beehive fences. Topics discussed in the interviews were

(a) main challenges of managing a beehive fence, (b) the perceived effectiveness of the beehive fence and changes compared to the situation before the beehive fence was installed, (c) how the beehive fence impacted the owner's life, and (d) whether the owner would recommend beehive fencing to other people in HEC areas.

2.3 | Data analysis

2.3.1 | Video clips classification

In collaboration with the Future For Nature Academy (www.ffnacademy.org), we initiated a citizen science project to help classify elephant behavior in the recorded video clips and to increase public awareness of HEC. Video clips were uploaded to the Zooniverse citizen science platform (www.zooniverse.org) in January 2019 (Figure 2d). Citizen scientists were recruited among biology and environmental science students from the Netherlands, UK, Sweden, France, South Africa, Australia, Canada, and the United States. The video clips were classified by 44 citizen scientists. All citizen scientists were given a field guide for identifying sex, age and elephant behavior, plus a tutorial that explained the classification process on Zooniverse (Supporting Information 2).

For each video clip, citizen scientists classified the total number of elephants, their sex (bull or cow) and whether or not any elephants crossed the fence. The behavior of elephants in response to beehives was classified according to behavioral categories indicating a heightened level of attentiveness or alarm (e.g., touching the fence, fleeing, foot swaying, ear flapping; Supporting Information 3). In addition, citizen scientists estimated their level of confidence in each classification (fully confident, quite confident, a bit confident, not confident at all/poorly visible). In total, our data included 804 citizen science classifications of 108 video clips with each video clip having a median of eight classifications. For each video clip, classifications from citizen scientists were aggregated as the median for the number of elephants and the most frequent selected category for sex, fence-breaking, and behavior (Swanson et al., 2015; Swanson, Kosmala, Lintott, & Packer, 2016). To prevent double-counting, video clips recorded within 60 min of each other were considered the same attempt to fence-breaking from the same group of elephants, resulting in 28 independent events of fence-breaking attempts. In the independent events, elephant group size was calculated as the maximum number of elephants observed in the clips belonging to that event.

To validate the results, classifications from citizen scientists were compared with classifications provided by five experts (researchers with several years of elephant field experience). All video clips had at least one expert classification. Whenever experts disagreed about the classification of a video clip, the first author made the final authoritative identification. Although less than half (44.3%) of the citizen scientists reported feeling "fully confident" or "quite confident" in their classifications, their classifications broadly corresponded to those of the experts for the number of elephants in the video clips (81.3% exact concordance with expert classifications; 92.8% concordance ±1 elephant) and for whether or not the fence was breached (92.5% concordance with expert classifications). Citizen scientists were less reliable in classifying the sex of the elephants in the video clips (71.6% concordance with expert classifications; Table A1). Because of the higher reliability, we only used expert classifications for the variables number of elephants, fence breach and sex in the statistical analysis. All classifications of elephant behavior were compared and if a type of behavior was not mentioned by all classifiers, the first author watched the specific video clip again to decide whether or not that behavior should be included in the analysis.

2.4 | Statistical analysis

Household questionnaire data were analyzed using descriptive statistics. For the beehive fence pilot study, we used statistical models to assess how elephant group size, the proportion of males per group, and moonlight affected the likelihood of fence-breaking. We performed the analysis for both the 108 individual video clips and the 28 independent events. For the individual video clips, we fit a generalized linear mixed model with fence-breaking (yes or no) as the binomial dependent variable. The number of elephants, sex of the group (all male or not), and percentage moon light (retrieved from www.vercalendario.info) observed in each clip were used as explanatory variables. Since individual video clips were not all independent (some were from the same group/event as mentioned above), we used a random effect for each group/event classification. For the 28 independent events, we conducted a similar analysis using logistic regression and the same explanatory variables. All statistical analyses were performed using SPSS Statistics version 25 and alpha was set at .05.

3 | RESULTS

3.1 | Household questionnaire

Table 1 presents demographics, HEC prevalence, and attitudes towards elephants of the respondents as per household questionnaire. The sample consisted of slightly

TABLE 1 Descriptive statistics, HEC experience, and attitudes towards coexistence and conservation among household survey respondents in Pawa sub-district (n = 296)[a]

	N (%)
Gender	
Male	116 (42.8)
Female	155 (57.2)
Age	
≤40 years	124 (45.8)
>40 years	147 (54.2)
Average monthly income	
<10.000 THB	106 (40.5)
>10.000 THB	156 (59.5)
Frequency of seeing/hearing elephants near property	
Almost daily	149 (51.0)
Once or twice a week	99 (33.9)
2–3 times a month	36 (12.3)
A few times a year	6 (2.1)
Once a year or less	2 (0.7)
Experienced negative impact from HEC over last 5 years	
No	52 (19.0)
Yes	221 (81.0)
Perceived change in HEC over last 5 years	
Increasing	211 (80.2)
Stable	42 (16.0)
Decreasing	10 (3.8)
Experienced benefit from elephants over last 5 years	
No	248 (90.5)
Yes	26 (9.5)
Feelings toward coexistence with elephants	
Tolerant	9 (4.1)
Conditional tolerant	143 (64.7)
Eradicate	69 (31.2)
Feelings toward investing in elephant conservation [a]	
Not important	194 (65.5)
Important	103 (34.8)
Future plans related to crop damage by elephants	
Continue current farming practices	49 (16.6)
Sell plantation if crop damage does not stop	30 (10.1)
Find better methods to prevent crop damage	45 (15.2)
Change to crop elephants dislike	117 (39.5)
Commonly used methods to deter elephants	
Lights	131 (44.3)
Noise	105 (35.5)
Electric fence	61 (20.6)
Fire	53 (17.9)
Unelectrified fence	18 (6.1)
Firecrackers	18 (6.1)
Gunshots	9 (3.0)
Revving of vehicle engine	8 (2.7)
Beehives	7 (2.4)
Chasing	6 (2.0)

[a]Not all numbers add up to 296 as some respondents skipped questions.

[b]In the original question, respondents could indicate multiple reasons why they felt it is important or not important to invest in elephant conservation; some respondents listed both reasons for and against investing in conservation. Among those that gave exclusive answers, 30.1% felt it was important and 69.9% felt it was not important to invest in elephant conservation.

more women, and just over half of the respondents were 41 years and older. About 40% stated to earn less than 10,000 THB (286 USD) a month.[1] The majority of the respondents reported seeing or hearing elephants near their property at least once a week (84.9%), and half of them reported encountering them daily. The majority stated that HEC was increasing (80.2%), that they had experienced a negative impact from elephants (81.0%), and that they or their family had not gained any benefit from living with elephants (90.5%). When asked about their feelings towards coexistence, almost two-thirds of the respondents reported to be conditionally tolerant (i.e., only if elephants would stop causing damage); about one-third preferred local eradication of elephants and only a small percentage was unconditionally tolerant. Two-thirds of the respondents stated not finding conservation investments important (footnote “b” in Table 1). The most commonly used methods to deter elephants were the use of lights, noise (banging/shouting/alarm), electric fence, fire, non-electrified fences, firecrackers, revving engines/chasing elephants by vehicle, and gunshots. When asked which statement described their future plans related to crop damage, only a minority of respondents believed they would be able to continue current farming practices, whereas about 15–40% believed better mitigation measures (e.g., changing to a different crop) would be needed.

3.1.1 | Elephant behavior and effectiveness of the beehive fence

In total, we observed 155 elephants in 108 video clips of 28 independent events (Table 2). The majority (59.2%) of

TABLE 2 Descriptive statistics of 108 camera trap video clips showing a total of 155 elephants approaching the beehive fence in Pawa sub-district at night time

	***N* (%)**
Total number of elephants	
Observed	155
Crossed the fence	18 (11.6)
Total number of elephant groups	
Observed	28
Crossed the fence	10 (35.7)
Mean number of elephants	
Elephants per video clip	1.8 (range 1–6)
Elephants per event	5.5 (range 1–37)
Median elephant group size	1
Sex of elephants in video clips ($n = 155$)	
Male	63 (40.8)
Female	92 (59.2)
Elephants per event ($n = 28$)	
All-male elephant groups	10 (35.7)
% of all-male elephant groups crossed the fence	3 (30.0)
Mixed-sex elephant groups	10 (35.7)
% of mixed-sex elephant groups crossed the fence	5 (50.0)
Solo females	8 (28.6)
% of solo females crossed the fence	2 (25.0)
Behavior observed by elephants near the beehive fence ($n = 174$)	
Relax	51 (29.3)
Attentive	85 (48.9)
Alarmed	38 (21.8)

the observed elephants were female. There was an average of 1.8 elephants per video clip and 5.5 elephants per event (video clips of the same event combined). Five events with groups of more than 10 elephants were recorded. Of those five groups with more than 10 individuals, only one group crossed the fence. Two-thirds of the fence-breaking attempts had three elephants or less. Sex of the elephant groups was approximately equally distributed, with 35.7% of the groups approaching the fence all-male groups, 35.7 mixed-sex groups, and 28.6% solo-female. Mixed-sex groups more frequently crossed the fence (50.0%) than all-male groups (30.0%) and solo-females (25.0%). Video clips indicated that the newly installed beehive fence deterred 64.3% of the elephant groups ($n = 28$) and 88.4% of the individual elephants ($n = 155$) that approached the fence. In the majority of the elephant-fence interactions (70.7%), the elephants exhibited some type of attentive or alarm behavior (Figure 3). The most commonly observed behaviors were touching or reaching out to the fence and slowly retreating or fleeing. Elephants also exhibited interruption of other behaviors (freezing), spreading of ears, ear flapping, tail in the air, and other behaviors in response to the beehive fence (Figures 3 and 4).

The generalized linear mixed model of the 108 video clips indicated no effect of elephant group size, all-male groups, or proportion of the moon illuminated on the likelihood of breaking the fence Table 3). Similarly, the logistic regression on the 28 independent events indicated no effect of elephant group size, all-male groups, or proportion moonlight. The proportion of moonlight was not correlated with elephant group size (Pearson's correlation = −0.029, $p = .882$).

During the 17 months of the study, most fence-breaking attempts (82.2%) happened between late August and early November. Figure 5 shows the percentages of individual elephants deterred by the beehive fence over time. The regression analysis shows that the deterrent rate of the beehive fence remained constant over the 17 months of the study ($p = .77$, $R^2 = 0.0229$).

3.1.2 | Post-study farm-owner interviews

When asked about the beehive fence's challenges during the post-study interview, the owner stated that the main challenge was the damage from bee-eater birds (e.g., *Merops orientalis*). She frequently had to ask support from the Phuluang Wildlife Research Station and others to develop solutions to mitigate this problem. The owner also noted that at the start of the project, she was not fully prepared for the amount of work beekeeping requires, nor for receiving all the people that visited to see the beehive fence and interview her. However, while she needed time to understand beekeeping, she emphasized that she started preferring beekeeping compared to agricultural work once she got used to it.

The farm owner stated she perceives the beehive fence as an effective method to deter elephants. She believed it was likely that all elephants that approached the fence would have entered the farm if not for the beehives. She stated that before the beehive fence implementation, the farm was damaged by elephants nearly every night, whereas after the fence was installed, the elephants only entered 1–2 times per month. When elephants breached the fence, she or her family members typically repaired the bamboo poles that were pushed over and closed the hives the next morning. Damage that

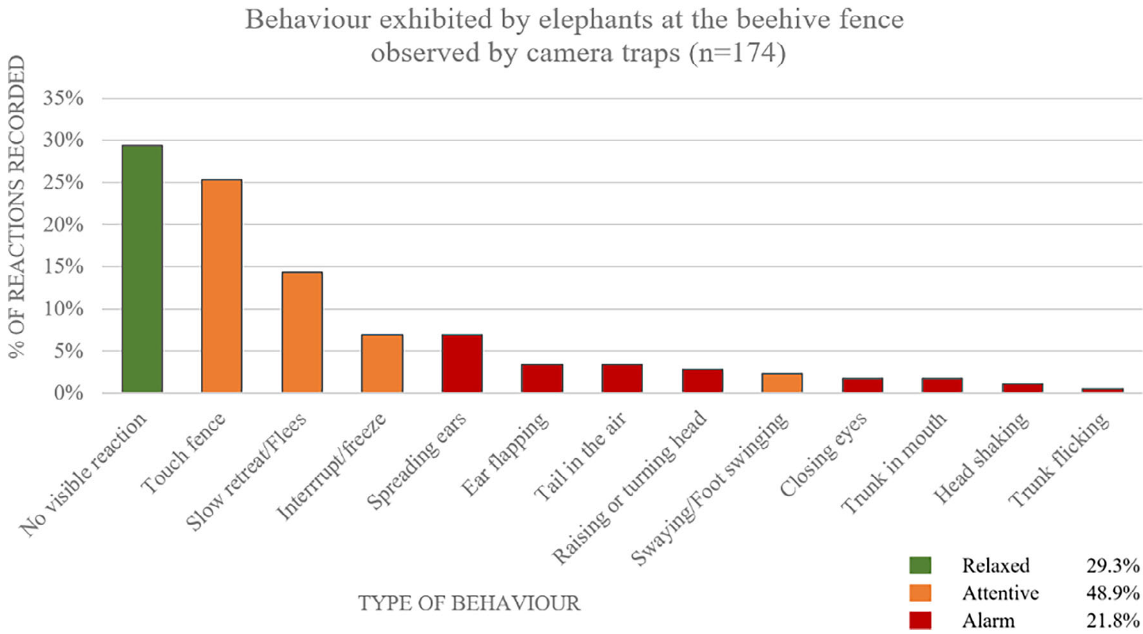

FIGURE 3 Classification of 174 observations of behaviors exhibited by the 155 elephants (the same elephant can show more than one behavior)

FIGURE 4 (a) an elephant closing its eyes when touching the fence, (b) an elephant spreading its ears, and (c) an elephant retreating with its tail in the air. Overall, 70.7% of behaviors suggested a heightened level of attentiveness or alarm

TABLE 3 Results of the generalized linear mixed model of 108 video clips and logistic regression of 28 independent events predicting the likelihood of elephants crossing the fence

Variable	P-value	Coefficient (95% C.I.)
Generalized linear mixed model ($n = 108$)		
Elephant group size	0.388	−0.261 (−0.860–0.337)
All male groups	0.937	0.060 (−1.499–1.570)
Proportion of moon illuminated	0.353	−0.011 (−0.034–0.012)
Logistic regression ($n = 28$)		
Elephant group size	0.556	−0.034 (0.864–1.082)
All male groups	0.390	−1.045 (0.033–3.802)
Proportion of moon illuminated	0.147	−0.020 (0.954–1.007)

occurred the year prior to installing the beehive fence included two water containers (5,000 THB/157 USD each), a car, the house, and to mangos, bananas, and papayas that would otherwise be sold. During the 17-month trial, the beehive fence produced 250 kg of honey, which generated ~50,000 THB (1,650 USD). The owner raised bee queens and sold occupied beehives to neighboring farmers for 20,000 THB (660 USD). Additionally, the owner stated she experienced benefits such as pride, skills development, and monetary benefits from hosting groups of local and international students interested in the beehive fence model. Furthermore, she stated that the method convinced her family to reduce the use of pesticides to maintain healthy bees and that the project helped to connect with nature. Finally, she stated that she experienced well-being by helping other people in HEC areas and by being able to care for her aging parents, as she and her sister could work at home instead of on neighboring rubber farmlands.

4 | DISCUSSION

The first objective of this multi-method study is to evaluate the prevalence of HEC and attitudes towards elephants in four rural villages in Thailand. Findings from our household survey and post-study interviews confirm that HEC is widespread and increasing in Kaeng Hang Maeo district, which is confirmed by Kitratporn and Takeuchi (2020). The majority of households in the Pawa sub-district stated they encounter elephants weekly and directly experience negative impacts from elephants, including damage to crops and property. Only a small proportion of villagers stated that they would continue current farming practices if HEC would persist, suggesting that the majority would be forced to either discontinue or change their practices. Yet, despite the scale and severity of HEC, most villagers in our study stated they do not support local eradication of elephants but prefer conditional tolerance. In addition to the widespread impact of HEC, our findings demonstrate that the majority of villagers do not gain any benefits from living near elephants. Potentially as a consequence of this, most of them do not feel it is important to invest in conservation. This idea is in line with qualitative findings from our farm-owner interviews, which highlight the importance of socio-economic benefits in realizing peaceful coexistence with elephants. Taken together, our results highlight a need for sustainable, integrated solutions that not only reduce damage by elephants but also increase their value for local people.

The second objective of this study is to evaluate the potential of beehive fences outfitted with Italian honey bees to deter elephants in Thailand. The *beehive* fence deterred 64.3% of the elephant groups and 88.4% of the individual elephants. Camera trap video clips reveal attentive and alarm responses of elephants at the fence, providing evidence of specific behavioral reactions to the presence of bees. In addition, the farm owner reported a significant reduction in crop damage after the fence was installed, as well as additional monetary and non-monetary benefits, including substantial supplemental income from the sale of honey and honeybee queens. These results suggest that beehive fences can be a sustainable local method to reduce crop damage by elephants and to generate supplemental income for farmers in Thailand. Implementation of beehive fences might be prioritized on smaller farms that are most proximal to significant elephant populations or located along commonly utilized elephant pathways.

The success rate of beehives in deterring elephants in our study (88.4%) is higher than that of a recent beehive fence experiment conducted with captive elephants in Thailand (51.0%, Dror et al., 2020). The difference may be due to differences between captive and wild elephants in social and physical conditions, stress levels, interactions with/exposure to humans and bees. For instance, captive elephants may be desensitized to situations that wild elephants would find alarming or are less likely to have encountered and developed fear for bees as compared to wild elephants with home ranges as large as 600 km^2 (Choudhury et al., 2008). Moreover, the experimental set-up in Dror et al. (2020) consisted of an enclosure with a bucket containing sunflower seeds, sugarcane, and bananas, which may encourage elephants more compared to a real farm situation in which elephants have less obvious rewards and the additional risk of being chased by farmers. Furthermore, the hives need time to establish large and healthy populations, which may not have been reached during trials over five consecutive days. Contrary to Dror et al., 2020, our findings suggest no habituation of elephants to the beehive fence for the 17 months of the study (Figure 5).

In addition to evaluating the overall potential of the beehive fence, we examined several variables that might affect the likelihood of elephants breaking the fence. Our results indicated no effect of elephant group size, all-male groups, or the proportion of the moon illuminated on the likelihood of elephants crossing the fence. This contrasts with studies that found crop damage to be more prevalent in relatively smaller groups (King et al., 2017; Kioko et al., 2006) and all-male or male-dominated groups (Srinivasaiah, Kumar, Vaidyanathan, Sukumar, & Sinha, 2019). Interestingly, compared to similar studies (e.g., King et al., 2017), we observed larger breeding herds near the beehive fence. Breeding herds of elephants may avoid damaging crops due to the presence of calves or other more vulnerable individuals. Our study showed that about two-thirds of the fence-breaking attempt events had three elephants or less, which is in concordance with findings from Kenya (i.e., 73%; King et al., 2017) and Indonesia (i.e., 74%; Nyhus, Tilson, & Sumianto, 2000). Compared to other studies, we observed a more equal distribution of all-male elephant groups, mixed-sex groups and solo females. In contrast, the majority of the elephants approaching the beehive fence in Kenya were males (King et al., 2017) and all of the elephants feeding on crops in a study in Tanzania were males (Smit, Pozo, Cusack, Nowak, & Jones, 2019). This may be because large breeding herds are permanently living outside PAs at our study site and, for safety reasons, fewer males may be living solitary. We have frequently witnessed adult males following breeding herds at a close

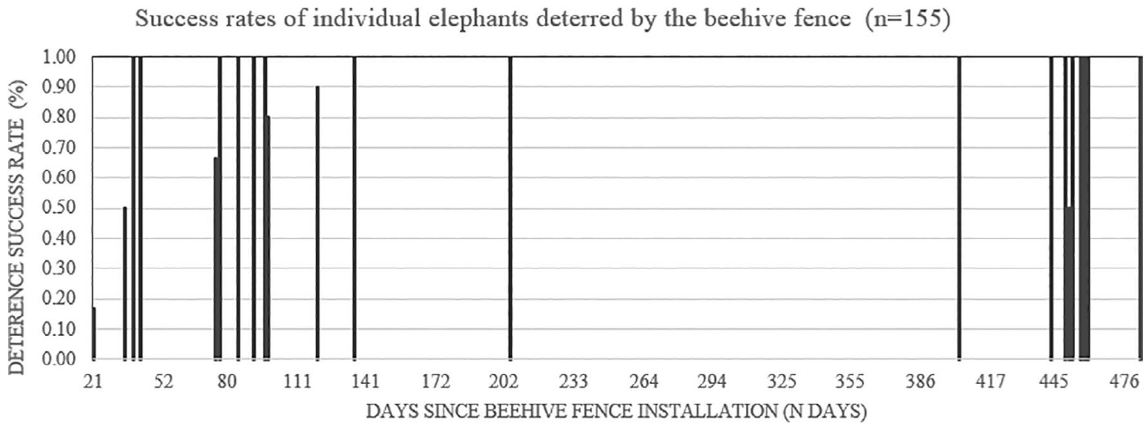

FIGURE 5 Success rates of individual elephants deterred by the beehive fence (% of individual elephants deterred on the total number of elephants approaching the fence) since the start of the study (August 1, 2016), by the number of days after the beehive fence has been installed

distance. In other HEC situations, it may be more common for breeding herds to stay inside PAs whilst bulls roam to nearby farmland.

The video clips showed that all of the fence-breaking attempts happened at night, which is in line with previous research (Gaynor et al., 2018; Gunn et al., 2014). We did not find a significant effect of moonlight on fence-breaking attempts. This may be due to the relatively small sample size and time duration of our study, or because other factors such as seasonality played a role. During the 17-month trial (August 2016–December 2017), 89.3% of the events happened between late August and early November, which is the rainy season in this province. Therefore, seasonality and the availability of plants that reward risk-taking behavior may have played a more significant role than moonlight on crop damage in this pilot study.

More than two-thirds of the elephant-fence interactions indicated some type of attentiveness of alarm, such as touching or reaching out to the fence, a sign of investigation or responsiveness (Bates et al., 2007; Polla, Grueter, & Smith, 2018; Poole & Granli, 2009), or elephants slowly retreating or fleeing from the threat (Poole & Granli, 2009). Another common response was an interruption of other behaviors (freezing), typically expressed when elephants use their senses to locate or identify a threat. These findings are in line with studies describing African elephants to exhibit freezing and slow retreat behaviors when confronted with African bees (King, Douglas-Hamilton, & Vollrath, 2007; Ndlovu, Devereux, Chieffe, Asklof, & Russo, 2016), both indicators of subordination (De Silva, Schmid, & Wittemyer, 2017). Other exhibited attentive or alarmed behaviors were the spreading of ears (expression of alarm, excitement or surprise, Poole & Granli, 2009), flapping ears (Ndlovu et al., 2016), tail in the air (fearful, playful or excitement, Poole & Granli, 2009). As bee stings are especially painful up the trunk, around the eyes and behind the ears (King, 2019), we specifically looked for behavior that would indicate elephants protecting these sensitive areas. Indeed, we observed elephants closing their eyes, putting their trunk in their mouth, and flapping their ears when attempting a fence break. Interestingly, our study showed that only 1.1% of the elephants responded to the bees with headshaking, which seems to be a more common reaction to bees in African elephants (King et al., 2007; Ndlovu et al., 2016; Soltis, King, Douglas-Hamilton, Vollrath, & Savage, 2014). However, our results are in line with the findings of a study in Sri Lanka that showed that none of the Asian elephants expressed head shaking as a response to bees (King et al., 2018). This difference could be explained by the fact that headshaking by African elephants indicates annoyance or disapproval and may be used to threaten others (Poole & Granli, 2009) whereas in Asian elephants it may indicate subordination (De Silva et al., 2017). Additional camera trap studies of elephant behaviors at beehive fences may enable additional comparisons across regions and in different ecological and social contexts.

In terms of data accuracy, we found that citizen science classifications of elephant number and fence break were largely in concordance with expert determinations while elephant sex was harder to determine (Table A1). Unlike African female elephants, female Asian elephants do not have tusks. As a result of selective hunting and capturing, some male Asian elephants have tusks and others do not (Chelliah & Sukumar, 2013). In addition, while adult males are larger than adult females, size differences were not easily determinable from the camera trap video clips. The project provided a unique interactive educational opportunity for citizens to learn about the complexity of HEC, fostering connections across the world, thus strengthening awareness and cooperation. For example, the beehive fence project in Thailand was developed under the guidance of the Elephants and Bees Project of Save the Elephants (www.savetheelephants.org). The Future For Nature Academy helped develop the citizen science project and hosted events at Utrecht University and Wageningen University. The project was recognized and promoted by Youth4Citizenscience of the United Nations Commission on Science and Technology for Development (https://twitter.com/UNMGCY/status/1128993772212228096?s=20). Several citizen scientists joined Bring The Elephant Home (www.bring-the-elephant-home.org) as volunteers. Our experience with citizen science highlights the value of this approach, not just for data generation, but also for creating collaborative opportunities and awareness (Poisson et al., 2020; Swanson et al., 2016).

We acknowledge that our study has several limitations and that further research is required to confirm these preliminary results. First, we could not establish a control plot because it was not possible to refrain farmers to not deter elephants near their property. However, in the interviews, the farm owner stated that prior to beehive fence implementation, the farm was damaged by elephants nearly every night, whereas after the fence was installed the elephants only entered 1–2 times per month. It can be assumed that the elephants that did not cross the fence were indeed deterred by the bees, as elephants approaching a farm would otherwise successfully enter (King et al. 2011). Future studies should either include a control plot or should include a before and after experimental design to compare elephants' behaviors before and after installing the beehive fence. Second, the camera traps may not have accurately detected the total number of elephants approaching the fence due to the limited field of view of the cameras (King et al., 2017). Our experiment has most likely underestimated the success rate of beehive fences, because more groups may have been deterred some distance away and out of camera reach. Future studies should test cameras with wide-angle lenses or with different viewing angles to enable a more accurate determination of elephant group size. Finally, our experiment was limited to one farm, 17 months and qualitative interviews with one farm-owner, while longer-term studies on more farms would be required to confirm the effectiveness of beehive fences and the perceptions of other beehive fence owners.

In terms of the wide-scale application of beehive fences, it is important to note that the construction of beehive fencing requires substantial financial resources. The investment for a fence of 40 hives is about 50,000 THB/1,604 USD for the needed materials (fence construction, beehives, bee veils and smokers) but additional budget is needed for training and monitoring. The costs would decrease with increasing local knowledge, and if farmers construct their own beehives and raise bee queens. Fences also need to encircle the entire farm to be effective and this might not be reasonable for larger farms. As the post-study farm-owner interviews showed, it is important to ensure that farmers are well informed about the amount of labor and receive proper training on beekeeping activities. As jealousy from farmers without beehive fences could potentially affect social cohesion, it is important to assess these perceptions in future studies and to develop a system that makes the method more accessible (e.g., a microloan program with the option to repay per honey harvest). Despite the above limitations, household-level solutions such as beehive fences can be empowering because they enable farmers to take on mitigation efforts themselves, instead of depending on external support such as governmental compensation schemes or rangers from nearby PAs (Scheijen, Richards, Smit, Jones, & Nowak, 2019). In addition to income generation, our study highlights less tangible outcomes, most notably increased well-being, empowerment, pride, skills development, and overall feelings of contentment and security which may contribute to increased tolerance, social cohesion, and coexistence with elephants (Branco et al., 2020; King et al., 2017; Van de Water & Matteson, 2018).

It is generally recognized that there is no “stand-alone solution” to HEC, which also counts for beehive fences (Fernando et al., 2008; King et al. 2011). To improve its effectiveness, beehive fences could be implemented with other mitigation methods, such as growing crops that are not attractive to elephants (Gross, Drouet-Hoguet, Subedi, & Gross, 2017). For instance, after the study, the farm-owner started growing chili and lemongrass along the beehive fence as an extra barrier and source of income. The chili harvest could also be applied to ropes to create and test “spicy beehive” fences (Branco et al., 2020). In addition, it would be interesting to test the effect on Asian elephants of bee alarm pheromone blend, which has shown some positive results on African elephants in South Africa (Wright et al., 2018). Importantly, preventing elephants from damaging crops cures the symptom but not the problem, which is often related to fragmented and modified habitat (Leimgruber et al., 2003). Integrated approaches utilizing multiple methods including habitat protection, ecological corridors, conflict mitigation at household level and initiatives raising awareness and providing access to the benefits of elephants to local communities need to be included to effectively reduce HEC and conserve elephants beyond the local scale (Breuer, Maisels, & Fishlock, 2016; Chen et al., 2016; Fernando, De Silva, Jayasinghe, Janaka, &

Pastorini, 2019; Shaffer et al., 2019; Van de Water, Henley, Bates, & Slotow, 2020). Such a coexistence approach, or "living in harmony" philosophy (Turnhout, Waterton, Neves, & Buizer, 2013), is now part of Sri Lanka's National Policy for Elephant Conservation and Management (Fernando et al., 2019).

This study provides insights into the potential of beehive fences with Italian honey bees to mitigate HEC in Asia. In order to confirm these preliminary results, further research should be conducted with a larger sample size of farms and including controls in the study design. Overall, our results indicate that beehive fencing can be a useful complement of methods to mitigate HEC and to create more positive perceptions of elephants and conservation work. Although the method is labor-intensive and relatively expensive, beehive fences have a positive effect on the livelihoods of households, in terms of reducing crop damage, generating alternative income, and skill development. Combined with other community-based conservation projects, beehive fences can help elephants and people to coexist in other HEC areas in South East Asia.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Antoinette van de Water, Lucy E. King, Rachaya Arkajak, Jirachai Arkajak, Liesbeth Sluiter, and Kevin Matteson designed the study. Antoinette van de Water, Rachaya Arkajak and Jirachai Arkajak collected camera trap data, Antoinette van de Water and Rachaya Arkajak collected the questionnaire data, Antoinette van de Water, Rachaya Arkajak, and David Owen conducted interviews, Antoinette van de Water, Nick van Doormaal, Viviana Ceccarelli, and Vera Praet designed the citizen science study, Antoinette van de Water, Nick van Doormaal, Suzan M. Doornwaard, and Kevin Matteson analyzed the data, Antoinette van de Water, Lucy E. King, Rachaya Arkajak, Jirachai Arkajak, Nick van Doormaal, Viviana Ceccarelli, Liesbeth Sluiter, Suzan M. Doornwaard, Vera Praet, David Owen, and Kevin Matteson wrote and contributed to the final paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The questionnaire was approved by the Miami University Institutional Review Board on February 8, 2017, with project reference number 01805e. The methods for the beehive fence camera trap study were reviewed by the Miami University Institutional Animal Care and Use Committee (IACUC) with approval received on October 26, 2016 (reference number 968_2019_Oct).

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ENDNOTE

[1] The average monthly wage in Thailand is 14,392 THB (412 USD) (National Statistical Office, 2020).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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