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RESEARCH ARTICLE

Between conflict and coexistence: Wildlife in rubber‐dominated landscapes

Franziska K. Harich‐Wloka[1] | **Anna C. Treydte**[1,2,3] | **Joseph O. Ogutu**[4] | **Chution Savini**[5] | **Kriangsak Sribuarod**[6] | **Tommaso Savini**[7]

[1]Department of Ecology of Tropical Agricultural Systems, University of Hohenheim, Stuttgart, Germany

[2]Department of Biodiversity Conservation and Ecosystem Management, School of Life Sciences and Bioengineering, Nelson Mandela African Institution of Science and Technology, Arusha, Tanzania

[3]Department of Physical Geography, Stockholm University, Stockholm, Sweden

[4]Biostatistics Unit, Institute of Crop Science, University of Hohenheim, Stuttgart, Germany

[5]International College for Sustainability Studies, Srinakharinwirot University, Bangkok, Thailand

[6]Department of National Parks, Wildlife and Plant Conservation, Khlong Saeng Wildlife Research Station, Surat Thani, Thailand

[7]Conservation Ecology Program, King Mongkut's University of Technology, Thonburi, Thailand

Correspondence
Franziska K. Harich‐Wloka, Department of Ecology of Tropical Agricultural Systems, University of Hohenheim, Garbenstr. 13, 70593 Stuttgart, Germany.
Email: franziska@wloka.org

Present address
Franziska K. Harich‐Wloka, BirdLife Switzerland, Zurich, Switzerland.

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Abstract

The continuing loss and degradation of their natural habitats forces some wildlife species to increasingly extend their habitats into farmlands, thereby intensifying conflicts with people as resources diminish. Despite massive expansion in rubber (*Hevea brasiliensis*) plantations in recent decades, little is known about the diversity and distribution of wild mammals in rubber‐dominated landscapes or the associated human‐wildlife conflicts. We assessed the presence and diversity of mammalian wildlife and damage occurrence in such rubber landscapes in southern Thailand, in and around Tai Rom Yen National Park. We interviewed 180 farmers about wildlife visits to their farms and the resulting damage. We conducted 50 transect walks within and adjacent to a natural forest and deployed camera traps at the boundary between the plantations and the forest, as well as deeper into the forest, to assess wildlife presence. A total of 35 mammal species were recorded inside the forest. More than 70% of these were also present at the forest boundary, but species presence and diversity were far lower in the farmland. Elephants (*Elephas maximus*) were responsible for 90% of wildlife damage incidents within the rubber plantations, with 86% of these cases affecting young plants that had not yet been tapped. Although almost half of the survey respondents reported elephants visiting their farms, less than half of them reported damage. These results suggest that rubber‐dominated landscapes surrounding protected areas have the potential to facilitate coexistence between people and certain wildlife species, particularly if young plants are better protected and plantation management is made more wildlife friendly.

KEYWORDS

Asian elephant, human–wildlife conflicts, rubber (*Hevea brasiliensis*) plantations, Thailand

Plain language summary

The loss of natural habitat forces some wildlife species to extend their habitats into farmlands. This often leads to increasing conflicts with people as wild animals consume or damage cultivated crops. However, there is limited information on how rubber cultivation affects wild mammal species. To fill this gap in our knowledge, we carried out a study to better understand how rubber plantations affect wildlife in Thailand. Our results showed that species' presence and diversity were far lower in the farmland compared with the adjacent natural forest. Moreover, >70% of the wildlife species found in the forest were also

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present at the forest-farmland boundary. Elephants were responsible for 90% of the damage incidents in the rubber plantations, with the majority of this damage restricted to young plants. While almost half of all the respondents experienced elephants visiting their farm, less than half reported any damage. These findings suggest that rubber plantations located near protected areas have the potential to facilitate coexistence between people and certain wildlife species. This is contingent upon young plants being better protected and plantation management becoming more wildlife friendly.

1 | INTRODUCTION

Unequivocally, wildlife conservation is best achieved by conserving species' natural habitats (see Brooks et al., 2002; Butchart et al., 2012; Myers et al., 2000; Pimm et al., 2014). The reality of ongoing land use transformations and diminishing tropical and subtropical forest areas nevertheless requires the consideration of alternative options for providing space for wildlife to live and thrive. Some species, such as leopards in India, have demonstrated a remarkable ability to adapt to life in close proximity to humans, managing to learn to survive even within the confines of megacities (Braczkowski et al., 2018). Other species, due to their size, nutritional requirements or overall biology, are less able to tolerate close contact with humans (Maddox et al., 2007; Yue et al., 2015). For species that fall between these extremes, there might be chances for long-term survival within the interface of natural habitats and human land use systems. Habitat quality in such transition zones often differs among species and is significantly influenced by the kind of land use system. It is particularly contingent on socio-economic factors characteristic of the local human population and their acceptance of wildlife species in the vicinity of their homes (Thirgood et al., 2005; Woodroffe et al., 2005). This, in turn, depends on the extent of conflicts that arise between humans and wildlife as a result of overlapping resource use, one of the major and persistent challenges to the long-term conservation of threatened species (Distefano, 2005). Conflicts are particularly severe at the fringes of protected areas, when wildlife enter farmlands in search of forage and water, increasing the likelihood of encounters with humans (Distefano, 2005; Karanth et al., 2013). Common types of conflicts are livestock depredation and crop raiding, with some charismatic species being the subject of recurrent complaints (Douglas & Veríssimo, 2013; Western & Waithaka, 2005). Elephants are a particularly noteworthy species in discussions of human–wildlife conflict, as the damage they inflict can be devastating for the affected farmers (Campos-Arceiz et al., 2009; Nyhus et al., 2000; Tchamba, 1996). However, these pachyderms are not the sole culprits; other species with a preference for nutritious and easily palatable crops, and smaller animals, such as rodents, can also account for considerable damage (Arlet & Molleman, 2010; Lahm, 1996).

Practitioner points

- Mammalian species richness and average species presence were much lower in the rubber-dominated farmland than in the adjacent natural forest.
- More than 70% of forest wildlife species were found close to the forest-farmland boundary. This gives some hope that, given a more wildlife-friendly and low-risk plantation management strategy, rubber farmlands outside protected areas may serve as extended habitats for some wild mammals, for example, by leaving some natural vegetation for wildlife to feed on and for cover on the farms and hence softening the forest-farmland edge.
- Elephants were responsible for 90% of the damage incidents in the rubber plantations, but as rubber is very rarely consumed and the damage was restricted almost exclusively to young plants, one key strategy for ensuring peaceful coexistence between people and elephants in rubber-dominated areas lies in the protection of young trees.

Although elephants are often blamed for 'attacking' or 'raiding' crops, such behaviours are part of their survival strategy in an environment with ever-shrinking natural resources (Hill, 2015; Peterson et al., 2010). Species with long lifespans, such as elephants, might continue to use traditional movement paths, even after the surrounding areas have been transformed into farmlands, or they may be attracted to water resources, both of which can lead to crop damage (Sarker & Røskaft, 2010; Sukumar, 1989; Thouless, 1994). Damage levels also depend on the kind and structure of overall cultural landscapes surrounding protected areas (Boafo et al., 2004). Although the susceptibility of plantations such as maize, sugarcane or bananas is well documented (e.g., Barnes et al., 1995; Inogwabini et al., 2013; Naughton-Treves, 1997), damage to some cash crops, such as natural rubber (*Hevea brasiliensis*), often occurs incidentally. Elephants, for example, seldom consume rubber but may trample young plants while walking (Chen et al., 2013, 2016). However, with increasing demand for latex and the associated expansion of rubber plantations, the potential for conflicts is likely to increase. As of 2021, the global area under rubber cultivation surpassed 12.9 million ha, with around 90% of the rubber produced in Asia (FAOSTAT, 2023). Although income from rubber production has contributed to poverty alleviation in some countries such as Thailand and Southwest China, the increased allocation of land for rubber cultivation has also accelerated the replacement of natural forests and traditional land-use types in these regions (Fox & Castella, 2013; Li & Fox, 2012; Liu et al., 2017).

Severe impacts on biodiversity can thus be expected from predictions indicating a surge in rubber demand and the associated projected expansion in rubber cultivation (He & Martin, 2015; Li & Fox, 2012; Warren-Thomas et al., 2015). Concurrently, people cultivating rubber in proximity to natural forests can expect increasing conflicts with elephants (de Silva et al., 2023). Over a 5-year period from 2008 to 2012, almost 11,000 incidents of damage to rubber plantations by elephants were recorded across 253 settlements in Southwest China (Chen et al., 2016). Historical records document damage to rubber crops by elephants as early as 1910–1930, with reports of several thousand pounds of damage in Malaysia alone in this period (Hubback, 1942). Continuous conflicts in the 1970s prompted the declaration of elephants as a serious pest to rubber cultivation (Olivier, 1978). In addition to elephants, species such as primates—specifically Thomas' leaf monkeys (*Presbytis thomasi*) and orangutans (*Pongo abelii*) in Sumatra—have also been reported to inflict damage on rubber plantations (Campbell-Smith et al., 2012; Marchal & Hill, 2009).

Despite the increasing extent of land area covered by rubber, relatively little information is available on conflicts with wildlife in rubber plantations. Data on the potential level and type of biodiversity of large wild mammals that can be sustained in rubber-dominated landscapes in the long term without causing substantial damage to rubber trees also remains limited (Harich & Treydte, 2016). The general aim of our study was to understand the impact of rubber plantations on mammal communities. The specific objectives were (1) to evaluate the presence and diversity of mammals in rubber plantations compared with nearby natural forests and (2) to examine associated conflicts with wildlife as a basis for developing wildlife-friendly and low-risk rubber farming strategies. We expected certain environmental variables that influence wildlife presence in rubber plantations and the risk of crop raiding to be identifiable. Such information could be instrumental in preventing crop loss and supporting conflict mitigation and wildlife conservation. Thailand was chosen as the focus of this study due to its status as the leading rubber-producing country, coupled with its long history of rubber cultivation (FAOSTAT, 2023; Li & Fox, 2012).

2 | MATERIALS AND METHODS

2.1 | Study site

The Tai Rom Yen National Park (TRY) is located in the south of Thailand, in Surat Thani province, between latitudes 8°36′–8°59′N and longitudes 99°22′–99°37′E. It borders the province of Nakhon Si Thammarat in the east (Figure 1). The Park covers an area of about 400 km^2, with elevations ranging from around 100 to 1200 m.a.s.l. TRY was established in 1991 and includes evergreen forests, partly characterized by limestone formations and associated vegetation types (DNP 2013; Pfeffer, 2013). The park's boundaries also include cultivated landscapes dominated by rubber plantations. The region is a traditional rubber cultivating area (Li & Fox, 2012), which lies within the transition zone of the Indo-Burma and Sundaland biodiversity hotspots, home to more than 300 mammal species (Myers et al., 2000). The annual average temperature in Surat Thani is 27.4°C and the average annual precipitation is 1862 mm (Pfeffer, 2013).

2.2 | Transect surveys

Direct and indirect observations of wildlife presence (i.e., dung, footprints, calls and other sounds, feeding signs, scratch marks, burrows and so on) were documented along fifty 1 km transects in the transition zone of TRY and the surrounding farmland (Figure 1). The 50 transects were arranged as 25 matched pairs; 25 were sampled within the natural forest and the other 25 within the plantations outside and adjoining the forest. Each transect started at the forest boundary and was oriented perpendicular to the forest edge as reasonably practicable. Accordingly, each transect running from the forest edge into the forest was matched with another transect running from the forest edge into the plantation outside the forest. We followed wildlife trails in the forest while keeping an approximately perpendicular direction to the forest edge (Buckland et al., 2008; Steinmetz et al., 2013) due to accessibility. Before the actual data recording, we marked trees every 100 m along the transect line. During the scheduled survey walks, we stopped at each of these marks for 5 min to listen to potential wildlife sounds and to record site covariates, such as habitat type (forest/farmland), habitat structure (percentage of ground cover, herbaceous layer height, tree/bush density), elevation, slope gradient, water availability, signs of human presence in the forest and type of crop in the farmland. Upon detection along the transect, each wildlife sign was classified to the appropriate species or taxonomic group, and the approximate distance of its location to the forest boundary was recorded, using 100 m intervals for measurement. Photos of species' signs that were hard to identify were shown to experts for verification. In instances

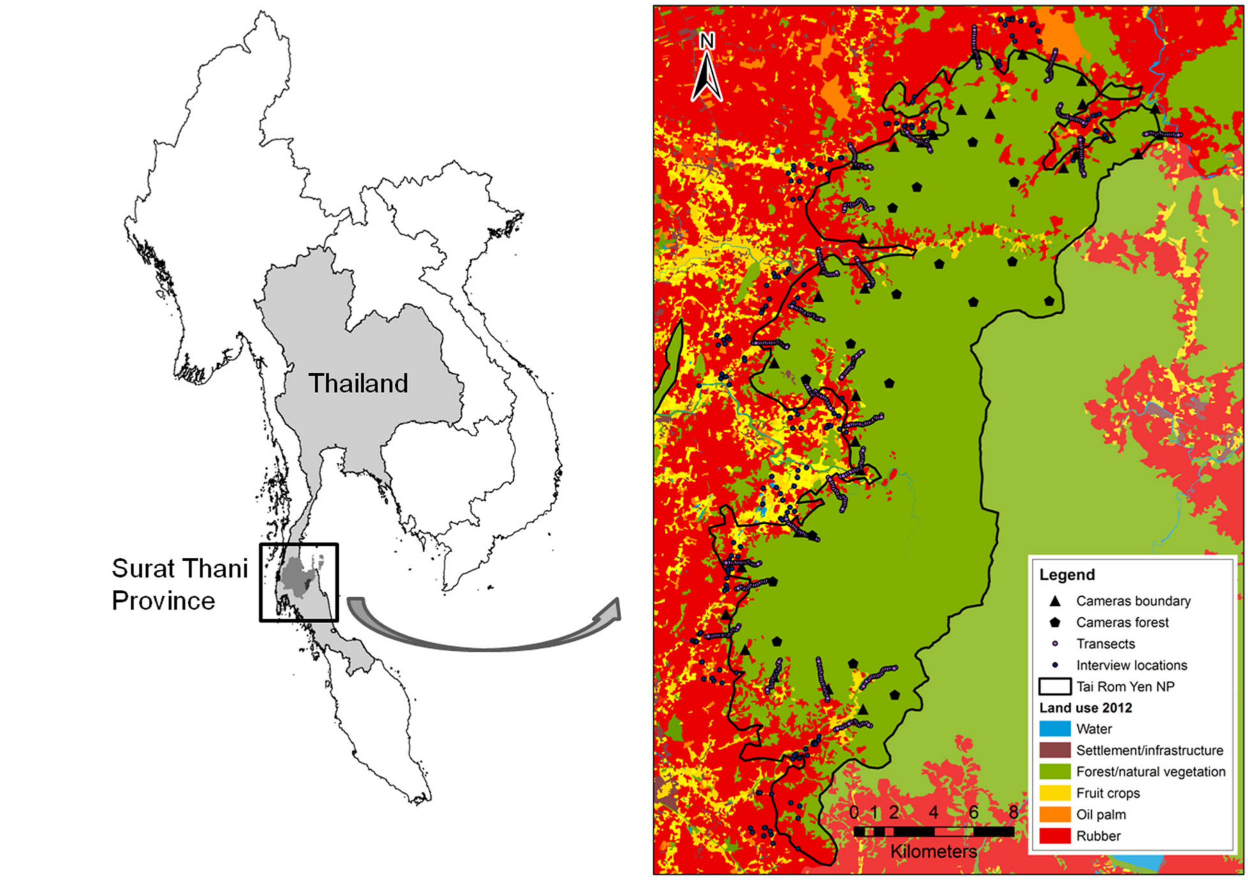

FIGURE 1 The location of the Tai Rom Yen (TRY) National Park in the Surat Thani Province in Thailand with the associated land-use map provided by the Land Development Department Thailand. The black line shows the boundary of the TRY National Park. Dotted lines are transects, black pentagons are camera locations inside the forest, and black triangles are the camera locations at the forest boundary. The forest edge in the map can vary from the actual forest cover due to changes since the map's publication in 2012 (For the colour interpretation of the map, the reader is referred to the online version of this article).

where definitive identification was not possible, signs were labelled as unidentified. Each transect was sampled three times over a period of 16 months, spanning the dry and rainy seasons in 2013 and 2014.

2.3 | Camera trap surveys

Cameras equipped with passive infrared motion detectors and nighttime infrared illuminators (model Reconyx™ HyperFire™ HC600) were installed at 30 locations along the boundary between the natural forest and rubber plantations. These cameras were operational for a total duration of 16 months. Criteria for selecting camera locations prioritized accessibility and areas with a high likelihood of animal activity, such as along wildlife trails or near streams. Where possible, cameras were set right at the forest edge or a maximum distance of 25 m into the forest and were located ~1–2 km (1000–2000 m) apart. A total of 13 cameras were alternately rotated between the 30 locations. Each location was sampled at least three times, with each sampling session spanning a minimum continuous recording duration of 2 weeks. This approach resulted in a minimum of 60 camera-days per location. In addition to the cameras set at the forest edge, 21 other locations, extending up to 3 km into the natural forest, were each sampled once for a minimum recording duration of 2 weeks. All cameras were mounted on forest trees at an average height of 1.5–2 m, depending on the slope and each tree's characteristics. They were angled slightly downward to ensure coverage of a range encompassing both small and large mammals. To mitigate the risks of damage or theft, each camera was accompanied by a small note, written in Thai, explaining the purpose of the survey.

2.4 | Interviews with local farmers

We interviewed 180 farmers around the TRY to gather information about wildlife presence on their farms and associated conflicts. Fifteen willing respondents were systematically chosen from 12 separate 3 km × 3 km blocks adjacent to the park's perimeter. The interviewed farmers inhabited land within a maximum distance of 3 km from the park's boundary. The questionnaires were semi-structured, with open and closed questions. To aid in the identification process, respondents were provided with pictures of native wildlife species representing major taxonomic groups. These images were used to determine which species groups they encountered on their farmland.

Photos of alien species were included as controls. In cases where damage was reported to have occurred recently, the information given by farmers was corroborated through on-site verification. In the interviews, we aimed to determine the extent of conflicts and their impacts on farmers' livelihoods relative to other factors causing crop loss. Using picture sheets, we further identified the species most frequently implicated in damage complaints. The questionnaires were also employed to assess general perceptions towards wildlife conservation and potential benefits from natural resources. Biophysical features such as water availability and individual farm management were also included in the evaluation. The questionnaires, administered in Thai, were completed with the help of a Thai translator within a duration of approximately 40 min. All personal data was treated with strict confidentiality and was anonymized before analysis. The research followed ethical procedures outlined by the National Research Council Thailand, in compliance with regulations in force at the time of data collection.

2.5 | Statistical analysis

Data from the transects, cameras and interviews were used to record species richness. For purposes of analysis, members of the order Artiodactyla and Proboscidea were categorized with the overall group of ungulates (see Table A1 in the supplementary material for a full species list and classification). Camera trap data was used to confirm species presence. From the transect data, we further calculated the average presence of the four taxonomic groups of carnivores, rodents, ungulates and primates: Presence or absence was recorded for every 100 m segment along the transects, resulting in 10 binary records (1/0) per transect walk. This generated a total of 30 binary records across the three repeated survey walks per transect. The average presence of wildlife was computed for each transect by calculating the mean of its 30 records, yielding a value between 0 and 1. This average was then graphically represented, depicting the aggregated wildlife presence across all the 100 m segments of the transect. The average presence for a species within either the forest or plantation landscape was then determined by calculating the mean presence across all 25 transects in each respective landscape.

A generalized linear model assuming a binary error distribution and a logit link function was used to select a subset of nine overall covariates most strongly correlated with the probability of crop damage by elephants from the interview data set (Table 1). Our analysis concentrated specifically on elephants, as they were the species most frequently reported to cause damage. The explanatory variables were preselected based on their perceived potential to influence the probability of elephant damage to crops before analysis. With the exception of the two continuous variables, 'distance from forest' and 'farm size', all the other variables were categorical. The full model included all possible

TABLE 1 Explanatory variables included in the generalized linear model to understand their influence on the probability of crop damage by elephants from the interview data set.

Variables	Categories	Assumptions
Region	North	Regional differences in conflicts
	Central	
	South	
Distance to natural forest (m)	Continuous	Lower crop damage risk with distance to forest
Size of farm (ha)	Continuous	Increasing crop damage risk with larger farm size
Water source (river, stream, pond)	Binary (yes/no)	Higher crop damage risk with water present on farmland
Rubber plantation age	Binary (mature/young)	Higher risk of damage to younger plants
Number of separate fruit crops in one farm	Comprises durian, rambutan, longkong/langsad, mangosteen	Higher crop damage risk with fruit diversity
Diversified farming/monoculure	Binary (yes/no)	Higher attraction and, thus, crop damage risk, with diversified farming
Natural vegetation present	Binary (yes/no)	Higher attraction and, thus, crop damage risk
Prevention measure	Binary (yes/no), comprises firecracker, guarding of crops, electric fences, none	Lower damage with prevention measures in place

Note: Data were collected from June to August 2013 around TRY, Surat Thani Province, Thailand.
Abbreviation: TRY, Tai Rom Yen National Park.

interaction terms between the different variables, in addition to quadratic terms for the two continuous covariates. The quadratic terms in the two continuous covariates were included to permit testing for potential nonlinearity in the relationship between the probability of crop damage and distance from forest or farm size. The two continuous variables were internally centred and scaled (standardized), but all parameter estimates and related statistics are reported on their original scale. We selected the covariates most strongly correlated with the probability of elephant damage using the forward selection method, adding covariate effects sequentially (Blanchet et al., 2008; Johnson & Omland, 2004; Ogutu et al., 2016). At each step of the selection process, covariate effects were chosen and added to the model based on the Akaike, corrected Akaike and Schwarz Bayesian information criteria. The selection of effects was made subject to the strong hierarchy (marginality) requirement, meaning that for any interaction term to be included in the model, all the main effects contained in the interaction term must also be included in the model. For example, in order for the interaction term region × farm size to enter the model, the main effects, region and farm size, must also be present in the model. Similarly, neither region nor farm size can leave the model while the interaction term region × farm size is still in the model. We re-ran the model selection process by replacing the categorical covariates, water and crops, with their more detailed derivatives. Model selection, including the forward variable selection, was carried out using the SAS GENSELECT procedure (SAS Institute 2016, Version 9.4, SAS/STAT Version 14.1) and SPSS (IBM SPSS Statistics 22).

3 | RESULTS

3.1 | Wildlife presence in the farm-forest transition zone

Through the combined methods of interviews, transects and cameras, we documented the presence of at least 35 wild mammal species, belonging to 21 families, in the farm-forest transition zone. Overall, 35 species were found inside the forest and 25 species at the forest edge. On the farmland transects, nine species were identified, a number that increased to 20 upon incorporating data from the interviews. However, species reported in the interviews could not be independently verified and were therefore treated in a conservative manner. During the transect surveys, we recorded a total of 25 species. Meanwhile, the cameras captured 371 identifiable pictures representing 26 species, taken over a total duration of 3090 camera trap days and nights.

Based on the combined data from transects, cameras and interviews, the taxonomic group Carnivora displayed the highest species richness, with a total of 10 species, followed by Rodentia (Figure 2). However, due to difficulties in accurately identifying rodent species from the camera trap pictures, physical signs or actual sightings, this group is likely highly underrepresented in our recorded species list. Species richness decreased for all taxonomic groups by about 43% on average from the forest to the farmland. This pattern was most pronounced for carnivores, for which we recorded a 70% decrease in species richness. At the farm-forest boundary, however, species richness was still relatively high, constituting around 71% of the total number of species recorded.

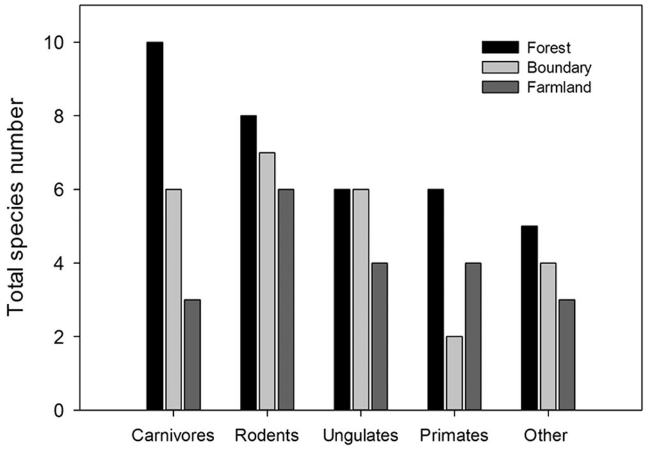

FIGURE 2 Total number of wildlife species belonging to different groups recorded in the natural forest (black bars), at the farm-forest boundary (light grey bars) and in the farmland (dark grey bars) based on data from transects, cameras and interviews combined.

Not only was the species richness reduced, but the average species presence (expressed as a percentage of all transects) was also lower in the farmland than in the forest (Figure 3). For all groups, excluding humans, the average species presence was 10% lower in the farmland than in the forest. Our transect records indicated that human presence was the most frequently observed, even in the forest. Our cameras recorded 20 instances of human passage; notably, half of these cases could clearly be identified as poaching trips. Excluding humans, rodents had the highest average presence in both the farmland and forest (14%), followed by ungulates (8%) and primates (5%). With only 1%, carnivores had the lowest average presence.

Based on the transect records as a function of distance from the farm–forest boundary, the average percentage of wildlife presence distribution varied remarkably among the four species groups. However, for all these groups, the presence was much higher at almost all distances inside the forest compared to in the farmland (Figure 4). Rodents were the only group continuously present up to one km into the farmland (Figure 4), although their frequency was 25% less than that inside the forest. Ungulate presence decreased strongly after the first 300 m from the forest boundary. In contrast, elephants were the only species for which signs

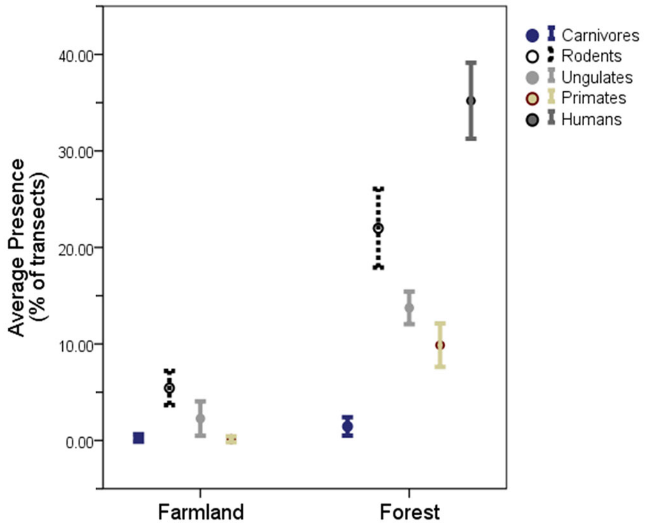

FIGURE 3 Average presence (expressed as a percentage of all farm or forest transects) of different wildlife groups in the farmland versus the natural forest (error bars represent 95% confidence intervals). As human presence in the farmland is close to 100%, we displayed human presence for the forest only.

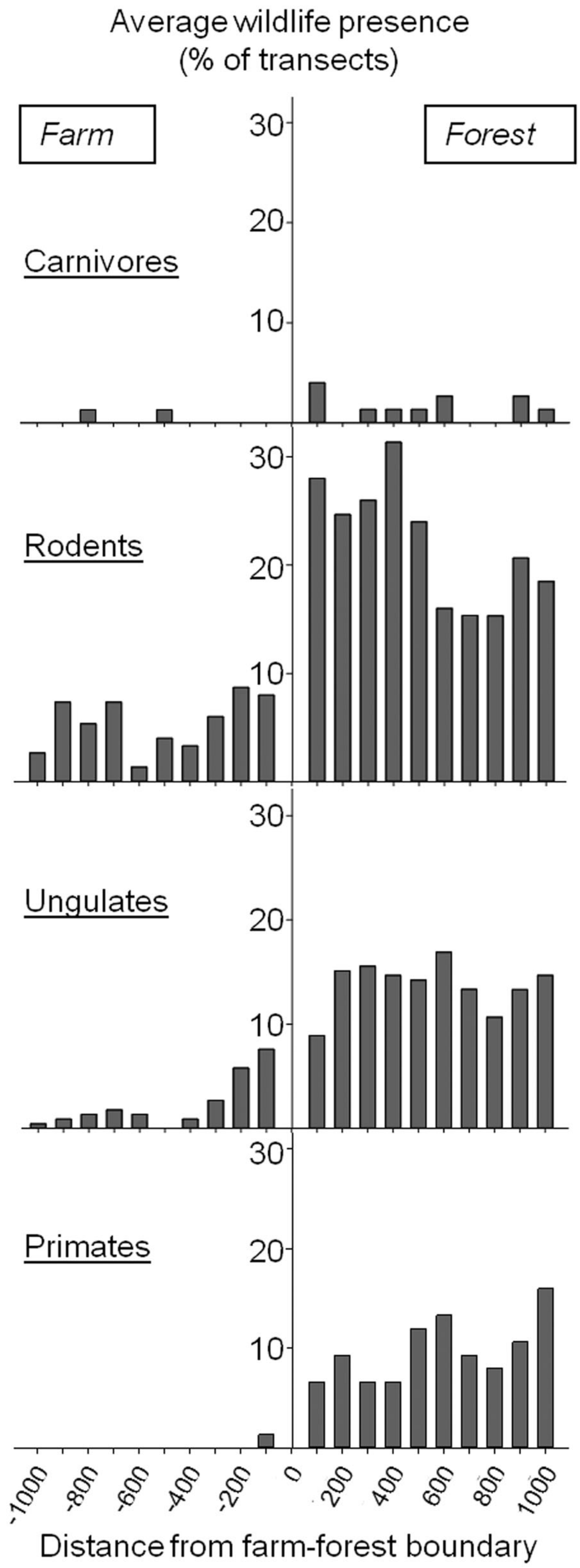

FIGURE 4 Average presence (in % of transects) of different wildlife species or groups recorded as a function of distance from the farm–forest boundary (0 represents the forest edge).

were found further into the farmland. Primate species presence could only be confirmed within 100 m of the forest edge. Carnivore signs were also seldom found in the farmland. Scat, likely from the hog badger (*Arctonyx collaris*), was found up to 800 m into the farmland, in an overgrown plantation patch, which had been abandoned for some time.

3.2 | Type and extent of wildlife damage

Farmers identified species from 15 taxonomic groups, which they had encountered on their farmlands (Figure 5 and Supporting Information S1: Table A1). Crop damage by wildlife affected 40% of farmers. A total of 82 out of the 180 interviewed farmers (46%) reported that elephants had come to their farms within the last 6 years. Less than half ($n = 39$) of those farmers suffered crop damage by elephants (22%). Many farmers reported elephant visits during which the animals consumed natural vegetation from the undergrowth or farm fringes and, where available, drank water. Still, elephants were the species most frequently reported to have caused damage (18% of respondents). More than 60% of the farmers who reported species other than elephants as the primary culprits of damage had not encountered elephants on their farms.

The average (±1 SD) farm size among respondents was 4.84 ha (±3.24). Ninety-seven percent of the interviewed farmers were cultivating rubber and approximately half of them were cultivating more than one crop. Crops that were most affected by damage were rubber (67% of all farmers that experienced damage), longkong (*Lansium domesticum*; 41%), durian (*Durio* spp.; 23%) and rambutan (*Nephelium lappaceum*; 15%), partly reflecting the relative abundance of crops cultivated in the area (Figure 6). Elephants seemed to prefer longkong fruits compared with other crops. This was evident as the ratio of the number of farmers who experienced crop damage to the total number of farmers cultivating the various crops was 1.8 times higher for longkong than for rubber. Despite their preference for other crops, elephants were

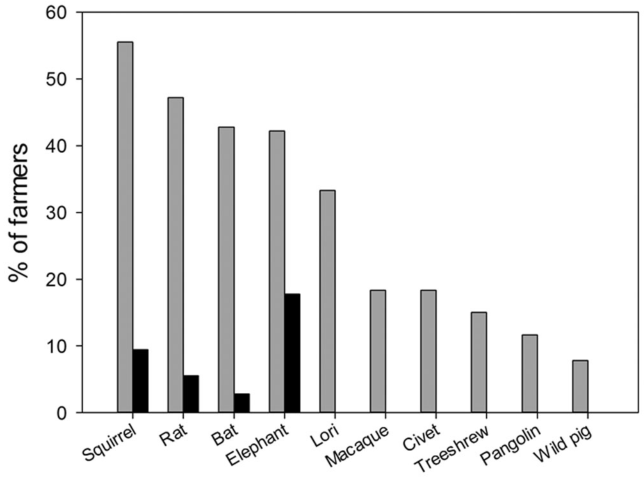

FIGURE 5 The top 10 wildlife species or groups encountered by the respondents on their farms (grey bars; % of interviewed farmers) and the species reported to be causing most damage (black bars).

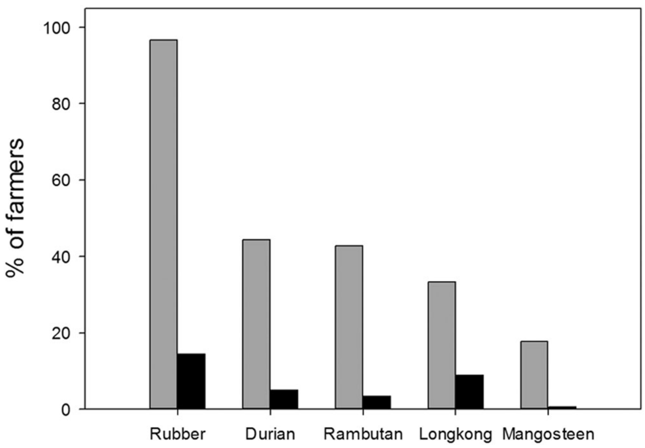

FIGURE 6 Crops cultivated in the study region (grey bars; % of respondents) and the proportion of farmers experiencing damage by elephants for each crop types (black bars).

responsible for 90% of the damage incidents in the rubber plantations. In 86% of these cases, the damage was inflicted to young rubber trees (below ~7 years of age).

Damage attributed to wildlife species other than elephants was generally perceived by farmers as minimal and not considered a major problem. Therefore, our statistical analyses focused specifically on elephant-related crop loss. The most effective logistic regression model for predicting the probability of elephant crop raids, as determined by the forward selection method, included region, distance to the forest edge, presence of natural vegetation, young rubber, presence of a water pond, farm size and the interaction between farm size and natural vegetation. These variables emerged as the best-supported and statistically significant explanatory variables (Table 2).

The model explained 54% (Nagelkerke r^2) of the variation in the probability of crop damage incidences and correctly classified 85.6% of the observed cases. According to the model, damage by elephants was 5.7 times more likely to occur in the north of the National Park than in the south. The presence of a young rubber plantation increased the likelihood of damage threefold and farmers with a water pond on or close to their farmland were 8.6 times more likely to experience crop damage. Furthermore, the distance to the natural forest emerged as a significant predictor of the probability of crop damage ($p = 0.019$). However, within the 3 km range considered in this study, each unit increase in distance from the forest edge was associated with only a slight reduction in the likelihood of crop damage.

3.3 | Farmers' perspectives on crop damage

With only around one-fifth of farmers experiencing crop losses due to elephants around the National

TABLE 2 Logistic regression model relating the probability of elephant damage to crops with predictor variables.

Variable	Estimate	SE	*p*	Exp (Estimate)	95% CI for Exp(Estimate) Lower	Upper
Region South	0.000	0.000				
Region North	1.736	0.556	0.002	5.677	1.910	16.876
Region Central	–0.998	0.813	0.220	0.368	0.075	1.814
Distance to forest	–0.001	0.001	0.019	0.999	0.998	1.000
Natural vegetation	0.242	1.224	0.843	1.274	0.116	14.043
Young rubber	1.140	0.500	0.022	3.128	1.175	8.329
Pond	2.148	0.950	0.024	8.567	1.332	55.111
Size of farm	–0.120	0.200	0.547	0.887	0.600	1.311
Size of farm ∗ natural vegetation	0.416	0.227	0.067	1.515	0.971	2.364
Constant	–3.210	1.226	0.009	0.040		

Abbreviation: CI, confidence interval.

Park, wildlife damage to crops was not among the major concerns of farmers in the region. Most farmers mentioned crop losses due to diseases, such as fungal infections, as the principal cause of crop damage (81% of farmers). This was followed by insect damage (13%) and only 8% considered wildlife, in particular elephants, as the major threat to their crops. Nevertheless, elephants occasionally inflicted substantial damage to crops on individual farms. Notably, mature rubber plantations rarely suffered damage caused by elephants (only 15% of all damage events for rubber). Moreover, when damage did occur, the trees were usually able to recover (e.g., broken branches). This finding is significant as 97% of the interviewed farmers were cultivating rubber.

Attitudes towards elephants were generally positive, with 68% of farmers stating they liked the pachyderms or at least liked them if they were not causing damage. Only 20% of the farmers expressed a clear dislike for the animals, a feeling significantly related to the perceived danger posed by elephants ($\chi^2 = 7.735$, df = 1, $p = 0.005$) but not to any actual crop damage experienced by individual farmers ($\chi^2 = 0.194$, df = 1, $p = 0.660$).

4 | DISCUSSION

Despite rubber being an important cash crop in Southeast Asia, conservation-related information, particularly concerning mammals, is still scarce (Harich & Treydte, 2016). The impacts of oil palm cultivation on biodiversity, including wild mammalian assemblages, are better documented in comparison to the effects of rubber cultivation (Danielsen et al., 2009; Fitzherbert et al., 2008; Freudmann et al., 2015; Harich & Treydte, 2016; Jennings et al., 2015; Sodhi & Brook, 2006; Yaap et al., 2011; Yue et al., 2015; Zemp et al., 2023). With this study, we provide a rare assessment of mammal diversity in the farm-forest transition zone of a rubber-dominated landscape and the challenges related conflicts pose to wildlife conservation. Although we identified several different species in the farmland, elephants were the only species of major conflict concern. Elephants are often considered the major problem despite other species or factors contributing substantially to crop loss (Arlet & Molleman, 2010; Daley et al., 2004; Decker & Brown, 1982; Thirgood et al., 2005). As hypothesized, we identified several factors that increased the probability of crop damage by elephants, some of which might be addressed through adapted farm management, ultimately helping to reduce crop loss and support human–wildlife coexistence.

4.1 | Presence and detection of wildlife

As is commonly observed, biodiversity levels are usually lower in farmlands compared to natural forests, a pattern that was evident in our study area (Crisol et al., 2016; Gilroy et al., 2014; Koh, 2008; Yue et al., 2015). Within a 2 km transition zone from natural forest to farmland, we observed a decline in mammalian species diversity by almost 75%. Including data from interviews within 3 km of the forest, the decline was still more than 40%. Ground-truthing of information obtained through interviews has been recommended in ecological surveys and the combination of transect, camera and interview surveys complemented our overall data collection well (White et al., 2005). In the case of carnivores, cameras rather than transects might be more effective tools for their detection. This is due to their relative rarity, nocturnal, secretive and elusive nature (Chutipong et al., 2014; Karanth et al., 2004). The relatively low presence of carnivores in the farmland, where we did not install cameras due to frequent human activity and the greater risk of theft, could be attributed to this. In contrast, transect surveys proved to be more effective for detecting primate species, as evidenced by the fact that we only recorded two out of four species with the cameras. Arboreal species such as gibbons (*Hylobates lar*) and loris (*Nycticebus coucang*) were recorded during transect surveys but were not detected by the cameras, possibly because our cameras were mounted at a slight angle to the ground. The rodent species we recorded were comparatively few, reflecting the difficulty in identifying animals down to species level from camera trap pictures or from direct sightings on transect walks.

4.2 | Factors influencing crop damage

Overall crop-raiding levels were comparatively low, including for elephants, as less than a fifth of farmers within a 3 km radius of the natural forest reported experiencing elephant crop foraging. Crop-raiding also decreases with increasing distance from natural elephant habitats. This spatial variation partly explains why, at a national scale, the aggregate crop loss through elephants is usually negligible, in contrast the more pronounced impact in regions adjacent to protected areas (Barnes et al., 1995; Chen et al., 2016; Naughton-Treves, 1997; Naughton-Treves & Treves, 2005; Sarker & Røskaft, 2010; Wilson et al., 2015). In areas in close proximity to the forest boundary, individual instances of damage can be very severe, consistent with the pattern of typically localized but severe crop loss attributed to elephants (Nath et al., 2015; Naughton-Treves, 1997; Naughton-Treves & Treves, 2005). The northern district around TRY was particularly affected by crop loss, making the region a significant predictor of damage probability. Unsurprisingly, damage levels were found to be higher for the northern sector than the other parts of the park. One village in the north, surrounded on three sides by forest cover, was particularly affected by elephant foraging. Still, only one-third of farmers in that village ranked wildlife as the most significant cause of damage to their crops. Across the entire surveyed area, even fewer respondents (8%) ranked wildlife as the topmost cause of crop damage. The vast majority of the respondents worried more about plant diseases as the leading cause of crop damage (Thirgood et al., 2005). Two reasons might account for the relatively low level of overall crop damage by wildlife. First, elephants were the species most frequently reported as causing damage, but the population is likely rather small (no exact records of elephant numbers are available for TRY). The elephant population for the overall forest complex to which TRY belongs was estimated to be <100 animals (Srikrachang, 2013). Based on our field observations and records, we assume that the population within TRY itself could be less than 50 elephants. Second, the land cover was dominated by rubber trees, which are hardly susceptible to damage by elephants once they reach maturity. The stems are strong enough to resist damage at around 5–8 years of age. A similar observation was also made on rubber plantations in China, where <1% of damaged rubber trees were above 8 years old (Chen et al., 2013). As >45% of farmers reported elephant visits to their plantations, yet less than half experienced actual damage, the low damage levels cannot be solely attributed to the small number of elephants. Instead, it is more plausible that damage was mainly restricted to young rubber plants. Elephants are reported to feed on rubber seedlings, but a high proportion of damage to seedlings and saplings probably occurs through trampling or other destructive behaviours when elephants pass through a rubber plantation (Blair & Noor, 1981; Chen et al., 2013; Olivier, 1978; Zhang, 2011). Consumption of rubber bark by elephants, as observed in other areas of Thailand (Dr. Mattana Srikrachang, personal communication) and in Malaysia (Blair & Noor, 1981), was neither observed nor reported at our study site. Damage to young rubber plantations can lead to economic losses due to delayed latex harvest and replanting costs, which averaged about 126 US$/ha and represented a mean loss in rubber of 2.6% per affected village in Southwest China (Chen et al., 2013). Although the monetary loss in the case of rubber as a cash crop is relatively high, the proportional loss of some crops in food crop plantations can be even higher (Adjewodah et al., 2005; Chiyo et al., 2005). In our study site in southern Thailand, elephants exhibited a marked preference for Longkong fruits, as evidenced by the disproportionately high level of damage to this crop relative to the number of farmers cultivating it. The spiky and strong-smelling Durian fruit also appears to be favoured, an observation made more than 70 years ago in Malaysia (Hubback, 1942). Although cultivating a variety of crops on a single farm increased the risk of elephant damage in Ghana (Sam et al., 2005), our logistic regression model revealed that a greater diversity of crops on individual farms had no significant influence on damage probability in our study area, possibly due to the predominance of rubber as the major crop in the region. Despite the high proportional damage to Longkong trees, they did not significantly explain the variation in damage probability in our model. The presence of ponds, in contrast, tremendously increased the risk of damage to crops and other assets in our study area, with one farmer losing almost his entire fish stock when elephants took a bath in his pond in 2014. Water sources are well known to be highly attractive to elephants, particularly during dry seasons, and can therefore be expected to elevate the risk of elephant damage to nearby plantations (Bal et al., 2011; Naughton et al., 1999; Thouless, 1994). In our model, the availability of natural vegetation on a farm was not a significant predictor of crop damage. Therefore, maintaining natural vegetation could potentially offer resources for wildlife not prone to conflict, provided there are no limitations in the management of the plantations or resultant collateral damage to crops. General biodiversity value in cash crop plantations such as rubber could be further enhanced, without reducing yields, through more agroforestry planning and enrichment with tree islands instead of monocultures (Warren-Thomas et al., 2020; Zemp et al., 2023).

4.3 | Farmers' attitudes towards elephants

Farmers hardly consider wildlife species other than elephants as causes of substantial damage, particularly in the case of rubber plants. As the vast majority of farmers cultivate rubber as a major crop, damage to this cash crop might be perceived more critically than the continuous but low-level consumption of other crop types by small mammals (Arlet & Molleman, 2010; Daley et al., 2004; Decker & Brown, 1982). Nevertheless, the majority of farmers had a positive or conditionally positive attitude towards elephants, which we expected to be associated with the overall low level of damage. However, attitudes seemed to be unrelated to experiences of actual damage, as only a fourth of farmers expressed a dislike towards crop losses caused by elephants. In contrast, negative attitudes towards elephants were associated with fear, which might be a result of the prevalent latex harvest procedure. Given that rubber trees are tapped in the dark hours of night or early morning, there exists a risk of accidental encounters between elephants and farmers, posing significant safety concerns. Sometimes, elephants stayed on or visited plantations for several days, forcing farmers to refrain from tapping. The relatively high tolerance for economic outfalls due to elephants in Thailand might also reflect cultural heritage. Elephants are highly revered and are believed to bring good luck (McNeely, 2000; Ringis, 1996). The killing of elephants is a cultural taboo in Thailand, whereas it is seen as a possible management option by many people coexisting with elephants in Africa

(Gadd, 2005; Harich et al., 2013; Hoare, 2001; Taylor, 1993). Although the Thai population residing near TRY have a relatively high tolerance towards elephants, this does not necessarily translate to support for the National Park. Many farmers were living in the area when TRY was established in 1991, and since then, have felt burdened by the restrictions imposed on them following the establishment of the park, particularly as TRY was a stronghold for communist insurgents in the 1980s (DNP, 2013a). The animosity towards these restrictions has not completely ceased, and the current high poaching levels can partly be regarded as continuing acts of defiance by some aggrieved groups in the local population.

4.4 | Management strategies for human–wildlife coexistence in rubber-dominated areas

The underlying problem of conflicts between people and wildlife is the continuous loss or degradation of wildlife habitat, and, in the case of TRY, the only remaining natural habitat left is in a mountainous area too unattractive to be converted to farmland. To enrich this restricted habitat and make it more attractive for wildlife to stay within the forest, it is essential to enhance its functional heterogeneity by following careful ecological guidelines or principles (e.g., Owen-Smith, 1996); a recent government project in TRY is addressing these challenges and related issues, focusing on habitat improvement through the establishment of artificial water sources and salt licks (Chandrajith et al., 2009; DNP, 2013b; Weir, 1972; Zhang & Wang, 2003). The project also involved planting tree species preferred by elephants in the forest. This approach is based on the premise that a decline in such food resources could prompt elephants to venture outside the protected area, thereby escalating conflicts with surrounding human communities (Osborn, 2002). Several farmers have attempted to deter elephants by erecting electric fences around their farms. However, the absence of fence controllers has inadvertently led to the creation of electric currents that are potentially lethal to elephants. Thus, electrocution poses a serious threat to these animals (Palei et al., 2014), illustrated by the deaths of two elephants in two separate incidents around TRY in 2013. Installing simple and cheap fence controllers and electric fences generally provides effective protection against elephants, but challenges stemming from design and maintenance often undermine their long-term success (Hoare, 2012; Sukumar, 1989). Fences could also be used to protect young rubber plantations until the risk of damage has substantially decreased. This should be accompanied with information on how to set up and maintain nonlethal fences correctly. Another option could be to set up chilli-grease fences, which have been successfully applied in parts of Africa (Sitati & Walpole, 2006). However, the effectiveness of such fences might be limited in humid environments where chilli grease would need to be applied more frequently (Chelliah et al., 2010). As elephants do not specifically target young rubber plantations, a small nuisance might theoretically be sufficient to prompt elephants to initiate alternative routes in the farmland. Although chilli-grease fences, combined with community-based guarding, have successfully kept elephants from fields in Indonesia, this method was no more successful than traditional methods like noise in combination with guarding (Hedges & Gunaryadi, 2010). Beehive fences, which provide a highly effective deterrence option in many African countries (King et al., 2011), have not consistently demonstrated similar efficacy in deterring wild elephants in Asia (Dror et al., 2020; van de Water et al., 2020). In the case of fruit crops or cereals, for which harvests are more seasonal than rubber, farmer collaborations for guarding crops were also found to significantly reduce damage in other areas of Asia (Nath et al., 2015). This could also be an option for those farmers around TRY cultivating fruits but would require good collaborative engagement at the community level. As fruit crops are more susceptible to elephant-induced damage, rubber could be planted as a buffer crop covering the first km from the forest, given young plantations could be protected sufficiently.

Regardless of the preventative measures taken, some crop damage is inevitable in areas where humans and elephants live in close proximity. Insurance schemes could help make these losses more tolerable for affected farmers if the reimbursement is fair and timely and does not prompt farmers to reduce their risk-averting management (Nyhus et al., 2005). In China, where an insurance scheme reimbursed the loss of rubber trees, the payout system was not adequate and did not account for temporal or spatial differences in risks. Nevertheless, improved compensation was opted for by farmers (Chen et al., 2013; Zhang, 2011). Chinese authorities have even started to establish crop fields whose only purpose is to distract elephants from the fields of local residents (Lin et al., 2011; Luo, 2007). To increase the resources available to elephants, corridors connecting fragmented natural areas should be established (Areendran et al., 2011; Lin et al., 2008). For example, a corridor could be established in the northeast of TRY to link it with the Sikiet Waterfall National Park. The two protected areas are located <500 m apart and the scarcely populated area separating them is not too steep (Mañas, 2015).

5 | CONCLUSIONS

The acceptance of wildlife in close proximity to human activities ultimately depends on how much the lives and livelihoods of people are affected. In the case of the rubber-dominated landscape around TRY, damage to rubber was restricted almost exclusively to young plants. This provides the opportunity to develop protection measures to reduce these collateral losses. Elephants' consumption of rubber tree bark to meet potential nutritional deficiencies occurs occasionally but is unlikely to be a major problem in mature plantations as this type of damage seems mainly confined to young plants (Blair & Noor, 1981; Olivier, 1978). One key strategy for ensuring peaceful coexistence between people and elephants in rubber-dominated areas, therefore, lies in the protection of young trees. Another challenge for ensuring the long-term conservation of wild mammals in areas with limited natural habitats, such as TRY, lies in providing wildlife access to resources in cultivated lands without causing damage to crops. One potential solution involves leaving some natural vegetation, both for wildlife to feed on and to provide cover on the farms, softening the forest-farmland edge. More than 70% of forest wildlife species were found close to the forest-farmland boundary in our study area. This gives some hope that, given a more wildlife-friendly and low-risk plantation management strategy, rubber farmlands outside protected areas may serve as extended habitats for some wild mammals. Our findings contribute valuable insights needed to guide the development of a set of wildlife-friendly measures. These measures would aim to lower the impact of human-wildlife conflicts on plantation economies, while simultaneously minimizing farmers' workloads and promoting coexistence.

AUTHOR CONTRIBUTIONS

Franziska K. Harich-Wloka: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing—original draft; writing—review and editing. **Anna C. Treydte**: Conceptualization; data curation; formal analysis; funding acquisition; methodology; project administration; resources; supervision; validation; writing—original draft; writing—review and editing. **Joseph O. Ogutu**: Data curation; formal analysis; software; validation; visualization; writing—review and editing. **Chution Savini**: Conceptualization; resources; writing—review and editing. **Kriangsak Sribuarod**: Investigation; resources. **Tommaso Savini**: Conceptualization; investigation; methodology; resources; supervision; validation; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

ORCID

Franziska K. Harich-Wloka http://orcid.org/0000-0002-2075-3478

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SUPPORTING INFORMATION

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

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