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Research

Human–elephant conflict mitigation as a public good: what determines fence maintenance?

Arjun Kamdar [1], *Hiten Kumar Baishya* [2], *Harini Nagendra* [3], *Jayashree Ratnam* [1], *David Smith* [2] *and Nitin Sekar* [4]

ABSTRACT. Negative interactions between humans and elephants are known to have serious consequences, resulting in loss of life and deterioration in the quality of life for both species. Reducing human–elephant conflicts (HEC) is essential for elephant conservation as well as social justice. Non-lethal electric fences placed around villages or communities are a widely used intervention to mitigate HEC. Such barriers act as non-excludable and non-subtractable resources—i.e., public goods—that must be maintained collectively by beneficiaries or the State. Despite being fairly effective when well maintained, most such fences in northeast India are poorly maintained. This leads to our central question: why are some fences well maintained and others poorly maintained? We studied 19 such fences using qualitative comparative analysis, Ostrom's social-ecological systems framework, and a grounded theory approach, incorporating qualitative social science tools. We found that, contrary to our hypothesis, the functionality of fences cannot be predicted based on the design of the fence, whether or not the community made cash payments, or ethnic homogeneity or leadership in the village. Instead, we found there are three potential pathways of maintenance: (1) a community maintainer, (2) the community self-organizes, and (3) the Forest Department. Maintenance occurs when there is a congruence between perceived costs and benefits for the entity responsible for fence maintenance. These costs and benefits are diverse, including not just material benefits but intangibles like goodwill, sense of safety, social standing, and a feeling of fairness. We highlight these factors and provide recommendations for practitioners and policy.

Key Words: *collective action problem; fence maintenance; grounded theory; human–elephant conflict; India; non-lethal fences; public good; qualitative comparative analysis; social-ecological systems*

INTRODUCTION

The increased prevalence of human–wildlife conflict around the globe (Dickman 2010) is highly relevant to both wildlife conservation and social justice. Human–elephant conflict (HEC) is a major threat to the conservation of elephants as well as to the people that share the landscape with them (Wilson et al. 2015, Munyao et al. 2020). Across their ranges in both Africa and Asia, elephants require substantial amounts of resources to survive, including from areas outside protected areas (Douglas-Hamilton et al. 2005, Kshettry et al. 2020). Thus, the survival of these species is contingent on safe places outside protected areas where the economic and socio-cultural conditions are conducive to co-existence with people (Rangarajan et al. 2010, Okello et al. 2015).

Unfortunately, human–elephant interactions in many parts of Africa and Asia appear to generally be growing more negative, with factors ranging from elephant habitat loss to human (and, at a local level, sometimes elephant) population growth leading to more direct competition over resources (Shaffer et al. 2019). More conflict has increasingly meant loss of property, livelihood, and mental and physical well-being of local people (Barua et al. 2013). Human–elephant conflict also leads to the loss of both human and elephant lives (Pinter-Wollman 2012, Wilson et al. 2015). This is perhaps starkest in India: between 2018–2020, it is reported that 1,082 people have lost their lives to HEC nationwide (compared with 31 people over a period of 27 mo in Mozambique; Dunham et al. 2010, Ministry of Environment, Forest and Climate Change (MoEFCC) 2021). Retaliatory killings by poisoning and electrocution (Gureja et al. 2007, Kalam et al. 2018) pose a major threat to India's elephants, killing 214 elephants in the same time period (MoEFCC 2021).

Several methods have been used across the world to mitigate HEC, such as acoustic deterrents, culling, translocation, physical barriers, and psychological barriers (Shaffer et al. 2019, Nath et al. 2009, Chelliah et al. 2010). A growing number of efforts involve the use of non-lethal solar-powered electric fences, which deter elephants from entering farms and villages and are seen to be more cost effective than sturdier barriers (Kioko et al. 2008, Sapkota et al. 2014). Non-lethal electric fences act as a deterrent for elephants by giving a high voltage (>5,500 volts), pulsed, non-lethal shock when touched. As a determined elephant can often charge through the fence without lasting pain, these fences are more a psychological barrier for elephants than a physical one (Desai and Riddle 2015), and their effectiveness relies on their regular maintenance so that the fence regularly delivers an effective shock (Mumby and Plotnik 2018). Fences are generally built using the same materials to a similar standard, varying in shape—either enclosing a village or running along a forest boundary. Local residents suggest that a well-maintained fence can be 80–95% effective in deterring elephants (K. Goala, *personal communication,* 2020). Yet despite the requirement that low-cost fences be well maintained to be effective, many if not most fences are known to be poorly maintained (Neupane et al. 2018; District Forest Officer (DFO) Konwar, Assam Forest Department, *personal communication,* 2019).

[1]Wildlife Biology and Conservation Program, National Centre for Biological Sciences, TIFR, Bangalore, India 560065, [2]WWF-India, Brahmaputra Landscape, Tezpur, Assam, India, [3]Centre for Climate Change and Sustainability, Azim Premji University, Buragunte Village, Sarjapura Hobli, Anekal Taluk, Billapura Gram Panchayat, Bengaluru – 562125, [4]Wildlife and Habitats Division, WWF-India, New Delhi, India

This leads to our central question: given their relative effectiveness, why are some of the non-lethal electric fences used to reduce HEC well maintained while others are not? We address this question by treating it as a public goods puzzle. Due to the high fixed costs involved in purchasing the technical components (ca. $1,500 USD), each fence is typically set up with the help of non-governmental organizations (NGOs) or government bodies and designed to protect a village rather than individual households (Assam Hathi Project 2008). Fence maintenance thus fits the description of a "public good" where the good is characterized by (a) non-subtractability, i.e., an individual deriving utility from the good does not impact the availability of the good for another individual, and (b) difficulty of excluding individuals that do not contribute to the provision of the good (McGinnis 2011). In principle, this public goods problem can be addressed through some combination of direct government provision (i.e., the government maintains the fence), civil society participation (e.g., an NGO ensures maintenance), and collective action by the community. In this study, we seek to understand empirically what leads to successful fence maintenance in the context of diverse, low-income, rural communities.

Other studies have explored factors that shape the successful provision of public goods, finding success is more likely in contexts where the provision of the public good is matched optimally with users (Sarker and Itoh 2001); users pay for the public good (Ponnusamy et al. 2016, Chai and Schoon 2016); and users are able to coordinate their action, either because of strong leadership or institutions (Jack and Recalde 2015) or characteristics such as small numbers or ethnic homogeneity (Miguel and Gugerty 2005). As such, we test the a priori hypothesis that successful fence maintenance requires the following three conditions be met:

1. the fence affects only the movement and activities of those who benefit from the fence, i.e., fences are geographically compatible with the user group (Feiock et al. 2009);
2. the community contributes cash toward the fence, causing the community to be invested in the success of the fence (Sawada et al. 2013); and
3. the community is more able to coordinate fence maintenance (including the enforcement of sanctions) successfully, either because:

- the community is ethnically homogenous (Habyarimana et al. 2007); and/or
- the community has proactive leadership (Agarwal 2001).

These hypotheses were tested using both (a) qualitative comparative analysis (Schneider and Wagemann 2012) and (b) a combination of the social-ecological systems framework (SES; Ostrom 2009*a*, Hinkel et al. 2015) and ethnographic methods (participatory observation and semi-structured interviews). In addition, the latter methods were used to identify other factors that might help explain fence maintenance. Through this, we endeavor to find conceptually robust and practical solutions that could broadly help ensure successful provision of public goods that reduce human–wildlife conflict.

METHODS

Study Area

India is home to a majority of the world's population of wild Asian elephants, *Elephas maximus*, with a population of close to 27,000 (MoEFCC 2017). In the northeast Indian state of Assam, large-scale deforestation and loss of habitat appear to be forcing many of the state's approximately 5,000 elephants to enter human-dominated spaces looking for food and shelter (Choudhury 2004, Kushwaha and Hazarika 2004). Sonitpur district, Assam, lost 403 km² of forests (or >35% of its forest cover) between 1994 and 2019 (Srivastava et al. 2002, World Resources Institute 2020) and is considered an epicenter of HEC. Most villagers in this area engage in *sali* rice paddy cultivation, which takes place between the months of June and December. Rice is generally the only grain crop that is cultivated in the year, is crucial to the food security of households, and has a strong cultural significance. The presence of elephants increases several-fold during the *sali* harvest months of October to December, with large herds moving through the landscape (Talukdar and Barman 2003). As a result, a spike can be seen in the levels of HEC in this time period (Zimmermann et al. 2009). A majority of the villages use conventional local methods to mitigate HEC, including the use of fire, firecrackers, shouting, catapults, and occasionally spears, bow and arrows, and guns.

Faced with high levels of HEC, several villages in this landscape, with external support from NGOs and government bodies, have established low-cost, non-lethal electric fences as an HEC mitigation strategy over the last 14 yrs. To date, several hundred kilometers of fences have been constructed in the region (DFO Konwar, Assam Forest Department, *personal communication*). These fences have been established with the help of WWF-India and other NGOs to differing degrees, with these organizations providing some combination of funds to cover part of the capital costs; technical knowledge; and, in a few cases, a stipend to a member of the local community to cover maintenance and operational costs. The arrangements for each fence were made in an ad hoc manner, based on local conditions and the intuition of the implementers. Fence lengths range from 0.6 km to 20 km; some enclose the area of interest completely, whereas others run along a boundary between the village and forests or protected areas. About two-thirds of the fences that were at least 2 yrs old were noted to have failed (DFO Konwar, Assam Forest Department, *personal communication*, 2019)—that is, they did not carry a voltage high enough (>5,500 V) to deter elephants. The other one-third still had >5,500 V, primarily because they were well maintained.

WWF-India participated in the establishment of fences in 42 villages across Nagaon, Biswanath, and Sonitpur districts of Assam. Due to time constraints, we couldn't conduct our study across this entire population. To home in on a sufficiently diverse sample, we conducted exploratory visits to each village to collect preliminary data from November–December 2019. These comprised (i) preliminary information on the status of the villages with respect to the hypothesized determinants of maintenance and (ii) other drivers that we came to believe might contribute to fence maintenance outcomes. We inductively coded this preliminary data, where we identified potential variables to guide our selection of sample villages (Galvin et al. 2018; see Append. 1). Ultimately, we chose 19 villages based on logistic

feasibility while ensuring variation in the following characteristics:

From our a priori hypotheses:

1. Fence shape;
2. Model of contribution toward fence by users;
3. Ethnic diversity of community;
4. Apparent presence/absence of proactive leader.

From the exploratory phase of data collection:

1. Pattern of raiding by elephants;
2. Technical capacity for fence maintenance within community;
3. Presence of political elite;
4. Presence of active committee for fence maintenance;
5. Presence of Forest Department for fence maintenance.

To understand long-term maintenance, villages were only included if fences had been established at least 2 yrs prior to fieldwork, as fences are often well maintained for the first few months post-establishment before falling into disarray (Desai and Riddle 2015; Assam Forest Department, *personal communication*, 2019).

The selected villages were studied over a period of 7 mos from November 2019 to June 2020 (Fig. 1). They comprised fences in tea estates, agricultural fields, industrial areas, forest-fringe interfaces, protected areas, and degraded forests. A majority of the residents were farmers, tea plantation workers, daily-wage workers, or workers in nearby industries, with most residing in stand-alone houses often with homestead gardens.

Data Collection

The study involved (i) measurements of the dependent variable (fence maintenance) and (ii) identification and assessment of the independent variables (factors that may determine fence maintenance). The latter involved both an examination of the a priori hypothesis and a grounded theory-based approach to understanding other variables of interest.

Measuring fence maintenance

To assess whether each village's fence was well maintained, we evaluated fence maintenance through both direct assessments of the functionality of fences as well as assessments of the quality of fence maintenance. The latter "indirect metrics" were used to complement the former "direct metrics" as only a limited number of visits to each fence (mean = 3.3 times, range 1–7 times) were feasible over the sampling period; we did not want unrepresentative direct measurements to disproportionately drive our fence assessments. The direct metrics were summarized as a "tech score" for each fence: fences received one point if they had an average voltage over 5,500 volts, and one-third of a point each for a well-functioning solar panel, battery, and energizer. Indirect metrics were measured using a "human maintenance score," which comprised three factors thought to influence fence functionality: (i) trimmed undergrowth to prevent the leakage of electric current, (ii) position and sturdiness of posts, and (iii) position of the insulators. We calculated the proportion of sampled units that were well maintained for each of these three factors and averaged the three proportions to yield a score. Other relevant contextual factors were also noted for each fence. The tech scores and human maintenance scores were used to classify each fence as "well maintained" or "poorly maintained" using independent blind and non-blind assessment by authors HK and DS, who worked with the communities to implement the fences. In the blind test, HK and DS were asked to assess whether a village had a well-maintained fence based on the empirical data from that fence (without disclosing the village name); in the non-blind test, they stated whether they believed a named village maintained its fence properly based on their experience with that village (cf. Append. 2 for the detailed methods).

Factors affecting maintenance: testing the a priori hypothesis

We defined the main variables in our a priori hypotheses as follows:

1. Geographically effective design (GEO): the fence was situated such that it included only communities that desired the fence and did not lead to a major hindrance to the livelihood of those communities (e.g., fence did not block access to firewood);
2. Cash buy-in (CASH): whether the community had contributed cash toward the upkeep of the fence, suggesting investment in the success or failure of the fence;
3. Ease of collective action: communities were able to act collectively to maintain the fence based on one or both of the following two factors:

- Ethnic homogeneity (HOMO): homogenous communities (>90% of one ethnicity) might find it easier to cooperate and hence undertake collective action due to lower transaction costs, greater trust, and shared social norms;
- Proactive leadership (LEAD): communities with a leader who proactively championed fence maintenance facilitated maintenance. (Heuristic: when community members unanimously or nearly unanimously named the same person as associated with and actively involved in fence maintenance.)

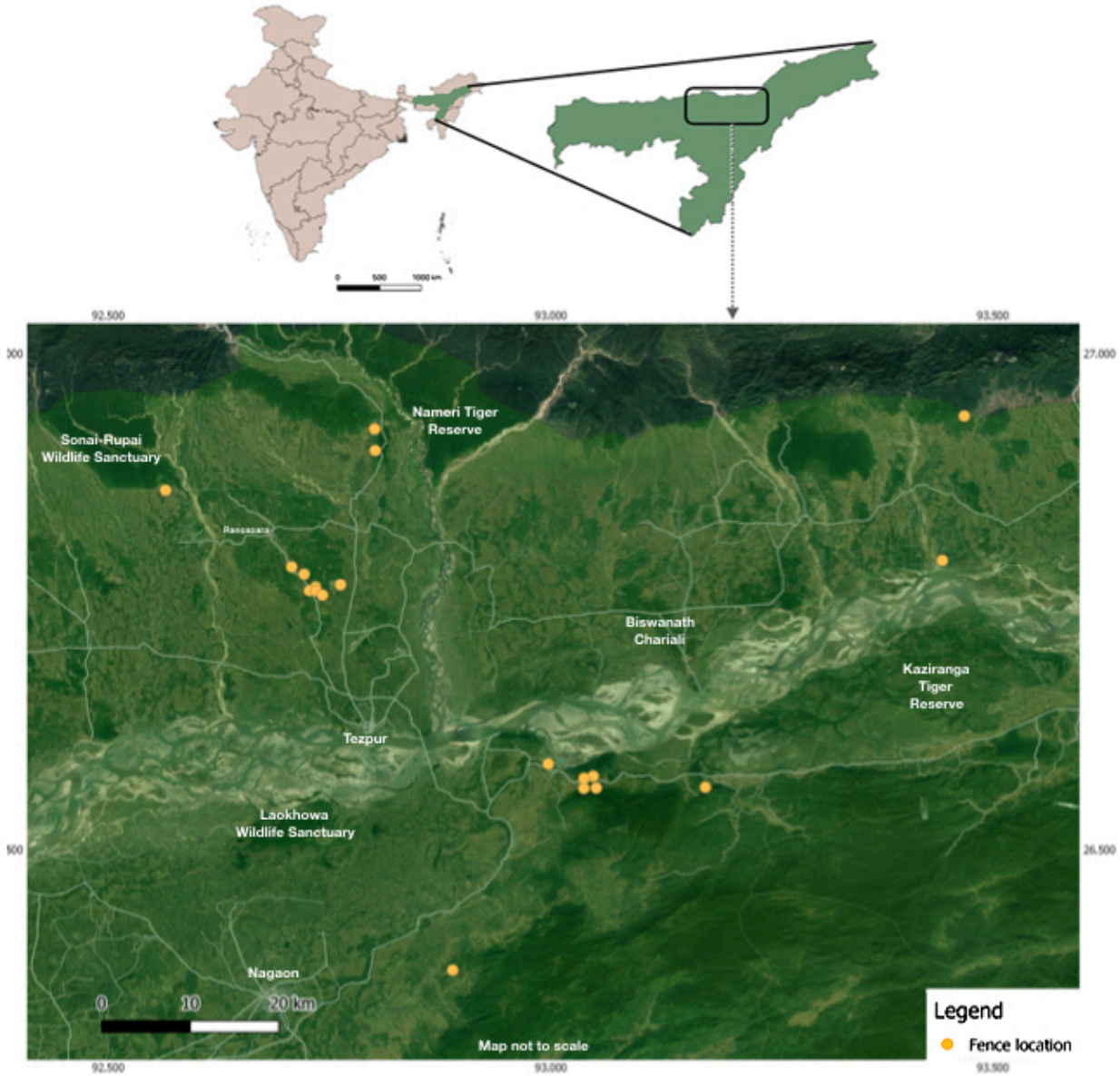
From November 2019–January 2020, in each of the 19 study villages, we conducted participant observations, unstructured interviews, and informal conversations, and we examined documentary materials where available (see Append. 3 for the detailed methods) to assess each of the study villages on all the variables of interest.

Using the assessments of whether each fence had a well-maintained fence (above) and whether they possessed or lacked each of the a priori hypothesis factors, we then ran a qualitative comparative analysis, or QCA (Schneider and Wagemann 2012), to examine our a priori hypothesis, namely:

GEO * CASH * (HOMO + LEAD) → Fence Maintenance

In the above Boolean construct, "*" refers to "and" and "+" refers to "or"; i.e., that geographic compatibility, cash buy-in, and collective action (enabled by either ethnic homogeneity, proactive leadership, or both) were necessary and sufficient conditions for fence maintenance. Qualitative comparative analysis is a set

Fig. 1. A map of the study area in the state of Assam, India, showing the 19 fences and corresponding villages studied.



theoretic method that uses Boolean algebra to identify the simplest combination of provided factors that explains the results for the outcome of interest (Schneider and Wagemann 2012). This approach is particularly useful in such complex systems in which multiple pathways might lead to the same outcome (Berg-Schlosser et al. 2009).

Factors affecting maintenance: identifying independent variables via grounded theory

From November 2019–January 2020, we also used a grounded theory (Glaser and Strauss 1967) approach to develop a model describing what explains variation in fence maintenance. Our methods were primarily ethnographic and included qualitative interviews and participant observations of behaviors such as fence guarding and maintenance (320 h). Given the social and ecological nature of the study system, Ostrom's SES framework was used to guide our identification of potential variables (Ostrom 2009, Hinkel et al. 2015). Authors involved in fence implementation did not participate in this field work so as not to bias the responses of those interviewed. Additionally, footage from camera traps (1,055 trap-nights) placed along fences to gauge elephants' interactions with fences incidentally provided insights on people's interactions with the fence (Bernard 2006, Newing et al. 2010; cf. Append. 3 for the sample sizes).

From January–June 2020, we tested and refined our provisional grounded model by using unstructured and informal conversations, documentary materials (40 documents collected over 140 d), semi-structured interviews (n = 266; cf. Append. 3 for detailed methods and Append. 4 for the survey instrument).

In each village, we conducted interviews with every fifth household, starting from the perimeter of the village (with greatest exposure to HEC) and working toward the center. On being denied consent (n = 6) or the house being empty (n = 18), an adjacent house was sampled. Each village was visited repeatedly across the fieldwork period and also at different times of the day so as to avoid a time-induced bias. Sampling in a particular village was stopped when we reached saturation—that is, each additional effort yielded little new information relevant to the research question, and we were able to "make sense" of the data (Glaser and Strauss 1967, Newing et al. 2010). Once this was done across all sample villages, our grounded model was finalized.

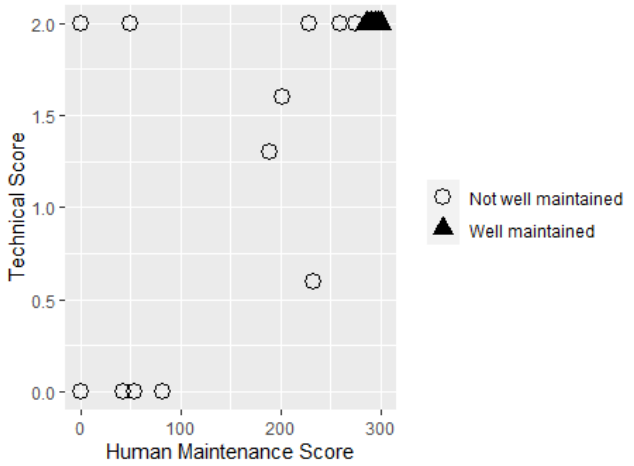
RESULTS

Fence Maintenance

Of the 19 fences assessed using the tech and human maintenance scores, 7 were classified as well maintained (37%), and 12 were poorly maintained (63%).

Seventeen of the 19 fences were classified the same way (as being either well maintained or poorly maintained) in blind and non-blind tests. Fences were ultimately classified as well or poorly maintained based on the blind tests: fences classified as well maintained had very high human maintenance scores and perfect tech scores (see Fig. 2).

Fig. 2. The technical score plotted against the human-maintenance score for both well-maintained and not well-maintained fences (as determined through the blind assessment).



A priori Hypothesis

Of our 19 sample communities with fences, 16 were found to have fences with geographically effective design, 7 provided some sort of cash buy-in for the fence, 13 were ethnically homogenous, and 12 were deemed to have proactive leaders.

Our QCA resulted in the following result:

LEAD (~HOMO*~CASH + CASH*~GEO) → Fence Maintenance

The solution term above proposes two pathways for maintenance: (i) maintenance will occur even if there is no cash buy-in and a non-homogeneous community so long as there is proactive leadership, or (ii) maintenance will occur if there is cash buy-in and no geographically effective design if there is proactive leadership. This result is thus incompatible with our a priori hypothesis. Furthermore, the combination of factors identified by the QCA as leading to fence maintenance does not seem to make logical sense. For instance, there is no reason to believe that cash buy-in would lead to maintenance when the fence design impedes non-users but then prevent maintenance in heterogenous communities. The result of the QCA is thus likely an artifact of chance (Ragin 2000), suggesting that our a priori variables do not meaningfully predict maintenance (refer to Append. 5 for detailed analyses).

Finally, one element of the a priori hypothesis was directly contradicted by the qualitative data collected. We found evidence that homogenous communities do not necessarily find it easier to cooperate, as sanctions against individuals that fail to pay for maintenance of the fence are rarely enforced. For instance, Rekha† from Jalokhiabasti† elucidates, "...since all of us belong to the same community, and the same namghar [temple], we all know each other well. Therefore, even though the rule is to pay a full day's wage as fine for shirking their duty to monitor the fence, it is rarely enforced."

Factors Contributing to Fence Maintenance Identified Via Grounded Theory

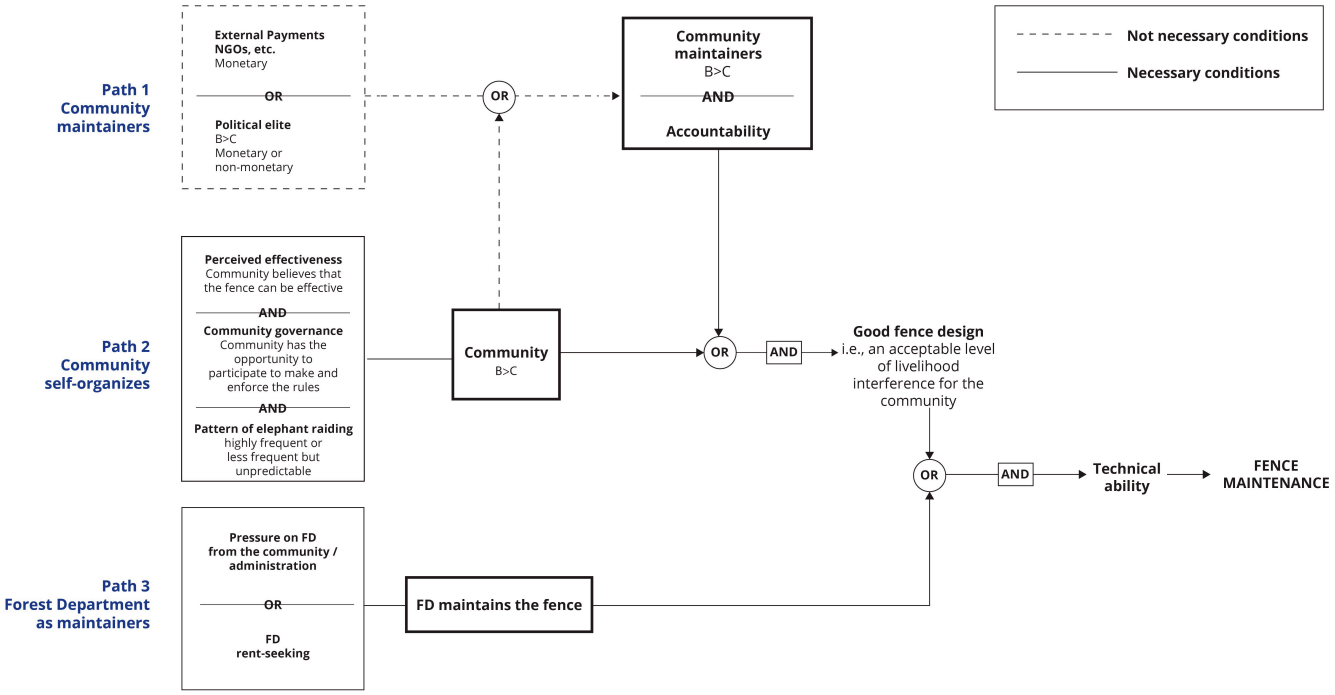
Our grounded approach suggested that successful fence maintenance could happen due to any of three mechanisms: (1) a small number of community fence maintainers ensure functionality of the fence, (2) community maintenance is enabled by self-organizing, and (3) maintenance is done by the Forest Department (cf. Fig. 3). Of the seven successfully maintained fences, two were maintained by community maintainers funded by individuals/organizations, two by community maintainers funded by the community, one by the community themselves, and two by the Forest Department. Of the 12 unsuccessfully maintained fences, none were found to be maintained by community maintainers funded by individuals/organizations, four by community maintainers funded by the community, eight by the community themselves, and none by the Forest Department (although other communities with Forest Department-maintained fences examined during exploratory study had failed fences; cf. Table 1).

Table 1. The pathways to maintenance and the number of fences maintained and not well-maintained

Pathway to maintenance	Well maintained	Not well maintained
Community maintainer		
externally funded	2	0
paid by the community	2	4
Community self-organizes	1	8
Forest Department	2	0

The results of our grounded approach suggest that successful fence maintenance is not fully predicted by the pathway it follows but rather by whether the key actors (political elites, community maintainers, the Forest Department, or the community as a whole) perceived the benefits of fence maintenance to be greater

Fig. 3. The three pathways to fence maintenance found in the study. Where benefits > costs refer to where the perceived benefits outweigh the perceived costs.



than the costs (cf. Append. 6 and 7 for more on perceived costs and benefits). Notably, in contrast with our a priori hypothesis, the perceived benefits and costs were diverse (see Table 2)—no three or four variables seemed to adequately explain whether fences would be adequately maintained. Instead, the most important factors leading to maintenance or non-maintenance could be highly idiosyncratic. In one community, the community maintainer noted that he was motivated to ensure the fence was effective because he had lost a family member to an elephant attack a few years ago. He said he did not want "anybody's family to suffer like me... people don't understand the consequences until a disaster happens... now, where the authorities have given us this fence for our safety, we must take care of it as the benefit is for us only."

Despite such idiosyncrasies, the weight of the evidence suggests some patterns in whether fences succeeded or failed in the case of each pathway. Community maintainers seemed to be most motivated by the direct payments they received and the goodwill they earned from the community for their work. The latter is not necessarily just a complement to the former. One community maintainer named Sing† from Gorumara† notes, "Dipen† and I anyway don't do this for the money, it is for the safety of the people of the village—and they know this and respect us for doing this. So we don't mind the fact that they have stopped contributing toward our stipend, Rs 5–10 is nothing anyway." In contrast, unaccountable community maintainers were able to extract payment from the community even when they failed to maintain the fence. In one village, the maintainer was also the village head and hence held power over the community members. In the other, the community did not possess the technical knowledge required to discern between well-maintained and poorly maintained fences, making them unable to hold the maintainer accountable.

When the community as a whole was responsible for fence maintenance, three social-ecological factors were particularly relevant to whether communities perceived the benefits of fence maintenance to outweigh the costs. First was the perceived pattern of elephant raiding: in order for benefits of the fence to be salient, elephant raiding instances needed to be either very frequent or somewhat frequent but unpredictable: if elephants visit only rarely, the costs of fence maintenance may be perceived to be higher than the benefits. If elephants visit infrequently but very predictably, fence maintenance and other mitigation measures need only be concentrated at the time of high risk, meaning fence maintenance efforts might flag at other times.

Second, communities had to perceive that fence maintenance significantly reduced HEC—i.e., that the fence could be effective at reducing HEC, giving communities a sense of safety, security, and peace of mind. Fences were seen as an especially useful tool in small villages that found it difficult to effectively chase elephants away. Noted a resident of Baghmara†, which comprised six households and a hospital, "We are a small cluster [of houses] and don't have young men to drive the elephants away like the neighboring villages. Therefore, the fence is even more important for us—prior to the fence, the Sister's house was broken four times in one month!" Trust in the effectiveness of the fence could become an issue if elephants breached the fence—even if the breach was due to poor maintenance. Even occasional breaches could lead to reduced perceived benefits from the fence, which could lead to reduced maintenance, causing a vicious cycle. Additionally, some members believed that even poorly maintained fences could be

Table 2. Description of the perceived costs and benefits found to shape whether key actors (community maintainers, the community as a whole, or political elites) found efforts to maintain low-cost electric fences to be worthwhile. Perceived benefits and costs relevant to each actor/set of actors is denoted using checks, while those suggested to be particularly important are underlined.

Perceived Benefits/Costs	Explanation	Relevant to...		
		Community maintainers	Community (whole)	Political Elites
BENEFITS				
Payments for fence maintenance	Those involved in repairing or upkeep of the fence earn income from the community or external entities only if the maintain the fence.	✓	✓	
Political support/goodwill from the community	Maintenance of the fence can result in those seen as responsible for successful maintenance earning social or political capital	✓		✓
Reduced damage to crops/homes due to HEC	By respondents' reckoning, well-maintained fences reduce the probability of elephants raiding crops or by some 90%+.	✓	✓	
Safety and security	Elephants wandering through a community at night can lead to accidental death/injury of community members; fences that discourage elephant entry help prevent this.	✓	✓	
Rest and sleep	Without fences, community members often have to spend sleepless nights chasing elephants from their crops. If a fence is effective, community members can often sleep through the night instead.	✓	✓	
Less guilt due to (potential) harm to elephants	Many villagers believe harming elephants is a sin, either because they believe elephants are compelled to enter human habitation due to hunger and habitat destruction, or because they are manifestations of Ganesh, or both. Fences are seen as less harmful than, say, pelting rocks or using guns.	✓	✓	
AVERTED COSTS (also benefits)				
Averted sanctions for failing to pay for maintenance	Members that fail to maintain the fence on their turn can face monetary sanctions. The amount is typically the cost of replacement, i.e., one day's wage rate. Repeated failure to help can lead to social sanctions and an erosion of goodwill of the community members.		✓	
Averted social costs of fence failure	Once maintainers are seen as responsible for the fence, community maintainers face social humiliation and an erosion of their reputation and goodwill in the community if the fence fails to stop elephants.	✓		
COSTS				
Hindrance of movement	Fences could act as a barrier for human movement, especially when carrying firewood. At night, individuals have to disembark from their vehicle to disengage the fence, cross over, and then reconnect it once again.		✓	
Time and effort for maintenance	Walking the length of the fence, clearing undergrowth, fixing fallen posts, fixing slipped insulators, require time and come with opportunity costs.	✓	✓	
Payment for maintenance	Salary (monetary or rice paddy) paid to community maintainers		✓	✓
Material costs for fence maintenance	The costs of replacing posts or missing insulators, repairing a faulty energizer, etc.		✓	✓
The "sucker" effect	The personal and social costs that one suffers such as shame, guilt, and social censure when an individual keeps a promise that others have broken (Ostrom 1990*a*)—experienced by those that pay for or maintain the fence when others refuse to.		✓	

deterring elephants due to prior negative experiences with live fences, suggesting that, "the elephants now know not to come here at all." This belief could also potentially lead to a decline in the perceived benefits of maintenance.

Finally, communities were more likely to perceive the benefits of the fence to outweigh the costs if they had an opportunity to make and enforce the rules governing the fence. This provided community members with a sense of participation and ownership and allowed for consensus rules that fairly distributed costs and benefits across members, reducing instances of non-participation and sabotage. Community-constructed rules included the opportunity to take part in deciding where the fence should be established and how it should be maintained. Such a process could also help community members develop a positive relationship with the people establishing or maintaining the fence, as well as cause villagers to anticipate social sanctions by the community if they failed to comply with agreed rules and processes. The most important rules had to do with financial contributions to fence maintenance. In communities where the process to construct rules was not sufficiently participatory, a few individuals found they were the only community members delivering on their commitments to maintain the fence. These individuals felt taken advantage of, so they stopped maintenance altogether, resulting in the fence failing. This is termed as the "sucker effect" and appears to be a more salient problem in smaller villages, contributing to the failure of three small-village fences in our study. Relatedly, if the community chose to pay a specific person to act as community maintainer, the maintainer had to be seen as trustworthy and having a good track record, even in non-fence related activities. In two instances where the maintainer was caught shirking duties or siphoning money, the trust was broken, payments ceased, and fence maintenance did not take place. Once this trust was broken, despite the benefits outweighing the costs for a maintainer, the cost of transitioning to another maintainer were too high for the community, leading to the fence failing.

In our two cases of Forest Department-maintained fences, we found maintenance to occur because (a) of political pressure from the community or an administrative body to reduce HEC, or (b) perverse incentives/rent-seeking opportunities associated with the fence. In the case of one community, a politically empowered Eco-Development Committee could mobilize (violent) protests if the Forest Department did not prevent HEC, motivating maintenance of the fence. In another case, officials were reported to have maintained the fence so that superiors and local residents would not protest when officials exploited natural resources and funds made available to reduce HEC.

Even when the perceived benefits of maintenance outweighed the perceived costs, other conditions had to be met to allow for fence maintenance. For all fences other than those maintained by the Forest Department, fences must be designed such that they do not unduly hinder movement (of people or livestock). For instance, we accidentally captured evidence on the camera traps of the fence obstructing villagers carrying head-loads of firewood. As a result, the fence was sabotaged repeatedly in order to aid access. Sabotage was found to generally not be as significant a concern for Forest Department-maintained fences as the Forest Department rapidly repairs any breaches, and local community members are afraid of antagonizing "the powerful people in uniform," hinting at the repercussions of getting caught. Finally, fence maintenance required that those responsible have the technical know-how required to maintain the fences.

DISCUSSION

Contrary to our hypothesis, successful maintenance of low-cost, non-lethal fences intended to reduce HEC could not be explained completely by whether fences were geographically well matched with their users, users paid for the fences, and community coordination was enabled by leadership or ethnic homogeneity. Instead, our results reflect the complexity of other social-ecological systems (Fleischman et al. 2014, Nagendra and Ostrom 2014). We found that fence maintenance is driven by a combination of ecological factors (pattern of elephant crop-raiding), political factors (pressures upon the Forest Department), the availability of technical ability, and the perceived costs and benefits of fence maintenance for several key actors. Even in our modest sample size of 19 villages, we found a diversity of explanations for fence maintenance and non-maintenance that defied simple summary. Some fences were successfully maintained through collective action, such as the collaboration of the entire community; some were maintained by a few dedicated community maintainers; and some by the State via the Forest Department. We found that fences could be successfully maintained due to the dedication of varying numbers of people, ranging from two highly motivated individuals to a small subset of approximately 10% of the households to nearly all the households in the village. In our initial exploratory survey of all 42 villages, there were also examples of unsuccessful maintenance from each of the three management arrangements we found.

The diversity of relevant perceived costs and benefits motivating action or inaction is of particular policy relevance. Emphatically, decisions were not necessarily made based on economic calculations. There was a general consensus that well-maintained fences helped reduce HEC by as much as 90%—but even when the benefits in terms of crops saved and protection of homes and safety almost certainly outweighed the costs in terms of time, effort, and money, this did not always lead to fence maintenance. For instance, when some community members felt that others weren't contributing fairly to the fence, they withdrew their own support (i.e., the "sucker effect"), even though it might have been in their economic interest to ensure fence maintenance. Conversely, we found community fence maintainers that ensured fence functionality (in one case, even at his own financial expense) even if they weren't paid, motivated by either social capital or their personal experiences with HEC. Although some fences succeeded despite non-payment, others failed despite fair payment due to a lack of accountability.

What, then, do these findings mean for conservation practitioners hoping to promote fence maintenance to stem HEC? Although fences could be maintained successfully via any of the three pathways we describe (Fig. 3), we believe working through community maintainers is the most dependable path to success. The appointment of one or two community maintainers can make it clear who is responsible for the fence and ensure a clear set of deliverables in exchange for pre-determined remuneration; such market norms—accompanied by a practical plan for accountability—can be easier for an NGO to navigate than unwritten social norms; these are typically complex and require a deeper understanding of intra-community dynamics, relationships, and the individuals' interactions with one another (Ariely 2010). In selecting community maintainers, conservation practitioners should be deliberate: a trusted maintainer with a strong record of honesty and diligence might be the difference between a successful and failed fence.

In some contexts, however, practitioners might want to avoid force-fitting the community maintainer model. Where communities are small (between six and 30 households), maintenance by the full community seems more likely to succeed than for larger communities, as noted in other contexts (Olson 1965 in Ostrom 2009*b*). If the political incentives happen to allow for a government department (in our case, the Forest Department) to maintain the fence, then that could also be a functional option —but such political conditions such as being areas of strategic importance, rent-seeking opportunities, and political ramifications for non-maintenance are generally beyond the control of conservation practitioners from the civil sector.

In addition, conservation practitioners can pay attention to several key elements of the process of establishing a fence (cf. Append. 8 for detailed recommendations). When establishing a fence, practitioners can attempt to involve all members of the community in designing the fence and orienting them with regard to how it functions. This allows for multiple benefits. First, it can help ensure that the fence does not hinder livelihood activities to the degree that it attracts sabotage. Second, skilled implementers can attempt to elicit an understanding of the perceived costs and benefits of the fence and ensure that the interests of various community members are addressed in the design and management of the fence. Third, by establishing a clear shared understanding of the fence as infrastructure meant to serve the whole community, and by making clear the roles and

responsibilities for fence maintenance to all community members, conservation practitioners can increase the (i) social costs of non-compliance and (ii) perception that compliance will be recognized by the community. We hope this will help prevent the sucker effect and the resultant vicious cycle of non-maintenance.

Conservation practitioners should also conduct training sessions and perhaps refreshers to ensure that those responsible for the fence learn and retain the technical ability to maintain the fence. Our findings suggest that communities might not openly ask to be given the skills they need to ensure fence maintenance.

Finally, when monetary contributions must be organized from the community to fund fence maintenance, we recommend that payments be structured as single large (perhaps annual) contributions instead of repeated small ones (e.g., weekly). Respondents indicated these larger payments would generally be feasible, and by reducing the transaction costs and making it easy for community members to monitor those failing to contribute (i.e., by increasing the social costs of non-compliance), such a system can help prevent the disintegration of collective action.

CONCLUSION

Our findings suggest that there are a variety of ways public goods can be successfully provisioned in low-resource rural settings. Public goods are often seen as best-met by government (Desai 2003, Flavin 2019), but even when political conditions do not allow this, community action or the dedication of well-incentivized individuals can work at the small scales we examined. However, that doesn't mean providing such public goods is straightforward: overall, although some best practices in fence establishment and maintenance can be scaled (cf. Append. 8 for recommendations), the diversity of reasons that appear to contribute to the maintenance or non-maintenance of non-lethal fences aimed at reducing HEC should push conservationists to better understand the particular socio-ecological, political, and economic contexts in which they aim to work (Akama et al. 1996, Dickman 2010, Bennett et al. 2017, Dhee et al. 2019). More generally, participatory approaches (Usongo and Nkanje 2004, Milich et al. 2020) can provide practitioners in conservation and other fields the tools they need to identify the particular costs and benefits salient to the communities they work with and optimize the probability that the public goods they try to establish take root and are well sustained, particularly in low-resource settings.

[†] Names changed to protect the identity of the respondent.

Responses to this article can be read online at:
https://www.ecologyandsociety.org/issues/responses.php/13271

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Data Availability:

The data/code that support the findings of this study are available on request from the corresponding author [AK]. None of the data/code are publicly available because of privacy restrictions, e.g., they contain information that could compromise the privacy of research participants. Given that a large component of the study comprised ethnographic, qualitative work, ensuring the privacy of the respondents is essential. Ethical approval for this research study was granted by the National Centre for Biological Sciences, India [NCBS - NCBS/IEC-15/007].

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Appendix 1

Tables of villages and exploratory variables

Table S1: the 9 potential variables identified from the exploratory phase of the study and their options

Potential variables	Options
Fence shape	linear / enclosing
Model of contribution towards fence by users	cash / kind frequency (weekly/ bi-weekly/ monthly/ half-yearly/ annually)
Ethnic diversity of community	yes / no
Apparent presence/absence of proactive leader	yes / no
Pattern of raiding by elephants	Frequency (number of times a year) Intensity (how much damage do the elephants cause in terms of crops, property, injury and death) Predictability (randomly through the year or during specific periods of time, such as the paddy harvest season)
Technical capacity for fence maintenance within community	Presence / absence
Presence of political elite	yes / no
Presence of active committee for fence maintenance	low to high
Forest Department role	low to high

Table S2: data of the 9 potential variables and 19 villages identified from the exploratory phase of the study

Village	Fence shape	Ethnic diversity of community	Apparent presence/absence of proactive leader	Pattern of raiding by elephants	Technical capacity for fence maintenance within community	Presence of political elite	Presence of active committee for fence maintenance	Forest Department role
Baghmari	enclosed	homogenous	absence	medium frequency, high intensity, low predictability	presence	no	medium	low
Haabasti	enclosed	homogenous	absence	medium frequency, high intensity, low predictability	absence	no	low	low
Gorumara	enclosed	homogenous	presence	medium frequency, high intensity, low predictability	presence	no	high	low
Jalokhiabasti	enclosed	homogenous	presence	medium frequency, high intensity, low predictability	presence	no	low	low
Ajgarjuli	enclosed	homogenous	presence	low frequency, medium intensity, medium predictability	presence	no	low	low
Kolbasti	linear	heterogenous	absence	low frequency, medium intensity, medium predictability	absence	no	low	high
Aadhiyachapori	linear	heterogenous	presence	high frequency, high intensity, low predictability	presence	no	high	high
Wenzajuli	enclosed	heterogenous	absence	low frequency, medium intensity, high predictability	presence	yes	medium	medium
Talabari	linear	heterogenous	presence	medium frequency, high intensity, medium predictability	presence	no	low	high
Botiagaon	linear	homogenous	presence	high frequency, medium intensity, low predictability	presence	no	low	low
Simalugaon	linear	homogenous	presence	high frequency, medium intensity, low predictability	absence	no	high	low
Sagunbasti	linear	heterogenous	presence	medium frequency, medium intensity, low predictability	absence	yes	low	low
Babamura	enclosed	homogenous	presence	low frequency, low intensity, high predictability	presence	no	low	low
Bihpukhuri	linear	heterogenous	absence	low frequency, medium intensity, medium predictability	absence	no	low	low
Balu Danga	enclosed	homogenous	absence	medium frequency, medium intensity, low predictability	absence	no	low	low
Manimuni	enclosed	homogenous	absence	medium frequency, high intensity, low predictability	presence	no	low	low

Mrigamari	linear	heterogenous	presence	medium frequency, medium intensity, medium predictability	presence	yes	low	low
Boribeel	linear	heterogenous	presence	medium frequency, medium intensity, medium predictability	presence	yes	high	medium
Pukhuripar	enclosed	homogenous	presence	medium frequency, medium intensity, low predictability	absence	no	medium	low

Appendix 2

Details of how fence maintenance was measured - score card and blind/non-blind test

In order to assess whether a fence is well-maintained or not, we created an index that incorporated the technical and human-maintained components as well as the context for each fence in order to provide a holistic, functional perspective.

Measuring the level of fence maintenance

Under ideal circumstances, a large number of randomly collected voltage readings repeated over the duration of the study period would have been an appropriate measure for assessing maintenance of each fence. Given the logistical constraints due to the short time period and large spatial spread of the study area, we had to devise a method that would accurately reflect the level of maintenance despite a lower number of visits to each fence. Furthermore, given that the specifications (length, power of the energizer, fence design, etc) for each fence are unique, an absolute threshold for the factors determining maintenance would not be functionally relevant, and thus each fence needs to be viewed and ranked in its specific context. For instance, some relatively short fences have disproportionately high-powered energizers powering them and therefore, undergrowth touching the fence and leaking current was less likely to functionally impact the functioning; ie, the fence yet had a high enough voltage to deter elephants. This would mean that less maintenance is necessary to maintain the functionality of short fences, making comparisons of any one or two fence maintenance measures across fences of different lengths or differently powered energizers an imperfect surrogate measurement of quality of maintenance. Furthermore, just as with voltage, fence maintenance might vary over time, meaning that there was a danger of small sample sizes leading to inaccurate assessments.

We took a two-pronged approach to addressing these constraints. First, we attempted to measure both the technical components (using a "tech score") and human maintenance ("human maintenance score") components of the fence to provide a holistic measurement of fence maintenance. We also noted any relevant contextual factors while visiting each fence. Second, we asked our co-authors to provide both blind (based on the data collected for each fence, but with no village name provided) and non-blind (based on the village name and our co-authors' long-term knowledge of those village fences) assessments of fence maintenance quality. Our approach helped prevent non-representative small samples from leading to inaccurate assessments of fence maintenance. For instance, a chance event like a storm toppling a tree on the fence could lead to having a low voltage but should have less effect on the other maintenance measures.

For both the tech score and human maintenance score, each of the components used to calculate the score were given a weight based on their relative importance for fence function (see Table S1-3). These weights were arrived at after detailed discussions with on-ground

practitioners, Forest Department officials, an energizer manufacturer, and fence technicians. The technical score was calculated using the condition of the solar panel, battery, energizer and the voltage. Where the voltage exceeded 5500V, the voltage score was treated as a '1' and where it was below, as a '0'. The human-maintenance score was calculated by averaging the proportional level of maintenance (number of units well-maintained divided by the total number of units sampled) on three factors suggested to influence maintenance in the index; (i) trimmed undergrowth, (ii) position of posts, and (iii) position of the insulators.

Table S3: the parts of the fence assessed for the technical score and how they were scored. In each component the unweighted score was out of one.

Apparatus	**Conditions to note**	**Mode of inspection**	**Rationale**	**Weightage**
Solar Panel	Dust-free, exposed to sunlight, connected to the battery, position with respect to the sun	Visual inspection and solar charge monitor	The solar panel needs to be exposed to direct sunlight in order to generate electricity.	1/3
Battery	Adequate fluid levels, voltage	Visual inspection and voltmeter	The battery should be producing an output of 12v for the energizer to work effectively.	1/3
Energizer	In-built 'strength' reading on the energizer when the wires are disconnected	Physical inspection of indicator on the energizer after disconnecting the fence and switching the energizer on	This helps understand whether the energizer unit is functional	1/3
Voltage	Voltage greater than 5500 v was considered to be adequate to deter elephants. (pers. comm. DFO Konwar, Assam Forest Department	Gallagher G50900 SmartFix Fence Tester to see the voltage as far as logistically possible from the energizer.	The voltage tends to decrease as one moves further away from the source, ie, the energizer and hence a reading was sought as	1

	2019; Sukumar 1986 suggests 5000 v)		far away from the energizer as logistically feasible.	

Table S4: Elements of the "fence maintenance score", their rationale for inclusion, and their relative weight in the final score. In each case, the proportion of sampled length/units in a satisfactory state was used as the unweighted score.

Variable	**Conditions to note**	**Mode of inspection**	**Rationale**	**Weightage**
Trimmed undergrowth	Proportion of sampled length of fence without undergrowth touching the live wire	Visual inspection	Undergrowth touching the live wire leads to a leak in the voltage.	1/3
Position of posts	Proportion of sampled posts firmly placed in the ground	Visual inspection	Posts that are not firmly placed in the ground are easier for elephants to breach and are also more likely to fall over, leading to a drop in the voltage.	1/3
Position of insulators	Proportion of sampled insulators in place, ie, insulating the live wire from the post	Visual inspection	Insulators ensure that the live wire does not come into contact with the posts, so as to prevent the current from leaking through.	1/3

Table S5: Contextual factors noted to inform blind assessments of each fence and rationale for their inclusion. These provided necessary information for interpretation of the technical and maintenance scores.

Contextual factor	**Conditions to note**	**Mode of inspection**	**Rationale**
Recent damage	Length of fence damaged recently (elephant breaches, storms, tree-falls etc); Presence of fresh signs such as footprints	Visual inspection	Recently damaged fences are not reflective of chronic levels of fence maintenance and hence circumstantial evidence in the form of footprints, debris, and condition of the damage were used to triangulate how recent the damage was.
Fence design	Description of fence; number of strands, position of posts (perpendicular or tilted)	Visual inspection	Whether the poles were placed in a tilted manner as recommended by fence technicians, the number of strands of wire as this helps make the fence comparable across sampling instances.
Fence modifications	Modifications post-implementation such as installing additional wires for post protection, gates	Visual inspection	Indicates investment in and maintenance of the fence.

Ease of maintenance	Terrain, proximity to road, kind of undergrowth	Visual inspection	Helps account for the difficulty of maintenance. For instance, fences installed in crop fields require lesser maintenance owing to lesser undergrowth that can potentially come in contact with the fence.

In order to calibrate and standardize the method of assessing fences, the indices were piloted in the field by four individuals who were briefed on the index, its components and the methodology. The individuals then independently surveyed a specified stretch of a fence on the same day, filling in the datasheet for the index. A similar design with two individuals was replicated across 4 stretches of fences during fieldwork.

There was a near-perfect congruence in measurements by all the individuals, suggesting that the method provided a consistent measurement of the level of maintenance.

Sampling strategy

Fences were repeatedly assessed (mean = 3.3 times, range 1-7 times) during the *sali* paddy ripening season which is when elephant presence and HEC peaks annually (Zimmermann et al. 2009). This helped make the fences comparable and account for the fact that some of the fences are set-up only for the duration of the *sali* paddy season while others are kept functional year-round.

A fence was assigned at random to each day when fieldwork was possible over the course of the season and was assessed based on the index created. Where sampling the entire length of the fence was not feasible owing to safety concerns or logistical reasons, the maximum length possible was sampled.

Additionally, once the randomly-sampled fence was assessed, other fences in the adjacent areas were assessed, time-permitting. This system ensured that fences were assessed as frequently as possible and gave a more robust assessment of the level of maintenance.

Going from empirical measurements to overall maintenance assessment

In order to verify the assessment of fence maintenance, the data were independently cross-verified by co-authors HKB and DS, who each had more than a decade of field experience regarding the use of fences for HEC mitigation in the study area. They were instructed to provide an assessment of the fences as 'poorly-maintained', 'well-maintained', or 'not sure'. This was done in two ways:

(1) **Blind assessment**: The conservationists were presented the empirical data collected for each fence with the names of the villages and other identifying information removed.

(2) **Non-blind assessment**: The conservationists were presented with the list of the villages mentioned without the data collected.

Comparison of the blind and non-blind assessments helped ensure that the measures of fence maintenance were reflective of the conservationists' field experiences (refer Fig 2 for the graph of assessment scores).

The blind assessments resulted in a quantitatively consistent assessment of what was considered well-maintained. The well-maintained fences (n=7) were those fences that had a technical score of 2 and a human maintenance score greater than 267. Furthermore, these were almost entirely consistent with the non-blind assessments.

Appendix 3

Details of methods

Villages with type of fence, number of camera trap nights, and number of semi-structured interviews conducted

Note: Forest Department officials interviewed were added as a separate row as they had jurisdiction over several of the selected villages.

Village name	Type of fence	Camera-trap nights	Semi-structured interviews
Baghmari	Enclosed	42	6
Haabasti	Enclosed	*NA*	18
Gorumara	Enclosed	61	20
Jalokhiabasti	Linear	*NA*	17
Ajgarjuli	Enclosed	35	18
Kolbasti	Linear	39	11
Aadhiyachapori	Linear	118	14
Wenzajuli	Linear	68	16
Talabari	Linear	2	21
Botiagaon	Linear	*NA*	12
Simalugaon	Linear	222	2
Sagunbasti	Linear	56	15
Babamura	Enclosed	*NA*	9
Bihpukhuri	Linear	220	18
Balu Danga	Enclosed	*NA*	5
Manimuni	Enclosed	*NA*	3
Mrigamari	Linear	110	27
Boribeel	Linear	52	17
Pukhuripar	Enclosed	30	6
Forest Department			11
		1055	266

Table S6: Table of villages with type of fence, number of camera trap nights, and number of semi-structured interviews conducted

I. Qualitative methods used for descriptive model of fence maintenance

Participant observations, informal conversations, and unstructured interviews

In order to get an understanding of the study system and triangulate the data collected on fence maintenance, elephant presence, governance, and monitoring systems, we engaged in participant observations (Bernard 2006, Newing et al. 2010) for 320 hours by taking part in fence maintenance activities, farming, guarding crops and property from elephants, cooking, celebrations and Forest Department-led HEC mitigation drives. In certain scenarios, we were participating observers, such as farming and guarding activities. In others, we were more observer than participant, such as during discussions and meetings. This helped build rapport with the community, enabling nuanced observations of peoples' interactions with elephants and the fences and improving the quality of information acquired (Bernard 2006). In most circumstances, AK's identity as a student attempting to understand human-wildlife interactions in the landscape was known to the community members. Comprehensive field notes with detailed descriptions were maintained over the course of fieldwork. The data collected through participant observations also helped build the context for semi-structured interviews and refine the questions to be clearer and more relevant to the social settings.

Elephant-fence interactions

Camera traps were placed at select locations along fences in order to assess elephants' interactions with the fence (~1000 trap nights, refer Appendix 3) and independently gauge whether and how elephants were able to breach fences (Ranjeewa et al. 2015, Liefting et al. 2018). This was done through the first and second phase of the study. Given that elephants and humans use the same paths (Keil 2016), we found that camera-trap data could also be used to triangulate the social science data, such as people's interactions with the fence, in an independent manner. The community members were aware of and accustomed to the camera trap and hence not deterred by its presence. This helped deal with the problem of reactivity, often encountered in observational social science studies (Bernard 2006).

Semi-structured interviews

In order to explore, triangulate, refine and empirically verify the broad theory comprising relevant variables identified in the initial phase of the study, a semi-structured interview was framed and used across the study area (n = 266, respondents from 19 villages and the Forest Department). This interview comprised a mix of open-ended as well as close-ended questions and were framed in a manner so as to avoid biasing the responses (Bernard 2006, Newing et

al. 2010, Cohen and Lea 2004, refer Appendix 3 for sample sizes and Appendix 4 for the survey instrument).

Sampling in a particular village was stopped when we reached saturation, that is, each additional unit of effort yielded little new information relevant to the research question and we were able to 'make sense' of the data (Glaser and Strauss, 1967, Newing et al. 2010). The theory, with additional data was constantly tested against observations to refine it. Once saturation was reached in each of the study sites, a model was put together describing the relationship between the variables and the outcome.

A human ethics clearance was obtained from the National Centre of Biological Sciences (ref no: NCBS/IEC-15/007).

Documentary materials

Following Glaser's dictum of grounded theory (2007) that 'all is data', we noted not only what was being said but also how, what, under what conditions and the background to what was being said as this help contextualize the data. Additionally, we used images, videos, books of accounts, camera-trap footage, attendance registers, newspaper articles, correspondences and any other information that revolved around the research question as data. This helped understand the data in its context as well as verify and triangulate it, serving as an additional line of evidence.

Appendix 4

Framework for semi-structured interviews

Please note that this is a broad framework; given the semi-structured nature of the interviews. On encountering a relevant line of thought, it was explored further with the respondents. Questions and mirrors were asked through the interview and not necessarily in the chronology below.

Interview code:
Village/community:
GPS reading:

Ice-breaker and general questions

How long have you been living here?
What is your age?
What is your occupation?
What crops do you grow? (if farming)
Do you experience any crop-related troubles? If so, please tell me more about them.

Elephants' ecology and mitigation

What animals visit your village? (if/when elephants come up)
How do they come, in what manner – such as loners, small groups, or large herds?
How predictable and regular are their visits?
Mirror: How often do the elephants come in a month? Can you predict when they shall come?
You have been here since XYZ years; have there always been elephants coming here? If no, since when did they start coming in these numbers/frequency?
Is there a change in where you used to see them and where you see them now?
Can you share some of your experiences with elephants?
Why do you think that the elephants come to your village?
(if chasing elephants away comes up) What mitigation measures are used?

Fence-related questions

If/when the fence comes up - if not, mention- 'On my way here, I saw an electric fence…' or 'I heard that there was an electric fence established as well...'

How was the fence designed? How was the location of the gates and the area it encloses decided upon?
Who all were involved in the establishment such as design, construction etc? Did the people have to contribute towards it (labour, capital, material)?
Mirror: How, when was this established?

How do elephants break the fence?
(if yes) Do they tend to break it at particular locations?
(If no) How do they interact with the fence?
(follow-up) Have you seen them do so?

How was the maintainer chosen?
What are their responsibilities (operational)? How were they determined? (eg. how often do they have to check the fence etc?) – is anyone from your household involved?
If you had wanted, could you have been part of the committee? Did they (if outsiders like FD, NGO, Tea Estate Management were involved) speak to you folks/ give you any training?
How are the other responsibilities with regard to commons such as water pumps, fishing etc distributed amongst the rest of the community?

Congruence in benefits and costs

Do the maintainers get paid for the maintenance? If yes, is that adequate for the work that they are doing?
Follow-up: Where does this money come from and why? (follow-up, why would the ones living in the centre of the village contribute?)
When/ if the fence breaks down, who pays the costs/ what do you do? (material, capital, labour)
(for maintainers) How do people react when the fence is broken? What do they expect you to do?
What utility does the fence provide? (is there any difference between before and after the fence? For instance, if there were 10 elephant visits per month prior to the fence – how many now?).
What are the kinds of benefits do you experience? Has it changed your routine?
What kinds of costs do you experience? Has it changed your routine?
Mirror: Have your daily chores/ movement patterns changed because of the fence? (and similar process-based contextualized questions that come up in the conservation)
How often/predictably do the elephants come?

Confidence in steward of public good

If the fence breaks down, what happens?
What do they do towards maintenance?
Do the maintainers have a good record/ history of maintenance?
Why do the stewards volunteer to be part of the committee?
Mirror: What do you think about their work?

Sense of dependency on the public good

Whose responsibility do you think the fence is (villagers, maintainers, FD, NGO, TE)? Why do you think so?
(if NGO/ FD are maintaining it) You had mentioned that the (entity maintaining it) are maintaining it– why do you think that they are maintaining it?
What used to happen without the fence?

(For the maintainers) Does it ever break? Are you able to keep the fence working? [do they point/insinuate at technical incompetence]
Mirror: have you ever been unable to fix the fence?

FD involvement

Which all entities are involved in the maintenance of the fence/ HEC mitigation? (is the FD involved?) What do they do?
Why do you think that they do/don't come here and partake in the maintenance?
What would happen if conflict continued here?

Appendix 5

Details of QCA

A priori variables for the QCA

1. Geographically effective design (GEO): The fence was situated such that it included only communities that desired the fence and did not lead to a major hindrance to the livelihood of those communities (e.g. fence did not result in blocking access to firewood)

2. Cash buy-in (CASH): whether the community had contributed cash towards the upkeep of the fence, suggesting investment in the success or failure of the fence;

3. Ease of collective action: communities were able to act collectively to maintain the fence based on one or both of the following two factors:
    a. Ethnic homogeneity (HOMO): homogenous communities might find it easier to cooperate and hence undertake collective action due to lower transaction costs, greater trust, and shared social norms;
    b. Proactive leadership (LEAD): communities with a leader who proactively championed fence maintenance facilitated maintenance. (Heuristic: when community members unanimously or nearly unanimously named the same person as associated with and actively involved in fence maintenance).

$$\text{LEAD}(\sim\text{HOMO}^{*}\sim\text{CASH} + \text{CASH}^{*}\sim\text{GEO}) \rightarrow \text{W}$$

1. Raw data matrix

The raw data matrix consists of each case as a row with the columns representing the variables of interest and outcome. We have used 'crisp-set' ('1' and '0') in order to define the set membership of the case to that variable, i.e., it is either a full member of the set or not a member at all. Crisp-sets were chosen over fuzzy-sets and multiple-value sets as they best reflected the nature of the variables on the field and our *a priori* hypothesis.

›mmunity/Areanar	GEO	CASH	HOMO	LEAD	outcome
Baghmari	1	0	1	1	1
Haabasti	1	0	1	0	0
Gorumara	1	0	1	1	1
Jalokhiabasti	1	1	1	0	0
Ajgarjuli	1	1	1	1	0
Kolbasti	0	1	1	1	1
Aadhiyachap...	0	1	0	1	1
Wenzajuli	1	0	0	0	0
Talabari	0	0	0	1	1
Botiagaon	1	0	1	1	0
Simalugaon	1	0	1	1	0
Sagunbasti	1	1	0	1	0
Babamura	1	1	1	0	0
Bihpukhuri	1	0	1	0	0
BaluDanga	1	0	1	1	0
Manimuni	1	1	1	0	0
Mrigamari	1	0	0	1	1
Boribeel	1	0	0	1	1
Pukhuripar	1	0	1	0	0

Fig 5.1: Villages with the variables of interest and outcomes

2. **Formation of truth table**

A so-called ‘truth table’ was created in the software where the configurations of conditions and the resultant outcomes appear with the number of times they appear. Contradictory conditions, ie, cases that have the same conditions but lead to contradictory outcomes were used to refine the theory. The threshold for consistency was kept at the suggested 0.75, owing to the fact that the data was crisp-set (i.e., ‘1’ and ‘0’) and of an intermediate n (Ragin 2008).

LEAD	HOMO	CASH	GEO	number	outcome	cases	raw consist.	PRI consist.	SYM consist
1	0	0	1	2	1	cases	1	1	1
1	0	0	0	1	1	cases	1	1	1
1	0	1	0	1	1	cases	1	1	1
1	1	1	0	1	1	cases	1	1	1
1	1	0	1	5	0	cases	0.4	0.4	0.4
0	1	0	1	3	0	cases	0	0	0
0	1	1	1	3	0	cases	0	0	0
0	0	0	1	1	0	cases	0	0	0
1	0	1	1	1	0	cases	0	0	0
1	1	1	1	1	0	cases	0	0	0

Fig 5.2: Truth table of the villages

3. Logical Minimization

After the process of creation of a truth table, the remainders were logically minimized, ie, of the potential of configurations, the configurations that did not appear in our cases were interpreted using the 'intermediate solution' where only those remainders that are consistent with the researcher's theoretical and substantive knowledge are included (Rihoux and Lobe 2009). This was done using the Quine-McCluskey algorithm. Here, since empirical evidence suggests that the presence of LEAD, HOMO, CASH, and GEO lead to an outcome of 1, they were marked as 'present'.

```
--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1
consistency cutoff: 1
Assumptions:
LEAD (present)
HOMO (present)
CASH (present)
GEO (present)
raw unique
coverage coverage consistency
---------- ---------- ----------
LEAD*~HOMO*~CASH 0.428571 0.428571 1
LEAD*CASH*~GEO 0.285714 0.285714 1
solution coverage: 0.714286
solution consistency: 1


Cases with greater than 0.5 membership in term LEAD*~HOMO*~CASH: Talabari
(1,1),
Mrigamari (1,1), Boribeel (1,1)
Cases with greater than 0.5 membership in term LEAD*CASH*~GEO: Kolbasti
(1,1),
Aadhiyachapori (1,1)
```

Appendix 6

Types of benefits involved in fence maintenance

Type of benefit	**Associated quotations**
Payments for fence maintenance (including employment and illegal payments)	Interviews with Riphu* from a fringe village with a well-maintained fence mentions, *"This is public property but nobody from the village comes and maintains the fence… I am given a salary of Rs 4000 a month and hence now it is my responsibility to maintain it all alone."* (BR03.10.6, June 2020). Kishor*, a community maintainer mentions why paying him for maintenance is beneficial to all the entities involved, "*without the fence, people would be facing massive losses due to the elephants, it was certain that we would lose several moons [1 moon = 40kg] of paddy; but now, by paying a part of this to individuals like myself in lieu of maintenance, the public has much higher yields, and their homes are protected and I also make a little money- whatever is left after subtracting the costs of maintenance etc".* (RL02.12.5, May 2020)
B > C for the political elite	Mathura*, a part of the political elite in Mrigamari* ensures the maintenance of the fence by delegating individuals because "*I have been elected as the ward member of the region and it is my duty to maintain the fence. I was the one responsible for collaborating with WWF and the Forest Department to get this here and see how useful it has been - [pointing at the ripe paddy fields] - before the fence you would not get even one handful of paddy but now see how productive this land is. So even if people do not want to take efforts etc, they know that I am here to take care of it and that is why they appreciate me and trust me - because I have their best interest in mind."* (JH.C.03, February 2020)

Goodwill from the community	Jishu*, a community maintainer highlights the reasons for him maintaining the fence, "*The maintenance is done by me, as I am the secretary. The fence has been given for the safety of the people and the houses so I do my best to maintain the fence. It is not to kill elephants. It is just for the safety of the people.* *Earlier we collected Rs 10 [0.13 USD] from each household towards a stipend for the community maintainer. However, now people don't want to give - when we ask for this contribution, they try to avoid it saying 'oh, we'll give it tomorrow or the day after'. Anyway, I don't really do this with the intention of getting a salary but rather, because people and the village should be saved. And the elephants too- we let them go to the farm and eat as they are hungry. It doesn't affect us. Let them eat the paddy [but not destroy our houses and injure/kill us]"* (GL01.23.2, February 2020). Pilot*, a community maintainer for a fence around the staff quarters within a tea estate mentions, *"I don't get anything and neither do the other members get any monetary compensation. We do it for the village's safety. We had initially thought of collecting Rs 20 [USD 0.26] from each house every month. Benedict* and I should have got that because we do a lot of work and go and talk to everyone, but some people didn't contribute and hence others stopped too. However, the people here are nice. They put the gate themselves and are aware- even if they forget to put the gate, someone else will do it. And the people know that we are all one village so it's okay, anyway, I wasn't doing this for the small amount. Now people know me as the fence-person and know that I am working for the betterment of the people.* (GM07.11.3, March 2020)
Reduction of the individuals' crop damage or house breakage or probability of loss of life	Bagh*, an individual in a village with a poorly maintained fence illustrates his reasons for engaging in fence maintenance. "*The fence maintenance committee had taken Rs 20 (0.26 USD) from each household to*

	repair the bamboo posts [of the fence] but instead, used that amount to party - blowing it up on meat and alcohol. When we asked them what happened to the money, they abused and swore at us and didn't give us an answer… After repeated attempts, I realised that they are not interested in taking care of the fence so Kulu and I took it upon ourselves to maintain it. Now we maintain the fence ourselves because the consequences of it not being there are deadly - his house was broken 2 years ago but still hasn't been repaired or even received a single rupee. Therefore, if we are to keep ourselves safe, we need to ensure that the poles haven't fallen down, and fix the places where there is a leak. The community maintainers say this- and you won't believe it but they really say this - and therefore do not maintain the fences, 'everybody has to die at some point of time, what is the point of constantly trying to avoid it and being fearful? Ah relax, you can be killed under a truck today, an elephant tomorrow..!"* (RJ.04.1.1, January 2020)
Peace of mind, rest and sleep	Purnima* from Kanimari* says, *"Now we can sleep peacefully at night- the elephants come and eat the vegetation outside the boundary of the fence and go. We don't have to use fire or anything as such. It's so much better now."* (EN2.17.5.2 May 2020) Molo* from Boribeel* mentions, "*Whether I grow paddy or not is immaterial because my house is still protected as it lays within the boundary of the fence. And now, I can sleep well at night only because of the fence.*" (GG2.15.6 June 2020) Richa* from Sagunbasti* finds the fence very useful *"...Because of the electric fence, now we can sleep peacefully at night- otherwise they would come and break houses. The wall of our house was broken a few months ago, fortunately none of us was injured."* (RL5.15.3 March 2020)

Security and safety	A resident of Babamura* remembers that circumstances had become so dire so that *"There was a time when there were no women in our village. Not even one, they had all gone back to their parents' homes owing to the threat from elephants. In those days, the elephants would wreak havoc every night; in fact, one night the elephants destroyed 10-12 houses".* (HA7.25.2 February 2020) Momi* from Kolbasti* describes the implications of conflict before the establishment of the fence, *"The electric fence was not set-up when we were farming here. We are a little distance from that spot now, but our house was near the bamboo clump there [pointing]. The elephants tried to come in from there in the dead of the night and on noticing them, I screamed that they were here! We burnt a fire as we had to save our paddy. There was nothing, no electric fence, nothing. They stayed the entire night. It was circular, we would chase them and they would come back again and the cycle went on like this the entire night. We couldn't sleep during the day because of work and not at night because of the elephants. We would end up sleeping only for 1-2 hours. It was a tough time.*" (CH5.19.2.2 February 2020)
Less guilt due to potential harm to elephants (potentially emanating from empathetic or religious beliefs)	Krishna* on why he prefers the fences as an HEC mitigation tool, *"We have destroyed the forests where elephants lived. We are settling down in forest areas by cutting forests. They don't have a place to live and the reason that they visit human habitation is their hunger. And to think, we work so much for food. Look at them! They need to eat quintals of food so they are compelled to come into human areas. That's why we like the electric fences, because they can go wherever they want but just not break our houses."* (SL01.19.1.2 January 2020) Zika*, on the reasons for coexistence, *"We feel bad because the people here, and not just here but in the places I have visited where they follow Hinduism, the*

	elephant is considered our living Lord Ganesh. That's what we feel and believe. In that sense, when they get hurt we are hurt too. That's why we don't want to harm them much but we also want that they get enough food to eat and live peacefully. We have our farms and we have our stomachs too" (JH3.25.12.1 December 2019).

Appendix 7

Types of costs involved in fence maintenance

Type of costs	**Associated quotation**
Hindrance of movement	Miri* a community member on how the fence is repeatedly sabotaged, *"Even if the fence works, people destroy it. The villagers end up dismantling it when they bring firewood, fodder etc from the forest. That's why it breaks and there's no point in repairing it."* (KP25.2 January 2020)
Time and effort for maintenance	Rabha* on maintenance, *"It is very difficult to maintain the fence, especially in the monsoon. Right now it is okay because it is not raining, but in the monsoon there is knee deep muck and so many leeches making it extremely difficult to maintain the fence. And the elephants are extremely smart, smarter than humans too; if they find even one spot where the post is a little rickety, they shall push it down and cross over! So come rain or shine we need to check on the fence."* (DSC.26.12 December 2019)
Payment for maintenance	Saloni* on the payments for maintenance, *"We have to give 1 moon [1 moon = 40 kg] of paddy to the community maintainer. Anyway the yields are less and on top of that paying this much is quite a sum - and there is no guarantee that the elephants won't come despite this."* (KP4.13.3 March 2020)
Material costs for fence maintenance	Koki* on the material costs of maintenance, *"They keep asking us to contribute more money. When they first got it, they asked for 500 and then again a few hundreds, and then for bamboos etc every now and then."* (CH1.19.2 February 2020)
Social costs of failed effectiveness for the maintainers	Selen* a community maintainer paid by an external entity, *"The people in the village are not good, they lack brains. They had initially proposed that if the fences fail then the damage that the elephants cause should be*

	recoverable from the community maintainers. Obviously, none of us volunteered to maintain the fence then, but later the authorities explained to them that that's not how it works…" (NM.S.1 February 2020) Tayeng*, a community maintainer frustrated with people holding him responsible for all fence related happenings, '*…Now, if somebody leaves the gate of the fence open and the elephants come in, is it my fault? Or if the maverick elephant, Laden, comes who sometimes breaks fences crosses over, can I be held responsible? Yet people shout at me. I am so fed up and am seriously thinking of leaving this post* [of a community maintainer]." (JC01.5, May 2020)
Economic and social sanctions of shirking/ free-riding	Gogoi* on sanctions, "*If somebody is unable to come on the designated day when the fence is to be maintained, then they have to pay a fine which is equivalent to a day's wage. And with that money, a daily wage worker is hired to complete the job."* (GM1.29.5, May 2020) Shweta* on the community sanctions, "*If it is someone's duty to maintain the fence on a particular day and they don't, and the elephants come on that day then they will be hauled up and asked to pay a fine for shirking their duties.*" (GM4.29.5, May 2020)
Social cost of lost collective chasing of elephants	Rudra* from Mrigamari*, *"When the elephant season starts, initially it is quite a hassle to keep guard all night and chase the elephants away. But then after a few days, you get used to it and chasing elephants is intoxicating, it is so thrilling! All of us friends are together and we go hollering and bursting crackers, shining lights when the elephants come- but now after this fence that has greatly reduced and to be honest, is a little boring right now (…) so we don't mind it not being there, since we were together, we had a great deal of fun.*" (DSC.26.12 December 2019)

The 'sucker' effect	In Jalokhiabasti*, individuals who did not engage in farming refused to take part in monitoring and maintaining the fence despite it being their turn to, according to the roster. They stated that it was unfair for them to be devoting as much time (approximately 1 hour every couple of weeks) as the farmers because the farmers not only had their houses protected but also their paddy-fields while the non-farmers had only their houses. On faced with this shirking, the farmers abandoned maintaining the fence saying, "*There is a problem. For instance, there are 110 houses here and we know because of the electric fence we are able to grow paddy and reap other benefits too. However, there are some people who are not as dependent on the fence as they go outside* [the village] *to work. Because of this, they don't even contribute the money required for the upkeep of the fence. This leads to people saying that if these people are not paying up, then neither shall I. This is a major problem. They feel that they are toiling away in the fields all day and then are checking the fence- and that they should not be doing everything alone. Whether or not they go outside to work, everyone should be giving money for maintenance as it is not only the paddy but also the houses that are protected.* *They then ask themselves, 'why must I do this? I don't need to. If you [non-contributors] are not doing it, then neither shall I. If the elephants come and cause damage, it will damage both of us'*." (GM1.15.6, June 2020) In Gorumara*, a village in the tea estate the contributions for fence maintenance stopped as stated by Benedict* a community member, *"About 5-6 households in the middle of the village stopped contributing the weekly Rs 10 for maintenance, saying that now the elephants don't come and that they don't feel the need to be part. Seeing this, the other people also stopped contributing, saying that if the others are not paying then why must we. And thus, they all stopped."* (GL2.7.3 March 2020)

Appendix 8

Recommendations

The maintenance of a fence is contingent on a host of perceived costs and perceived benefits which differ in different social-ecological systems. This diversity in incentives across communities makes it difficult to give cookie-cutter guidance on how to make a fence successful. However, our findings suggest many steps that can be taken to ensure a process that makes maintenance of fences more likely to occur.

A

Stage of fence establishment: Defining the "area of interest" to be protected by the fence.

Current practice: Practitioners tend to use official administrative boundaries such as villages, irrespective of the governance system and social norms in the area they are trying to protect from elephants. The governance system actually in use often spans across multiple physical boundaries.

Shortcomings in current practice: Since, in practice, governance occurs based on locally recognized boundaries and not official boundaries, setting up a fence based on administrative boundaries leads to a mismatch. Existing governance bodies may not have jurisdiction over the full fence.

Recommended action: When defining a 'community,' attempt to use already existing spatial demarcations recognized by the communities you are working to protect. This aids coordination and conforms to an established set of norms. The normative boundaries could be administrative boundaries like villages and staff quarters, or boundaries observed by existing social institutions like the *raije*, a body that governs commons like temples, shared agricultural land, etc.

B

Stage of fence establishment: Assigning a pathway of maintenance (e.g., an assigned community maintainer, collective community maintenance, or Forest Department maintenance)

Current practice: Done in an *ad-hoc* manner often based on the intuition of implementers. It typically starts by setting the stage for the community to self-organize by aiding the creation of a committee that is to look after maintenance-related activities.

Shortcomings in current practice: This fails to take into consideration the social-ecological conditions of the scenario, which may lead to some pathways being more conducive in certain settings and leading to failures in others.

Recommended action: First, examine the perceived costs and benefits of the key actors in the situation (the community overall, would-be community maintainers, the political elite,

and the Forest Department) and try to see who would find maintenance in their interest. If the situation seems like it would allow for Forest Department maintenance of a fence, that should be the first choice-- these fences, as public goods aiming to help protect elephants (another public good), should ideally be institutionalized with a stable bureaucracy. The next best choice is for a community maintainer to be hired, as that frequently resulted in success. If the community seems actively enthusiastic about performing community maintenance, it may then be promoted as it is cheaper and can foster a public sense of responsibility for preventing HEC.

C

Stage of fence establishment: Explaining the fence to the users

Current practice: All households that were likely to benefit from the fence were involved in the decision-making process.

Shortcomings in current practice: Given that sabotage, shirking, and non-compliance were often noted to be the reason for the failure of a fence, the current practice means that those that might ultimately cause the failure of the fence are not included in the process, meaning their interests cannot be addressed.

Recommended action: While establishing a fence, attempt to involve members of all households in the area protected by the fence in designing the fence and orienting them with regard to how it functions. This is irrespective of whether they see themselves benefitting from it or not. Ensuring that all individuals affected by the fence participate in the establishment of the fence has two main effects. First, it provides an opportunity for those that do not benefit to voice grievances and identify remedies. Second, including them creates a shared context that reduces the chances of the sucker phenomenon playing itself out. Those who do not benefit substantially (such as people who do not engage in agriculture) but still pay some of the costs (such as hindrance to movement) are less likely to engage in sabotage and non-compliance related to fence maintenance rules as it is public knowledge that they know how the fence works and that the implications of sabotaging the fence/ non-compliance are potentially large.

D

Stage of fence establishment: When the community organizes the process for supporting maintenance

Current practice: The decision on how and how much to collect from each household is not explicitly recommended by the implementers

Shortcomings in current practice: The community members, when self-organizing, are susceptible to the notion that each household contributing a small amount at regular periods is a sustainable pathway to maintenance. However, this approach ignores the resultant increase in transaction costs that comes with multiple small payments. As some individuals become

delinquent on payments, others might feel like “suckers” for shouldering the full cost of a public good and then also stop contributing-- i.e., the “sucker effect.”

Recommended action: When the community is deliberating on process, encourage the collection of a single large contribution (eg. annual) as opposed to repeated small ones (eg. weekly/fortnightly), reducing the transaction costs. Despite both the alternatives resulting in the same amount of contributions, respondents indicated that repeated contributions pinch the members more and lead to non-compliance. Additionally, given that it is a small amount, the recovery of arrears becomes logistically challenging. A larger contribution also creates a buffer reserve fund for urgent repairs.

E

Stage of fence establishment: Post-fence establishment, during fence maintenance.

Current practice: Poor maintenance of fences can then lead to more breaches by elephants, resulting in a drop in perceived benefits of the fence, which then means less enthusiasm for maintenance--ie., a vicious cycle or socio-ecological trap. Practitioners typically react by trying to nudge the community members into undertaking maintenance by verbally engaging with them

Shortcomings in current practice: Community members are often unconvinced of the effectiveness of the fences after they fall into the social-ecological trap.

Recommended action: A potential solution would be to hire a community maintainer to maintain the fence for a specified, predetermined period of time in order to make the benefits of the fence more salient. This maintainer should be from an external entity (ie, not from the village as this could lead to maintenance being considered his/her job even after the specified time), and s/he should undertake maintenance along with the community members, thus imparting the technical know-how as well.

F

Stage of fence establishment: Scaling-up maintenance of fences in a landscape

Current practice: Done in an *ad-hoc* manner often based on the intuition of implementers.

Shortcomings in current practice: Because of the idiosyncracy of incentives across communities, attempting to scale up fences based primarily on active community maintenance can lead to failure. Similarly, Forest Department officials cannot easily be induced to maintain fences across contexts unless there is top-down pressure to do so.

Recommended action: The pathway with the most potential to be scaled up with ease is that of the community maintainer: since this pathway is maintained through well-established market norms, it scales better than pathways that rely heavily on community context or variable political incentives. In this scenario, the maintainer is appointed and has a clear set

of deliverables in exchange for a pre-decided remuneration, and any transgressions on either side can be navigated more easily than with unwritten social norms or complex political incentives.

Appendix 9

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