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Human-Elephant Conflict: A Review of Current Management Strategies and Future Directions

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Human-elephant conflict is a major conservation concern in elephant range countries. A variety of management strategies have been developed and are practiced at different scales for preventing and mitigating human-elephant conflict. However, human-elephant conflict remains pervasive as the majority of existing prevention strategies are driven by site-specific factors that only offer short-term solutions, while mitigation strategies frequently transfer conflict risk from one place to another. Here, we review current human-elephant conflict management strategies and describe an interdisciplinary conceptual approach to manage species coexistence over the long-term. Our proposed model identifies shared resource use between humans and elephants at different spatial and temporal scales for development of long-term solutions. The model also highlights the importance of including anthropological and geographical knowledge to find sustainable solutions to managing human-elephant conflict.

Keywords: coupled-natural-human systems, human-elephant conflict, human-wildlife conflict, land management, resource management, species coexistence, wildlife conservation

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INTRODUCTION

Expansion of human settlements and agricultural fields across Asia and Africa has resulted in widespread loss of elephant habitat, degraded forage, reduced landscape connectivity, and a significant decline in elephant populations relative to their historical size and overall range (Thouless et al., 2016; Calabrese et al., 2017). As their habitats shrink, elephants are progressively forced into closer contact with people, resulting in more frequent and severe conflict over space and resources with consequences ranging from crop raiding to reciprocal loss of life (e.g., Leimgruber et al., 2003; Newmark, 2008; Mcdonald et al., 2009; Western et al., 2009; White and Ward, 2011; Liu et al., 2017). Human-elephant conflict has become a threat to biodiversity conservation, and the management of such conflict is a primary goal for elephant conservation in range countries. Growing understandings of wildlife behavior and spatio-temporal patterns of human-wildlife conflict have led to the suggestion, development, and adoption of a wide variety of prevention and mitigation approaches (e.g., Fernando et al., 2005; Gubbi, 2012; Baruch-Mordo et al., 2013; Hoare, 2015). Current conflict management approaches focus on prevention through exclusion and on-site deterrents, and mitigation via elephant translocation or selective culling and monetary compensation for losses. However, these management approaches merely address the symptoms, rather than the underlying drivers of human-elephant conflict associated with cultural values, resource use decision-making, and the increasing fragmentation and isolation of elephant populations.

Long-term resolution of human-elephant conflict and promotion of peaceful coexistence requires a simultaneous focusing of management efforts on site-specific considerations as well as the formulation and application of strategic plans at the landscape level that directly address underlying anthropogenic drivers and their spatio-temporal variation. We suggest that just as wildlife needs are measured and modeled to improve conservation management planning, information about cultural values, norms, and decision-making regarding the spatial and temporal use of habitat to support local livelihoods and household production are also valuable. This sociocultural component of human-elephant conflict, while addressed by anthropologists, human geographers, and other social scientists, has not been effectively integrated into previous conflict management models. A coupled natural and human systems approach offers a potential framework for understanding the interaction of human and elephant behavior and resource use at the landscape level. In this paper, we highlight various costs associated with human and elephant conflict and discuss the limitations of current prevention and mitigation approaches. Finally, we offer a model to guide future research that supports long-term solutions for sustainable land management decisions and promotes peaceful coexistence of humans and elephants.

ELEPHANT SPECIES' RANGE AND ECOLOGY

The Elephantidae family once ranged across the American, European, Asian, and African continents, but now only occurs in parts of Asia and sub-Saharan Africa (**Figure 1**) (Thouless et al., 2016; Calabrese et al., 2017). The International Union for Conservation of Nature (IUCN) lists extant Asian elephants (*Elephas maximus*) as endangered, and African savanna (*Loxodonta africana*) and forest (*L. cyclotis*) elephant species as vulnerable (IUCN, 2017). The population of Asian elephants is estimated at 41,410 to 52,345 individuals scattered among fragmented habitats in 13 range countries in Asia, and currently occupying 5% of their historic geographic range (Sukumar, 2006). The population of African elephants is much larger; estimated at 550,000 to 700,000 individuals living in 37 range countries in sub-Saharan Africa. Yet more than 70% of the geographic range is unprotected and poaching for the illegal ivory trade continues to decimate Africa's elephant populations (Chase et al., 2016). India holds the largest population of Asian elephants (60% of total population), while Botswana and Zimbabwe have the largest populations of African elephants (combined 47% of the continental population) (Choudhury et al., 2008; Chase et al., 2016; Thouless et al., 2016).

Elephants are long-lived animals, and their survival depends upon regular migration over large distances to search for food, water, and social and reproductive partners (Sukumar, 2003; Whyte, 2012). As a generalist mega-herbivore, elephants consume a maximum of 150 kg of forage and 190 L of water daily (Vancuylenberg, 1977; Sukumar, 2003). Meeting these basic needs requires a large foraging area to provide a variety of grasses, shrubs, and tree leaves, roots, and fruits. A typical family herd of Asian elephants (∼5–20 individuals) has a home range size of 100–1,000 km^2 (Fernando and Lande, 2000; Williams et al., 2001; Alfred et al., 2012); while an African elephant family herd ranges over an area 11–500 km^2 (Shannon et al., 2006; Thomas et al., 2008). As they range and feed, elephants affect the surrounding biodiversity. Researchers have found strong correlations between the loss of Asian elephants and reduced dispersal and survival of seeds for large-fruiting trees at a protected area (PA) in India, indicating an engineering influence of elephants on forested ecosystems in Asia (Fritz, 2017; Sekar et al., 2017). Long-term research in African savannas and forested areas documents the keystone role of African elephants in shaping surrounding landscapes through feeding activities that damage tree canopies, uproot small trees and shrubs, and disperse seeds (Kohi et al., 2011; Coverdale et al., 2016; Fritz, 2017). Given their keystone role, wider biodiversity conservation goals require maintaining healthy populations of elephants throughout their ranges in Asia and Africa.

CAUSES AND CONSEQUENCES OF HUMAN-ELEPHANT CONFLICT

Human-elephant conflict is a major challenge for supporting the survival and persistence of elephants in their range countries because these are places where the development and well-being of human communities sharing space with these mega-herbivores is also important. As humans transform the landscape, pushing human and elephant populations to live in ever closer proximity, the likelihood of conflict increases with often fatal results. India alone reports annual deaths of 400 people and 100 elephants during conflict incidents, with additional direct effects to 500,000 families through crop raiding (MOEF, 2010). Sri Lanka annually documents over 70 human and 200 elephant mortalities from conflict (Santiapillai et al., 2010; Fernando and Pastorini, 2011). Illegal poaching for the ivory trade complicates calculations for elephant losses in Africa. However, Kenya reports that 50–120 problem elephants are shot by wildlife authorities each year and that about 200 people died in human-elephant conflict between 2010 and 2017 (Mariki et al., 2015). Other Asian and African range countries document similar or worse consequences (e.g., Graham et al., 2009a; Saaban et al., 2011; Webber et al., 2011; Tchamba and Foguekem, 2012; Chen et al., 2013; Mariki et al., 2015; Sarker et al., 2015; Acharya et al., 2016; Pant et al., 2016). Elephant conservation efforts have thus expanded their focus over time from reducing habitat damage and loss of elephant lives to ivory poaching and trafficking to managing the potential for human-elephant conflict resulting from increased space and resource competition (Caughley, 1976; Douglas-Hamilton, 1987; Caughley et al., 1990; Kangwana, 1995; Sukumar, 2006; Hoare, 2015).

Many of the world's 1.2 billion people who live on <\$1.25 USD per day reside in Asian and African elephant range countries. These regions are also experiencing human population growth of 1–3% per year in Asia and 1–3.5% per year in sub-Saharan Africa (World Bank, 2018). As some of the planet's poorest

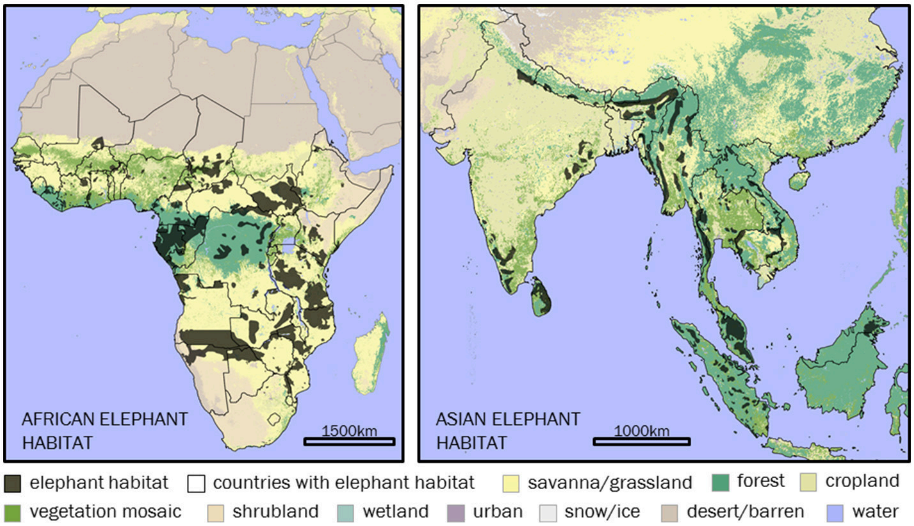

FIGURE 1 | Map of global elephant species ranges. Land cover based on mode value of 500-m resolution NASA MODIS Land Cover Type product (MCD12Q1), 2000–2016. (Elephant population data from Friedl et al., 2010; IUCN, 2017).

people, these marginalized communities increasingly compete with other species, like elephants, for space and resources. Low-income subsistence farmers often live near forests and PAs due to limited arable land, minimal to no irrigation access, and cultural ties to PA landscapes. Accessing resources in these forests and PAs supports a more diversified livelihood portfolio and offers subsistence households resources to meet their basic needs (Riddle et al., 2010; Angelsen et al., 2014; Babigumira et al., 2014). Additionally, many rural communities move closer to more permanent water sources during dry periods to ensure stable water access for their household needs, crops, and livestock. Yet competition for increasingly scarce water sources and other resources during and/or after droughts increases the risk of conflict between elephants and humans (Osborn, 2004; Ntumi et al., 2005; Graham et al., 2009a; Shaffer and Naiene, 2011; Sitienei et al., 2014; Mariki et al., 2015). Poverty also reduces household coping ability and adaptive capacity to respond to harvest losses by crop-raiding elephants (Eriksen and Silva, 2009; Snyman, 2014; Nsonsi et al., 2017), which further undermines conservation efforts by engendering animosity and intolerance toward elephants.

Similar to elephants, humans are also ecosystem engineers and greatly influence their surrounding landscape. Their livelihood activities limit elephant home range and population density through direct and indirect competition for water, food, and space (de Beer and van Aarde, 2008; Alfred et al., 2012; Hoare, 2015; Bi et al., 2016). Research in Zimbabwe suggests that elephant populations will co-exist to varying degrees with human communities until a threshold of about 15–20 people/km^2 is reached (Hoare and Du Toit, 1999). At this point, the habitat loss and fragmentation accrued from a 40–50% transformation of the landscape for human livelihood activity use renders the area unfit for elephants. Farmers and pastoralists alter biophysical dynamics and habitat patterns through subsistence agricultural production and management of key natural resources (Shaffer, 2010; McHale et al., 2013). Cutting trees and burning to clear land for agricultural expansion and improve livestock forage may draw elephants to patches of new vegetative growth (Shaffer, 2010; Babigumira et al., 2014). Planting fields adjacent to water sources and digging holes to access groundwater may alter elephant migration routes. Fencing agricultural areas and PAs to minimize crop raiding and protect vegetation from grazing and trampling intensifies livestock grazing in human settlement areas and elephant feeding inside PAs, while restricting movement of both humans and elephants (Campos-Arceiz et al., 2008; Guldemond and Van Aarde, 2008; Riddle et al., 2010). The combined results of these livelihood activities confine elephant herds to small patches of minimally-developed lands and PAs that restrict natural migration patterns, increasingly deprive elephants of their preferred forage, and contribute to biodiversity losses in small to medium-sized PAs due to concentrated elephant foraging.

Habitat fragmentation fuels human-elephant conflict potential, as roads and farms surrounding fragmented feeding grounds are more conflict prone (Fernando et al., 2005). In the most common form of human-elephant conflict, crop-raiding elephants forage in agricultural fields to meet dietary requirements (e.g., Sukumar, 1990; Williams et al., 2001; Sitati et al., 2003; Graham et al., 2010; Sitienei et al., 2014; Goswami et al., 2015; Liu et al., 2016). Growing evidence suggests that crop raiding peaks near harvest time, potentially provoking retaliatory killings in response to high crop losses that threaten the survival of farming households (Chen et al., 2006; Graham et al., 2010; Webber et al., 2011; Gubbi, 2012). Although crop depredation and human casualties are the most commonly reported and publicized costs of conflict (Ngure, 1995; Lahm, 1996; He et al., 2011; Nath et al., 2015), hidden costs in the form of diminished psychosocial well-being and disrupted social activities raise additional concerns (Jadhav and Barua, 2012; Barua et al., 2013). These physical and hidden costs make it difficult to impossible for people to develop an appreciation for and tolerance of elephants living in their community.

CONFLICT PREVENTION AND MITIGATION STRATEGIES

Conflict Prevention Strategies

Much of the effort aimed at addressing conflict has focused on prevention by keeping humans and elephants separated. In this section, we first describe exclusionary methods. We then discuss additional methods commonly used by land managers and farmers to prevent conflict. Although we review methods individually; in practice, managers frequently combine multiple techniques, and change strategies over time as elephants will test enacted measures to gain access to desired resources.

Exclusionary Methods

Protected areas and ecological corridors

Through the establishment of PAs and efforts of conservationists and wildlife managers, wildlife conservation has become synonymous with the physical separation of humans and wildlife (Rodrigues et al., 2004; Hansen and DeFries, 2007). Ecological corridors stitch together fragmented habitat and isolated PAs, facilitate connectivity between herds, offer demographic rescue effects, and enhance gene flow (Brown and Kodric-Brown, 1977; Hanski, 1998; Blanc, 2008; Rabinowitz and Zeller, 2010). Corridors that account for the ecological needs and ethological characteristics of both humans and elephants help to prevent human-elephant conflict by providing elephants additional routes for seasonal migration and assisting ranging behavior for resources and water (Adams et al., 2017). While ecological corridors are gaining popularity in Asia and Africa (Roever et al., 2013; Pittiglio et al., 2014; Adams et al., 2017; Puyravaud et al., 2017), development pressures and infrastructure expansion in or surrounding elephant ranges are commonly executed without concern for ecological impact, resulting in opposition to plans for, and needs of, corridor construction (Johnsingh and Williams, 1999; Pan et al., 2009). Moreover, ecological corridors, or even fencing for a PA, may contribute to "green grabbing," whereby subsistence farmers lose access to privately-owned or communally-held arable lands along elephant migration routes that are fenced off to reduce conflict between humans and elephants without fair compensation (Fairhead et al., 2012; Thakholi, 2016). Thus, a more robust understanding of human-driven land use change and a greater concern for its impacts on elephant habitat, connectivity, and migratory patterns needs to be considered.

Electric fences and trenches

Physical exclusion methods such as electric fences and trenches are commonly used to deter elephants from entering farmland and human settlements. Substantial costs of construction and long-term maintenance confer challenges for larger scale application of these physical barriers, especially in fragmented landscapes with high forest/farm frontage (Kioko et al., 2008; Perera, 2009; Wijayagunawardane et al., 2016). Long-term effectiveness may be further hindered by design, responses to reports of fence breaks and fence-breaking animals, and overall PA enforcement and management (Graham et al., 2009b; Massey et al., 2014). Studies show that once African elephants learn that their tusks do not conduct electricity, they may use their tusks to break an enclosing electric fence, resulting in costly damage to the fence (Graham et al., 2009a; Mutinda et al., 2014). Physical barriers also negatively affect long-term survival by further isolating already fragmented elephant populations, disrupting movement, and access to seasonal food and water resources, and impeding gene flow between herds (Lee and Graham, 2006). Fencing effectiveness remains largely unexplored in Asia.

Other Methods

Acoustic deterrents

Farmers guard crops and scare away crop-raiding elephants by yelling, setting off firecrackers or carbide cannons, hitting metal objects, and throwing stones (Nyhus et al., 2000; Fernando et al., 2005; Gunaryadi et al., 2017). These techniques are effective in keeping elephants away from crops (Hedges and Gunaryadi, 2010; Davies et al., 2011), but they disrupt psychosocial well-being and livelihood activities of farmers (Tchamba, 1996; Nath et al., 2009; Jadhav and Barua, 2012; Barua et al., 2013). High tech acoustic deterrents remain problematic too. Audio playbacks of threatening sounds like wild cat growls, human shouts, and vocalizations from elephant matriarchal groups have only been tested as short-term and short-distance elephants repellents (Thuppil and Coss, 2016; Wijayagunawardane et al., 2016). Some studies show that elephants quickly learn to tolerate these sounds and return to raid crops (Sikes, 1971; Moss, 1988). Moreover, the installation and regular monitoring and maintenance of these playback systems present logistical challenges in remote areas. Although reportedly 65–100% effective in the tests performed (Thuppil and Coss, 2016), the potentially negative feedbacks of audio playbacks on other species merit further assessment before wider adoption (Gamage and Wijesundara, 2014; Zeppelzauer et al., 2015). Recent studies in Africa show promising results using bio-acoustic methods such as beehive fences to deter elephants, and have the added benefit of providing pollinators and honey (King et al., 2011, 2017).

Light-based deterrents

Farmers may light bonfires and use flaming torches or flashlights to guard ripening crops and deter raiding elephants (Nyhus et al., 2000; Fernando et al., 2005; Shaffer, 2010; Davies et al., 2011). Solar spotlights, which are shone in elephants' eyes to drive them away from agricultural fields, have been tested on a limited basis for communal fields; however, initial purchase costs prevent widespread adoption by low-income rural households and communities (Davies et al., 2011; Gunaryadi et al., 2017). Like the acoustic methods, light-based deterrents are short-term solutions which lose effectiveness over the long-term as elephants adapt to the deterrent or move to a different location (Sukumar, 1991, 1992).

Agriculture-based deterrents

In comparison to exclusion, acoustic, and light methods, agriculture-based deterrents like chili-grease covered fences and chili dung have had limited testing and use (Graham et al., 2009a; Hedges and Gunaryadi, 2010; Chang'a et al., 2016). Existing field tests show wide variation in the effectiveness of chili deterrents from no effect to some reduction of crop-raiding (Sitati and Walpole, 2006; Graham et al., 2009a; Hedges and Gunaryadi, 2010). Furthermore, high costs for application and maintenance make this technique economically prohibitive for many communities (Baishya et al., 2012). Another agriculture-based deterrent involves the spatial strategy of interspersing commonly raided crops with crops that are less attractive or palatable to elephants (Santiapillai and Read, 2010; Gross et al., 2016, 2017). In addition to serving as repellents, these alternative crops including chamomile, coriander, mint, ginger, onion, garlic, lemongrass, and citrus trees can economically benefit farmers by compensating for reduced cultivation of main crops. While fences smeared with chili powder and small-scale cultivation of elephant-unfriendly unpalatable crops to buffer out crop raiding elephants from main crops are the commonly reported form of agriculture-based deterrents (Osborn, 2002; Chang'a et al., 2016), commercial cultivations of chilis and other less attractive crops in large scale do not appear to be tested yet. Besides driving away the elephants because of their repellant nature, such large-scale cultivation could benefit the farmers economically (Parker and Osborn, 2006). Buying back guarantee of such commercially cultivated alternative crops is necessary, however, for the continuity of the approach if functioned effectively. Regardless of scale of the cultivation of alternative crops, they are yet highly likely to be trampled during the growing stage. In general, economic losses from crop-raiding deserve greater consideration, since proper and timely compensation could contribute to an increased tolerance toward elephants and acceptance of agriculture-based deterrents (Gross et al., 2017).

Early detection and warning

Techniques for early detection and warning of elephants involve using mobile phones for quick communication among farmers, and between farmers and local officials, to facilitate cooperation in driving away potentially problematic elephants (Graham et al., 2012). Early warning systems may also incorporate the placement of detectors at conflict-prone locations to monitor infrasonic calls that elephants use to enable detection and localization of individuals over long distances (Venkataraman et al., 2005; Poshitha et al., 2015; Zeppelzauer et al., 2015). These devices, however, require internet connectivity or network coverage to transfer alerts to farmers, which limits the practicality of infrasonic receivers in remote areas (Poshitha et al., 2015). Similarly, satellite tracking of radio-collared elephants facilitates early warning of potentially problematic individuals and herds (Venkataraman et al., 2005). While collected data are helpful for understanding the movement patterns and habitat selection of elephants, the value of satellite tracking in human-elephant conflict prevention is thus far limited due to the initial challenges of capturing and collaring elephants, and sometimes considerable subscription costs for regular data transfer to research facilities.

Conflict Mitigation Strategies

After a human-elephant conflict event, affected farmers, and local communities may demand a response from government agencies or non-governmental organizations that deal with elephant conservation to mitigate future conflict. Below, we first review the domestication, culling, and translocation of problematic individual elephants or herds. We then discuss conflict mitigation programs that economically compensate farmers for lost crops or lives.

Domestication

Domestication practices in Asia have long served to remove or reduce human-elephant conflict pressures. Although Asian elephants can breed in captivity, it is preferred to capture and train wild females (Clutton-Brock, 2012). Once captured and domesticated, Asian elephants have integrated into human society serving in temples and at community festivities, transporting people and heavy loads for agriculture, warfare, and hunting, and helping to capture other wild elephants. Indian records show that domestication practices date back to ∼4,500 BCE, and cave paintings suggest even earlier dates (Sukumar, 2008; Clutton-Brock, 2012). Asian elephant domestication continues today although the practice is declining. History documents Hannibal's use of elephants to cross the Alps in 218 BCE, yet large-scale domestication of African elephants ended around 2000 years ago(Sukumar, 2008; Clutton-Brock, 2012). The loss of these positive human-elephant connections in local communities and productive management of wild populations likely contributes to human-elephant conflict and the associated negativity toward species conservation. However, domestication remains problematic as negative impacts on captive as well as wild elephant welfare are well documented (Bist et al., 2002; Leimgruber et al., 2008; Duffy and Moore, 2010; Mar et al., 2012) and preferences for females may alter gene pools.

Culling

Consistently problematic elephants, including those that have killed humans, are frequently culled to resolve resentments and prevent future clashes and losses in communities in both Asia and Africa. Contrary to Asia's focus on domestication, the culling of crop raiding elephants or those that kill humans has been regularly practiced in Africa to manage elephant populations and human-elephant conflict (Sukumar, 1991, 1992). African culling practices have historic roots in both pre-Colonial and Colonial elephant hunting, where the practice reduced resource competition, supported food security by providing meat to affected communities, and offered ivory for trade. As the African ivory trade grew, culling for mitigation expanded into more widespread killing of elephants for ivory in southern and eastern Africa. By the late nineteenth century ivory hunting severely reduced elephant populations and supported colonial settlement and an expansion of agricultural cultivation (Ballard, 1981; Beinart, 1990; Forssman et al., 2014).

Although current estimates of annually culled elephants are largely unknown, selective culling of elephants is acceptable and periodically practiced in many elephant range countries. The efficacy and necessity of culling for maintaining elephant populations and mitigating conflict is controversial and questionable, as culling mainly targets bull elephants because of their wide territorial ranges that bring them close to human settlements (Sukumar, 1991, 1992; van Aarde et al., 1999). Given the endangered and/or vulnerable status of elephants, as well as skewed sex ratio due to ivory poaching, culling potentially degrades the genetic health of remaining albeit fragmented elephant populations.

Translocation

Translocation involves the drugging, immobilization, and transportation of problematic elephants from human settlements or farms to PAs for release (Nyhus et al., 2000; Massei et al., 2010; Saaban et al., 2011; Fernando et al., 2012). Although the efficacy and long-term feedbacks of elephant translocation have not been extensively tested, initial results suggest that translocated elephants often return to their original territory and tend to propagate conflict around the release area while returning toward their original home range (Pinter-Wollman, 2009; Fernando et al., 2012). Moreover, translocation often undermines conservation goals because of increased elephant mortality during capture and transportation, and sometimes deliberate killing in the release area (Pinter-Wollman, 2009; Fernando and Pastorini, 2011; Fernando et al., 2012).

Compensation

More market-based strategies for mitigating human-elephant conflict provide financial compensation to those affected. The perceptions and attitudes of people who inhabit conflict-prone areas are crucial to the management of human-elephant conflicts (Adams and Hutton, 2007; Treves and Bruskotter, 2014), and offsetting economic losses plays a major role in building positive attitudes toward wildlife and fostering tolerance toward elephants (Sodhi et al., 2010; Hartter and Goldman, 2011; Brooks et al., 2013; Hartter et al., 2014; Snyman, 2014). Requesting compensation involves reporting the property damage and/or loss to park officials or an authorized local body; followed by a visual assessment of damage by the authorities. The lack of standardized assessment guidelines and compensation approaches creates opportunities for conflict and corruption (Ogra and Badola, 2008). Compensation schemes often target the market price for victims' crops and livestock losses without recognition of opportunity costs of conflict mitigation and transaction costs of getting compensation, or the hidden costs of declined psychosocial and social well-being (Hoare, 2000; Ogra, 2008). Difficulties also exist in placing economic value on, and providing adequate compensation for, humans injured or killed by elephants. Examples of successful compensatory programs that increased tolerance toward aggressive wildlife exist elsewhere (Nyhus et al., 2000; Bruner et al., 2001), yet compensatory programs have not been similarly successful for human-elephant conflict. In elephant range countries, compensatory programs face often severe criticism due to insufficient compensation, logistical challenges, ineffective governance, a lack of transparency, reduced local understanding of program scope, and limitations, and fraudulent claims (Naughton-Treves et al., 2003; Bulte and Rondeau, 2005; Nyhus et al., 2005; Ogra and Badola, 2008; Nath et al., 2009). Building on successful models, and with a knowledge of factors leading to compensation program failures, future compensatory programs should be adapted and strengthened for inclusion in a suite of management tools. Yet, economic compensation for the damage incurred does not address the underlying root causes of the conflict, and thus do not appear to be a viable or sustainable solution.

A CONCEPTUAL MODEL FOR REDUCING AND MITIGATING HUMAN ELEPHANT CONFLICT

On-going and future changes to land use, conservation policy, economic markets, and climate challenge the efficacy of current human-elephant conflict prevention and mitigation strategies. These and other disturbances increase the dependency of both species on a shared but shrinking resource base (Otiang'a-Owiti et al., 2011; Im et al., 2017). Effective strategic planning that seeks to support the mutual well-being of humans and elephants centers on their coexistence rather than their conflict, addresses underlying conflict drivers and their spatial variation, and considers the intersecting and evolving needs of both humans and elephants (Peterson et al., 2010; Chartier et al., 2011; Madhusudan et al., 2015; Dubois et al., 2017). Building on prior work, we contribute a conceptual model (**Figure 2**) of a coupled natural and human systems approach that focuses on promoting peaceful co-existence and reducing conflict through landscape-level planning informed by open-data and tools along with ethnographic data and community-based education and mitigation approaches. Our model draws upon theories and analytical methods from anthropology, ecology, geography, remote sensing, climate science, and spatial statistics to assess the needs of *both* humans and elephants, as well as the spatio-temporal variability of the resources on which *both* species depend.

Given the central role of resource competition in human-elephant conflict, our model highlights patterns of water and vegetation quality and quantity across space and time. Precipitation events and processes such as storms, seasonal climate patterns, interannual cycles, and long-term climate changes underpin natural landscape dynamics by driving changes to surface and groundwater sources including lakes, rivers, and aquifers. Seasonal climate parameters including precipitation, temperature, and photosynthetically active radiation affect vegetation patterns across the landscape, while external disturbances like global climate changes will shift landscape vegetation dynamics over the long-term. Greenness and the location of preferred vegetation and specific plant species, along with surface water availability, influences land use and species' movement as elephants migrate seeking food and water and humans pursue livelihood activities.

Local, national, and international policies regarding land use and resource conservation regulate the location and intensity of human livelihood activities like subsistence agriculture, pastoralism, and foraging, as well as the resources accessed

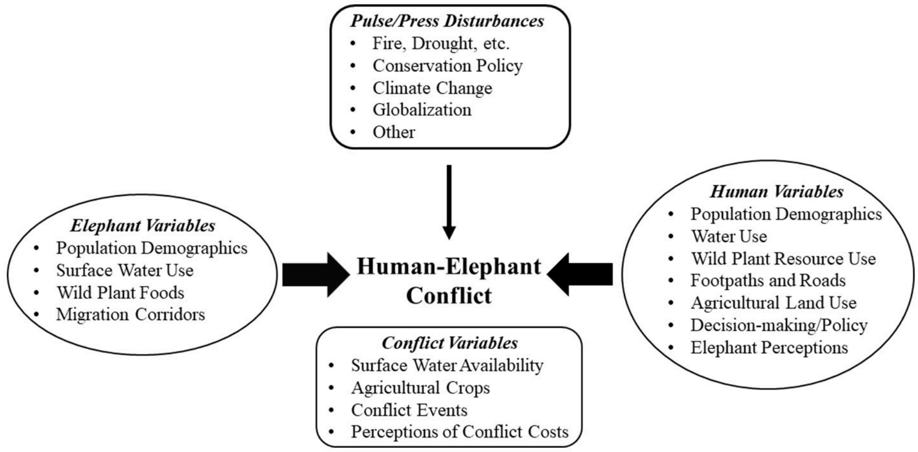

FIGURE 2 | Human and elephant population variables drawn from a multitude of coupled system components and processes. Additional information for variables is provided in the text.

for these activities by households and communities. Resource preferences for particular types of wild plant materials, potable water sources, and arable, fertile soil also influence household decision-making about livelihood activities and locations. Pressing globalization forces connected to and through local markets affect supply, demand, and prices for foods and other goods that cannot be produced at the household level. Policy creation and market shifts act as pulse disturbances by motivating local community adaptation to new resource use regulations and access. Footpaths and roads link households within and across communities, and the wider world. These paths conduct goods and services, connect households to livelihood practice spaces, and facilitate human, and sometimes elephant, migration.

Biophysical processes and livelihood practices intersect with species population dynamics to generate the conditions leading to human-elephant conflict. Elephant herd sizes, densities, growth rates, and regular movements directly impact conflict locations, timing, and intensity (Goswami et al., 2014; Chen et al., 2016; Goswami and Vasudev, 2017). This intensity includes the perceived risks to human well-being, as well as the amount of damage a household or community sustains and the ability to sustain future conflict damage. Although conflict events often unfold as pulsed disturbances in agricultural fields at the end of the growing season, wild plant use or access of water sources by elephants can also lead to conflict in situations where wild plants or water sources are shared with humans. On the other side of the conflict equation, human population dynamics directly influence land use and resource access during livelihood activities as a form of press disturbance, although burn practices to manage landscapes are pulse events. Historic shifts to livelihood practices due to sociocultural, economic, political, climate, and biophysical changes inform decision-making about land use and resource access, conflict responses, perceived risks, and ultimately the sustainability of any plans undertaken to reduce or prevent future conflict. Site specific information regarding perceptions of elephants and the costs of conflict identify areas where mitigation and educational programs may be reconfigured or new opportunities introduced that allow communities to benefit from an elephant presence to build tolerance and increase appreciation for elephants. Acquiring this information requires an objective, "boots on the ground" approach to observe and learn about community needs and decision-making practices, as well as identify residents that can lead the co-development, co-implementation, and co-management of long-term, conflict reduction strategies in their communities.

Conservation and long-term sustainability of co-existing human and elephant populations therefore depends upon the adaptive capacity, resilience, and vulnerability of a variety of biophysical and social components, and the processes that link them together, within a coupled natural and human system. Our conceptual model focuses on resource competition and the resulting conflict for water, food, and space between humans and elephants. It also addresses press and pulse disturbance processes influencing this human-elephant resource competition (Collins et al., 2011). Once conflict hotspots and areas of shared resource use are identified through landscape modeling that integrates natural and human systems information, alternative strategies may be proposed. Strategies could include digging new wells and installing bore holes for human communities or creating new water sources along known elephant migration paths that could divert these animals away from human areas, to support adequate water access during dry periods. Communities could work with government agencies and NGOs to co-develop policies and programs that protect important elephant range areas and ecological corridors while supporting human well-being by offering new economic opportunities and ensuring access to culturally important resources in a sustainable manner.

CONCLUSIONS

Human-elephant conflict remains a significant problem for many communities in Asia and Africa, threatens human lives, livelihoods, and local communities, and drives habitat degradation and elephant population declines. Current strategies to manage human-elephant conflict largely focus on either physical separation, or mitigating the problem by domesticating, translocating, or culling problematic elephants and/or compensating farmers. While these tools remain important conflict management strategies, the majority appear to be driven by short-term, site-specific factors that often transfer the problems of human-elephant conflict from one place to another. In this paper, we reviewed causes and consequences of human-elephant conflict, and current approaches to preventing and mitigating human-elephant conflict. We then proposed a conceptual model that recognizes the competition for water, land, and plant resources between these species, and seeks to identify conflict hotspots and alternative resource access options for effective land management now and in the future. We highlighted the application of ecological, anthropological, and geographical knowledge and tools for developing long-term sustainable solutions to this complex problem, and hope our conceptual model provides guidance for future research focus.

The diverse data needed to build out our conceptual model require interdisciplinary cooperation to synthesize multiple historic, contemporary, and projected datasets from the biophysical and social sciences. While biophysical data may already be in a form that readily lends itself to landscape level modeling and planning, integration of ethnographic information will likely involve more effort including extensive social science fieldwork in conflict-prone communities. However, understandings of how people living in or near conflict prone areas use natural resources, and how they make decisions about current and future resource use, remains key to addressing the underlying drivers of human-elephant conflict and their spatial variation. Without this knowledge, the task of resolving human-elephant conflict and finding a means for these species to coexist in the Anthropocene is sisyphean.

AUTHOR CONTRIBUTIONS

LS, KN, and JV designed the conceptual model, all authors contributed equally to the writing of the manuscript.

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