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Triage of Conservation Needs: The Juxtaposition of Conflict Mitigation and Connectivity Considerations in Heterogeneous, Human-Dominated Landscapes

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Conservation of wide-ranging endangered species is increasingly focused on large heterogeneous landscapes. At such scales, particularly when conservation landscapes are human dominated, it is imperative that prioritization techniques be used to allocate limited resources wisely. Moreover, spatial aspects of conservation planning warrant key consideration within these landscapes, such that certain sites that are key to either mitigating threats to species or to maintaining ecological processes, are prioritized. However, there are often multiple conservation needs, and multiple associated constraints, for species conservation in such landscapes. While there are tools to prioritize sites based on single or few conservation requirements and constraints, there is less knowledge on how these conservation needs, or corresponding management interventions, relate to each other in a scenario where conservation focus on one issue potentially detracts from another. We take the specific example of two conservation needs that are central to landscape-scale conservation of the endangered Asian elephant *Elephas maximus*, namely the maintenance of connectivity, and the mitigation of human–elephant conflict. We show that conservation decision making, in addition to considering which species and sites to focus on, should also prioritize conservation needs. We review documentation of conflict mitigation and examine if the maintenance of connectivity was simultaneously addressed, and if so, whether optimal conservation solutions differed when connectivity considerations were included. We conclude with a discussion on the triage of conservation needs, and future prospects and challenges in ensuring that landscape-scale conservation strategies account for multiple interacting conservation needs for endangered species in heterogeneous human-dominated landscapes.

Keywords: conservation planning, elephants, human–wildlife conflict, movement, spatial conservation prioritization

LANDSCAPE-SCALE CONSERVATION INVOLVES MULTIPLE CONSIDERATIONS

Species that tend to range widely and have a low reproductive potential require very large amounts of habitat for persistence (Fahrig, 2001). Large-bodied mammals fit this description perfectly as they have extensive home ranges (Karanth and Sunquist, 2000; Crooks, 2002; Fernando et al., 2008b), and are intrinsically rare and extinction prone (Madhusudan and Mishra, 2003). To meet the habitat requirements of such species, many of which are endangered, conservation programs are increasingly expanding their scale of focus from individual protected areas to heterogeneous landscapes (Sanderson et al., 2002; Wikramanayake et al., 2004). Such a landscape-scale conservation strategy hinges on the use of human land-uses by wildlife (Athreya et al., 2013; Goswami et al., 2014a), but the co-occurrence of large mammal species and people can often lead to negative interactions and conflict between them (Naughton-Treves, 1998; Woodroffe et al., 2005; Goswami et al., 2014b).

Elephants are among the most severely impacted species when it comes to human–wildlife conflict. For example, India—a country that houses nearly 60% of the extant Asian elephant population (Sukumar, 2003)—is estimated to experience an annual mortality of approximately 100 elephants and 400 people because of human–elephant conflict (Rangarajan et al., 2010). Crop depredation by elephants is the primary form of human–elephant conflict (HEC), and one that imposes substantial costs on the lives and livelihoods of local people (e.g., Naughton-Treves, 1998; Madhusudan, 2003). Recurrent conflicts can not only encumber local support for conservation (Naughton-Treves et al., 2003), they can also lead to levels of retributive killing of elephants that can seriously undermine long-term persistence of elephant populations (Goswami et al., 2014b). Effective mitigation and management of HEC is thus a critical conservation requirement.

Conflicts between elephants and people are inevitable in a scenario where nearly half of the Asian elephant's range lies in habitats that are both fragmented, and heavily impacted by humans (Leimgruber et al., 2003). India is no exception, with human-impacted landscapes comprising as much as two-thirds of existing elephant habitat (Leimgruber et al., 2003). A leading strategy to mitigate HEC in India and elsewhere has therefore been to minimize the interface between elephants and people, typically implemented in two broad forms: (a) strategies designed to keep elephants within forested habitats through the use of barriers at the forest edge; (b) strategies focused on keeping elephants out of cultivated areas and human habitation (see Fernando et al., 2008a, for a review). The former includes the implementation of various forms of barriers including elephant-proof trenches, solar-powered electric fences, and metal fences of different shapes and designs. The second strategy typically involves community-based guarding where elephants are deterred from entering agricultural areas using noise, light and different chili-based tools, or through the use of barriers such as solar fences around cultivated areas and human habitation (Hedges and Gunaryadi, 2009; Davies et al., 2011). Other strategies to mitigate HEC and other forms of human–wildlife conflict, that do not rely on the physical separation of wildlife and people include early warning systems to reduce threat to human safety through accidental encounters with elephants (Fernando et al., 2008a); farming of crops that are unpalatable for elephants (Fernando et al., 2008a); economic incentive schemes (Zabel and Holm-Müller, 2008); government-sponsored compensation (Karanth et al., 2013) and insurance schemes (Mishra et al., 2003) to offset economic losses due to wildlife.

Conserving species in heterogeneous landscapes, however, often entails addressing multiple conservation needs, and multiple associated constraints. Securing long-term species viability in large landscapes, for instance, hinges on establishing (or maintaining) connectivity, or the movement of individuals and genes, among habitat patches (Doerr et al., 2011). Connectivity enhances species viability through demographic rescue effects (Brown and Kodric-Brown, 1977), inbreeding avoidance (Frankham et al., 2010), colonization of unoccupied habitat (Hanski, 1998) and ameliorating negative impacts of climate change (Doerr et al., 2011). As a result, connectivity is increasingly included into species conservation programs worldwide (Sanderson et al., 2002; Wikramanayake et al., 2004; Worboys et al., 2010). Connectivity is an inherently spatial process arising out of an interaction of dispersing individuals with landscape features (Taylor et al., 1993; Vasudev et al., 2015). Similarly, HEC shows spatial patterns such that there exist "hotspots" that are prone to conflict; these patterns are typically driven by spatial covariates, such as distance to forests, rainfall, or terrain (Goswami et al., 2015). Consequently, spatial aspects of conservation planning warrant key consideration within heterogeneous landscapes, such that conservation efforts focus on sites that are key to either mitigating threats to species or to maintaining ecological processes (Moilanen et al., 2009).

There are a number of tools to prioritize sites (Moilanen et al., 2009), but in practice these often focus on single conservation requirements or constraints (e.g., Vasudev and Fletcher, 2015). There is less clarity on how conservationists should integrate multiple and potentially conflicting conservation needs that show spatial patterns across heterogeneous landscapes, into a single holistic conservation program (**Figure 1**). Here, we take the specific example of the Asian elephant to examine how HEC mitigation and the maintenance of landscape connectivity can potentially detract from each other. We pull from recent developments in the theory of connectivity conservation to demonstrate that the simultaneous consideration of the two issues could change recommendations for optimal landscape-scale conservation strategies. We then review the current literature on HEC in India, and Asia, to examine the current state of practice with regards to simultaneous consideration of the two conservation requirements, namely HEC mitigation and maintenance of landscape connectivity. We conclude by drawing inferences and making recommendations for future conservation programs to acknowledge and account for multiple conservation constraints that play out in heterogeneous, human-dominated landscapes.

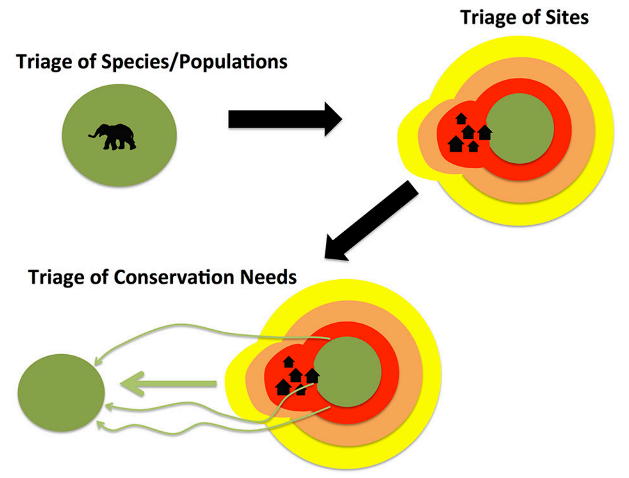

FIGURE 1 | A hypothetical scenario depicting the multi-dimensionality of conservation decision-making. Conservationists may first prioritize species or populations—triage of species/populations—in this hypothetical example, the Asian elephant in a habitat fragment (depicted as a green circle). Conservation investments may then be focused on high-conflict zones (depicted in red), over medium (orange) or low (yellow) conflict zones—triage of sites. We consider a simple scenario here where HEC decreases as one moves further away from the habitat fragment, and is high around human settlements (depicted as a cluster of huts). We highlight an added dimension in conservation contexts where strategies that address one conservation need may detract from others. Here, high-intensity HEC zones are also important for elephant connectivity, and hence, spatially informed landscape-scale HEC mitigation strategies are optimal—triage of conservation needs—such that implemented strategies additively address multiple conservation needs. Elephant silhouette (licensed public domain) was sourced from publicdomainpictures.net, Karen Arnold.

CONFLICT MITIGATION STRATEGIES AS BARRIERS TO CONNECTIVITY

Connectivity is forged through interactions between species and landscape elements (Taylor et al., 1993). A number of factors can limit connectivity; Vasudev et al. (2015) classify these as (a) spatial constraints, which limit connectivity by virtue of their spatial location, (b) environmental constraints, which include biotic (e.g., predators, competitors) and abiotic (e.g., wind, terrain) factors, and (c) intrinsic constraints, which include species-, population-, sub-population-, or individual-level traits that impact a disperser's ability or motivation to traverse the landscape. Vasudev et al. (2015) point out that these factors can limit connectivity through either (a) an alteration of demographic parameters (e.g., mortality), or (b) through a modification of movement behavior. In the latter case, barriers to connectivity need not be imposed through physiological constraints of dispersers, but rather through individual behavioral restraints (behavioral barriers to dispersal; sensu Harris and Reed, 2002). For example, factors that (a) heighten perception of risk (Laundré et al., 2001; Ciuti et al., 2012), (b) modify the ability of animals to navigate landscapes (Pijanowski et al., 2011), or (c) impact identification of high-quality habitat (Robertson and Hutto, 2006; Gilroy and Sutherland, 2007), may serve as behavioral barriers to connectivity.

Several HEC mitigation strategies are adopted to suppress elephant use of, and presence within, human land-uses, and in serving this function, they may strongly impact elephant landscape connectivity (**Figure 1**). Physical barriers, particularly those implemented at large spatial scales along the forest edge, are designed to restrict elephants to forested habitats and as such directly impede elephant movement between habitats. Veterinary fences in Botswana, for instance, have been shown as a barrier for elephant landscape connectivity (Cushman et al., 2010). Community-based guarding or antagonistic responses of local people to elephant presence in their lands can result in an increased perception of risk for elephants traversing human land-uses, thereby limiting their use of these areas (Goswami et al., 2014a). Thus, such strategies or responses can impose a behavioral barrier to connectivity. Finally, HEC-induced mortality, which may be viewed as an extreme barrier-type conflict mitigation strategy, can depress survival rates of dispersing individuals, thereby hindering connectivity and exacerbating threats to elephant population viability (Goswami et al., 2014b).

A REVIEW OF CURRENT HEC MITIGATION PRACTICE: ARE CONNECTIVITY ISSUES CONSIDERED?

We conducted a literature review to assess the level of integration of the two specific conservation needs for the wide-ranging Asian elephant—HEC mitigation and connectivity considerations. We conducted the review at two spatial scales: one at the scale of the entire geographical range of elephants in Asia, and second, at the scale of India. We chose India specifically as (a) India is believed to house 60% of the global Asian elephant population despite accounting for 17% of its geographic range (Leimgruber et al., 2003); (b) a large proportion of studies from Asia originated in India; and (c) India presents an ideal context for the problem outlined in our study as many of the landscapes that house elephants in India are fragmented—typically comprising protected areas surrounded by densely populated settlement and/or agricultural lands—where issues of connectivity and conflict are very relevant. We searched for all studies with the term "human elephant conflict" and "India" or "Asia," through the search engine Google Scholar, to obtain papers that have researched Asian elephant conflict in India, or throughout Asia, respectively. We conducted the literature survey in March 2016, and consider the papers thus obtained as a representative sample of papers on HEC.

We first made an assessment of all mitigation strategies recorded in the studies reviewed, based on the impact they may potentially have on connectivity. To assess the level of integration of connectivity aspects into HEC mitigation in practice, we simply examined (a) whether the papers included the spatial context of either a source population for elephants, or a larger elephant conservation landscape, (b) the proportion of papers that mentioned connectivity in some form, and (c) what aspect of connectivity was described. We note that no study simultaneously aimed at assessing both conflict and connectivity; the studies we found were primarily focused on HEC, and we assessed the proportion of these studies that placed their study within the larger context relevant to connectivity. We further assessed if simultaneous consideration of HEC mitigation and connectivity modified optimal conservation solutions by evaluating if suggested mitigation measures varied when connectivity was considered. We then focused on assessments of the efficacy of strategies in mitigating HEC, in relation to whether the mitigation strategies impeded elephant movement or not.

In total, we obtained 48 papers on HEC in India, spanning the years 2001–2016, and 93 papers in Asia, from 1978 to 2016. The 93 papers we obtained for Asia were inclusive of the 48 papers we shortlisted as those involving HEC in India. These articles included studies of HEC that focused on ecology (24% in India, and 30% in Asia), socio-ecology/anthropology (35% in India, 33% in Asia) or both (41% in India, 37% in Asia). As expected the majority of studies either recommended or studied HEC mitigation measures (90% in India, 82% in Asia).

We classified mitigation measures described in these papers under the following categories. The HEC mitigation strategies that potentially act as behavioral or other forms of barriers to connectivity (henceforth, "barrier strategies") included: (a) fences or physical barriers to elephant movement such as electrified or non-electrified fences or elephant-proof trenches, (b) chemical deterrents, (c) bio-deterrents, such as bees, and (d) use of light and sound to chase elephants. (e) Monetary or other forms of compensation for loss incurred due to HEC, and (f) education and awareness programs fall under a broader category of strategies aimed at enhancing human–elephant interactions, or encouraging human–elephant coexistence (henceforth, "coexistence strategies"). Planning strategies included those related to (g) law, national or regional policy, or the implementation of the same, as well as (h) research, which through increased accrual of knowledge, can lead to more informed policy in the future. Lastly, landscape-scale strategies included (i) protection of source elephant populations in the larger elephant conservation landscape, (j) land-use planning, and (k) connectivity conservation.

The project location for 67% of the papers from both India and Asia were adjacent to a protected area or some other habitat fragment, while 48 and 39% of the papers in India and Asia, respectively, included context regarding the larger elephant conservation landscape. Thirty three percent of papers in India, and 45% of those in Asia explicitly identified the purported source population of elephants in the study area. Forty two percent of papers in India and 49% in Asia included some mention of connectivity considerations. These largely referred to the project area being located along elephant corridors, or movement routes (84% in India, 82% in Asia), while some studies mentioned colonization of elephants into the project location from nearby forests or refuges (28% in India, 33% in Asia). Note that these percentages do not add up to 100% as some papers included mention of more than one aspect of connectivity. Our review showed that nearly half (43%) of all HEC studies in India recorded their study location as also being important for connectivity. Similarly, 34% of all studies across Asia recorded the same. We consider this an underestimate of HEC locations that also have a bearing on connectivity, as many of these studies did not take the larger elephant landscape into consideration (c. 52–61% of studies).

We found that landscape-scale HEC mitigation strategies were often recommended, and this was particularly so when connectivity was an explicit consideration in the study (**Figure 2**). Barrier strategies were also recommended, and though these were mostly recommended when connectivity was not an explicit consideration, we found that this did not hold for fences (i.e., the proportion of studies recommending fences remained unchanged when connectivity was considered; **Figure 2**). We delved deeper into land-use planning, as this is a truly landscape-scale strategy that has potential for being an effective long-term conservation solution. Land-use was recommended almost twice as often in papers that considered connectivity issues, as compared to those that did not. Land-use planning sometimes included suggestions for habitat consolidation (in 38% of studies) or connectivity (in 15% of studies), but most often suggested a change in crops planted or in cropping pattern (71% of studies). Interestingly, 70% of studies included engagement of local communities with suggestions for land-use planning, when connectivity issues were also considered, in comparison to 50% when connectivity was not considered; we highlight this aspect as stakeholder engagement is a critical component of successful landscape-scale land-use planning programs.

We further evaluated 27 assessments of the impact of various mitigation measures. 74% (20) of these were of a barrier strategy, while 15% (4) were not. We note that 19 of the assessments recorded a positive impact of reducing HEC—by this we mean either reduced the incidence of crop loss or the entry of elephants into agricultural fields, or caused increased tolerance of elephants—but we do not place much importance on this high proportion as: (a) negative results are less likely to be reported unless when compared with mitigation measures that did show a positive impact, (b) an ideal study would be a comparison of multiple measures within a single landscape over a period of time, but such studies are rare, and (c) >50% of assessments did not involve a quantification of HEC reduction. We also note that barrier methods being more localized are probably more amenable to study, while coexistence methods that aim to modify people's perspectives toward elephants, or planning methods that work at a much larger landscape scale, are not. Nonetheless, we found that 50% of the times assessed, non-barrier methods showed a positive effect in reducing HEC ($n = 4$), while a much higher 85% of barrier methods reported a positive effect ($n = 20$).

TRIAGE OF CONSERVATION NEEDS

Making smart and informed decisions on where to allocate limited resources is required for increased efficiency, efficacy, and transparency in the practice of conservation (Margules and Pressey, 2000; Bottrill et al., 2008). We note here that we use the term triage throughout to depict smart and informed decision-making (Bottrill et al., 2008). Decisions, traditionally, have

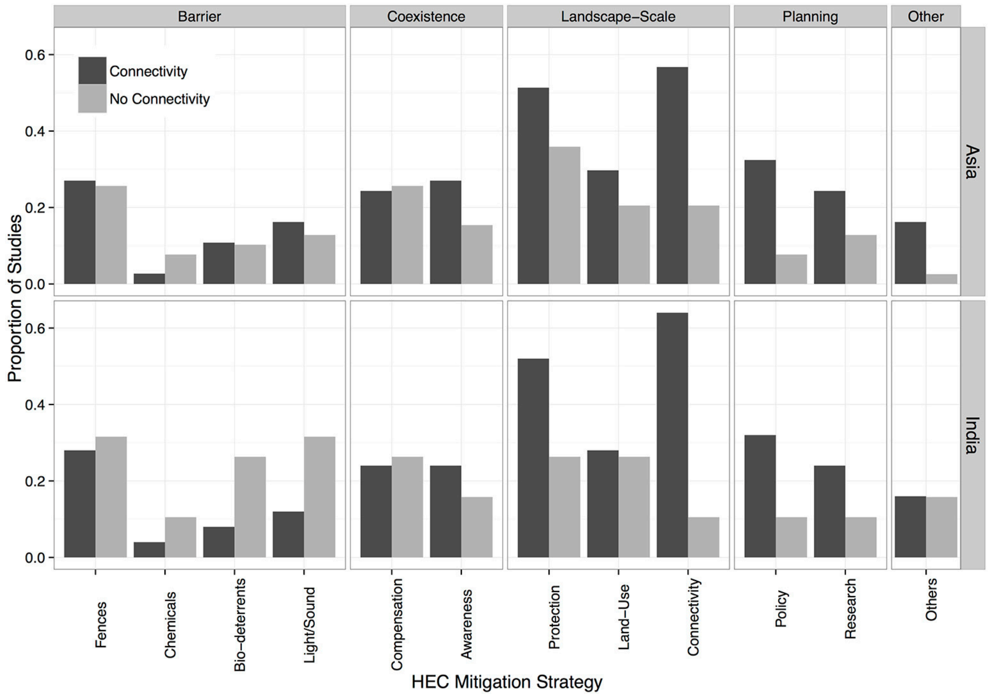

FIGURE 2 | The proportion of studies that either recommended, described or studied various HEC mitigation measures, when connectivity was explicitly considered (dark gray bars), and when connectivity was not considered (light gray bars). Measures include barrier strategies (*fences*–physical barriers, *chemicals*–chemical deterrents, *bio-deterrents*, *light/sound*–use of light and sound to chase elephants), coexistence strategies (*compensation*–financial or monetary compensation for HEC-incurred losses, and *awareness*–education and awareness programs) which are aimed at enhancing human–elephant positive interactions, landscape-scale strategies (*protection*–protecting source populations, *land-use*–land-use-planning, and *connectivity*–connectivity conservation) which are geared toward conserving the larger elephant conservation landscape, planning strategies (*policy*–law, national or regional policy measures, and *research*), and other strategies that do not fall under any of the above categories.

centered on prioritizing species of conservation focus (Jachowski and Kesler, 2009) and more often on deciding locations of conservation importance (Wilson et al., 2006; Moilanen et al., 2009). In heterogeneous landscapes, where species' resources and threats show spatial patterns, the question of *where* to allocate limited conservation resources is of particular importance. We highlight another dimension to this decision-making process, applicable in contexts of multiple conservation needs, the strategies and solutions for which may detract from each other.

While landscape-scale HEC mitigation strategies were by far the most recommended in the literature we reviewed, barrier strategies, which can restrict elephant movement (e.g., Cushman et al., 2010), are frequently and widely implemented (see Fernando et al., 2008a; Davies et al., 2011). Clearly, the spatial placement of these barriers needs to be carefully considered such that we do not unknowingly sacrifice one conservation priority—landscape connectivity—for another—HEC mitigation. Our review clearly shows that half or more sites experiencing HEC are also important for elephant connectivity. In such sites, employing barrier HEC mitigation strategies can severely undermine the overall conservation goal of ensuring long-term persistence of elephants, even when they successfully decrease elephant use of human-use lands and consequently reduce HEC. Moreover, given that the implementation of certain types of physical barriers involves substantial monetary and manpower investment (Fernando et al., 2008a), their unwise placement could be financially wasteful in addition to being ecologically damaging. There is need, therefore, for landscape-scale conservation programs to adopt strategies that facilitate conflict mitigation with the simultaneous maintenance of connectivity, and by extension, strategies that additively serve multiple conservation needs.

We make the following four recommendations for future HEC mitigation studies that emerge from our review. (1) We emphasize that at the minimum, a mention of the relevance of the project area for connectivity should be mentioned in all HEC studies or reports. (2) Despite their potential efficacy, the use of barrier strategies for HEC mitigation in areas that are potentially important for connectivity would be counterproductive for elephant (or wildlife) conservation, and hence should be used with great caution. (3) We noted that the use of local barriers (fences around individual agricultural field) was not clearly distinguished from large-scale fencing off of forests; we stress on the importance of distinguishing between these two forms of fences as their implication for connectivity is likely to be very different, even if their impact on reducing HEC at the local context is similar. (4) Assessments of the effectiveness of HEC mitigation measures should be comparative in nature and should ideally cover a landscape scale, rather than be focused on a small, localized scale. (5) Research on the impact of barrier methods for connectivity is crucial, especially on the potential for HEC mitigation strategies to act as behavioral barriers to connectivity. Goswami et al. (2014b) demonstrate how matrix population models can be used to assess the importance of HEC on elephant viability; an extension of similar population models to include impacts of the loss of connectivity can further shed light on the interplay between these two conservation considerations.

CONCLUSION

Species are faced with a multitude of threats and challenges that increasingly threaten their persistence in a rapidly changing world. In such a context, conservationists, wildlife managers and policy makers are faced with the responsibility of making smart decisions about which species to focus on, and where to invest limited resources. Whilst there exist sophisticated tools to aid conservation decisions, these tools are often focused on addressing, or used in practice to address, a single conservation requirement, particularly when it comes to conservation prioritization at the scale of landscapes. The juxtaposition of HEC mitigation and connectivity conservation highlights by way of an example, how landscape-scale conservation may involve multiple, and often-divergent conservation requirements. If we address and acknowledge this reality, and thereby identify optimal strategies based on a holistic view of multiple conservation needs, we stand to achieve greater efficacy and success at conserving threatened species in heterogeneous, human-dominated landscapes.

AUTHOR CONTRIBUTIONS

VG and DV conceived and designed the study. DV analyzed the data with assistance from VG in data interpretation. VG and DV wrote the manuscript and approved it for publication.

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