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RESEARCH

Stakeholder values on the management of African elephants for large tree conservation in protected areas

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Abstract

Stakeholder perspectives play a crucial role in conservation decisions, particularly for species with complex ecological and social impacts, such as African savanna elephants (*Loxodonta africana*). In a South African protected area experiencing high elephant densities and significant tree loss, we surveyed 170 stakeholders, including conservation managers, property owners, tourists, and tourism personnel. Using a Likert scale and thematic analysis, we evaluated their attitudes towards tree protection, waterhole closures, contraception, and culling to mitigate elephant impacts on large trees. Results showed strong support for waterhole closures and tree protection, particularly among younger conservation managers and property owners, who viewed these methods as effective in dispersing elephant populations and safeguarding valuable trees. Conversely, tourists and younger stakeholders preferred non-lethal strategies like contraception, while conservation managers expressed practical concerns about its feasibility. Culling emerged as the most divisive strategy, supported primarily by older and male stakeholders in conservation but largely opposed by tourists due to ethical concerns. The chord diagram illustrated distinct patterns, with conservation managers aligning more with waterhole closures and culling, while property owners and tourists favoured tree protection and contraception. These findings highlight the diversity in stakeholder values, shaped by demographic factors, and underscore the need for adaptive, context-specific management strategies. Our study provides a framework for conservation policies that balance ecological objectives with social acceptability, promoting sustainable coexistence between elephants, large trees, and diverse stakeholder interests.

Keywords Ecosystem governance · Elephant impact · Non-lethal control · Megaherbivores · Protected areas · Values-based conservation

Introduction

Assessing stakeholder perceptions is crucial in the management of African savanna elephants (hereafter: elephants) (*Loxodonta africana*) in southern Africa, where conservation goals intersect with human livelihoods and ecological dynamics (Van de Water et al. 2022). Elephants, as keystone species, play a significant role in maintaining ecosystem health (Kohi et al. 2011), yet their growing populations can lead to human-elephant conflicts (HEC), including crop damage (DeMotts and Hoon 2012), threats to local communities (Witter 2013), and concerns over the impact that high elephant densities can have on ecological integrity of protected areas (PAs) (Henley and Cook 2019). In this complex socio-ecological landscape, the success of management strategies hinges on understanding and integrating the diverse perspectives and values of stakeholders (Manfredo et al. 2021). By evaluating these societal perspectives

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and values, we can identify areas of conflict and consensus, ensuring that management approaches are socially acceptable and ecologically sustainable, thus enhancing both conservation outcomes and community well-being (Madden and McQuinn 2014).

While numerous social studies have examined societal values related to HEC, particularly in the context of crop damage and safety concerns (Nyirenda et al. 2018; Musakwa et al. 2020; Tickle et al. 2024), there is a notable gap in research addressing societal values surrounding elephants' impact on the ecological integrity of PAs. Elephant impact on vegetation structures within PAs, particularly through the reduction of tree species and the confounding effects on tree-reliant fauna species (Guldemond et al. 2017), is a conservation management concern in several southern African countries with expanding elephant populations (Huang et al. 2024), commonly termed the 'elephant problem' (Glover 1963).

Elephants, as a megaherbivore and keystone species (Owen-Smith 1988), can significantly alter their environment, often through the reduction of large tree (≥5 m; Shannon et al. 2008) cover and promotion of landscape openness (Asner et al. 2016). Large-scale tree loss would however decrease important ecological roles provided by trees such as nutrient recycling, shade and food provision, and habitat creation, including bird nests (Dean et al. 1999; Ward et al. 2018). Large trees also provide positive landscape aesthetics for human stakeholders (Edge et al. 2017).

Varying societal values emerge regarding how high densities of elephants should be managed in PAs where tree loss is a concern (Dickson and Adams 2009), with some stakeholders prioritising perceived ecological preservation through the reduction of elephant numbers (Whyte et al. 1998), and others emphasising the need to maintain elephant populations for perceived biodiversity and tourism benefits (Gillson and Lindsay 2003), as well as animal welfare concerns (IFAW 2005). Understanding these societal values is essential for developing comprehensive management strategies that balance ecological health with human interests.

In this paper, we investigate levels of agreement and non-agreement among stakeholders in a South African protected area concerning (i) elephant impacts on tree species and (ii) management strategies to mitigate these impacts. Specifically, we aim to understand stakeholder support levels and demographic influences on four key management strategies: waterhole closures, tree protection, contraception, and culling.

This study contributes to understanding how different stakeholder groups prioritise the ecological and social values of elephants and large trees, revealing preferences for lethal and non-lethal management interventions. Differences in values, such as ecological priorities and ethical considerations, are expected to influence stakeholder support for these strategies (Manfredo et al. 2021). By clarifying these preferences, our findings can guide adaptive, socially driven conservation strategies that align ecological objectives with stakeholder values and foster more inclusive management planning.

Case study: Kruger National Park (KNP) and the Associated Private Nature Reserves (APNR), South Africa

A key example of societal debates surrounding managing elephant impact on trees can be found in South Africa's Kruger National Park (KNP), where over 14,000 elephants were culled from 1967 to 1994, before the implementation of an internationally-pressured moratorium (Whyte et al. 1998). Post-moratorium elephant numbers in the KNP have increased from an artificially controlled number of 6,000–8,000 elephants, to over 30,000 (GLTFCA 2022).

Increasing elephant numbers have also been observed in one of the large adjoining PAs to KNP, the Associated Private Nature Reserves (APNR). The APNR, a collection of privately owned PAs, dropped its fence-line with the KNP in 1993, and has since had its elephant population rise from 500 elephants to a fluctuation of between 2,000 and 3,000 (Greyling 2004; Peel 2015). This increase, coupled with the APNR's high (largely artificial) waterhole density in comparison to the neighbouring KNP, has resulted in a steady decline in the numbers of large trees (Cook et al. 2023). A high density of artificial waterholes results in elephants contracting their spatial and temporal distributions, thereby increasing the likelihood of local tree impact (O'Connor et al. 2007). Given the complexity of ecological systems, aspects of the decline in large trees can thus directly be attributed to elephant effects on older age classes of trees while mesoherbivore densities and other environmental elements such as topography, fire and climatic events are also known to affect tree dynamics (Henley and Cook 2019).

Irrespective of the causal links, the combination of rising elephant numbers and declining large trees has induced the development of proposed management plans on how to manage elephant effects on large trees in a PA that contains a range of stakeholder groups including photographic safaris, trophy hunting, research facilitation, and shareblock incorporations (Child et al. 2013).

Conflictions over elephant management strategies

Proposed methods to managing elephant impact on large trees in the APNR include: spatial and temporal manipulation methods (artificial waterhole closure, translocation of elephants, zones of increased vigilance); methods for directly protecting trees against elephant impact; as well as elephant population control measures (contraception and culling) (Owen-Smith et al. 2006; Pienaar 2012).

The closure of artificial waterholes has been carried out in the neighbouring KNP to limit the temporal and spatial distributions of elephants, thereby promoting density-dependent habitat selection and competition for resources (Robson and Van Aarde 2018). It is argued though, that large-scale waterhole closures could be detrimental to tourism (Van Wyk 2001).

Translocation, the physical relocation of elephants from areas of high density to other reserves or countries, has been used to reduce localised pressure on vegetation and promote genetic diversity. However, it is logistically complex, expensive, and often limited by the availability of suitable recipient areas (Maraï et al. 2004; Ferreira et al. 2011).

Zones of increased vigilance refer to strategically monitored areas where elephant impact is closely tracked, and interventions such as deterrents, intensified ranger presence, or disturbance shooting are employed to reduce damage to key ecological features, such as large trees (Owen-Smith 1989; Owen-Smith et al. 2006). While potentially effective at a local scale, these methods require significant resource investment and coordination.

Tree protection methods, such as wrapping up tree trunks with chicken-mesh (to prevent bark-stripping), or hanging beehives in tree branches to scare off elephants, have been used to protect individual trees from elephant impact (Cook et al. 2023). The increased effectiveness of tree protection methods depends on correct application and monitoring of method longevity (Cook et al. 2023).

Contraception of elephant cows with native porcine zona pellucida (PZP) has been used to decrease the growth rate of elephant populations by either preventing female elephants from conceiving, or by increasing the intervals between calving (Delsink et al. 2023). Opponents however have observed its limitations in large populations where follow-up treatments may be logistically unattainable (Whyte 2007), however effectiveness within a number of PAs has recently been cited (Delsink et al. 2023).

Culling elephants directly lowers the number of elephants in a PA and was indiscriminate of sex and age (Whyte et al. 1998). Whilst proponents of culling argue that a reduction in elephant numbers will lower impact on large trees (Whyte et al. 1998), opponents cite animal welfare concerns (Slotow et al. 2021) and evidence that elephant densities are not directly linked to tree losses (Abraham et al. 2021). Although trophy hunting generates an income, it has limited applicability as an ecological management tool as it is directed towards bulls and is selective of certain phenotypic traits (e.g. large tusks), making it ineffective as a population control method and in need of effective management to prevent evolutionary consequences over time (Harris et al. 2002).

The diversity of available management strategies, coupled with the variety of societal views, highlights that selecting for the best method that appeases both the concern over the loss of large trees and satisfies stakeholder values is critical for conservation managers.

Materials and methods

Study area

The APNR (size: 2,089 km^2) is situated in the north-eastern region of South Africa (24˚04–24˚55′ S; 30˚82′–31˚48′ E), sharing an open boundary with the KNP since 1993 and forms a part of the Great Limpopo Transfrontier Conservation Area (GLTFCA 2022; Fig. 1). Five privately owned PAs make up the APNR, including the Balule-, Klaserie-Thornybush-, Timbavati-, and Umbabat-Private Nature Reserves. These PAs are comprised of delineated properties owned by private (non-State) individuals who have made the choice to operate the activities on their properties for commercial (e.g. photographic or hunting safaris) or for private usage only. APNR stakeholder groups were categorised as the following: conservation management (reserve management and biological scientific researchers), tourism and hospitality (tourist lodge personnel, tour operators and field guides), property owners (landowners and shareholders), and tourists (leisure travellers). The APNR has a waterhole density of 2.5 waterholes per km^2, which means that water is readily available in comparison with the neighbouring regions of the KNP, which have a waterhole density of 0.1 per km^2 (Child et al. 2013). Whilst elephant densities across the APNR and KNP fluctuate throughout the year, census data in the dry season estimate the APNR elephant density at 1.67 elephants per km^2 (2022 census) and the KNP elephant density at 1.54 elephants per km^2 (2022 census) (GLTFCA 2022).

Survey design and sampling

Non-medical human ethics clearance for this survey was granted by the University of the Witwatersrand's Human Research Ethics Committee (protocol number: H22/11/54). A participatory consent sheet was emailed to all potential participants explaining the purpose and content of the questionnaire (Participatory information sheet S1).

Likert scales are a frequently used tool in fields such as psychology and sociology for measuring respondent values

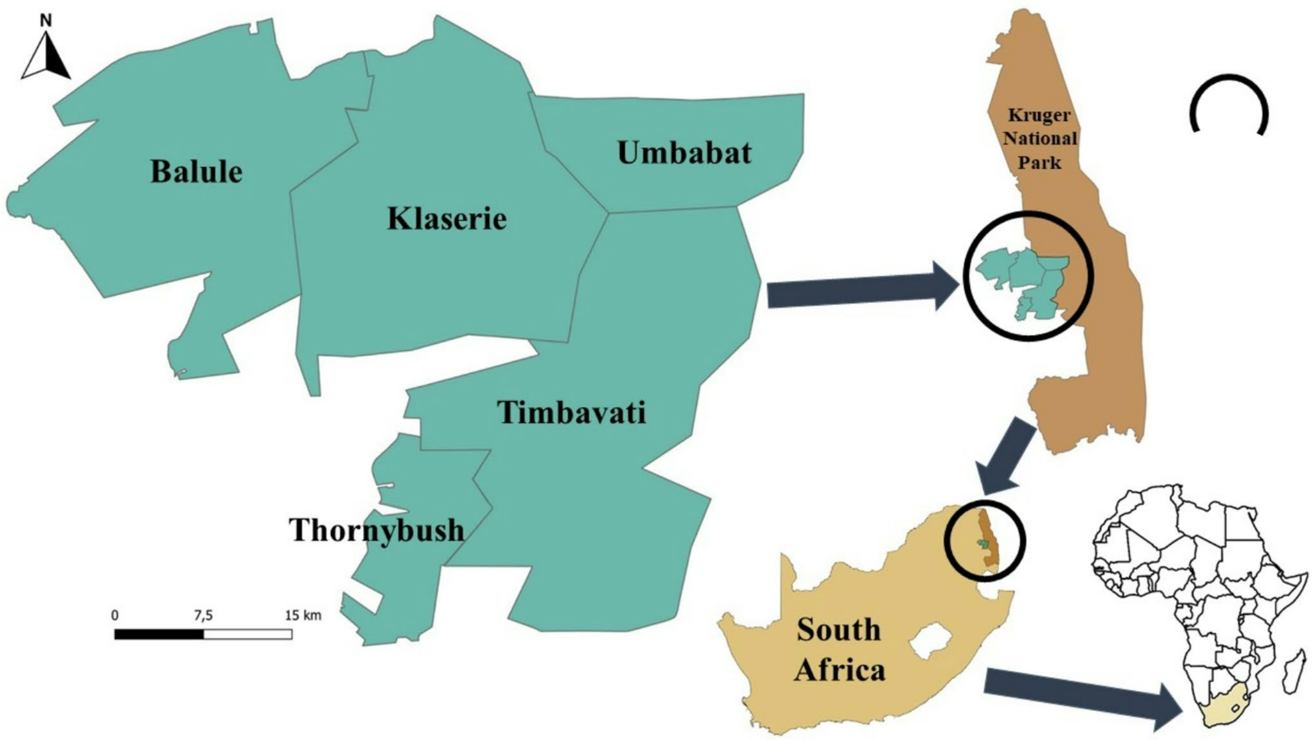

Fig. 1 Location of the Associated Private Nature Reserves (APNR), South Africa, comprised of five private protected areas sharing an open boundary with the Kruger National Park (KNP)

in an ordinal quantitative format (Sandiford and John 2003; Taherdoost 2022), and allow for quantitative data to be compared and combined with qualitative data-gathering techniques (Nemoto and Beglar 2014).

We used Likert-scale items to quantify stakeholder attitudes, while open-ended responses provided qualitative data analysed thematically. We constructed 36 Likert items from existing scientific literature on the debates surrounding the management of elephants in the KNP and APNR, covering a broad base of elephant-large tree ecological and societal values (Tables S1 and 2). Conservation managers of the APNR were also consulted to ensure that current management issues were represented. We then conducted a thematic analysis (*Taguette* software, Rampin and Rampin 2021) to identify common themes across the Likert items and divided them into two sections (Sects. 1 and 2) of 18 items each. Section 1 referred to the theory of elephant and large tree population dynamics (Table S1) and Sect. 2 referred to management practices of protecting large trees where they co-occur with elephants (Table S2).

We then constructed a web-based questionnaire (KoBoToolbox 2023), placing the Likert items in a 5-option Likert framework (Strongly disagree, Disagree, Neutral, Agree, Strongly agree). Demographic data of each participant was also collected, which included: nationality, gender, age class, education level, number of years as a stakeholder (number of years since the participant first assumed their stakeholder title within the APNR), visitation rate to the APNR, and stakeholder group (Table 1). Demographic details were used for Sect. 2 of the analyses. Each Likert item had an open-ended comments section where participants could voluntarily elaborate on their answer if they so wished.

The Likert items were first piloted with 6 participants (both South African and international). Upon feedback minor alterations were made to Likert items that required clarification. The survey was launched on 26 July 2023 and distributed to all conservation managers of the APNR, as well as a subgroup of lodge owners, private landowners, and shareblock representatives (total of 127 submitted surveys) whose contact details were available due to historical communication and in compliance with the South African Protection of Personal Information Act (POPIA). From there on, the survey was distributed through targeted snowball sampling (Burger and Silima 2006), whereby respondents were asked to pass on the online survey to relevant stakeholder associates, bringing the survey total to 170 participants responses. The survey was closed on 17 November 2023.

Table 1 Participant sample size and demographic information, separated by stakeholder group for the Associated Private Nature Reserves (APNR), South Africa

Demographic factor	Category	Conservation management ($n=54$)	Hospitality and tourism ($n=42$)	Property owner ($n=41$)	Tourist ($n=33$)	Total ($n=170$)
Nationality	South African	38 (70.4%)	31 (73.8%)	30 (73.2%)	26 (78.8%)	125 (73.5%)
	International	16 (29.6%)	11 (26.2%)	11 (26.8%)	7 (21.2%)	45 (26.5%)
Gender	Female	18 (33.3%)	21(50%)	17 (41.5%)	25 (75.8%)	81 (47.6%)
	Male	36 (66.7%)	21 (50%)	24 (58.5%)	8 (24.2%)	89 (52.4%)
Age class	<50 years	40 (74.1%)	34 (81%)	14 (34.1%)	18 (54.5%)	106 (62.4%)
	>50 years	14 (25.9%)	8 (19%)	27 (65.9%)	15 (45.5%)	64 (37.6%)
Education	High school	4 (7.4%)	5 (11.9%)	5 (12.2%)	1 (3%)	15 (8.8%)
	Tertiary certificate	0 (0%)	4 (9.5%)	1 (2.4%)	0 (0%)	5 (2.9%)
	College diploma	4 (7.4%)	13 (31%)	5 (12.2%)	10 (30.3%)	32 (18.8%)
	Bachelor's degree	14 (25.9%)	12 (28.6)	21 (51.2%)	14 (42.4%)	61 (35.9%)
	Master's degree	20 (37%)	8 (19%)	8 (19.6%)	7 (21.2%)	43 (25.3%)
	Doctorate	12 (22.3%)	0 (0%)	1 (2.4%)	1 (3%)	14 (8.2%)
Residency period (number of years as a stakeholder)	<10 Years	32 (59.3%)	30 (71.4%)	19 (46.3%)	16 (48.5%)	97 (57.1%)
	>10 Years	22 (40.7%)	12 (28.6%)	22 (53.7%)	17 (51.5%)	73 (42.9%)
Visitation rate	Less than once a year	7 (10.7%)	1 (2.4%)	1 (2.4%)	8 (24.2%)	17 (10%)
	Once a year	11 (21.4%)	2 (4.9%)	3 (7.3%)	11 (33.3%)	27 (15.9%)
	At least once every 6 months	7 (3.6%)	6 (14.3%)	17 (41.5%)	9 (27.3%)	39 (22.9%)
	At least once a month	10 (10.7)	5 (11.9%)	11 (26.8%)	2 (6.1%)	28 (16.5%)
	resident	19 (53.6%)	28 (66.5%)	9 (22%)	3 (9.1%)	59 (34.7%)

Data cleaning and Preparation

A total of 170 APNR stakeholders responded to the survey (Table 1). Due to the relatively small number of available participants, we combined the age classes of those below 50 years and those above 50 years of age, whereby those≥50 years would have had a minimum period of 20 years during the 'command-control-era' (management focused on the direct manipulation of animal numbers through human intervention) when culling was permitted (Whyte et al. 1998). Respondents in the above 50 years cohort would have spent their early to middle age years at a time when culling was operational (years 1973–1994). We also combined the representatives of all non-South African respondents (13 different countries), as international stakeholders for statistical purposes. Participant education classes were not included in the analyses due to the small sample sizes per category.

Statistical analyses

Statistical analyses were carried out in R version 4.3.1 (Development Core Team 2012) and were considered significant at $p<0.05$. Responses to the Likert items were displayed in a Likert chart in order of responses with the highest cumulative percentages of 'Agree' and 'Strongly agree' (*Likert* package, Bryer and Speerschneider 2016).

Polarisation tests were performed on each Likert item (*agrmt* package, Ruedin and Aeppli 2023). This test measures the level of dispersion amongst data in an ordered rating scale, providing an output from 0 to 1, where an output of 0 signifies perfect agreement amongst respondents; an output of 0.5 signifies no agreement; whilst an output of 1 signifies perfect polarisation (Ruedin and Aeppli 2023). No agreement consequently signifies a lack of agreement and a lack of polarisation amongst participant responses. Polarisation scores are calculated using the following formula: Polarisation score (Pol) = (1-*agreement*)/2, whereby *agreement* is calculated using Cohen's Kappa coefficient:

$$K = P_o\ P_e\ /l - P_e$$

Where: P_o is the observed agreement and Pe is the expected agreement by chance (Ruedin and Aeppli 2023).

We then ran four separate ordinal logit models (OLMs) (*MASS* package, Ripley et al. 2023) to examine how stakeholder demographics influenced stakeholder values concerning the effectiveness of the four elephant management strategies of interest, using results from the following four Likert items:

i) I think that a decrease in APNR waterholes would limit elephant movements and their consequential impact to large trees in proximity to waterholes (*Waterhole closure*).
ii) I think that tree protection methods (such as wire-netting/rocks/beehives) should be used to protect

individual trees from elephant impact (*Tree protection methods*).

iii) I think that the contraception of elephants is a viable management tool for lessoning elephant impact on large trees within the APNR (*Contraception*).

iv) I believe that culling elephants will reduce elephant impact on large trees (*Culling*).

Our OLMs examined how stakeholder demographics influenced perceptions of four key management strategies, each operationalised as an ordered Likert-scale response variable (1 = Strongly Disagree to 5 = Strongly Agree): (1) Waterhole closures limiting elephant impacts, (2) Tree protection methods (e.g., wire-netting), (3) Contraception as a viable tool, and 40 Culling to reduce tree impacts. The following categorical predictor variables from Table 1 were tested: stakeholder group, nationality, gender, age class, residency period, and visitation rate. Predictor variables were removed iteratively via likelihood ratio tests to assess their contribution to model variance (Guisan and Harrell 2000). This approach allowed us to isolate demographic effects on support for each management strategy while accounting for the ordinal nature of our response variables (Zheng et al. 2014). Each management strategy was modelled separately to avoid conflating distinct stakeholder value systems.

We then constructed a chord diagram (*circlize* package, Gu 2022) to visually illustrate the interrelationships between stakeholder groups and their support for various strategies. We then conducted a thematic analysis using Taguette software (Rampin and Rampin 2021) to examine participant comments on each management method. Comments were coded to identify prominent response themes, allowing us to capture a broad range of perspectives. Each management method's comments were analysed independently, and themes were categorised to reflect the variety of viewpoints expressed. This analysis helped highlight patterns in stakeholder opinions, providing insight into shared and divergent values across the different management approaches.

Results

Stakeholder perspectives on elephant and large tree dynamics

The survey revealed generally high awareness among stakeholders about the ecological and tourism value of both elephants and large trees. Most participants (82%) identified themselves as having a strong understanding of elephant impacts on large trees, with high agreement that both elephants (97%) and large trees (81%) add significant tourism value (Fig. 2). Stakeholder perspectives on elephant impact, however, varied considerably by group. Property owners and tourism stakeholders frequently cited aesthetic and economic benefits, describing large trees as "irreplaceable" and "essential for tourism appeal." In contrast, conservation managers showed a more ecosystem-focused view, emphasising that these trees contribute to habitat diversity and ecosystem stability. One conservation manager noted "Large trees are essential for ecosystem services, yet excessive elephant activity cannot go unchecked."

Despite this shared value, attitudes differed regarding the impact of elephants on large trees. While 69% of participants expressed concern over current levels of elephant impact on large trees (Pol = 0.21), only 48% agreed there were too many elephants (Pol = 0.39). These differences highlight a tension between recognising tree loss as an ecological issue and viewing it as an inevitable aspect of elephant dynamics in PAs. Additionally, 79% agreed that elephants can increase habitat for lizards and insects (Pol = 0.15), while 76% acknowledged that elephant impact could decrease habitat availability for tree-nesting birds (Pol = 0.16) (Fig. 2).

Management strategies for protecting large trees

Strong support emerged for certain management strategies, reflecting a broad recognition of the need to mitigate elephant impacts on large trees. However, preferences and concerns varied widely by stakeholder group and demographic factors, illustrating the diverse values and priorities within the population surveyed. These variations were influenced by factors such as age, stakeholder role, and familiarity with conservation practices, with some strategies generating consensus across groups while others, like culling and contraception, revealed notable divisions (Fig. 3).

Waterhole closure

Support for waterhole closures to reduce localised elephant impacts on trees was high (59%, Pol = 0.39), especially among younger conservation managers (Table 2), who saw it as a natural way to manage elephant movement across the landscape. As one conservation manager put it, "Waterhole closure could encourage elephants to spread out, reducing pressure on specific areas." Tourism stakeholders expressed significant reservations about waterhole closures (59% agreed it would reduce sightings), with one noting, "Wildlife sightings are what keep tourists coming back - if elephants aren't near waterholes, they'll be harder to find." This aligns with broader concerns that reduced access could limit wildlife viewing opportunities, a primary draw for

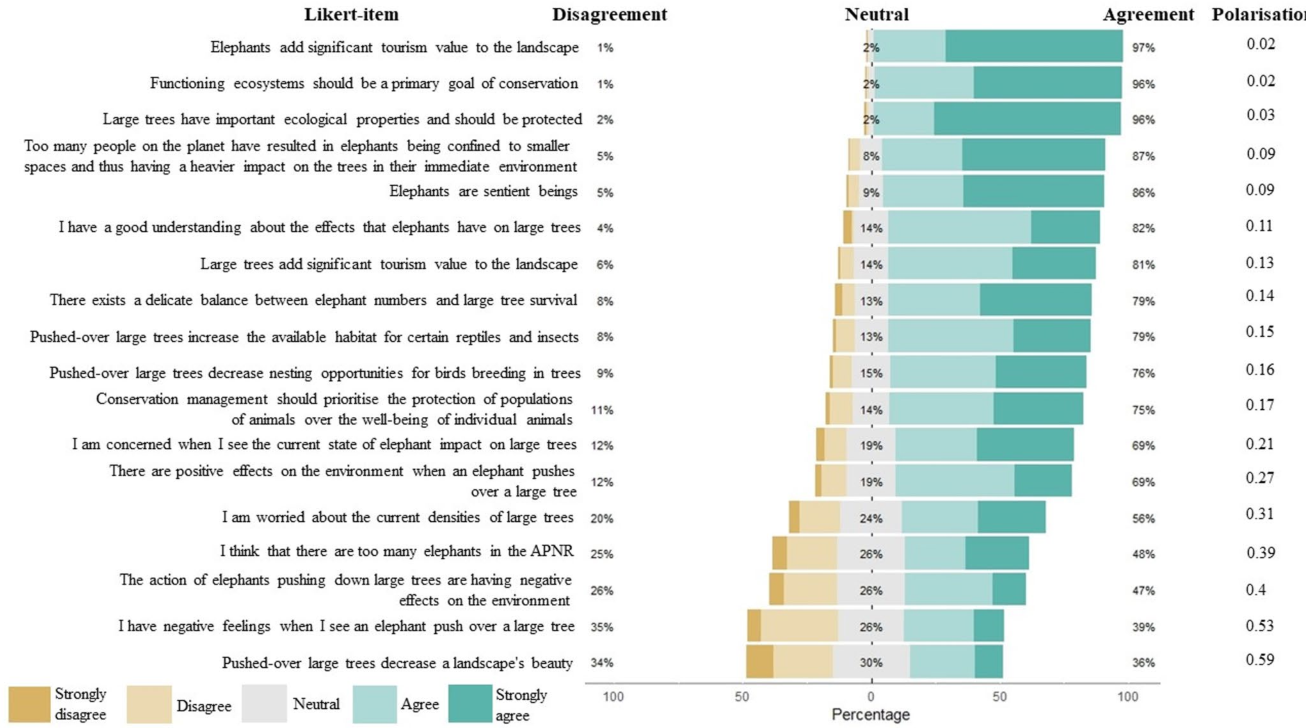

Fig. 2 Section 1: The views of stakeholders on value statements related to elephant and large tree population dynamics in the Associated Private Nature Reserves (APNR), South Africa

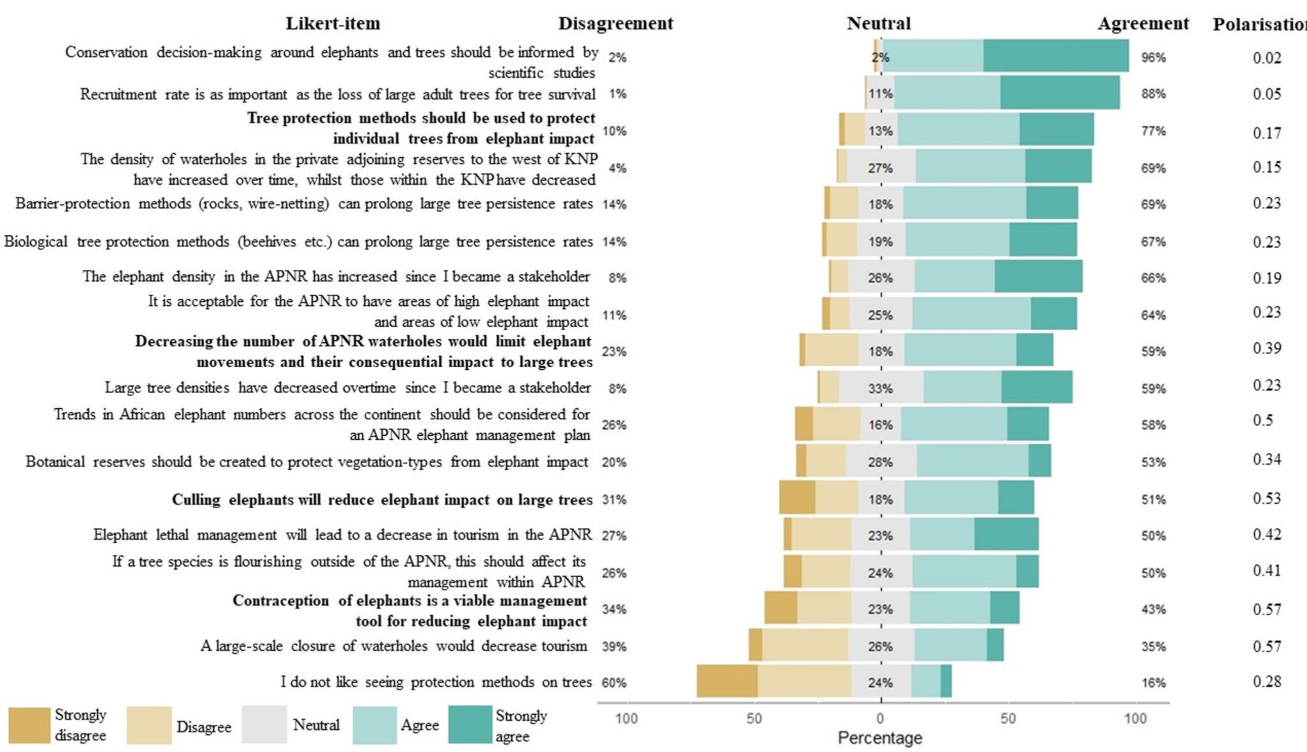

Fig. 3 Section 2: The views of stakeholders on value statements related to management practices for protecting large trees where they co-occur with elephants in the Associated Private Nature Reserves (APNR), South Africa. Bold Likert items represent terms used in the ordinal logit models (OLMs)

visitors (Pol = 0.57; Fig. 3). However, perspectives varied, as another tourism stakeholder cautioned, "If elephants move away from popular spots, we lose what brings tourists here." highlighting the industry's reliance on predictable wildlife encounters.

Tree protection methods

Methods to protect individual trees, such as wire-netting or beehives, received broad support (77% agreement, Pol = 0.17), particularly from property owners. Qualitative responses revealed strong valuation of both ecological and economic benefits, with one property owner stating, "These trees are irreplaceable and essential for tourism appeal," while another described the methods as "a good way to keep the iconic trees safe." Tourists similarly valued the aesthetic advantages of tree preservation. However, scalability concerns were frequently noted, with participants observing: "It's not realistic to protect every tree this way," and "Such methods are not feasible on a landscape scale." Age significantly influenced support levels, with younger participants more likely to endorse these methods (Table 2).

Contraception

Contraception was a more divisive method, with mixed support among stakeholders (43%, Pol = 0.57). Tourists showed the most openness to contraception, viewing it as a non-lethal approach that aligns with ethical conservation practices. In contrast, stakeholders with > 10 years of residency in the APNR (predominantly older property owners and conservation managers (Table 1) expressed scepticism, questioning both the logistics and cost-effectiveness of large-scale contraception. This aligned with our OLM results showing significantly lower support for contraception among long-term stakeholders ($\beta = -0.60$, $p < 0.05$; Table 2). A property owner remarked, "It sounds good in theory, but how practical is it in the wild?" The residency period was a significant predictor of support for contraception, with those involved for over 10 years showing lower support (Table 2). Some conservation managers raised concerns about contraception's potential behavioural impacts. One noted, "We don't fully understand how contraception affects social dynamics," reflecting uncertainties about long-term effects on elephant herds (Table 2).

Table 2 Retained variables of the four ordinal logit models (OLMs) for stakeholder values on four potential elephant management strategies to reduce elephant impact on large trees in the Associated Private Nature Reserves (APNR), South africa. The following baseline variables are used for comparison: age: <50 years; gender: female; residency period: <10 years; stakeholder: conservation management

Elephant management method	Factors	Estimate	Standard error	t-value	*p*-value
Waterhole closure	Age: ≥50 years	−0.86	0.33	−2.56	0.02*
	α_1	−1.66	0.32	−5.08	< 0.001***
	α_2	−0.81	0.3	−2.65	0.04**
Tree protection methods	Age: ≥50 years	−0.96	0.45	−2.16	0.03*
	Stakeholder: Property owners	1.74	0.6	2.89	0.003**
	Stakeholder: Tourism and hospitality	0.4	0.46	0.85	0.4
	Stakeholder: Tourists	2.33	0.81	2.88	0.002**
	α_1	−2.19	0.39	−5.67	< 0.001***
	α_2	−0.96	0.32	2.99	0.002**
Contraception	Residency period: ≥10 years	−0.6	0.31	−1.98	0.04*
	Stakeholder: Property owners	0.7	0.4	1.74	0.08
	Stakeholder: Tourism and hospitality	0.15	0.39	0.38	0.7
	Stakeholder: Tourists	0.82	0.42	1.95	0.04*
	α_1	−0.54	0.3	−1.84	0.07
	α_2	0.44	0.3	1.5	0.13
Culling	Gender: Male	1.12	0.32	3.44	< 0.001***
	Residency period: ≥10 years	0.57	0.33	1.72	0.09
	Stakeholder: Property owners	−0.34	0.42	−0.82	0.41
	Stakeholder: Tourism and hospitality	−0.27	0.42	−0.64	0.52
	Stakeholder: Tourists	−1.11	0.48	−2.31	0.02*
	α_1	−0.47	0.35	−1.33	0.18
	α_2	0.41	0.35	1.15	0.25

p-values: * <0.05; ** <0.01, *** <0.001

α_i indicates the intercepts estimated to predict the different ordinal classes

Culling

Culling was the most contentious strategy, with 51% of participants agreeing it would reduce elephant impact on large trees (Pol = 0.57), though with high non-agreement on its effects on tourism (Pol = 0.53). Support for culling varied by age, with stakeholders > 50 years showing significantly higher approval ($\beta = 1.12$, $p < 0.05$; Table 2). One participant remarked, “We’ve seen it work in the past, and we need definitive action.” Tourists overwhelmingly opposed culling (Fig. 4), with one remarking, “Culling is too harsh; we should seek humane methods,” and another stating, “It sends the wrong message about conservation ethics.” This contrasted sharply with conservation managers’ views (Fig. 4). Conservation managers were generally more open to culling as a practical solution for population control, but some expressed ethical reservations. One manager explained, “Reducing numbers this way works, but it’s not the ideal answer.” Tourists, on the other hand, largely opposed culling, indicating a preference for humane alternatives. Gender differences were notable, with male participants significantly more likely than female participants to support culling as a management strategy (Table 2).

Summary of management preferences by stakeholder group

The chord diagram displayed the relationships between stakeholder groups and their preferences for specific elephant management strategies (Fig. 4). Conservation managers showed strong support for waterhole closures, with moderate support for culling. Property owners and tourists aligned more closely with tree protection methods and contraception, indicating a preference for non-lethal

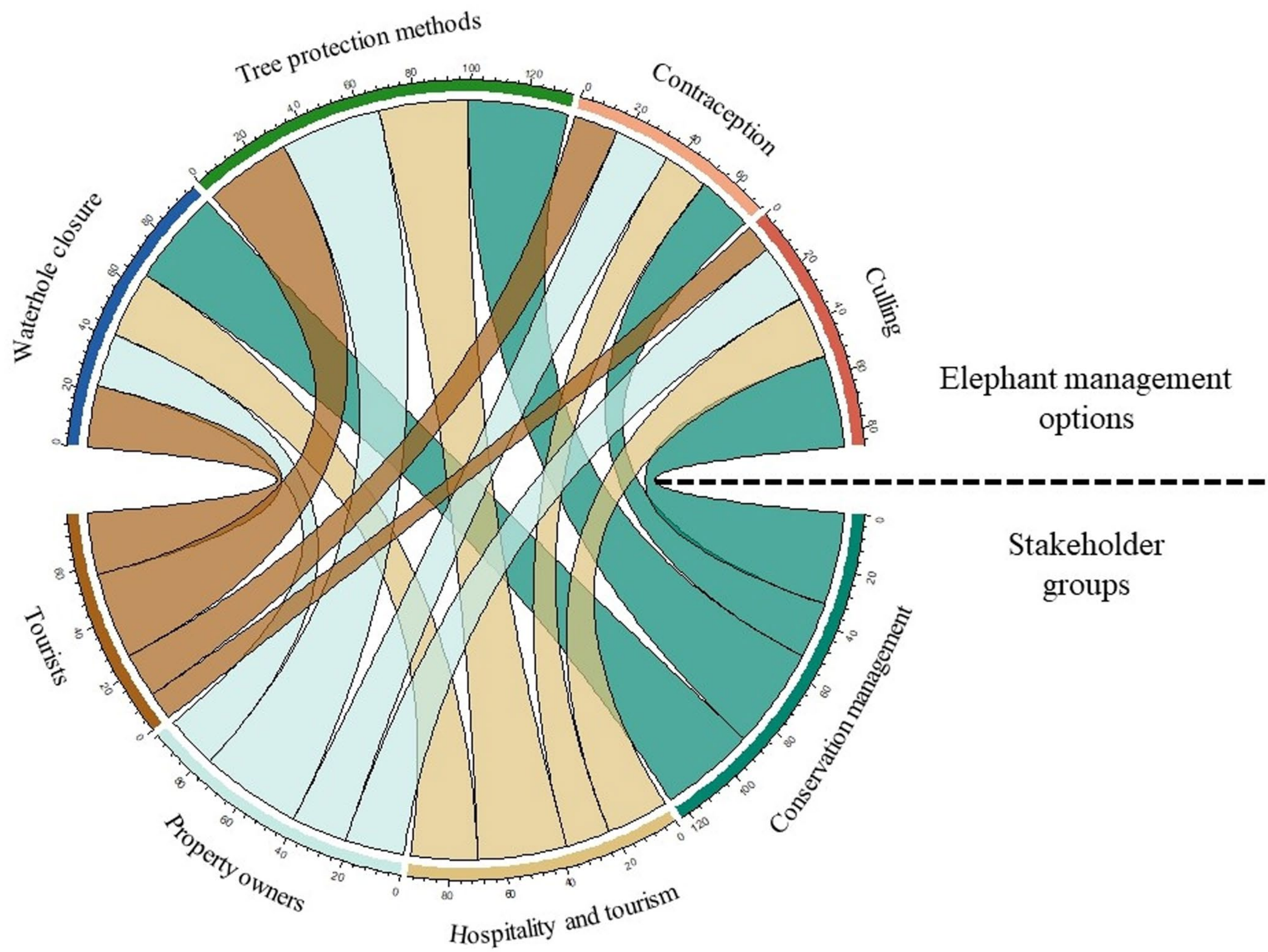

Fig. 4 Chord diagram representing stakeholder agreement support for four potential elephant management methods in the Associated Private Nature Reserves (APNR), South Africa, based on responses by participants to Likert items suggesting the effectiveness of each method to reduce elephant impact on large trees. Larger arcs represent stronger levels of agreement support

management approaches. Tourism and hospitality stakeholders exhibited a similar pattern to property owners and tourists, favouring tree protection methods while showing limited support for culling. The diagram illustrated distinct patterns of alignment between stakeholder groups and management strategies, highlighting areas of overlap and divergence among their preferences.

Discussion

Stakeholder perspectives on elephant and large tree dynamics

Our results reveal a complex array of stakeholder perspectives on elephant impacts and management strategies, underscoring the need for multifaceted approaches in conservation policy. Many stakeholders recognise both elephants and large trees as ecologically and economically valuable, but they vary significantly in their responses to tree damage caused by elephants.

While these views illustrate shared concerns across stakeholders, divergent opinions on the aesthetics and ecological roles of trees suggest that differing values and experiential backgrounds influence attitudes (Edge et al. 2017). Property owners, for instance, showed a strong attachment to iconic trees near their properties. This attachment likely stems from the immediate economic and visual benefits that these trees provide, as they enhance property value and tourist satisfaction. By contrast, tourists appreciate these trees primarily for their scenic and photographic appeal, often viewing them as emblematic of the African landscape (Duvall et al. 2018). Unlike property owners, tourists have a more transient connection to these trees, valuing them for their aesthetic contribution to a temporary experience rather than for their ongoing presence. Conservation managers, on the other hand, would likely prioritise ecosystem function and sustainability over individual trees, viewing them as part of a broader ecological framework (Dickson and Adams 2009). Notably, stakeholders' awareness of elephants' contrasting impacts, benefiting ground-dwelling fauna (79% agreement) while disadvantaging tree-nesting birds (76% agreement), mirrors scientific evidence of elephant-mediated habitat heterogeneity (Guldemond et al. 2017). This suggests their support for management strategies may be informed by ecological realism, not just ethical or economic concerns. These differences in stakeholder perspectives underscore the importance of aligning conservation policies with the specific priorities of each group, recognising the varying degrees of attachment and the motivations behind them (Mushove and Vogel 2005).

Management strategies and stakeholder demographics

Our analysis shows distinct demographic predictors for support or opposition to various management interventions, including waterhole closure, tree protection methods, contraception, and culling. These differences underscore the critical role of stakeholder experience, age, and residency in shaping attitudes. Older stakeholders (> 50 years), who have witnessed historic culling programs, showed more support for culling as an effective management tool. This reflects an intergenerational value shift, where established methods like culling are more accepted by older stakeholders who view them as necessary for ecological stability (Manfredo et al. 2009).

Conversely, younger conservation managers and tourists generally opposed culling (72% disagreed/strongly disagreed), favouring non-lethal methods such as contraception or tree protection. Their qualitative responses emphasised ethical concerns about animal welfare, reflecting what Ramp and Bekoff (2015) identify as a generational shift toward compassionate conservation principles. This tension between population-level ecological outcomes and individual animal welfare concerns presents a key challenge for conservation policy-making (Slotow et al. 2021). The lower support for contraception among stakeholders with > 10 years of residency (Table 2) may reflect institutional memory of past management challenges (Whyte 2007) or a preference for established interventions like culling during the 'command-control' era (Whyte et al. 1998). This aligns with broader findings that conservation practitioners with long-term field experience often prioritize pragmatic, historically tested methods over newer approaches (Manfredo et al. 2021). By understanding these demographic differences, conservation managers can incorporate stakeholder-specific preferences into an adaptive management plan, adjusting strategies based on evolving stakeholder concerns and ecological needs (Gaylard and Ferreira 2011).

Thematic insights into non-lethal management preferences

Our thematic analysis reveals that while there is strong support among stakeholders for both waterhole closures and tree protection methods, these preferences are tempered by practical concerns about feasibility and potential impacts. For instance, conservation managers advocate for waterhole closures to reduce localised elephant impacts on large trees, suggesting that "waterhole management could balance elephant distribution naturally." Their perspective reflects an ecological approach, proposing that by reducing artificial water sources, elephant impact levels will reflect a more heterogenic pattern, rather than being homogenised across a PA (Robson and Van Aarde 2018). However, tourism-focused stakeholders express reservations, fearing that waterhole closures would limit wildlife sightings, thus affecting tourism revenue. These tourism concerns about reduced wildlife sightings contrast with ecological evidence that strategic waterhole closures may actually diversify viewing opportunities by dispersing elephants (Krag et al. 2023). This highlights the tension between immediate tourism economics and long-term ecological benefits, suggesting adaptive approaches like rotational closures could balance both needs (Van Wyk 2001).

The strong support for tree protection methods, especially among property owners, aligns with studies linking large trees to enhanced property value and visitor experience (Edge et al. 2017; Duvall et al. 2018). However, the expressed concerns about landscape-scale feasibility underscore a critical limitation: while these methods are effective for high-value individual trees, broader interventions (e.g., habitat restoration, waterhole management) may be needed to address ecosystem-wide tree loss (Henley and Cook 2019). Prior work documented that wire-netting can cause stem abrasion or girdling if improperly maintained (Cook et al. 2023), while beehives may fail to deter elephants during dry seasons when bee activity declines (Cook and Henley 2024; King et al. 2024). Rocks, though low-cost, require frequent upkeep to remain effective (Henley and Cook 2019). These trade-offs underscore that even non-lethal interventions carry ecological and logistical costs, a critical consideration when scaling protection beyond high-value individual trees (Henley and Cook 2019). However, protecting every tree with such methods is not the intention. Rather, future research could focus on identifying the seed dispersal kernels of key tree species to inform spatially explicit strategies for protecting select, high-value trees at a landscape scale. Broader-scale interventions, such as habitat restoration or strategic waterhole closures, may also complement these efforts to address tree loss across the entire landscape (Henley and Cook 2019).

These insights highlight that while stakeholders may agree on certain strategies, applying these methods effectively requires an adaptive, context-specific approach (Gaylard and Ferreira 2011). By aligning management with both ecological and economic priorities, conservation managers can protect high-value large trees in tourism areas while also addressing broader landscape needs.

Ethical and practical considerations for contraception and culling

Contraception emerged as a controversial strategy, especially among long-term stakeholders who doubted its effectiveness due to logistical and financial constraints. While some managers expressed concerns about contraception altering elephant social dynamics, empirical studies of immunocontraception have found minimal behavioural disruptions (Delsink et al. 2013, 2023). This perception gap highlights the need for continued stakeholder education about modern contraceptive protocols. Future studies could explore the alignment between stakeholder perceptions and real-world ecological data to further substantiate the validity of these perspectives and inform targeted educational strategies.

Culling, while historically used, remains contentious, with conservation managers showing the highest support due to its perceived efficacy in reducing elephant numbers quickly. Yet ethical opposition was strong, particularly among tourists. This divide reflects a broader global trend away from lethal population control in favour of methods that align with animal welfare standards (Sutton and Taylor 2019), suggesting that transparency and stakeholder involvement are crucial if culling is to be considered.

Implications for conservation management

The diversity of perspectives highlighted in this study further suggests that a one-size-fits-all approach to elephant management in protected areas is unlikely to succeed (Cilliers et al. 2013). Conservation managers in the APNR must balance ecological, economic, and ethical considerations, recognising that stakeholder support is critical for the long-term sustainability of conservation initiatives (Manfredo et al. 2021). Our findings suggest that participatory management approaches, where stakeholders are provided with regular, scientifically informed updates and opportunities for input, could enhance acceptance and reduce conflict.

By understanding and respecting the values of diverse stakeholder groups, conservation strategies can be more adaptive, resilient, and effective (Manfredo et al. 2009). This approach aligns with the broader need to balance HEC in a socially and ecologically sustainable manner, promoting both conservation outcomes and stakeholder satisfaction in the APNR and similar protected areas across Africa (Edge et al. 2017; Gross et al. 2022).

While stakeholders evaluated management strategies individually, real-world conservation requires integrated, adaptive approaches. As demonstrated in Kruger National Park (Pienaar 2012), effective elephant-tree balance combines: (1) population control (e.g., contraception), (2) spatial manipulation (e.g., waterhole closures), and (3) targeted tree protection, all while navigating ecological complexity (Asner et al. 2016) and social values. Our findings suggest stakeholder preferences should inform, but not dictate, such strategies. A structured decision-making framework

(Gaylard and Ferreira 2011; Manfredo et al. 2021) can balance these priorities by using ecological thresholds (e.g., tree loss rates) to determine when intervention is needed, while incorporating stakeholder preferences to guide the choice of methods. Ongoing monitoring then ensures ecological integrity and social buy-in, exemplifying the 'adaptive' in adaptive management.

Limitations of the study

Our study has two primary limitations. First, while the four-month survey period (July–November 2023) ensured comprehensive stakeholder representation, temporal biases - such as fluctuating perspectives due to seasonal workforce dynamics or evolving conservation discourses - cannot be entirely discounted. That said, longitudinal consistency in responses was observed, and no material shifts in elephant management policies or stakeholder roles occurred during this interval. Second, although snowball sampling was instrumental in accessing hard-to-reach groups (e.g., private landowners), this approach may inadvertently marginalise dissenting or less-connected voices within the stakeholder landscape (Heckathorn 2011). These methodological trade-offs were carefully weighed against the imperative of capturing diverse, on-the-ground perspectives.

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Data availability Data is provided within the manuscript or supplementary information files.

Declarations

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