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Using irregular ranger patrols to quantify elephant occupancy in non-protected and community-modified landscapes

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elephant occupancy; spatial monitoring; community conservation; ranger patrols; spatial distribution; community-led strategies; SMART; human–wildlife coexistence.

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Abstract

While wildlife management efforts have primarily focused on protected areas, unprotected areas – including community-owned lands – are becoming increasingly important as habitat linkages and dispersal areas between multiple protected areas for species and processes that sustain them. However, these unprotected areas and community lands often lack structured protection measures and face numerous threats to both species and habitats. Involvement of local communities in the management of these areas through community-led strategies can enhance safety for both people and wildlife, thereby promoting coexistence. To examine the effectiveness of community-led strategies for managing wildlife outside protected areas, we fit multi-season occupancy models on African elephant (*Loxodonta africana*) sightings data collected by volunteer Village Game Scouts (VGS) while on irregular and demand-driven patrols within Mwanga district in Northern Tanzania. Patrol data were processed using the Spatial Monitoring And Reporting Tool (SMART). We estimated elephant probability of occupancy, detection, colonization and extinction, identifying key elephant dispersal areas in the community-modified areas within the district. Our results indicate that proximity to Tsavo West National Park and the availability of seasonal water sources positively influenced the probability of elephant colonization. In contrast, the proportion of built-up and farmed areas, and distance to permanent water sources, negatively influenced the probability of colonization. The number of scout patrols did not significantly influence the probability of elephant colonization or extinction, and elephant occupancy remained relatively stable during the study period. Our study highlights the complementary role of non-protected areas in maintaining populations of endangered species such as elephants. We demonstrate that structured, volunteer community-led strategies coupled with effective communication with authorities, can be used to monitor wildlife spatial distribution and identify factors influencing their distribution in non-protected areas. We recommend community-led protection measures for corridors and dispersal areas, as well as transboundary collaboration to maintain landscape connectivity for endangered species such as elephants.

Introduction

Wildlife management and conservation have mostly concentrated resources in protected areas globally compared to non-protected areas, due to their economic value and because they are reservoirs of wildlife species (Fjeldså *et al.*, 2004; Naughton-Treves, Holland, & Brandon, 2005; Viña & Liu, 2017). However, in the recent past, protected areas have been threatened by poaching (Schulze *et al.*, 2018), land use changes (Hoffmann, 2022), human–wildlife conflicts and habitat fragmentation (Kiringe & Okello, 2007). On average, a 59% decline in wildlife population abundance has been recorded in Africa's protected areas (Craigie *et al.*, 2010; Robson *et al.*, 2022). As a result, unprotected areas have become instrumental in conserving wildlife populations, with some areas having similar wildlife densities and richness as the protected areas, and importantly as linkage zones between the protected areas (Kiffner *et al.*, 2020a,b; Crego *et al.*, 2021).

Surveillance and conservation efforts for wildlife in non-protected areas are typically less organized and financially supported compared to protected areas (Kideghesho *et al*., 2013; Hoffmann, 2022) often due to inappropriate management structures and lack of policies (Tyrrell, Toit, & Macdonald, 2020). Consequently, non-protected areas are often undervalued (Avigliano *et al*., 2019) and susceptible to conflicts and poaching (Okello *et al*., 2016). Given their location within community and private lands, there is often resistance to adopting conservation practices due to lack of incentives (Norton-Griffiths & Said, 2009). Further, studies have shown that increased human–wildlife conflicts negatively influence the perceptions of communities living adjacent to protected areas and areas harboring wildlife (Merkebu & Yazezew, 2021) threatening co-existence. However, communities that benefit directly from wildlife have demonstrated positive correlations with conservation practices (Williams *et al*., 2018a,b; Angwenyi, Potgieter, & Gambiza, 2021).

Ranger patrols effectiveness and efficiency have also traditionally focused on protected areas (Critchlow *et al*., 2017). Surprisingly, there has been few studies assessing the spatial distribution of wildlife in non-protected areas in relation to ranger patrol coverage, and even fewer attempts to optimize ranger patrol strategies if any, to target areas with a higher likelihood of illegal activities in these non-protected areas (Critchlow *et al*., 2017). This is of particular importance in areas where wildlife and human coexist, such as in Kenya and Tanzania. In Kenya, the conservancy model has been adopted, where community and privately owned lands are set up for wildlife to coexist with other uses (KWCA, 2016). This approach enables local communities to derive income from wildlife tourism while simultaneously managing their livestock herds on their lands. These unprotected areas account for 70% of the wildlife populations in Kenya (Western, Russell, & Cuthil, 2009). In Africa, such unprotected areas host 85% of the total potential range of African elephant, a species listed as endangered in the IUCN Red List (Wall *et al*., 2021; Gobush *et al*., 2022).

In Tanzania, unlike the conservancy model in Kenya, Wildlife Management Areas (WMAs) have been established as alternative conservation approach where local communities come together to protect wildlife and generate income from tourism-based activities and trophy hunting concessions. Mwanga District in Northern Tanzania has no WMA and therefore all wildlife is governed by the state through the Tanzania Wildlife Management Authority (TAWA) with no income generation from wildlife available for the communities. Consequently, the area often lacks adequate protection and government resources for human–wildlife conflict management despite being home to diverse wildlife species and populations throughout the year.

Since patrols conducted in a coordinated manner have proven to have impacts on minimizing threats to wildlife in protected areas (Moore *et al*., 2018; Gonedelé Bi *et al*., 2019; Kablan *et al*., 2019), it is possible that these unprotected areas could also benefit from coordinated protection efforts. Currently, these non-protected areas lack well-coordinated patrols and therefore are subject to more threats than protected areas (Gonedelé Bi *et al*., 2019) including habitat degradation and human–wildlife conflicts (especially during the dry season). Unprotected areas adjacent to protected areas are key in ensuring wildlife thrive in protected areas (Thirgood *et al*., 2004) and thus suggests the importance of implementing coordinated patrols in both protected and unprotected areas.

Non-protected areas in Tsavo-Mkomazi landscape act as habitat linkages and dispersal areas for the four protected areas (Tsavo West, Tsavo East, Chyulu and Mkomazi National Parks) constituting the larger Tsavo-Mkomazi landscape (Ojwang *et al*., 2017). Like other corridors and dispersal areas, these unprotected areas are affected by conflicts caused by incompatible land use practices, illegal hunting, habitat destruction and livestock incursions. To address these challenges, local communities in Mwanga District, Northern Tanzania came together to form the volunteer Village Game Scouts (VGS) who were tasked with countering and deterring conflicts while protecting wildlife in this otherwise unprotected corridor. African Wildlife Foundation (AWF) partnered with the district and village councils to train and equip the scouts to conduct foot, vehicle and motorbikes patrols, to manage conflicts and to record wildlife incidents. Here, we use 3 years of data (May 2019–May 2022) collected by volunteer Village Game Scouts (VGS) while on irregular and demand-driven patrols within Mwanga district to: (a) establish whether elephant occupancy and detection changed with improved interventions by the village game scouts, (b) pinpoint the key drivers of elephant occupancy in this community-dominated landscape and (c) identify key elephant hotspots. We predicted that elephant occupancy in a human-dominated landscape would be low near human settlements and higher near the protected areas, waterbodies and preferred forage influenced by seasons and availability (Martin *et al*., 2010; Jathanna *et al*., 2015; Anderson *et al*., 2016; Davis *et al*., 2023). We also predicted that elephant occupancy would be higher in areas that are highly patrolled because of improved security and as such occupancy will increase as patrols increase over time due to increase in safety (as observed by Kablan *et al*., 2019).

Materials and methods

Study area

This study was conducted in Mwanga district, Northern Tanzania, covering the four wards of Toloha, Kwakoa, Kigonigoni and Mgagao, for a total area of about 795 km^2. The wards lie between a wildlife dispersal area and corridors connecting Tarangire ecosystem and Mkomazi National Park in Tanzania, Tsavo West National Park in Kenya and Mkomazi in Tanzania (Fig. 1; MNRT, 2022). This area forms part of the eastern lowland side of the north Pare Mountains with an altitude range of about 500–700 m above sea level. The average rainfall is 700 mm per year split into two seasons with short rains occurring November–December and long rains May–July (Bagambilana & Rugumamu, 2019). Temperatures range between 14 and 30°C, with the coldest months in June–July and hottest in January (Bagambilana & Rugumamu, 2019).

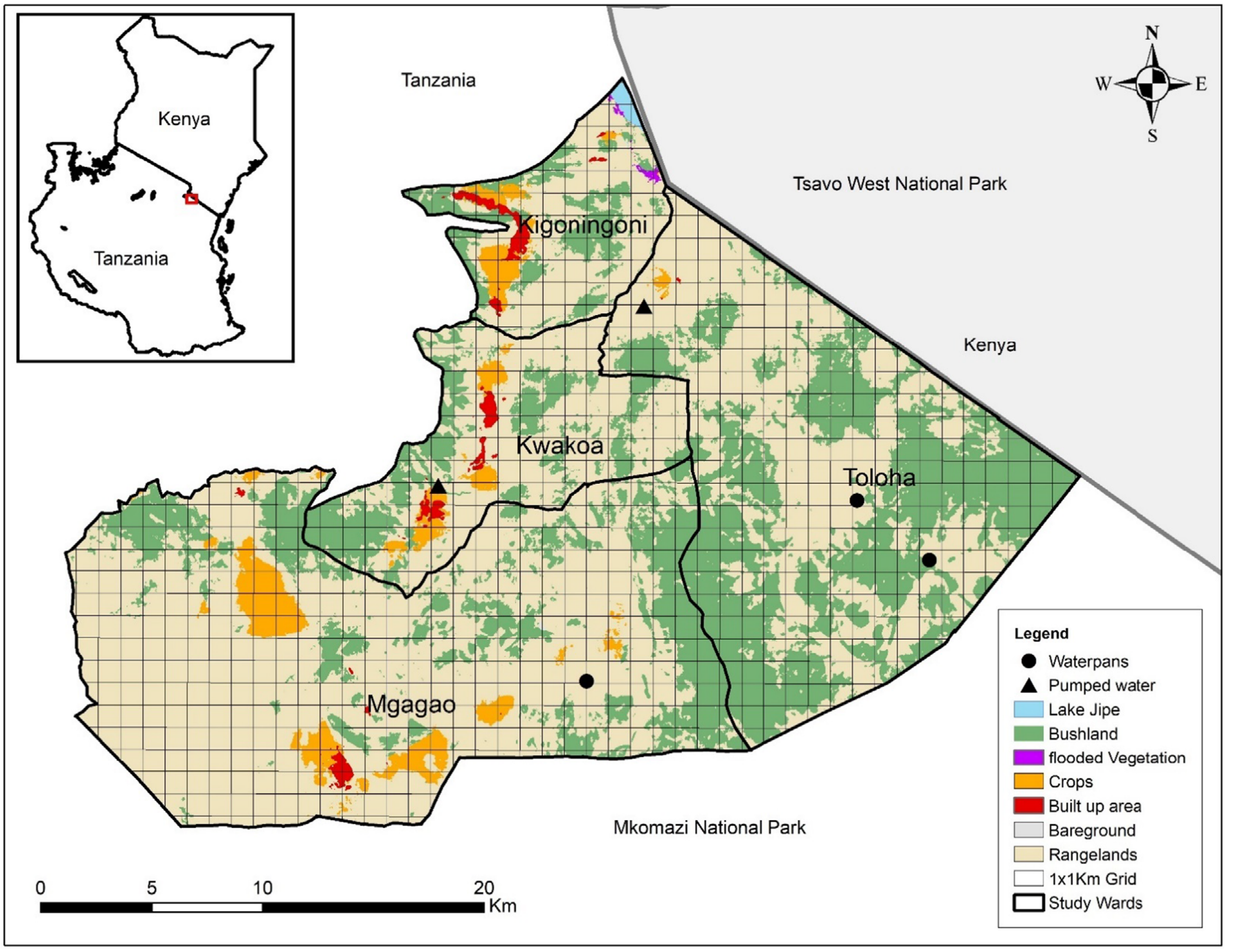

Figure 1 Study area showing 1x1 km grid (sites) with land use/land cover classified using Sentinel 2 image from 2021 and adjacent protected areas.

The area is inhabited by the Maasai and the Pare communities. Maasai are predominantly pastoralists while Pare communities are mixed farmers. Historically, the area has been home to a variety of species and populations. However, poaching, land degradation and livestock incursions led to the extinction of some species such as the black rhino and there was rampant elephant poaching in early and late 1980–1990s (Brockington & Homewood, 2001). Mkomazi National Reserve was gazetted in the early 1950s and upgraded to a National Park status in 2008. Part of Mwanga district was highlighted as a corridor connecting Tarangire and Mkomazi through Mgagao in 2021 (MNRT, 2022). However, Toloha corridor, which maintains part of the connectivity with Tsavo West National Park in Kenya has no legal framework or gazettement.

Methods

In 2019, 19 Village Game Scouts were selected by the four wards in Mwanga district Northern Tanzania to deter human–elephant conflict (HEC) and address illegal activities such as poaching and logging. With the guidance of the District Game Officer and Mwanga District Council, a six-member unit from each ward was formed considering age, gender and willingness to volunteer. The members were endorsed by the village councils and assemblies. The VGS underwent a 1-month induction training on patrolling, mitigating human–wildlife conflict, reporting and wildlife laws and policies in Tanzania. After the training, African Wildlife Foundation (AWF) trained the scouts for 2 weeks on data recording using the Cybertracker application (https://cybertracker.org/) and analysis was performed using the Spatial Monitoring And Reporting Tool (SMART 5.4 software https://smartconservationtools.org/).

Scouts were issued with mobile phones which contained a preconfigured data collection model for them to record their patrol routes, wildlife sightings (live and carcass), illegal human activity (poaching, snares and wood collection, among others) and human–wildlife conflict incidents (crop destruction, property damage, human attack, and livestock depredation). Later they were issued with uniforms and simple elephant deterrent tools (torches, fireworks and highpressure horns) to deter elephant conflicts. The VGS conducted irregular patrols and on request by the village council within the four wards from May 2019 to May 2022. All the patrols were conducted at irregular time intervals of the day and night when human–elephants conflicts occurred. The patrols were either conducted on foot, by vehicles (supported by the government authorities) or by motorbikes. All data from the patrols conducted were downloaded monthly from the mobile phones into the SMART database and cleaned.

Elephant data analysis

Elephant presence data were obtained from the SMART database (direct elephant observations only; indirect sightings were not recorded). The data were collected from May 2019 to May 2022 in the unprotected area of Mwanga district between Tsavo West National Park in Kenya and Mkomazi National Park in Tanzania (Fig. 1). The data were fit to multi-season occupancy models to estimate elephant occupancy, probability of colonization and extinction and probability of detection over 3 years. Occupancy models use spatially or temporally replicated detection/non-detection surveys (i.e. sampling occasions) to estimate the probability of detecting a species (P) and derive unbiased probabilities of sites being occupied or used by the species (ψ) while explicitly accounting for imperfect detection (MacKenzie *et al.*, 2005). Since multi-season occupancy models require detection/non-detection data on the species of interest at a set of sites that are visited multiple times each season, years were classified as seasons or primary occasions, while each scout patrol was classified as a secondary occasion.

Since we did not have set study sites, we divided the study area into 1 km^2 grid cells and assigned each grid cell a unique code in ArcGIS 10.5, resulting in 891 sites in the entire study area (Fig. 1), herein referred to as 'sites'. The size of the grids was selected to allow conclusions based on our covariates and to be large enough for sufficient elephant detections and scout patrols to allow model convergence. For each site, we determined the number of times each site was visited by VGS patrols each season (i.e. year). As the number of patrols conducted each year varied across sites, the number of secondary occasions per site was the highest number of patrols to any one site in each year. If a particular site was visited less than this number, all the remaining occasions were assigned a NA, or missing data. During each of the VGS patrols, the detection history was 1 if elephants were detected in that site during the patrol, or a 0 if elephants were not detected. To avoid violating the closure assumption of occupancy modeling (MacKenzie *et al.*, 2005; Rota *et al.*, 2009), we assumed that elephants would use sites randomly within each year rather than persistent occupation throughout the year. To avoid temporal autocorrelation, we used VGS patrols as secondary occasions rather than summarizing data in months or seasons as secondary occasions. Models were run in program MARK (White & Burnham, 1999) using the *RMark* package version 2.2.0 (Laake, 2013) in the R computing environment version 4.3.1 (R Development Core Team, 2015).

Covariates

We described probability of colonization and extinction as changes in 'site use' rather than occupancy, and we selected covariates that determine probability of site use by elephants for the period between May 2019 and May 2022. This approach has been used before (Anderson *et al.*, 2016; Davis *et al.*, 2023) to estimate occupancy in savannah habitats and areas where habitat use is influenced by human activity. We therefore included covariates in the model that determine elephant detection, occupancy (site use), colonization and extinction in the unprotected areas and human-modified landscape. The covariates included (range in meters between the sighting and the covariate) distance to protected areas: Tsavo West National Park (57–35 833 m), and Mkomazi National Park (32–25 393 m), which have shown correlation with elephant occupancy (Davis *et al.*, 2023). We separated the two distances to identify the core area of the elephants between the two parks. We also included distance to permanent water sources (Boreholes) (58–20 817 m), distance to seasonal water sources (dams and water pans) (18–23 768 m), which previous studies have shown to correlate with African elephant distribution (Moses *et al.*, 2015; Madsen & Broekhuis, 2020; Kirathe *et al.*, 2021), and based on the ecological demands of elephants (Martin *et al.*, 2010; Jathanna *et al.*, 2015). Water points data were recorded from the watering points using a GPS Garmin Etrex 10. Euclidean distance was calculated using the 'near' tool and 'zonal' statistics in ArcGIS 10.5.

We evaluated whether land use and land cover types affected the probability of occupancy, colonization and extinction in this community-modified area. Land use types included: proportions of rangelands (open grasslands with scattered trees), flooded vegetation (swampy vegetation adjacent to Lake Jipe), open water (primarily Lake Jipe), bare ground (because of overgrazing), bushland while land use included crops/agricultural areas and built-up areas in each site. These covariates have been shown to be correlated with elephant occupancy and the probability of site use (Anderson *et al.*, 2016; Madsen & Broekhuis, 2020). Land use/land cover data were obtained from the Sentinel 2 10 m resolution land cover image from 2021 (Karra *et al.*, 2021), downloaded from (Sentinel-2 Land Use/Land Cover Downloader arcgis.com) and processed using ArcGIS 10.5. The image was chosen due to the high-level accuracy and K coefficient (Nasiri *et al.*, 2022).

Although types of patrols (foot, vehicle and motorbike) could influence detection, we did not include them in our occupancy analysis as the patrols were dynamic and some were reactive (responding to reported elephants). Additionally, the patrol objectives changed based on demand. For example, a surveillance foot patrol might change to HEC management vehicle patrol halfway, making it difficult to account for the detection of elephants based on patrol type. However, number of patrols and all other covariates were included in the probability of colonization and extinction. Detection models included site area with most of the sites = 1 km^2 (but sites on the boundary could be smaller than

1 km^2), number of patrols, and year since we predicted detection probability would vary between years due to habitat conversions and temporal resource variation (Williams *et al.*, 2018a,b) as well as security improvements.

Models were built using different combinations of the covariates across the four parameters of interest, namely: occupancy, colonization, extinction and detection. We tested all possible combinations of singular covariates for each parameter and compared using Akaike information criterion (AICc) corrected for small sample size (Burnham & Anderson, 2004). We did not include multiple covariates per parameter (except year and area on detection) to avoid collinearity and overparameterization. To evaluate the influence of a particular covariate on the model parameters, we checked if the 95% confidence interval (95% CI) for the regression coefficient (β parameter) included zero using the top model including each covariate. Additionally, using the most parsimonious model, we predicted occupancy and developed a probability distribution map, showing the predicted occupancy for each site for each year of the study. This is inferred as the probable distribution of elephants across the study area.

Results

During the study period, scouts conducted 1433 patrols across 610 sites: 126 patrols by foot, 293 vehicle patrols and 1085 patrols using motorbikes. In total, 37 805 km within the four wards were patrolled. The maximum number of patrols per site in any 1 year was 372, while the minimum was 79. The total number of patrols declined over the years of the study. One thousand, one hundred and fifty-four (1154) elephant sightings were made in 211 sites.

Effects of covariates

Overall, we were interested in management actions that can be implemented for protecting elephants and the effect of these covariates on the probability of occupancy, colonization and extinction even if the covariates were not included in the most parsimonious model. These relationships can provide insight into where elephants are most likely to be distributed throughout the landscape, as well as important habitat or landscape features that could influence elephant occupancy, colonization or extinction. One of the key parameters we were interested is the voluntary patrols conducted by the VGS in the district. Although the patrols were meant to control human–elephant conflict (HEC), these patrols did not have significant influence on probability of colonization (β = 0.001, SE = 0.25) or the probability of extinction (β = 0.39, SE = 0.25) and were not included in the top models (i.e. $AIC_c < 5$).

The two most parsimonious models ($AIC_c < 2$) included distance to Tsavo West National Park on occupancy and colonization, proportion of built-up areas on extinction, and site area and year on detection probability (Table 1). Sites that fell on the boundary of the study area and were smaller in size (<1 km^2) recorded lower detections while detection was highest in the larger sites (=1 km^2), and changed over the years with the lowest detection of 0.062 in 2020 (SE: 0.004) and the highest detection of 0.075 (SE: 0.004) in 2021.

Table 1 Top-ranked models used to assess probabilities of elephant detection and site use: Model comparison statistics for multi-season occupancy models testing for covariate effects on elephant occupancy, probability of extinction (ϵi), probability of colonization (γi) and detection probability (P)

Models	npar	AIC_c	ΔAIC_c	Weight
ψ (Tsavo west) ϵi (built-up) γi (Tsavowest) P (year+area)	11	9675.12	0.00	0.38
ψ (Tsavo west) ϵi (built-up) γi (TsavoWest) P (area)	8	9675.82	0.69	0.27
ψ (Tsavo west) ϵi (built-up) γi (TsavoWest) P (year)	10	9678.06	2.94	0.08
ψ (Tsavo west) ϵi (built-up) γi (TsavoWest) P (1)	7	9679.12	4.00	0.05
ψ (Tsavo west) ϵi (built-up) γi (seasonal water) P (year+area)	11	9680.09	4.97	0.03

Model structure, npar (number of parameters). AIC_c, Akaike Information Criterion corrected for small sample size; ΔAIC_c, difference in AICc between top model and a selected model; and model weight (evidence given by the model compared to full model set) are also given. Models with $\Delta AIC_c < 5$ are presented. Covariates are: Proximity to Tsavo West National Park (Tsavo west); proximity to seasonal (seasonal water); proportion of built up areas (built-up); size of the site (area); year.

Distance to protected areas

The probability of occupancy decreased significantly with the increasing distance from Tsavo West National Park (β = −1.43, SE: 0.218) Fig. 2. We found a significant relationship with the probability of site colonization increasing closer to Tsavo West National Park (β = −0.674, SE: 0.218, Fig. 3). Additionally, the probability of extinction increased further from Tsavo West National Park (β = 1.124, SE: 0.325, Fig. 4). There were no significant relationships between any of the parameters and the distance to Mkomazi National Park.

Land use and land cover types

Probability of extinction significantly increased with increasing proportion of built-up areas in the sites (β = 28.81, SE = 13.93) while probability of occupancy decreased significantly with an increase in the proportion of built-up areas (β = −1.44, SE = 0.22; Fig. 5). Similarly, probability of extinction increased significantly with an increase in the proportion of crops per site (β = 42.00, SE = 15.16; Fig. 6). All other relationships between land use and land cover types and occupancy parameters were not significant. Since we were also interested in identifying whether elephants share the grazing fields with livestock, we checked whether rangelands had significance in the models although not included in the most parsimonious model. Our results showed that probability of extinction increased

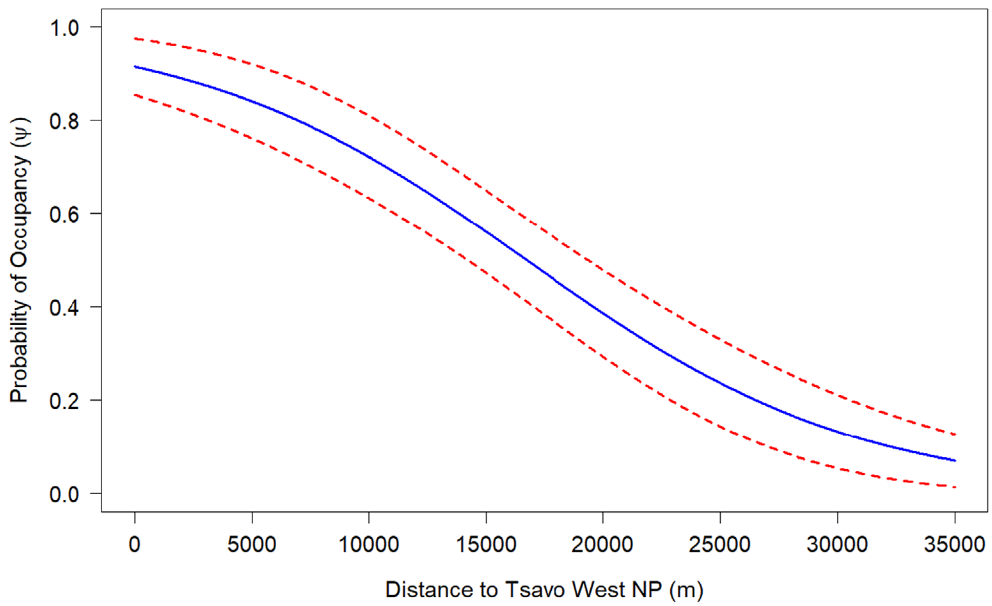

Figure 2 Probability of occupancy with distance from Tsavo West National Park.

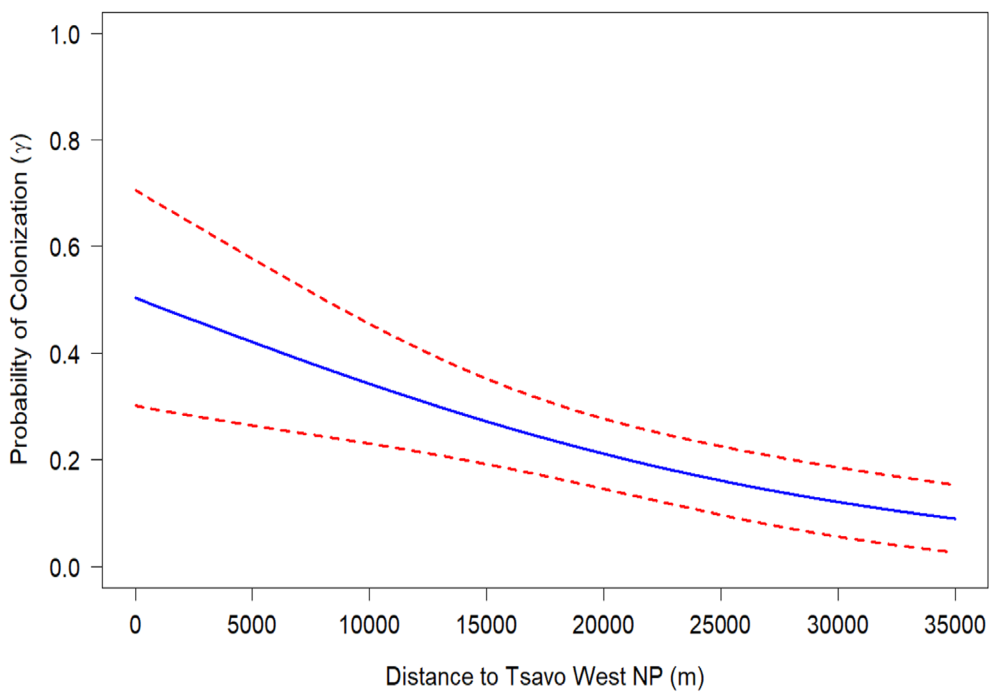

Figure 3 Probability of colonization against distance to Tsavo West National Park.

significantly with increased proportions of rangelands per site ($\beta = -1.32$, SE = 0.59).

Distance to water sources

Although not included in the most parsimonious model, distance to seasonal water sources (dams and water pans) was significant for both probability of colonization and extinction, with the probability of colonization increasing closer to seasonal water sources ($\beta = -0.62$, SE = 0.25), and the probability of extinction decreasing closer to seasonal water sources ($\beta = 0.603$, SE = 0.23; Figs 7 and 8). In contrast, distance to permanent water sources (pumped water and boreholes) was not significant for either probability of colonization ($\beta = -0.45$, SE = 0.25) or probability of extinction ($\beta = -0.14$, SE = 0.19).

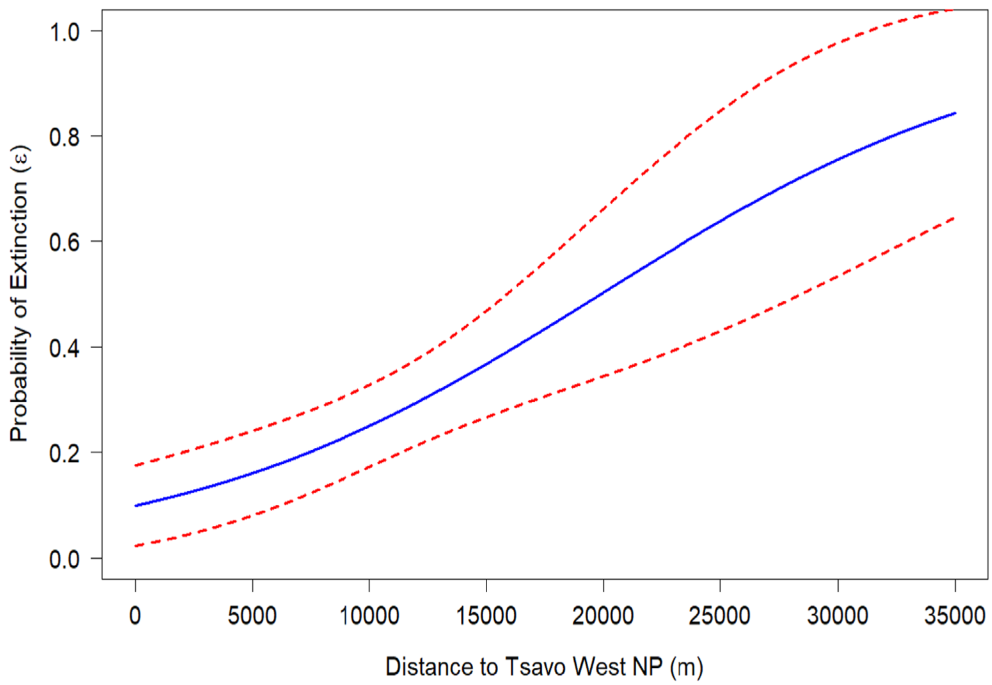

Figure 4 Probability of extinction against distance from Tsavo West National Park.

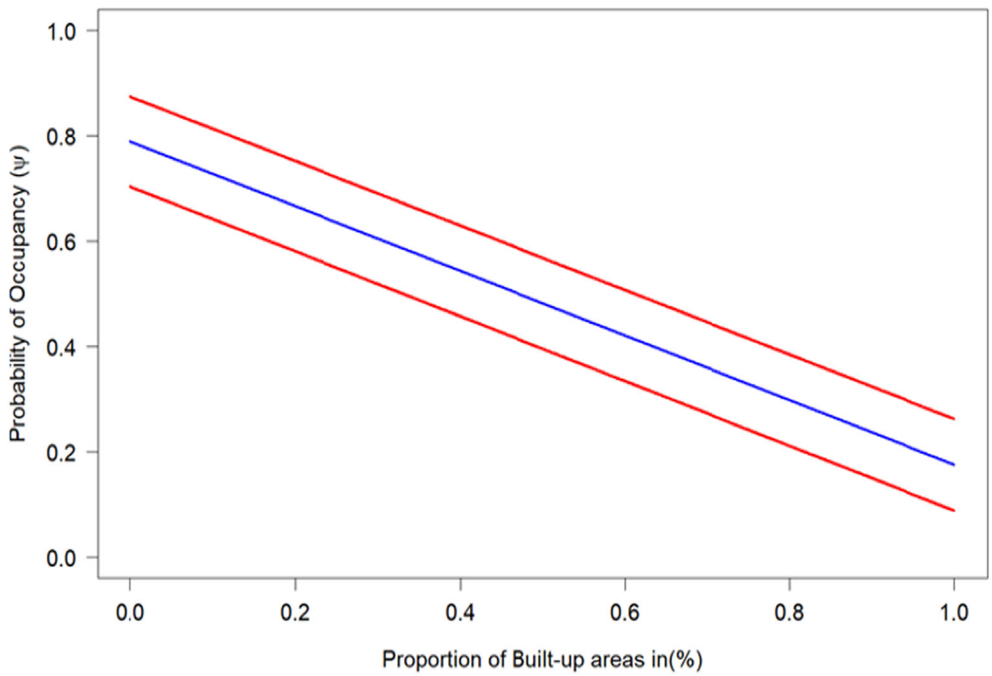

Figure 5 Probability of occupancy against proportion of built-up areas per site.

Elephant distribution

Overall, elephants were detected in 211 sites (34.59% of the total patrolled sites) between May 2019 and May 2022. Areas with the highest probability of occupancy included sites in the north-east near the boundary to Tsavo West National Park, and near watering points. The probability of detection decreased from 2019 to 2022 (0.072–0.069), and the probability of occupancy decreased from 0.54 (SE: 0.04) in 2019 down to 0.48 (SE: 0.04) in 2022. The distribution of

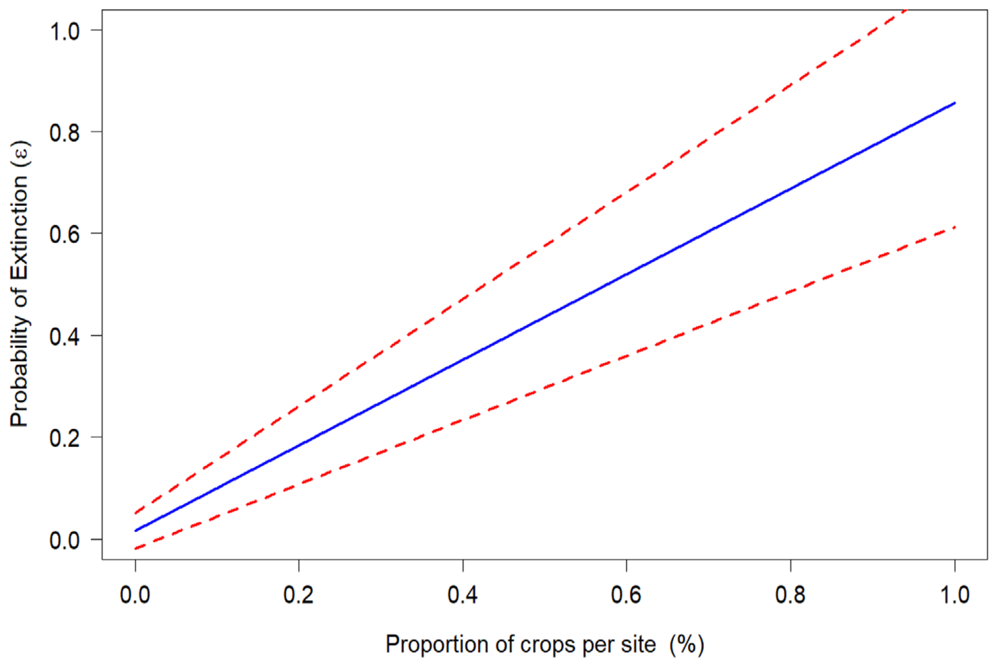

Figure 6 Probability of extinction against proportion of crops per site.

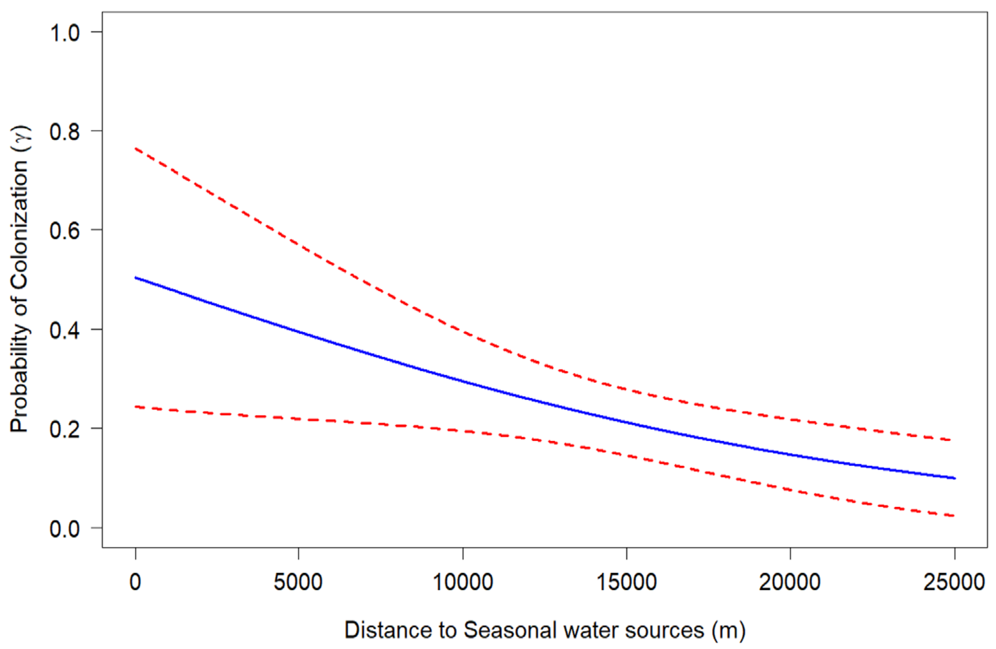

Figure 7 Probability of colonization against the distance to seasonal water based on the top-ranked model from the candidate model set.

elephant shifted slightly away from Tsavo West National Park during this time (Figs 9 and 10).

Discussion

Using a volunteer Village Game Scout (VGS) patrol-based monitoring system – developed by local communities, supported by the government authorities, local authorities, and African Wildlife Foundation (AWF) – with a dynamic occupancy modeling framework, we quantified the probability of elephant occupancy, colonization and extinction as proxies for site use and examined the drivers of elephant distribution in this unprotected and community-modified landscape. This modeling framework directly accounts for

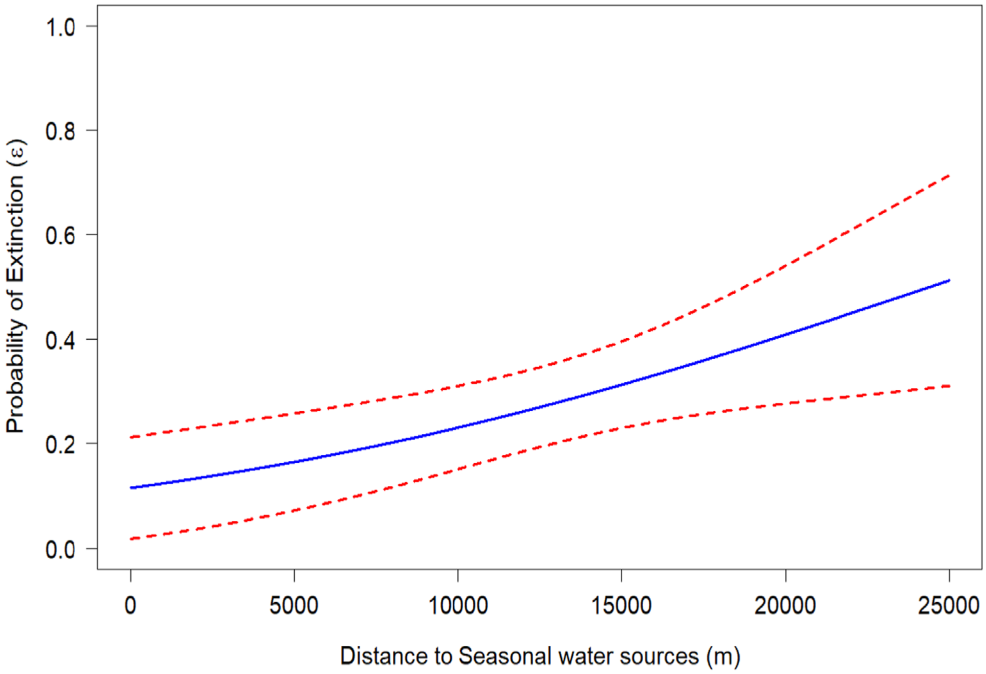

Figure 8 Probability of extinction against seasonal water sources based on the top-ranked model from the candidate model set.

imperfect detection of elephants. This study has shown how local communities in an unprotected and community-dominated landscapes with no legal wildlife framework can complement authorities' efforts in monitoring, protecting and maintaining populations of elephants while managing conflicts and identifying key elephant hotspots.

Elephants occupied sites near Tsavo West National Park with occupancy increasing closer to the park but varying slightly across years. In 2019, high occupancy levels (>0.74) were observed in sites near the park boundary. However, occupancy decreased to <0.65 by 2022 when elephants were spread further from the park into the community lands. Overall, 34.59% of the sites patrolled were occupied by the elephants. Proximity to Tsavo West National Park appears to be a crucial factor, likely due to the lower levels of human activity in this area. This relationship is further supported by the increasing probability of colonization closer to the park and the decreasing probability of extinction.

Elephants generally avoided sites with large proportion of built-up areas and croplands. These findings agree with previous studies (Jathanna *et al.*, 2015; Green *et al.*, 2018; Madsen & Broekhuis, 2020; Davis *et al.*, 2023), who indicated that elephants tend to avoid areas dominated by human activities. This underscores the importance of protected areas in maintaining elephant populations and serving as reservoirs for endangered species. However, it is crucial to implement equitable measures and transboundary collaborations to protect elephants both inside and outside protected areas, given that these elephants originate from Kenya's protected areas.

Habitat and protected area connectivity loss are key challenges affecting wildlife specifically in Tanzania (MNRT, 2022). In addition, the conversion of corridors to agricultural farms and lack of legal protection significantly affects habitat connectivity zones (Sawyer, Epps, & Brashares, 2011; Bond *et al.*, 2017; Crego *et al.*, 2021; Riggio *et al.*, 2022). Factors influencing species occupancy in these unprotected areas remain less understood and investigated leading to lack of structured conservation initiatives. In this study, we have identified land use (agriculture and settlement) as a key deterrent to elephant colonization given the negative relationship with increasing proportion of agriculture and built-up areas. To effectively manage the area, spatial planning is required to ensure that agriculture does not extend to elephant-dominated areas and where they are likely to occur. Gazettement and institutionalization of the corridor as a Wildlife Management Area (WMA) could potentially allow local communities to derive benefits from wildlife through tourism while maintaining transboundary connectivity. This approach has demonstrated effectiveness in Tanzania (Kiffner *et al.*, 2020a,b).

Studies have shown that water availability can significantly influence the occupancy and colonization patterns of elephants, as they are water dependent (Jathanna *et al.*, 2015; Green *et al.*, 2018; Amorntiyangkul *et al.*, 2022). The presence of seasonal water sources such as dams and water pans in community areas significantly increased probability of colonization and extinction. This variability was attributed to the availability of water in these temporal sources, highlighting the importance of unprotected areas in providing water seasonally. During the study period, drought conditions were experienced in the years 2021 and 2022 (Mwiu *et al.*, 2022), which likely underscored the significance of seasonal water sources during this period.

Permanent water sources, on the other hand, had no significant influence on model parameters. This is probably because the permanent water sources are close to built-up

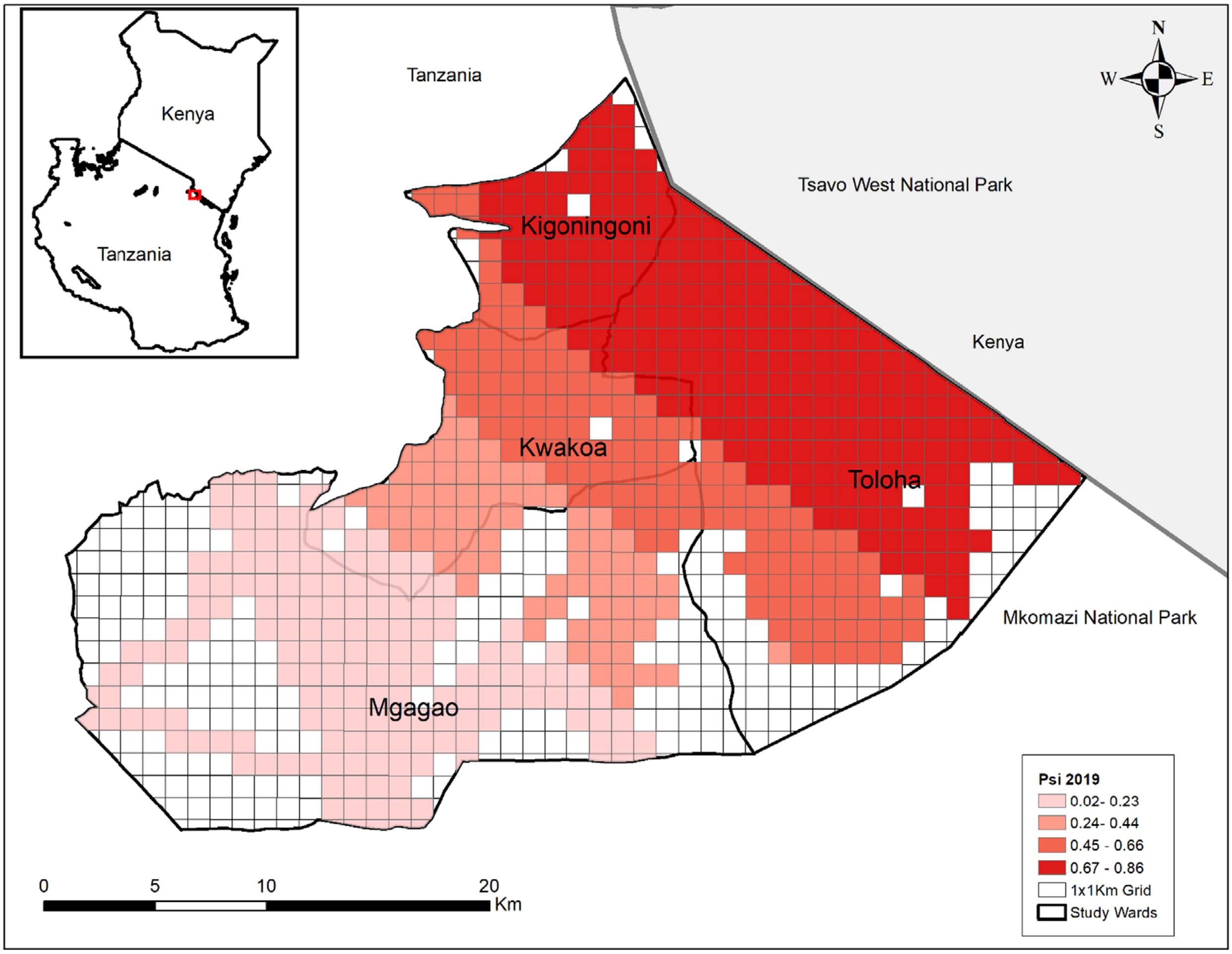

Figure 9 Probability of elephant's occupancy in 2019.

areas, where the probability of extinction was high. Water is a scarce resource in the landscape, and the provision of water in both protected areas and adjacent unprotected areas, where elephants are prevalent, could potentially limit elephant movements into community-dominated landscapes, thus reducing conflicts, especially during periods of drought.

Although bushlands and rangelands adjacent to community farms had no significant influence on model parameters based on the most parsimonious models, they were important dispersal areas for elephants as they accessed resources as shown by Figs 9 and 10. Furthermore, such habitats near protected areas have functioned as buffer zones (Kiffner *et al.*, 2020a,b) between local communities and wildlife (Green *et al.*, 2018), and a preference for such habitats has been documented in Sundaic elephants (de la Torre *et al.*, 2022). Similarly, the proportions of such habitats have been positively correlated with elephant occupancy (Moses *et al.*, 2015; Okello *et al.*, 2016; Tripathy *et al.*, 2021). Given the high level of elephant occupancy in these areas, measures such as providing water and other resources and including them in spatial plans can help mitigate conflicts with communities in built-up areas and farms. Additionally, efforts to protect farmers should be strengthened to ensure sustainable coexistence between farmers and wildlife, particularly during cultivation periods.

Finally, we examined the impact of patrols conducted by the VGS as they can provide valuable insights for management and scientific understanding of elephant distribution. Though the number of scout patrols did not significantly affect the probability of colonization ($\beta = 0.001$, SE = 0.25) and probability of extinction ($\beta = 0.39$, SE = 0.25), sites that had a higher number of patrols over the years had probabilities of elephant colonization and extinction of 21 and 27%, respectively. High probability of extinction was recorded in the sites with a large proportion of built-up areas where patrols were also prominent as one of the main tasks for the scouts was to manage human–elephant conflicts in these community-dominated habitats. Although these findings do not agree with others who conducted their studies in protected areas (e.g. Goswami *et al.*, 2014; Moore *et al.*, 2018; Amorntiyangkul *et al.*, 2022), it is evident that volunteer VGS patrols can effectively be used to detect the occurrence and distribution of elephant populations in unprotected areas, thereby reducing human–wildlife conflicts in the community-

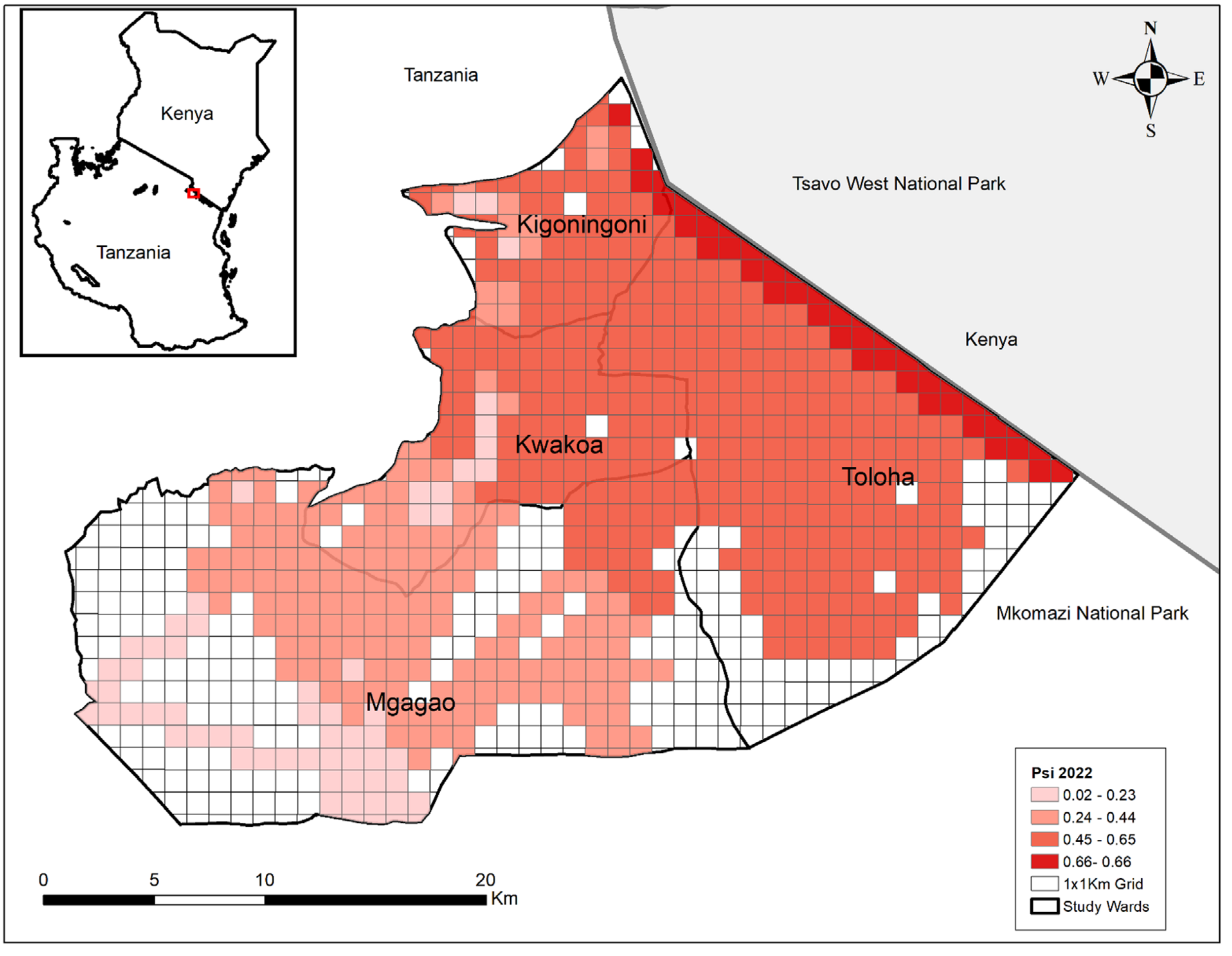

Figure 10 Probability of elephant's occupancy in 2022.

dominated areas. This highlights the potential of volunteer community patrols as a proxy for maintaining the safety of elephant populations and people in community-dominated landscapes.

Conclusion

Our study highlights the complementary role of non-protected areas and local communities in maintaining populations of endangered species such as African elephants. Elephant site use in community-modified habitats was influenced by water and proximity to protected areas. Spatial planning and providing essential resources such as water near protected areas can help mitigate human–elephant conflicts by serving as buffer zones and sources of necessary resources, thereby potentially reducing elephants' dispersal to community-dominated areas. Additionally, the gazettement of the corridor and establishment of a Wildlife Management Area (WMA), could potentially contribute to conflict reduction and enhance community benefits from tourism and other compatible uses in the area. However, transboundary collaboration will be crucial, as Tsavo West National Park in Kenya appears to be a core area for elephants. We demonstrate that structured volunteer-led community strategies, coupled with effective communication with authorities, can effectively detect wildlife spatial distribution and identify factors influencing their distribution. Therefore, community-led conservation strategies are essential in wildlife management outside protected areas. Finally, our results indicate that organized community strategies can complement authorities' efforts to manage wildlife outside protected areas while providing proactive responses to conflict management in community-dominated landscapes. However, it is essential to recognize that community involvement, awareness and participation are critical for ensuring the sustainability of community-led strategies, particularly in areas with low wildlife economic gain.

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Author contributions

ACM and JFM conceived the idea and designed the methodology. ACM designed the data collection model and trained the scouts, conducted: data collection, data curation, data analysis, methodology, writing – original draft, writing – review and editing; JFM: Developed R code, conducted data analysis, writing – review and editing. KKK: Administration of the project in Tanzania, training of scouts and writing – review, PMM: project administration in Tanzania, writing – review and editing. All authors contributed to the draft and gave final approval for publication.

Conflict of interest

All the authors declare no competing interests or financial interest to this paper.

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