Factors affecting detection probability of elephant *(Loxodonta africana)* carcasses in an African conservation area

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ABSTRACT

Poaching for ivory has led to massive population declines of African savannah elephants *(Loxodonta africana)*. To prioritize anti-poaching efforts, elephant poaching hotspot maps were created. However, these might be biased because they are not corrected for the detection probability of elephant carcasses. Carcass decomposition state was defined as a proxy for detection probability. Detection probability was influenced by the Normalized Difference Vegetation Index (NDVI) influencing live elephant densities across the area. Our results show the importance of accounting for detection probability to achieve true estimates when predicting poaching risk to successfully direct anti-poaching efforts in African conservation areas.

Keywords

Detection probability, Loxodonta africana, Hotspot maps, Anti-Poaching efforts

INTRODUCTION

By providing protection, conservation areas function as an important refuge for many endangered wildlife species, including megaherbivores such as the African savannah elephant *(Loxodonta africana)*. An estimated 84% of savannah elephants occur in protected areas (Schlossberg et al., 2016). By engineering the physical environment and playing various roles in the ecosystems they occupy, elephants are an important key species (Maingi et al., 2012). However, illegal activities such as poaching threaten the existence of elephants (Lockwood et al., 2006). In the past, poaching for ivory has led to massive population declines of elephants (Maingi et al., 2012). The enforcement of law and legislation in the field is challenged by extensive area sizes and limited financial and human resources (Maingi et al., 2012). To prioritize anti-poaching efforts, elephant poaching hotspot maps were created which give insight into the areas where elephant poaching occurs most (Beale et al., 2018; Maingi et al., 2012; Rashidi et al., 2016). By modelling elephant carcass density and distribution, they identify biophysical factors that influence the risk of poaching. However, in less than 25% of the ecological papers, researchers account for detection probability, although it is rarely perfect nor constant (Kellner et al., 2014). The failure of accounting for the differences in detection probability of elephant carcasses might have a great impact on the perceived distribution of poaching hotspots (Moore et al., 2018). Variation in detection probability can be caused by site-specific characteristics, such as the biophysical factors. Besides site-specific characteristics, species- and carcass-specific characteristics influence detection probability (Field et al., 2005; Mackenzie et al., 2002; Schlossberg et al., 2016).

The aim of this study was to gain insight into the site-specific characteristics that influence the detection probability of elephant carcasses. It can therefore be of use to provide information on which site-specific characteristics influence the detection probability of elephant carcasses and may help when assessing the landscape of a conservation area.

Vegetation is one of the most prominent habitat characteristics and Bukombe et al. (2016) confirm, that vegetation growth influences visibility of carcasses. We hypothesized that closed landcover types such as forests as well as dense vegetation resulting in a high Normalized Difference Vegetation Index (NDVI), lead to a reduced visibility and would therefore decrease detection probability of elephant carcasses (Bukombe et al., 2016).

MATERIAL AND METHODS

Study Area

We studied the detection probability of elephant carcasses in the Tsavo East National Park (TENP; 13 700km^2) and the adjacent, privately owned Taita Ranches (5 800km^2) (figure 1). The National Park located in the south-east of Kenya is managed by the Kenya Wildlife Services (KWS). The Taita Ranches consist of farms, ranches and estates that are used for farming, wildlife conservation and tourism (Kenya Wildlife Services, 2017a). The total number of reported elephant deaths between 2011 and 2017 was 227 individuals, 93% of which due to poaching (Kenya Wildlife Services, 2019).

The majority of the area is covered by savannah with varying densities of trees and shrubs. The plant communities are dominated by *Commiphora* and *Acacia* species (Gillson, 2004; Ngene et al., 2017).

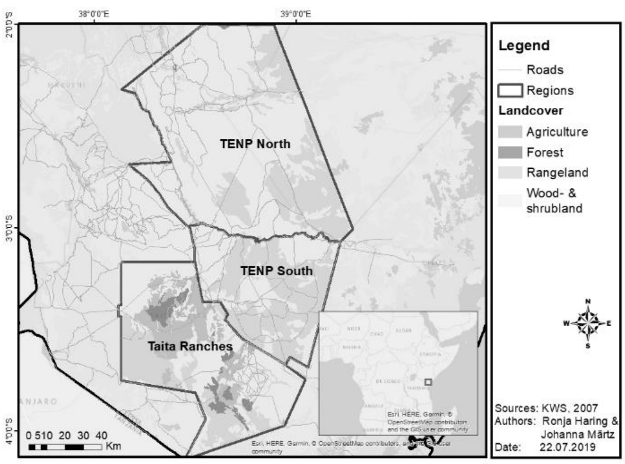

Figure 1 Location of the study area in south-east Kenya.

Data collection

Data on elephant mortality was recorded by anti-poaching patrols active in the study area. When a carcass was detected, the individuals' details such as location, carcass decomposition state and life stage were noted.

The time that has elapsed since an elephants' death is indicated by the state of decomposition of the carcass (Coe, 1978) and can be taken as a proxy for detection probability (Ferreira et al., 2015).

Carcass state was re-classified into two classes: fresh (=<4 weeks) and not fresh (>4 weeks), based on the decomposition process of elephant carcasses (Craig, 2012). In the first four weeks after death carcasses are most likely to be detected, because the carcass still has flesh, a rounded appearance and is intact for the most part (Craig, 2012). During this stage, signs of scavengers (hyena tracks, flying or resting aggregations of vultures), odors and visibility of the relatively large and intact carcass indicate its location to rangers (Coe, 1978; Ferreira et al., 2015). When a carcass is not detected by patrols within four weeks, it is likely that biophysical factors have reduced the detection probability (Ferreira et al., 2015).

Carcass-specific characteristics, such as carcass location and life stage, were extracted from the data set on elephant mortality (Kenya Wildlife Services, 2019). Life stage was taken as an indicator for body size. Jachmann (2002) has demonstrated that body size has an influence on the visibility by observers. Older elephants are likely to be larger and are accordingly more visible to patrols. The increased visibility might increase detection probability.

For generalization, classes were used for all cases. The life stages of an elephant had been classified into juvenile (0<5 years), sub-adult (5-20 years), which were added together into the class "immature" and adult (>20 years), which was categorized as "mature" (Lee et al., 1995).

Elephant density as a species-specific characteristic was obtained from Ngene et al (2017), who described the three main areas as shown in figure 1 for aerial elephant counts and provided elephant densities per area every three years (2011, 2014, 2017). Live elephant density is dependent on forage and water availability (Wato et al., 2016) and therefore influenced by site-specific characteristics. We hypothesize a positive relation between elephant density and the detection of elephant carcasses (Maingi et al., 2012).

Biophysical factors such as land coverage and the NDVI value were extracted for the location of each carcass using ArcGIS (ESRI, 2019; Kenya Wildlife Services, 2017a). The map of the average NDVI we used, had been generated from monthly images of the years between 1999 and 2001 to correct for variability in time. Due to the resolution of the raster (8x8km) and the averaging process, it was assumed that there was no noticeable change in average NDVI to the present. Because of low numbers in the land coverage classes agriculture and forest, they were reclassified to rangeland and wood-/shrubland respectively.

Data analysis

We tested (explanatory) variables for outliers, normality, multicollinearity and homoscedasticity according to the protocol of Zuur et al. (2009). If correction for outliers was necessary or explanatory variables were skewed, variables were either square root transformed, or the logarithm was taken.

To test for the correlation between carcass state (dependent variable; binary) and site-specific characteristics, a Generalized Linear Model (GzLM) with binomial distribution was fitted in R (R Core Team, 2019) using the *lme4* package (Bates et al., 2015). Carcass- and species-specific characteristics, including carcass size and elephant density, were included as control variables to be able to account for their influence on the variation in detection probability. NDVI also functions as an indicator for available elephant forage and can influence elephant densities (Duffy et al., 2012), therefore the interaction between elephant density and NDVI was included.

To achieve convergence in the model and overcome scale problems between variables, continuous, explanatory variables were standardized by scaling. The variables were scaled by first subtracting the mean of the variable and afterwards dividing the centered values by their standard deviation (Zuur et al., 2009).

To model the probability of two possible outcomes (fresh/not fresh), a binomial distribution with N=1 was selected.

Preselection of variables was carried out to construct a global model. The procedure is based on univariable analysis in which each explanatory variable is analyzed separately to determine its effect on the dependent variable (Bendel et al., 1977). Variables which were not strongly correlated with the dependent variable ($p>0.25$), were excluded from further analysis (Bendel et al., 1977).

According to the protocol of Zuur et al. (2009), the "drop 1" command was applied, excluding the variables from the global model in turns. Each time the difference in deviance was calculated and the difference compared to a Chi-square distribution. If the variable contributed to the model and the difference showed to be significant ($p<0.05$), the variable was kept within the model. In case the difference did not improve the model significantly, the variable was removed, and the procedure repeated, eventually resulting in the optimal model. Model validation showed that no dependence of covariates was observed, neither was spatial or temporal correlation. The Cooks distance of the data points stayed below >0.2, consequently the threshold of >1 was not exceeded and none of the data points was considered as influential (Zuur et al., 2009).

RESULTS

In total we analyzed 227 carcasses from the years 2011 to 2017 found in the TENP North and - South as well as the Taita Ranches, from which 20 were classified as "not fresh" and 207 as "fresh".

Carcass state of decomposition as a proxy for detection probability of elephant carcasses was best explained by live elephant density (1.07±0.37 ($\bar{X}$±SE), $p=0.004$, $df=1$) and

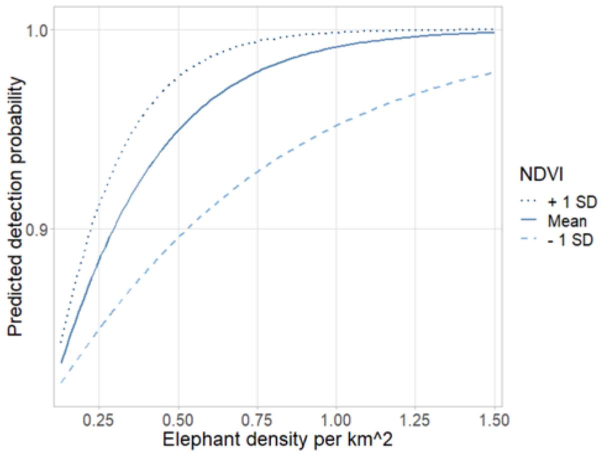

Figure 2 The predicted detection probability of elephant carcasses for the interaction between elephant density (km²) and the NDVI.

NDVI (0.79±0.32 (X±SE), p=0.012, df=1) as well as their interaction (0.55±0.25 (X±SE), p=0.029, df=1; figure 2) (AIC=130.84, df=223, pseudo R^2=0.0925).
Elephant density was at a mean of 0.17±0.03 ($\bar{x}$±SD) elephants/km^2 in TENP North and 0.33±0.10 ($\bar{x}$±SD) in the Taita Ranches. With a mean of 1.28±0.20 ($\bar{x}$±SD) the highest density of elephants could be found in TENP South. Although elephant densities varied across regions and between years (range: 0.13 individuals/km^2 TENP North 2014 to 1.50 individuals/km^2 TENP South 2017), the order of regions from highest to lowest density remained constant. Mean NDVI at carcass locations was 339.24±60.18 ($\bar{x}$±SD) (range: 176.58-535.88).

DISCUSSION

When using the state of decomposition of carcasses as a proxy for carcass detection probability, elephant density had a positive influence on the detection probability. This corroborates with Wato et al. (2016) who described that elephant mortality increases with elephant density. Additionally, poaching contributes to elephant mortality in high elephant density areas, because poachers target these areas to achieve the maximum harvest for their labor (Maingi et al., 2012). Elephant carcasses furthermore tend to aggregate spatially (Beale et al., 2018) if elephants died due to draught (Wato et al., 2016) or poaching (Maingi et al., 2012), which represent the major causes of mortality. Consequently, carcasses are located in proximity to each other and would be more numerous when elephant density increases. Aggregations of animals are easier to detect than individuals (Jachmann, 2002). The same applies to carcasses, in which aggregations are more easily detected by observers. Moreover, if one carcass is detected then most likely carcasses in its proximity are detected, because the detection of a carcass leads to a temporary increase of search effort in its immediate surrounding (KWS Ranger, 2019, Personal Communication). Detection probability thus increases with carcass density and aggregations that indirectly result from high elephant densities.
Besides elephant density, the NDVI influenced detection probability. Contrarily to our hypothesis, the likelihood of detecting a carcass increased with an increase in NDVI. Although studies have related NDVI to landcover type, vegetation condition, -biomass and -density (Bounoua et al., 2000; Defries et al., 1994), the NDVI needs to be interpreted with caution. A positive relation between NDVI and detection probability might suggest that detection probability is higher in dense shrublands than in grasslands. However, flourishing grasslands also receive high NDVI values that are similar to those of shrublands. Nevertheless, the NDVI values we used were averaged over the year to correct for variability in the time profile. Tsavo National Park experiences longer dry than wet periods (Tyrrell et al., 2006). Compared to grasses, shrubs are more resistant to draught, because their root system allows them to access water in deeper soil layers (Schenk et al., 1984). Accordingly, the decline in NDVI of sites with shrublands during dry periods is lower than in grasslands. As a result, shrub dominated areas on average score higher NDVI values than grassland dominated areas. The common occurrence of evergreen shrubs like the mustard bush *(Salvadora persica)* possibly contributes to this effect (Pers. Obs., 2019).
To explain the increase in detection probability with an increase in NDVI, we suggest two possible explanations. First, the attraction of elephants towards food rich sources might explain the positive relation. Several studies that investigated the relationship between vegetation and elephants have applied vegetation indices like the NDVI as a proxy of elephant forage (Duffy et al., 2012). The interaction observed between a high elephant density and high NDVI values led to the same conclusion. Further, elephant movement closely follows precipitation driven vegetation dynamics (Bohrer et al., 2014). Wato et al. (2016) found that during dry season, elephants tend to aggregate close to water sources and due to extensive browsing, vegetation diminishes over time and extensive draughts eventually lead to starvation. Therefore, elephants that died of malnourishment can often be found close to water sources where the NDVI is low at that particular time. However, during rainy season, the vegetation flourishes (Klein et al., 2006) and the vegetation along the rivers maintain their state, due to prolonged water availability, resulting in a high NDVI. Correspondingly, the average NDVI is raised and the average NDVI does not reflect the condition of the vegetation at the particular time of the elephants' death but rather gives an indication of vegetation density over time and relative to the other parts of the park. In conclusion, a high average NDVI could be scored in areas where elephants used to browse, especially in dry periods but starved during severe draughts.
Second, poachers seek camouflage in vegetation cover (i.e., a high NDVI value) and track large elephant herds that occur where elephant density is high (Maingi et al., 2012), which could lead to more carcasses found in areas with a high NDVI. Both arguments suggest that elephant mortality is likely to be high in areas with a high average NDVI and in addition elephant density acts reinforcing. An increase in elephant mortality ultimately results in a higher carcass density and aggregations. As discussed earlier, carcasses are more likely to be detected when their densities are high.

CONCLUSION

In conclusion, our results show that the detection probability of elephant carcasses was influenced by elephant density, NDVI and the interaction between the two factors. As suggested by the interaction term and literature, elephant density was driven by the site-specific characteristics.

The same factors were identified as predictors for poaching risk (Maingi et al., 2012; Rashidi et al., 2016) and might therefore have an impact on both detection probability of elephant carcasses and elephant poaching risk. However, because of the factors' influence on the detection probability, poaching risk in areas with high elephant densities might be overestimated whereas in areas with lower elephant densities poaching risk might be underestimated. Therefore, our study suggests that estimates of elephant mortality are biased if not corrected for detection probability.
Consequently, it is crucial to account for detection probability to achieve true estimates to effectively direct anti-poaching efforts against elephant poaching in African conservation areas.

ROLE OF THE STUDENTS

We, Johanna Märtz and Ronja Haring worked under the supervision of Martijn Weterings and Ignas Dümmer on this paper as our bachelor thesis within the major Wildlife Management at Van Hall Larenstein University of Applied Sciences. It was written in collaboration with Lekishon Moses Kenana from the Kenya Wildlife Services. The topic was proposed by Moses Kenana, while the design was entirely worked out by the students. Data collection in Kenya, data analysis and representation as well as discussion and conclusion were worked out by the students, who operated closely together in all sections.

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