The Levels of Crop Raiding by Rodents and Primates in a Subsistence Farming Community, in South Africa

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Abstract. Globally, human-wildlife conflict often arises from crop raiding. Therefore, there is a need to quantify crop damage by the suspected animals around protected areas. We assessed and quantified crop damage by wildlife on subsistence farms on the edge of the Hluhluwe Game Reserve, northern KwaZulu-Natal, South Africa. Twenty farms were assessed monthly from April 2016 to March 2017, using direct observations of wildlife, detectable evidence of their consuming crops and remote camera trap footage of their presence. We recorded the animals involved in raiding, crops affected, and differences in the level of crop damage by season and farm proximity to the reserve boundary. Rodents, arthropods (mainly insects) and birds were found to feed on crops on the 20 farms, with rodents causing the highest levels of crop damage as compared to the other animals. Contrary to expectations, primates (vervet monkey *Chlorocebus pygerythrus* and chacma baboons *Papio ursinus*) identified by our camera traps were not identified as raiders during our study, since these species never left the reserve to raid farms. However, camera trap footage showed that both primate species engaged in feeding behaviour on the inside boundary edge of the reserve (close to farms) during the dry season. Maize (*Zea mays*) was the main affected crop throughout the study. The highest level of crop damage was during the dry season compared to the wet season. The distance of farms from the reserve was not a significant predictor of the level of crop damage in the farms sampled, contrary to the findings of other studies, which mentioned that crop raiding decreases further from protected area boundary. Using trapping, crop assessment and observation, our study showed that small rather than larger animals from the neighbouring conservation area were the main crop raiders and that maize was the most affected crop, especially during the dry season.

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1 Introduction

Crop raiding by wildlife is amongst the most critical problems experienced by farmers, particularly those farming adjacent to protected areas (Siljander et al. 2020). However, the extent of the problem has not been addressed in subsistence farmers (Seoraj-Pillai 2016). Thus, case-specific studies are needed from farmland bordering protected areas, with different potential crop types and crop pests, to enable us to generate a global understanding of crop-raiding patterns. Crop raiding by wildlife has been extensively studied in Africa (Montgomery et al. 2021; Gloriose 2019), with focus being placed on flagship species such as elephant (*Loxodonta africana*). However, raiding by rodents and primates together has received little attention in the scientific literature.

Systematic surveys of rodent damage are scarce in Africa (Dossou et al. 2020). Moreover, the impact of these animals on subsistence homesteads is not well documented. Unsurprisingly, crop raiding by primates is common, yet studies of primate feeding ecology do not adequately consider their impact on subsistence homesteads, as well as seasonal changes in their raiding behaviour for agricultural and non-agricultural food (Naughton-Treves et al. 1998). Most crop raiding by wildlife is reported to occur on farms that are in close proximity to protected areas (Siljander et al. 2020). Naughton-Treves (1997) hypothesized that crop raiding, in general, is limited to a few hundred meters from the protected area boundaries. However, we are not aware of any studies that have tested the distance-related hypothesis for rodents and primates in rural subsistence farmers of South Africa.

We investigated the levels of crop raiding by rodents and primates in a subsistence farming community, abutting the Hluhluwe Game Reserve, KwaZulu-Natal Province, South Africa. The literature maintains that crop-raiding levels vary seasonally (Raphela and Pillay 2021; Mukeka et al. 2019). In particular, it is reported that crop-raiding incidences decrease during the wet season. Therefore, we predicted that the level of crop damage by both rodents and primates would increase during the dry season. We also tested the hypothesis proposed by Naughton-Treves (1997) that crop raiding decreases away from the game reserve boundary. We predicted that the level of crop damage by both rodents and primates would be greater on farms that are closer to the game reserve. We also predicted that maize (*Zea mays*) would experience the highest level of damage as compared to all the other crop types. Previous research has reported that maize is the most depredated crop because of its nutritional value (Ghimirey et al. 2018; Raphela and Pillay 2021).

2 Materials and Methods

2.1 Study Site

The study was conducted at Phindisweni village (28°26’ S; 31°43 ’E), bordering the Hluhluwe Game Reserve. Subsistence farming is the main source of income in this community (StatsSA 2011). Phindisweni village is vulnerable to crop raiding according to previously undocumented farmer reports. We sampled wildlife in 20 subsistence farms adjacent to the Hluhluwe Game Reserve in the dry (April to August) and wet (September to March) seasons from April 2016 to March 2017.

2.2 Farm Attributes

A Garmin GPSMap62 handheld device was used to record several farm attributes. We recorded the geographical location (GPS coordinates of the farms) and elevation of the central position of each of the 20 farms sampled. The area of each farm and the area cultivated were established by walking the perimeter of each sampled farm and cultivated land separately and calculating the area of each in m^2. The distance between each farm and the reserve boundary was determined by a straight-line shortest distance from the center of the farms to the reserve boundary fence using ArcMap (ArcGIS, V10.3, software package, ESRI). The measurements were grouped into intervals of <1 km, 1–2 km and 2–3 km.

2.3 Farm Sampling

We sampled food crops at Phindisweni farms, during the dry season and the wet seasons. 1 m^2 quadrats were placed to cover at least 20% of the cultivated area for each farm. Quadrats were randomly placed flat on the ground in the farmed areas and left lying there for 10 consecutive days each month per farm throughout the study. The joint ends of the quadrats were covered in bright insulation tape to locate the quadrats later. Most farmers planted their crops in rows (personal observation). Therefore, the quadrats were placed to cover all crop types planted per farm. To cover at least 20% of the cultivated land, we set 6 to 16 quadrants, depending on the surface area of the cultivated land in each farm.

2.4 Crop Damage Assessment

We visited the farms for 10 consecutive days, twice a day every month for the duration of the study to assess the amount of damage caused by animals on food crops. We counted the number of individual food crops damaged daily in each quadrat, irrespective of where the damage occurred (i.e. mostly on the leaves of crops or seeds for maize). The damaged part/s of the plants were pricked with a pin around the destruction sites to identify damage and to avoid later resampling. Crop types were also recorded. Animals that were directly observed causing damage were arthropods (mainly insects) and birds (species unknown).

Even though rodents were trapped inside the farms (see Results), they were never witnessed directly feeding on crops. Therefore, we used impressions and indentations on food crops to identify damage. We used the following evidence to categorise crop raiders: rodents, from tooth marks and ragged breaks with shredded edges and holes; insects from round holes on the leaves; and birds from tears off the food crops.

Crop damage was quantified by counting the total number of damaged crop parts, mostly leaves (sampling unit), of each individual food crop inside each quadrat, and was recorded as the level of crop damage by rodents, insects, and birds in a farm. Since we used impressions and indentations on food crops to identify damage, in cases where more than one crop raider damaged a crop part, we recorded the damage by each crop raider suspected to have caused the damage. The total number of counts per quadrat for a particular crop and pest species was recorded. Because the focus of the study was on rodents, the damage that was caused by other pests (insects and free-living birds) was compared to the damage caused by rodents.

2.5 Rodent Trapping

The capture, mark, identify and release protocol technique was used to sample rodents (Mills et al. 1995). Trapping was done monthly from April 2016 to March 2017. Each trapping session lasted 10 consecutive days each month per farm. PVC live-traps (290 × 60 × 80 mm) were set randomly on each farm, resulting in 1200 (smallest farm) to 1680 (largest farm) trap nights. Traps were baited with a mixture of peanut butter, oats, coarse salt, sunflower oil, and raisins (De Bondi et al. 2011). Cotton wool was inserted into traps to provide insulation for trapped animals during the colder periods. Also, we covered traps with surrounding vegetation for insulation against lethal temperatures. Traps were set in areas preferred by small mammals, such as next to fallen trees/shrubs, next to holes in the ground and areas with small mammal runways.

Traps were checked twice a day, once in the morning (9 am to 10 am) and in the afternoon (3 pm and 5 pm). We identified trapped individuals to species level. The trapped animals were transferred from the traps to a clear plastic bag and weighed (to the nearest gram) using a DKD handheld spring balance. Individuals were sexed based on the ano-genital distance and obvious genital differences. To recognise previously captured individuals, we marked each captured individual by trimming the hair on the back of the neck with a pair of scissors to reveal the different colour undercoat (Mills et al. 1995). Gentian violet was sprayed on the clipped area as a semi-permanent marking to also assist in identifying recaptures. The individuals were released at the point of capture and the traps were re-baited when necessary. Trapping was conducted with the approval of the local government conservation authority, Ezemvelo KZN Wildlife (permit number: OP 711/2016), and the University of the Witwatersrand Animal Ethics Screening Committee (AESC protocol number: 2015/011/48/B). This study followed the guideline for capturing and handling rodents (Mill et al. 1995).

2.6 Monitoring Primates

Direct observation and camera trap methods were used to sample primates for this study. The 20 farms were sampled for four hours a day randomly from 6 am to 8 am and, again, from 4 pm to 6 pm for 10 days a month from April 2016 to March 2017. To assess primate behaviour in the mornings and in the afternoons before they disappeared into the surrounding bush, we walked along the sampled farms to identify whether they raided crops. During these walks, we aimed to record the presence and demographic parameters (number of groups, juveniles, and adult males and adult females) of primates raiding crops and the type of crops they raided. We carried a digital camera during the walks to capture any evidence of crop raiding, as well as other evidence, such as droppings, bite marks on crops, and tracks. However, throughout the study, primates never transgressed the reserve boundary to raid crops. Therefore, their potential to raid crops was analysed from the camera trap footage (see below), to assess their behaviour on the edge of the reserve.

2.7 Camera Trap Surveillance

At 10 sites determined to be frequently visited by primates, according to farmer reports, we set up 10 × 8-megapixel infrared camera traps (Bushnell®, trophy camera, China), with 32 GB memory cards. The cameras were positioned at appropriate angles at approximately 0.7 m above the ground. All the cameras faced onto the farms and were secured using multiple lengths of coated flexible wire and a padlock to prevent theft. Also, for five farms that were adjacent to the Hluhluwe Game Reserve, the cameras were set up strategically facing the reserve to record the occurrence and behaviour of primates and other mammals, particularly if they transgressed the reserve/farm boundary. The five farms were separated from the reserve by a gravel road that was created by reserve management as a safety measure for fence workers. The five farms shared a fence with the reserve and with each other and were separated by distance of 100 m from each other.

The cameras were housed within an aluminum camera housing to reduce damage from moisture and for protection from rain and tied to tree trunks/logs. The camera started recording when a motion was sensed at a distance up to 18 m and recorded high-definition videos (1280 × 720 pixels) for 30 s. A delay period of 15 s between recordings was programmed into cameras to avoid too many records of a single motion trigger. The videos were automatically dated, and time stamped. Cameras were operational 24 h a day for 10 days per month in each of the sites throughout the study and checked every three days to replace data storage card and batteries, if necessary. Video footage was downloaded onto a laptop computer from each memory card every three days and organized into folders labelled with the location and date.

All visible animals on the video footage were identified according to primates or in other broad animal categories. The frequency of occurrence of primates and other animal groups on the edge of Hluhluwe Game Reserve were noted. To avoid pseudo-replication of primates and other animals on one video, we scored each animal species as one occurrence per day from the video footage, regardless of the number of times per day they appeared in the footage. We also recorded each primate's behaviour (feeding and traveling) by season separately.

To investigate the potential of primates to raid crops, we scored two behaviours, feeding (i.e., manipulation and ingestion of food), considered to have priority over other activities and traveling (i.e., walking, running) which was found to have a positive relationship with feeding in Japanese macaque (*Macaca fuscata*; Agetsuma et al. 2015). The travelling and feeding behaviours are fundamentally important when addressing the crop-raiding behaviour of primates because these two behaviours are indicative of current or future raiding. Agetsuma et al. (2015) found that Japanese macaques decreased feeding time when fruits are available and increase traveling time when the density of fruit-food trees is low during the dry season, requiring greater travelling and searching for trees.

3 Statistical Analyses of Data

Rodent trapping data were analysed using descriptive statistics first. All other statistical analyses were done using R statistical software (version 4.1.0; 2020). Statistical tests were two-tailed, and significance levels were set at $P \leq 0.05$. Data were mostly categorical and did not meet the assumptions of normality (Shapiro-Wilk test). Accordingly, nonparametric analyses were used.

The Spearman's rank order correlation coefficient (Spearman's rho) was performed to analyse the relationship between farm proximity to the reserve boundary and the level of crop raiding by animal groups separately (rodents, insects, birds) and collectively. For each species, the level of crop damage was set as the response variable and distance from the game reserve was the explanatory variable.

To assess seasonal variations in the level of damage by 1) crop type and 2) crop raiding animals, we applied two separate Generalised linear mixed models (GLMM) with a *glmer* function and a Poisson distribution (lme4 package, Bates *et al*. 2015). For both models, we included farm size as a random factor (intercepts only) to account for the potential sizes effect. We checked the model fit for the variables described below, and used the most appropriate model, based on the plot of the residuals against the fitted values from each model (Crawley 2007). For model 1: we used season, crop raiding animals, and two-way interactions of season*crop raiding animals as independent variables with the level of damage as a dependent variable and for model 2: we used season, crop type and the interaction between season*crop type as independent variables with the level of damage as the dependent variable. We generated P values using likelihood ratio tests (Bates *et al*. 2015).

Primates did not transgress the reserve boundary to raid crops throughout the study. Therefore, we investigated their potential to raid crops by assessing their behaviour on the edge of the reserve. We analysed the numerical frequencies of occurrences (1 occurrence per day; see above) of two behaviours (travelling and feeding) along the reserve boundary for chacma baboon (*Papio ursinus*) and vervet monkey (*Chlorocebus pygerythrus*) separately with Generalised linear models (GLMs), with a *glm* function and Poisson distribution. We included season, species, and the two-way interactions season* species as independent variables. Significance was determined using Wald (χ^2) statistics. Data for this study are presented as boxplots and scatterplots, produced using a Ggplot2 package from R software.

4 Results

4.1 Rodent Trapping

A total of 96 individual rodents were captured in 20 sampled farms from April 2016 to March 2017, in 30600 trap nights (0.3% trap success), comprising of two species: red bush rat (*Aethomys spp.*) and pouched mouse (*Saccostomus campestris*). *Aethomys spp.* (67.7%; 51 males and 28 females) was most trapped and is a common murid rodent in savanna habitats in KwaZulu-Natal Province. The pouched mouse (*Saccostomus campestris*) represented the remaining 32.3% (14 females and three males). Both the *Aethomys spp* and the *Saccostomus campestris* were mostly captured during the dry season.

4.2 Crop Raiding and Farm Proximity to the Game Reserve

The Spearman's rho did not reveal a statistically significant relationship between the level of damage and distance of farms from the reserve boundary ($r_s = -0.07$, P = 0.438), although the highest level of damage was in farms further away from the reserve (Fig. 1).

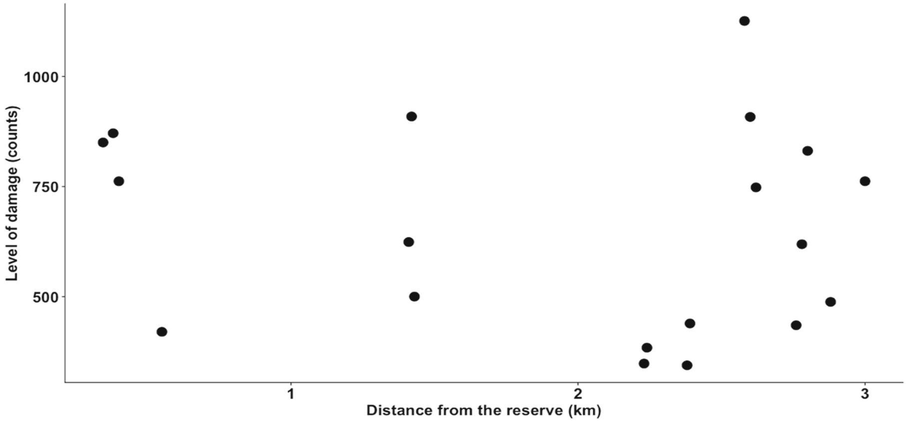

Fig. 1. Scatterplot of the distribution of the overall level of crop damage (counts per farm) across different farm distances for 20 sampled farms abutting the Hluhluwe Game Reserve, South Africa.

We then ran three separate Spearman rank analysis for the different crop raiding animal type (rodents, insects, and birds) to ascertain the relationship between the distance of farms from the reserve boundary and the level of crop damage. There was again no significant correlation between farm distance from the reserve boundary and the level of crop damage by rodents ($r_s = -0.18$, P = 0.262), insects ($r_s = -0.06$, P = 0.700) and birds ($r_s = -0.09$, P = 0.601; Fig. 2).

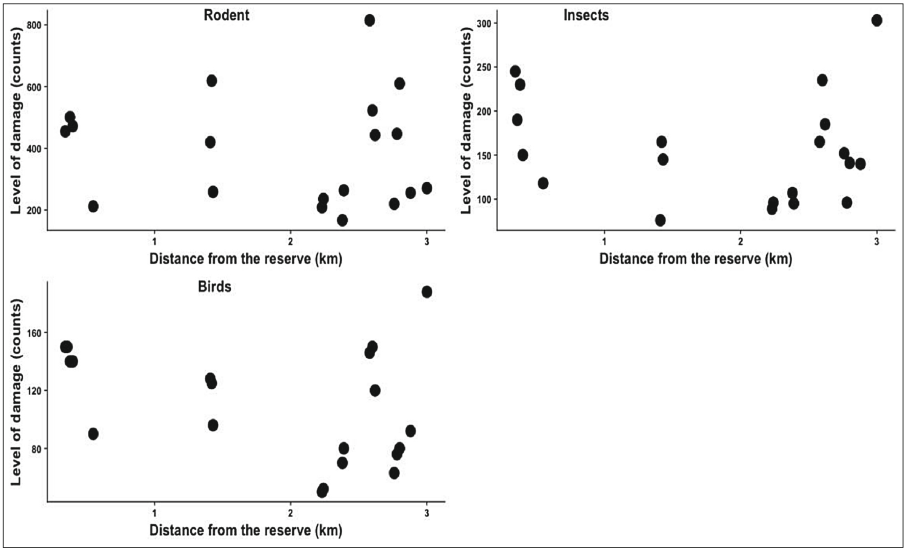

Fig. 2. Distribution of the levels of crop damage (counts per farm) by crop raiding rodents (top left), insects (top right) and birds (bottom left) across 20 sampled farms situated at different distances from Hluhluwe Game Reserve, South Africa.

4.3 Variation in the Level of Crop Damage by Crop Raiding Animals

The results of a GLMM showed that season (Wald $\chi_1^2 = 17.02$; $P < 0.001$), crop raiding animal type (Wald $\chi_1^2 = 302.76$; $P < 0.001$) and the interaction between season and crop raiding animal type (Wald $\chi_2^2 = 165.57$; $P < 0.001$) were significant predictors of the level of damage. Farmers experienced the highest level of crop damage during the dry season as compared to the wet season. Rodents followed by insects and birds caused the highest level of crop damage. The highest level of crop damage was caused by rodents during the dry and wet season as compared to insects and birds, but the highest level of rodent crop damage was during the wet season as compared to the dry season in contrast to the highest level of crop damage caused by insects and birds, which was in the dry season (Fig. 3).

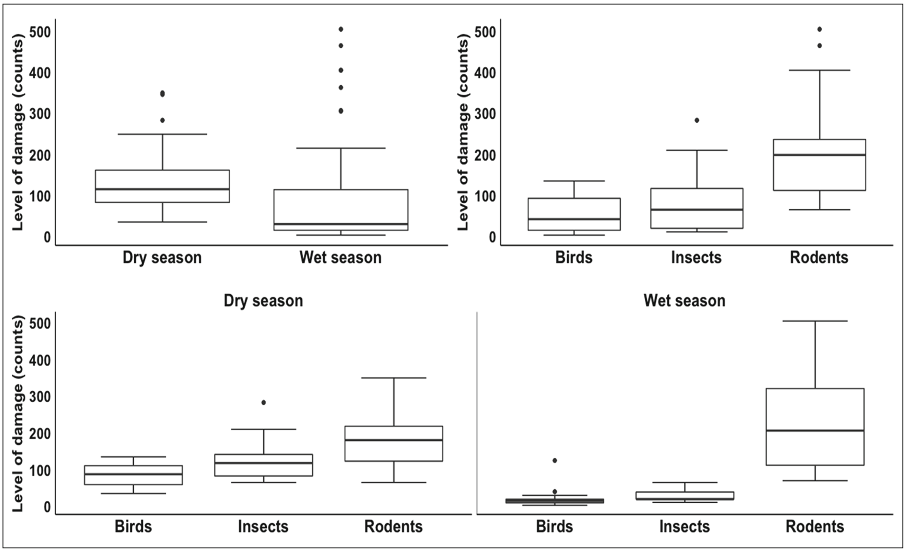

Fig. 3. Levels of damage (counts per farm) by season (top left), crop raiders (top right) and season*crop raiders (bottom) in farms on the edge of Hluhluwe Game Reserve, South Africa. Boxes show medians (solid black line across the box) and 1st (top box) and 3rd (bottom box) quartiles. Whiskers show total range and dots outside of boxes indicate outliers.

4.4 Variation in the Level of Crop Damage by Crop Type

The GLMM results showed that season (Wald $\chi_1^2 = 962.23$; $P < 0.001$), crop type (Wald $\chi_4^2 = 7725.42$; $P < 0.001$) and the interaction between season and crop type (Wald $\chi_3^2 = 118.25$; $P < 0.001$) were significant predictors of the level of damage. Farmers experienced the highest level of crop damage during the dry season as compared to the wet season. The highest level of crop damage was for maize followed by spinach, common bean, and beetroot. Crop damage for maize was higher during both the dry and wet season than the damage for all the other crop types, but the highest level of damage for maize and the other crop types was during the dry season than the wet season (Fig. 4).

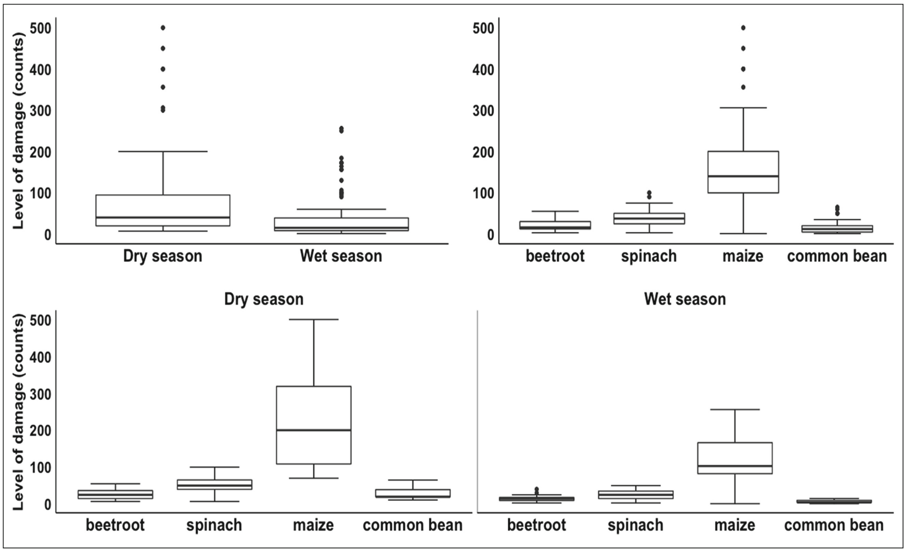

Fig. 4. Levels of damage (counts per farm) by season (top left), crop type (top right) and season*crop type (bottom) in farms on the edge of Hluhluwe Game Reserve, South Africa. Boxes show medians (solid black line across the box) and 1st (top box) and 3rd (bottom box) quartiles. Whiskers show total range and dots outside of boxes indicate outliers.

4.5 Seasonal Variations in Primate Behaviour

Overall, primate occurrence along the reserve boundary was significantly influenced by season (Wald $\chi^2_2 = 1358.33$; $P < 0.001$) and species (Wald $\chi^2_1 = 12.43$; $P = 0.000$), with the highest occurrence recorded during the dry season as compared to the wet season and the highest occurrence recorded for vervet monkey compared to chacma baboon. Primate occurrence along the reserve boundary was not significantly influenced by the interaction between season and species (Wald $\chi^2_1 = 2.36$; $P = 0.124$).

4.6 Feeding Behaviour

Species (Wald $\chi^2_1 = 3.19$; $P = 0.073$) and the interaction between species and season (Wald $\chi^2_1 = 0.11$; $P = 0.736$) were not significant predictors of the feeding behaviour of chacma baboons and vervet monkeys along the reserve boundary. Feeding behaviour was significantly influenced by season (Wald $\chi^2_2 = 16.41$; $P = 0.000$), with the highest feeding behaviour occurring in the wet season as compared to the dry season (Fig. 5).

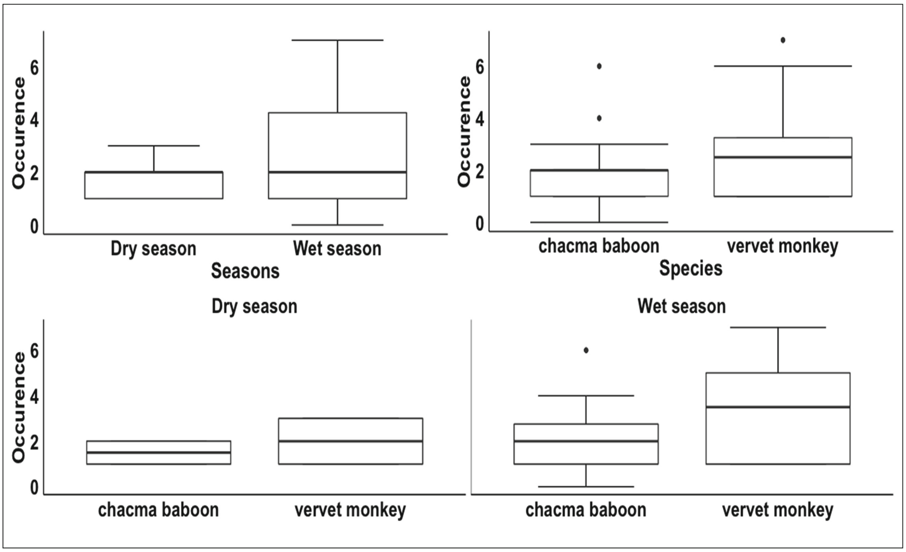

Fig. 5. Frequency of occurrence of primate feeding behaviour by season (top left), species (top right) and by season*species (bottom) along the Hluhluwe Game Reserve boundary in South Africa. Boxes show medians (solid black line across the box) and 1st (top box) and 3rd (bottom box) quartiles. Whiskers show total range and the dot outside of boxes indicate outliers.

4.7 Travelling Behaviour

Season (Wald $\chi^2_2 = 18.70$; $P < 0.001$), species (Wald $\chi^2_1 = 10.86$; $P = 0.000$), season*species (Wald $\chi^2_1 = 5.28$; $P = 0.021$) had a significant effect on the frequency of the travelling behaviour of primates along the Hluhluwe Game Reserve boundary. The most frequent occurrence of travelling behaviour was recorded during the dry season as compared to the wet season. Vervet monkeys travelled along the reserve borders more frequently than chacma baboons. The highest frequency of occurrence of the travelling behaviour by vervet monkey was during the dry season as compared to the wet season.

5 Discussion

We trapped 96 individual rodents of two species (79 *Aethomys spp* and 17 *Saccostomus campestris*). These two murids are common in the savanna biome (Skinner and Chimimba 2005; De Graaff 1981) and were also reported by other studies in the Hluhluwe-iMfolozi Game Reserve complex (Hagenah et al. 2009; Taylor 1998). However, these two species are not the most common species in the study area (Hagenah et al. 2009). Thus, the diverse assemblage of rodents present at Hluhluwe Game Reserve was not reflected in my study. The reduced rodent species richness and diversity in our study was an indication of a disturbed ecosystem, probably also due to the drought disaster that was experienced during the study in the study area. In summary, the absence of some rodents species which also occurs in the study area, the open habitat and drought conditions might have favored the occurrence of *Aethomys spp.* And *Saccostomus campestris.*

We found differences in the level of crop damage between rodents, insects, and birds, as well as differences in their level of crop damage between the dry and the wet season. Worldwide, rodents are considered as the second most important pest of farms (after insects), but farmers claim to have the least control of rodent pests (Tomass et al. 2020). In Uganda, Hill (1997) found that rodents, insects, and birds caused widespread damage to crops. The higher levels of crop damage caused by rodents in both seasons fond by our study may be due to their not being "controlled", as were insects and birds in the studied farms.

We did not find any indication of raiding by primates. Instead, primates were observed feeding only on the edge of the reserve, so our expectation that crop raiding by primates will occur in farms that are closer to the reserve was not supported. However, we found some evidence to suggest the potential of primates to raid crops based on their behaviour on the reserve edge. Feeding on the edge of the reserve was the most common behaviour for primates during the wet season as compared to the dry season.

Consistent with our prediction, we found that the highest level of crop damage occurred during the dry season as compared to the wet season. Mekonnen et al. (2018) suggested that lower quality and reduced availability of natural food between the wet and dry season encourages and can exacerbate crop raiding.

Crop type is known to influence the level of crop damage (Emberson et al. 2018), as occurred in our study. Maize experienced the highest level of crop damage compared to other crops, especially during the dry season. This was not surprising considering the high nutritional value of this crop (Kontsiotis et al. 2020).

Contrary to the hypothesis by Naughton-Treves (1997), we found that the level of crop damage by rodents, insects and birds was not correlated with distance from the reserve boundary. Consistent with our study, Pittiglio et al. (2014) also found that the impact of crop raiding in three villages in Tanzania did not appear to be consistently related to distance. In contrast, Saj *et al.* (2001) reported that the proximity of farms to protected areas is a significant positive predictor of crop raiding in Uganda, and farms closer to forests were reported to receive more raids than those farther away from the forest.

In conclusion, rodents appeared to be the most important damage-causing agents in the farms considered in our study, although the low diversity of rodents captured in our study might have been due to the drought that was experienced during the study. Nonetheless, some important patterns were highlighted. Even though many studies on crop raiding indicated that farms that are near protected areas are more vulnerable to crop raiding (Branco et al. 2020; Gontse et al. 2018), our study showed no distance relationship. Although no primate raiding was recorded during our study, the potential for increasing human–primate conflict throughout Africa is increasing and the attractiveness of farm crops to primates (from camera trap footage) indicates a high probability of future raids. It is crucial to gain a better understanding of the ecological determinants of primate crop-raiding. Investigations should incorporate more detailed nutritional analyses of cultivated foods consumed at different times of the year, and patterns and changes over longer periods of time. Future studies during periods with greater rainfall should be done to holistically capture the crop raiding behaviour of a range of wildlife and provide an important comparison for the data obtained in our study, conducted during a drought.

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Nomenclature Acts. This work and the nomenclatural act it contains have been registered in ZooBank.

Conflicts of Interest. The authors declare that there is no conflict of interest that may have influenced either the conduct or the presentation of this research.

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