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Trends in vervet monkey admissions to a wildlife rehabilitation centre: a reflection of human-wildlife conflict in an urban-forest mosaic landscape

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Abstract

Despite the common destructive effects of urbanisation on biodiversity assemblages, certain species thrive in urban environments. One mammalian species that has persisted in the urban-forest mosaic landscape is the vervet monkey (*Chlorocebus pygerythrus*). It is a common resident primate in Durban, eThekwini Municipality, KwaZulu-Natal Province, South Africa, with frequent contact with humans and domestic wildlife. Due to their adaptability in using human-altered landscapes, the interactions between humans and vervet monkeys have increased and are often negative. Our study determined trends in the admission cases of vervet monkeys to a Durban wildlife rehabilitation centre and assessed the main factors contributing to these admissions to mitigate human-vervet monkey conflict. Our analyses were conducted on recorded admission data for vervet monkeys at a wildlife rehabilitation centre from 2011 to 2018. Members of the public (90.0%) mostly reported vervet cases, with admissions mostly recorded from the central district (46.8%) of the municipality. The number of admitted vervet monkeys increased significantly over the years and months, with a mean (± SE) of 127.3 ± 21.34 and 84.8 ± 5.37, respectively. Only 34.3% of vervet monkeys were alive at the end of the admission process from the 83.7% that were admitted alive at the rehabilitation centre. The high number of deaths resulted from anthropogenic activities, primarily motor vehicle strikes (30.8%) and domestic dog (*Canis lupus familiaris*) attacks (13.9%). We modelled survivability for vervet monkeys, and our results showed that season, age category, and the cause of admission were all significant factors influencing survival after admission. The sex of vervet monkeys had no significant effects on survivability after admission to the rehabilitation centre. We suggest that wildlife rehabilitation centres in priority areas use these findings in education to improve human coexistence with vervet monkeys. The trends also serve as a foundation for human-vervet conflict resolution programmes. The advantages of publishing records from rehabilitation centres are that they will raise awareness of the challenges posed by vervet monkeys in urban environments, where they are sometimes perceived as a nuisance because of anthropogenic influences in the urban mosaic landscape.

Keywords *Chlorocebus pygerythrus* · Anthropogenic impacts · Rehabilitation efforts · Urbanisation · Wildlife rescue

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Introduction

Presently, 55% of the world's human population lives in urban areas, and this is expected to grow to 2.5 billion people by 2050 in the same area, with close to 90% of this increase taking place in Africa (UN 2018). Urbanisation is a contributing factor to land-use change that threatens biodiversity in the resulting towns and cities as people migrate from rural to urban and suburban landscapes (Grimm et al. 2008; Nuissl and Siedentop 2021). Urban sprawl and human expansion give rise to anthropogenic activities such as land transformation for infrastructure development, industrialisation, recreation, and agriculture, which generally negatively

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impact biodiversity and ecosystem functioning (Hunter 2007; Schwarz et al. 2017; Festus et al. 2020). Despite people aggregating in cities and moving away from rural areas, this urbanisation trend potentially opens opportunities for conservation efforts in rural areas. Overall, it remains to be seen whether this shift is a net benefit for conservation. Presently, the major threat to biodiversity loss is the transformation of natural areas as exhibited in the metropolitan areas of Durban, eThekwini Municipality, KwaZulu-Natal Province, South Africa (EPCPD 2020). With a population of ~ 3.9 million people, spanning an area of ~ 2555 km^2 (COGTA 2020), the conversion of natural land to accommodate the rapid expansion of urbanisation has led to an overlap of humans and wildlife in this urban-forest landscape mosaic, ultimately leading to various human-wildlife conflicts in the municipality (Zungu et al. 2020; McPherson et al. 2021).

Historically, humans and wildlife have coexisted; however, the magnitude of human-wildlife interactions has risen recently (Peterson et al. 2010; Manfredo 2015; Anand and Radhakrishna 2017; Parathian et al. 2018). Urban wildlife differs from other wildlife by increased interaction with people and human-modified environments, which can be displayed as positive, neutral, or negative interactions (Soulsbury and White 2015, 2019; Mormile and Hill 2017). Previous research examined negative associations around human-wildlife conflict (HWC) and documented direct factors implicating wildlife through physical attacks, property damage and disease transmission (Distefano 2005; LaBarge et al. 2020; Siljander et al. 2020). HWC occurs in a heterogeneous mosaic landscape that contains a large network of buildings, manicured gardens, linear infrastructure (e.g., walls, roads, bridges), and rivers, interconnecting remanent patches of natural forests and green belts (Werner 2011; McPherson et al. 2021). The frequency of interactions between humans, infrastructure, and wildlife occur because of encroachment increases the likelihood of conflict events (Soulsbury and White 2015). Human-induced environmental changes typically act as a non-random filter, allowing only the most adaptable species to survive under modified conditions, known as biotic homogenisation (Smart et al. 2006). Certain species, often generalists, show behavioural plasticity and persist in transformed urban landscape mosaics (Downs et al. 2021). Under intensive human activity, mammalian species that use and exploit sources of food and shelter while attaining abundance and biomass in their population are known as urban adapters and can be described as species that can survive equally well in the urban and natural environment (McKinney 2002, 2006; Fischer et al. 2015).

It is important to understand how wildlife populations and human communities respond to urbanisation and the associated increased human interactions to deal with potential HWC. Despite the commensal relationship with urban development, primates are responsible for some of the most intense HWC worldwide (Hill and Webber 2010; Dickman 2012; Seoraj-Pillai and Pillay 2017). Notably, urbanisation intensification has been linked to the extinction of many primate species (Estrada et al. 2017, 2020; Torres-Romero et al. 2023). In developing countries like South Africa, HWC is a concern for food insecurity and economic losses as the conflict is primarily associated with crop-raiding events by primates (Sillero-Zubiri and Switzer 2001; Hill 2005; Warren 2009; Findlay 2016). Following the conflict arising through direct or indirect human negative interactions, many injured primates are admitted to rehabilitation centres (Grobler et al. 2006; Wimberger and Downs 2010; Guy 2013; Guy et al. 2013).

Primate species like the vervet monkey (*Chlorocebus pygerythrus*) are highly adaptable and exhibit urban adaptations as they can opportunistically exploit resources in anthropogenic landscape mosaic habitats (Patterson et al. 2018; Thatcher et al. 2019a, 2023). This habitat generalist has adapted and shown persistence in fragmented and cultivated landscapes, including the urban environment, maintaining an omnivorous diet based on the seasonal availability of plants, berries, shoots, fruits, and invertebrates (Butynski and De Jong 2019). The vervet is a semi-arboreal primate occurring in all nine provinces of South Africa (Turner et al. 2016). Often widespread and abundant in its present geographic distribution range, vervet monkeys are tolerant to a wide variety of niches that include riverine woodland, open savannah, forest-grassland mosaics, and coastal scrub forest, but are limited to available drinking water and sleeping sites (Skinner and Chimimba 2005; Turner et al. 2016).

Classified as "Least Concern" on the International Union for Conservation of Nature Red List, the present population trend for vervet monkeys is decreasing in Africa (Butynski and De Jong 2019). In South Africa, vervet monkeys are protected by law. However, according to the Nature Conservation Ordinance 15 of 1974, KwaZulu-Natal Province, vervet monkeys can be legally kept in captivity subject to permits for research, zoos, circuses, and museums, but not as pets. Although there are no official data on population counts of vervet monkeys within the municipality, vervet monkeys are relatively common and highly visible in an urban-forest mosaic landscape in KwaZulu-Natal (Patterson et al. 2017, 2018). People perceive that the population of vervet monkeys is increasing, but more so that they are observing and interacting more frequently and directly with vervet monkeys in urban and suburban areas.

Generally, people have a low tolerance for vervet monkeys and consider them pests upon entering gardens and homes searching for food, inadvertently causing property damage, and bringing about conflict (Saj 1998). Apart from raiding events, vervet monkeys rummage through garbage and waste tips, further escalating animosity towards the species (Patterson et al. 2017). While human

attempts to deter vervet monkeys from urban areas are common, instances of HWC may occasionally involve direct interaction with domestic animals, and individuals, particularly women and young children. These conflict events contribute to the prevalent discourse of assigning blame to vervet monkeys, often fuelled by emotions such as anger and frustration (pers. comms). Additionally, vervet monkeys are considered vermin by farmers because of their raiding nature on crops grown for agricultural or subsistence farming (Naughton-Treves et al. 1998; Hill 2005; Loudon et al. 2014; Cancelliere et al. 2018; Findlay and Hill 2020). In addition, the lack of natural predators in urban areas, such as pythons (*Python* spp.), leopards (*Panthera pardus*) and raptors (McPherson et al. 2016; Isbell and Etting 2017) enable relatively unhindered movement of vervet monkeys in human-modified landscapes (Patterson et al. 2018, 2019; Mikula et al. 2018; Thatcher et al. 2019a, b; LaBarge et al. 2020; Pillay et al. 2023).

Coupled with these conflict events, vervet monkeys are prone to persecution by humans because of their nuisance foraging habits, resulting in their relatively high admissions at several rehabilitation facilities centres across South Africa (Wimberger and Downs 2010; Guy and Curnoe 2013; Thatcher et al. 2019b). Repeated incidents include domestic pet attacks, shootings, car accidents and poisonings (Wimberger and Downs 2010; Guy et al. 2011; Guy and Curnoe 2013). The possibility of vervet monkeys surviving injuries by anthropogenic encounters in urban and suburban areas has been poorly documented. Previous studies have reported vervet monkey admittance data for a specialist vervet monkey rehabilitation centre (Healy and Nijman 2014) and account for some conflict because of anthropogenic threats (Wimberger and Downs 2010). However, our study is the first long-term, continuous dataset, from 2011 to 2018, assessment of vervet monkeys admitted to a wildlife rehabilitation centre that caters for all injured wildlife species in one of South Africa's largest metropolitan cities, Durban. Our study aimed to comprehensively investigate the trends and key factors contributing to HWC through the analysis of admission records for vervet monkeys. These records serve as a valuable resource for gaining insights into the challenges faced by this primate species in the urban-forest mosaic landscape. Furthermore, the findings of this study carry practical significance by informing the development of effective mitigation strategies and interventions aimed at addressing HWC. By examining the causes of admission and identifying areas of concern for HWC, we contribute to a deeper understanding of the anthropogenic threats faced by vervet monkeys and the outcome of survivability from their encounters with human activities. We predicted temporal and seasonal variations in trend data because of anthropogenic factors.

Methods

CROW: Centre for Rehabilitation of Wildlife

The Centre for Rehabilitation of Wildlife is a registered non-profit organisation dedicated to the rescue, rehabilitation and release of indigenous wildlife, and it is a registered wildlife rehabilitation centre in Durban, eThekwini Municipality, South Africa. Founded in 1977, CROW is situated in the suburb of Yellowwood Park and annually assists over 3000 orphaned, injured, and displaced wildlife from the municipality (Wimberger and Downs 2010; unpublished data). As part of the International Wildlife Rehabilitation Council, CROW prioritises rehabilitation and release as its main conservation efforts while promoting conservation through education initiatives and active participation by the community. Ezemvelo KZN Wildlife permitted CROW to keep 150 vervet monkeys at its on-site rehabilitation facility in large outdoor enclosures, mostly used for recovering, rehabilitating or unreleasable vervet monkeys (CROW management pers. comm.). Vervet monkeys were either reported to CROW or brought in by the public. In addition, CROW goes out on rescues to assist incapacitated, or injured vervet monkeys reported. This project was conducted as part of an MOU with the University of KwaZulu-Natal (UKZN) and CROW.

Data acquisition

We obtained data from hard copy files that documented comprehensive information recorded by the staff employed at CROW for the rescue and rehabilitation of vervet monkeys admitted to CROW from 01 January 2011 to 31 December 2018. Admission records included the date, admission source, location, history, type of rescue, alive on admission, sex, age, cause of admission and the final outcome. All information was manually entered into Microsoft Excel (Version 2111), cleaned, and categorised for data interpretation to identify trends. Graphical data representations were prepared using the most significant findings and displayed.

We classified the data into categories for statistical analyses to determine trends in the number of vervet monkey admission cases. Years were grouped annually (2011–2018), and months by austral seasons, spring: September–November; summer: December-February; autumn: March–May; and winter: June–August. The admission sources of vervet monkeys were grouped into two main categories: a member of the public or another wildlife rehabilitation centre. Geographical source locations of vervet monkeys were grouped into the following

districts of the municipality: Central, North, South, Inner West, Outer West and 'other', which included all admissions from outside the boundary of the municipality and unknown/not recorded locations. Types of vervet monkey rescues were grouped as 'rescue and callouts or 'drop-offs'. Vervet monkeys alive on admission were classified as yes or no based on the historical context of the case at the beginning of the admission to the centre. The sexes of vervet monkeys admitted were listed as male, female, undetermined, or not recorded. The age of vervet monkeys admitted was classified into age categories which were determined by their size and dental form by CROW and kept as-is for this study: infant: 0–6 months; juvenile: 6 months—1.5 years old; subadult: 1.5 to 2–3 years old; adult: + 4 years old; undetermined—unidentifiable by CROW because of severe body injuries. We identified nine main causes of admission and listed them as per their categories for admission, with some pooled (e.g., 'sold as pet' and 'kept as pet', Supplementary information in Table S1). The main causes of admission were identified as (1) attacked by a domestic dog (*Canis lupus familiaris*), (2) attacked by another monkey, (3). malicious, (4) motor vehicle strike, (5) orphaned, (6) other, (7) pet, (8) shot and (9) unknown. The final outcomes of vervet monkey admissions were classified as died, euthanised, housed in captivity or released. The survivability of each vervet monkey admitted was categorised as dead or alive at the end of the admission process based on its final outcome.

Statistical analyses

We analysed the data using IBM SPSS Statistics 27.0 (IBM, Armonk, USA). Chi-square goodness-of-fit tests were performed to determine if any relationship exists between the categorical data for admission source, district of the municipality, type of rescue, alive on admission, cause of admission and final outcome. We also determined the overall relationship of vervet monkey admissions compared between the sexes and age categories. Linear regression was used to determine the annual trends of admission cases, and Chi-square goodness-of-fit tests were computed for monthly and seasonal trends. The values were presented as means (± SE) where applicable, and significance was set at $p < 0.05$ for all tests.

Survivability

To identify the factors associated with survivability of vervet monkeys, we used a binomial generalised linear model (GLM) with mixed effects regression as a function of covariates using the lme4 package (Bates et al. 2014) in R (R Development Core Team 2014). Binary classification of survivability was used as the dependent variable for the model classified as 'dead' (not alive: euthanised or dead) was '0' and 'alive' (survived: housed in captivity and released) represented '1' in the statistical model; to model the likelihood of survival. Five covariates (season, sex, age class and cause of admission) and location within the municipality were used as the fixed and random effects in the model, respectively (Supplementary Information in Table S2). Admission cases with information 'not recorded' and 'unknown' information were removed from the model (Table 1). To avoid issues related to multicollinearity among variables, we ran a Pearson correlation co-efficient

Table 1 Summary of demographic information of vervet monkey admissions to CROW from 2011 to 2018

Variable	Category	*N*	%
Admission source	Another WRC	102	10.0
	MOP	916	90.0
Municipality district	Central	476	46.8
	Inner west	271	26.6
	North	37	3.6
	Other	158	15.5
	Outer west	32	3.1
	South	44	4.3
Type of rescue	Rescue/callouts	259	25.4
	Drop-off	759	74.6
Alive on admission	No	170	16.7
	Yes	848	83.3
Sex	Female	376	36.9
	Male	521	51.2
	Not recorded	32	3.1
	Undetermined	89	8.7
Age	Adult	340	33.4
	Infant	204	20.0
	Juvenile	367	36.1
	Subadult	98	9.6
	Unknown	9	0.9
Cause of admission (COA)	MVS	313	30.8
	Unknown	217	21.3
	ABD	141	13.9
	Orphaned	140	13.8
	Other	47	4.6
	Pet	42	4.1
	Malicious	41	4.0
	ABM	39	3.8
	Shot	38	3.7
Final outcome	Captivity	278	27.3
	Died	243	23.9
	Euthanised	484	47.5
	Released	13	1.3

WRC Wildlife Rehabilitation Centre, *MOP* Member of Public, *MVS* Motor Vehicle Strike, *ABD* Attacked by Dog, *ABM* Attacked by Monkey

test before running our analyses (Graham 2003). We used the framework of Burnham and Anderson (1998) to select the best-fit candidate models of the interested predictors. Akaike's information criterion (AIC), standardised residuals, and observed vs. predicted values were examined to assess the model fit. We evaluated the significance of individual regression coefficients at the $\alpha = 0.05$ level. A combination of examining plots of residuals and AIC values was used to compare candidate models, and models were selected based on p values < 0.05. Models were ranked based on AIC values to identify the top-performing models with delta AIC values ≤ 2.00, providing sufficient evidence for the model (Burnham and Anderson 2002). Candidate models were ranked by the delta AIC values ≤ 2.00 criteria to guide the selection of the best-fit models that explain factors associated with the survivability of vervet monkeys. The relative importance of estimates for predictor variables were calculated by summing the Akaike weights (wi) across all the models in which the variable occurred (Burnham and Anderson 2002). Trend direction and effects of variables were evaluated based on average estimates of the parameter coefficient and its precision across the entire set of models (Burnham and Anderson 2002). Statistical analyses were performed in the programme R, version 4.3 (R Development Core Team 2014) using other supporting packages of lme4, including effects (Fox et al. 2022) and MuMIn (Bartoń 2013).

Results

Vervet monkey admissions

Between January 2011 and December 2018, a total of 1018 vervet monkeys were admitted to the wildlife rehabilitation centre, CROW, in eThekwini Municipality (Fig. 1). Vervet monkey admissions were significantly reported more by members of the public (90.0%, $N = 916$) than another wildlife rehabilitation centre (10.0%, $N = 102$) ($x^2_{(1)} = 650.880$, $p < 0.05$, Table 1). The distribution of vervet monkey admissions from districts in eThekwini Municipality differed significantly by geographical location with most cases admitted

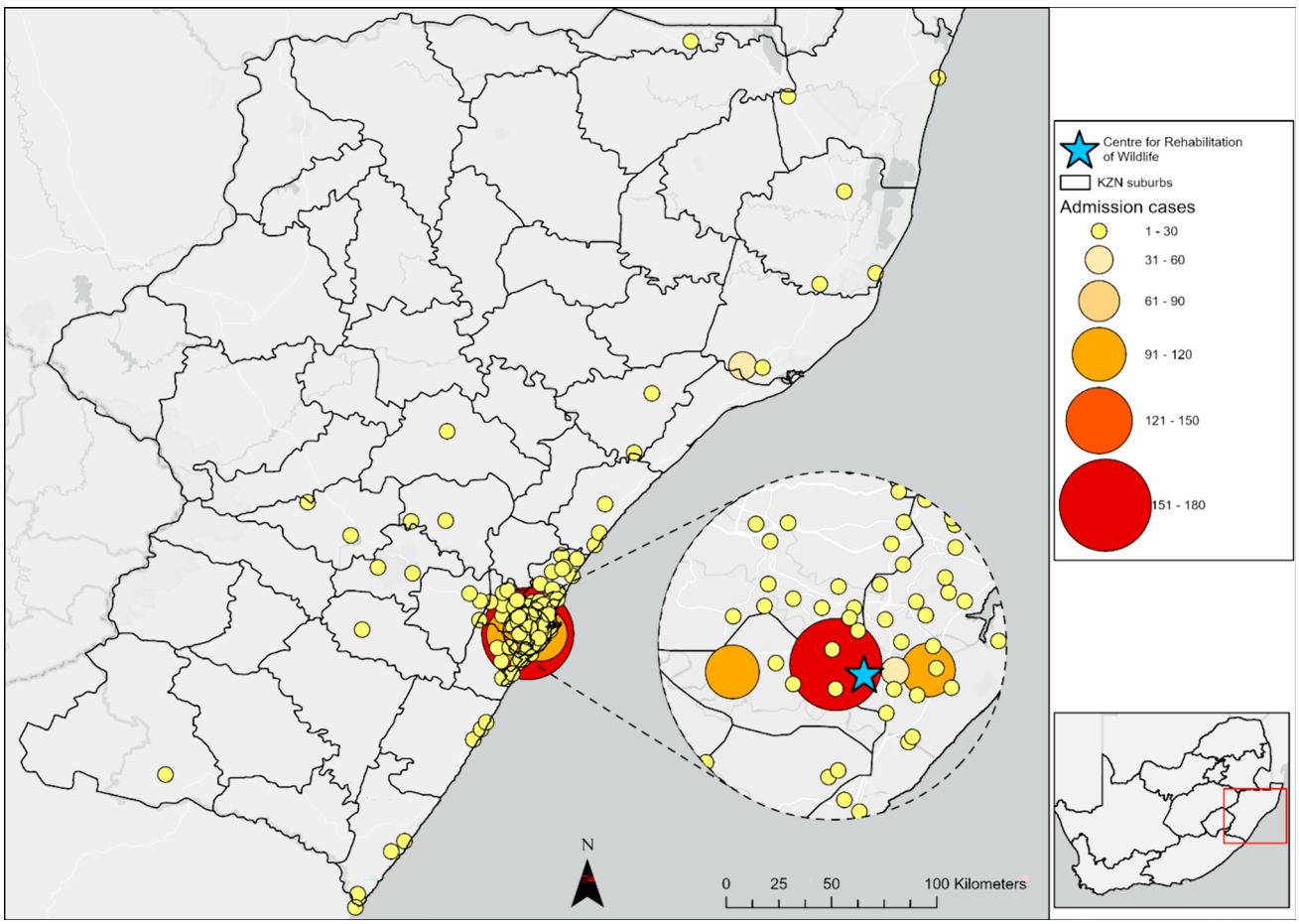

Fig. 1 Vervet monkey admission cases ($N = 1018$) located in the nearest suburb and reported to an urban wildlife rehabilitation centre in KwaZulu-Natal, South Africa, between 2011 and 2018 in the present study

from the Central (46.8% $N=476$), Inner West (26.6%, $N=271$) and other districts (15.5%, $N=158$), followed by relatively low admissions from South (4.3%, $N=4$), North (3.6%, $N=37$) and Outer West district (3.1%, $N=32$) ($x^2_{(5)} = 922.923$, $p<0.05$), Fig. 1, Table 1). There were far more rescues and callouts (74.6%, $N=759$) than drop-offs (25.4%, $N=259$) of vervet monkey admissions. On arrival of admission, vervet monkeys differed, with the majority arriving alive (83.7%, $N=848$) rather than dead (16.7%, $N=170$) (Table 1).

The sexes and age categories of vervet monkey admissions are summarised in Table 1. Overall, more male (51.2%, $N=521$) than female (36.9%, $N=376$) vervet monkeys were admitted to the centre. Juveniles (36.1%, $N=367$) were the largest age class admitted, followed by adults (33.4%, $N=340$), infants (20.0%, $N=204$), subadults (9.6%, $N=98$ and unknown age (0.9%, $N=9$). There were significant differences between the sexes and age categories of vervet monkey admissions ($x^2_{(1)}= 245.580$, $p<0.05$, Fig. 2, Supplementary information in Table S3). The final outcome of vervet monkeys admitted differed significantly, with most being euthanised (47.5%, $N=484$), followed by those housed in captivity (27.3%, $N=278$), died (23.9%, $N=243$) and released (1.3%, $N=13$) ($x^2_{(3)}= 438.809$, $p<0.05$), Table 1).

Trends in admissions

The number of vervet monkeys admitted ($N=1018$) increased significantly annually during the study period ($F_{(1,6)}=56.233$, $R^2=0.904$, $p<0.05$, Fig. 3, Supplementary Information in Table S4), with an annual mean intake rate of 127.3 ± 21.34 SE admissions per annum. We observed the highest increase change of 82% in admission cases in 2015. Total monthly admission cases were significantly different ($x^2_{(11)} = 44.790$, $p<0.05$), with mean monthly admission cases of 84.8 ± 5.37 SE, peaking in November and December and then dropping in January and February (Fig. 4, Supplementary Information in Table S4).

We observed seasonal admission trends in the admittance of vervet monkeys: spring (27.0%, $N=275$), summer (26.5%, $N=270$), autumn (23.6%, $N=240$), winter (22.9%, $N=233$), Supplementary information in Table S4, Fig. 4). Although the number of admissions did not differ between seasons ($x^2_{(3)}= 5.238$, $p=0.155$, Fig. 4, Supplementary Information in Table S4), seasons did have a significant effect on the sex, age class, district of the municipality and the final outcome of vervet monkey admission cases (Fig. 5, Supplementary Information in Table S5). The number of admissions for seasons compared with age categories, sexes, district of the municipality, and final outcome are summarised (Fig. 5, Supplementary Information in Table S6). Male vervet monkeys were admitted mostly in autumn (53.0%, $N=143$) than spring (44.4%, $N=122$), whereas most females were admitted mostly in spring (45.8%, $N=126$) than winter (32.5%, $N=78$). In comparison, juvenile vervet monkey admittance was highest in winter (52.1%, $N=125$) and autumn (40.4%, $N=109$) and lowest in summer (22.3%, $N=52$). In contrast, infant vervet monkey admittance was highest in summer

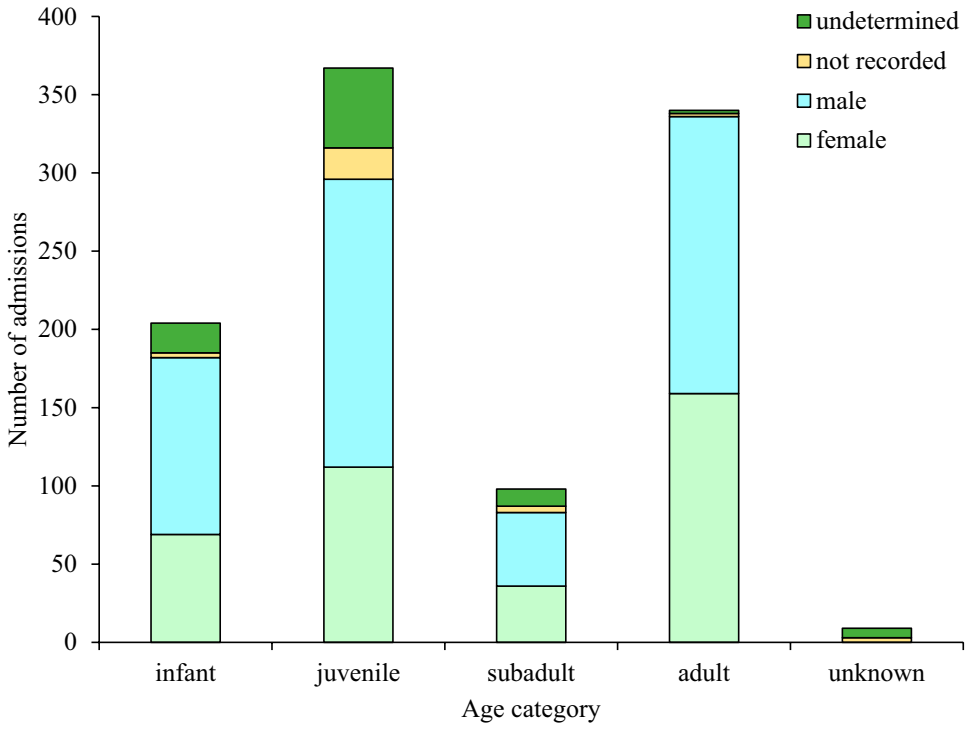

Fig. 2 The number of admissions of vervet monkey age categories grouped by sexes reported to an urban wildlife rehabilitation centre between 2011 and 2018 in the present study

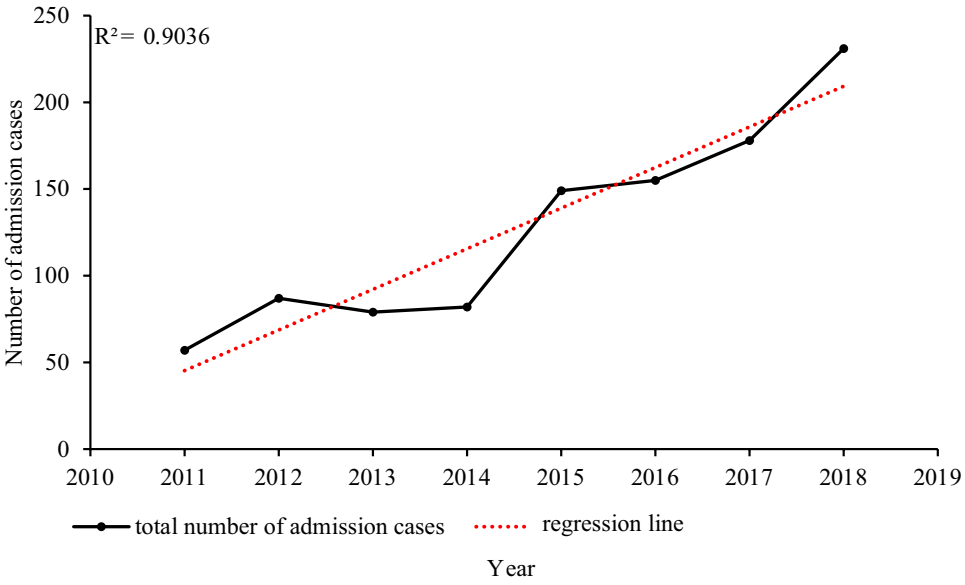

Fig. 3 Annual total number of admissions of vervet monkeys reported to an urban wildlife rehabilitation centre between 2011 and 2018. A linear regression trendline ($y = 23.43x + 47.070$) indicates an increasing number of admissions of vervet monkeys per year

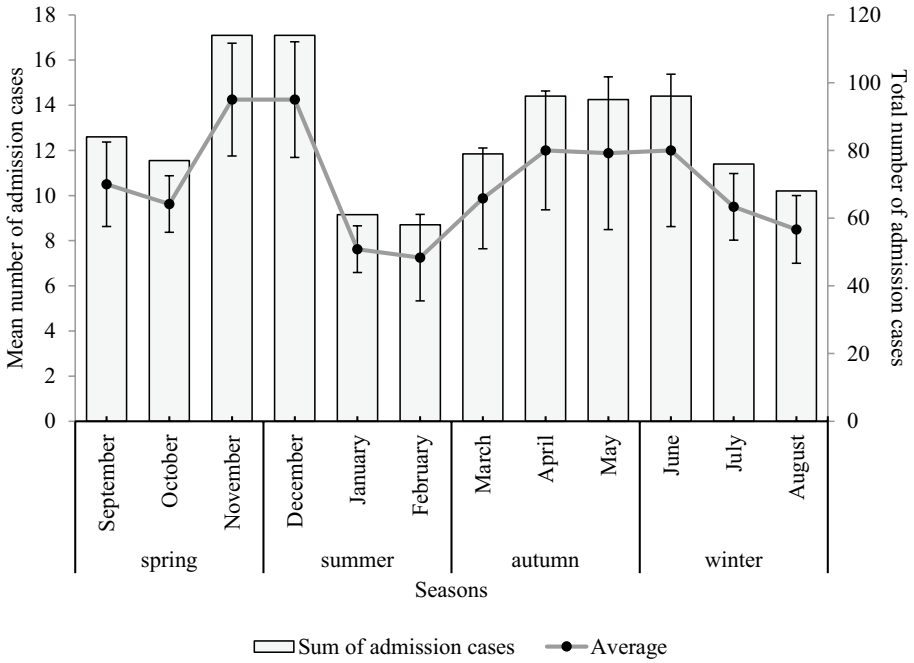

Fig. 4 Mean (±SE) and the total number of admissions (sum) of vervet monkeys reported monthly and seasonally to an urban wildlife rehabilitation centre between 2011 and 2018

(36.5%, $N = 85$) and spring (30.2% $N = 83$) and lowest in winter (2.9%, $N = 7$). Adult vervet monkey admittance had the most cases in autumn (36.3%, $N = 98$) and spring (33.1%, $N = 91$), while subadult vervet monkey admittance was low in all seasons. A substantial number of juveniles could not be sexed because of extreme injuries to the body.

The highest reported admission cases came from the Central district of the municipality during autumn (53.7%, $N = 145$), followed by the Inner West (28.9%, $N = 78$); however, other districts typically had low admission cases in autumn and their highest admission cases in spring (20.2%, $N = 57$). There were relatively few admissions throughout the year from the municipality's South, North, and Outer West districts. The final outcome for autumn had the highest cases of euthanasia (59.3%, $N = 160$) and deaths (27.7%, $N = 75$), whereas spring had the highest number of vervet monkeys housed in captivity (40.7%, $N = 112$). Although there were relatively few releases across the seasons (1.3%, $N = 13$), most releases occurred in the winter (2.1%, $N = 5$).

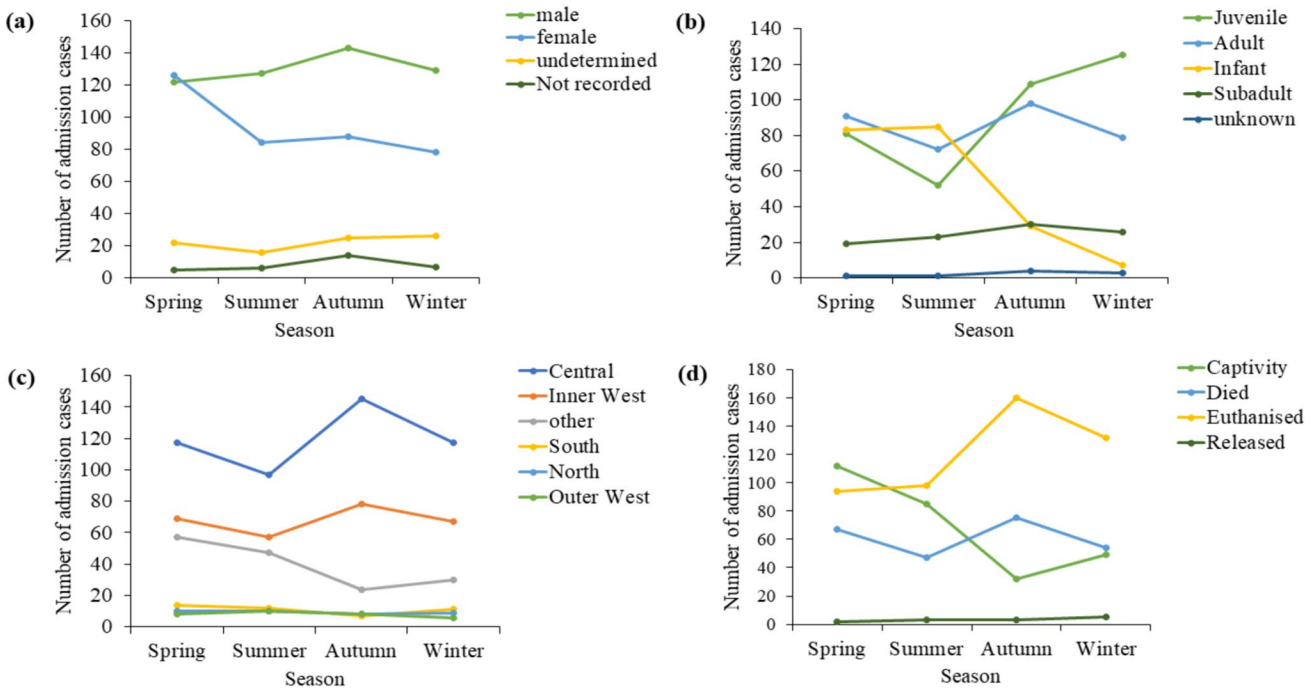

Fig. 5 Seasonal differences in admissions of vervet monkeys to an urban wildlife rehabilitation centre for **a** sex, **b** age class, **c** district of the municipality and **d** the final outcome reported between 2011 and 2018

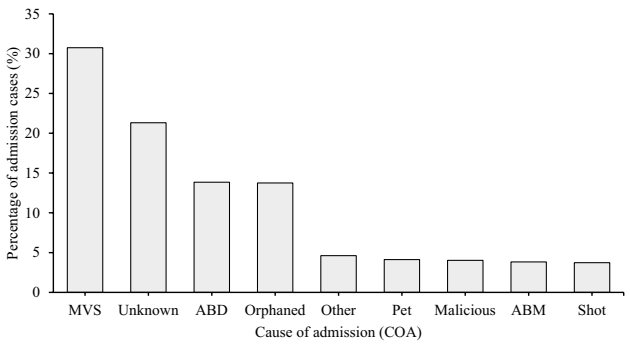

Fig. 6 Frequency of the causes of admissions (%) of vervet monkeys reported to an urban wildlife rehabilitation centre between 2011 and 2018

Causes of admission

The most prevalent cause of vervet monkey admissions was motor vehicle strikes, accounting for 30.8% ($N = 313$) of admission cases, followed by attacks by dogs at 13.9% ($N = 141$). Notably, motor vehicle strikes doubled in frequency compared to the second leading cause of admission. Additional information regarding admission causes can be found in Fig. 6 and Table 1. Statistical analysis revealed significant differences among the various causes of admission ($x^2_{(8)} = 689.684$, $p < 0.05$). Consistent with the overall increase in vervet monkey admissions over the study period (2011–2018), the number of admissions due to each cause increased annually ($x^2_{(56)} = 93.725$, $p < 0.05$, Supplementary information in Fig. S2a), monthly ($x^2_{(24)} = 160.939$, $p < 0.05$, Supplementary Information in Fig. S2b), and seasonally (Fig. 7, Supplementary Information in Table S6). Motor vehicle strikes, dog attacks, malicious acts, and attacks by other monkeys were most common in autumn, while cases of orphaned, other, and pet admissions peaked in spring. Incidents involving shooting and unknown causes were highest in winter (Supplementary Information in Table S6). Specifically, motor vehicle strikes were most prevalent in autumn (37.4%, $N = 117$) and least in summer (21.7%, $N = 68$), while orphaned vervet monkeys were more frequent in spring (47.1%, N = 66) and summer (44.3%, $N = 62$), with minimal occurrences in autumn and winter (4.3%, $N = 6$ each) (Fig. 7, Supplementary Information in Table S6).

Survivability of admission

After removing information that was labelled 'not recorded' and 'unknown' from the dataset, 894 records were used in the analyses (Fig. 8). For the survivability of vervet monkeys on admission, the two best models were identified based on ≤ 2.00 delta AICc (Table 2). The relative variable importance across the models were Age (wi = 1), Condition on admission (wi = 1), Season (wi = 1) and Sex (wi = 0.57). Coefficient estimates of the top two models suggested an increase in survivability of vervet monkeys

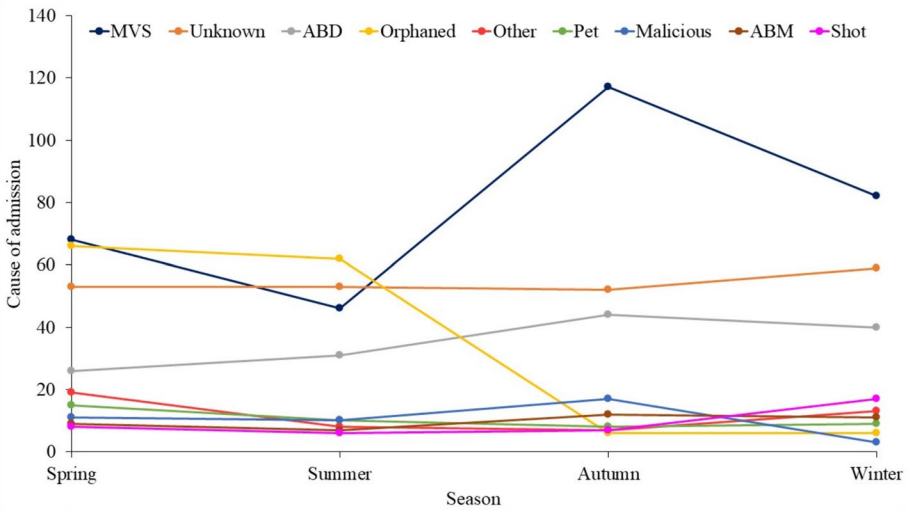

Fig. 7 Seasonal differences of admissions of vervet monkeys showing the cause of admissions reported to an urban wildlife rehabilitation centre between 2011 and 2018

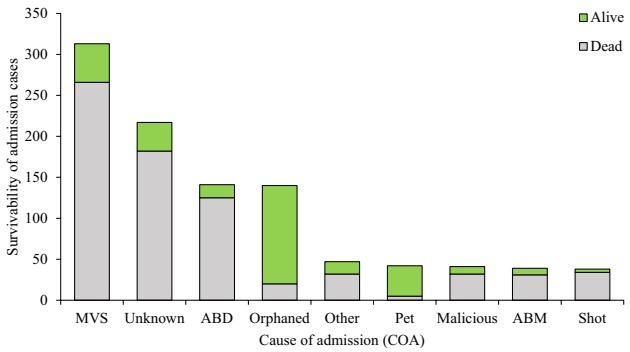

Fig. 8 Survivability of vervet monkey admissions admitted to an urban wildlife rehabilitation centre between 2011 and 2018 in the present study

admitted as: infants ($\beta = 1.83 \pm 0.35$ SE, $p < 0.001$), post-pet attack ($\beta = 3.59 \pm 0.62$ SE, $p < 0.001$) during spring ($\beta = 1.19 \pm 0.30$ SE, $p < 0.001$). Survivability of admitted male vervet monkeys was higher than that of females but not significantly ($\beta = 0.33 \pm 0.20$ SE, $p = 0.11$). Overall, GLM mixed model coefficients showed a significant relationship between the probability of survivability of vervet monkeys admitted to CROW facilities with age, condition on admission and season (Fig. 9).

Table 2 The top generalised linear mixed effect multi models showing the effects of covariates on the survivability of vervet monkeys (*Chlorocebus pygerythrus*) admitted to CROW facilities from 2011 to 2018

Selected models	*df*	logLik	AICc	Delta AICc	Weight
Age + condition on admission + season + sex	17	− 346.27	727.24	0	0.57
Age + condition on admission + season	16	− 347.6	727.82	0.58	0.43
Age + condition on admission	13	− 357.25	740.91	13.67	0
Age + condition on admission + sex	14	− 356.25	740.98	13.74	0
Condition on admission + season + sex	14	− 366.07	760.62	33.37	0
Condition on admission + season	13	− 368.49	763.39	36.14	0
Condition on admission + sex	11	− 374.75	771.8	44.55	0
Condition on admission	10	− 376.57	773.39	46.15	0
Age + season + sex	9	− 392.81	803.82	76.58	0
Age + season	8	− 394.56	805.27	78.03	0
Age + sex	6	− 409.88	831.86	104.62	0
Age	5	− 411.05	832.17	104.93	0
Season + sex	6	− 462.67	937.44	210.2	0
Season	5	− 467.29	944.65	217.41	0
Sex	3	− 490.03	986.1	258.85	0
Null	2	− 493.04	990.1	262.86	0

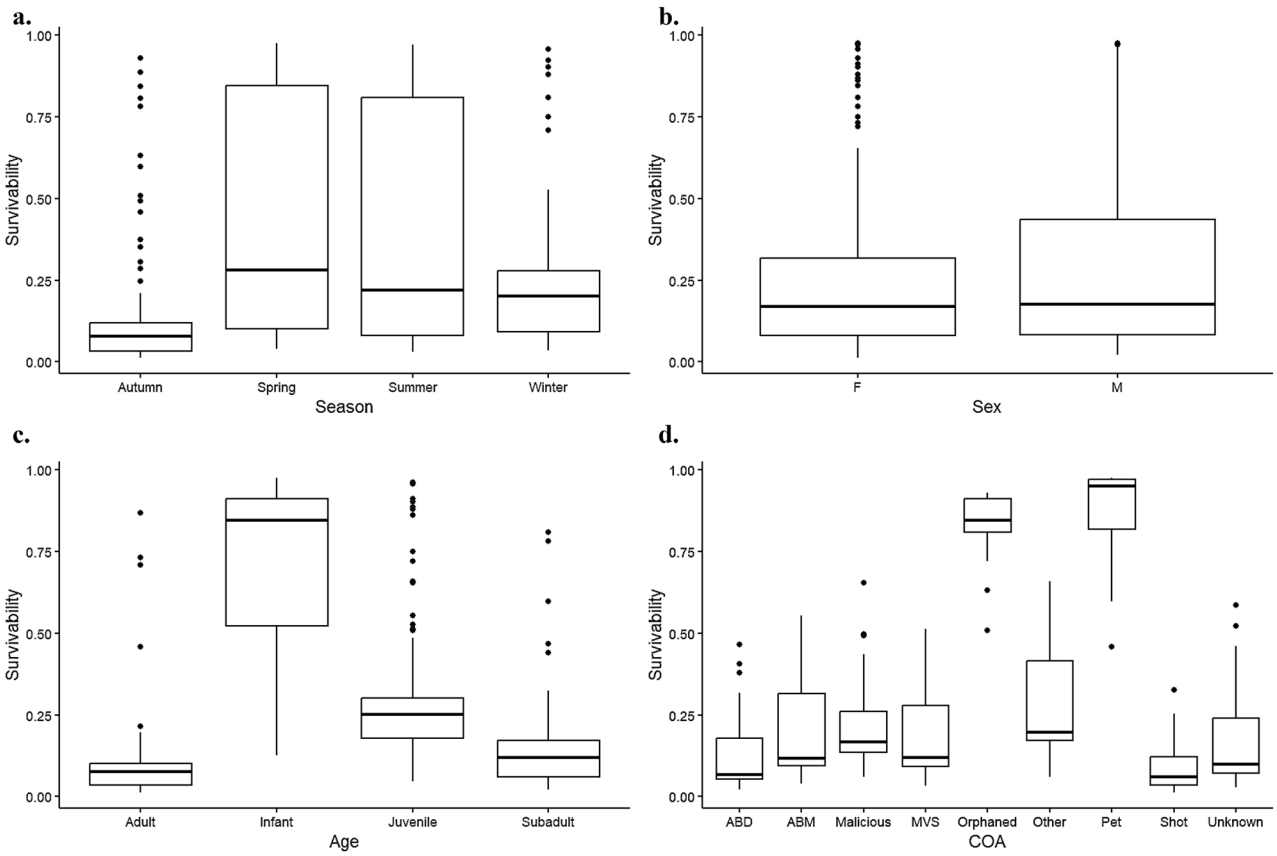

Fig. 9 Generalised linear mixed effect model (±95% confidence intervals) on the survivability of vervet monkeys (*Chlorocebus pygerythrus*) admitted to CROW facilities from 2011 to 2018 and covariates (season (**a**), sex (**b**), age (**c**) and COA (**d**) from the best models (≤2.00 ΔAIC)

Discussion

Vervet monkey admissions

We present data on 1018 admission cases of vervet monkeys admitted to a wildlife rehabilitation centre, CROW, in Durban, eThekwini Municipality, KwaZulu-Natal, South Africa, between January 2011 and December 2018. Our study aimed to understand the trends in key factors contributing to conflict events between humans and vervet monkeys, and the collective interactions of aspects such as season, sex, age, geographical location, causes of admission, and survivability to determine how particular HWC influences their demise. The long-term data explained the plight and conditions of vervet monkeys in urban-forest landscape mosaics such as eThekwini Municipality. Therefore, providing evidence to support conflict mitigation and recommendations for 'problem' species in a shared landscape is critical to avoid the compromised welfare and local extinction of the species.

We found a considerable number of members of the public reporting injured vervet monkeys to the centre through telephonic calls to the centre's main contact number. Although public perceptions of vervet monkeys are divided on the likeability of this 'pest' species (Patterson et al. 2017), people made an effort to report injured vervet monkeys to the centre. More notably, 25% of people went to the extent of dropping off an injured vervet monkey at the centre for treatment. These findings support the suggestion that some people perceive this primate positively and would help an animal in distress (Alexander 2000; Mormile and Hill 2017). Other wildlife rehabilitation centres like the Society for the Prevention of Cruelty to Animals (SPCA) and other primate or wildlife rehabilitation centres from KwaZulu-Natal also used CROW as a drop-off point for vervet monkeys (KP unpublished data). Since these centres were often at full capacity or unable to accommodate the vervet monkeys at the time (Taylor Hill pers. comm.), CROW was the nearest and biggest centre in terms of space to assist. The central district of eThekwini Municipality was the location reported to have the highest number of vervet monkey admission cases. The proximity of the centre to most urban dwellers living in the central district and increased public awareness could explain the high admission cases as depicted in the vicinity closest to CROW. The number of vervet monkeys admitted alive to the centre was significant at 83.7%. This further asserts the sentiments of concern from the greater

public of KwaZulu-Natal, that they would rather assist an injured or dying animal than see it suffer.

Over the study period, significantly more male than female vervet monkeys, across all age categories, were reported to the centre, possibly because of their home range size and activities. This is of concern as studies on vervet monkey troops in the wild have shown higher female to male sex ratios (Pasternak et al. 2013). Vervet monkeys are sexually dimorphic, with males occupying larger home ranges than females in terms of feeding and mating habits, which could have contributed to higher admissions (Isbell et al. 1990; Patterson et al. 2019; Pillay et al. 2023). Furthermore, females are philopatric and stay bonded within the troop because of their social structure, often moving close with the younger individuals, while dominant males often move ahead of the troop (Teichroeb et al. 2015). Juveniles were the highest reported age class of vervet monkeys, as similarly documented by Wimberger and Downs (2010). Teichroeb et al. (2015) reported the spatial positioning of juveniles is often left behind at the back of the troop because they are still scrounging for leftovers and busy eating. This can be hazardous in urban areas as there are numerous anthropogenic risks. We also note that a substantial number of juveniles could not be sexed because of extreme bodily injuries, further exacerbating the danger vervet monkeys face in the urban-forest landscape mosaic. Juvenile males were the highest admitted cases, which can be attributed to their risk-taking behaviour (Fairbanks 1993; Blaszczyk 2017). During peak times of wildlife admissions, some vervets' sex or age classes were not recorded (pers. comm.), assuming the centre's rush of intakes at the time.

Most vervet monkeys that were severely injured on arrival died in transition or had to be euthanised. Rehabilitators at the centre are tasked with the decision of euthanasia. This humane solution is regarded as the most viable option to minimise the pain or suffering, specifically when the animal's life cannot be saved, an illness cannot be cured, or there are not enough resources available to accommodate each sick or injured animal (Hanger and Tribe 2005). Furthermore, severely injured vervet monkeys could not be released back into the wild if they could not survive using their natural or physical capabilities. Mortality is inevitable, considering failed medical treatment or unresponsive treatment attributable to the severity of illness or injury. On the other hand, 27% could be rehabilitated and kept alive at the centre for recuperation until eventual release. In contrast, no more than 1% could be immediately released back into the wild if healthy and unharmed. Admitted vervet monkeys that were to undergo the rehabilitation process and release, and the vervet monkeys that were immediately released back into the wild were returned to the areas from which they were reported to have been removed and subsequently admitted to the rehabilitation centre.

Trends in admissions

As predicted, we did observe significant temporal and seasonal trends across the years and months of vervet monkeys admitted to the centre. The annual increase in admissions demonstrates the scale of the human-vervet problem in the urban-forest mosaic landscape of eThekwini Municipality, which justifies an effective management proposal for this primate species. Increasing admission cases can be linked to urbanisation and the reduction of natural habitats or managed green spaces for vervet monkeys (Alexander et al. 2021) as well as negative human interactions. There has been a constant increase in urban development infringing on green ecosystems because of population growth in eThekwini Municipality (Otunga et al. 2014). Furthermore, unemployment and poverty place low-income individuals living in high densities in informal settlements in environmentally sensitive areas, whereas former sugar cane farms are being converted to eco-estates, often for the affluent (eThekwini Municipality 2021). Land-use change is the biggest driver of habitat loss of green areas and contributes to human-vervet conflict, which will continue to increase as trends show (Taylor-Brown et al. 2019; Burroughes et al. 2021; Dessalvi et al. 2021).

Overall, reported admission cases were highest in November and December, accounting mainly for human activities and the behaviour of vervet monkeys. During these months, the longer hours of sunlight increase vervet monkey activity (McFarland et al. 2014; Thatcher et al. 2019a). Vervet monkeys' activity budgets are generally higher in the wet and warmer months because of increased foraging, socialising, and active birthing events (Baldellou and Adan 1998; Canteloup et al. 2019). Additionally, December is a peak period for holidaymakers, and the coastal province of KwaZulu-Natal brings in high volumes of tourists (Wyllie and Tifflin 2020). The influx of people and outdoor recreational activities in the area increases direct interactions with vervet monkeys. Additionally, there is an abundance of anthropogenic food scraps during this period, resulting in vervet monkeys foraging openly in garbage tip sites, aggravating HWC (Newsome and Van Eeden 2017). Since outdoor recreational activities are elevated during the festive period, more cases could have been reported to the centre. The lowest number of admission cases were reported in February, and this could be caused by the warmest month in eThekwini Municipality, with an average high temperature of 26.5 °C and the month with the most sunshine, an average of 8.5 h (SAWS 2021). The extreme heat deters the movement of vervet monkeys, and resting is greater, possibly reducing the overall admissions since their movement generally decreases during the hotter months of January and February (McFarland et al. 2014; Thatcher et al. 2019a).

We observed a seasonally distinct temporal pattern of admissions, with a peak in admission cases in spring and the lowest in winter, as observed in the study by Healy and Nijman (2014). Taking into account the sex and age categories of vervet monkeys, only spring had more females than males admitted, possibly because of the birthing season and the added complications experienced by females, particularly during parturition (Fairbanks and McGuire 1984; pers. comm.) Male vervet monkeys have more flexibility over their ranging behaviour and are known to disperse from their natal troops before reaching sexual maturity, especially during the breeding season (De Moor and Steffens 1972; Cheney and Seyfarth 1983; Schoof et al. 2009) accounting for high admission cases in autumn as revealed in this study. Adult vervet monkeys' admittance was highest in spring and lowest in summer, while infants' admittance was highest in summer and lowest in winter, indicative of the gestation and birthing periods occurring in the warmer, wetter season, with the fewest births occurring in winter. Juveniles admitted in autumn and winter were the highest across all age categories and seasons, probably because of food scarcity or emigration of lower-ranking individuals (Cheney and Seyfarth 1983; Van Vuren and Isbell 1996). The general admission of adults across the seasons could have affected the population of adults in the wild. This might have led to juveniles and subadults fending for themselves and displaying risky behaviour (Fairbanks et al. 2004). The central and inner west districts of eThekwini Municipality accounted for similar admissions patterns throughout the seasons, peaking in autumn. These districts consist of urban and suburban gardens with forest patches that vervet monkey troops frequent (Patterson et al. 2018; Zungu et al. 2020). In autumn, there was a decrease in admissions from outside eThekwini Municipality and other municipalities, further emphasising those urban districts accounted for more admissions in vervet monkeys' breeding and dispersal season. Low admissions could also be accounted for considering the locality of the centre, suggesting that farther away the distance of the centre led to lower reported incidences. The geographic landscape and human population density are less concentrated away from the central district of eThekwini Municipality, thus suggesting less HWC. The final outcome of vervet monkeys euthanised or that died after admission was highest in autumn and winter; respectively, they could not survive because of the severity of their injuries. Captive vervet monkeys were highest in spring, suggesting that it was possible to save individuals as their injuries were not fatal. Determining seasonal effects on the final outcome can assist rehabilitators with pre-emptive decisions on wildlife rehabilitation, especially in urban areas (Sherman et al. 2020).

Causes of admission

The most common cause of vervet monkeys' admission was motor vehicle strikes. Prior studies have documented vehicle collisions as the leading cause of primate deaths (McLennan and Asiimwe 2016; Hetman et al. 2019). This has also been documented at a specialist vervet monkey rehabilitation centre in Limpopo Province, South Africa (56%, $N = 50$) (Healy and Nijman 2014). High motor vehicle strikes can be attributed to urban areas typically associated with higher road densities. In addition, the vervet monkeys use roads as pathways for troop movements in the urban-forest mosaic landscape (Patterson et al. 2018). Our study reported a considerably high number of admissions in autumn. During this time, vervet monkeys are particularly vulnerable to the risk of collisions with vehicles as they expand their home ranges in search and fight for females (Cheney and Seyfarth 1990). In autumn, the biggest driver of home ranging behaviour is breeding for males and females (Henzi and Lucas 1980), resulting in strikes in high-traffic areas. The second most reported admissions were termed 'unknown'. Unknown causes of vervet monkey admissions included already sickly, emaciated monkeys, and weak when admitted, with no historical context of the admission documented. Unknown causes of admissions were previously documented in wildlife rehabilitation centres (Cheney and Seyfarth 1990; Molina-Lopez et al. 2017; Garcês et al. 2019). The third highest cause of admissions was domestic dogs attacking vervet monkeys. Pet attacks by dogs were also previously documented in vervet monkey admissions and are another source of anthropogenic pressure on vervet monkeys in the urban mosaic landscape (Healy and Nijman 2014; Long et al. 2020). Most dog attacks are fatal (Fernandes et al. 2020), with kidney lesions common when dogs attack primates. The highest attacks by dog cases were in winter, probably because of relatively low natural food to forage, which led to vervet monkeys entering gardens and homes with pets searching for food scraps (Thatcher et al. 2019b). Considerably, most injurious and fatal dog attacks on primates occurred near human settlements, similar to our study (Anderson 1986). Surprisingly, Patterson et al. (2018) revealed increased levels of vervet monkeys playing in gardens with dogs in the urban-forest landscape mosaic, possibly attributing to the high admission cases documented in this study. Presently, the primary predator of vervet monkeys is domestic dogs, specifically in human-modified areas (Teichroeb et al. 2015). The fourth highest cause of admissions was orphaned vervet monkeys, recorded highest during the warmer seasons of spring and summer and when mostly infants, typical of their natural birthing cycle, were admitted (Fairbanks and McGuire 1984; Healy and Nijman 2014). Orphaned vervet

monkeys came into the centre when their mothers were directly impacted by the various causes of admissions and were immediately taken to the nursery for hand-rearing. Orphans were housed in captivity with other rehabilitating monkeys for release when they were older.

For each of the causes of admissions: other, pet, malicious, attacked by another monkey, and shot, accounted for less than 5% in this study. However, this still showed the challenges that vervet monkeys face in urban areas. The cause of admissions regarded under 'other' comprised of vervet monkeys admitted for being caught or stuck in a fence, stung by bees, fell from an object like a tree, wall, or building, electrocuted by a transformer or electrical wiring, and/or pregnancy complications experienced by females who had difficulties during birth. These result from the human-modified landscape. Our study also found that some people kept vervet monkeys as pets, often found lost, abandoned, or sold for money. In South Africa, removing and keeping wild animals as pets is illegal and detrimental to the welfare of wildlife, especially when an animal becomes habituated to the presence of people (Grobler et al. 2006; Guy and Curnoe 2013; Healy 2017). Once habituated, any wild animal can experience difficulties being released back into the wild because it has lost its fear of humans, and its instincts to survive in the wild and could have developed diseases that can infect wild populations (Burton and Doblar 2004). Although infant vervet monkeys are cute and appealing to keep, people should avoid hand-rearing at all costs and rather report this to the national conservation authority or rehabilitation centre. The public does not have adequate support and equipment to hand-rear infant wildlife. The centre reported some vervet monkeys brought to the centre wearing human diapers and playing with infant toys. This happens typically when pet vervet monkeys become unmanageable and show aggression (pers. comm.). Admission cases also recorded malicious harm or injury inflicted directly by a person through a physical attack, poisoning, and painting. Although these were a few cases, they highlighted animal cruelty and the extent to which people will go to deal with the 'problem' of vervet monkeys.

A few cases of admissions of vervet monkeys attacked by another monkey were also brought to the centre, and this generally took place during the mating seasons of autumn when males dispersed or attempted mating with females within the troop. Aggression between males and females were observed in wild populations, which could explain the attacks on each other (Cheney 1981). Vervet monkeys were admitted for being shot at with pellet guns. On several occasions when vervet monkeys were admitted for any of the above reasons, x-rays showed metal pellets lodged in the body. In some cases, vervet monkeys can survive with the pellets lodged in their flesh without deterring their natural abilities; however, lethal shots to the head or spine result in death (pers. comm.).

Survivability

The binomial GLM results established a relationship between anthropogenic pressures and the survivability of vervet monkeys admitted to the centre. Although several significant factors (season, age, cause of admission) for whether a vervet monkey was dead or alive at the end of the admission process, the predictor responsible for most admission cases surviving admission was the cause of admission being a pet. Additionally, the chances of surviving were high for being attacked by a dog, other, malicious, or shot. Using models to predict admissions can assist rehabilitation centres like CROW in determining, before the process of admission, whether an animal will survive (Molony et al. 2007; Maphalala et al. 2021). Notably, of the 83.7% admitted alive at the beginning of intake, only 34.2% survived.

Admission record data from an urban wildlife rehabilitation centre in eThekwini Municipality of South Africa highlighted the trends, seasons, causes and survivability of an Old World primate species that encountered multiple anthropogenic challenges in the urban-forest landscape mosaic. There exists a preconceived notion from the public in eThekwini Municipality that the population of vervet monkeys is expanding. Though we did not quantify the total population of vervet monkeys in eThekwini Municipality to determine the effects of mortality on the overall population, further studies are required. An overabundance of vervet monkeys cannot explain the high levels of human-vervet monkey conflict, but rather, there is an increased presence of vervet monkeys in human landscapes because of opportunities created by artificial food sources vervet monkeys have adapted to live in close proximity to humans and human-modified landscapes (Fuentes 2006). Instead of opposing wildlife interactions in urban areas, the most promising future approach will incorporate resilience to conflict via human governance and education. Educating people on how to live with vervet monkeys could reduce conflict, specifically in urban, industrial, and greater suburbia, and this was noted by people reporting cases actively throughout the years. CROW has played an active role in community involvement and active education initiatives (pers. comm.). Finally, information on the number of monkeys released into the natural environment per year from CROW was not available because of the limitations in data recording and tracking procedures for the release of vervet monkeys in long-term rehabilitation.

Conclusions

This retrospective study found an increase in the trends of admission records of vervet monkeys in the urban forest mosaic landscape of eThekwini Municipality in South Africa over eight years. Previous studies have highlighted vervet monkeys at rehabilitation centres but never from one established in the central region of an urban area, with long-term data highlighting that HWC was lacking in the scientific domain. Information gathered from admission records provides the support needed to determine how vervet monkeys are impacted in urban areas, particularly HWC. Additionally, admission records in this study report on hot-spot areas of eThekwini Municipality and assess the importance of wildlife rehabilitation centres in urban areas. Given the above, comprehensive data collated and collected from wildlife rehabilitation centres provide large, extensive databases with opportunities for further analysis through research. Scientists and animal welfare organisations, who work independently can provide valuable evidence for wildlife management through shared conservation efforts.

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Author contributions KP and CTD authors contributed to the study's conception and design. Data collection and analyses were performed by KP and JS. KP drafted the manuscript preparation. CTD and JS edited the manuscript, and all authors read and approved the final manuscript.

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Data availability The data that support the findings of this study belong to CROW and the University of KwaZulu-Natal. They are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no conflicting nor competing interests.

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Consent to participate Not applicable.

Consent for publication Not applicable.

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