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Impact of electric shock and electrocution on populations of four monkey species in the suburban town of Diani, Kenya

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Corresponding Author:	Pamela May Karen Cunneyworth, MA Colobus Conservation Diani, KENYA
Corresponding Author Secondary Information:	
Corresponding Author's Institution:	Colobus Conservation
Corresponding Author's Secondary Institution:	
First Author:	Pamela May Karen Cunneyworth, MA
First Author Secondary Information:	
Order of Authors:	Pamela May Karen Cunneyworth, MA
	Alice M. Slade, MSc
Order of Authors Secondary Information:	
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Abstract:	We investigated 320 cases of electric shock and electrocution between 1998–2019 in four sympatric species of monkeys: Peters's Angola colobus (*Colobus angolensis palliatus*), Zanzibar Sykes's monkey (*Cercopithecus mitis albogularis*), Hilgert's vervet (*Chlorocebus pygerythrus hilgerti*), and the Southern yellow baboon (*Papio cynocephalus cynocephalus*). These represent 16% of the total cases (320/2,017) that community members reported to a local conservation organization in the oceanside suburban town of Diani, in southeast Kenya. Deaths occurred in 73% (*N* = 233) of the cases. The number of cases did not increase through the study period, presumably because of the mitigations jointly implemented by the power distribution company and the conservation organization, offsetting the risks associated with electrical infrastructure expansion. Colobus accounted for 80% (*N* = 256) of cases, representing ~4.6% of the population annually, which is considered greater than what is sustainable. For the colobus, adult males were shocked or electrocuted more than expected while all other age-sex classes were involved in proportion to the population structure. Frequency of cases was low for Sykes's monkeys (13%, *N* = 42), vervets (5%, *N* = 16), and baboons (2%, *N* = 6). Our findings assert that electrical infrastructure differentially affects species; those that are more arboreal and individuals ≥8 kg, are at higher risk of injury and death. Minor injuries are expected to be more common than reported, which raises welfare concerns. These results provide an understanding of the electrical infrastructure threat to primates with varying behavioral and morphological attributes and have far-reaching implications for conservation planning.

Impact of electric shock and electrocution on populations of four monkey species in the suburban town of Diani, Kenya

Pamela M.K. Cunneyworth[a] and Alice M. Slade[b]

Corresponding author: Pamela Cunneyworth

[a]Colobus Conservation
P.O. Box 5380
Diani, 80401
Kenya
+254 (0)724972543
pam@colobusconservation.org

[b] Faculty of Health Sciences
University of Bristol
5 Tyndall Avenue
Bristol, UK
BS8 1UD
+44 (0) 7481750597
alicemslade@gmail.com

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Supporting data

Supporting data will be supplied to IJP as supplemental files.

REVIEWER COMMENTS	REVISION
Keywords	Added: Electric shock
Abstract:	Revised: These represent 16% of the total cases (321/2,017) that community members reported to a local conservation organization in the oceanside suburban town of Diani, in southeast Kenya.
	Deleted: Electric shock and electrocution affect at least twenty-seven primate species; however, studies on how electrical infrastructure impacts populations are rare.
Analysis:	Deleted: of landscapes
L212	Deleted: for the four species of monkeys (colobus, Sykes's monkey, vervet, and baboon)
The hypotheses and predictions need some work, to ensure that the hypotheses are genuine theoretical explanation for what you predict you will observe - please see the details below.	Revisions made as noted below
I also found some of the statistical analysing confusing - again, the details are below.	Revisions made as noted below
Use mass or body mass, not weight, throughout, unless you actually mean weight (the force exerted on an object by gravity).	Revised: weight to body mass in all instances
Please check the relationship between your hypotheses and predictions and the discussion. Numbering the hypotheses might help the reader follow your argument.	Revisions made as noted below
L35: do you need “prognostic”? It’s not a very familiar word	Revised “prognostic” to survivorship
LL59-70: the reasoning underlying your predictions is not theoretical, so you don’t really test hypotheses. In at least some cases you can easily transform your reasoning into a hypothesis. For example, the theory underlying this prediction: “We also predicted that there would be species differences; cases involving the arboreal colobus and Sykes's monkeys would be higher in number than cases involving the more terrestrial vervets and baboons” involves the relative risk to arboreal and terrestrial species, and you can spell this out. Then explain clearly in the methods how your analyses test your predictions (e.g., to test the prediction that ..., we ...)	Revised: To address this, we investigated the hypotheses: 1) If members of the community are more likely to report an individual once injuries are apparent and presumably life-threatening, we predict that the percentage of reported cases resulting in the death of the monkey would be higher than those that survived. 2) If the number of electric shock and electrocution cases increases with expansion of the electrical infrastructure, we predict that the number of annual cases reported would increase through the study period concurrently with Diani’s growth. 3) If there is a difference in the relative risk to arboreal and terrestrial species, we predict that there would be species differences; cases involving the arboreal colobus and Sykes's monkeys would be higher in number than cases involving the more terrestrial vervets and baboons. 4) As electrical infrastructure related injuries and deaths are caused by the individual creating a short-circuit typically between two cables, we predict that electric shocks and electrocutions would occur differentially across the age-sex classes according to body mass as larger individuals are more likely to cause short-circuits. 5) If months with lower rainfall increase the daily path length and consequently monkeys use electricity cables, poles, and transformers more frequently as they respond to variation in resource distribution

	and intragroup feeding competition, then we predict an inverse relationship between rainfall and the number of cases.
L67: you can't test a prediction of similarity using null hypothesis statistical tests, you can only test for difference	Hypotheses revised noted above.
LL67-70: here, you can rewrite the first sentence as the hypothesis that underlies the prediction. Perhaps "Lastly, if vegetation growth around the electrical infrastructure during the months with higher rainfall creates increased opportunities for monkeys to use electricity cables, poles, and transformers, then we predicted that electric shocks and electrocutions would occur more often in months with higher rainfall than ...." (complete the comparison in the final sentence)	We have rewritten the hypothesis based on rainfall to match the results for clarity. 5) If months with lower rainfall increase the daily path length and consequently monkeys use electricity cables, poles, and transformers more frequently as they respond to variation in resource distribution and intragroup feeding competition, then we predict an inverse relationship between rainfall and the number of cases.
L65: "hypothesise" not "expect"	Revised: deleted and revised
L84: "vertical" not "vertically-placed" (are you sure you mean vertical, not horizontal? I'm not quite sure what you're describing here, sorry!)	Revised to include more details on the power poles and cables: Older utility poles are wood while more recently installed poles are concrete. These poles route either three or four cables, depending on the voltage, with one cable as neutral. The cables are placed vertically or horizontally at the top of the poles.
L104: "Colobus is" doesn't work. Perhaps "The colobus is"? You might be able to come up with something better	Revised: Colobus are a medium-sized primate
L104, L107, L112: you provide relative sizes for colobus and baboons, but not for the guenons	Revised: Two species of guenon—Sykes's monkeys and vervets—occur in Diani. For Sykes's monkeys, adult female body mass is 4 kg, and adult male body mass is ~8 kg and for vervets, adult female body mass is 3 kg, and adult male body mass is 5 kg (Harvey et al. 1987).
L156: Clarify the exact comparisons you made here. At first I thought you compared sexes within age-classes, based on the pairs in the parentheses, but then I got confused because this doesn't answer the question in LL157-8	Reviewed and revised the age-sex class analyses: We tested if the age-sex classes were involved in the electrical infrastructure incidents in proportion to their occurrence in the population. We first established the structure of the population by determining the proportion of the population for each age-class (adult, subadult, juvenile, and infant) for each census year (2004-2006, 2010-2019), then calculated a mean across the years. Because we assumed that for each age class, there were an equal number of females and males in the population (Bronikowski et al. 2016), we equally divided the proportion of the age-class population as females and males. Using a chi-square goodness of fit test, we tested if the mean proportion of age-sex classes in the population differed from the proportion of the age-sex classes involved in the incidents. For the post hoc test, we used a Bonferroni correction for multiple tests, to calculate the z-score and determined the probability for each cell based on the adjusted residuals.
LL159-160: what are the denominators in this Chi2?	Revised analyses
LL160-2: I also don't understand exactly what you tested with the Spearman correlation	Reviewed and revised the analysis: We compared the distribution of body mass (kg) between those cases of electric shock and electrocution, against the distribution of body mass

	for all other welfare cases (i.e., vehicle-monkey collisions, abuse, dog attacks, illness, and injuries) ($N_{electrocutions}$ = 145, $N_{other\ causes}$ = 264). We then compared the body mass (kg) of females and males involved in electrical related incidents ($N_{females}$ = 66; N_{males} = 115). The Mann-Whitney U test was used for both tests.
LL163-5: "We used a two-tailed Spearman's rho correlation for 1998-2019 (N = 264 months) to test whether the monthly number of electric shock and electrocution cases was associated with the monthly rainfall (mm)."	Revised: Lastly, we used a two-tailed Spearman's rho correlation for 1998-2019 (*N* = 264 months) to test whether the monthly number of electric shock and electrocution cases was associated with the monthly rainfall (mm).
L184: this is methods	Removed: To investigate if the number of reported cases increased over time, we correlated the annual number of cases for all species combined, by the study year
L192: species differences in what?	Revised: Of the 320 reports, the number of incidents reported by members of the community varied by species: colobus, *N* = 257 (80%), Sykes's monkeys, *N* = 42 (13%), vervets, *N* = 16 (5%), and baboons, *N* = 6 (2%).
L104: this is methods	Removed: For each study year with census data (2004–2006, 2010–2019), we calculated the percentage of the population involved for each of the four species of monkeys.
L195: "We found significant differences between the four species in the percentage of the population involved in ??".	Revised: We found significant differences between the four species in the percentage of the population involved in electric shock and electrocution incidents (X^2 = 32.3, *N* = 52; *df* = 3, *P* < 0.001).
L212: cut "the" because it refers to the text	Removed: the
L217: add that these are annual data (I think)	Added: annual
L221: cut the first sentence. Rephrase the second one because failing to get electrocuted in sufficient numbers is not a real failure :0)	Removed: We carried out the analyses for the age-sex classes and the body mass only for colobus as Sykes's monkeys, vervets, and baboons were rarely shocked or electrocuted.
LL223-4: cut the repeat of the methods	Removed: We assumed that for each age class (infant, juvenile, subadult, and adult), the number of females and males in the population was equal.
L224-7:Do you mean: "There was no significant sex difference in the number of electric shocks and electrocutions infants, juveniles, and subadults, but adult females were significantly less frequently involved than adult males (Table 2)."	Revised: There was no significant sex difference in the number of electric shocks and electrocutions for infants, juveniles, and subadults, but adult females were significantly less frequently involved than adult males.
LL228-32: I don't see how you can test this relationship with a correlation – please check	Revised: We compared the body mass of colobus for cases of electric shock and electrocution to those of colobus from all other welfare cases recorded to the conservation organization. The distributions of body mass were significantly different (Mann-Whitney U = 13,301, $N_{electrocutions}$ = 144, $N_{other\ causes}$ = 264, *P* <.001); the body mass of individuals involved in electrical infrastructure related cases was higher than those colobus involved in other incident types
LL235-8: "Table 2. Number of cases of electric shock and electrocution recorded by age-class and sex for four species of primate in Diani, Kenya, 1998–2019. Asterisks indicate significant sex differences. Only cases with known age-classes are included."	Revised to a figure: **Fig 4** Number of cases of electric shock and electrocution recorded by age-sex class for four species of monkey in Diani, Kenya, 1998–2019. Only cases with known age-sex classes are included.

Table 2: remove the = signs in the column headings	Table deleted
The data in Table 2 would be easier to interpret if presented as a figure	Have changed from a table to Figure 4
L257: you can cut "found to be". The correlation is not at all strong (r = -0.15), although it is statistically significant. Please show these data, so the reader can interpret the result	Removed: found to be Revised: Monthly rainfall and monthly electric shock and electrocutions were found to be correlated (*r* = -0.16, *N* = 264 months, *P* = 0.01). In months with lower rainfall—but specifically months with rainfall between 0-50 mm—there were a higher number of cases reported Added a graph as Figure 7 to show the data.
L263: begin the discussion with a summary of the results, as instructed	Inserted summary of the results: We used data derived from monkey welfare incidents reported by members of the community in Diani, Kenya. While almost three-quarters of the cases resulted in the death of the individual, the number of cases was consistent through the study years though more cases were reported when rainfall was ≤50 mm. We found species, age-sex class, and body mass differences for individuals reported shocked or electrocuted.
L283: rephrase "our prediction assumed" to refer to your hypothesis	Revised: We hypothesized that stratum use—arboreal versus terrestrial—determined species risk from the electrical infrastructure, where more arboreal species are at substantially higher risk than those that are primarily terrestrial
L289: which of your results show this? Do you mean Table 2? If so, that's not what Table 2 shows	Revised: Our study and others (Kumar and Kumar 2015) suggest that for terrestrial primates, juveniles are involved more frequently than the other age classes. Play behavior may be implicated but further research is required to understand the reasons for juvenile involvement.
L291: the prediction didn't fail, although the data do not support it	Revised: Despite more terrestrial species being at relatively lower risk, the data do not support the prediction that the more arboreal species, colobus and Sykes's, are at higher risk as the percentage of the Sykes's monkey population reported was similar to that of the more terrestrial species.
L301: why would polyspecific assocations mean there's no height difference? There is often a height difference between the species in polyspecific assocations	Revised: Differences in foraging area is an unlikely explanation as hotspots of electric shock and electrocution of these two species are strongly correlated in Diani (Katsis et al. 2018), presumably because they negotiate the suburban environment in similar ways. In addition, the size of the home range and daily path length are also an unlikely explanation as colobus are folivores and rest between 50–70% of the day (Wijtten et al. 2012), and, therefore, they should be at lower risk of electrocution due to less time spent moving and therefore, in potential contact with the electrical infrastructure than Sykes's monkeys.
L301, L302: perhaps say these are unlikely explanations, rather than ruling them out	Revised: as above
L308: complete the comparison – more often than what?	Revised: The age-sex classes for colobus and Sykes's monkey followed the same pattern with adult males more often shocked or electrocuted.
L309: shorter as "than smaller individuals"	Revised: Both species are sexually dimorphic suggesting that larger individuals are at greater risk of electric shock and

	electrocution than individuals with shorter limbs.
L312: greater than what?	Revised: We suggest that arboreal individuals with body mass ≥8 kg are at greater risk than terrestrial species, and arboreal individuals with body mass <8 kg.
L314, L316: “capped” not "Capped"	Revised: capped
L315: “direction we suggest”. Alternatively, formalise the hypothesis you propose so you can make a prediction	Revised: The results were in the direction consistent with our study.
L327: “The efficacy of the tree trimming and insulation mitigations remains to be tested”	Revised: Efficacy of the tree trimming and insulation mitigations remains to be tested.
L333: “rhesus” not "Rhesus". Which result is unlike that for rhesus?	Revised: rhesus Revised: Our result is opposite to that found for rhesus macaques (*Macaca mulatta*) in Shivalik Hills, India (Kumar and Kumar 2015) which showed a higher percentage of cases occurring in the rainy months.
L338: “rhesus” not "Rhesus". Clarify why this statement is the converse of the previous one	Revised: As colobus are arboreal and rhesus macaques are terrestrial, and the electrocutions occurred more often with adults and juveniles, respectively, this suggests that factors other than rainfall may be implicated.
Reviewer #1: OVERALL COMMENT	
The authors refer to "electric shock and electrocution" throughout the manuscript. I agree with their terminology, however I'm not sure all readers will understand the subtlety of what the authors are intending to convey. I would add a brief explanation. Something along the lines of, "Electric shocks occur when an organism, a monkey in the case of this study, serves as a pathway for electric current but is not immediately killed by that current. It may die later of electric shock injuries. Electrocution occurs when the organism is killed at the time of incident." There is not much wildlife-related literature on the topic, though it is described in Dwyer, J.F. 2006. Electric shock injuries in a Harris's Hawk population. Journal of Raptor Research 40:193-199.	Revised: We note that electric shock occurs when an organism, a monkey in the case of this study, serves as a pathway for electric current but is not immediately killed by that current, although it may die later of electric shock injuries. Electrocution occurs when the organism is killed at the time of the incident.
ABSTRACT 10: If there is room in the Abstract given the word limitations, I would change "…in the suburban town of Diani, Kenya." To "…in the oceanside suburban town of Diani, in southeast Kenya."	Revised: These represent 16% of the total cases (320/2,017) that community members reported to a local conservation organization in the oceanside suburban town of Diani, in southeast Kenya.
12: I expect new electrical infrastructure is being added regularly, so I would change "…presumably because of the mitigations jointly implemented by the power distribution company and the conservation organization…" to "…presumably because of offsetting effects of increasing volume of electric infrastructure increasing electrocution risk for monkeys and increasing the mitigations jointly implemented by the	Revised: The number of cases did not increase through the study period, presumably because of the mitigations jointly implemented by the power distribution company and the conservation organization, offsetting the risks associated with electrical infrastructure expansion.

power distribution company and the conservation organization decreasing electrocution risk for monkeys…"	
INTRODUCTION	
28-58: Great introductory paragraphs. Well supported with literature and good flow of ideas. Nice work!	
29: "exploit" is a loaded word. I would replace with "use". You can Google "loaded word" if unfamiliar with the term	Revised: use
50: Same comment as 10 in the Abstract.	Revised: … in the oceanside suburban town of Diani, in southeast Kenya…
50-52: Same Latin names as in the Abstract, but different English names. Make consistent throughout.	Revised to full English names
53-54: Great point!	It is a very special place!
METHODS 99-101: Same Latin names as in the Abstract, but different English names. Make consistent throughout. I would probably use the full English names of each species throughout the manuscript. It is unwieldy, but it's clear to the reader. If that is too burdensome, I would in the first paragraph of this section use this sort of abbreviation for each species: "…Southern yellow baboon (Papio cynocephalus cynocephalus, hereafter "baboon").	Revised: Corrected the inconsistencies Inserted: Hereafter, these are referred to as colobus, Sykes's monkey, vervet and baboon.
116-125: Great paragraph. Thank you for the work that Colobus Conservation does.	
130: Wow, daily rainfall data is amazing. There is no acknowledgements section in the manuscript I received. I think that protects the double-blind review system. Presumably, the source of the rainfall data is acknowledged by name in that section. If not, s/he should be.	Acknowledgement is given by name in the acknowledgement section.
134-155: Well described. All makes sense to me.	
158: Is there previously published data to support this assumption? If so, cite the publication. Or maybe Colobus Conservation has unpublished data that can be cited?	Note: We found supporting evidence. Bronikowski et al 2016, Female and male life tables for seven wild primate species. Revised: As we assumed that for each age class, there were an equal number of females and males in the population (Bronikowski et al. 2016), we equally divided the proportion of the age-class population as females and males.
RESULTS Overall, well done with the Results. 195-198 and Table 1: The statistical test here appears correct, but didn't add much for me. If the Editor requests that the manuscript be shortened at all, this might be an easy place to cut.	
221-222: Could the data be consolidated across age groups to compare all males to all females? Or could it	Revised completely the analysis of the age-class proportions and sex.

be consolidated across sexes to compare older animals to younger animals?	
224: Here's that assumption again. Previously stated in the Methods, so not needed here.	Deleted the assumption
DISCUSSION 263-272. Good paragraph. At the end, "Though individuals that survive their injuries would not negatively 271 impact population sustainability,..." Are you sure about this? Is an individual that survives with a substantial and permanent physical disability likely to contribute to future generations as it would have if it were healthy?	Deleted as revised the paragraph
274: Again, the species names issue.	Inserted in methods
276-282: This is important. Add to Abstract.	Added to abstract
289-290: Why are juveniles more vulnerable? Any guesses?	Inserted: Play behavior may be implicated but further research is required to understand the reasons for juvenile involvement.
306-312: Great explanation, good job!	
315: Change "predicted by" to "consistent with".	Revised: consistent with
329-339: I expected you to find higher electrocutions during rainy periods because water is conductive so water sitting on poles and equipment may increase electrocution risk. You expected higher electrocutions during dry periods for the reasons you stated. Perhaps both situations occurred, balancing out the net effect and indicating no statistical effect? Alternatively, perhaps the analytical method obscured pattern. What if you put all incidents into just two categories (wet and dry) and reran the analyses? Perhaps you could use the daily rainfall data to ask, "Did it rain with 24 hours prior to the incident?" You may get a different result.	I have some behavioral observation projects upcoming to try to understand what is happening. Vehicle-monkey collisions also occur in months that are dryer. I am wondering (and will test) whether this is as simple as when it is raining, monkeys move around less. So on dry days they move about more frequently – so are at greater risk. Analyzing by wet/dry also shows a dry month correlation. I looked at the daily rainfall as well! But I think if has to do with the time and amount of rain. Raining heavily for one hour or the same amount of rain over 12 hours. This will differentially affect the daily path length. This needs to be teased apart.
REFERENCES Generally, a good job with formatting. 359, 361, 367: Italicize species names.	I have gone through and deleted the Doi and italicized where necessary.
FIGURES AND TABLES Again, inconsistent English names. Make consistent throughout, maybe by using the "hereafter" approach described above.	Updated
Reviewer #2: Discussion part is needed to be properly strengthened.......	Discussion revised as requested

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Abstract

We investigated 320 cases of electric shock and electrocution between 1998–2019 in four sympatric species of monkeys: Peters's Angola colobus (*Colobus angolensis palliatus*), Zanzibar Sykes's monkey (*Cercopithecus mitis albogularis*), Hilgert's vervet (*Chlorocebus pygerythrus hilgerti),* and the Southern yellow baboon (*Papio cynocephalus cynocephalus*). These represent 16% of the total cases (320/2,017) that community members reported to a local conservation organization in the oceanside suburban town of Diani, in southeast Kenya. Deaths occurred in 73% (*N* = 233) of the cases. The number of cases did not increase through the study period, presumably because of the mitigations jointly implemented by the power distribution company and the conservation organization, offsetting the risks associated with electrical infrastructure expansion. Colobus accounted for 80% (*N* = 256) of cases, representing ~4.6% of the population annually, which is considered greater than what is sustainable. For the colobus, adult males were shocked or electrocuted more than expected while all other age-sex classes were involved in proportion to the population structure. Frequency of cases was low for Sykes's monkeys (13%, *N* = 42), vervets (5%, *N* = 16), and baboons (2%, *N* = 6). Our findings assert that electrical infrastructure differentially affects species; those that are more arboreal and individuals ≥8 kg, are at higher risk of injury and death. Minor injuries are expected to be more common than reported, which raises welfare concerns. These results provide an understanding of the electrical infrastructure threat to primates with varying behavioral and morphological attributes and have far-reaching implications for conservation planning.

Keywords:

Colobus angolensis palliatus; primate; monkey; electrical infrastructure; electric shock; electrocution; power lines; urban environment

Introduction

Urbanization is a major cause of wildlife extinction (McKinney 2006). However, many species of wildlife have adapted to using urban habitats (Hulme-Beaman et al. 2016), but in doing so, they are exposed to novel threats (Beamish and O'Riain 2014; Sol et al. 2013). One of these threats results from the electrical infrastructure (Dwyer et al. 2014; Katsis et al. 2018) as some species use electricity cables, poles, and transformers as aerial pathways due to limited tree coverage (Rodrigues and Martinez 2014). This enables them to remain arboreal while accessing food resources and sleeping sites, searching for mates, and dispersing (Ram et al. 2015).

Studies investigating the survivorship from electrical injuries in wildlife indicate poor outcomes because the unique pathophysiology affects the whole body (Ampuero and Sá Lilian 2012; Kumar and Kumar 2015). In severe cases, these injuries present as tissue burns where the current enters and exits the body, respiratory paralysis, cardiac arrest, muscle necrosis, systemic infections, and organ damage (Fish and Geddes 2009; Koumbourlis 2002). The severity of an injury varies with voltage, type of current and amperage, and duration of exposure, and is often compounded by secondary trauma when the individual falls from the infrastructure (Fish and Geddes 2009; Koumbourlis 2002; Kumar and Kumar 2015).

The literature records injuries and deaths from electrical infrastructure in eight families and twenty-seven species of primates. Reports typically note that the electrical infrastructure is a threat to a species (Boinski et al. 1998; Kumara et al. 2006; Nowak et al. 2016) or the reports present a small number of cases (Lokschin et al. 2007; Moore et al. 2010; Printes et al. 2010). Social media, especially the YouTube platform, and websites of conservation organizations, document species injured or killed by the electrical infrastructure undescribed in the scientific literature. Few reports provide a sample size robust enough for statistical analysis (Goulart et al. 2010; Katsis et al. 2018; Kumar and Kumar 2015; Ram et al. 2015).

In the oceanside suburban town of Diani, in southeast Kenya, four species of monkeys occur sympatrically: Peters's Angola colobus (*Colobus angolensis palliatus*), Sykes's monkey (*Cercopithecus mitis albogularis*), Hilgert's vervet (*Chlorocebus pygerythrus hilgerti),* and the Southern yellow baboon (*Papio cynocephalus cynocephalus*). This town provides an opportunity to study electric shock and electrocution trends at one site across species varying in behavioral and morphological attributes.

Colobus Conservation is a local primate conservation organization that investigates primate welfare cases reported by members of the community. We analyzed the records of injuries from electric shock and deaths from electrocution between 1998–2019 and investigated the impact on the populations of these species using annual population census data. We note that electric shock occurs when an organism, a monkey in the case of this study, serves as a pathway for electric current but is not immediately killed by that current, although it may die later of electric shock injuries. Electrocution occurs when the organism is killed at the time of the incident. In our study, we did not differentiate between the two for the analyses.

Although electrical infrastructure injuries and deaths affect a broad range of primate species, little is known about its impact on the populations. To address this, we investigated the hypotheses: 1) If members of the community are more likely to report an individual once injuries are apparent and presumably life-threatening, we predict that the percentage of reported cases resulting in the death of the monkey would be higher than those that survived. 2) If the number of electric shock and electrocution cases increases with expansion of the electrical infrastructure, we predict that the number of annual cases reported would increase through the study period concurrently with Diani's growth. 3) If there is a difference in the relative risk to arboreal and terrestrial species, we predict that there would be species differences; cases involving the arboreal colobus and Sykes's monkeys would be higher in number than cases involving the more terrestrial vervets and baboons. 4) As electrical infrastructure related injuries and deaths are caused by the individual creating a short-circuit typically between two cables, we predict that electric shocks and electrocutions would occur differentially across the age-sex classes according to body mass as larger individuals are more likely to cause short-circuits. 5) If months with lower rainfall increase the daily path length and consequently monkeys use electricity cables, poles, and transformers more frequently as they respond to variation in resource distribution and intragroup feeding competition, then we predict an inverse relationship between rainfall and the number of cases.

Methods

Study site

We conducted our study in Diani, an oceanside suburban town in southeastern Kenya between Southern Palms Beach Resort (*−4.267569°*, *39.595537°*) and KFI Supermarket (*−4.342196°*, *39.563738°*), an area of approximately 6.5 km^2 (Figure 1). Diani is a linear development lying parallel to the Indian Ocean coastline, with an economy based on beach tourism. Phytogeographically, this area lies within the Zanzibar-Inhambane Undifferentiated floristic region, which historically extended from southern Somalia to the Limpopo River in Mozambique (White 1976). Diani retains original forest trees and fragments interspersed with exotic vegetation planted among the houses, hotels, and shopping areas.

Kenya Power & Lighting Company is responsible for transmitting and distributing electricity in the country. In Diani, the company positioned the medium voltage distribution line alongside Beach Road, which bisects the town from north to south. Along some sections of the road, the powerline was placed within the roadside vegetation. Older utility poles are wood while more recently installed poles are concrete. These poles route either three or four cables, depending on the voltage, with one cable as neutral. The cables are placed vertically or horizontally at the top of the poles. Uninsulated transformers step down the voltage from medium to low voltage distribution lines, connecting the utility to the consumer. The cables are uninsulated except where Kenya Power & Lighting Company and Colobus Conservation have jointly added insulation as mitigation to primate electrocutions.

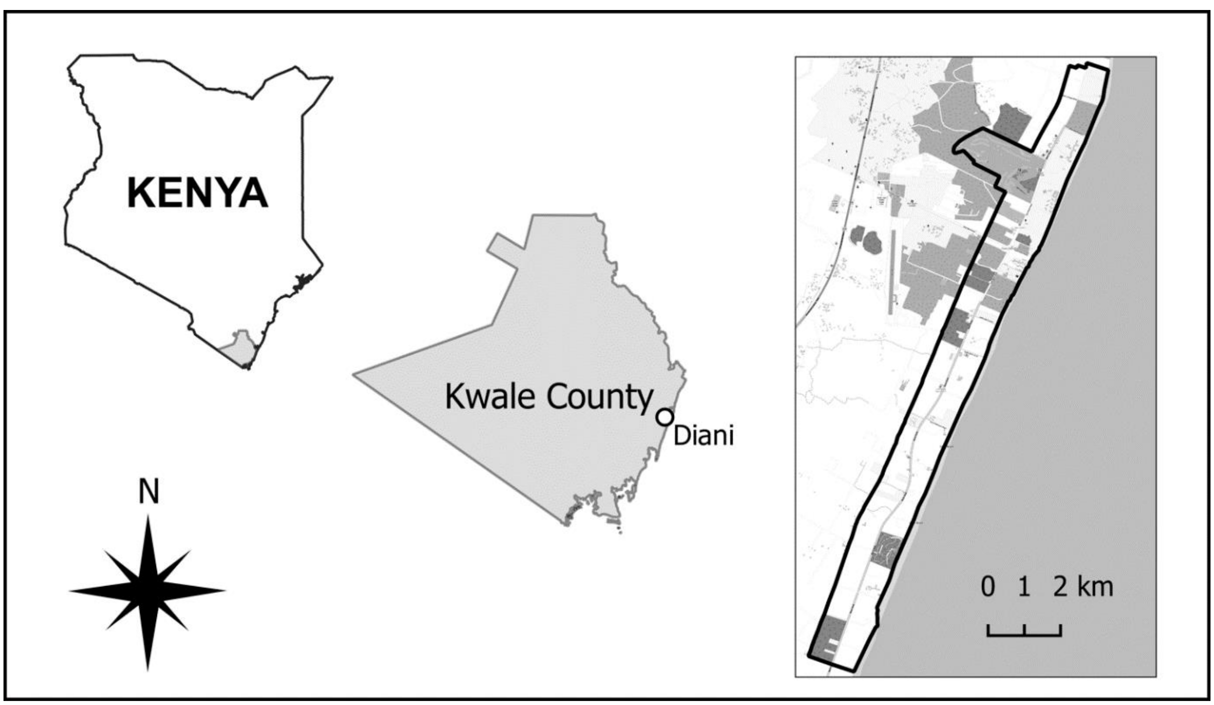

Fig 1 The study area within the oceanside suburban town of Diani, located in Kwale County, southeastern Kenya (Cunneyworth and Duke 2020).

The climate of Diani is hot and humid, influenced by the sea-level altitude and the monsoon winds from the Indian Ocean. Although variable, typically there are two dry seasons and two rainy seasons annually. The long rains occur from April to June, and the short rains occur from October to November. The dry seasons occur from July to September and December to March (J. Beakbane, unpublished data).

Study species

There are four species of monkeys living sympatrically in Diani: Peters's Angola colobus (*Colobus angolensis palliatus*), Zanzibar Sykes's monkey (*Cercopithecus mitis albogularis*), Hilgert's vervet (*Chlorocebus pygerythrus hilgerti*), and the Southern yellow baboon (*Papio cynocephalus cynocephalus*). Hereafter, these are referred to as colobus, Sykes's monkey, vervet and baboon. These species vary in habitat use, social organization, and morphology (Cunneyworth and Duke 2020), and all species exhibit sexual dimorphism.

Colobus are a medium-sized primate; adult female body mass is 9 kg, and adult male body mass is 11 kg (Harvey et al. 1987). They are highly arboreal and folivorous (Davies and Oates 1994; Dunham 2017). Groups typically consist of six individuals; a single adult male, multiple adult females, and offspring (Anderson 2005).

Two species of guenon—Sykes's monkeys and vervets—occur in Diani. For Sykes's monkeys, adult female body mass is 4 kg, and adult male body mass is 8 kg and for vervets, adult female body mass is 3 kg, and adult male body mass is 5 kg (Harvey et al. 1987). Molecular studies propose that Sykes's monkeys and vervets belong to different phylogenetic clades; Sykes's monkeys are in the arboreal clade, and vervets are in the terrestrial clade (Xing et al. 2007). Both species are omnivorous. Sykes's monkeys live in one-male, multi-female groups, and vervets live in multi-male, multi-female groups (Emerson *et al*. 2011).

Baboons are the largest primate in Diani; adult female body mass is 15 kg, and adult male body mass is 20 kg (Harvey et al. 1987). Baboons are omnivorous, primarily terrestrial, and live in multi-male, multi-female groups (Altmann et al. 1993).

Data collection

Colobus Conservation, a local conservation organization, operates an emergency rescue service responding to primate welfare cases reported by members of the community. The staff follow up each report in the field and provide veterinary care when appropriate or collect the carcass if the individual is dead. The staff inputs each case into a database as part of the organization's internal reporting. The information recorded includes species, date, cause and description of the incident, age-class, sex, body mass, clinical presentation of the individual, and case outcome (alive not captured, treated and released, dead on arrival, died under treatment, euthanized, not found, or unknown). The veterinarian or field assistant categorizes electric shocks and electrocutions at the time of the incident by physical presentation of the monkey and/or proximity of the injured or dead individual to electricity cables, poles, or transformers.

We used previously published population census data for each species (Cunneyworth and Duke 2020). These data were available for 2004–2006 and 2010–2019. We delineated the census study area and then reviewed the location information in each case report and created a subset of cases occurring within the census area.

A Diani resident provided rainfall data collected at ~09:00 h daily for the entire study period. A standard rainfall gauge measured the rainfall in mm. The location of the rainfall gauge was 1.7 km south of the study area (*-4.3556, 39.5615*).

Statistical analysis

We analyzed data using IBM SPSS version 23. For all tests, the probability level of significance was .05. We carried out assumption testing and used Shapiro-Wilk's test to test for normally distributed data and the Levene's test to test for homogeneity of variance.

We analyzed twenty-two years of the organization's records from January 1998–December 2019. We calculated: 1) the number of electric shock and electrocution reports for all species of monkeys as a percentage of the total number of welfare reports of monkeys for the same area and time frame, 2) the mean and standard deviation for the number of monthly electric shock and electrocution reports (N = 264 months), and 3) the percentage of each category of case outcome for the monkey (alive not captured, treated and released, dead on arrival, died under treatment, euthanized, not found, or unknown).

We then proceeded with a Pearson's correlation to test if there was an association between the study year and the number of reported cases. We chose a one-tailed test as we predicted that the number of reported cases would increase over the study years, corresponding to Diani's expanding electrical infrastructure.

We investigated the impact of electric shocks and electrocutions on the population of each species using the annual census data. We calculated the number of cases annually as a percentage of the population size in that year. Using a Kruskal-Wallis test, we determined if the distributions of the annual percentages of the population shocked or electrocuted were different across species. Because this test was significant, we used a Mann-Whitney U test to carry out planned pairwise comparisons. We determined which pairs of species were statistically different and reported the adjusted significances using the Bonferroni correction for multiple tests for all species pairs.

We tested if the age-sex classes were involved in the electrical infrastructure incidents in proportion to their occurrence in the population. We first established the structure of the population by determining the proportion of the population for each age-class (adult, subadult, juvenile, and infant) for each census year (2004-2006, 2010-2019), then calculated a mean across the years. As we assumed that for each age class, there were an equal number of females and males in the population (Bronikowski et al. 2016), we equally divided the proportion of the age-class population as females and males. Using a chi-square goodness of fit test, we tested if the mean proportion of age-sex classes in the population differed from the proportion of the age-sex classes involved in the incidents. For the post hoc test, we used a

Bonferroni correction for multiple tests, to calculate the z-score and determined the probability for each cell based on the adjusted residuals.

We compared the distribution of body mass (kg) between those cases of electric shock and electrocution, against the distribution of body mass for all other welfare cases (i.e., vehicle-monkey collisions, abuse, dog attacks, illness, and injuries) ($N_{\text{electrocutions}}$ = 145, $N_{\text{other causes}}$ = 264). We then compared the body mass (kg) of females and males involved in electrical related incidents ($N_{females}$ = 66; N_{males} = 115). The Mann-Whitney U test was used for both tests.

Lastly, we used a two-tailed Spearman's rho correlation for 1998-2019 (*N* = 264 months) to test whether the monthly number of electric shock and electrocution cases was associated with the monthly rainfall (mm).

Ethical note

Our study adhered to the legal requirements of Kenya with permission from the Kenya Wildlife Service. NACOSTI granted this research permission through permit number NACOSTI/P/16/10434/11346. The University of Bristol ethics committee approved the protocols. The authors have no conflicts of interest or competing financial interests to declare.

Results

Within the study area, members of the community reported 2,017 welfare cases involving monkeys between January 1998 and December 2019. Of these, 320 cases (16%) were electrical infrastructure related. The mean number of cases reported to the organization was 1.2 per month (range = 0–6, *N* = 264 months, *SD* = 1.3). The case outcomes show low survivorship as only 25% (*N* =79) of the shocked and electrocuted individuals were alive and not captured or treated and released. Death occurred in 73% of cases (*N* = 233), and of those cases, 149 died at the time of the incident, 31 died under veterinary care, and 53 were euthanized because of extensive injuries. The team did not find the monkey in the field in six cases and did not note the case conclusion in two cases.

The annual number of electric shock and electrocution cases ranged 6–23 ($\bar{X}$ = 15, *SD* = 4) (Figure 2) and did not increase over the study period (one-tailed Pearson's correlation = 0.005, *N* = 22 years, *P* = 0.49).

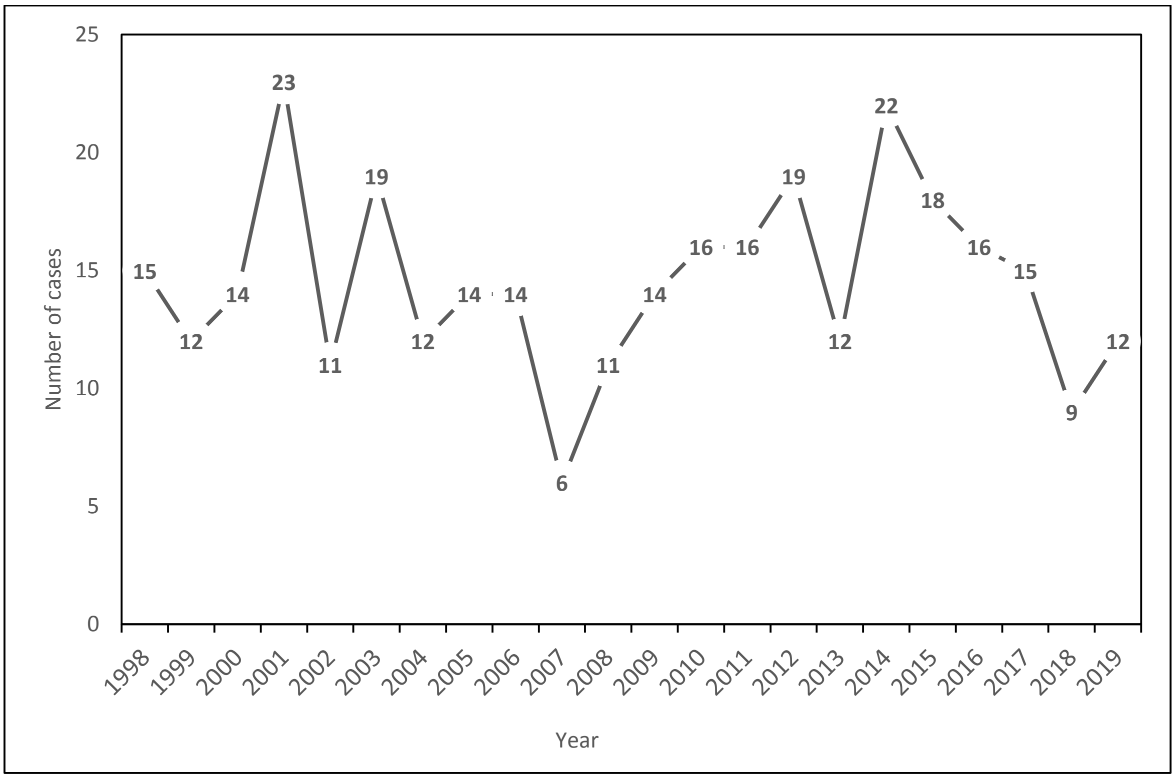

Fig 2 The number of electric shock and electrocution cases reported by members of the community in Diani, Kenya, 1998–2019 (*N* = 22 years), for all species combined (colobus, Sykes's monkey, vervet, and baboon).

Of the 320 reports, the number of incidents reported by members of the community varied by species: colobus, *N* = 256 (80%), Sykes's monkeys, *N* = 42 (13%), vervets, *N* = 16 (5%), and baboons, *N* = 6 (2%). We found significant differences between the four species in the percentage of the population involved in electric shock and electrocution incidents (X^2 = 32.3, *N* = 52; *df* = 3, *P* < 0.001) (Figure 3). In planned pairwise comparisons (Table 1), the annual percentage of the colobus population shocked and electrocuted (range = 2–6%, $\overline{X}$ = 4.6, *SD* = 1.2) was higher than that for the other species, while for Sykes's monkeys (range = 0–1%, $\overline{X}$ = 0.3, *SD* = 0.2) , vervets (range = 0–2%, $\overline{X}$ = 0.4, *SD* = 0.6) , and baboons (range = 0–1%, $\overline{X}$ = 0.2, *SD* = 0.3), the percentages of the population involved were similar.

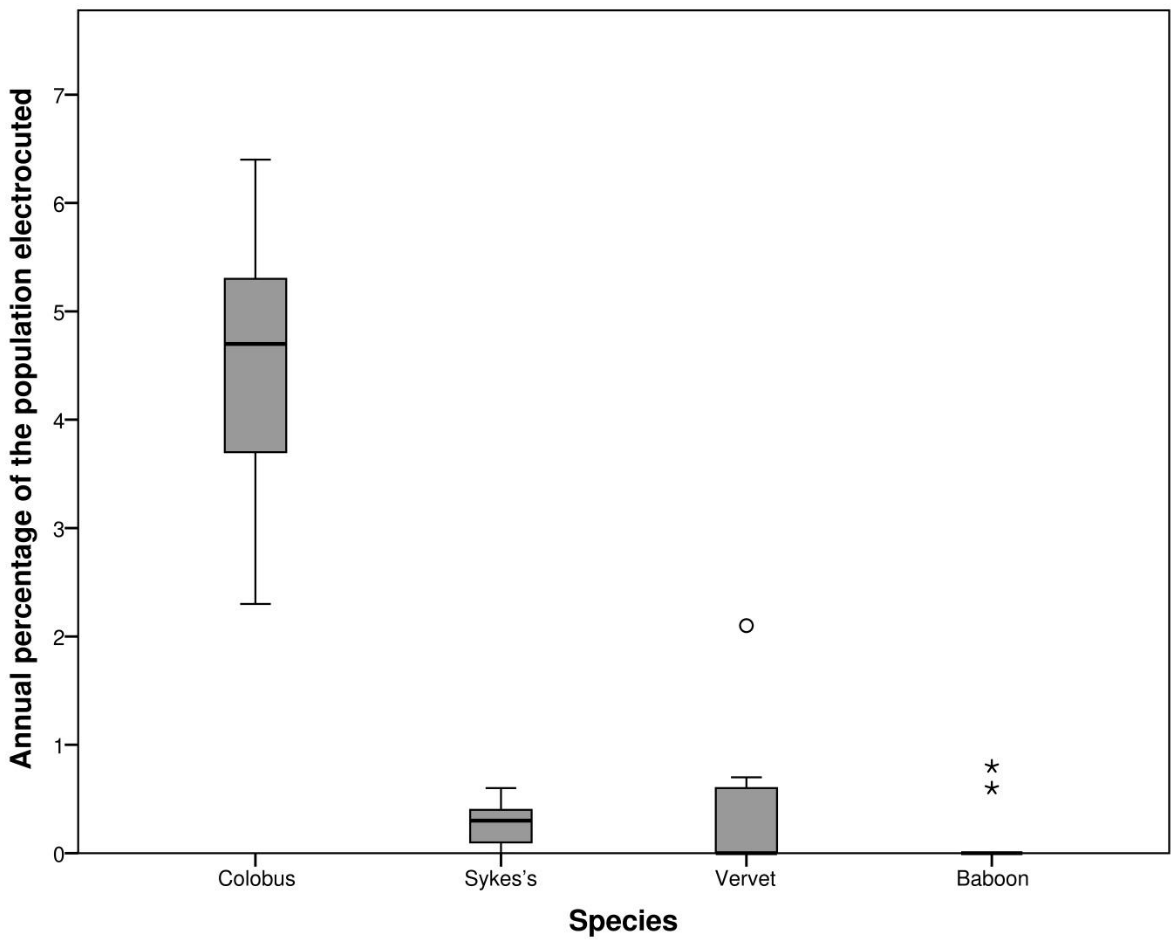

Fig 3 The annual percentage of the population reported for electric shock and electrocution in Diani, Kenya, 2004-2006, 2010-2019 (*N* = 13 years) for each species of monkey in Diani, Kenya. Boxes represent 50% of the dataset with the line indicating the median value. The whiskers represent the top and bottom quartiles. The circle indicates an outlier, and the asterisks indicate extreme outliers.

Table 1. Mann-Whitney U tests of pairwise comparisons for the annual percentage of the population involved in electric shocks or electrocutions for four species of monkey (colobus, Sykes's monkey, vervet, and baboon) between 2004–2006 and 2010–2019 in Diani, Kenya. Asterisks indicate highly significant results.

Species	***X²***	***N***	***df***	***P***
Colobus–Sykes’s	21.9	13	1	0.001**
Colobus–Vervet	25.5	13	1	<0.001**
Colobus–Baboon	30.6	13	1	<0.001**
Sykes’s–Vervet	3.7	13	1	1.00
Sykes’s–Baboon	8.8	13	1	0.789
Vervet–Baboon	5.1	13	1	1.00

We carried out the analyses for the age-sex classes and the body mass only for colobus as Sykes's monkeys, vervets, and baboons were rarely shocked or electrocuted. For the age-sex classes, the proportion of the cases significantly differed from the proportion of the age-sex classes within the population involved (X^2 = 15.9, N = 231, df = 7, P = 0.03) (Figure 4): adult males were more often involved. All other age-sex classes were involved at similar proportions as they occurred in the population.

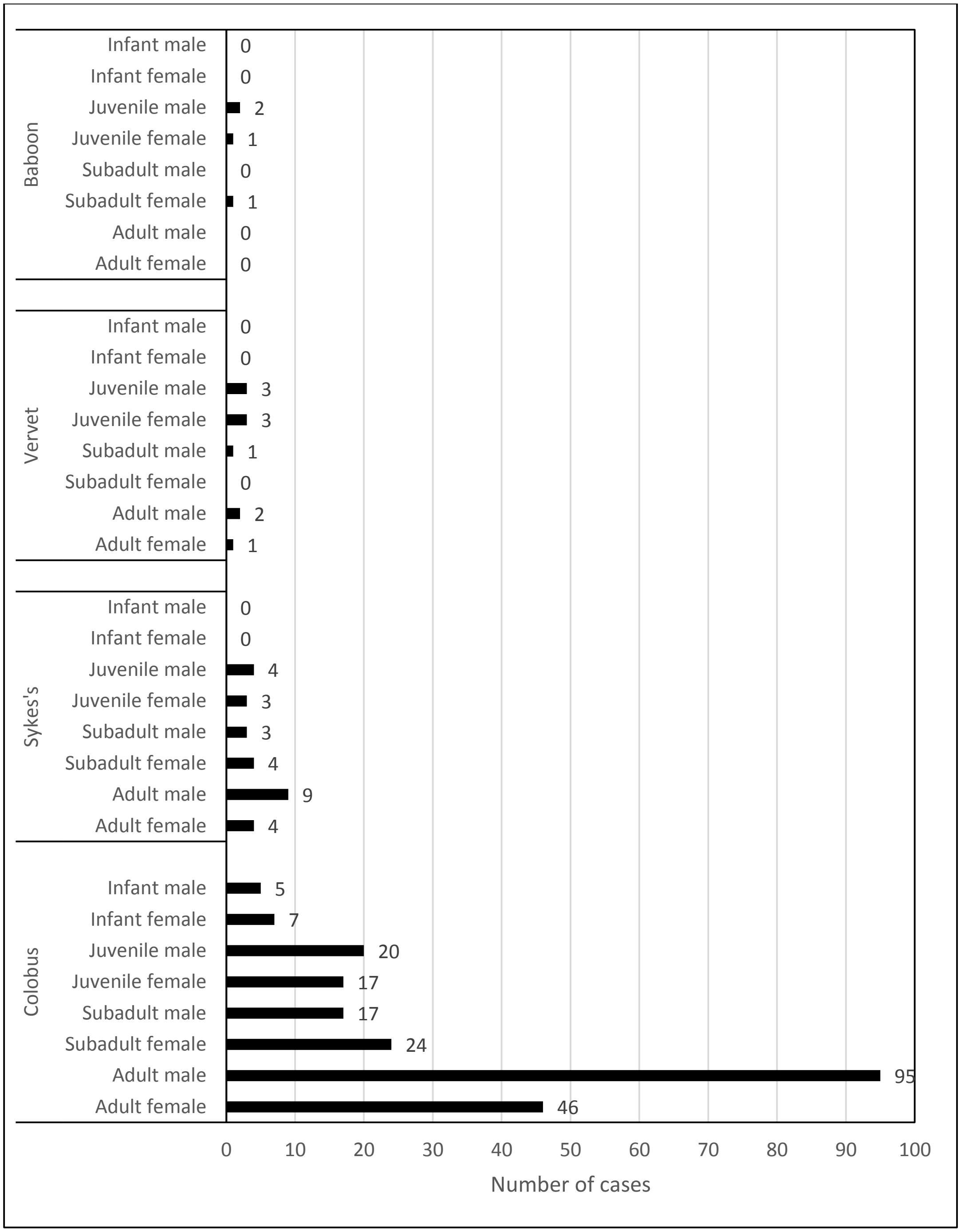

Fig 4 Number of cases of electric shock and electrocution recorded by age-sex class for four species of monkey in Diani, Kenya, 1998–2019. Only cases with known age-sex classes are included.

We compared the body mass of colobus for cases of electric shock and electrocution to those of colobus from all other welfare cases recorded to the conservation organization. The distributions of body mass were significantly different (Mann-Whitney U = 13,301, $N_{electrocutions}$ = 144, $N_{other\ causes}$ = 264, *P* <.001); the body mass of individuals involved in electrical infrastructure related cases was higher than those colobus involved in other incident types (Figure 5). When the body mass of shocked or electrocuted individuals was analyzed by sex (female: range = 1-10, $\overline{X}$ = 6.3, SD = 2.3, N = 66; male: range = 1-12, $\overline{X}$ = 8.5, SD = 2.7, N = 115), there were significant differences in the body mass between the sexes (*U* = 3638, *N* = 144, *P* = <0.001) (Figure 6).

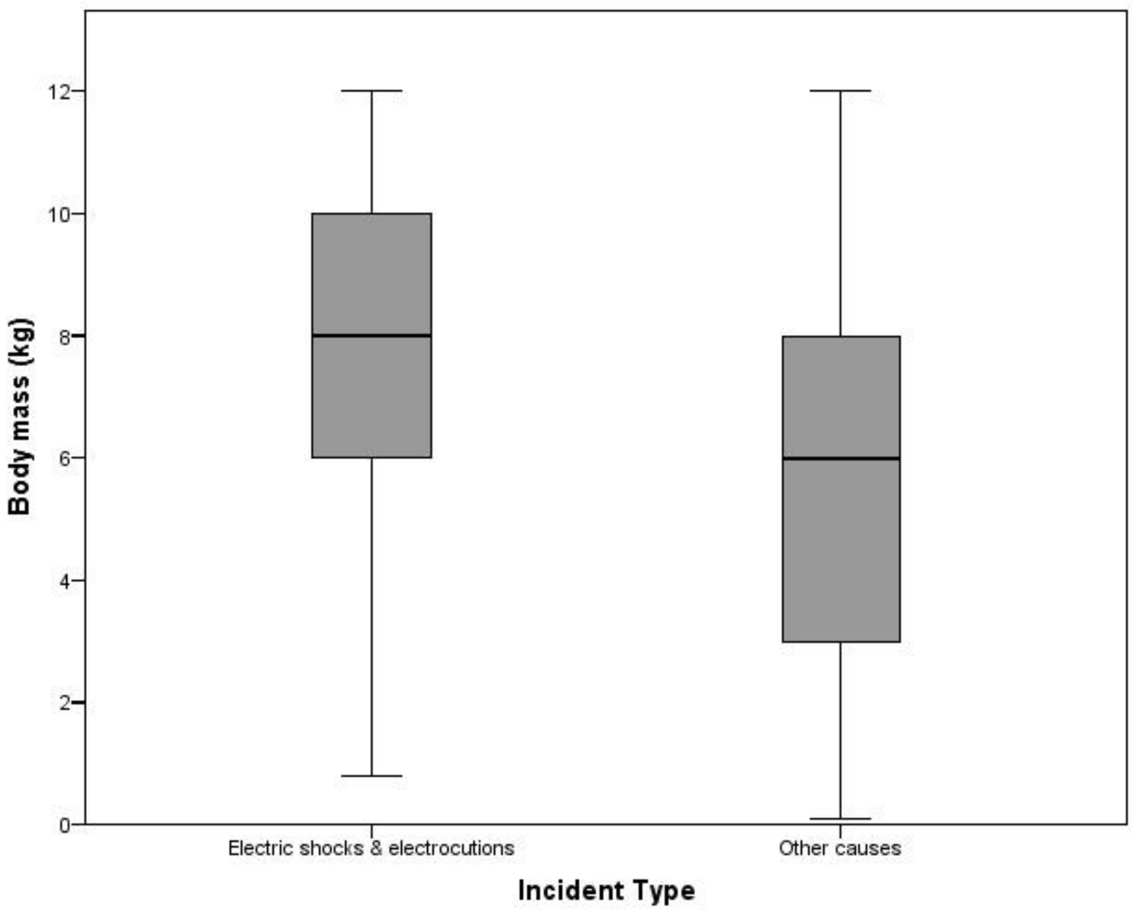

Fig 5 Body mass (kg) of colobus individuals involved in electric shock and electrocution cases (*N* = 144) compared with all other welfare causes (*N* = 264). Boxes represent 50% of the dataset with the line indicating the median value. The whiskers represent the top and bottom quartiles.

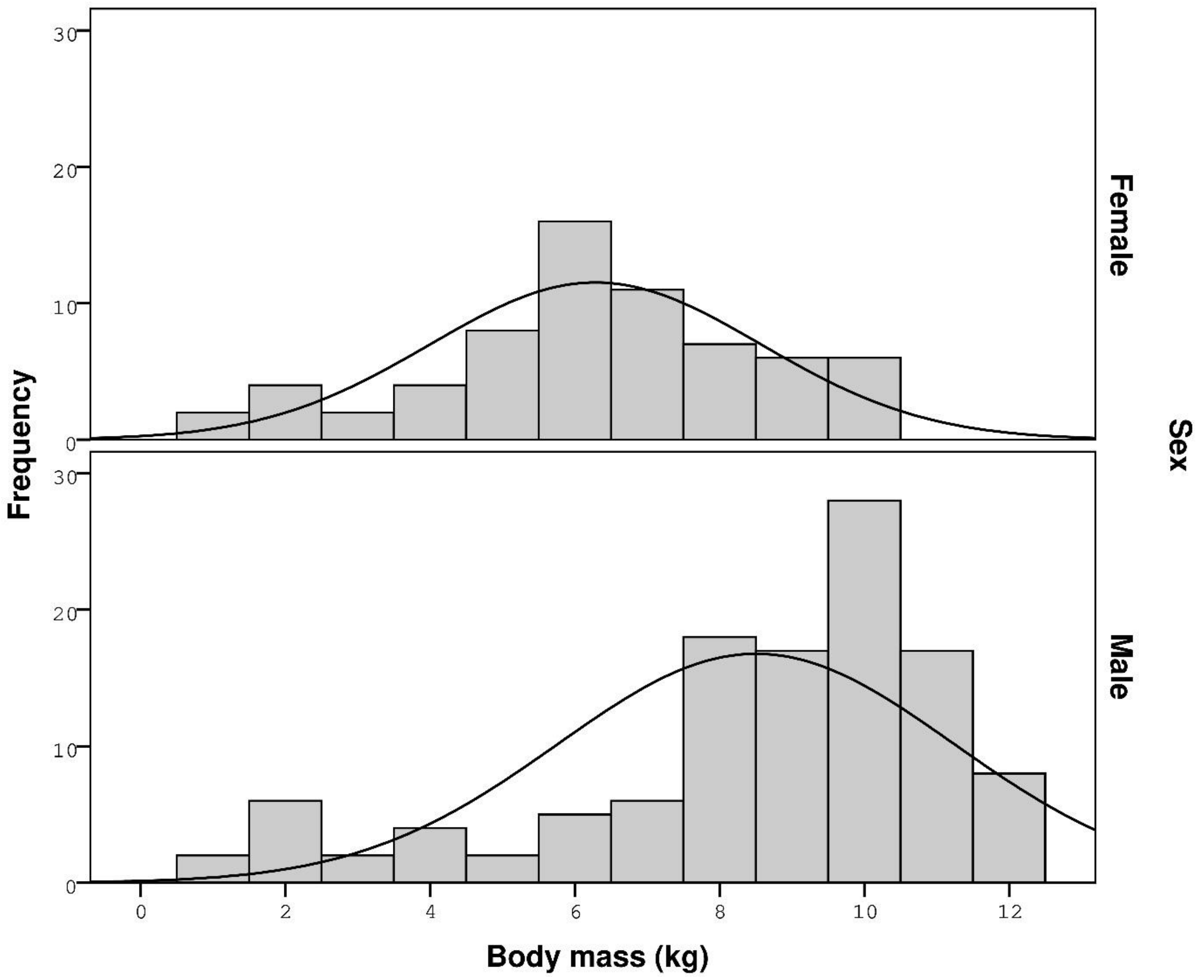

Fig 6 The frequency of colobus body mass (kg) categories for females (*N* = 66) and males (*N* = 115) involved in electric shock and electrocution incidents in Diani, Kenya, 1998-2019.

Monthly rainfall and monthly electric shock and electrocutions were found to be correlated (r = -0.16, N = 264 months, P = 0.01). In months with lower rainfall—but specifically months with rainfall between 0-50 mm—there were a higher number of cases reported (Figure 7).

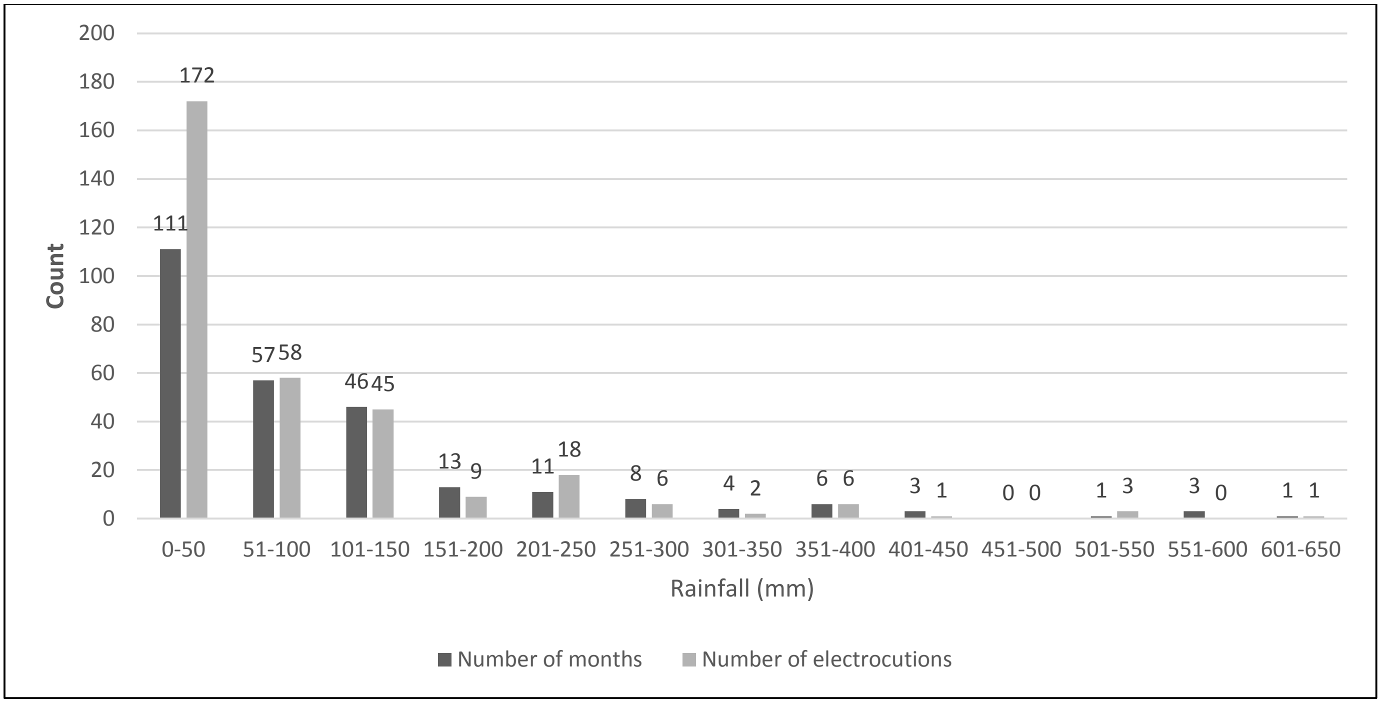

Fig 7 The number of months (*N* = 264) between 1998-2019 with rainfall (grouped in 50 mm bins) compared to the number of electric shock and electrocution cases in those months (*N* = 320) in Diani, Kenya for four species of monkeys (colobus, Sykes's monkey, vervet and baboon) combined.

Discussion

We used data derived from monkey welfare incidents reported by members of the community in Diani, Kenya. While almost three-quarters of the cases resulted in the death of the individual, the number of cases was consistent through the study years though more cases were reported when rainfall was ≤50 mm. We found species, age-sex class, and body mass differences for individuals reported shocked or electrocuted.

Of the 2,017 welfare incidents reported to the conservation organization between 1998-2019, 16% (320) were electric shock or electrocution cases. This was considerably lower than the 34% reported in a similar study for vehicle-monkey collisions in the study area (Cunneyworth and Duke 2020). This informs that electrical infrastructure is the second most frequent cause of injury and death of monkeys. Reports of injuries and deaths due to the electrical infrastructure did not increase over time as predicted, given the growth of Diani during the study years. We attribute this to the mitigations that the power company and the conservation organization participated jointly in to reduce electric shocks and electrocutions of the monkeys. Since 2002, the teams have been trimming vegetation growing around electricity cables, poles, and transformers. The amount of trimming varied month by month and year by year, but typically, the team trimmed 500 m, two times per month. Since 2010, implementation of long-term mitigations began by insulating cables, and moving transformers known to cause electric shocks and electrocutions. Efficacy of the tree trimming and insulation mitigations remains to be tested.

While our data showed that the majority of cases resulted in the death of the individual, it is likely that electric shock incidents are underrepresented as members of the community are more likely to report cases of individuals with injuries obvious to the casual observer (Kumar and Kumar 2015). This is indicated by a study of three colobus groups within our study area (N = 21 individuals) where five electrical infrastructure related incidents occurred in 336 study days (N. Dunham *unpubl. data*). Of these, there was one electrocution case (adult male) and four electric shock cases (two adult males, one adult female, one juvenile female). Of the electric shock cases, all four individuals survived but sustained burn injuries, but members of the community did not report the cases. If electric shock cases are as frequent as those observations suggest, then this represents substantial welfare concerns regarding the installation of uninsulated electrical infrastructure in primate areas (Printes et al. 2010).

Our study has shown that not all species of monkeys are at equal risk of electric shock and electrocution. Of the four species of monkeys that live sympatrically in Diani, Kenya, three—Sykes's monkeys, vervets, and baboons—experienced injuries and deaths infrequently, indicating that the electrical infrastructure is a negligible conservation threat to these populations. However, the reports of colobus injured or killed consistently exceeded 4% of the annual population, which is the upper limit of the sustainable mortality rate for primates (Robinson and Bodmer 1999). The annual censuses of colobus in Diani indicate that their numbers are decreasing (Cunneyworth and Duke 2020). As the Diani colobus represent the second largest population in Kenya and are a substantial source of individuals for the Kenyan metapopulation (Anderson 2005), we consider that the electrical infrastructure is an on-going conservation threat to this Vulnerable subspecies (Cunneyworth et al. 2020).

We hypothesized that stratum use—arboreal versus terrestrial—determined species risk from the electrical infrastructure, where more arboreal species are at substantially higher risk than those that are primarily terrestrial (Al-Razi et al. 2019). Our results support the prediction that the more terrestrial species are at low risk of electric shock and electrocution, as many of the study years did not record cases for either vervets or baboons. In the years with cases, the annual percentage of the population affected was well within the range of sustainable mortality (Robinson and Bodmer 1999). Our study and others (Kumar and Kumar 2015) suggest that for terrestrial primates, juveniles are involved more frequently than the other age classes. Play behavior may be implicated but further research is required to understand the reasons for juvenile involvement.

Despite more terrestrial species being at relatively lower risk, the data do not support the prediction that the more arboreal species, colobus and Sykes's, are at higher risk as the percentage of the Sykes's monkey population reported was similar to that of the more terrestrial species. This result is surprising as both colobus and Sykes's monkeys are primarily arboreal (~1% and ~6% terrestrial, respectively) (Coleman and Hill 2014; Dunham 2017), and they extensively overlap in Diani due to the compact nature of suitable habitat in the town.

The disparity of the population impact by electric shocks and electrocutions between colobus and Sykes's monkeys indicates that stratum use is not the only factor determining electrical infrastructure risk for arboreal species. Differences in foraging area is an unlikely explanation as hotspots of electric shock and electrocution of these two species are strongly correlated in Diani (Katsis et al. 2018), presumably because they negotiate the suburban environment in similar ways. In addition, the size of the home range and daily path length are also an unlikely explanation as colobus are folivores and rest between 50–70% of the day (Wijtten et al. 2012), and, therefore, they should be at lower risk of electrocution due to less time spent moving and therefore, in potential contact with the electrical infrastructure than Sykes's monkeys.

We suspect that body mass is an important factor in understanding electrical infrastructure risk. The age-sex classes for colobus and Sykes's monkey followed the same pattern with adult males more often shocked or electrocuted. Both species are sexually dimorphic suggesting that larger individuals are at greater risk of electric shock and electrocution than individuals with shorter limbs. This is supported by the body mass of the colobus injured and killed by the electrical infrastructure; these were significantly higher than the body mass of those colobus individuals involved in other welfare incident types. We suggest that arboreal individuals with body mass ≥8 kg are at greater risk than terrestrial species, and arboreal individuals with body mass <8 kg.

We found only one study that provided data on the number of electrocutions of two sympatric arboreal species of different adult body mass—capped langur (*Trachypithecus pileatus*) with a body mass of 9.5–14 kg and Phayre's langur (*Trachypithecus phayrei*) with a body mass of 6.5–7.5 kg. The results were in the direction consistent with our study. The capped langur was exclusively killed by electrocution, in comparison with the Phayre's langur which was killed by electrocutions and vehicles, and the number of electrocution cases of the capped langur were more than twice that of Phayre's langur (Al-Razi et al. 2019). Given the paucity of data from other studies, however, our observations are difficult to corroborate across species, warranting the collection and publication of body mass of individuals involved in electrical infrastructure incidents.

We reported electric shocks and electrocutions more frequently in the months with rainfall between 0-50 mm compared to higher rainfall months. One might expect that this result is because of higher daily path lengths during the drier months as food is less readily available and consequently, more time is spent using the electrical infrastructure. However, for colobus in Diani, this is not the case. Colobus home ranges are small (~6-11 ha: Dunham 2017), and daily path lengths are not correlated with rainfall (Noah Dunham, unpubl data; Santarsieri 2019). Our result is opposite to that found for rhesus macaques (*Macaca mulatta*) in Shivalik Hills, India (Kumar and Kumar 2015) which showed a higher percentage of cases occurring in the rainy months. Further investigation is needed to determine if these differences are due to study methodology or environmental factors. While we correlated 22 years of monthly reports to monthly rainfall, Kumar and Kumar (2015) correlated two years of cases to one of the three seasons—winter, summer, rainy—where each season was denoted by specific months of the year. As colobus are arboreal and rhesus macaques are terrestrial, and the electrocutions occurred more often with adults and juveniles, respectively, this suggests that factors other than rainfall may be implicated. The sample size was too small to correlate monthly vervets and baboons cases to monthly rainfall.

In conclusion, we reviewed electric shock and electrocution reports for four sympatric species of monkeys. Colobus consistently exceeded 4% of the annual population, which is the upper limit of the sustainable mortality rate for this Vulnerable species. This study clearly shows that species are not equally likely to be involved in electrical infrastructure related injuries and deaths. We suggest that susceptible species are arboreal, and individuals ≥8 kg are more frequently affected, especially during months of lower rainfall. For susceptible species, electric shocks are likely common with lower survivorship because of delayed treatment, raising welfare concerns from poor site-selection and unsafe electrical hardware. This work has far-reaching implications for conservation planning for primates, even where the impact on the population is not known, or the species is not a conservation priority.

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