Spatial patterns of primate electrocutions in Diani, Kenya

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By

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Declaration

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Abstract

Electrocution from power lines threatens many primate species, yet knowledge of effective evidence-based mitigation strategies is limited. Mitigation planning requires an understanding of the spatial distribution of electrocutions for prioritisation of high-risk areas. In Diani, a coastal town in Kenya, electrocution is a significant mortality factor for five primate species. The aim of this study is to describe the spatial patterns of electrocutions and to identify electrocution hotspots in order to guide an effective mitigation approach in Diani. A secondary aim is to assess the effectiveness of power line insulation in reducing electrocution rates. Colobus Conservation, a primate conservation organisation, provided records of electrocution incidents, annual primate census data and power line insulation data from 1998 to 2016. I georeferenced electrocution incidents and analysed them using QGIS. I used kernel density estimation (KDE) and Getis-Ord-Gi* to identify and compare hotspots across species, seasons and time, and employed spatial regression to test whether primate population density predicted the location of hotspots. I found that electrocutions were clustered into hotspots that showed little variation in location between species and seasons. The location of hotspots changed over time, likely due to new development in Diani and varying primate detection rates by community members. Primate density was a significant predictor of electrocution density for colobus, Sykes and vervet monkeys, however the relationship was weak suggesting the presence of additional risk factors. Preliminary analysis of insulation data was suggestive of a decline in electrocution rate, but the dataset was too limited to be conclusive. In summary, this study provides a framework for systematic spatial prioritisation of power lines that can be

used to reduce primate electrocutions in Diani, and can be adopted in other areas of the world where primates are at risk from electrocution.

Keywords: Electrocution, GIS, Hotspots, Mitigation, Power lines, Spatial analysis

Introduction

Primates are at high risk of extinction due to unsustainable human activity, which is causing extensive habitat loss and degradation (Estrada et al., 2017; Rudran, 2015). Consequently many species are restricted to human dominated landscapes (Arroyo-Rodríguez and Fahrig, 2014) where their survival is threatened by novel risks including electrocution from overhead power lines (Parker et al., 2008; Ram et al., 2015; Slade, 2016).

Primates are exposed to power lines as they use them to travel across the landscape, especially between isolated tree patches, and to escape from aggressors (Boinski et al., 1998; Dittus, 1986; Goulart et al., 2010; Ram et al., 2015). As cables are rarely insulated, this behaviour poses a high risk of electrocution, which occurs when individuals simultaneously grasp two conductors or a conductor and an earthed device (Bevanger, 1998). Electrocutions also result from wet vegetation contacting energised components, which can create short circuits from power lines to the ground (Kumar and Kumar, 2015). Published fatality rates range between 31-48% (Kumar and Kumar, 2015; Slade, 2016), with individuals dying from the effects of electric current passing through the body (Schulze et al., 2016), or from the subsequent impact of falling from a height (Kumar and Kumar, 2015). Survivors are frequently left with injuries to the hands, head and chest and may later die from secondary infection (Kumar and Kumar, 2015). Additionally these incidents cause power outages, equipment damage and fires, which impact human communities (APLIC, 2006; Dwyer et al., 2014; Harness and Wilson, 2001; Printes, 1999).

Electrocutions are documented for a range of primate species across Asia (Kumar and Kumar, 2015; Nekaris and Jayewardene, 2004; Roscoe et al., 2013), Africa (Maibeche et al., 2015; Slade, 2016) and Latin America (Goulart et al., 2010; Printes, 1999; Rodrigues and Martinez, 2014). It is a principal mortality factor for the Endangered Central American squirrel monkey subspecies *Saimiri oerstedii* ssp. *citrinellus* and *Saimiri oerstedii* ssp. *oerstedii* (Boinski et al., 1998), and was found to be the most common cause of death for a local population of Hanuman langurs (*Semnopithecus entellus*) (Ram et al., 2015). There is limited knowledge about population-level effects of electrocution mortality on primates, however avian studies have demonstrated that even low electrocution rates can drive declining populations to local extinction (Hernández-Matías et al., 2015). Therefore evidence of electrocutions of Critically Endangered species including the Javan slow loris (*Nycticebus javanicus*) (Moore and Nekaris, 2014) and the western purple-faced langur (*Trachypithecus vetulus* ssp. *nestor*) (Moore et al., 2010; Parker et al., 2008) is a cause for conservation concern.

As habitat encroachment increases and power line networks rapidly expand, this problem is likely to escalate in the future (Bevanger, 1994; Jenkins et al., 2010), and development of effective evidence-based mitigation strategies is crucial (Sutherland et al., 2004). Current strategies include power line insulation, tree-trimming around power lines, artificial canopy bridges and braiding of power lines (Lokschin et al., 2007; Printes, 1999; Roscoe et al., 2013), however their effectiveness in reducing electrocutions is rarely evaluated (Teixeira et al., 2013). Limited funding makes installation of measures across the entire power grid infeasible, therefore mitigation measures must be targeted to high-risk areas (Dwyer et al., 2014; Lokschin et al., 2007). This requires an understanding of the spatial distribution of electrocutions (Guil et al., 2011; Malo et al., 2004), which is rarely studied for primates.

In the Kenyan town of Diani, electrocution contributes to mortality for five of the six primate species: Angolan black and white colobus monkeys (*Colobus angolensis* ssp. *palliatus*), Sykes monkeys (*Cercopithecus mitis* ssp. *albogularis*), white-tailed small-eared galagos (*Otolemur garnettii* ssp. *lasiotis*), vervet monkeys (*Chlorocebus pygerthrus* ssp. *hilgerti*) and northern yellow baboons (*Papio cynocephalus* ssp. *ibeanus*) (Slade, 2016). Colobus monkeys are particularly affected, with annual population off-take rates estimated between 1.7- 7.9% (Slade, 2016). Other common mortality sources include road traffic accidents and dog attacks (Colobus Conservation, 2016). The aim of this study is to describe the spatial patterns of primate electrocutions in Diani and to identify electrocution hotspots in order to inform an effective evidence-based mitigation strategy. A secondary aim is to assess the efficacy of power line insulation in reducing electrocutions. Hypotheses are: i) electrocutions will be clustered into hotspots, ii) hotspots will be species-specific, iii) hotspots will differ between seasons, iv) hotspots will change over time, v) hotspots will be associated with high primate density, and vi) insulation will be associated with reduced electrocution rates.

Methods

Study Site

Diani is a touristic coastal town in southern Kenya, located 30 km south of Mombasa in Kwale District (Appendix 1). It is situated within the fragmented Diani

Forest, a narrow strip of coastal rag forest approximately 10 km long by 0.5 km wide (Dunham, 2014). This forest is part of the Zanzibar-Inhambane Undifferentiated Floristic Region, a global biodiversity hotspot undergoing extensive habitat loss (Brooks et al., 2002; Myers et al., 2000). Rainfall is bimodal, with long rains occurring from March to June and short rains from October to December (Mwamachi et al., 1995).

Due to expansive human development in Diani, over 75% of the forest cover has been lost and the remaining forest is highly fragmented by roads, resorts, developed land and overhead power lines (Kanga and Heidi, 1999; Moreno-Black and Maples, 1977). Consequently primates are frequently threatened by human activity, and a local non-governmental organisation, Colobus Conservation, operates a primate rescue centre in this area.

Data Collection

Kenya Power and Lighting Company (KPLC) provided a map of power lines in Diani. Colobus Conservation provided electrocution data from 1998 to the end of 2016. Welfare cases and dead animals are reported by community members and attended to by their emergency response team. Details of each case are recorded, including species, description of the incident and incident location, and records since 2010 have GPS coordinates. This information is logged onto a record sheet and entered into an electronic database. Due to inconsistencies with record keeping, I organised and crosschecked welfare sheets against the electronic database to compile a comprehensive database of 370 incidents. Where provided, I checked coordinates against a base map and updated incorrect coordinates.

I collected coordinates for 266 incidents using descriptions of incident locations from the records and a GPS (Garmin eTrex 30x). In cases where records only provided the name of the property where the incident occurred, I took coordinates for all power lines associated with the property, and then assigned a random point to the power line using the QGIS random points tool. 41 incidents had insufficient information on location and were excluded from the dataset.

Colobus Conservation insulates some power lines with PVC tubes to reduce electrocutions and provided records of date and location of insulations. They also provided annual census data collected by transect surveys for colobus, Sykes and vervets, and repeated counts for individual baboon troops. Census data were available for 1997-2002, 2004-2006 and 2010-2016. For colobus, Sykes and vervets this information included coordinates of troop location and composition. Due to inconsistent GPS use, I checked coordinates against a base map to identify incorrect coordinates, and removed inaccurate years. This left eight years of accurate census data for colobus, and seven years of accurate data for vervets and Sykes.

Analysis

Clustering of electrocutions

To assess clustering of electrocutions I calculated the nearest neighbour index (NNI) (Clark and Evans, 1954) using the vector analysis toolbox in QGIS 2.18.7. The NNI is a ratio of the observed distance between points and the expected distance between points in a random distribution. If the NNI is greater than 1, the distribution of points is dispersed and if it is less than 1, it is clustered. The NNI tests the null hypothesis that points are randomly distributed, and the Z score and

P value measure statistical significance. I calculated the NNI for all species, and separately for each species.

To visualise electrocution hotspots I used two techniques: i) kernel density estimation (KDE) and ii) Getis-Ord-Gi*. KDE is a common technique used to visualise road traffic accident hotspots (Gomes et al., 2009; Mohammadi and Kaboli, 2016). I implemented this using the QGIS Heatmap plugin, which creates a density surface of the electrocution points based on the number of points per unit area. A moving function weights points within a region of influence based upon the distance of each point to the location of interest. The area of influence is determined by the bandwidth, with larger bandwidths resulting in a smoother surface (Gatrell et al., 1996). I used a bandwidth of 500 m for each heatmap as it enabled good resolution of hotspots and allowed for comparison between data subsets. I used this tool to visualise hotspots for all electrocution records, for individual species, and for individual seasons.

As KDE does not provide a measure of statistical significance of hotspots, I used the QGIS Hotspot Analysis plugin to calculate Getis-Ord-Gi* statistics (Getis and Ord, 1992; Oxoli et al., 2016). To use this tool, I aggregated electrocution points into a 150 m by 150 m grid, with each cell containing a value representing the number of electrocutions. This tool finds clustering by comparing values of each cell and its neighbours to the sum of all cells. Resultant Z scores give a measure of clustering, with high positive Z scores indicating clustering of high values (hotspot) and high negative Z scores indicating clustering of low values (coldspot). Corresponding P values indicate statistical significance of clusters. I used this tool to identify hotspots for all electrocution records, for individual species, and for individual seasons. I overlaid hotspots identified by KDE and Getis-Ord-Gi* onto the power line map to calculate the percentage of power lines each hotspot is associated with.

Comparison of electrocution hotspots

To compare electrocution hotspots between species and seasons, I used the KDE and Getis-Ord-Gi* outputs. Using the KDE, I divided each heatmap into five equal interval levels of density and extracted the highest two levels to create a vector outline of hotspots. I overlaid the hotspot outlines for each species onto one map to visualise hotspot overlap, and repeated this to visualise overlap between seasons.

To quantitatively assess differences I transformed the Getis-Ord-Gi* output into a binary variable representing electrocution hotspot presence or absence ($P \leq 0.05$). With this data I used Pearson's correlation tests on R. 3.2.3 to test association between variables (Teixeira et al., 2017). Resultant values gave a measure of resemblance of hotspots between species and seasons.

Electrocution hotspots over time

To assess change in electrocution rate over time, I performed an ordinary least squares regression (OLS) of yearly electrocution rate against year using R 3.2.3. To account for varying population sizes, I repeated this OLS using electrocutions year^{-1} population^{-1} for each species excluding the galago, which did not have census data.

To visualise change in electrocution hotspots over time, I divided the dataset into three study periods, 1998-2003, 2004-2009 and 2010-2016, and created a KDE overlay map of hotspots using the previously mentioned method for species and seasons.

Electrocution hotspots and primate density

To assess whether electrocution density was associated with primate density I performed regression analyses using GeoDa 1.10 (Anselin et al., 2006). This could only be assessed for colobus, Sykes and vervets, as georeferenced census data were not available for galagos and baboons. For each species I aggregated census and electrocution data onto a 150 m by 150 m grid, and calculated the mean density of monkeys per cell across the total number of years of census data, and the mean density of electrocutions per cell across all years. I used OLS to evaluate whether the mean density of electrocutions in a cell was correlated with the mean density of monkeys in that cell. As spatial autocorrelation of the parameters violates the independence assumption of OLS, I subsequently employed spatial regression models using the maximum likelihood approach and a queen's contiguity spatial weights matrix. I selected the most appropriate models based upon Akaike's Information Criterion (AIC), which gives a measure of relative fit of statistical models (Akaike, 1974). Using these criteria, I selected spatial lag models for colobus and Sykes, and a spatial error model for vervets. To visualise the relationship I overlaid electrocution hotspots identified by KDE onto a heatmap of mean population density for each species.

Preliminary evaluation of insulation

Insulation data was limited to ten locations, providing a sample size too small for statistical analysis. I calculated monthly electrocution rates before and after insulation at each site, and then calculated the reduction in rates. Rates before insulation were calculated from the date of the first electrocution recorded at each site to the date of insulation. This was to account for the addition of new power lines at some sites. Rates after insulation were calculated from the date of insulation to the end of 2016.

Ethical Note

This study was approved by the Kenyan government and received ethical approval from the Animal Welfare Ethical Review Body at the University of Bristol.

Results

Between 1998 and the end of 2016, 329 electrocutions were recorded and georeferenced in Diani (69.6% colobus, 14.3% Sykes, 9.4% galagos, 3.6% vervets and 2.1% baboons).

Clustering of electrocutions

NNI values were below 1 and statistically significant ($p \leq 0.02$) for all groups except baboons, for which the sample size was too small (Table 1). Therefore electrocutions are spatially clustered.

Group	No. Points	NNI	Z Score	P value
All species	329	0.16	-29.28	< 0.00001
Baboon	7	1.10	0.50	0.61
Colobus	229	0.00	-28.95	< 0.00001
Galago	31	0.50	-5.32	< 0.00001
Sykes	47	0.22	-10.29	< 0.00001

Vervet	12	0.64	-2.42	0.016

Table 1. Nearest neighbour index (NNI) for all species and individually for each species, with associated Z scores and P values.

All species electrocution hotspots

Getis-Ord-Gi* results showed statistically significant electrocution hotspots for all species, with 72.3% of electrocutions occurring along 11.8% of the power line network (Figure 1). The KDE identified five electrocution hotspots (Figure 1), which showed good agreement with the Getis-Ord-Gi* hotspots. These hotspots accounted for 51.4% of electrocutions along 4.9% of the power grid (Table 2).

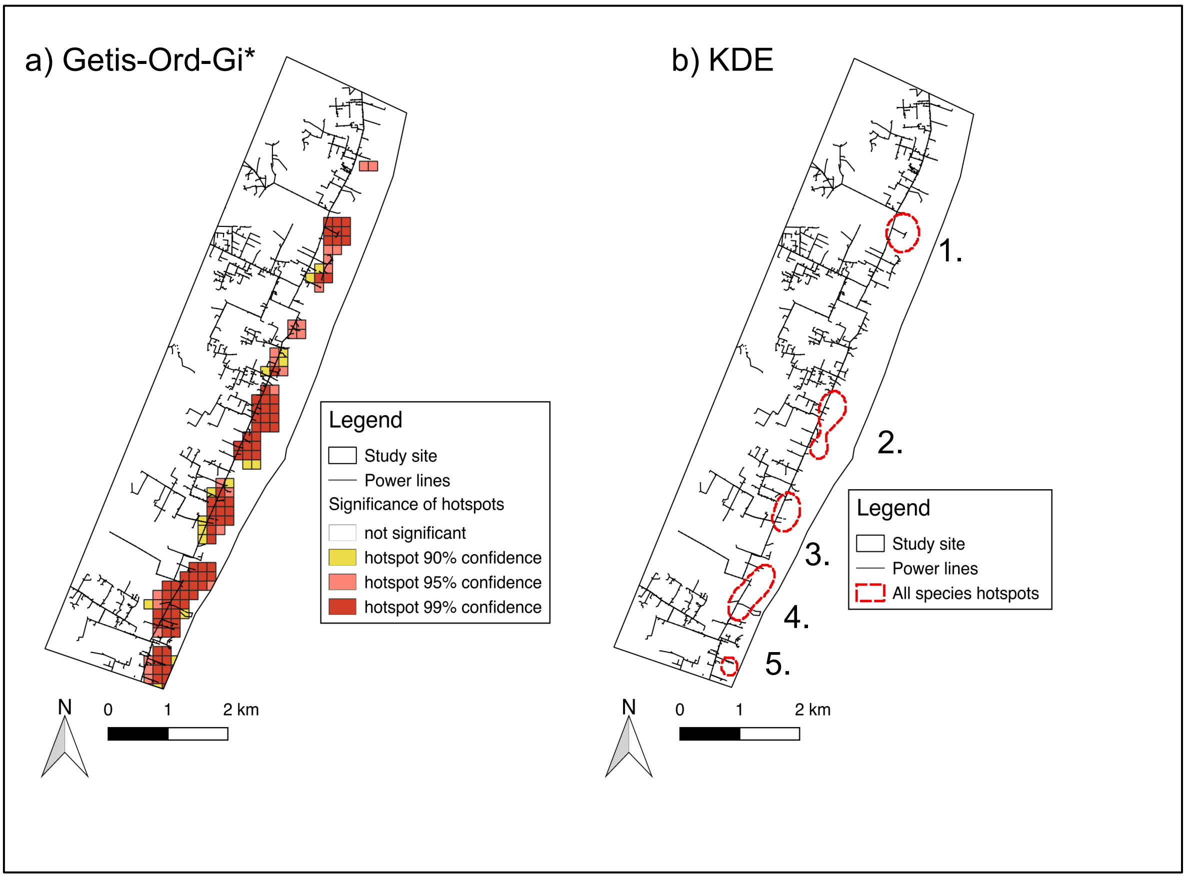

Figure 1. Electrocution hotspots identified for all species. 1a) Shows the statistically significant electrocution hotspots identified by Getis-Ord-Gi*, 1b) shows the outline of hotspots identified by kernel density estimation (KDE), numbered 1-5.

Hotspot no.	Power line (m)	% Total electrocutions	Electrocutions per m
1	990	10.6	0.035
2	1383	14.6	0.035
3	1461	7.9	0.018
4	1534	13.1	0.028
5	303	5.2	0.056

Table 2. Electrocution hotspots for all species, identified by kernel density estimation, along with percentage of electrocutions and metres of power line they are associated with. N.B. Measurement of power line length is representative of the length of linear corridors, not the absolute length of cables.

Species-specific electrocution hotspots

Getis-Ord-Gi* results identified statistically significant hotspots for each species (Figure 2). Colobus hotspots accounted for 77.3% of their electrocutions along 10.2% of the power grid. Galago hotspots accounted for 58.1% of electrocutions along 8.8% of the power grid. Sykes hotspots accounted for 89.3% of electrocutions along 13.3% of the power grid. Vervet hotspots accounted for 100% of electrocutions along 8.4% of the power grid, and baboon hotspots accounted for 100% of electrocutions along 3.3% of the power grid.

The KDE identified four colobus hotspots that accounted for 62.5% of electrocutions along 8.6% of the power grid. Five galago hotspots were identified that accounted for 67.7% of electrocutions along 5.4% of the power grid. Eight Sykes hotspots were identified that accounted for 59.6% of electrocutions along

2.4% of the power grid. Two vervet hotspots were identified that accounted for 41.7% of electrocutions along 0.3% of the power grid. One baboon hotspot was identified that accounted for 57.1% of electrocutions along 0.02% of the power grid.

The hotspot overlay map shows high overlap of electrocution hotspots between different species, excluding one Sykes, one vervet and two galago hotspots which are isolated (Figure 3). The most northerly hotspot shows high overlap between all species excluding baboons. Pearson's correlation showed highest similarity between colobus and Sykes, and galago and Sykes hotspots (Table 3).

	Baboon	**Colobus**	**Galago**	**Sykes**	**Vervet**
Baboon	-	0.22 *	-0.04	0.21 *	0.27 *
Colobus	-	-	0.31 *	0.55 *	0.34 *
Galago	-	-	-	0.46 *	0.19 *
Sykes	-	-	-	-	0.25 *
Vervet	-	-	-	-	-

Table 3. Results of Pearson's product moment correlation showing correlation coefficient (r) and significance level between each species-specific hotspot. (*) Indicates statistical significance at $P \leq 0.01$.

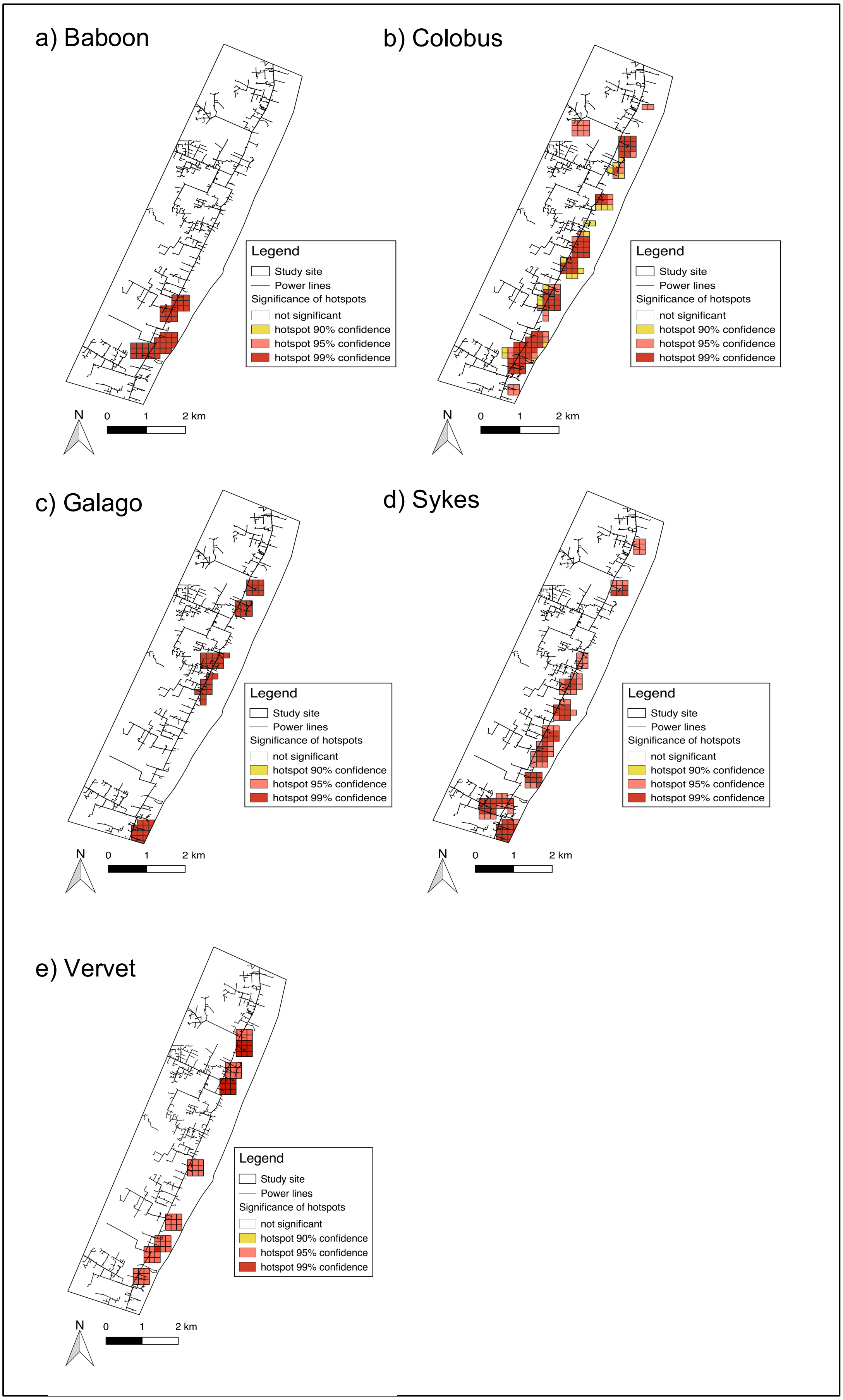

Figure 2. Statistically significant electrocution hotspots identified by Getis-Ord-Gi* for a) baboon, b) colobus, c) galago, d) Sykes and e) vervet monkeys.

Comparison of seasonal electrocution hotspots

Electrocutions occurred at a rate of 1.44 per month during the short dry season, 1.32 per month during the long rains, 1.96 per month during the long dry season and 1.35 per month during the short rains. Visual comparison of seasonal hotspots showed high overlap across all seasons (Figure 3). Pearson's coefficients were statistically significant for all comparisons ($P < 0.0001$), and suggested considerable overlap between most seasons. Similarity was highest between the long rains and the long dry season ($r = 0.65$), and the short rains and the long dry season ($r = 0.64$). Similarity was moderate between short dry season and the long dry season ($r = 0.51$), the short dry season and the long rains ($r = 0.51$), and the short rains and the long rains ($r = 0.53$). Similarity was lowest between the short rains and the short dry season ($r = 0.38$).

Changes over time

Electrocutions occurred at a mean rate of 20.45 per year. OLS regression showed no significant trend in yearly rate (Coefficient = 0.36, $R^2 = 0.078$, df = 18, P = 0.12). OLS of electrocutions year^{-1} population^{-1} for colobus, Sykes, vervets and baboons also showed no trend (Colobus: coefficient = 0.0014, $R^2 = 0.099$, df = 9, P = 0.35, Sykes: coefficient = 0.00020, $R^2 = 0.20$, df = 8, P = 0.19, vervet: coefficient = -0.00011, $R^2 = 0.0052$, df = 8, P = 0.84, baboon: coefficient = -0.00013, $R^2 = 0.048$, df = 9, P = 0.51)

The hotspot overlay map (Figure 3) generally shows high overlap of hotspots since 1998. One hotspot from 1998-2003 has disappeared, one has grown in area, and between 2010-2016 two new hotspots have appeared.

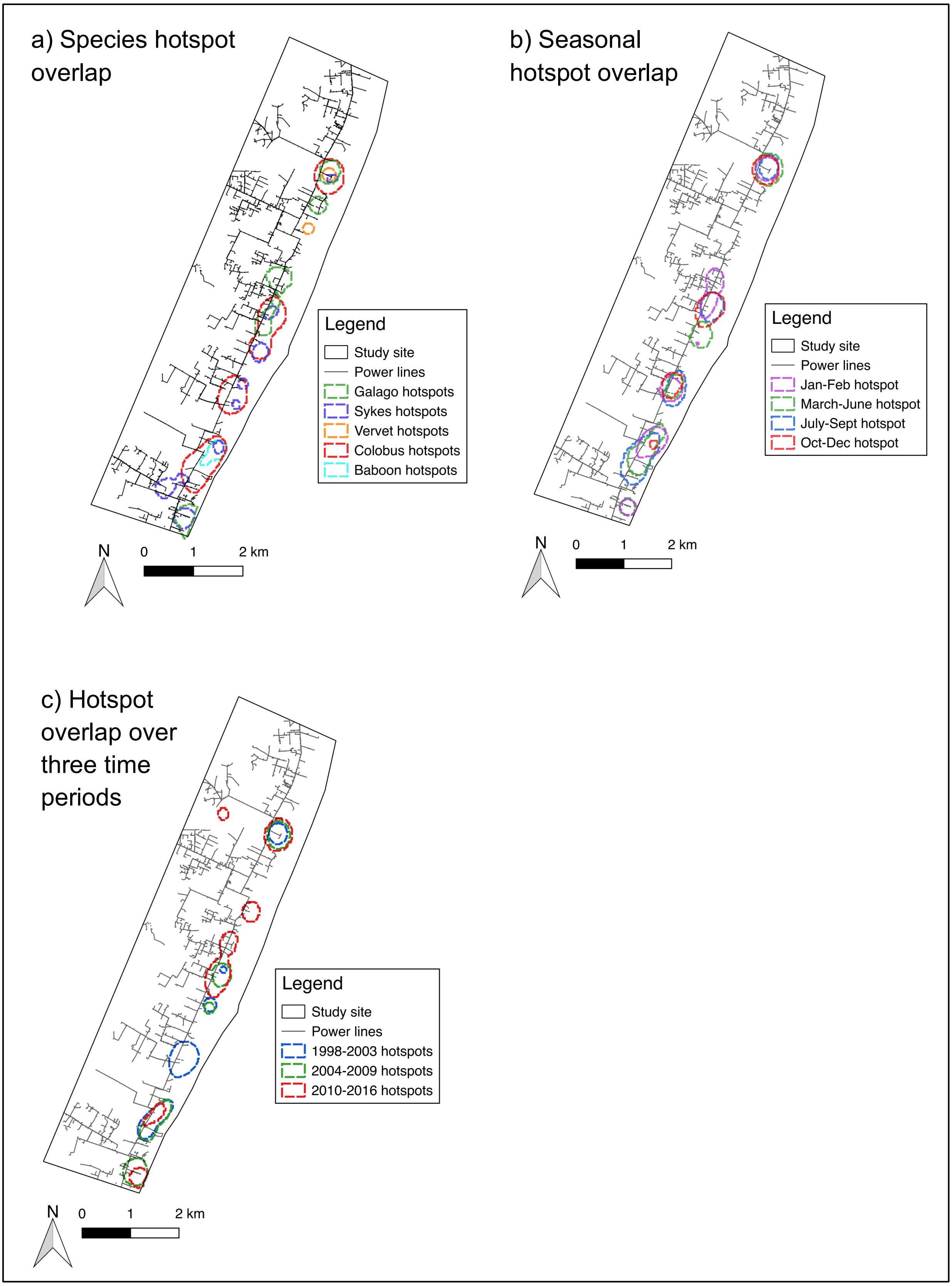

Figure 3. Overlap of hotspots identified by kernel density estimation. a) Shows overlap of hotspots between species, b) shows overlap of hotspots between seasons, c) shows overlap of hotspots between 1998-2003, 2004-2009 and 2010-2016.

Association of electrocution hotspots with primate population density

For colobus and Sykes, OLS indicated a positive association between primate density and electrocution density (Table 4). Spatial lag models support this relationship and show an improved fit. OLS indicated no trend between primate density and electrocution density for vervets, however the spatial error model showed a statistically significant positive relationship and improved fit (Table 4).

Overlay of electrocution hotspots onto primate density KDE showed that hotspots generally coincide with areas of high primate density (Figure 4). However some areas of high primate density coincide with power lines and are not associated with electrocution hotspots.

	Colobus		**Sykes**		**Vervet**	
	OLS	**Spatial lag**	**OLS**	**Spatial lag**	**OLS**	**Spatial error**
Coefficient	0.014	0.011	0.0019	0.0018	0.00044	0.00063
R^2	0.041	0.083	0.039	0.048	0.0030	0.0064
AIC[a]	-26893	-26927	-29834	-29840	-31688	-31691
P Value	<0.0001	<0.0001	<0.0001	<0.0001	0.061	0.0053
Degrees of freedom	1169	1168	1169	1168	1169	1169

Table 4 Ordinary Least Squares (OLS) and Spatially Weighted Regression scores for colobus, Sykes and vervet monkeys with mean density of electrocutions per cell as the dependent variable and mean density of individuals per cell as the explanatory variable. [a]AIC: within each group, a lower score of at least 3 indicates the model has a better fit.

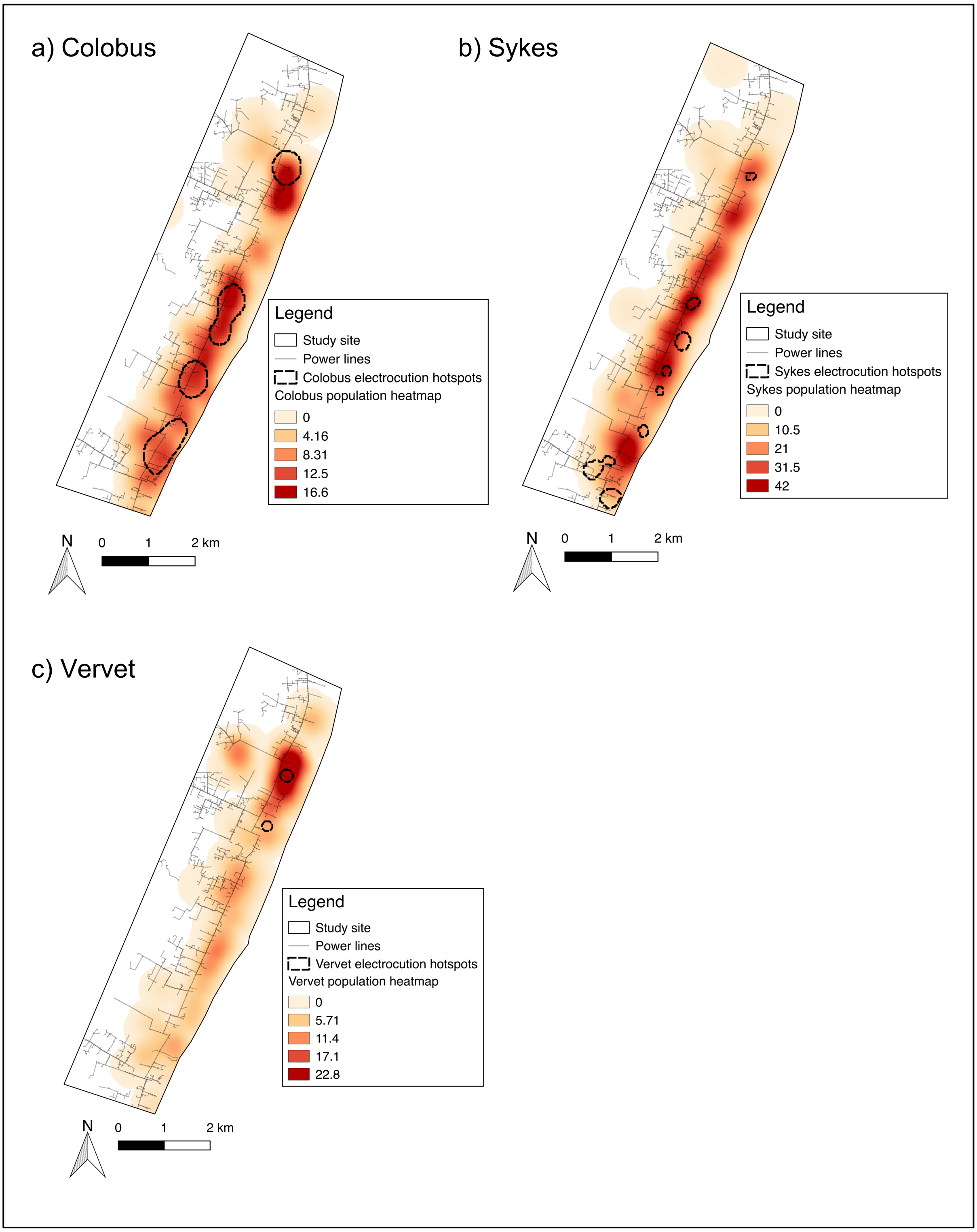

Figure 4 Map showing overlay of electrocution hotspots and mean density of individuals calculated by kernel density estimation for a) colobus, b) Sykes and c) vervet monkeys in Diani.

Preliminary assessment of insulation effectiveness

All sites experienced a decrease in monthly electrocution rate following insulation (Appendix 2). This decrease ranged between 20-100%, with a mean of 64.51 ± 38.14 SD %.

Discussion

Primate electrocutions are not randomly distributed across the landscape in Diani, but are clustered into hotspots that show little variation in location between species and seasons. Whilst yearly electrocution rate is stable, the location of hotspots has changed over time. Primate density is associated with hotspots, however the weak relationship is suggestive of additional risk factors. Evaluation of power line insulation suggests a decline in electrocution rate.

Hotspots identified in this study show that most primate electrocutions occur on a small proportion of the power grid, which should be targeted for mitigation. This pattern was reported for Hanuman langurs in India, whereby a high incidence of electrocutions occurred in one location at the same power pole (Ram et al., 2015), and is commonly observed in avian studies (Dwyer et al., 2014; Guil et al., 2011; Mañosa, 2001; Tintó et al., 2010). Hotspots identified by KDE were narrower than those identified by Getis-Ord-Gi*, and may be a more cost-effective guide for mitigation as they account for more electrocutions per metre of power line. Targeting hotspots 2 and 4 should reduce the highest proportion of electrocutions, however targeting hotspot 5 is the most cost-effective as it accounts for the most electrocutions per m of power line.

Understanding how species hotspots relate to each other is important to ascertain whether species-specific mitigation strategies are required (Teixeira et al., 2017).

Results of the Pearson’s correlation suggest low similarity between species-specific hotspots however overlay of KDE hotspots demonstrated substantial overlap for most species. Pearson’s correlation therefore may be an unreliable technique to assess hotspot similarity (Teixeira et al., 2017). Sykes and colobus hotspots showed high similarity, likely explained by their frequent inter-specific associations (Moreno-Black and Maples, 1977). Sykes and galago hotspots also showed high similarity, although little is known about sympatric associations or resource competition between these species. The species-specific hotspots generally fall within the KDE hotspots created for all species, excluding one Sykes, one vervet and two galago hotspots. This suggests a general approach would be beneficial for most primates, but a more specific approach may be needed to further reduce Sykes, vervet and galago electrocutions.

Hotspots showed little variation between seasons, although electrocution rate increased during the long dry season. This suggests that increased seasonal risk is location-dependent, and therefore season should not be considered for spatial prioritisation. Whilst season is a known electrocution risk factor, higher risk is typically associated with wet seasons (Olendorff et al., 1981; Palei et al., 2014), as demonstrated for rhesus macaques in northern India (Kumar and Kumar, 2015). A proposed explanation for elevated dry season risk in Diani is increased vegetation growth towards the start of the long dry season, resulting in increased contact between trees and power lines (Slade, 2016). An alternative explanation is seasonal use of power lines by monkeys, possibly linked to the availability of food resources (Lokschin et al., 2007).

Since 1998 yearly electrocution rates have remained stable, however the location of hotspots has varied. Changes in location of hotspots may be due to the rapid development of Diani, which has resulted in the construction of new power infrastructure and changes in resource distribution. Alternatively these changes may be associated with variable detection rates in some areas due to the movement of people. For instance a hotspot from 1998-2003 that has disappeared is associated with an abandoned hotel that burnt down in 1998 (Colobus Conservation, pers. comm. 2017) therefore electrocutions are unlikely to be reported. Due to these confounding factors, it is important to include data from the whole study period when planning mitigation strategies (Eberhardt et al., 2013).

Electrocution hotspots are associated with primate density however this does not explain all the variation, implying the importance of other risk factors. This is supported by the significant positive trends and low fit values of the linear models. These additional risk factors may be associated with power line structure and environmental factors such as vegetation cover and food abundance, as shown in avian studies (Dwyer et al., 2014; Guil et al., 2011; Mañosa, 2001; Tintó et al., 2010). It is important to identify these risk factors in order to proactively identify high risk areas before electrocutions are reported, and target them for mitigation (Dwyer et al., 2014; Shaw et al., 2010).

Analysis of insulation data suggests a decrease in monthly electrocution rate following power line insulation, however conclusions are tentative due to uncertainty on exact locations of insulations and a small dataset. 100% reduction in electrocution rate was only observed in locations that already had low rates. In high-risk areas reduction in rate was lower and there were some incidences of electrocutions after insulation. This could be due to degradation of insulation materials over time (Guil et al., 2011), incomplete insulation, exposure of the power pole terminal (Lokschin et al., 2007), or high tension cables and transformers that cannot be insulated in close proximity to insulated lines (Lokschin et al., 2007).

Limitations of this study primarily relate to biased data collection techniques. As Colobus Conservation relies on reports from community members, incidents in inaccessible areas are likely to go underreported. Furthermore, data may be biased by the escape of wounded animals and removal of carcasses by scavengers (Bevanger, 1999). It is unknown how far electrocuted primates travel, therefore the location where animals were found could be some distance from the electrocution incident. However the inclusion of only incidents that were directly observed or where the primate was found attached to the power line resulted in an insufficient dataset. A further limitation related to reliance on a historic dataset that had a number of inconsistencies, making it necessary to estimate several electrocution locations. Despite these limitations, this study benefits from data spanning 18 years, which is beneficial for using hotspots to guide mitigation strategies (Eberhardt et al., 2013).

Conclusion

Electrocution is an issue for many threatened primate species, yet the development of effective evidence-based mitigation strategies is limited. This study provides a framework for systematic spatial prioritisation of high-risk areas that will contribute to more effective mitigation planning. This framework can be utilised across the world to reduce primate electrocutions. Furthermore this study evaluates the efficacy of power line insulation in reducing electrocution rates. Whilst this evaluation was only preliminary, it is an essential component that is lacking from the literature. Recommendations for future work include further objective evaluations of mitigation measures. Additionally, electrocution hotspots should be profiled to identify risk factors such as habitat and high-risk power line components, to guide a proactive mitigation approach that aims to reduce the risk before mortality has occurred.

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References

Akaike, H. (1974). A new look at the statistical model identification. *IEEE Transactions on Automatic Control, 19*(6), 716-723.

Anselin, L., Ibnut, S., & Youngihn, K. (2006). GeoDa: An introduction to spatial data analysis. *Geographical Analysis, 38*(1), 5-22.

APLIC. (2006). *Suggested practices for avian protection on power lines: The state of the art in 2006*. Edison Electric Insitute, Washington D.C. and APLIC and the California Energy Commission, Sacramento, CA.

Arroyo-Rodríguez, V., & Fahrig, L. (2014). Why is a landscape perspective important in studies of primates? *American Journal of Primatology, 76*(10), 901-909.

Bevanger, K. (1994). Bird interactions with utility structures: Collision and electrocution, causes and mitigating measures. *Ibis, 136*(4), 412-425.

Bevanger, K. (1998). Biological and conservation aspects of bird mortality caused by electricity power lines: A review. *Biological Conservation, 86*(1), 67-76.

Bevanger, K. (1999). Estimating bird mortality caused by collision and electrocution with power lines: A review of methodology. In G. F. Janss & M. Ferrer (Eds.), *Birds and Power Lines. Collision, Electrocution and Breeding.* (pp. 29-56). Madrid: Quercus.

Boinski, S., Jack, K., Lamarsh, C., & Coltrane, J. A. (1998). Squirrel monkeys in Costa Rica: Drifting to extinction. *Oryx, 32*(1), 45-58.

Brooks, T. M., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., Rylands, A. B., Konstant, W. R., et al. (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology, 16*(4), 909-923.

Clark, P. J., & Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationships in populations. *Ecology, 35*(4), 445-453.

Colobus Conservation. (2016). *Colobus Conservation Annual Report*

Dittus, W. P. (1986). Sex differences in fitness following a group take-over among toque macaques: Testing models of social evolution. *Behavioral Ecology and Sociobiology, 19*(4), 257-266.

Dunham, N. T. (2014). Positional behavior and habitat use of Peters' Angola black and white colobus monkey (Colobus angolensis palliatus) in structurally distinct areas of the Diani Forest, Kenya. *African Primates, 9*, 1-14.

Dwyer, J., Harness, R., & Donohue, K. (2014). Predictive model of avian electrocution risk on overhead power lines. *Conservation Biology, 28*(1), 159-168.

Eberhardt, E., Mitchell, S., & Fahrig, L. (2013). Road kill hotspots do not effectively indicate mitigation locations when past road kill has depressed populations. *The Journal of Wildlife Management, 77*(7), 1353-1359.

Estrada, A., Garber, P. A., Rylands, A. B., Roos, C., Fernandez-Duque, E., Di Fiore, A., et al. (2017). Impending extinction crisis of the world's primates: Why primates matter. *Science Advances, 3*(1), e1600946.

Gatrell, A. C., Bailey, T. C., Diggle, P. J., & Rowlingson, B. S. (1996). Spatial point pattern analysis and its application in geographical epidemiology. *Transactions of the Institute of British Geographers, 21*(1), 256-274.

Getis, A., & Ord, J. K. (1992). The analysis of spatial association by use of distance statistics. *Geographical Analysis, 24*(3), 189-206.

Gomes, L., Grilo, C., Silva, C., & Mira, A. (2009). Identification methods and deterministic factors of owl roadkill hotspot locations in Mediterranean landscapes. *Ecological Research, 24*(2), 355-370.

Goulart, V. D., Teixeira, C. P., & Young, R. J. (2010). Analysis of callouts made in relation to wild urban marmosets (Callithrix penicillata) and their implications for urban species management. *European Journal of Wildlife Research, 56*(4), 641-649.

Guil, F., Fernández-Olalla, M., Moreno-Opo, R., Mosqueda, I., Gómez, M. E., Aranda, A., et al. (2011). Minimising mortality in endangered raptors due to power lines: The importance of spatial aggregation to optimize the application of mitigation measures. *PLoS ONE, 6*(11), e28212.

Harness, R. E., & Wilson, K. R. (2001). Electric-utility structures associated with raptor electrocutions in rural areas. *Wildlife Society Bulletin, 29*(2), 612-623.

Hernández-Matías, A., Real, J., Parés, F., & Pradel, R. (2015). Electrocution threatens the viability of populations of the Endangered Bonelli's eagle (Aquila fasciata) in southern Europe. *Biological Conservation, 191*, 110-116.

Jenkins, A. R., Smallie, J. J., & Diamond, M. (2010). Avian collisions with power lines: A global review of causes and mitigation with a South African perspective. *Bird Conservation International, 20*(3), 263-278.

Kanga, E., & Heidi, C. (1999). Survey of the Angolan black-and-white colobus monkey, Colobus angolensis palliatus, in the Diani Forests, Kenya. *African Primates, 4*(1-2), 50-54.

Kumar, V., & Kumar, V. (2015). Seasonal electrocution fatalities in free-range rhesus macaques (Macaca mulatta) of Shivalik hills area in northern India. *Journal of Medical Primatology, 44*(3), 137-142.

Lokschin, L. X., Rodrigo, C. P., Hallal Cabral, J. N., & Buss, G. (2007). Power lines and howler monkey conservation in Porto Alegre, Rio Grande do Sul, Brazil. *Neotropical Primates, 14*(2), 76-80.

Maibeche, Y., Moali, A., Yahi, N., & Menard, N. (2015). Is diet flexibility an adaptive life trait for relictual and peri-urban populations of the Endangered primate Macaca sylvanus? *PLoS ONE, 10*(2), e0118596.

Malo, J. E., Suarez, F., & Diez, A. (2004). Can we mitigate animal–vehicle accidents using predictive models? *Journal of Applied Ecology, 41*(4), 701-710.

Mañosa, S. (2001). Strategies to identify dangerous electricity pylons for birds. *Biodiversity and Conservation, 10*(11), 1997-2012.

Mohammadi, A., & Kaboli, M. (2016). Evaluating wildlife-vehicle collision hotspots using kernel-based estimation: A focus on the endangered Asiatic cheetah in central Iran. *Human-Wildlife Interactions, 10*(1), 103.

Moore, R., & Nekaris, K. (2014). Compassionate conservation, rehabilitation and translocation of Indonesian slow lorises. *Endangered Species Research, 26*(2), 93-102.

Moore, R., Nekaris, K., & Eschmann, C. (2010). Habitat use by western purple-faced langurs Trachypithecus vetulus nestor (Colobinae) in a fragmented suburban landscape. *Endangered Species Research, 12*(3), 227-234.

Moreno-Black, G., & Maples, W. R. (1977). Differential habitat utilization of four Cercopithecidae in a Kenyan forest. *Folia Primatologica, 27*(2), 85-107.

Mwamachi, D., Audho, J., Thorpe, W., & Baker, R. (1995). Evidence for multiple anthelmintic resistance in sheep and goats reared under the same management in coastal Kenya. *Veterinary Parasitology, 60*(3), 303-313.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*(6772), 853-858.

Nekaris, K., & Jayewardene, J. (2004). Survey of the slender loris (Primates, Lorisidae Gray, 1821: Loris tardigradus Linnaeus, 1758 and Loris lydekkerianus Cabrera, 1908) in Sri Lanka. *Journal of Zoology, 262*(4), 327-338.

Olendorff, R. R., Miller, A. D., & Lehman, R. N. (1981). *Suggested practices for raptor protection on powerlines. The state of the art in 1981. Raptor Research Report No. 4*: The Raptor Research Foundation

Oxoli, D., Zurbarán, M. A., Shaji, S., & Muthusamy, A. K. (2016). Hotspot analysis: A first prototype Python plugin enabling exploratory spatial data analysis into QGIS. *PeerJ Preprints, 4*, e2204v2202.

Palei, N. C., Palei, H. S., Rath, B. P., & Kar, C. S. (2014). Mortality of the Endangered Asian elephant Elephas maximus by electrocution in Odisha, India. *Oryx, 48*(04), 602-604.

Parker, L., Nijman, V., & Nekaris, K. (2008). When there is no forest left: Fragmentation, local extinction, and small population sizes in the Sri Lankan western purple-faced langur. *Endangered Species Research, 5*(1), 29-36.

Printes, R. (1999). The Lami Biological Reserve, Rio Grande do Sul, Brazil, and the danger of power lines to howlers in urban reserves. *Neotropical Primates, 4*(7), 135-136.

Ram, C., Sharma, G., & Rajpurohit, L. (2015). Mortality and threats to Hanuman langurs (Semnopithecus entellus entellus) in and around Jodhpur (Rajasthan). *Indian Forester, 141*(10), 1042-1045.

Rodrigues, N. N., & Martinez, R. A. (2014). Wildlife in our backyard: Interactions between Wied's marmoset Callithrix kuhlii (Primates: Callithrichidae) and residents of Ilhéus, Bahia, Brazil. *Wildlife Biology, 20*(2), 91-96.

Roscoe, C. J., de Silva, M. A., Hapuarachchi, N. C., & Krishantha, P. R. (2013). A new color morph of the southern purple-faced langur (Semnopithecus vetulus vetulus) from the rainforests of southwestern Sri Lanka. *Primate Conservation, 26*(1), 115-124.

Rudran, R. (2015). Western purple-faced langur Trachypithecus (Semnopithecus) vetulus nestor Bennett, 1833, Sri Lanka (2004, 2006, 2008, 2010, 2012, 2014). In C. Schwitzer, R. Mittermeier, A. Rylands, F. Chiozza, E. Williamson, J. Wallis & A. Cotton (Eds.), *Primates in Peril: The World's 25 Most Endangered Primates 2014-2016* (pp. 63-66). Arlington, VA: IUCN SSC Primate Specialist Group (PSG), International Primatological Society (IPS), Conservation International (CI), Bristol Zoological Society (BZS).

Schulze, C., Peters, M., Baumgärtner, W., & Wohlsein, P. (2016). Electrical injuries in animals: Causes, pathogenesis, and morphological findings. *Veterinary Pathology, 53*(5), 1018-1029.

Shaw, J. M., Jenkins, A. R., Smallie, J. J., & Ryan, P. G. (2010). Modelling power-line collision risk for the blue crane Anthropoides paradiseus in South Africa. *Ibis, 152*(3), 590-599.

Slade, A. (2016). *Survivorshop, demographics and seasonal trends among electrocuted primate species in Diani, Kenya.* Unpublished MSc Thesis, School of Veterinary Sciences, University of Bristol.

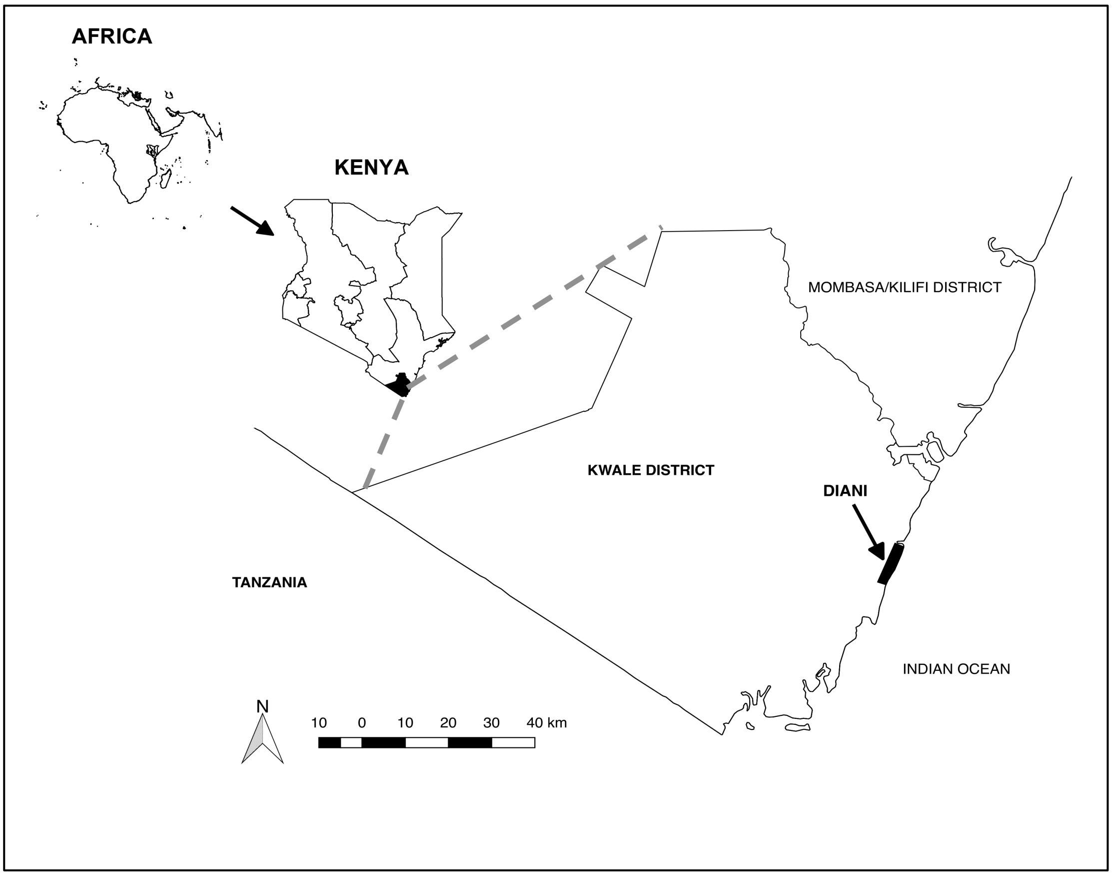
Sutherland, W. J., Pullin, A. S., Dolman, P. M., & Knight, T. M. (2004). The need for evidence-based conservation. *Trends in Ecology & Evolution, 19*(6), 305-308.

Teixeira, F. Z., Coelho, I. P., Esperandio, I. B., da Rosa Oliveira, N., Peter, F. P., Dornelles, S. S., et al. (2017). Are road-kill hotspots coincident among different vertebrate groups? *Oecologia Australis, 17*(1), 36-47.

Teixeira, F. Z., Printes, R. C., Fagundes, J. C. G., Alonso, A. C., & Kindel, A. (2013). Canopy bridges as road overpasses for wildlife in urban fragmented landscapes. *Biota Neotropica, 13*(1), 117-123.

Tintó, A., Real, J., & Mañosa, S. (2010). Predicting and correcting electrocution of birds in Mediterranean areas. *Journal of Wildlife Management, 74*(8), 1852-1862.

Appendix 1 – Map of study site.



Appendix 2 – Table of insulation data showing decrease in monthly electrocution rates after installation of insulation.

Location	Year of first electrocution	Year insulated	No. Electrocutions before	No. Electrocutions after	% Decrease in monthly rate
Kila Kitu	1999	2010	5	2	23.24
96 Beach Road	2007	2011	1	0	100.00
Kirstin's House	2010	2011	1	0	100.00
Kennaways Hotel	2000	2011	3	2	21.85
Manyatta	2004	2012	3	1	33.33
Seacrest School Staff Quarters	2004	2012	1	0	100.00
Kivulini Villas	2011	2013	2	2	20.00
Private Property near Pinewood	2013	2013	2	0	100.00
Tradewinds Hotel	1998	2013	8	1	46.64
Sean White's House	2014	2014	1	0	100.00

Application for Ethical Approval of an Investigation Involving Animals (UIN)

This form should be used for studies on animals, other than humans, at any stage of development that is to be carried out at the University of Bristol and that is not regulated by the Animals (Scientific Procedures) Act, 1986. All experiments to be carried out by a member of the University in another establishment, including one abroad, should also be included, whether or not they have local ethical/regulatory approval. It is very difficult to define the species that should be subject to ethical approval because it is impossible to predict accurately how much a given species would suffer under particular experimental conditions. As a guide to the species for which approval should be sought, include any for which ethical issues have been raised seriously in the past. For example include lobsters but not worms. If in doubt, submit an application.

Project Title	Identification of primate electrocution hotspots and factors associated with electrocution risk along power-lines in Diani, Kenya		
Investigator	Lydia Katsis	**Supervisor (if applicable)**	Katy Turner
Department	Health Sciences	**Telephone**	07947584939
Anticipated end date	21st August	**E-mail**	Lk16878@my.bristol.ac.uk
If appropriate, have you applied for/received approval from the Human Ethics committee (FREC)?	n/a		

Does this investigation:	**Yes/No**
Cause pain, suffering, distress or lasting harm. These terms encompass any material disturbance to normal health and include disease, injury and physiological or psychological discomfort.	No
Require any biological samples to be taken from living animals?	No
Require animals to be housed under conditions that are outside the Home Office Codes of Practice*?	No
Require animals to be placed in a modified environment, or metabolism cages/pens?	No
Require animals to be kept in isolation?	No
Require animals to have food or water withheld, or restricted access to diet or water (such as reduced trough space)?	No
Will animals be offered altered (e.g. to make it unpalatable) or marked (e.g. with radioactive additives) food or drink?	No
Will animals receive any medication (topically, parenterally or enterically)?	No
Will any necessary medication or veterinary treatment be withheld?	No
Will animals be killed by a method other than Schedule 1?	No

* Home Office Codes of Practice are available at: https://www.gov.uk/government/publications/extracts-from-the-code-of-practice-for-the-housing-and-care-of-animals-used-for-scientific-purposes

*If you have answered "**Yes**" to any of the questions above, the study may require a **Project Licence** and you should consult the Home Office Liaison Team (HOLT) at asu-holt@bris.ac.uk before proceeding with your plans.*

	Yes / No
Has sufficient funding been assured for the duration of the investigation?	Yes
Have you approached ASU regarding space for this investigation? *If no, please see NACWO if work is to take place at UoB*	No

Historical data analysis and Observational data collection	Yes / No
Does the study involve historical data ONLY and therefore not involve any new data collection?	No
Does the study involve observational data collection ONLY and therefore not involve any interaction with animals beyond what they experience normally?	Yes

*If you have answered "**Yes**" to either of the two questions above, simply complete the **Project Summary** box overleaf.*
If you have answered "No" to both of the two questions above, please complete the rest of the form.

The HOLT is a function of the Animal Services Unit and deals with both regulated and non-regulated research.

All applications should be submitted electronically to asu-holt@bristol.ac.uk, and include:

1. This page with your electronic signature.
2. A Lay Statement - details overleaf. Please answer all the questions as accurately as possible.
   Projects involving only historical or observational data need only to complete the Project Summary box.
3. Applications for experiments on living animals (excluding those involving Schedule 1 killing only) should include a concise description of the procedures to be carried out, and their possible adverse effects.

- Following submission of your application, it will be reviewed by the HOLT and the Animal Welfare and Ethical Review Body (AWERB). If approved, you will be notified of your University Investigation Number (UIN) and the end date.
- UINs on animals are authorised for up to **three** years.

DECLARATION BY THE APPLICANT

I understand that, if permission is granted for this research, I will be responsible for the supervision, conduct and competence of all animal users working on this project.

SIGNATURE		Date	20/03/2017

Project Summary ***(for projects involving historical data analysis or observational data collection ONLY)*** *Please provide a short abstract of your research project written in a format suitable for a lay audience. Include the species involved, main outcome measures and a brief summary of the methods involved.*
Expanding human development in Diani Beach, Kenya has resulted in increasing human encroachment into habitats of wild animals. As a result, populations of wild primates are coexisting in semi-urban environments alongside humans. Primate species found in Diani Beach include the Angolan black and white colobus (*Colobus angolensis ssp palliatus),* the vervet monkey (*Cercopithecus aethiops*), the Sykes monkey (*Cercopithecus albogularis),* the yellow baboon *(Papio cynocephalus),* and bushbabies (*Galago senegalensis* and *Otolemur crassicaudatus).* The semi-urban environments they live in present multiple threats to the survival of these primate species, the biggest of which is death by electrocution from power-lines, a danger faced by many endangered primate species across the globe. Arboreal primates living in semi-urban environments are frequently electrocuted as they use aerial power-lines to travel between trees, access food sources and disperse.

Colobus Conservation, a primate conservation organisation in Kenya, operates a primate rescue centre and treats primates affected by electrocution. Electrocuted primates found in the area are collected by Colobus Conservation and given veterinary treatment, and if appropriate are rehabilitated and subsequently released back into the wild. If monkeys suffer injuries that are too severe to recover from, then they may be euthanized by the resident veterinary surgeon. Colobus Conservation has collected data on their primate electrocution cases since 1998, including locations of where the primate casualties were found. My project will map the locations of electrocutions and compare this to primate population distribution data, vegetation data and locations of all power-lines in the area, with the aim of uncovering patterns of electrocution locations and gaining a deeper understanding of the problem. It is important to understand patterns of electrocution locations in order to best implement mitigation strategies. An effective mitigation strategy is power-line insulation, however this is an expensive option, therefore it is necessary to first prioritise which power-lines pose the most risk to primates.

This project will use multiple sources of data that have all already been collected by Colobus Conservation, as well as data collected by the principal investigator. Data collection will involve utilising data that has previously been collected by Colobus Conservation to obtain locations of primate electrocutions, the principal investigator will then collect GPS points of these electrocution locations. Statistical analysis will include this data, as well as primate distribution data and a map of the power-lines, all pre-collected and provided by Colobus Conservation. This data will be analysed to identify electrocution 'hotspots' and factors associated with electrocution risk such as the primate population distribution. This data will be incorporated into a model that can be used to identify potentially high-risk areas for electrocution in other areas.

Lay Statement

Please answer <u>all</u> the following questions in clear non-scientific terms, (bearing in mind that some of the information you provide could be disseminated, if requested, under the Freedom of Information Act, 2000). Please restrict your submission to two sides of A4, typing your answers directly underneath the questions.

The Scientific Problem *What scientific problem are you studying?* *How are you going to investigate this problem?*
Possible Outcomes *What do you hope to achieve?* *How might these achievements benefit man or other animals?*
Animal Source and Authorisation *State the species, stage of development and source of the animals you wish to use.* *Is authorisation required for the use of any of these animals from a regulatory authority such as English Nature or DEFRA? If so, please give details.*
Reduction, Refinement and Replacement

Why use living animals? What alternatives have been considered? *Which species will be used, and why?* *How many animals do you propose to use? How did you calculate that figure?* *(please give, at least, an estimate of tens, hundreds or thousands)*
Experimental Procedures (Detailed) *What are you going to do to the animals?* *Describe any possible adverse effects, and the measures you will take to prevent these from occurring.* *Describe the end-points that should be used so that animal care staff can be clear at what stage it would be necessary to terminate an experiment.* *What will happen to the animals at the end of the study?* *If the animals are to be killed, what method will be used?*
Peer Review *Have all the experiments and procedures included in this proposal been peer reviewed? (Yes/No) If yes, please list reviewers. Who will be funding this research?*