Applied Geography 117 (2020) 102185

Contents lists available at ScienceDirect

Applied Geography

journal homepage: http://www.elsevier.com/locate/apgeog

Primates on the farm – spatial patterns of human–wildlife conflict in forest-agricultural landscape mosaic in Taita Hills, Kenya

Mika Siljander[a,b,*], Toini Kuronen[a], Tino Johansson[a,e], Martha Nzisa Munyao[c,d], Petri K. E. Pellikka[a,b]

[a] Earth Change Observation Laboratory, Department of Geosciences and Geography, University of Helsinki, P.O. Box 64, 00014, Finland
[b] Institute for Atmospheric and Earth System Research, Faculty of Science, University of Helsinki, P.O. Box 64, 00014, Finland
[c] Biodiversity Research and Monitoring Division, Department of Planning and Environmental Compliance, Kenya Wildlife Service (KWS), P.O. Box 40241, 00100, Nairobi, Kenya
[d] School of Science & Informatics, Department of Computing and Informatics, Taita Taveta University, P. O. Box, 635-80300, Voi, Kenya
[e] International Centre of Insect Physiology and Ecology (icipe), Duduville Campus, Kasarani, P.O. Box 30772, 00100, Nairobi, Kenya

A R T I C L E I N F O

Keywords:
Human–wildlife conflict
Crop-raiding
Human–primate conflict
Food security
Vulnerability
Primates

A B S T R A C T

Human–wildlife conflict (HWC) is a growing concern for local communities living in the vicinity of protected areas. These conflicts commonly take place as attack by wild animals and crop-raiding events, among other forms. We studied crop-raiding patterns by non-human primates in forest–agricultural landscape mosaic in the Taita Hills, southeast Kenya. The study applies both qualitative and quantitative methods. Semi-structured questionnaire was used in the primary data collection from the households, and statistical tests were performed. We used applied geospatial methods to reveal spatial patterns of crop-raiding by primates and preventive actions by farmers. The results indicate most of the farms experienced crop-raiding on a weekly basis. Blue monkey (*Cercopithecus mitis*) was the worst crop-raiding species and could be found in habitats covered by different land use/land cover types. Vervet monkey (C*hlorocebus pygerythrus*) and galagos crop-raided farms in areas with abundant tree canopy cover. Only few baboons *(Papio cynocephalus)* were reported to raid crops in the area. Results also show that the closer a farm is to the forest boundary and the less neighbouring farms there are between the farm and the forest, the more vulnerable it is for crop-raiding by blue monkeys, but not by any other studied primate species. The study could not show that a specific type of food crop in a farm or type of land use/land cover inside the wildlife corridor between the farmland and the forest boundary explain households' vulnerability to crop-raiding by primates. Preventive actions against crop-raiding by farmers where taken all around the studied area in various forms. Most of the studied households rely on subsistence farming as their main livelihood and therefore crop-raiding by primates is a serious threat to their food security in the area.

1. Introduction

Human–wildlife conflicts (HWC) are incidences where wildlife's needs become incompatible with those of human populations, with costs both to humans and to wild animals (IUCN, 2004). HWCs can appear in the form of crop damage, livestock loss, disease transmission, human injury and death, around protected areas (e.g., Adams, 2004; Anand, Binoy, & Radhakrishna, 2018; Campbell-Smith, Simanjorang, Leader-Williams, & Linkie, 2010; Dickman, 2010; Dittus, Gunathilake, & Felder, 2019; Freitas, Setz, Araújo, & Gobbi, 2008; Kolowski & Holekamp, 2006; Linkie et al., 2007; Metcalfe & Kepe, 2008; Naughton-Treves, 1998; Naughton-Treves, Holland, & Brandon, 2005; Naughton-Treves & Treves, 2005; Nicole, 2019; Ogra, 2008; Packer, Ikanda, Kissui, & Kushnir, 2005; Wallace & Hill, 2012; Webber & Hill, 2014; Yeo & Neo, 2010). HWCs exists in most places of the world and are not limited to developing countries or rural settings alone. The phenomenon is also present in urban areas where wildlife and humans share the same space (Fehlmann, O'Riain, Kerr-Smith, & King, 2017; Hoffman & O'Riain, 2012a; Hoffman & O'Riain, 2012b; Mochizuki & Murakami, 2013; Sillero-Zubiri & Switzer 2001; Thatcher, Downs & Koyama, 2019). Expansion of human activities – whether they are agricultural, industrial or related to urbanization – has caused wildlife habitats to

* Corresponding author. Earth Change Observation Laboratory, Department of Geosciences and Geography, University of Helsinki, PO Box 64, 00014, Finland.
E-mail addresses: mika.siljander@helsinki.fi (M. Siljander), toini.kuronen@gmail.com (T. Kuronen), tino.johansson@helsinki.fi (T. Johansson), marthan@kws.go.ke (M.N. Munyao), petri.pellikka@helsinki.fi (P.K.E. Pellikka).

https://doi.org/10.1016/j.apgeog.2020.102185
Received 5 August 2019; Received in revised form 8 January 2020; Accepted 2 March 2020
Available online 14 March 2020

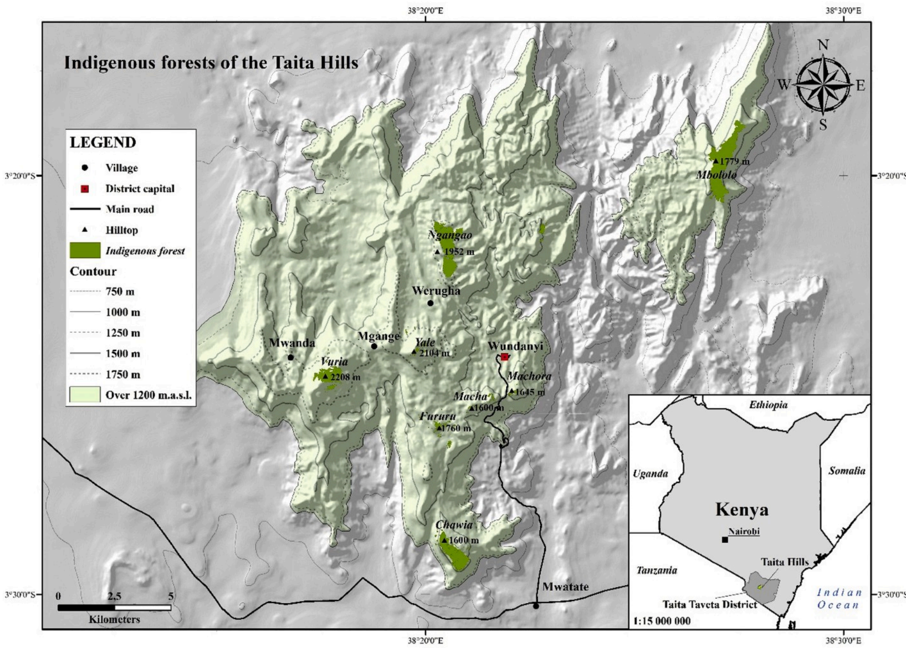

Fig. 1. Indigenous cloud forest remnants of the Taita Hills and location of the study site, Ngangao forest.

become more and more fragmented, and they have become disrupted by human activities (Lamarque et al., 2009). Since 1980s, human-wildlife conflicts have raised growing interest globally among ecologists, biologists, wildlife conservationists, geographers, primatologists, government agencies, and United Nation organizations, such as Food and Agriculture Organization (FAO), among many other stakeholders who aim at addressing the HWC dilemma.

Case studies on HWC are found throughout the world. In rural Africa, most studies refer to human–elephant conflicts (HEC) (e.g., Mayberry et al., 2017; Naughton-Treves & Treves, 2005; Nsonsi et al., 2017; Sitati et al., 2003) and to human-carnivore conflicts (e.g., Mitchell et al., 2018; Packer et al., 2005; Thorn et al., 2015). In recent years, however, awareness and discussion of human-primate conflict has increased and the current knowledge on human-primate conflict is based on studies in different locations around the world. In Africa, research on human-primate conflict has been carried out, for example, in: Guinea-Bissau (Hockings, 2009; Hockings & Sousa, 2013), Madagascar (Freed, 2012), Rwanda (McGuinness & Taylor, 2014), South Africa (Findlay, 2016), Tanzania (Gillingham & Lee, 2003), and Uganda (Aharikundira & Tweheyo, 2011; Hill, 2000; Hill & Webber, 2010; Naughton-Treves, 1998; Saj, Sicotte & Paterson, 2001; Tweheyo, Hill, & Obua, 2005; Wallace & Hill, 2012). A number of studies have also been carried out in the context of Asia (e.g, Campbell-Smith, Sembiring, & Linkie, 2012; Johnson, Karanth & Weinthal, 2018; Marchal & Hill, 2009; Nekaris et al., 2013; Priston, Wyper & Lee, 2011; Riley 2007) and in both Africa and Asia (Priston & McLennan, 2013).

Most of these earlier studies have acknowledged that human-primate conflict is a real and severe issue that has drastic impacts on the livelihoods of rural households. Subsistence farmers are highly dependent on their agricultural production and therefore crop-raiding by wildlife, such as primates, poses a serious threat to local food security. According to FAO (2015), in African mountains and highlands, more than 33 million people living between 1500 and 2500 m above sea level were considered vulnerable to food insecurity in 2012. Majority of people in these areas are smallholder farmers who earn their livelihood from rain-fed agriculture. Crop-raiding by primates may aggravate their coping strategies towards climate variability and climate change through reduced quantity and quality of staple and cash crop yields.

Most conflicts between humans and primates are related to crop-raiding and three main types of research methods seems to dominate: (i) interviewing farmers about their perceptions of the crop damage (Hill & Webber, 2010; Marchal & Hill, 2009; Saj, Sicotte & Paterson, 2001; Tweheyo, Hill, & Obua, 2005); (ii) measuring the exact crop damage during a certain period of time (Hill, 2000; Naughton-Treves, 1998; Siex & Struhsaker, 1999), and (iii) observing primate crop-raiding behaviour in farmlands (Priston, Wyper & Lee, 2011). In addition, spatial analysis methods have been utilized in human-primate conflict studies e.g. in Africa, Hoffman & O'Riain, (2012a) used spatial techniques to analyse landscape requirements of primates in Cape Peninsula and Hoffman & O'Riain (2012b) used logistic regression models to create crop-raiding prediction maps in the same area. Webber & Hill (2014) created participatory risk maps in Uganda and Fehlmann et al. (2017) used spatial modelling to analyse adaptive space use by baboons in a human-changed landscape in Cape Peninsula. Thatcher et al. (2019) used kernel density estimator (KDE) to study positive and negative aspects of human–wildlife interactions in anthropogenically disturbed urban environment in KwaZulu-Natal, South-Africa and Wallace & Hill (2012) utilized spatial statistics to quantify the key parameters of primate crop-raiding events in farms. In Asia, Campbell-Smith et al. (2012) used geospatial methods to determine crop-raiding mitigation strategies in Sumatra and Linkie et al. (2007) used spatial methods to analyse patterns and perceptions of wildlife crop-raiding in Sumatra. In Japan, Mochizuki & Murakami (2013) conducted study with radio-tracking data and spatial modelling to analyse crop-raiding Japanese macaques in an urban setting. In South Asia, Karanth, Gopalaswamy, DeFries, and Ballal (2012) used Kriging technique to generate probabilities maps for crop loss and livestock predation loss in Kanha Tiger Reserve in India, and Karanth et al. (2013) applied Kriging method to study spatial patterns of human–wildlife conflicts in Western Ghats in India. In Sri Lanka, Nijman & Nekaris (2010) used spatial techniques to model farm-specific risk values for primate crop-raiding. In Brazil, Spagnoletti et al. (2017) compared Capuchins (*Sapajus libidinosus*) observational data with farmers' perceptions of crop losses.

It is clear, that a number of HWC studies have used spatial analysis methods, however, especially in human-primate conflict studies, more applied geospatial techniques need to be investigated to exploit full potential of contemporary GIS and remote sensing analysis capabilities. This study represents unique effort to contribute to the existing human-

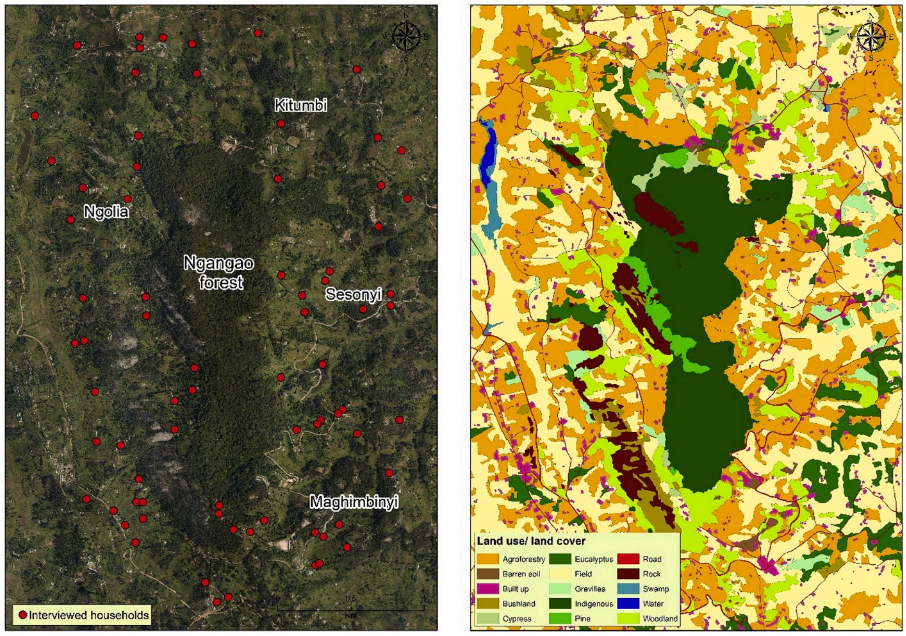

Fig. 2. On the left, the study area Ngangao indigenous forest, surrounded by many small village centers seen from an aerial true-color image mosaic from year 2012. Red dots in the image shows the location of interviewed households. On the right, land use/land cover classification map on-screen digitized from the aerial image mosaic, see Pellikka et al., 2009. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

primate conflict studies by applying GIS and remote spatial analysis methods and semi-structured questionnaires data to determine various spatial patterns and factors to best explain farmers vulnerability and their preventive actions against primate crop-raiding in forest-agricultural landscape mosaic in Taita Hills, Kenya.

1.1. In this study we examined

(a) Which are the most problematic primate species involved in human-wildlife conflicts in the study area?
(b) What time of day do most of these human–wildlife conflicts occur, what is their frequency, and how much is the estimated loss to the farmers?
(c) Does the distance of a farm from the forest edge and the number of neighbouring farms have any effect to crop-raiding by primates?
(d) What influence does the land use/land cover type between the farm and the forest have on the farms' vulnerability to crop-raiding by primates?
(e) Can Thiessen polygons be used to enhance spatial pattern analysis of crop-raiding?
(f) Which crops are mostly raided by primates and what preventive actions farmers take against these incidences?

2. Material and methods

2.1. Study site

The Taita Hills (3°25′S, 38°20′E) are located in Taita Taveta County ca. 150 km inland from the coast of the Indian Ocean in the southeast Kenya and are the northernmost extension of the Eastern Arc Mountains (EAM) (Fig. 1). The EAM is considered as one of the world's biodiversity hotspots based on global concentrations of species endemism (Myers et al., 2000; Rogers et al., 2008). In prehistoric times, the Taita Hills may have been covered with continuous indigenous cloud forests. Afro-montane forests in the Sub-Saharan Africa have been decreasing at an annual rate of 3.8 percent, and also Taita Hills have experienced over 90 percent of forest loss during the past 200 years (Eva, Brink, & Simonetti, 2006; Pellikka et al., 2013). Today, only four larger fragments of indigenous cloud forests, between 100 and 200 ha, and nine smaller patches of remain in the area. Despite the extensive fragmentation of the indigenous forests, Taita Hills still hosts several endemic species of invertebrates, vertebrates and plants (Beentje, 1988; Bytebier, 2001; Rikkinen, 2014). The area experiences a bimodal pattern of rainfall which, characterizes the agricultural growing seasons. Short rains occur in November–December, while long rains dominate in March–May.

This study was conducted in the surrounding areas of the second largest remaining indigenous cloud forest fragment on the Taita Hills, Ngangao forest (38°20′33″E, 3°21′55″S). The forest is part of the Dabida Hills and it is surrounded by seven villages. Agricultural land, agroforestry and exotic tree plantations of eucalyptus (*Eucalyptus saligna*), cypress (*Cuppressus lusitanica*), silky oak (*Grevillea robusta*) and pine (*Pinus patula*), are the dominant land use/land cover types around the Ngangao forest. On its western side, open rock dominates the landscape, whereas the eastern side is steep and forested (Fig. 2). In the area, there is growing evidence of anthropogenic disturbances such as land development, forest cutting and fuel wood collection (Pellikka et al., 2009). The forest itself can be characterized as moist montane to intermediate montane forest (Aerts et al., 2011) consisting of indigenous trees of about 100 species (Rogers et al., 2008; Schäfer et al., 2016) accompanied by exotic tree stands of pine and cypress and some other individual exotic trees (Omoro et al., 2013; Pellikka et al., 2009).

The average farm holding size for smallholder farmers in the agro-ecological zone (highlands) where the study was conducted varies from 0.4 ha to about 1.5 ha. This results in low yield per unit area for most farming households (Taita Taveta County Government, 2013). The farmers grow a variety of crops, maize being the most typical crop, others include cassava, sweet potato, banana and fruit trees like avocado. The farmers keep some domestic animals like dogs, chicken, goats, and 1–2 cows in zero-grazing practice. Isolated indigenous trees, such as *Prunus africana* and *Ficus thonningii*, and exotic trees like cypress and avocado (*Persea americana*) may grow on the fields.

2.2. Studied species

The four primates of this study consist of three Old World monkeys –

blue monkey (*Cercopithecus mitis*), vervet monkey (*Chlorocebus pygerythrus*) and yellow baboon (*Papio cynocephalus)* – and a family of strepsirrhini – galagos or so-called bush-babies. Generally, blue monkey is a medium-sized diurnal animal, which lives in humid areas that offer lots of tree canopy cover. They spend less than 5 percent of their time in ground level. Blue monkeys are highly social and move in troops of tens of members. They are not very selective with their feeding pattern and, in addition to wild foods, the species can also eat farm crops and sometimes prey galagos. Vervet monkey (*Chlorocebus pygerythrus*) is also a diurnal monkey, which can live in larger troops (up to 50 members) than blue monkey. They are smaller than blue monkeys and highly adaptable to different habitats, so can be found in grasslands, tree savannas and forest edges. The vervet monkey is perceived as an "agricultural pest" by many farmers across rural Africa as it is known to raid crops. Yellow baboon (*Papio cynocephalus*) is not a common primate in the Ngangao forest area because it is normally found in semi-arid areas of lower altitudes in the Taita Taveta County. Still, yellow baboon was included in the studied primates as some of the respondents had seen it on their compound during the past 12 months of the research time frame. Yellow baboon can move long distances in large troops. They are also notorious for raiding farm crops and forcefully grabbing food from people in many places in Africa.

Galagos differ from the three other primates by belonging to the suborder strepsirrhini or the lower primates and not suborder haplorrhine or the higher primates. They are nocturnal primates that jump and move fast in trees and move mostly individually when foraging. In the Taita Hills there exists three species of galagos and in this study no distinction between different sub-species of galagos were made.

2.3. Household questionnaires field survey data

A semi-structured questionnaire survey was conducted in the households in the vicinity of the Ngangao indigenous cloud forest in May–June 2015. Before the survey, a sample of households were randomly selected with the following methodology; firstly, the study area was determined within a 800 meter radius (buffer zone) from the edge of the Ngangao forest. All households within this radius were identified from a very high spatial resolution true color digital image mosaic (ca. 10 cm pixel size) acquired in January–February 2012 during an aerial flight campaign using Nikon D3X digital camera equipped with a 14 mm lens producing a 78° opening angle (Fig. 2). The camera is part of the EnsoMOSAIC system consisting of flight planning software, navigation software, triggering unit, GPS and power source (see Holm et al., 1999; Pellikka et al., 2009; Piiroinen et al., 2015). Secondly, household objects' locations were identified and digitized as points in QGIS, but objects that were visually interpreted as schools, churches, shops or other publicly used buildings were not included in the sample. After all the households (N = 630) within the buffer zone area were digitized, sample size calculator was used to determine a suitable household sample size. Thirdly, a random selection -function in QGIS was then used to randomly pick a sample of 100 households from all the 630 candidates.

Before visiting the households, the semi-structured questionnaire was pre-tested on fifteen randomly picked households outside the selected 100 sample in different sides of the Ngangao forest. Pre-testing helped to find the best way to work with the questionnaires, estimate the time used for conducting each questionnaire and to find local names for those species of wildlife that the local research assistant could not interpret.

Using a topographic map of the area along with very high resolution color-printed aerial photos (acquired from 2012 flight-campaign), and a Garmin handheld GPS unit, we traced all the selected 100 households. We were able to visit from four to ten households per day depending on the distance of one farm to another, roughness of the terrain, weather conditions and the number of successful interviews. All the household interviews took place in the respondents' home or compound. In the end, out of the 100 households, we were able to conduct the questionnaire survey in 75 homes. In the questionnaire, we asked the respondents e.g. what primates and other animals they have seen on their property and have these species caused any crop-raiding at the farm in the past year. The respondents were also asked what crops and trees they grow in their field. Farmers were also asked what local wildlife species are important and useful to them; what type of problems if any they have with the local wildlife; and with which species, and what prevention or mitigation actions they have taken to prevent or reduce HWC. Finally, the respondents were asked in an open-ended question to explain what management actions, in their perspective, should be taken to combat the HWC. The data collected from the household questionnaires was processed into spreadsheet software and questions related to primate crop-raiding were selected for statistical and spatial analysis.

2.4. Statistical analysis

Statistical program IBM SPSS Statistics for Windows, version 23 (IBM SPSS Statistics, 2015) was used for the household questionnaire data to find if there are correlations between primate conflicts and possible explaining factors. Kolmogorov-Smirnov and Shapiro-Wilk tests confirmed non-normal distributions of data, hence non-parametric tests were used for primary analysis. A point-biserial correlation, which is a special short cut formula equivalent to the Pearson correlation coefficient, was used for the correlations between two variables that are dichotomous and nominal (either 0 or 1) and quantitative. Phi coefficient was used with variables that were both dichotomous and nominal.

2.5. Spatial analysis using GIS

Household questionnaire spreadsheet data with coordinate information was imported into ArcGIS for spatial analysis. In ArcGIS, households that perceived to experience primate conflicts were spatially mapped and every conflict site was symbolized with a pie chart in which each primate was given a distinctive color. Spatial analysis was also performed to find out whether distance or the number of neighbouring farms between each farm and the forest edge was related with the perceived conflicts, and if the land use/land cover type near each farm was explaining the conflicts. To do this, all the 75 household points were buffered to represent the average size of a farm in this study – 3 acres, which meant a 62-m radius for each circle that represented a farm. Then, the shortest straight line to the edge of the Ngangao forest from the center of each circle was drawn in ArcView 3.2 software using an extension tool *Identify Features Within Distance* (Jenness, 2003). Then, these lines were buffered with the same 62-m radius to represent possible corridors for the primates to access each farm.

The household point layer was further utilized, by calculating how many households are overlapping with each buffer, or more clearly, how many farms there are on each wildlife corridor between the farms and the forest edge. These imagined wildlife corridors were given graduated colors to represent the number of neighbouring households within the corridor. Distance zones were also calculated and visualized by placing the darkest colors near the forest and the lightest furthest from the forest to assist in estimating how far or close each farm is situated in relation to the forest when interpreting the map (Fig. 5).

The same wildlife corridors were used to analyse land use/land cover types and human-primate conflicts. A land use/land cover layer of the Ngangao area (Pellikka et al., 2009) was clipped with the wildlife corridors and some land use/land cover types were reclassified. Classes for exotic tree species, namely 'eucalyptus', 'pine', 'grevillea' and 'cypress' were dissolved and reclassified as a new class: 'exotic'. Then, all the land use types within the wildlife corridors were visualized (Fig. 6).

The share of different land use/land cover type in each wildlife corridor was calculated in ArcGIS with functions *Tabulate Intersection and Pivot Table*. The shares of agroforestry and exotic tree species were then summed and a new class for their combined share was added. This

Table 1
Primate species ranked as crop-raiding problem in Ngangao area.

Species name	Problem in the farm (n)	% of all farms	Seen in the farm (n)	% of all farms
Blue monkey	61	81.3	74	98.7
Galago	36	48	63	84
Vervet monkey	23	30.7	41	54.7
Baboon	2	2.7	12	16

new class was symbolized with graduated colors to represent the share of agroforestry and exotic plantations in the wildlife corridors (Fig. 7).

Thiessen polygons, also known as Voronoi polygons, were generated around the household points, so that any location inside the polygon is closer to that point than any of the other sample points (Yamada, 2016). Thiessen polygons can be used to model territory characteristics (Schlicht, Valcu, & Kempenaers, 2014), and we therefore used Thiessen polygons to analyse the spatial patterns of crop-raiding by different primate species that the farmers have perceived as problematic in their farm. We joined the crop-raiding data from the questionnaire in GIS and we used simple attribute table binary coding (1 = crop-raiding/0 = no crop-raiding) to create crop-raiding maps based on the Thiessen polygons (Fig. 8). In addition, point pattern map for crop-raiding event frequency and pie chart map showing the preventive actions used in the households were created (Figs. 3 and 9).

2.6. Calculated risk of crop-raiding

Using the formula developed by Priston & Underdown (2009) with the collected household level data on farming patterns, the risk of raiding by primates was calculated for the most commonly cultivated food crops in the Ngangao area. The formula is as following:

$$[a/(a+b)] \quad (1)$$

where, a denominator (a) was calculated for each food crop as number of households who perceived that the crop was raided by one or more species of primate. Then, (b) is the number of households that cultivated the crop on their farmland but claimed that it is not raided by any primate. In this study, the risks of raiding were also changed into percentages by multiplying the score with 100.

3. Results and discussion

3.1. The most problematic primates species

In the questionnaire, the respondents could mention primate species they considered as a crop-raiding problem animal to them. From Table 1 it can be seen that out of the 75 households, all but one respondent had seen blue monkey in their compound and it was mentioned by 61 respondents as one of the most significant crop-raiders. Out of 63 respondents who reported to have seen galagos in their farm, 36 named this nocturnal primate as a problematic species. On the other hand, vervet monkey was seen by 41 farmers and perceived problematic by 23 respondents. Yellow baboon was mentioned by two people in the top five problematic animals, although 12 respondents had seen the animal near their compound in the last year. Spatial patterns of primate crop-raiding will be covered in the forthcoming sections.

3.2. Human-wildlife conflict time, frequency and perceived losses

The perceived periods or months of highest human-wildlife conflict in the Ngangao area were from November to January (between 29.3% and 48% of the respondents) and from July to September (between 30.7% and 34.7% of the respondents). The most problematic time or times of the day regarding to HWC are mornings (6 a.m.–10:59 a.m.) and afternoons to early evenings (2 p.m.–5:59 p.m.). Night-time (6 p.m.–5:59 a.m.) was perceived as the least severe time of the day for HWC. This was an expected result taking into account that most studied primate species are diurnal animals.

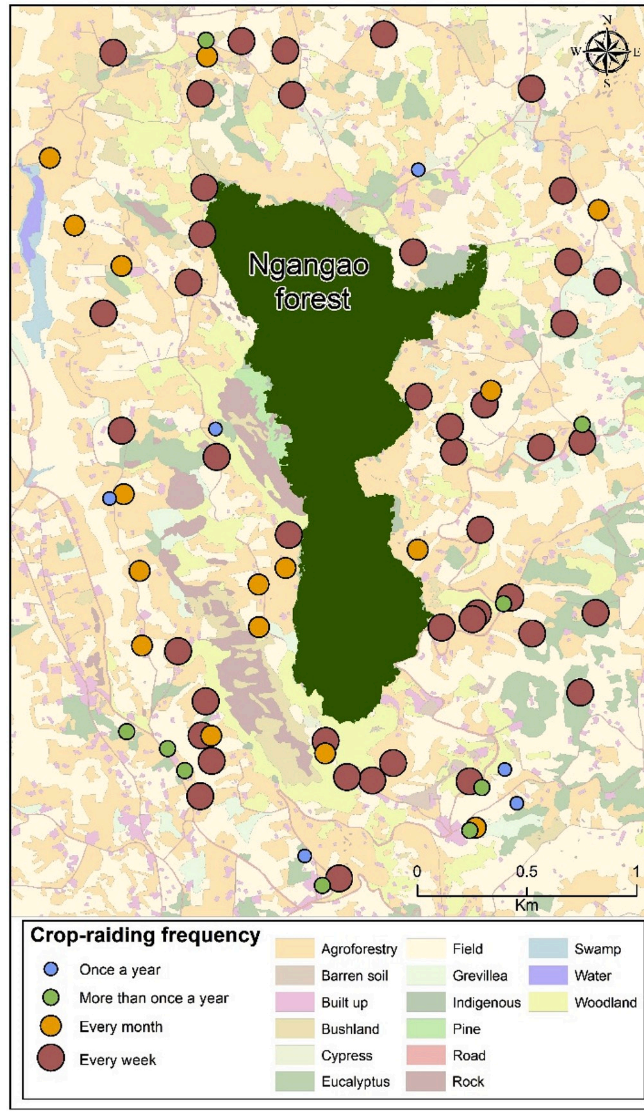

Fig. 3. Crop-raiding event frequency around Ngangao forest.

Frequency of the perceived crop-raiding events was clear. Over half of the respondents claimed that wild animals are raiding their crops at least every week, while a fifth thought that crop-raiding happens monthly. Only few said that they experience it only once a year. This reveals that it is likely that many of the farming households around Ngangao forest experience weekly crop-raiding. Fig. 3 shows the spatial distribution of crop-raiding event frequency around Ngangao forest and it can be seen that crop-raiding at least once a week happened all around the forest.

The respondents who mentioned losing harvest due to crop-raiding were then asked to estimate how much economical damage in a year this generates to their household annually. It was found, that the mean loss estimate was 54 439 Kenyan shillings (KSh) (489 €) and median loss estimate was 18 000 KSh (162 €). The most common estimate that was reported ca. 10 000 KSh which is approximately 90 euros.

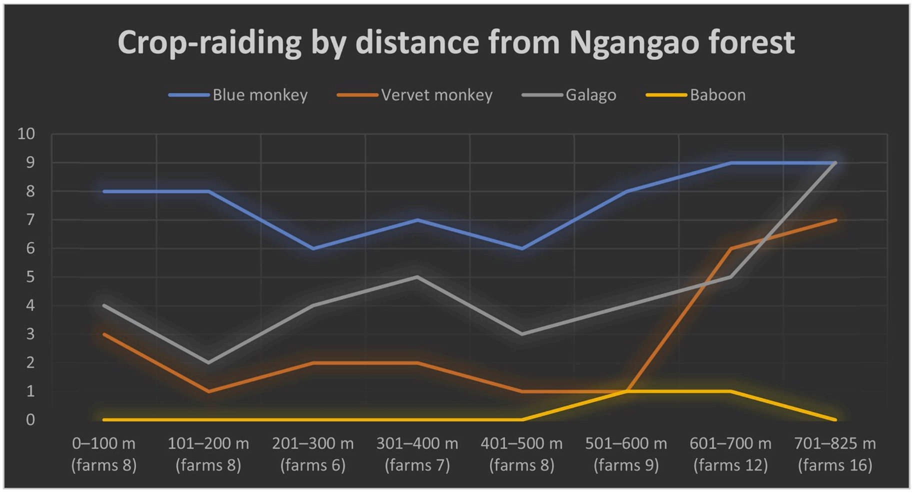

Fig. 4. The number of households in different distance zones and their reports on crop-raiding frequencies by different species from the Ngangao forest edge.

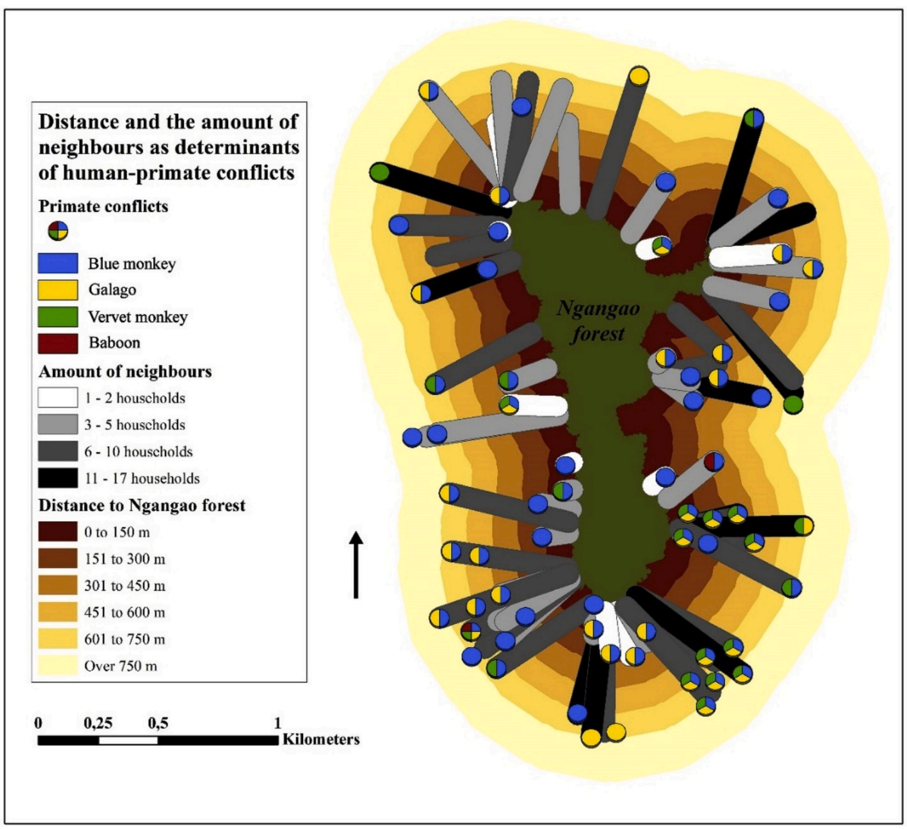

Fig. 5. Location of human-primate conflict sites, and the number of neighbouring farms in wildlife corridors. The distance between the Ngangao forest edge and farms with conflicts is visualized as colored buffers. The primate species involved are shown in pie charts.

3.3. Distance and the number of neighbouring farms influencing farm's vulnerability to crop-raiding by primates

According to the defined study area with a 800-m radius from the Ngangao forest, all the pre-selected households' locations varied between 1 and 800 m from the forest edge. However, one household which was located 25 m outside this radius was included in the sample. Fig. 4 shows the distribution of the 75 surveyed households and their crop-raiding frequencies in each of the 100-m buffer zone calculated from the Ngangao forest. Results show that crop-raiding by blue monkeys was experienced in each of the distance-zones, whereas the other primate species presence at different distance zones was not so prominent. Crop-raiding was experienced close to the forest, however, highest values were experienced at a distance more than 700 m. This pattern may be explained by the fact that more households are situated away from the forest edge and there were more farms surveyed at this distance.

3.4. Distance and the number of neighbouring farms influencing farm's vulnerability to crop-raiding by primates

Some studies, for example (Aharikundira & Tweheyo, 2011; Hill, 2000), mention another determining factor for these conflicts: *the*

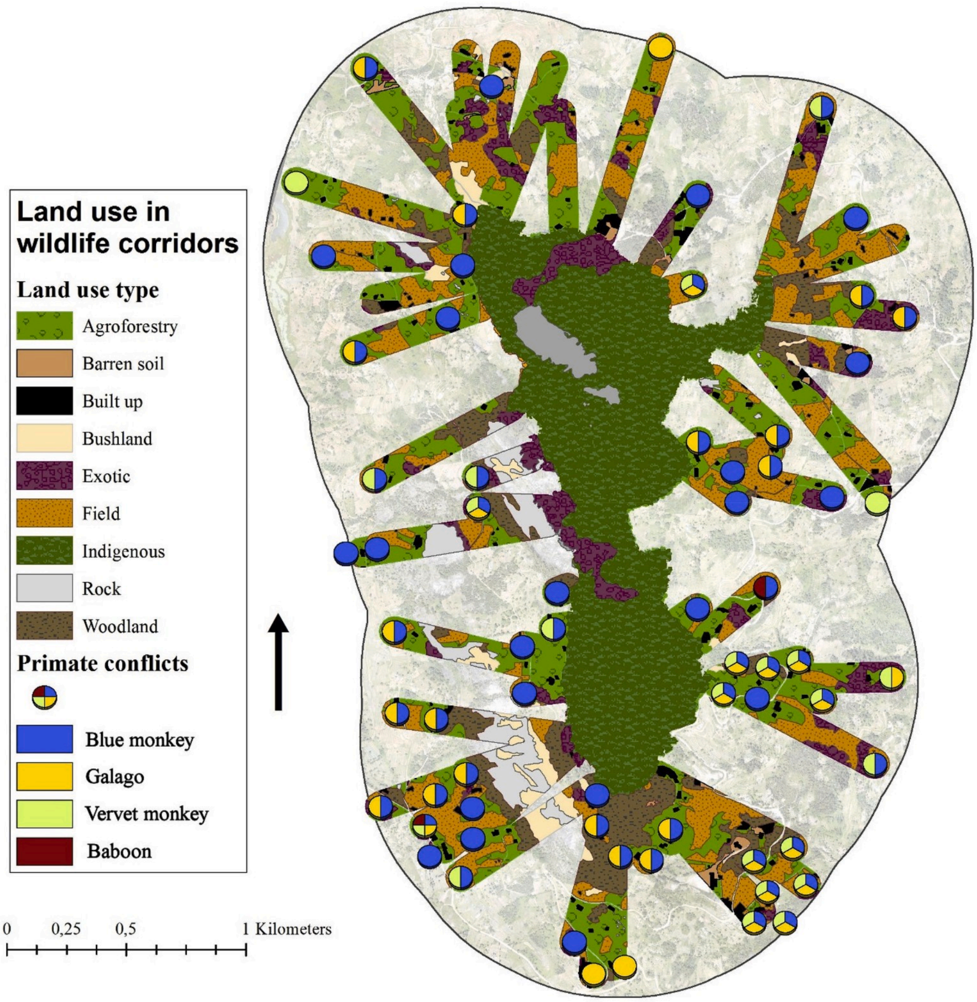

Fig. 6. Human-primate conflict sites and land use types in wildlife corridors between the Ngangao forest and the farmland. Land use/land cover layer altered from Pellikka et al., 2009.

number of neighbouring farms between a farm and the edge of a primate habitat. In the Ngangao area, many people living further away from the forest, mentioned their neighbours as a preventive factor for primate crop-raiding. They referred to their neighbour as taking all the crop damage on their behalf by acting as a human buffer. The neighbouring factor was spatially analysed using GIS. A visual interpretation of the conflict map (Fig. 5) shows that as distance from the forest edge grows, the number of neighbours within a wildlife corridor also increases. The conflict sites for all primates are very scattered around the forest and for the most part, each farm is experiencing crop-raiding by one or two primate species. Yellow baboon conflicts are only experienced in two plots and these seem to be isolated events.

All households within 0–300 m distance from the forest were crop-raided by blue monkeys. Farms within 0–450 m distance and which had from one to two neighbours, all but one of these farms were raided by blue monkeys and in some cases, also by vervet monkeys and galagos. This indicates that especially blue monkey raid farms closest to the forest and farms that may not have neighbouring farms to protect them. However, also farms further than 300 m from the forest were also experiencing primate conflicts, thus, a farm which is not situated in the immediate vicinity of the primate habitat and that has a substantial amount of neighbouring households can still experience crop-raiding by primates.

Most of the households that did not experience primate conflicts were over 451 m away from the forest and had many neighbours. These conflict-free plots are situated in the north and northwest of the Ngangao forest, though, visual interpretation cannot explain why these farms were not experiencing crop-raiding. One reason for this may be that main land use/land cover type is agroforestry or cultivated fields and in addition, north and north-western part of the forest is not only covered with indigenous tree species but with some exotic pine- and cypress tree plantations (Pellikka et al., 2009). In comparison, most farms located in the southeast of Ngangao forest edge, appear to experience conflicts with many primates: galagos, blue and vervet monkeys. Especially vervet monkey conflicts are confined in this side of the forest. In the southeast from the forest edge, the results indicate that for households which are raided by vervet monkeys, a high number of neighbours in a wildlife corridor does not seem to prevent these farms from damage, and in the plots located furthest from the forest, the main crop-raiders are vervet monkeys or galagos.

In line with these visual map interpretation findings, statistical analysis did not point to the number of neighbouring farms being a meaningful determinant of a farm being raided by galago or yellow baboon. However, with blue monkey the number of neighbours within a wildlife corridor had a significant negative correlation with crop-raiding ($r_{pb} = -0.367$, $n = 75$, $p = .001$) and with vervet monkey there was a significant positive correlation ($r_{pb} = 0.291$, $n = 75$, $p = .011$).

The results indicate that blue monkeys avoid raiding farms that are far from their habitat along with farms that have many neighbouring farms between them and the forest. With vervet monkeys, it seems that

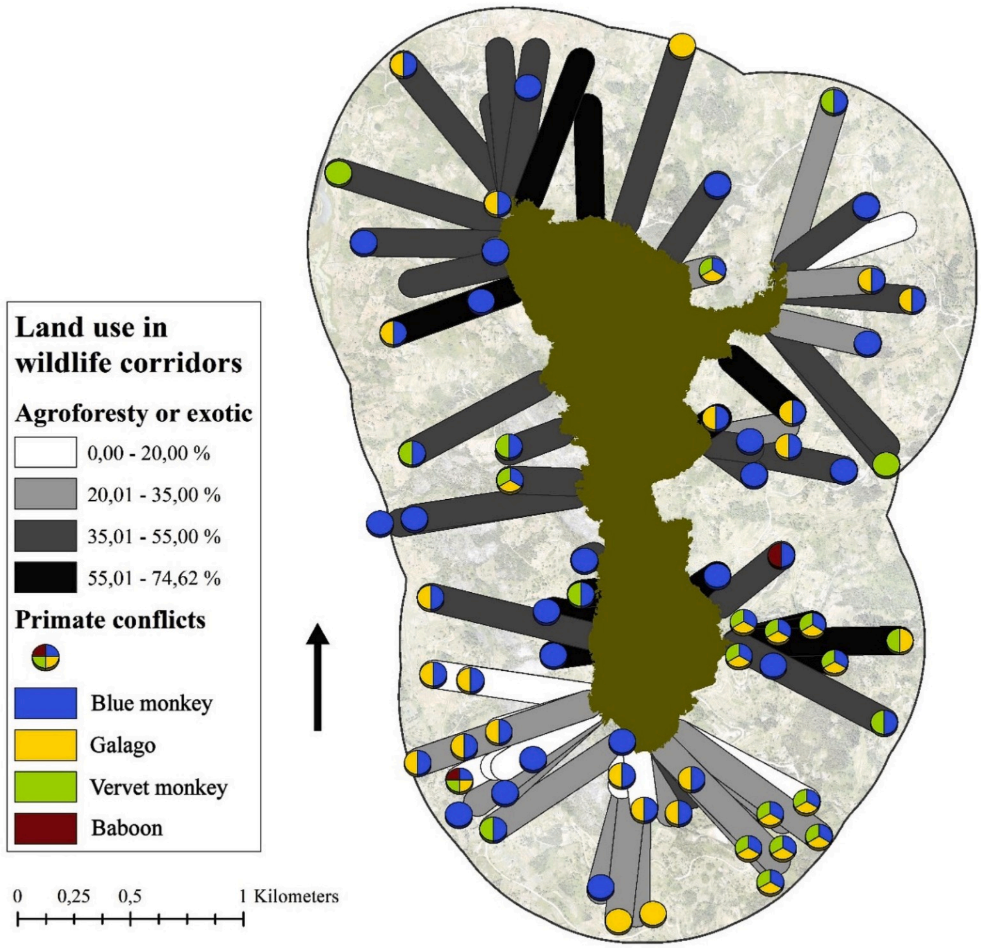

Fig. 7. The combined share of agroforestry and exotic trees in wildlife corridors as a determinant for human-primate conflicts. Land use/land cover layer altered from Pellikka et al., 2009.

the distance from the forest edge to a farm does not appear to determine whether a farm is raided or not. In addition, the growing number of neighbouring farms between each farm and the forest does not lead to less crop-raiding by vervet monkeys and vice versa. With galago and yellow baboon, distance and the number of neighbouring farms in wildlife corridors do not appear to determine crop-raiding on farms.

Overall, almost all households in the sample perceived to experience crop-raiding by some or all of the four studied primate species. However, distance and the number of neighbours do not sufficiently explain the reasons why a farm is or is not raided by a primate. Thus, a more in-depth explanation why some farms are vulnerable to crop-raiding by primates might lie in an additional determinant, such as the type of crops grown on the farm, the land use type near the farm or the prevention and mitigation actions taken in household level.

3.5. Land use type influencing farm's vulnerability to crop-raiding by primates

According to Johansson (2009) land use may explain why some farms are raided and he suggested that in Ngangao area, agroforestry near the fields may increase connectivity and allow primates to easily enter farms through agroforestry corridors between the forest and a farm. Therefore, the presence of exotic trees and agroforestry in the wildlife corridors may expose a farm to primate crop-raiding. When looking at two land use maps (Figs. 6 and 7), it is quite evident that exotic trees and agroforestry in wildlife corridors do not appear to explain the occurrence of human-primate conflicts better than any other land use type. For example, some farms located in the north side of the Ngangao forest do not experience primate menace at all, although the wildlife corridors between them and the forest edge are dominated by exotic trees and agroforestry.

In the south side of the forest, even though these two land use types represent less than 35 percent of the total land cover in the wildlife corridors, all farms are experiencing primate crop-raiding. Moreover, a series of correlations between perceived primate conflicts and these two land use types alone as well as them combined, indicated non-significant correlations. Therefore, it seems like there is no correlation between human-primate conflict sites and exotic trees and agroforestry as a dominant land use type in the wildlife corridors.

3.6. Spatial pattern analysis of crop-raiding primates using Thiessen polygons

To gain a better understanding of the spatial distribution patterns of primate crop-raiding that was perceived as problematic by the farmers, Thiessen polygons were used. Fig. 8 shows of the different studied primate species crop-raiding. Thiessen polygons reveal the spatial distribution crop-raiding by blue monkeys are basically distributed all over the study area and it is absent only in small areas in the northern, southern and eastern part. The reason for this may be that landscape in these areas is very open and there exist only little or none suitable forests or trees and the main land use/cover type is cultivated fields or agroforestry (Figs. 8 and 2). On the contrary to blue monkeys, vervet monkeys are not raiding crops in close vicinity to Ngangao forest, except only

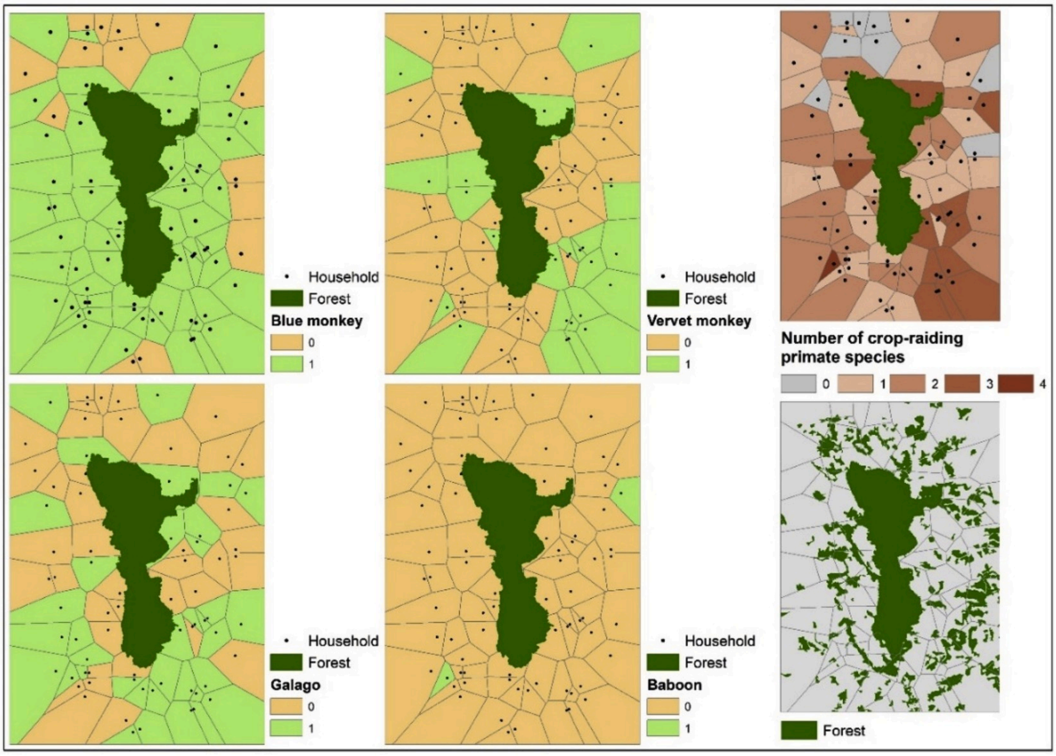

Fig. 8. Thiessen polygons created from the surveyed household points (n = 75) showing different primate species crop-raiding spatial patterns (1 = crop-raiding/0 = no crop-raiding), and a frequency of crop-raiding primates combined species map and a forest cover map.

Table 2
Type of crop grown and its calculated risk of becoming raided by primates in Ngangao. Calculated by using a method by Priston & Underdown (2009).

Crop type	Number of farms with crop raided by a primate (a)	Number of farms with crop present but not raided by any primate (b)	Denominator (a+b)	Risk of raiding (%) $[\frac{a}{a+b}]$
Maize	65	10	75	86.67
Avocado	20	47	67	29.85
Beans	15	52	67	22.39
Banana	16	56	72	22.22
Macadamia	8	38	46	17.39
Sugarcane	10	51	61	16.39
Cassava	65	10	75	11.76
Irish potato	3	56	59	5.09
Sweet potato	2	54	56	3.57

at some places. Crop-raiding is found clearly in areas where there are plenty of forest cover like in the southeastern part of the study area as seen from Fig. 8. It can be also interpreted from Figs. 8 and 2 that vervet monkeys may avoid very high-density developed areas. These findings thus differ from previous studies where vervet monkey is seen to be highly adaptable to different habitats and seen as “agricultural pest” (e.g. Hill, 2005).

Crop-raiding patterns of galagos are partly similar than for vervet monkey, and seems that they prefer areas where abundant forest cover is present. However, contrarily to vervet monkeys, it seems that galagos are also present in high-density developed areas. In addition, galagos seems to avoid habitats where open rock dominates the landscape. In the study area only two household reported crop-raiding by baboons (Fig. 8). Baboons are not often seen on the highlands but they are in plenty in the lowlands. Fig. 8 shows also a Thiessen polygon map, displaying summary of how many of the four studied primate species were crop-raiding in the area. Evidently, areas with abundant forest cover attracts crop-raiding, and not only closeness to the protected forest. Moreover, it was an interesting finding that in the areas close to the steep and forested eastern side of Ngangao forest, crop-raiding was experienced only by one species i.e. blue monkey.

3.7. Crops grown in the households influencing farm's vulnerability to crop-raiding by primates

Earlier studies on human–primate conflicts have shown that growing the types of crops that attract wildlife in agricultural areas explains why some farms experience crop-raiding when others do not (e.g. Hill, 2000; Tweheyo, Hill, & Obua, 2005). The most attacked crop is maize along with cassava and avocado (Table 2). The risk of crop-raiding (Priston & Underdown, 2009) by primates was calculated for each commonly cultivated crop and for all four species of primates this risk was the highest with the most common staple crop maize (almost 87 percent), avocado (almost 30 percent), banana and beans (both around 22 percent). For the other commonly grown crops in the area, the risk of raiding is indicated on Table 2. Unlike that we expected, we did not find significant correlation between primate crop-raiding sites and high-risk food crops presence in farms. Thus, this indicates that no clear conclusions can be made to whether the types of crops grown explain crop-raiding by primates in Ngangao surroundings.

3.8. Preventive actions against crop-raiding by farmers

These aforementioned factors – distance, the number of neighbouring farms, crop type and land use – might in some extent explain the vulnerability of a farm to crop-raiding, but some studies (e.g. Hsiao et al., 2013) claim that the actions farmers have taken or not taken to prevent the conflict explain the vulnerability to crop-raiding as well. These preventive actions are: taking watch in the field; which according to Hill (2000) and Warren et al. (2007) is the most common crop-protection measure adopted; having a guard dog; chasing the

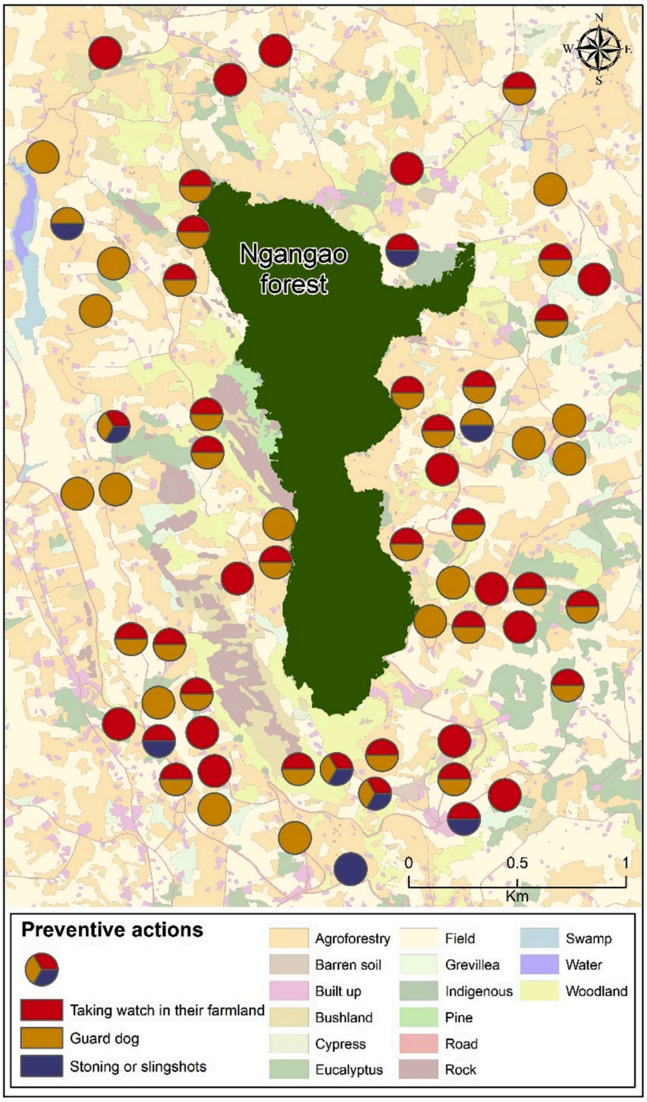

Fig. 9. Pie chart map showing preventive actions against crop-raiding used by farmers around the Ngangao forest.

Table 3
Local perception for suggested actions to solve HWC in the Ngangao area.

Suggested action	Respondents
Relocation of the problematic wildlife	18
Hiring more people to take care of the wildlife/Special technical people/Officials should do it	18
Fencing the forest	14
Killing the problematic wildlife	10
Having a meeting in the community/Informing the locals about wildlife	9
Planting fruit trees inside Ngangao/Feeding the wildlife	8
Compensation for damages caused by wildlife	7
Chasing animals collectively back to the forest	3
Paying locals upfront a small amount for wildlife losses	3
No idea	3
Trapping	1
Alternative livelihoods	1

wildlife back to the forest by shouting and scaring the animals; using slingshots; and growing unattractive crops. In Ngangao, 45 respondents explained that when taking watch in their farmland the methods used to scare wildlife away were fire, as well as using radios, bells and shouting to make noise. Out of the 75 households interviewed, 36 households told that they have a guard dog to protect their farm. In addition, nine households used stoning or slingshots to scare animals away. Spatial patterns of preventive actions can be seen from Fig. 9.

3.9. Actions to mitigate the human-wildlife conflict issues in the study area

In the household questionnaire, the respondents were asked in an open-ended question to explain what actions, in their perspective, should be taken to combat the HWC that the farmers are experiencing in Ngangao area. Not surprisingly, relocation of problematic wildlife and hiring more people in charge of wildlife management were the most mentioned actions (Table 3). Fencing the Ngangao forest and killing problematic wildlife were also mentioned. Some respondents even stated that if they had the permission, they would be more than willing to kill the problem animals. It was also proposed that some of the villagers could be trained as wildlife rangers and this would create jobs in the area. In their perception, it would also make use of local knowledge of the area. Another mitigation method could be to provide the wildlife food by planting fruit trees inside the Ngangao forest. We intentionally did not show any spatial distribution on these issues as some information may be too sensitive to map at a local scale and human–wildlife conflict is very hot topic in the area. It should be also be pointed out that the local experts and village chiefs share the same opinion that the primates are perceived to live and belong in the Ngangao forest, but some locals do not agree this opinion as can be seen from Table 3.

3.10. Limitations of the data and analysis

The reasons why some determinants of crop-raiding were not explaining crop-raiding by the four primate species in this study may result from a number of factors. For example, the method to create imagined wildlife corridors for spatial analyses to analyse the link between number of neighbouring houses and specific land use type for primate crop-raiding was over-generalizing. Creation of straight corridors using the average size of farm as a wildlife corridor buffer width as a starting point does not represent the real situation. Another approach could have been chosen e.g. by creating buffers around each farm and analyse the land use type in that buffer or to digitize corridors along exotic trees and agroforestry between farms and the Ngangao forest from the high resolution true-color aerial image mosaic. This would represent a more realistic model of how primates likely move between the forest and the farmlands.

To achieve even more realistic routes and corridors and timing for primate movement patterns airborne light detection and ranging (LiDAR) based tree canopy height model (CHM) along with wildlife radio telemetry tracking data could have been additional data as suggested by McLean et al. (2016). We did have LiDAR data as used in Pellikka et al. (2018), but no radio telemetry data. In our future studies, we aim to use both airborne LiDAR and terrestrial LiDAR data for studies linking forest characteristics to primates distribution as suggested by Palminteri et al. (2012). Airborne LiDAR from the northeastern corner of Ngangao forest is used in Fig. 10 to show that forest characteristics such as canopy height may act as an important factor to determine primate crop-raiding patterns.

Even though exotic trees and agroforestry as types of land use did not prove to explain crop-raiding by primates in this analysis, land use as a determinant of human-primate conflicts should be studied further. Naughton-Treves et al. (1998) suggested that planting agroforestry buffers on the edges of forests or parks creates an ideal habitat for crop-raiding wildlife as it has been noted that forest fragmentation increases edge habitat and decreases the ability of large animals to range widely without crossing agricultural lands. In forest-agriculture landscape mosaic like the Ngangao area, this is likely to apply.

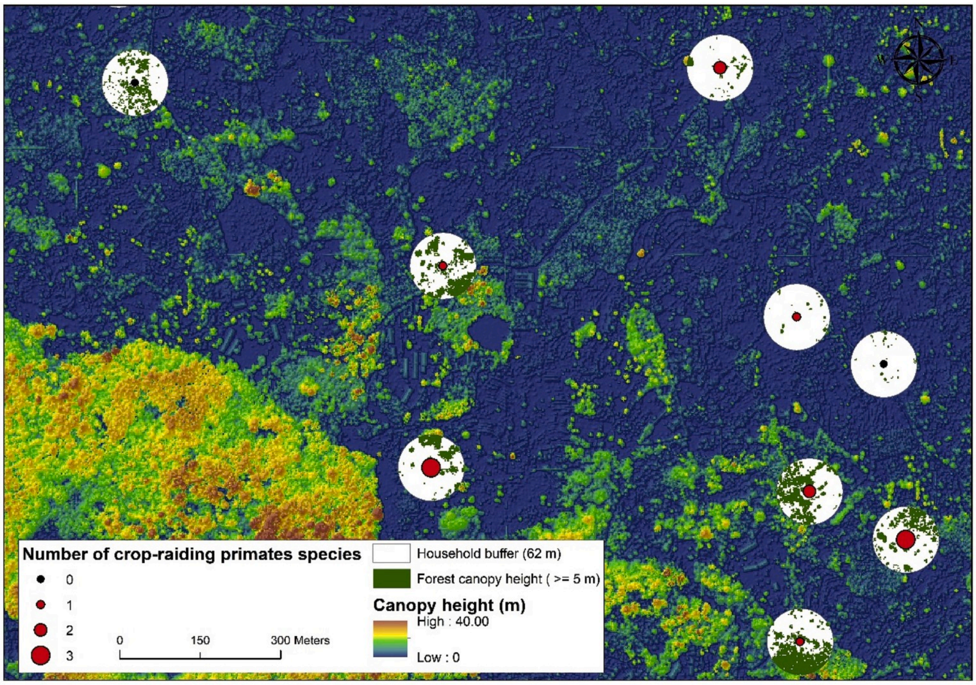

Fig. 10. Map of forest characteristic (canopy height) and canopy height ≥ 5 m inside 62 m household buffer zone, and number of crop-raiding primate species in the selected farms northeast of Ngangao forest.

4. Conclusions

Crop-raiding by wildlife, such as primates, is a severe threat to the food security and livelihoods of smallholder farmers' households, and therefore perceived as a significant problem in the Taita Hills. The most problematic crop-raiding primate species in the area is the blue monkey which has been causing problems in almost all the interviewed households. The closer a farm is to the forest boundary and the less neighbouring farms there are between the farm and the forest, the more vulnerable that farm is to crop-raiding by blue monkeys. It could not be shown that a specific type of land use/land cover between the farmland and the forest boundary explain vulnerability to crop-raiding by primates in the wildlife corridors. On the other hand, Thiessen polygon based spatial analysis techniques can be used to create maps showing areas that attract primate crop-raiding. Thiessen polygons can also be useful in explaining the spatial patterns of crop-raiding by different primate species. For example in this study, it could be more clearly shown that vervet monkey and galagos crop-raiding incidences are related to areas with dense forest cover and therefore, distance to the forest was not the only important factor explaining crop-raiding for the studied species. Farmers' preventive actions against crop-raiding can also be efficiently mapped, however, data sensitivity considerations need to be made before showing mitigation actions for the human-wildlife conflict issues at a local scale.

Spatial patterns of human–wildlife conflicts are complex, and to gain clearer insight of these, multiple geospatial modelling techniques should be explored. This study shows unquestionably that household interview data with GIS and remote sensing techniques can improve our understanding on human–primate crop-raiding patterns. There is still a need for further studies using state-of-the-art spatial analysis techniques for analyzing these complex crop-raiding patterns, and for providing information to improve conflict management which as a result will strengthen the food security of smallholder farmers who simultaneously have to cope with the impacts of climate variability and climate change.

CRediT authorship contribution statement

Mika Siljander: Conceptualization, Methodology, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Funding acquisition. **Toini Kuronen:** Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Tino Johansson:** Writing - review & editing, Supervision, Funding acquisition. **Martha Nzisa Munyao:** Writing - review & editing. **Petri K.E. Pellikka:** Conceptualization, Methodology, Writing - review & editing, Project administration, Supervision, Funding acquisition.

Acknowledgements

The authors would like to acknowledge the funding from the Ministry for Foreign Affairs of Finland for CHIESA project (http://chiesa.icipe.org) and TAITAGIS project supported by Board of Education of Finland (http://cimo.innofactor.com/programmes/hei_ici_index/programmes/hei_ici/projects/taitagis), and funding from the Academy of Finland for TAITAWATER, and the funds provided from the Friends of the Environment Fund and Taita Research Station Fund of the University of Helsinki. We acknowledge Mwadime Mjomba and Darius Kimuzi for assistance in the field and Taita Research Station of the University of Helsinki for logistical support. We also acknowledge Dr. Rami Ratvio and Dr. Michael Gentile for their invaluable and straightforward advice when formulating the questionnaire. Research permit from the National Council for Science and Technology of Kenya NCST/RCD/17/012/33 is gratefully acknowledged.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.apgeog.2020.102185.

References

Adams, W. M. (2004). Biodiversity conservation and the eradication of poverty. *Science, 306*, 1146–1149.

Aerts, R., Thijs, K. W., Lehouck, V., Beentje, H., Bytebier, B., Matthysen, E., et al. (2011). Woody plant communities of isolated Afromontane cloud forests in Taita Hills, Kenya. *Plant Ecology, 212*, 639–649.

Aharikundira, M., & Tweheyo, M. (2011). Human-wildlife conflict and its implication for conservation around bwindi impenetrable National park. In *USDA forest service proceedings, RMRS-P-64* (pp. 39–40).

Anand, S., Binoy, V. V., & Radhakrishna, S. (2018). The monkey is not always a god: Attitudinal differences toward crop-raiding macaques and why it matters for conflict mitigation. *Ambio, 47*(6), 711–720.

Beentje, H. (1988). An ecological and floristic study of the forests of the Taita Hills, Kenya. *Utafiti, 1*(2), 23–66.

Bytebier, B. (2001). *Taita Hills biodiversity project report*. Nairobi: National Museums of Kenya.

Campbell-Smith, G., Sembiring, R., & Linkie, M. (2012). Evaluating the effectiveness of human–Orangutan conflict mitigation strategies in Sumatra. *Journal of Applied Ecology, 49*, 367–375.

Campbell-Smith, G., Simanjorang, H., Leader-Williams, N., & Linkie, M. (2010). Local attitudes and perceptions toward crop-raiding by Orangutans (*Pongo abelii*) and other nonhuman primates in northern Sumatra, Indonesia. *American Journal of Primatology, 72*, 866–876.

Dickman, A. J. (2010). Complexities of conflict: The importance of considering social factors for effectively resolving human–wildlife conflict. *Animal Conservation, 13*, 1–9.

Dittus, W. P. J., Gunathilake, S., & Felder, M. (2019). Assessing public perceptions and solutions to human-monkey conflict from 50 years in Sri Lanka. *Folia Primatologica, 90*, 89–108.

Eva, H. D., Brink, A., & Simonetti, D. (2006). *Monitoring land cover dynamics in sub-Saharan Africa. A pilot study using earth observing satellite data from 1975 and 2000* (p. 44). Institute for Environment and Sustainability, Joint Research Centre of the European Commission.

FAO, Food and Agricultural Organization of the United Nations. (2015). In R. Romeo, A. Vita, R. Testolin, & T. Hofer (Eds.), *Mapping the vulnerability of mountain peoples to food insecurity* (p. 68) (Rome).

Fehlmann, G., O'Riain, M. J., Kerr-Smith, C., & King, A. J. (2017). Adaptive space use by baboons (*Papio ursinus*) in response to management interventions in a human-changed landscape. *Animal Conservation, 20*, 101–109.

Findlay, L. J. (2016). ***Human-primate conflict: An interdisciplinary evaluation of wildlife crop raiding on commercial crop farms in Limpopo Province, South Africa***. Durham theses. Durham University http://etheses.dur.ac.uk/11872/.

Freed, B. Z. (2012). Primates of the edge: An ethnoprimatological study of human and wildlife interaction bordering a Malagasy National park. *KJAS, 2*(2), 133–148.

Freitas, C. H. de, Setz, E. Z. F., Araújo, A. R. B., & Gobbi, N. (2008). Agricultural crops in the diet of bearded capuchin monkeys, Cebus libidinosus Spix (Primates: Cebidae), in forest fragments in southeast Brazil. *Revista Brasileira de Zoologia, 25*(1), 32–39.

Gillingham, S., & Lee, P. C. (2003). People and protected areas: A study of local perceptions of wildlife crop-damage conflict in an area bordering the selous game reserve, Tanzania. *Oryx – The International Journal of Conservation, 37*(3), 316–325.

Hill, C. M. (2000). Conflict of interest between people and baboons: Crop-raiding in Uganda. *International Journal of Primatology, 21*(2), 299–315.

Hill, C. M. (2005). People, crops, and primates: A conflict of interests. In J. D. Paterson, & J. Wallis (Eds.), *Commensalism and conflict: The human-primate interface* (pp. 40–59). Norman, Oklahoma: American Society of Primatologists.

Hill, C. M., & Webber, A. D. (2010). Perceptions of nonhuman primates in human–wildlife conflict scenarios. *American Journal of Primatology, 72*, 919–924.

Hockings, K. J. (2009). Human-chimpanzee competition, coexistence and conflict in Africa. *Social Animal Cognition, 10*(2), 183–205.

Hockings, K. J., & Sousa, C. (2013). Human-chimpanzee sympatry and interactions in Cantanhez National park, Guinea-Bissau: Current research and future directions. *Primate Conservation, 26*, 57–65.

Hoffman, T. S., & O'Riain, M. J. (2012a). Landscape requirements of a primate population in a human-dominated environment. *Frontiers in Zoology, 9*(17).

Hoffman, T. S., & O'Riain, M. J. (2012b). Monkey management: Using spatial ecology to understand the extent and severity of human-baboon conflict in the Cape Peninsula, South Africa. *Ecology and Society, 17*(3), 13.

Holm, M., Lohi, A., Rantasuo, M., Väätäinen, S., Höyhtyä, T., Puumalainen, J., et al. (1999). Creation of large image mosaics of airborne digital camera imagery. In *Proceedings of the 4th international airborne remote sensing conference and exhibition* (Vol. II, pp. 520–526). Ottawa, Canada, 21–24 June.

Hsiao, S. S., Ross, C., Hill, C. M., & Wallace, G. E. (2013). Crop-raiding deterrents around Budongo forest reserve: An evaluation through farmer actions and perceptions. *Oryx, 47*(4), 569–577.

IBM Corp. (2015). *IBM SPSS statistics for Windows, version 23.0*. Armonk, NY: IBM Corp (Released 2015).

IUCN World Park Congress. (2004). Preventing and mitigating human-wildlife conflicts, World park congress recommendation. *Human Dimensions of Wildlife, 9*(4), 259–260.

Jenness, J. (2003). ***Identify Features within distance***, 29.3.2016 http://www.jennessent.com/arcview/within_distance.htm.

Johansson, T. (2009). Coexistence of people and wildlife in the Tsavo ecosystem. In T. Johansson, P. Pellikka, & J. Sorvali (Eds.), *SAFARI NJEMA – an interdisciplinary field expedition to South-East Kenya* (Vol. 46, pp. 44–57). Expedition Reports of Department of Geography, University of Helsinki.

Johnson, M. K. F., Karanth, K. K., & Weinthal, E. (2018). Compensation as a policy for mitigating human-wildlife conflict around four protected areas in Rajasthan, India. *Conservation and Society, 16*(3), 305–319.

Karanth, K. K., Gopalaswamy, A. M., DeFries, R., & Ballal, N. (2012). Assessing patterns of human-wildlife conflicts and compensation around a Central Indian protected area. *PloS One, 7*(12), e50433. https://doi.org/10.1371/journal.pone.0050433.

Karanth, K. K., Gopalaswamy, A. M., Prasad, P. K., & Dasgupta, S. (2013). Patterns of human–wildlife conflicts and compensation: Insights from western Ghats protected areas. *Biological Conservation, 166*, 175–185.

Kolowski, J. M., & Holekamp, K. E. (2006). Spatial, temporal and physical characteristics of livestock depredations by large carnivores along a Kenyan border reserve. *Biological Conservation, 128*, 529–541.

Lamarque, F., Anderson, J., Fergusson, R., Lagrange, M., Osei-Owusu, Y., & Bakker, L. (2009). Human-wildlife conflict in Africa: Causes, consequences and management strategies. In *FAO Forestry Paper 157* (p. 98) (Rome).

Linkie, M., Dinata, Y., Nofrianto, A., & Leader-Williams, N. (2007). Patterns and perceptions of wildlife crop raiding in and around Kerinci Seblat National park, Sumatra. *Animal Conservation, 10*, 127–135.

Marchal, V., & Hill, C. (2009). Primate crop-raiding: A study of local perspectives in four villages in north Sumatra, Indonesia. *Primate Conservation, 24*, 107–116.

Mayberry, A. L., Hovorka, A. J., & Evans, K. E. (2017). Well-being impacts of human-elephant conflict in Khumaga, Botswana: Exploring visible and hidden dimensions. *Conservation and Society, 15*(3), 280–291.

McGuinness, S., & Taylor, D. (2014). Farmers' perceptions and actions to decrease crop raiding by forest-dwelling primates around a Rwandan forest fragment. *Human Dimensions of Wildlife, 19*(2), 179–190.

McLean, K. A., Trainor, A. M., Asner, G. P., Crofoot, M. C., Hopkins, M. E., Campbell, C. J., et al. (2016). Movement patterns of three arboreal primates in a Neotropical moist forest explained by LiDAR-estimated canopy structure. *Landscape Ecology, 31*(8), 1849–1862.

Metcalfe, S., & Kepe, T. (2008). "Your elephant on our land": The struggle to manage wildlife mobility on Zambian communal land in the Kavango-Zambezi Transfrontier Conservation Area. *The Journal of Environment & Development, 17*, 99–117.

Mitchell, A. M., Bruyere, B. L., Otieno, T. O., Bhalla, S., & Teel, T. L. (2018). A comparison between human-carnivore conflicts and local community attitudes toward carnivores in Westgate Community Conservancy, Samburu, Kenya. *Human Dimensions of Wildlife*. https://doi.org/10.1080/10871209.2018.1548671.

Mochizuki, S., & Murakami, T. (2013). Scale dependent effects in resource selection by crop-raiding Japanese macaques in Niigata Prefecture, Japan. *Applied Geography, 42*, 13–22.

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

Naughton-Treves, L. (1998). Predicting patterns of crop damage by wildlife around Kibale National park, Uganda. *Conservation Biology, 12*(1), 156–168.

Naughton-Treves, L., Chapman, C., & Wrangham, R. (1998). Temporal patterns of crop-raiding by primates: Linking food availability in croplands and adjacent forest. *Journal of Applied Ecology, 34*(4), 596–606.

Naughton-Treves, L., Holland, M., & Brandon, K. (2005). The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annual Review of Environment and Resources, 30*, 219–252.

Naughton-Treves, L., & Treves, A. (2005). Socio-ecological factors shaping local support for wildlife: Crop-raiding by elephants and other wildlife in Africa. In R. Woodroffe, S. Thirgood, & A. Rabinowitz (Eds.), *People and wildlife. Conflict or coexistence?* (pp. 252–277). U. K: The Zoological Society of London. Cambridge University Press. Conservation biology 9.

Nekaris, K. A., Boulton, A., & Nijman, V. (2013). An ethnoprimatological approach to assessing levels of tolerance between human and commensal non-human primates in Sri Lanka. *Journal of Anthropological Sciences, 91*, 219–231.

Nicole, B. F. (2019). An assessment of the human-wildlife conflict across Africa. In M. Ferretti (Ed.), ***Wildlife population monitoring***. https://doi.org/10.5772/intechopen.82793.

Nijman, V., & Nekaris, K. A. (2010). Testing a model for predicting primate crop-raiding using crop- and farm-specific risk values. *Applied Animal Behaviour Science, 127*, 125–129.

Nsonsi, F., Heymans, J. C., Diamouangana, J., Mavinga, F. B., & Breuer, T. (2017). Perceived human-elephant conflict and its impact on elephant conservation in northern Congo. *African Journal of Ecology, 56*(2), 208–215.

Ogra, M. (2008). Human-wildlife conflict and gender in protected area borderlands: A case study of costs, perceptions, and vulnerabilities from Uttarakhand (Uttaranchal), India. *Geoforum, 39*, 1408–1422.

Omoro, L. M., Starr, M., & Pellikka, P. K. E. (2013). Tree biomass and soil carbon stocks in indigenous forests in comparison to plantations of exotic trees in the Taita Hills of Kenya. *Silva Fennica, 47*(2). https://doi.org/10.14214/sf.935.

Packer, C., Ikanda, D., Kissui, B. M., & Kushnir, H. (2005). Lion attacks on humans in Tanzania. *Nature, 436*, 927–928.

Palminteri, S., Powell, G. V. N., Asner, G. P., & Peres, C. A. (2012). LiDAR measurements of canopy structure predict spatial distribution of a tropical mature forest primate. *Remote Sensing of Environment, 127*, 98–105.

Pellikka, P. K. E., Clark, B. J. F., Gonsamo Gosa, A., Himberg, N., Hurskainen, P., Maeda, E. E., et al. (2013). Agricultural expansion and its consequences in the Taita Hills, Kenya. Developments in earth surface processes. In P. Paron, D. Olago, & C. T. Omuto (Eds.), *Kenya: A natural outlook – geo–environmental resources and hazards* (Vol. 16, pp. 165–179). Amsterdam, The Netherlands: Elsevier.

Pellikka, P. K. E., Heikinheimo, V., Hietanen, J., Schäfer, E., Siljander, M., & Heiskanen, J. (2018). Impact of land cover change on aboveground carbon stocks in Afromontane landscape in Kenya. *Applied Geography, 94*, 178–189.

Pellikka, P. K. E., Lötjönen, M., Siljander, M., & Lens, L. (2009). Airborne remote sensing of spatiotemporal change (1955–2004) in indigenous and exotic forest cover in the Taita Hills, Kenya. *International Journal of Applied Earth Observation and Geoinformation, 11*(4), 221–232.

Piiroinen, R. T., Heiskanen, J. H., Maeda, E. E., Hurskainen, P. J., Hietanen, J. O., & Pellikka, P. K. E. (2015). In *The international archives of the photogrammetry, remote sensing and spatial information sciences, XL-7/W3* pp. 1277–1282).

Priston, N. E. C., & McLennan, M. R. (2013). Managing humans, managing macaques: Human–macaque conflict in Asia and Africa. In S. Radhakrishna, M. A. Huffman, & A. Sinha (Eds.), *The macaque connection: Cooperation and conflict between Humans and macaques, 225–250*. New York: Springer.

Priston, N. E. C., & Underdown, S. J. (2009). A simple method for calculating the likelihood of crop damage by primates: An epidemiological approach. *International Journal of Pest Management, 55*(1), 51–56.

Priston, N. E. C., Wyper, R. M., & Lee, P. (2011). Buton macaques (*Macaca ochreata brunnescens*): Crops, conflict, and behavior on farms. *American Journal of Primatology, 73*, 1–8.

Rikkinen, J. (2014). Taitan vuoristometsien selkärankaisia. *Luonnon Tutkija, 4*, 156–169.

Riley, E. P. (2007). The human–Macaque interface: Conservation implications of current and future overlap and conflict in Lore Lindu National park, Sulawesi, Indonesia. *American Anthropologist, 109*, 473–484.

Rogers, P. C., O'Connell, B., Mwang'ombe, J., Madoffe, S., & Hertel, G. (2008). Forest health monitoring in the Ngangao forest Taita Hills, Kenya: A five year assessment of change. *Journal of East African Natural History, 97*(1), 3–17.

Saj, T. L., Sicotte, P., & Paterson, J. D. (2001). The conflict between vervet monkeys and farmers at the forest edge in Entebbe, Uganda. *African Journal of Ecology, 39*, 195–199.

Schäfer, E., Heiskanen, J., Heikinheimo, V., & Pellikka, P. (2016). Mapping tree species diversity of a tropical montane forest by unsupervised clustering of airborne imaging spectroscopy data. *Ecological Indicators, 64*, 49–58.

Schlicht, L., Valcu, M., & Kempenaers, B. (2014). Thiessen polygons as a model for animal territory estimation. *Ibis, 156*, 215–219.

Siex, K., & Struhsaker, T. T. (1999). Colobus monkeys and coconuts: A study of perceived human-wildlife conflicts. *Journal of Applied Ecology, 36*, 1009–1020.

Sillero-Zubiri, C., & Switzer, D. (2001). *Crop raiding primates: Searching for alternative, humane ways to resolve conflict with farmers in Africa. People and Wildlife Initiative. Wildlife Conservation Research Unit*. Oxford University.

Sitati, N. W., Walpole, M. J., Smith, R. J., & Leader-Williams, N. (2003). Predicting spatial aspects of human-elephant conflict. *Journal of Applied Ecology, 40*(4), 667–677.

Spagnoletti, N., Cardoso, T., Fragaszy, D., & Izar, P. (2017). Coexistence between humans and Capuchins (Sapajus libidinosus): Comparing observational data with farmers' perceptions of crop losses. *International Journal of Primatology, 38*(2), 243–262.

Taita Taveta County Government. (2013). The first Taita Taveta county integrated development plan 2013–2017. In *Supporting quality life for the People of Taita Taveta* (p. 260).

Thatcher, H. R., Downs, C. T., & Koyama, N. F. (2019). Positive and negative interactions with humans concurrently affect vervet monkey (*Chlorocebus pygerythrus*) ranging behavior. *International Journal of Primatology, 40*(4–5), 496–510.

Thorn, M., Green, M., Marnewick, K., & Scott, D. M. (2015). Determinants of attitudes to carnivores: Implications for mitigating human-carnivore conflict on South African farmland. *Oryx, 49*(2), 270–277.

Tweheyo, M., Hill, C. M., & Obua, J. (2005). Patterns of crop-raiding by primates around the Budongo forest reserve, Uganda. *Wildlife Biology, 11*(3), 137–147.

Wallace, G. E., & Hill, C. M. (2012). Crop damage by primates: Quantifying the key parameters of crop-raiding events. *PloS One, 7*(10), e46636.

Warren, Y., Buba, B., & Ross, C. (2007). Patterns of crop- raiding by wild and domestic animals near Gashaka Gumti National Park, Nigeria. *International Journal of Pest Management, 53*(3), 207–216.

Webber, A. D., & Hill, C. M. (2014). Using participatory risk mapping (PRM) to identify and understand people's perceptions of crop loss to animals in Uganda. *PloS One, 9*(7), e102912. https://doi.org/10.1371/journal.pone.0102912.

Yamada, I. (2016). Thiessen polygons. *International Encyclopedia of Geography: People, the Earth, Environment and Technology, 1–6*.

Yeo, J.-H., & Neo, H. (2010). Monkey business: Human–animal conflicts in urban Singapore. *Social & Cultural Geography, 11*(7), 681–699. https://doi.org/10.1080/14649365.2010.508565.