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Cropping patterns along an altitudinal gradient and their implications to wildlife conservation in Rombo, Tanzania

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ABSTRACT

Ecosystem and livelihood sustainability of small-scale farmers in Eastern Africa are often challenged by climate change and unsustainable land use practices. Little is known on the small-scale temporal processes of cropping systems in relation to long-term climatic conditions. To understand the climatic influence on the cropping patterns, and its implications to wildlife/elephant conservation, our study used a combination of time-series datasets on crop and climate as well as geo-spatial layers spanning more than three decades. To validate the information analyzed from secondary data, we carried out participatory observation and interviews, whereby about 5% of village households were selected along an altitudinal gradient of Rombo area, Tanzania. We generated land use change maps using Geographical Information System (ArcGIS 10.4) and used Spearman's correlation analysis to assess the influence of rainfall, temperature, and crop yield on the observed longitudinal changes in the crop types and other land use patterns both within and across altitudinal gradients. We found that perennial crops like coffee and banana concentrated in upper agro-ecological zones, with a clear division line above 1230 masl while seasonal crops like maize and beans were mostly cultivated in lowlands (below 1230 masl). The results further showed that coffee yields significantly declined with higher average annual minimum temperatures over the last 16 years. Within the same time period, there was a disproportionate shift from coffee to seasonal crop cultivation such as maize and beans. Elephant numbers declined by about 38%, while human settlement area increased by 28% over the last 30 years. We conclude that changes in land use and shifts in climate and cropping patterns have important implications for elephant conservation and sustainability of the ecosystem in Rombo area, Tanzania.

1. Introduction

Globally, both the rural and urban population is growing fast and the demand for food production is increasing (Cairns et al., 2013). The sustainability of ecosystem services and functions as well as human livelihoods in this changing climate calls for attention on agricultural practices and their impacts on wildlife conservation (Ogutu et al., 2014; Said, 2019). By 2050, the major food crop production is expected to increase by 70% to sustain an increment of 3.5 billion people on the planet (Borlaug, 2007; Cairns et al.,

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2013). In sub-Saharan African countries, the majority of the human population depends on small-scale agriculture to sustain their livelihoods. For instance, in Tanzania, most people (12.5 million) live below the national poverty line and agriculture contributes by about 30% to the GDP (Ahmed et al., 2009; Said, 2019). However, agricultural production is challenged by climate extremes, leading to food insecurity (Lobell et al., 2008; Muthee et al., 2015; Ogutu et al., 2014; Thi et al., 2018). Climate change is considered to have a significant influence on agricultural production in the tropics and subtropics of sub-Saharan Africa due to the low adaptive capacity of current agro-ecosystems (Solomon, 2007). Africa is believed to warm faster than the rest of the world (Collier et al., 2008), and average temperatures are projected to rise drastically over the next century, in addition to unpredictable rainfall patterns (Battisti and Naylor, 2009; Häder and Barnes, 2019). On the other hand, declines in crop yields in areas adjacent to protected areas or within wildlife migratory routes is contributing to unprecedented increases in human-wildlife conflicts and illegally hunting wildlife species (Barua et al., 2013; Gubbi, 2012; Said et al., 2016). The predicted prolonged droughts and unreliable and poor distribution of rains (Häder and Barnes, 2019; Kumssa and Bekele, 2013) will affect ecosystem productivity and wildlife resources. Unsustainable agricultural production and changing climate have been associated with a consequent loss of biodiversity (Arets et al., 2019; Barua et al., 2013). About 30% of species biodiversity is threatened by extinction if exposed to a temperature increase of 2 °C (Davies et al., 2009). Currently, almost 40% of Tanzania's total land area is covered by unfenced protected areas (PAs) (Stellmacher et al., 2012), including the highly endemic and species-rich Eastern Arc Mountains (Bayliss et al., 2014). Areas adjacent to PAs, such as Rombo area, are often at risk to be a source of human-wildlife conflicts. Rombo encompasses high-potential agro-ecological zones on the one hand but is also located in between various protected areas such as the renowned Kilimanjaro National Park (URT, 2013), and has been known as a human-wildlife conflict hotspot (Mmbaga et al., 2017a, 2017b, 2017c).

The sustainability of wildlife and agricultural production in such a conflict hotspot under a changing climate demands a wide adoption of environmentally-friendly cropping systems based on renewable resources and natural processes (Doré et al., 2011; Said, 2019). Climatic change poses difficulties to managing wildlife and enhanced conflicts with humans due to challenges in balancing the interests of wildlife conservation and resource use by local human populations (Bailey et al., 2015; Harich et al., 2013; Namgail et al., 2007). The conflicts between wildlife and people can even more strongly increase with increasing temperature and drought as was observed in Nepal (Aryal et al., 2014). Particularly elephants are attracted by seasonal crops, especially maize, and will destroy yields and farmers' income (Mwakatobe et al., 2014).

Despite various studies on how crops or wildlife populations are affected by climate change, little is known about the combined effects of land use and climate change as well as which threat is more imminent in creating conflicts. To our knowledge, there has been no study that combined climate change, agricultural productivity, and wildlife conflict occurrence in such a conflict-prone but highly agriculturally productive area as Rombo, Tanzania.

Our study used data of climatic, crop and geo-spatial factors that had been collected over decades and investigated the spatial and temporal distribution of cropping patterns and performance of different crop types across different agro-ecological zones. There were associated with climate change and human elephant conflicts along an elevation gradient on Mount Kilimanjaro, in Rombo area. We hypothesized that a shift from perennial crops to seasonal crops has important implications in elephant numbers as well as their habitats. We further hypothesized that shifts in agricultural land use more strongly impact human-elephant conflicts compared to the more long-term effects of climate change.

2. Material and methods

2.1. Study site

Our study site was located in Rombo District, North-East Tanzania (3°09' S and 37° 33' E; URT, 2013), which lies between two major protected areas, namely Kilimanjaro National Park (KINAPA) and Tsavo West National Park (TWNP) in the South-East. This study concentrated outside these protected areas (KINAPA and forest plantations) of the district, here referred to as "Rombo area", with an area of 47,851 ha. The climate is tropical but strongly influenced by Mount Kilimanjaro, situated on the Northern site (URT, 2013). Rainfall is bimodal, with long rains from March to June and short rains from November to December, which also define the two cropping seasons of the area (Soini, 2005). The area is further divided into three agro-ecological zones: The upper zone lies between 1600 masl and 2000 masl and receives rainfall ranging between 1000 mm and 2000 mm per annum; the intermediate zone lies between 1000 masl and 1500 masl and receives rainfall ranging from 900 mm to 1000 mm per annum; the lower zone lies below 1000 masl and receives rainfall ranging from 200 mm to 500 mm per annum (URT, 2013). The main economic activity for the local people is agriculture, with the majority of people (90%) cultivating coffee (*Coffea arabica*), banana (*Musa* sp.), maize (*Zea mays*) and common beans (*Phaseolus vulgaris*) (URT, 2013). The human population in Rombo area is about 260,963 people, having increased by 30% between the years 1988 and 2012 (URT, 2013).

2.2. Sampling strategy and data collection methods

2.2.1. Geo-spatial and secondary data

The GPS locations for different crop types were taken (Garmin 64s) during field visits and interviews across the three agro-ecological zones. Village meetings and expert interviews, i.e., with the District Agriculture Officers, were conducted to capture an overview of crop performance and major threats. Secondary data on crop types cultivated, crops destroyed by elephants, and their yields for at least 16 years (2000–2015) were obtained from unpublished reports (Rombo District Wildlife and Agricultural offices). Climate (rainfall and temperature) data for the Rombo area were obtained through the Tanzania Metrological Agency (TMA) (http://

www.meteo.go.tz/) for 46 years (1970–2015). Shape-files for study site boundaries were obtained from The National Bureau of Statistics (NBS; https://openmicrodata.worldpress.com).

2.2.2. Household interviews and focused group discussion

Household interviews were conducted with 261 households, who were randomly located in the study area. Respondents comprising of at least 5% of the total number of households per village were randomly selected from the administrative study divisions

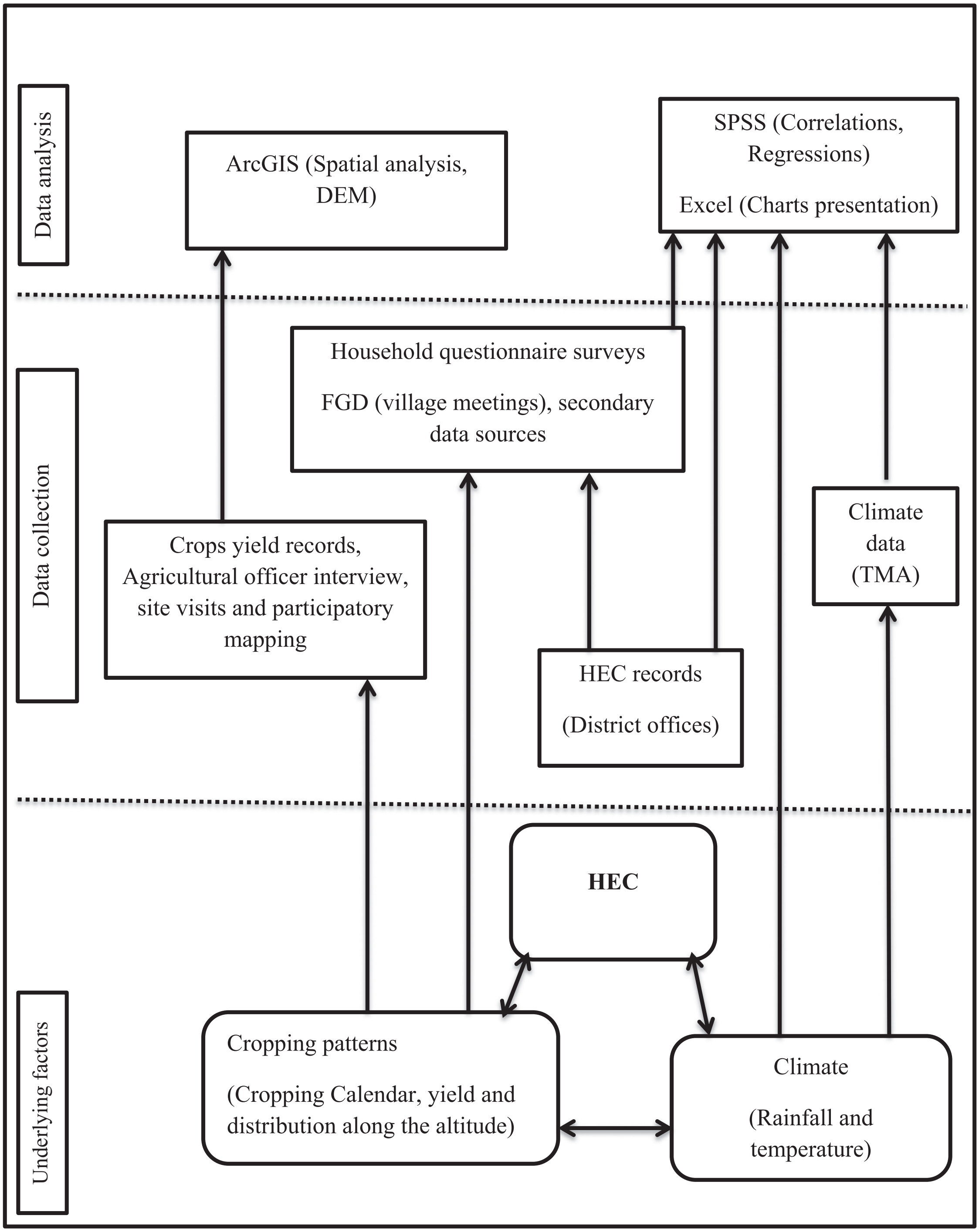


Fig. 1. Workflow of the data collection and analysis on human-wildlife conflicts with respect to climate and agricultural development over the last decades in Rombo, northern Tanzania.

(Mengwe, Mashati and Tarakea), with a total land size of 31,084 ha. Three field assistants who participated in administering the questionnaire were well trained on how to translate and administer semi-structured questionnaires (Appendix I in the Supplementary Material) verbally to the respondents. The questionnaires were prepared in English (Appendix I) but administered in Swahili language. Interviewed households were located along different agro-ecological zones (upper, intermediate and lower zones) of Rombo area. The respondents were the heads of the households or representatives, aged 25 years and above, who had lived in the respective location for at least 5 years (Appendix 6). Perceptions of respondents on crop performance were recorded, which included production costs per ha per season, yield per season, the trend of crop yield per ha and the major threats to their crops, including rainfall changes, and crop raids by the African elephant (Loxodonta africana). These data were further combined with information obtained from village meetings (Appendixes 2 and, 5) district records, and site observations as well as expert interviews (Appendixes 3 and 4) and participatory mapping of cropping sites and crop raid locations.

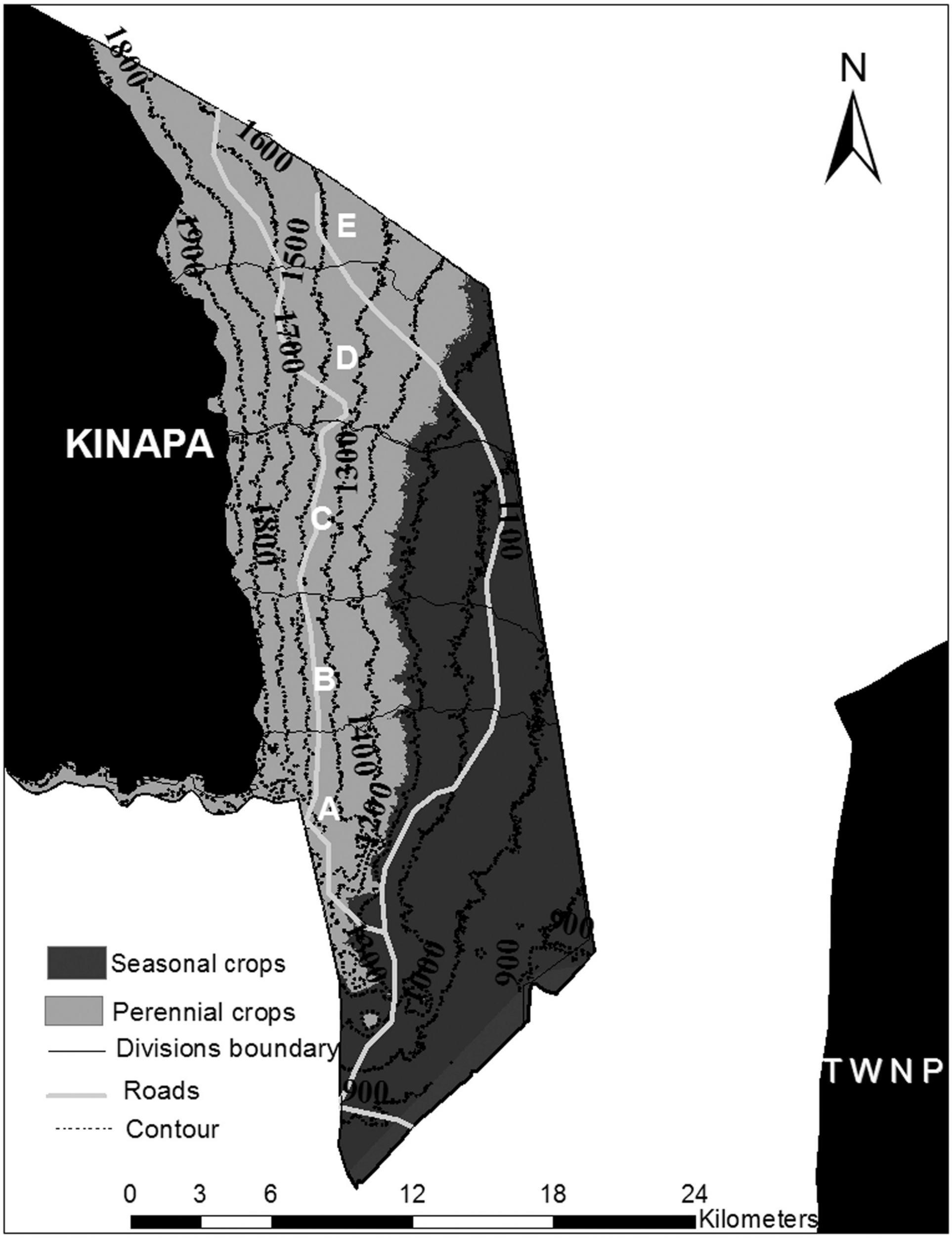


Fig. 2. Crops cultivated in different agro-ecological zones of Rombo area (A = Mengwe, B = Mkuu, C = Mashati, D = Useri and E = Tarakea) adjacent to Kilimanjaro National Park (KINAPA) and Tsavo West National Park (TWNP).

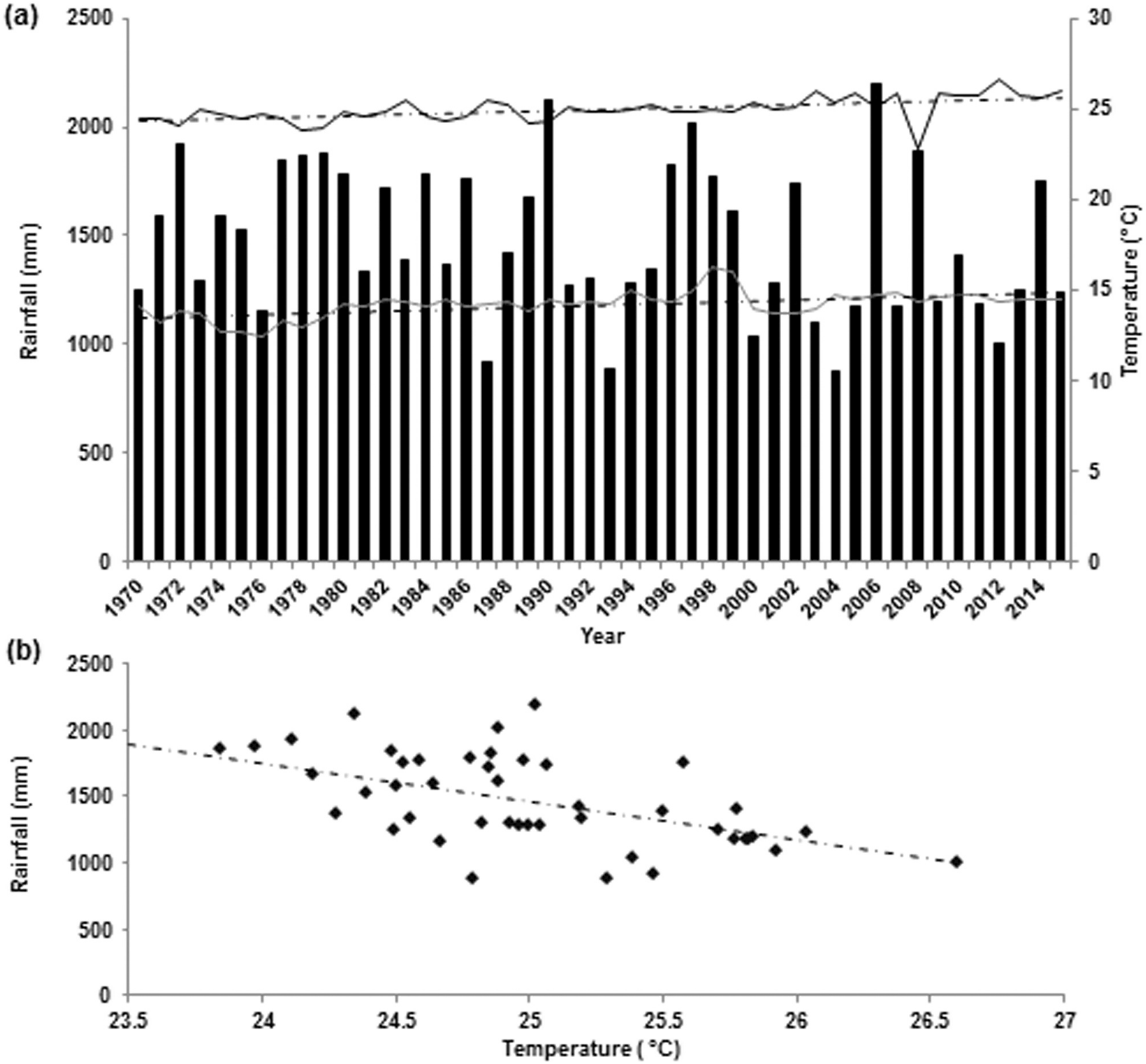


Fig. 3. (a) Rainfall and temperature trends over 45 years in Rombo, Tanzania. Average annual rainfall (black bars), minimum and maximum average annual temperatures (curved black lines) and trend lines (straight dashed lines); (b) Correlation of rainfall and temperature over a period of 45 years (1970–2015) in Rombo area.

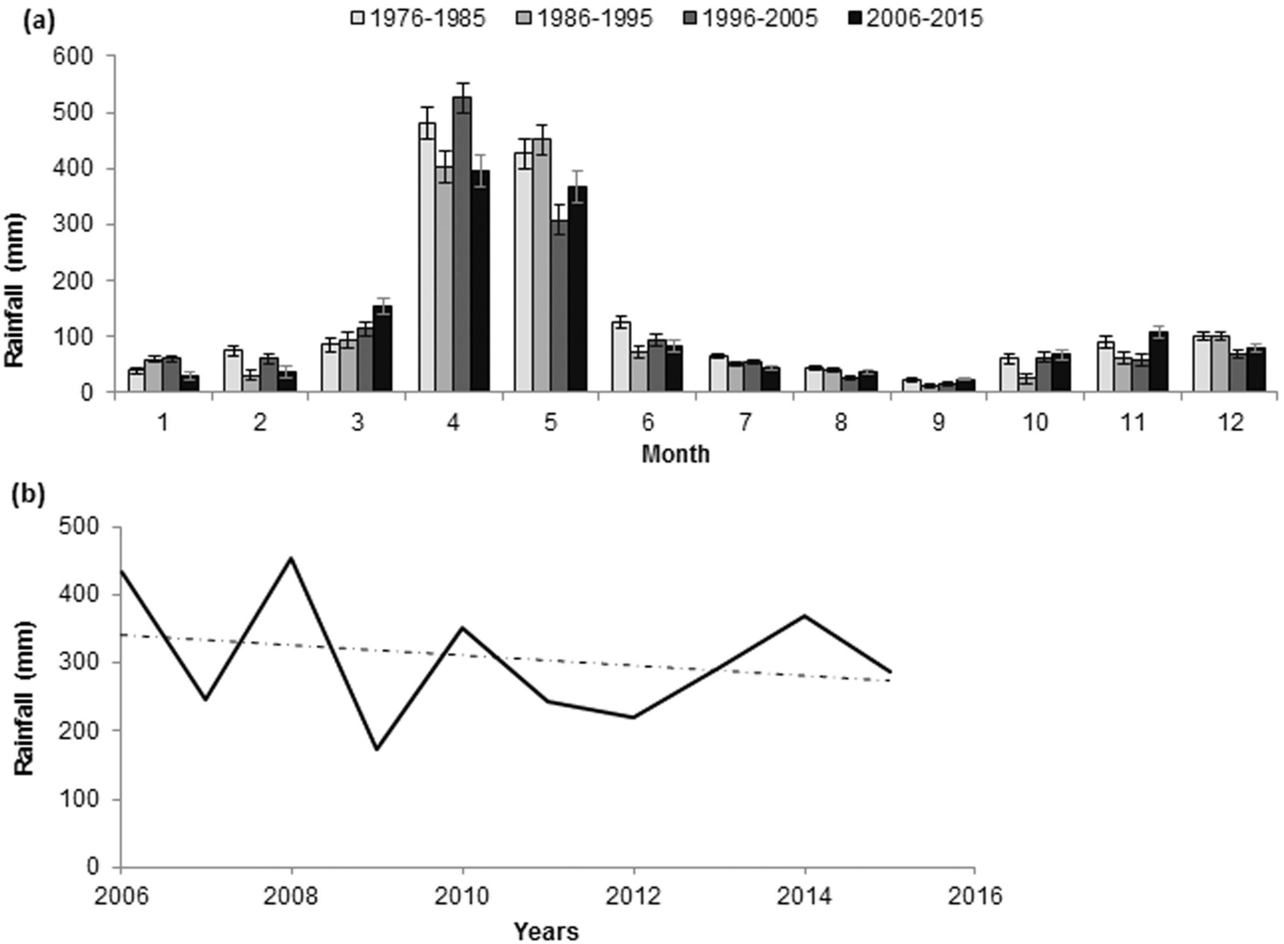
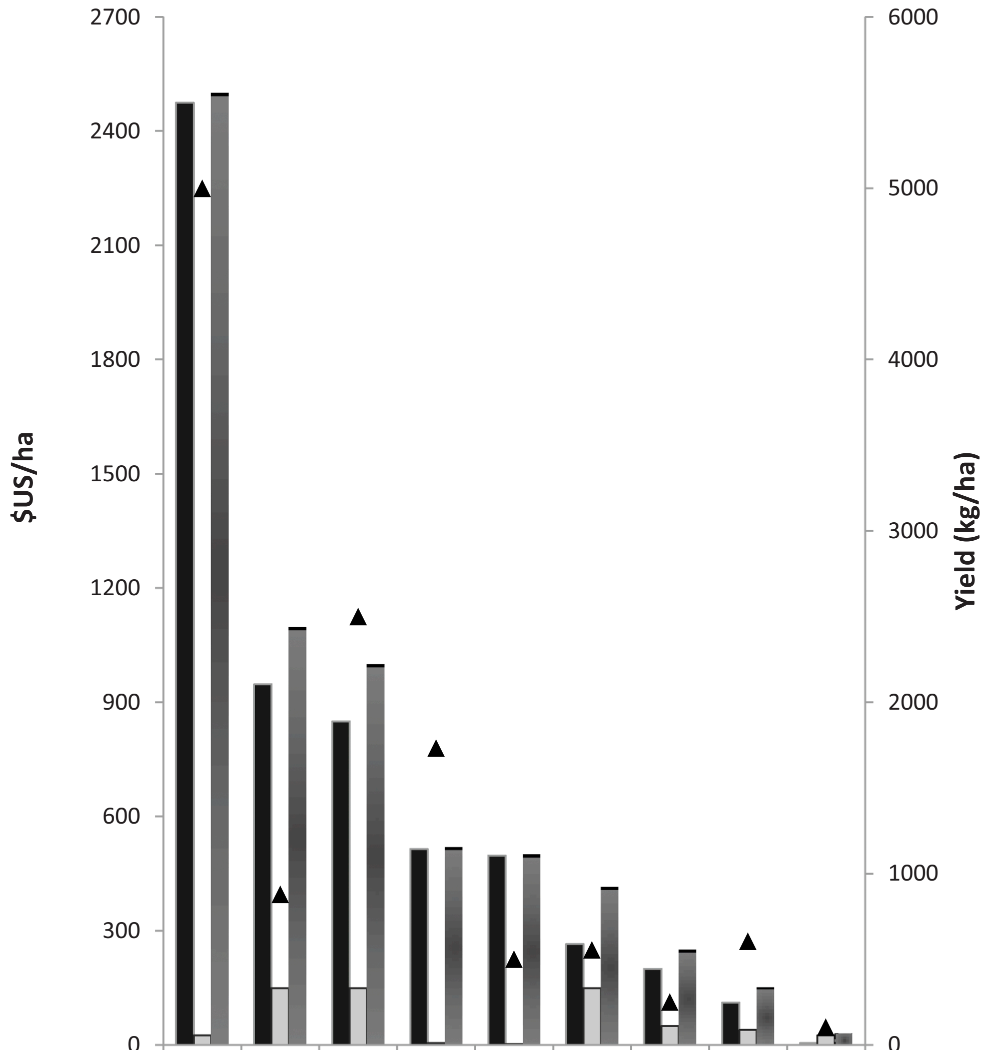


Fig. 4. (a) Average monthly rainfall trend in the past four decades (1976–2015) across the months of the year in Rombo area, Tanzania. (b) Average annual rainfall (March-May) over the last ten (2006–2015) years in Rombo, Tanzania.

2.3. Data analysis

To generate maps, spatial analysis was performed using Geographical Information System (ArcGIS 10.4), where GPS coordinates from household surveys on crop types and shape-files of Rombo district boundaries were imported into Arc map, geo-referenced to the 1984 World Geographical System (WGS) and projected to Universal Transverse Mercator (UTM) Zone 37S prior to analysis. To convert point data to raster data, the Inverse distance weighted (IDW) interpolation tool was used. Digital Elevation Models (DEM) was used to generate a contour map of the study area, which was overlaid with the crop map of the study area. Different time period spans were used for different analyses based on the availability of data. Shifts in temperature and rainfall events were analyzed over a time period of 46 years (1970–2015), while crop performance with respect to climatic parameters was analyzed over a period of 16 years (2000–2015), and elephant incidents versus climate and crop related factors were analyzed over a 6-year period (2006–2011). The in-depth information obtained based on people's perceptions and attitudes were analyzed qualitatively. Descriptive statistics were used (e.g., frequencies of crop types cultivated across the study area, trends of crop yields, and threats to crops). Spearman's correlation



	BAN	NUT	POT	MAI	PPEA	BEAN	CPEA	SOR	COF
■ Profit ($US/ha)	2475	948	850	515	498	265	200	111	6
□ Production costs ($US/ha)	25	150	150	5	3	150	50	40	25
■ Revenues ($US/ha)	2500	1098	1000	520	500	415	250	151	31
▲ Yield (kg/ha)	5000	878	2500	1732	500	554	250	605	103

Fig. 5. Performance of different crops in Rombo area. BAN = banana, NUT = ground nuts, POT = Irish potatoes, MAI = maize, PPEA = pigeon pea, BEAN = beans, CPEA = cow pea, SOR = sorghum, COF = coffee.

analysis was carried out to assess the influence of rainfall and temperature on the observed longitudinal changes in the crops and other land use patterns both within and across altitudinal gradients in Rombo area, using the Statistical Package for Social Science (SPSS Inc. 2.1) (Fig. 1).

3. Results

3.1. Patterns of crops cultivated in Rombo area

In our study area, crops were categorized in two main groups: seasonal crops (major crop was maize) and perennial crops (major crops were coffee and banana). Banana, coffee, maize, beans, Irish potatoes (*Solanum tuberosum*) and others (ground nuts (*Arachis hypogaea*), cow pea (*Vigna unguiculata*), pigeon pea (*Cajanus cajan*), sorghum (*Sorghum bicolor*)) covered 30%, 30%, 22%, 11%, 5%, and 2% of the Rombo land area, respectively. Maize was cultivated by more than 50% of the interviewed farmers while other crops were less common. This was also confirmed by direct field observations and responses of participants in focus group discussions. Divisions such as Mengwe, Mkuu, Mashati and Useri comprised both seasonal and perennial crops across different agro-ecological zones, while Tarakea consisted of mostly perennial crops and only few seasonal crops, cultivated inside the mostly protected Kilimanjaro forest plantation. GIS analyses revealed that there was a sharp division line between perennial and annual crops at an elevation of about 1230 masl. In the entire Rombo area, seasonal crops covered about 21,700 ha, mainly in the lower and middle agro-ecological zones (Fig. 2). Perennial crops covered an area of about 25,871 ha, occupying the intermediate and upper agro-ecological zones (Fig. 2).

3.2. Climate trends

Over the period of 46 years (1970–2015), the maximum average annual temperature significantly increased by about 1 °C

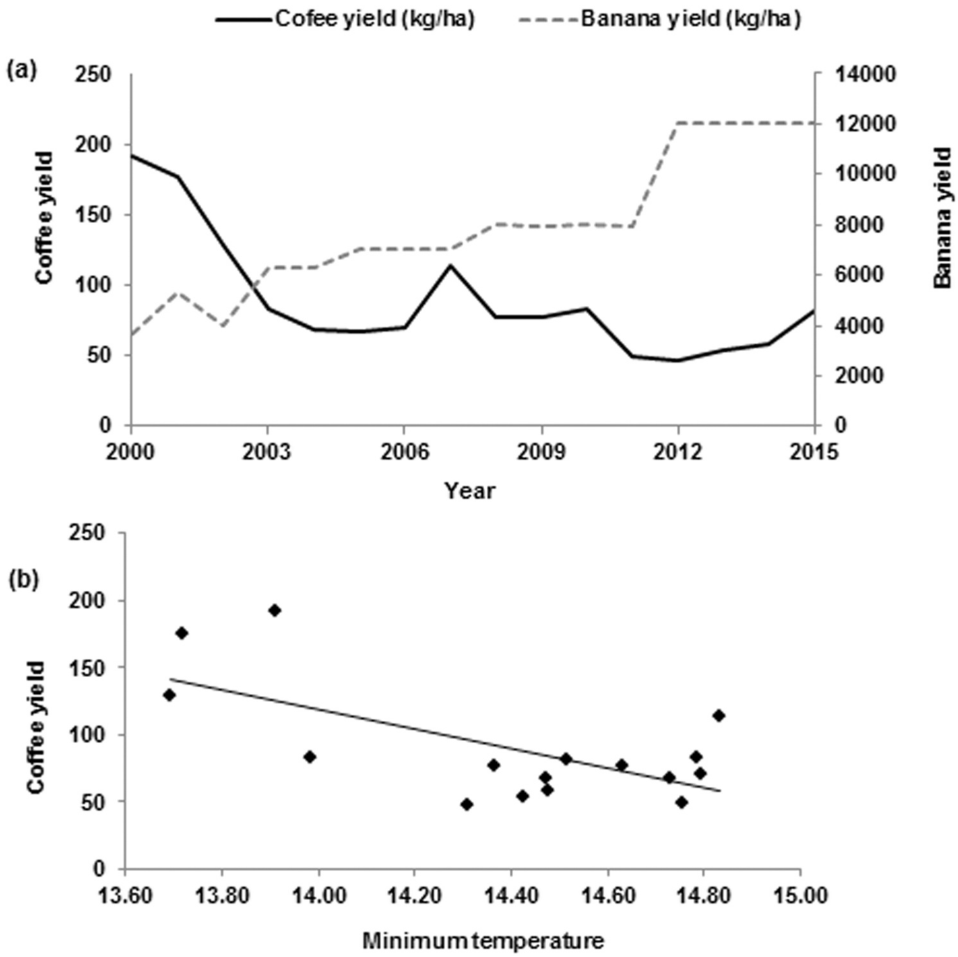


Fig. 6. (a) Trend of coffee and banana yields in the time period of (2000–2015) and (b) correlation between coffee yield and average minimum annual temperature in Rombo area, Tanzania.

($p < 0.0001$, $R^2 = 0.36$, $\beta = 0.60$). The same significant trend was visible for the average annual minimum temperature, which was below 14 °C for the first 9 years and then rose steadily (Fig. 2a; $p < 0.0001$, $R^2 = 0.313$ and $\beta = 0.6$). Average annual rainfall decrease in these 46 years was statistically not significant ($p = 0.12$, $R^2 = 0.05$ and $\beta = -0.23$) although high rainfall events seemed to decrease in frequency in the last decades (Fig. 3a). Rainfall and temperature were negatively correlated over the last 46 years ($p = 0.0004$, $r = -0.55$ (Fig. 3b)).

Seasonal rainfall patterns varied only slightly across four decades over the last 46 years (Fig. 4). The largest variations in average rainfall per year were observed in March, April and May (SE = 13, 27 and 27, respectively), which are important growing months for seasonal crops such as maize. The peak rains were in April and May, when on average 75 mm per decade fell (Fig. 4a). Additionally, over three decades, rainfall seemed to decrease with time, except in one decade (1996–2005), which was caused by abnormal heavy rains of "el Nino" in the year 1996. The short rainy season peak was in December for the decades 1976–1985 (100 mm), 1986–1985 (101 mm) and 1996–2005 (68 mm), while for the decade of 2006–2015, the peak (109 mm) was already in November, followed by only little rain in the following months. Surprisingly, the most recent decade (2006–2015) had the lowest rainfall amount during the long rainy season but the highest one during the short rainy season, although the difference was not statistically significant (Fig. 4a). During the interviews, respondents claimed that rainfall amount had decreased over time and seasonal fluctuations have increased over the recent 10 years. We found the claim of the farmers to be true, although the decrease was not significant ($p = 0.498$, $R^2 = 0.050$ and $\beta = -0.244$) (Fig. 4b).

3.3. Crop performance under climate change

By combining the recorded data on crop performance (production costs, yield, and price) of 16 years (2000–2015) and interview results, we found that current farmers make most profit with banana (2475 $US/ha) while coffee provided lowest profit (6 $US/ha). These two crops are usually cultivated together on the same farm. Among the seasonal crops, ground nuts brought most profit, followed by Irish potatoes and maize (about 948 $US/ha, 850 $US/ha and 515 $US/ha, respectively). The remaining crops provided income of less than 500 $US/ha (Fig. 5). Respondents claimed that they had adopted ground nut cultivation in recent years only (since the year 2000) due to this crop's low input cost and high profit, which was also observed through participatory field observation.

Banana production had increased significantly within the last 16 (2000–2015) years (r = 0.93, $p = 0.05$) (Fig. 6a) and production was not affected by either rainfall or temperature variations (Table 1). In the same time period, coffee production decreased significantly (r = - 0.719, $p = 0.05$), with a minimum yield of 47 kg/ha in the year 2012 (Fig. 6a; Table 1). The decline in coffee production was also significantly negatively correlated with increasing minimum temperatures ($p = 0.006$, r = − 0.65) (Fig. 6b) but was not affected by rainfall or maximum temperature (Table 1). Coffee yield decreased by 120–160 kg/ha, with an average increase of 1 °C of minimum temperature. During our interviews, most respondents (94%) confirmed that coffee yield has decreased over the past years, and as a consequence, about 30% of respondents said they shifted their cultivation from coffee to seasonal crops, especially maize. This was also observed during focused group discussion with key informants and participatory field observations, where some coffee farms were observed to remain with few coffee stems only and dominated by maize. In contrast, seasonal crop production increased over the last 16 years, particularly that of maize and beans ($p = 0.001$, r = 0.599 and $p = 0.05$, r = 0.815, respectively) (Table 1). Maize and beans had a maximum production of 2424 kg/ha and 1417 kg/ha in the year 2013 and 2015, respectively. Both crops were not significantly affected by variations in rainfall or temperature (Table 1).

3.4. Elephant crop raiding in relation to the climatic variations and harvesting time

Based on interviews and the crop damage records, seasonal elephant crop raiding incidents were highest from May to July, i.e., shortly after peak rainfall in April and May (Fig. 7). On average, a high frequency of conflicts (91 incidents) and greatest crop losses (of about 5000 $US/household) were encountered in May, when rains amounted to 400 mm on average and average temperatures ranged between 17 °C and 19 °C over the recorded 6 years (Fig. 7). Generally, rains peaked in April (500 mm) while elephant incidents were highest in June (125 incidents), i.e., during crop maturity and harvesting period (Fig. 7). However, in general over 6 years (2006–2011) elephant incidents decreased, as did rainfall, but the relationship was no significant ($R^2 = 0.11$, $p = 0.53$, $\beta = -0.324$).

In our interviews, 70% of farmers reported a decrease, 16% increase, and 8% a fluctuation while 5% of respondents reported no change in crop yield over the last 5 years. They further claimed that the main threats to crops were drought (43%), elephant crop raiding (24%), and insect pests (22%), which were confirmed by more than 90% of the members in meetings.

Table 1
Pearson correlation coefficient (r) of different crop type yields (kg/ha) with climate variables (rainfall (mm) and temperature (°C)) over the time period of 16 years (2000–2015) in Rombo area, Tanzania.

	Maize	Beans	Coffee	Banana
Years (2000–2016)	0.599*	0.815**	-0.719**	0.929**
Maximum temperature (°C)	0.417	0.406	-0.202	0.307
Minimum temperature (°C)	0.335	0.264	-0.649**	0.331
Rainfall (mm)	-0.407	-0.061	-0.081	0.065

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

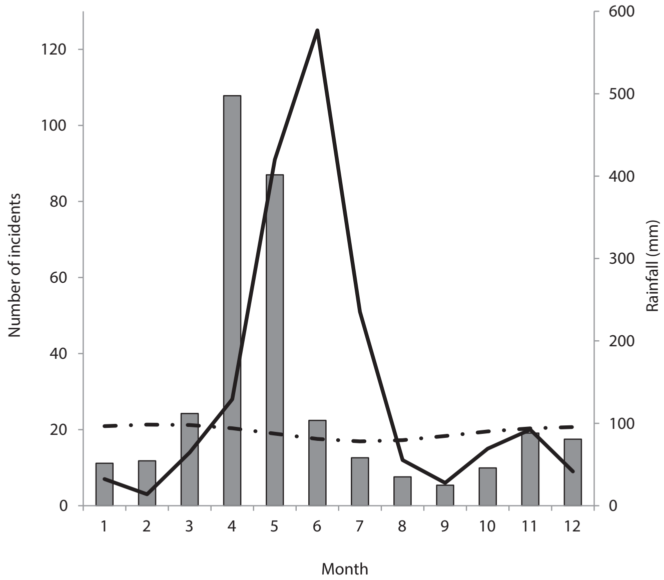


Fig. 7. Elephant incidents (solid line) in relation to the variations of average rainfall (gray bars) and average temperature (dotted line) (2006–2011).

4. Discussion

4.1. Crop performance across agro-ecological zones

The clear boundary between the area dominated by perennial and annual crops at around 1230 masl was surprising, and we recorded that maize has recently encroached further into upland areas. The Chagga tribe is traditionally settled, with perennial crop cultivation and livestock in higher elevations, and cultivates annual crops in lower elevations (Soini, 2005). However, in recent decades, major changes of the land use have occurred, and the Chagga of Rombo have increasingly settled in the lower altitudes also (Mmbaga et al., 2017a, 2017b, 2017c), probably due to decreasing elephant numbers in the area due to a locally high human population pressure. Surprisingly, in spite of the changing climate, we found that banana, maize and bean production had been increasing under rain-fed scenarios, while other studies reported decreasing crop (maize) yield due to the changing climate (Mourice et al., 2017). Our observation that the cultivated crops shifted from perennial coffee to seasonal crops agrees with studies in Kenya (Muthee et al., 2015), where coffee was abandoned or replaced with other crops like pea, passion-fruit and banana in higher altitudes. This shift was reported to be due to climate change and increasing pests and diseases affecting coffee (Jaramillo et al., 2013; Said, 2019), which was confirmed by interviewees in our study. Additionally, we found that low market prices and high production costs of coffee compared to other seasonal crops have led to lower overall profit. Moreover, farmers in our study claimed that the less frequent elephant incidents also lowered chances of their maize being attacked by elephants and promoted cultivation of maize.

4.2. Temperature and rainfall patterns affecting crop performance and elephant incidents

In our study, over the period of the last 16 years, only coffee was negatively affected by an increasing minimum temperature among four different crops (maize, beans, banana and coffee). However, our results indicated that a further decrease of average annual rainfall below 1250 mm and an increase in temperature above 25.8 °C might lead to declines in maize and bean yields, which might further put local farmers under pressure. Globally, minimum temperatures have increased twice as strongly as maximum temperature (Arets et al., 2019; Skansi et al., 2013), which has affected mostly tropical crops, e.g. in India and Asia (Bapuji Rao et al., 2014; Baskaran et al., 2013). *Coffea arabica* is among the most valuable crops for global export (Craparo et al., 2015) and in Tanzania, coffee production has generated income of about 100 million $US per annum and sustains about 2.4 million of Tanzanian livelihoods (Craparo et al., 2015; Jassogne et al., 2013). Coffee production also has a valuable ecological importance as it supports agro-forestry systems in different equatorial countries like Kenya, Uganda, Burundi, and Ruanda (Williams and Funk, 2011). In our observations, farms with coffee cultivations supported agro-forestry, i.e., a mixture of planted trees such as Mango (*Mangifera indica*), Orange (*Citrus aurantium*), Papaya (*Carica papaya*) and Avocado trees (*Persea americana*) with crops like banana. These so-called “Chagga home gardens” are essential for keeping high agrobiodiversity and microclimate maintained (Said, 2019). In spite of this importance to the livelihoods of the people and the ecological benefits, there has been a significant shift away from this cultivation type. Our findings confirm the projections made by Craparo et al. (2015), who stated the decrease of coffee yield by 137 ± 16.87 kg/ha with an increase of 1 °C minimum temperature in the northern highlands of Tanzania from 2012 onwards.

We observed decreasing elephant incidents over time but they were not significantly related to rainfall or temperature. Throughout the years, however, most elephant incidents and conflicts arose during the peak rainy months, May and June, confirming that these incidents were mainly driven by maturity of seasonal crops, mostly maize (Boult et al., 2019; Mwakatobe et al., 2014; Sitienei et al., 2014). While some studies show that elephants like coffee (Bal et al., 2011) and banana (Mwakatobe et al., 2014), records and responses from the local people of Rombo showed that elephants do not often raided coffee or banana but rather preferred maize (Mmbaga et al., 2017a, 2017b, 2017c). The declining elephant occurrence incidents distribution might be linked to the decreasing number of elephants in the study area (Mmbaga et al., 2017a). Due to increasing habitat fragmentation, encroachment and poaching for ivory trade some studies reported a declining elephant population in the KINAPA ecosystem from 1200 individuals in 1970s (Afolayan, 1975) to about 750 in 2003 (Munishi and Maganga, 2003) and 450 in 2010 (Mduma et al., 2010). Further, conflicts seem to rise with increasing human population growth (Häder and Barnes, 2019; Reid, 2012; Wittemyer et al., 2008), which agrees with our findings for Rombo, where the local human population has increased by 30% over the last 25 years (Mmbaga et al., 2017a, 2017b, 2017c). Land use changes also strongly influence human-elephant conflicts (Afolayan, 1975). In Rombo, where 28% of agricultural land has been converted into settlement over the last 28 years, and where settlements have increased by 30%, human-elephant conflict was shown to be severe (Mmbaga et al., 2017a, 2017b, 2017c). Ogutu et al. (2014) argued that human-wildlife conflicts are mainly driven by other factors than climate variability, which we can confirm through our study. We claim that land use pressure and habitat changes seem to play a much larger role for elephant movement and, thus, arising human elephant conflicts (HECs), than do shifts in rainfall and temperatures in the Kilimanjaro ecosystem. We also highlight that decreasing HECs over the recent years in Rombo have triggered more people to cultivate seasonal crops in monoculture, which will lead to further habitat destruction, connectivity loss and a less favorable environment for elephants.

4.3. Implications to future livelihoods and elephant populations

The pragmatic shift from coffee production to seasonal crops might be beneficial to farmers in the short run as it increases food production but will most likely lead to negative future impacts to ecosystem services and livelihoods in Rombo area. Clearing of coffee plantations and replacing it by seasonal monocultures highly contributes to the increasing temperature and decreasing rainfall in the area as valuable carbon stored in the terrestrial vegetation is lost (Muthee et al., 2015; Rahn et al., 2014). Further, coffee plantations, i.e., woody vegetation, can buffer shifts in climate due to stabilization of the ambient microclimate, which is important for the water household (Hemp, 2005; Said et al., 2019). In our study, we found that climatic shifts, such as a further decrease of the average annual rainfall as predicted in various studies (Bapuji Rao et al., 2014; Häder and Barnes, 2019; Lin, 2007), might lead to a decrease of seasonal crop yields?, particularly in maize and beans. Cairns et al. (2013) argued that a potential 2.1 °C increase in average temperature by the year 2050 will lead to declines in crop production, including maize, across sub-Saharan Africa. This may result in severe long-term inadequate food and cash crop production resulting in unsustainable livelihoods. This situation will also inevitably lead to wildlife (elephant) habitat loss and fragmentation as a result of unsustainable ecosystem functions and services resulting from land use shifts and climate change (Ogutu et al., 2014).

5. Conclusion

To maintain the sustainability of human livelihoods and elephants, anthropogenic activities need to be monitored. Shifts from perennial cultivations such as coffee to seasonal crops such as maize will in the long run put the ecosystem in Rombo out of balance. Since perennial crops like coffee support agroforestry systems, its replacement with seasonal crops might further contribute to already rising temperatures and decreasing rainfall events. Tree planting campaigns should be emphasized by the Government and NGO's in the Rombo area to boost a microclimate favorable to Arabica coffee and other perennial crops such as cocoa (*Theobroma cacao)* and Robusta coffee (*Coffea canephora*). For example, "Greening Tanzania" under Tanzania Forestry Services (TFS) and REDD+ projects would give incentives to local communities through carbon trading, water and energy security. We propose that HECs are more strongly determined by land use rather than by climatic changes, highlighting that immediate action needs to be taken to identify suitable land use systems in this area that can host elephants and act as buffer zones. An improved land use system would result in a range of additional environmental benefits such as afforestation that are important for the improvement of local livelihoods and ecosystem sustainability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2021.e01683.

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