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Climate change and hunter-gatherers in montane eastern DR Congo

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Research Highlights

- Twa and Tembo perceived reduced rainfall and fog, but increased temperatures
- Meteorological data available shows reduced rainfall and increased temperatures
- Twa and Tembo reported reduced crop yields and reduced abundance of forest products
- Tembo are already implementing some climate adaptation, but not the Twa

Abstract

Mountain environments experience more rapid changes in temperature than lower elevations. However, little is known about the climatic changes already observed in African mountains, or the adaptation strategies used by hunter-gatherer communities. Semi-structured interviews were administered to 100 Twa hunter-gatherers living around Mt Kahuzi in eastern Democratic Republic of the Congo (DR Congo). We also organized 10 focus-group discussions with Tembo farmers living in the same area and we gathered historical from Kamembe meteorological station. Twa respondents perceived reduced rainfall and fog, and increased temperatures. They also reported reduced crop yields and abundance of forest products (caterpillars, mushrooms, honey). Tembo perceptions of climatic changes and impacts agreed with the Twa. Meteorological data available shows reduced rainfall and increased temperatures – but there are no records on fog. Despite being aware of climatic changes and impacts, Twa are not using any adaptation strategy, while Tembo farmers are using some (as they own land for farming or animal rearing, and are more business minded). For the Twa, their socioeconomic condition create high sensitivity to climate change and constrain adaptive capacity. To help the Twa, we recommend the use of "science with society" (SWS) participatory approach.

Keywords: Mountains; forests; local knowledge; adaptation; livelihood strategy

1. Introduction

There is increasing interest in local communities' perceptions of climatic changes, as a strategy for complementing meteorological data scarce areas, and as a way to better understand the impacts of climate change on the biophysical and the social systems at local scales (Klein et al., 2014; Reyes-García et al., 2016; Savo et al., 2016). Local communities' knowledge can also be used to develop more effective and locally tailored strategies for adapting to climatic change (Cuni-Sanchez et al., 2019a). A significant amount of the literature about climate change perceptions and adaptation, and the socio-economic parameters affecting both, has been published in the past decade (see Savo et al., 2016; Reyes-García et al., 2016 for reviews). Most literature has focused on agricultural communities, and therefore, documented impacts on the agricultural system and adaptation strategies with regard to agriculture (Reyes-García et al., 2019). Relatively few studies have documented pastoralist, fishing or hunter-gatherer communities' responses to climate change, or documented the interaction between different communities in the same area. The reports from IPCC (Intergovernmental Panel on Climate Change) highlight an important information gap regarding climate change impacts on hunting and wild food collection (Cramer et al., 2014).

The Albertine Rift region of Africa (the western branch of the East African Rift, covering parts of Uganda, the DR Congo, Rwanda, Burundi and Tanzania) is a climatically complex transition zone between eastern and central equatorial Africa, spanning bimodal and unimodal rainfall regime zones, and experiencing rain shadow effects from highly variable topography (Salerno et al., 2019). Our understanding of this region's climatic patterns and controls is still limited, largely due to the unreliable rain gauge coverage over central equatorial Africa (Washington et al., 2013) and disagreement among satellite rainfall products (Maidment et al., 2015; Salerno et al., 2019). While several studies using satellite-based rainfall estimates reported a drying trend for the Congo Basin (e.g. Cook et al., 2020), recent work from Uganda, which combined satellite and gauge-based rainfall estimates with farmers' perceptions, reported wetting trends caused by increased rainfall during the rainy seasons (Salerno et al., 2019). Changing seasons' lengths were also reported, which, combined with wetter seasons, caused substantial declines in potato and bean harvests due to fungal outbreaks and other diseases (Salerno et al., 2019).

The mountain forests of the Albertine Rift are particularly threatened by the predicted displacement of people in response to climate-related changes in crop suitability (Phillipps & Seimon, 2009; Watson & Segan, 2013). These mountain forests are also threatened by climate change: a recent study showed that 76% of mountain forests' current extent will experience different environmental conditions by 2070, challenging the continued existence of these habitats, the biodiversity they harbour, and the ecosystem services they provide to people (Ponce-Reyes et al., 2017). As the rate of warming is amplified with elevation, mountain environments will differentially experience more rapid changes in temperature than environments at lower elevations (Pepin et al., 2015). Raising temperatures affects cloud formation (e.g. rising cloud base or reduced overall cloud incidence), further reducing water inputs in mountain forests where leaves and branches from trees collect cloud/fog water droplets (Bruijnzeel et al., 2011). Cloud/fog water harvesting by mountain forests can be of key importance for local and regional livelihoods: e.g. in Mt Kenya, the deforestation which occurred between 2000 and 2010 diminished dry-season river flows due to reduced fog water harvesting, which reduced revenues from irrigated agriculture, hydropower and inland fisheries, and increased costs of water treatment for potable use, costing Kenya over US$33 million (UNEP, 2012).

Remarkably, little information is available on the changes observed in cloud or fog incidence in the mountains of tropical Africa. In Mt Marsabit in Kenya, using a 30-year data of fog occurrence recorded at a meteorological station, a 60% reduction in fog hours per year was reported, which was in agreement with local communities' perceptions of changes in fog occurrence (number of hours/days with fog) for the same time period (Cuni-Sanchez et al., 2019a). Local communities in the East Usambaras in Tanzania also reported changes in fog occurrence (Hamilton & Bensted-Smith, 1989). It is very likely that changes in fog occurrence have been observed in the mountains of the Albertine Rift, but that it has not been documented as studies have focused on lower altitudes (e.g. Bele et al., 2014) or, when focused on mountain areas, did not investigate fog (e.g. Bomuhangi et al., 2016; Few et al., 2017; Salerno et al., 2019; Zizinga et al., 2017).

Investigating local perceptions of climatic changes, and their impacts on the biophysical system, can provide insights on appropriate adaptation strategies. For instance, a study focused on farmers around Bukavu in DR Congo showed that non-timber forest products (NTFPs) were considered as a safety net for when agricultural production failed (Bele et al., 2014). In Cameroon, farmer communities also turn to forests when crops fail: e.g. they replace groundnuts with seeds of the tree *Ricinodendron heudelotii* (Bele et al., 2013). Farmer communities in both studies perceived NTFPs as being less affected by climatic changes than agriculture (Bele et al., 2013; 2014). The Twa hunter-gatherers living in the mountain forests near Bukavu, who use and value these forests differently to Bantu agriculturalist communities (Cuni-Sanchez et al., 2019b), might report different changes in NTFPs, and might also have different coping and adapting strategies to climatic changes compared with farmers.

In tropical Africa there are about 1 million 'Pygmy' hunter-gatherers (Olivero et al., 2016). The term Pygmy is often used to describe several ethnic groups (e.g., Aka, Baka, Bezan, Efe, Twa, Mbuti, etc.) of short stature, who speak different languages, have different cultural and morphological characteristics, and even live in diverse ecological areas, including lowland and mountain forests (Verdu, 2016). Most of these ethnic groups are the poorest of the poor in the areas where they live (e.g., Mbote: Batumike et al., 2020; Twa: Cuni-Sanchez et al., 2019b), suggesting that they are particularly vulnerable to climatic changes, especially if NTFPs abundance is being affected by climatic changes. However, to our knowledge, no study has investigated if this is the case.

This paper, focused on the Twa hunter-gatherer communities of the mountain forests of Mt Kahuzi in eastern DR Congo, aims at filling in these knowledge gaps regarding i) changes in fog occurrence, ii) impacts of climate change on NTFPs, and iii) hunter-gatherer adaptation strategies. The main objectives are to: (1) identify the changes in climate and their impacts on the biophysical system as perceived by the Twa; (2) assess if these changes are consistent with those perceived by nearby Tembo farmer communities and/or meteorological data available in the region; and (3) determine which strategies Twa and farmers are using to adapt to these climatic changes and their impacts. Given that socio-economic parameters such as gender or wealth group might affect both perceptions of climate change and adaptation strategies (see Savo et al., 2016), we also investigated the effects of gender and wealth group on perceptions of climate change and adaptation strategies within the Twa. To our knowledge, this is the first study focusing on local perceptions of climatic changes and their impacts by forest hunter-gatherer communities in Africa. A study from Cameroon (Few et al., 2017) included some hunter-gatherers but combined different livelihood-strategy groups when analysing the data.

2. Methodology

2.1. The study area

This study focused on the communities living adjacent to Mt Kahuzi (3320m asl) in eastern DR Congo (Fig. 1). Annual rainfall ranges between 1500 and 2000mm, mean annual temperature is 20°C, and relative humidity is close to 76% (Fischer, 1996). The main habitat types are submontane forests dominated by *Anonidium mannii, Carapa grandifolia, Strombosia scheffleri* and *Trichilia welwichii*; and montane forests dominated by *Hagenia abyssinica, Macaranga kilimandscharica* and *Rapanea melanophloeos* (Imani et al., 2016). Bamboo (*Sinarundinaria alpina*) formations and alpine grasslands can be found at higher altitudes. These forests are part of the Albertine Afromontane Biodiversity Hotspot (Mittermeier et al., 2004), and support globally important populations of Grauer's gorilla (*Gorilla beringei graueri*), eastern chimpanzee (*Pan troglodytes schweinfurthii*) and forest elephant (*Loxodonta africana* var. *cyclotis*) (Plumptre et al., 2009).

Mt Kahuzi mountain forest is located within the Kahuzi-Biega National Park (NP) (Fig. 1). Created as a Zoological and Forest Reserve in 1937, it became a National Park in 1970, when human inhabitation in the park was prohibited and communities living inside (mainly the Twa) were evicted with no compensation (Barume, 2000). The National Park was extended into the lowlands in 1975, and more people were evicted (more Twa and other ethnic groups). In 1981, it became a World Heritage Site, because of the remaining population of Grauer's gorilla. In 1997, during the first Congo War, it was listed as a World Heritage Site in Danger as a consequence of armed conflict in the eastern parts of the country. In 2020, it remains a World Heritage Site in Danger because of illegal mining, bush meat hunting, presence of mining villages within the park in the lowlands and presence of armed militia (who are poaching and create a lack of security for park rangers to patrol). Access to Mt Kahuzi mountain forest is restricted (hunting, farming or collection of NTFPs is illegal, Cuni-Sanchez et al., 2019b).

The park is in one of the most densely populated areas of the country, surrounded by over 300 habitants/km^2, ICCN, 2009). The major ethnic groups around Mt Kahuzi are Twa ('Pygmy' hunter-gatherers), Tembo and Shi (both Bantu farmers). We use livelihood strategy (farmer or hunter-gatherer) to refer to the main activity used to provide food, shelter and income for a given household, which, in our study area, is related to people's identity and culture. Livelihood strategy not only involves making a living, it also means making it meaningful (Bebbington, 2000). The Twa are the poorest members of the current society: they are landless, they barely own domestic animals, they have limited access to education, healthcare, microfinance or training opportunities, and they are continuously marginalized by other ethnic groups (see Appendix A1 for details). Since Twa eviction from the national park (their ancestral lands) most live in very small parcels of land borrowed from Tembo and Shi farmers, where they have created 'villages' embedded within farmers' ones.

2.2. Data collection among communities and analysis

First, exploratory focus-group discussions (FGDs) were conducted with 4-7 male and female elders in eight Twa villages located at similar altitudes on both sides (east/west) of Mt Kahuzi (Fig. 1). These were used to design the semi-structured questionnaires and to build trust among the Twa communities (see Appendix B). Then, we administered semi-structured questionnaires to 100 Twa household heads (50 men and 50 women) in the same villages. Questionnaires addressed household characteristics and assets, perceived changes in climate and impacts on the biophysical environment, and adaptive strategies used to cope with or adapt to observed changes (see Appendix B1 for details, including participant selection). The exploratory FGDs and the interviews were translated and facilitated by the same Twa field assistant. All participants (FGDs and interviews) were selected on a voluntary basis and were first informed that the aim of the study was to better understand the perceived changes in climate and its impacts. FGDs guiding questionnaire can be found in Appendix B2.

In order to compare Twa responses with those of farmers living in the area, FGDs were organized in 10 Tembo villages (located on the western part of Mt Kahuzi, where 50% of the Twa interviews had taken place, Fig. 1). Each FGD involved 4-8 elders (including the village chief, as it is a custom in the area). We focused on elders as these have been living and farming in a given area for a longer period of time (there is little migration in the communities studied) and can potentially report a larger number of climatic changes and impacts. These FGDs were facilitated and translated by one of the co-authors who is from the Tembo ethnic group. All participants were selected on a voluntary basis. Participants were first informed that the aim of the study was to better understand the perceived changes in climate and its impacts. Then, informal discussions centred on perceived changes in climate and impacts on the biophysical environment, and adaptive strategies used to cope with or adapt to these changes (see Appendix B2).

We use 'adaptive strategies' to refer to (i) strategies which evolved to manage climate shocks impacts ex-post (sometimes called '*coping strategies*') and (ii) strategies which evolved to reduce overall vulnerability to climate shocks (sometimes called *'true adaptive strategies*'). We do not differentiate between both types as some strategies which start as ex-post interventions in exceptional years can become 'truly' adaptation strategies for households or whole communities over time (Morton, 2007). It could be argued that some 'adaptive strategies' mentioned here are related to other non-climatic stresses such as population growth or land use change, as we mention in the discussion.

For the Twa, the percent of respondents (n=100) was the main unit of analysis. To analyse the effects of gender in the responses (males=50, females =50), the data were pooled per gender. Then, data were pooled by wealth group (poor, average, wealthy) based on a wealth index created from ten asset indicators (Córdova, 2008; Berman et al., 2014). Assets that varied most across households were weighted greater than those more commonly found (see Appendix A2). Paired T-test was used to assess significant differences between genders or wealth groups. For the Tembo, data were pooled per FGDs (n=10) and thematic analysis (Braun & Clarke, 2006) was used to identify the main themes of the discussions. Given the different nature of the data, results from Twa (questionnaires) and Tembo (FGDs) should be compared with caution, as e.g. FGDs might not be statistically representative samples of the whole population in a region (Cruz-Garcia et al., 2019).

2.3 Meteorological data

Monthly rainfall, minimum (T_{min}) and maximum (T_{max}) monthly temperature (period 1971–2019) were obtained from the Rwanda Meteorology Agency for Kamembe town meteorological station (located at 1500 m asl, Fig. 1). There were missing values for rainfall and temperature for the period 1994-1997 (extending to 1998 for temperature) and 2000-2001, related to the political situation in Rwanda at that time. Although Lwiro meteorological station is located closer to the Twa villages found in the eastern part of Mt Kahuzi, it has missing values for longer periods. Akonkwa et al. (2015) compared rainfall and temperature data from both stations (period 1971-2013) and found similar patterns. Annual values were used to compute the 10-year running mean for rainfall. Seasonal averages refer to the dry season (June-August) and the rainy season (September-May). Temporal trends for rainfall and temperature were tested using a linear regression. Increased urbanization and urban heat island effect is unlikely to be a driver of increased temperatures around Kamembe town meteorological station given limited asphalting and use of cement for construction.

3. Results and discussion

3.1 Perceptions of climatic changes and meteorological data

Most Twa (>60% respondents) reported a reduction in the amount of rainfall and the length of the rainy season (late onset) while a few respondents also mentioned an increase in dry spells during the rainy season or increased showers during dry season (Fig. 2). Most Twa also reported a reduction in fog (number of days with fog and quantity of fog), frost, strong winds and hail storms (Fig. 2). About 50% of the Twa also reported warmer temperatures during the dry season (Fig. 2). There were no significant differences between male and female respondents (paired T-test, $p > 0.05$), see Fig. 2. This lack of differences between Twa male and female perceptions differs from other studies: e.g. from farmers in Mt Elgon in Uganda, or the Tsimane' and other peoples in the Amazon (Bomuhangi et al., 2016; Fernández-Llamazares et al., 2017; Funatsu et al., 2019). Most likely the explanation is that contrary to gender-based roles in other societies, both male and female Twa spend long periods of time in the forest (female Twa also go hunting, and male Twa also collect NTFPs). Wealth did not affect Twa responses (see Appendix A2). This is likely to be explained by the limited differences between wealth groups in the Twa, with 'rich' Twa also being extremely poor, e.g. owning a torch or a soap (not e.g. a car or solar panels). We could not explore the effects of education or e.g. access to credit as none of the interviewees mentioned having access to credit, and only two out of 100 had been to a primary school (see Appendix A2).

Overall, there were little differences on the climatic changes reported by Twa and Tembo (although we used different methods, household questionnaires vs FGDs, respectively). Tembo reported the same direction of change as Twa for amount of rainfall, dry spells, showers, temperatures, fog and hail storms, but opposite direction of change for length of the rainy season and wind (Table 2). It is possible that most Tembo mentioned increased length of the rainy season because of a perceived increase in showers during the dry season (Table 2). The percent of respondents who mentioned an increase in dry spells during the rainy season was also greater for Tembo than for the Twa (>70% compared with <25% for the Twa, Table 2). It is likely that more Tembo reported these changes (compared with Twa) because for most Tembo farming is their main livelihood activity, and they have to pay particular attention to these changes due to the effects they have on crop yields and pests (dry spells cause crop failure and showers increase pest prevalence). The overall agreement between Twa and Tembo perceptions of climatic changes support the notion that groups having different livelihood strategies but living in the same area report similar changes in climate (e.g. Cuni-Sanchez et al., 2012; 2019a).

Climatic changes reported by Twa (and Tembo) agree with farmers' perceptions in the Bukavu area, who also reported increased temperatures, shorter and less rainfall during the rainy season, dry spells during rainy season, rain showers during dry season, and increased strong winds during rainy season (Bele et al., 2014). Compared with other studies in mountains in the Albertine Rift region, increased temperatures were also reported by farmers in the Rwenzori Mts, while a late (or unpredictable) onset of the rainy season was also reported in Kibale NP and Volcanos NP (Few et al., 2017; Hartter et al., 2012; Zizinga et al., 2017). Overall reduced rainfall was reported from Kibale NP, like in our study, but increased rainfall, mostly due to fewer but heavier precipitation events, was reported in the Rwenzori Mts (Hartter et al., 2012; Zizinga et al., 2017). Although there is limited certainty about future rainfall projections in tropical Africa, projected changes in rainfall by late century (2071–2100, RCP4.5) indicate divergent patterns in different mountains in the region: e.g. decreased amount of rainfall in eastern DR Congo, Volcanos NP and the Rwenzori Mts, but increased amount in Kibale NP (Platts et al., 2015). Divergent patterns in rainfall seasonality have also been predicted for the different mountains (Platts et al., 2015).

The study in Bukavu did not report changes in fog or hail storms (Bele et al., 2014), which are likely to be restricted to higher altitudes than those they studied. In terms of the reported changes in fog (shared by both ethnic groups), this study adds to the few case-studies available for African mountains, which also reported a reduction in both quantity and number of fog days (Cuni-Sanchez et al., 2019a; Hamilton & Bensted-Smith, 1989). With regard to hailstorms, eastern DR Congo is recognized for frequent hailstorms, compared with the rest of Africa (Frisby & Sansom, 1967). It is known that with increased temperatures, increased amounts of moisture in the air can lead to heavier precipitation during an individual storm, including hail. Contrary to our findings, communities in Mt Elgon in Uganda (which is not in the Albertine Rift region) reported increased hailstorm frequency (Bomuhangi et al., 2016). A recent study showed an increase in extent and intensity of thunderstorms observed over the Congo Basin (Raghavendra et al., 2018), but, to our knowledge, no studies have focused on quantifying changes in hail storms in the region.

No trend in annual rainfall was observed at Kamembe meteorological station, but a significant decrease for the 10-year running mean was found (Fig. 3). A similar significant trend was observed for the 10-year running mean of the rainy season (September-May), but no trend was found for the dry season (June-August) (see Appendix A3). A significant trend in T_{max} was observed (Fig. 4), but not for T_{min} or for temperature range (Figure not included). A significant trend in T_{max} for the dry season (June-August) was also observed (see Appendix A3).

Overall, the historical meteorological data available from Kamembe is consistent with the narratives from local peoples with regard to changes in a) rainfall during the rainy season (reduced amount) and b) temperature during the dry season (greater T_{max}). Unfortunately, we were unable to obtain daily values to investigate the narratives from local people in further detail (e.g. late onset rainy season); and there is no fog data available for this station. Several authors have shown the agreement between local perceptions on climatic changes and meteorological data (see Savo et al., 2016 for a review). Mountain regions characterized by high topographic heterogeneity, modelling and remote sensing data may fail to capture spatial climatic heterogeneity on the ground (Platts et al., 2013; 2015). In such mountain regions where meteorological data is scarce, local perceptions of climate variability can help increase our knowledge on the climatic changes observed (e.g. Savo et al., 2016; Cuni-Sanchez et al., 2019a).

3.2 Perceived impacts of the climatic changes

Most Twa (>70% respondents) reported a decrease in floods, stream flow, landslides and soil erosion (Fig. 2). In terms of changes in the biological domain, most Twa (>70% respondents) mentioned a reduction in the abundance of caterpillars, honey, mushroom and crabs, a reduction in fruit yields of wild fruiting plants and that some tree and wild animal species had become rare (Fig. 5). They also reported a decrease in yields of several crops (Fig. 5). There were no differences between male and female respondents (Fig. 5) except for two observations: only a few men reported a decrease in Marihuana yields and only a few females reported a decrease in wild yam abundance (activities restricted to males and females, respectively). As abovementioned, the lack of differences between Twa male and female perceptions differs from other studies (Bomuhangi et al., 2016; Fernández-Llamazares et al., 2017; Funatsu et al., 2019) and is likely to be related to limited gender-based roles in Twa society. Wealth did not affect Twa responses regarding the impacts of climatic changes (see Appendix A2).

Remarkably, contrary to the Twa, most Tembo mentioned an increase decrease in floods, stream flow, landslides and soil erosion, which is completely opposite to what most Twa reported (Fig. 2, Table 1). These divergent perceptions can be explained by the fact that Tembo own land for farming (which may be damaged by floods, landslides and soil erosion), and that they live in larger villages. About 50% of the Twa respondents live in the same area where Tembo live (western part of Mt Kahuzi), so local topography such as slope or aspect is unlikely to explain these differences in direction of change. While Twa respondents did not have an explanation for the reported changes in the physical environment, most Tembo mentioned that these changes were related to deforestation in the area, with comments such as e.g. '*Now there is less forest on top of hills, that is why there is more soil erosion and landslides*'. It is possible that Tembo perceptions reflect increased storm intensity -something we could not confirm with meteorological data available.

Increased floods was reported by farmers in Bukavu area (Bele et al., 2014), while increased soil erosion associated with heavy rains was also reported by local famers living around Volcanos NP, and increased floods and landslides were reported in Mt Elgon NP (Bomuhangi et al., 2016; Few et al., 2017). In Mt Elgon NP in Uganda, an increase in landslides over time has been attributed to changing landuse patterns, including increased numbers of settlements and farms on steep slopes, as well as prolonged rainfall of low intensities, which has high chances of infiltrating and soaking the soil thus increasing the chances of landslides over steep slopes (Kitutu et al., 2011; Masaba et al., 2017). It is possible that increased urbanization among the Tembo (which in some cases pushes people to construct houses on steep slopes), might have also affected perceptions with regard to landslides.

In terms of changes in the biological domain, Tembo responses (from FGDs) agreed with Twa responses (from questionnaires) (Table 2). The only difference was the tree species discussed: Tembo mentioning cultivated tree species instead of wild ones (Table 2). Compared with other studies in the region, reduced crop yields and increased disease prevalence were also reported as consequences of changing rainfall patterns in Volcanos NP in Rwanda (Few et al., 2017) and in Kibale NP and the Rwenzori Mts in Uganda (Salerno et al., 2019). The observed decline in abundance of several NTFPs (caterpillar, honey, mushroom and crabs), and the reported relationship with climatic changes, is in disagreement with Bele et al. (2014), who, focusing on farmers in the nearby Bukavu area, reported these products as being less affected by climatic changes than agriculture. Farmers who mainly only harvest NTFPs when crops fail are likely to have lower awareness NTFPs change over time –given their intermittent interaction with these. In Cameroon, local residents (some of which were hunter-gatherers) also reported a decrease in NTFPs availability, related to deforestation and increased demand (Few et al., 2017). Several studies have highlighted that forests can be used as source of food when crops fail (e.g. Cuni-Sanchez et al., 2012; Balama et al., 2017). However, few have investigated changes in NTFPs abundance over time, related to climatic changes or other factors. For instance, two recent publications have highlighted changes in edible caterpillar abundance in Cameroon, related to logging and perceptions of climatic changes (Muvatsi et al., 2018; Ngute et al., 2019). More research on the impacts of climatic changes on NTFPs is needed.

For the Twa the perceived causes of the observed reduction in NTFPs' abundance were climatic, but that for wildlife it was overhunting (Table 3). Ancestors' will – with comments such as '*the ancestors have left with their treasures, as we are no longer taking care of the forest*' - were mentioned by a few participants. Note that Twa have a view of nature where humans (Twa) have to take care of Nature (the forest) (see Cuni-Sanchez et al., 2019b). The perceived cause of all the observed changes in the biological domain for the Tembo was deforestation. Tembo respondents explained that: e.g. '*before there were more patches of forest between farmers' fields, the area was more humid and cooler and avocado trees produced more fruits*' and '*before there were more forest patches with insects, which would eat the pests of cassava, now there are fewer forests and insects, and cassava is more sick*'. Perceived changes in crop yields could also be related to nutrient depletion in the soils, related to shorter fallow rotations. Preliminary investigations show that fallow rotations have been significantly reduced in Tembo farms (ongoing research).

3.3. Twa and Tembo adaptive strategies or lack of

Twa did not report using any adaptive strategy to the observed changes in climate and their impacts, although they did recognize that climatic changes and impacts in the biophysical domain (as shown above). They said that the greatest change for them was the fact that they had been evicted from the forest, forcing them to change their livelihood strategy (hunter-gathering), but they had been given no land to e.g. start farming or rearing animals. A study focused on Twa living near Bwindi Impenetrable Forest NP in Uganda showed that child mortality (under five years of age) was 59% for households without land while only 18% for households with land (Balenger et al., 2005), which highlights the importance of access to farming land for household nutrition, health and well-being. Most of our Twa study participants cultivate < 0.01 ha of land- if they have any (see Appendix A). As highlighted in Indonesian Papua, for some indigenous peoples, there are more pressing issues than climate change impacts (Boissiere et al., 2013). Climate change will likely exacerbate Twa current food insecurity because the landless Twa have fewer opportunities (e.g. no land to grow improved seed varieties). This is another example of how policies made by those living outside of the mountains can reduce climate adaptation options (Yeh et al, 2014; Klein et al, 2019).

Contrary to the Twa, the Tembo have used a range of strategies to adapt to the observed changes in climate and their impacts, mostly related to growing new crops or crop varieties, cultivating larger farms (to compensate for lower yields), rearing animals, or complementing farming with other off-farm activities, such as mining, timber harvesting or charcoal production (Table 4). These strategies -including the diversification of livelihoods- are often mentioned by farmers elsewhere in Africa (e.g. Cuni-Sanchez et al., 2012; Zizinga et al., 2017). Changing planting dates, soil conservation practices, irrigation and agroforestry, mentioned by farmers e.g. in the Rwenzori Mts (Zizinga et al., 2017), and were not mentioned by the Tembo. Most likely these are limited in our study area due to the unpredictability of the onset of the rainy season, steep slopes near streams which make irrigation difficult, lack of training and funds to start soil conservation and agroforestry practices (participants' comments during FGDs).

While most of the strategies mentioned by the Tembo have been initiated by NGOs, two strategies were initiated by the farmers themselves: i) the cultivation of a fast-growing variety of maize, and ii) the cultivation of pineapples. In both cases, the initiatives were driven by a combination of climatic and economic drivers: maize is high in demand in Bitale village due to the presence of miners from other ethnic groups who prefer this to cassava as a staple (contrary to Twa and Tembo people); moreover, farmers believe that pineapples are better adapted to drought than other crops and they can sell them to MONUSCO staff (MONUSCO is the French acronym of The United Nations Organization Stabilization Mission in DR Congo). Remarkably, using forest products as a safety-net was not mentioned in any Tembo FGDs, which is different from a previous study on farmers in Bukavu area (Bele et al., 2014), and in Volcanos NP in Rwanda (Few et al., 2017).

Our study approach has some limitations. First, we compared questionnaire data from Twa with FGDs data from Tembo elders only (see Table 1 and 2). Although FGDs can help have a general understanding of a topic in a given area, a larger number of questionnaires can provide more detailed insights, particularly if they cover a wider range of household heads' age classes. We recommend further work using questionnaires for the Tembo, which could help investigate the effects of gender and wealth within this ethnic group. Second, we only used data from one meteorological station. Combining data from different stations is preferred, especially if some are located within the villages surveyed. Increased use of automatic weather stations or gauges could help reduce this challenge.

4. Implications of the results and conclusions

Our findings have four major implications. First, climatic changes have already been perceived by local communities in the mountains of eastern DR Congo, which are supported by meteorological data available from a nearby station (for rainfall and temperature), and which agree with changes reported by farmers in other mountains of the Albertine Rift. Notably, local communities highlighted reduced fog, which plays an important role in the ecology of mountain forests in the region. Despite its importance, fog is not recorded by most meteorological stations (but see Cuni-Sanchez et al., 2019a; Los et al., 2019 for Kenya). Local perceptions of climate variability can help increase our knowledge on the climatic changes observed, and their impacts (e.g. Savo et al., 2016; Cuni-Sanchez et al., 2019a). Several authors have called for greater integration of indigenous knowledge and experience in IPCC assessment reports (e.g. Ford et al., 2016). We provide evidence of how indigenous peoples can provide insights for variables beyond rainfall and temperature (e.g. fog, hailstorms).

Second, we report that Twa are not using any adaptation strategy, which is not related to a lack of perception of changes in climate or in the biological domain. The key reason is that their livelihood base (hunter-gathering inside the park) has become illegal; and issues of power, land tenure, and access are much more tangible. These issues will likely exacerbate Twa's vulnerability to climatic changes, including food insecurity, in the nearby future. Twa hunter-gatherers are found around several parks in the Albertine Rift, including e.g. Volcanos NP in Rwanda, studied by Few et al. (2017) (see Fig. 1). But these authors did not investigate the differences in perceptions and adaptation -or lack of- between farmers and the Twa. A study focused on vulnerability of health to climate change in Twa villages around Bwindi Impenetrable Forest NP in Uganda also highlighted that their vulnerability is largely driven by socioeconomic conditions which create high sensitivity to climate change and constrain adaptive capacity (Berrang-Ford et al., 2012). Preliminary data from Kibira NP in Burundi also indicates that the Twa are facing a similar situation: no adaptation to climatic changes because limited livelihood options following eviction. To help Twa adapt to climatic changes, we recommend the use of "science with society" (SWS) participative (or transdisciplinary) approach (Steger et al., 2021), an iterative process that brings together actors (including local communities) to engage in knowledge co-production: in this case, to identify the best pathway towards adaptation. Notably, given that Twa are a marginalized remote community, the longer-term actions towards increasing desirable forms of resilience need to take account short-term realities and needs, including food security (Maru et al., 2014).

Third, contrary to the Twa, Tembo farmers already use some adaptive strategies. Although the effectiveness of the strategies reported here should be assessed, this study provides new ideas which could be tested in other mountain areas in the region (e.g. pineapple cultivation). The off-farm activities mentioned most often (mining, timber harvesting, charcoal production) can have severe impacts on the natural environment (e.g. pollution related to small-scale gold mining) that can further compound the wider impacts of climate change. More support (such as training and access to micro-finance to start animal rearing) could help reduce the use of these unsustainable off-farm activities (comments' made by Tembo during FGDs). Our data on adaptation strategies used by Tembo contributes to filling in the data gap on indigenous adaptation strategies used in Central Africa (Petzold et al., 2020), key information needed if the IPCC is to better integrate indigenous knowledge (e.g. Ford et al., 2016, Petzold et al., 2020).

Fourth, relying more heavily on forests was not mentioned as an adaptive strategy by any group studied (farmers or hunter-gatherers), due to the perceived reduction in forest products. This is different from other studies in Africa, where such products are used as a safety net when crops fail. This finding is particularly important: the lack of this safety net makes these communities even more vulnerable to climatic changes, particularly the Twa, which still heavily rely on forests for their livelihoods (see Appendix A1).

If we are to help the most vulnerable communities in society -e.g. hunter-gatherers- adapt to a changing climate, we need to acknowledge that they have different vulnerability and adaptation potential than nearby farmer communities. For example, if they do not have access to land, they cannot use improved seed varieties as an adaptation option. Instead of focusing on their weaknesses (limited farming skills), interventions should focus on diversifying livelihoods using their existing strengths (e.g. caterpillar rearing, see Cuni-Sanchez et al., 2019b; pottery, Ndayizeye et al., 2020). Overall, this research contributes to the still limited but emerging knowledge base to inform the identification of adaptation needs and opportunities in highly vulnerable indigenous populations in Africa.

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Tables and figures

Fig. 1 Study area and selected Twa villages (1500-1900m asl) and Tembo villages (1400-1900m asl). Kamembe Meteorological station is at 1500 m asl. NP refers to National Park. Twa hunter-gatherers are also found around Kibira NP, Volcanos NP and Bwindi NP.

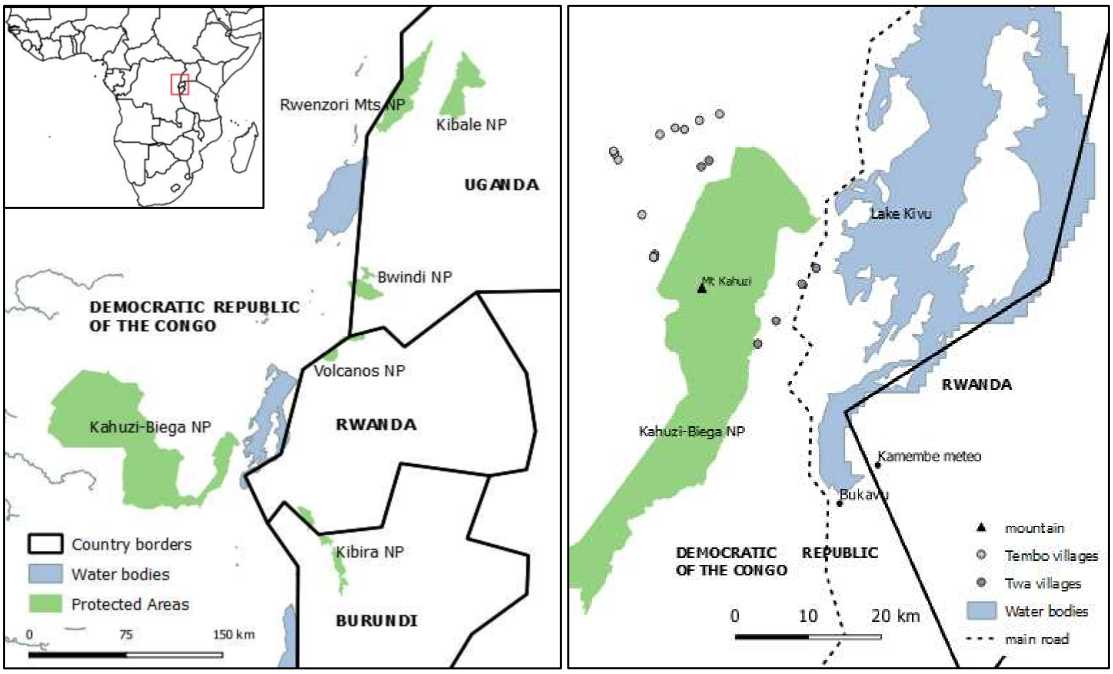

Fig. 2 Perceived changes in climate and physical environment, as reported by male (n=50) and female (n=50) Twa respondents. Responses between male and female respondents are not significantly different (paired T-test p=0.08).

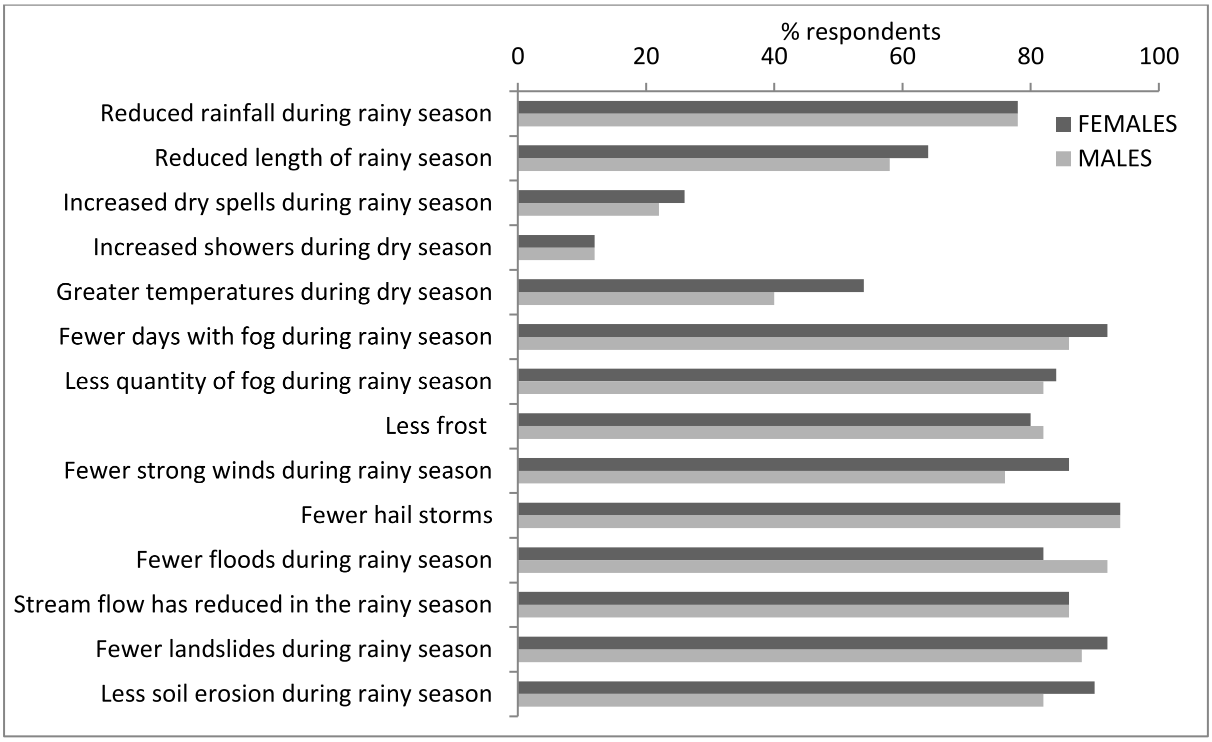

Fig. 3 Annual rainfall for Kamembe Meteorological station, 1500 m asl. Grey line refers to annual rainfall and black line refers to the 10-year running average. Trend for annual rainfall is not significant (line not included) but trend for running mean (thin black line) is significant at $p < .05$ ($R^2 = 0.44$). Missing values (1994-1997 and 2000-2001) relate to the political situation in Rwanda at that time. Note that 2016-2017 were the driest years on record, related to the greatest 'El Nino' event in central Africa (Bennett et al. 2021).

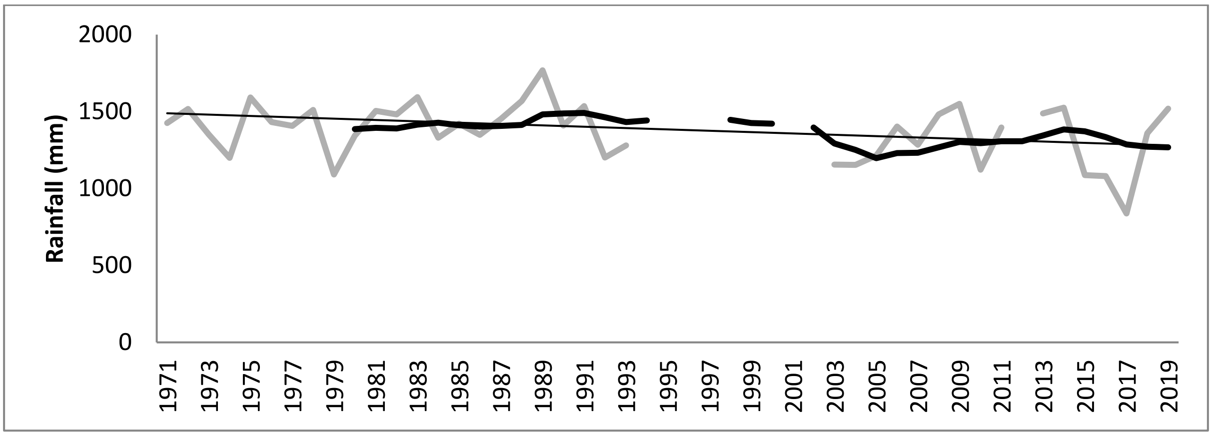

Fig. 4 Annual maximum temperature for Kamembe Meteorological station, 1500 m. Grey line refers to annual maximum temperature. Trend is significant at $p < .05$ ($R^2 = 0.62$). Missing values (1994-1998 and 2000-2001) relate to the political situation in Rwanda at that time.

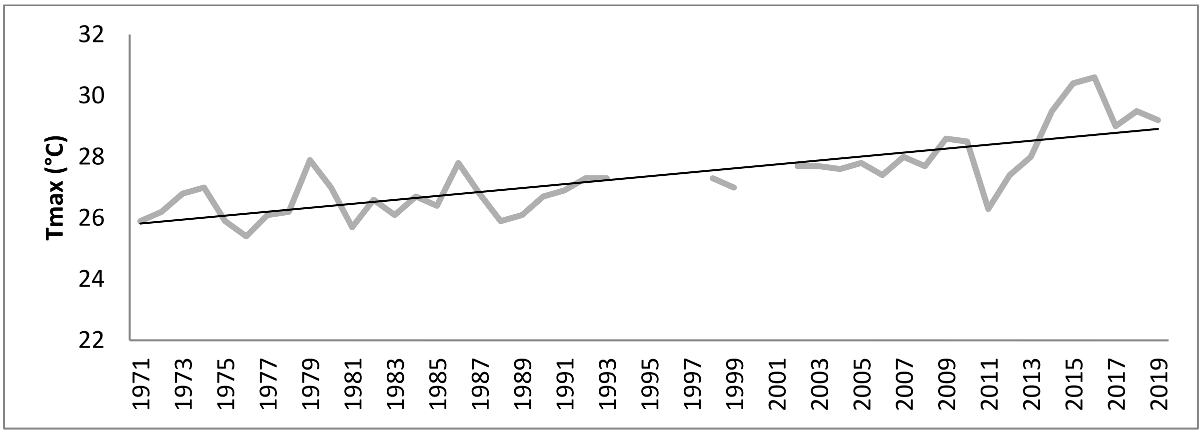

Fig. 5 Perceived changes in non-timber forest products, wild animals and trees, domestic animals and crops, as reported by male (n=50) and female (n=50) Twa respondents. For wild fruits the trees *Myrianthus holstii, Dacryodes klaineana* and the lianas *Landolphia owariensis* were those most commonly mentioned. The wild yam species most frequently harvested is likely to be *Dioscorea praehensilis*. Guinea pig rearing was first introduced to Twa by an NGO in 1995. Responses between male and female respondents are not significantly different (paired T-test p=0.14).

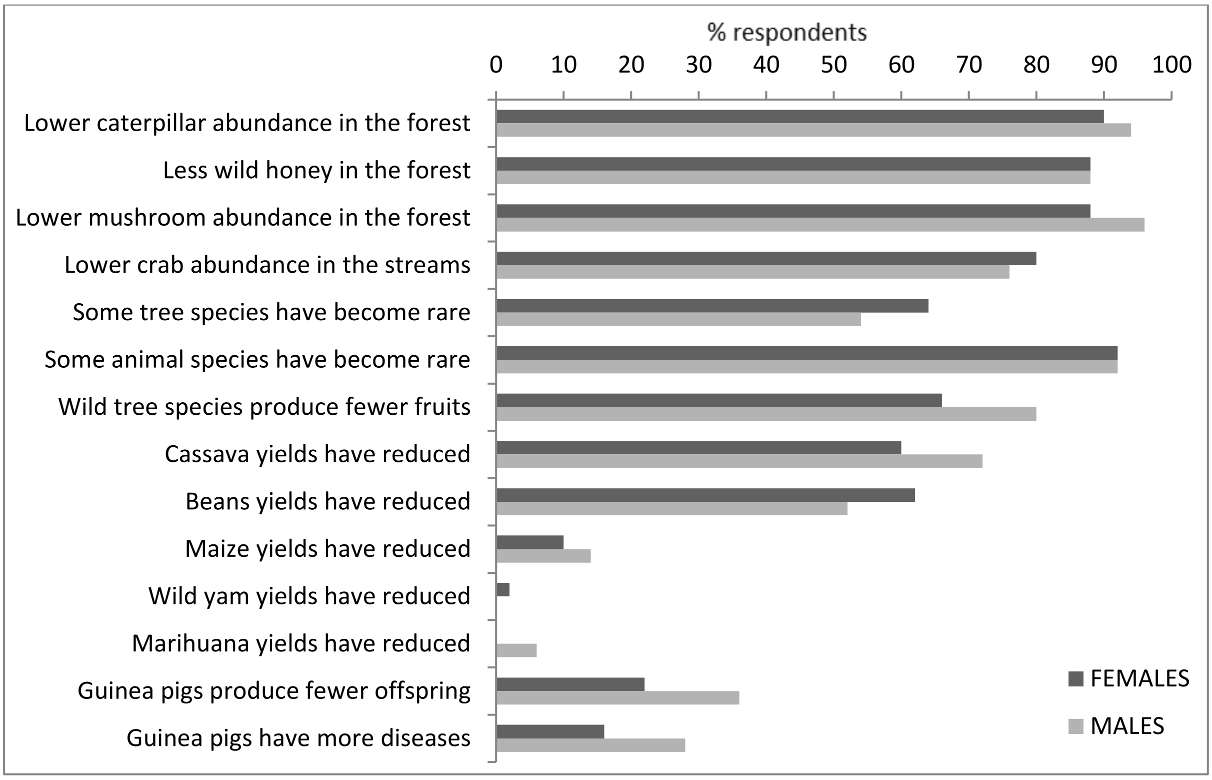

Table 1 Comparison between perceived changes in climatic variables and in the physical domain as reported by Twa hunter-gatherers (n=100 questionnaires) and Tembo farmers (n=10 focus-group discussions). * denotes opposite direction of change.

	Twa hunter-gatherers	**Tembo farmers**	
Rainfall during rainy season	↓ (78%)	↓ (90%)	
Length of rainy season	↓ (61%)	↑ (60%)	*
Dry spells during rainy season	↑ (21%)	↑ (70%)	
Showers during dry season	↑ (12%)	↑ (80%)	
Temperatures during dry season	↑ (47%)	↑ (90%)	
Days with fog during rainy season	↓ (89%)	↓ (70%)	
Quantity of fog during rainy season	↓ (83%)	↓ (80%)	
Frost	↓ (81%)	No change	*
Strong winds during rainy season	↓ (81%)	↑ (70%)	*
Hail storms	↓ (94%)	↓ (90%)	
Floods during rainy season	↓ (87%)	↑ (70%)	*
Stream flow during rainy season	↓ (86%)	↑ (90%)	*
Landslides	↓ (90%)	↑ (60%)	*
Soil erosion during rainy season	↓ (86%)	↑ (80%)	*

Table 2 Comparison between perceived changes in the biological domain as reported by Twa hunter-gatherers (n=100 questionnaires) and Tembo farmers (n=10 focus-group discussions). * for the Twa fruiting trees are trees found in the wild (e.g. *Myrianthus holstii, Dacryodes klaineana*) but for the Tembo fruiting trees are cultivated species (e.g. mango, avocado, banana).

	Twa hunter-gatherers (%)	**Tembo farmers (%)**
Lower caterpillar abundance in the forest	92%	60%
Less wild honey in the forest	88%	50%
Lower mushroom abundance in the forest	92%	80%
Lower crab abundance in the streams	78%	
Some tree species have become rare	59%	100%
Some animal species have become rare	92%	100%
Some tree species produce fewer fruits*	73%	90%
Cassava yields have reduced	66%	60%
Beans yields have reduced	57%	40%
Maize yields have reduced	12%	10%
Groundnut yields have reduced		70%
Goats produce fewer offspring		90%
Chicken have more diseases		80%

Table 3 Perceived causes of the observed changes in the biological domain as reported by Twa respondents (n=100).

	Caterpillars	**Wild honey**	**Mushrooms**	**Crabs**	**Wild fruits**	**Wild animals**	**Crop yields**
Reduced rainfall	21%	10%	22%	6%	11%		3%
Increased temperatures	3%	2%	8%	2%	11%	1%	1%
Increased wind	1%				1%		
More hail storms					1%		
Decreased stream flow				12%			
Deforestation/habitat destruction	18%	2%	2%			7%	
Overhunting/overharvesting				8%		72%	
Decreased soil fertility							13%
Increased pests and diseases							60%
God's will	2%	2%			2%	2%	
Ancestors' will	10%	10%	10%		2%	12%	

Table 4 Adaptive strategies mentioned by the Tembo farmers (n=10 focus-group discussions or FGDs).* refers to activities promoted by an NGO. Off-farm activities include e.g. being involved in small-scale mining, small-scale timber harvesting or charcoal production.

Adaptation strategy	Tembo farmers
To grow new varieties of cassava resistant to diseases*	100%
To grow new varieties of maize	10%
To grow new varieties of beans (fast-maturing)*	50%
To grow new crops (soya)* (pineapple)	50%
To start farming near streams (to irrigate)	20%
To cultivate larger farms to compensate for low yields	60%
To start rearing animals (goat, chicken)*	100%
To complement farming with other off-farm activities	80%