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Full Length Research Paper

The physicochemical properties of surface water resources around fuel filling stations and auto-mobile repair workshops in Bamenda-City, North West Region of Cameroon

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Surface and ground water resources in urban areas are at risk of contamination from many human activities such as oil spills due to improper location of fuel filling stations and auto mobile repair workshops in fast developing cities in third world countries like Cameroon. The study was aimed at determining the physicochemical properties of surface water resources around fuel filling stations and auto-mobile repair workshops in the Bamenda city, North West Region of Cameroon. Ten water samples were collected from surface water sources around two fuel filling stations and three auto-mobile repair workshops. The pH, temperature and electrical conductivity were tested using a Bluelab pH meter, Mercury in glass thermometer, and a WTW LF 91 meter, respectively. The total hardness of water was measured using EDTA titrimetric method; alkalinity was determined using titrimetric method with 0.01 M concentration of HCl as titrant while the concentrations of calcium, magnesium and chlorine were measured using complexometric titration. Results showed that the pH values ranged from 5.62 to 6.24 for auto-mobile repair workshops and 6.15 to 6.70 for fuel filling stations which were below the World Health Organization (WHO) range (6.5 to 8.5) recommended for potable water. Other physicochemical parameters like electrical conductivity, water hardness, temperature and alkalinity were all within WHO recommended range. Ca^{+} and Mg^{2+} concentration was within limits while Cl was above WHO recommended limits. The study concludes that the amount of waste oil generated at fuel filling stations and auto mobile repair workshops is significant to cause negative effects on the environment in the Bamenda city, North West Region of Cameroon.

Key words: Fuel filling stations, auto-mobile repair workshops, physicochemical properties, WHO limits.

INTRODUCTION

One of the adverse environmental impacts of urbanization globally is the changes in the physical, chemical and the biological properties of basic natural resources such as soils, air and water. In the case of water for example, the pollution and contamination of this resource does not only affect its quality or physicochemical properties but equally serves as a threat to public health since humans depend on it for various purposes such as domestic use and agriculture (Nganje et al., 2007). Surface and ground water resources in urban areas are at risk of contamination from many human activities such as oil spills due to haphazard location of fuel filling stations and auto mobile repair workshops along surface water resources especially in developing countries. Spilled oil contains carcinogenic or toxic components such as heavy metals, total petroleum hydrocarbons (TPH) which affects human health both directly and indirectly (Nganje et al., 2007). With the increasing rate of urbanization in developing countries like Cameroon, there has been an increasing number of fuel filling stations and author-mobile repair workshops with high potentials risk of contamination of water resources which is yet to be investigated.

At gas stations, fuel is stored and transferred between tanker trucks, storage tanks, and vehicle tanks. During both storage and transfer, a small fraction of unburned fuel is typically released. If a spill occurs while runoff occurs, the hydrocarbon can be expected to float on top of the water sheet, because gasoline, diesel oil, and lubricants are typically less dense than water. While the fraction may be small, the cumulative release can be substantial because of the large quantities of fuel sold (Hilpert et al., 2015). At auto-mobile repair shops, spilled oil is often used oil. The US Environmental Protection Agency (EPA) (2001), defined used motor oil as “any petroleum-based or synthetic oil that has been used for vehicle lubrication and as a result of normal use, motor oil becomes contaminated with various impurities such as dirt, water, chemicals or metals from vehicle engine”. Once degraded motor oil escapes the engine, it has the potential to pollute waterways in the form of runoff and soil. The US EPA reported that 1 gallon of used motor oil can contaminate 1 million gallons of fresh water. Used oils are therefore considered as one of the most hazardous mainstream categories of environmental pollutants, posing a major threat to the environment and public health.

A common practice in Cameroonian cities is to allocate large tracts of land, sometimes reaching 5 ha or more to groups of small-scale auto-mechanic businesses and designate these as villages where they locate their workshops and repair yards to offer their services to the public (Adelekan and Abegunde, 2011). In most cities, fuel feeling stations are also located near sensitive ecosystems without any proper environmental impact assessment (Adelekan and Abegunde, 2011). Most of these fuel filling stations and auto-mobile repair workshops are located near streams and rivers which the population depend on for domestic and agricultural purposes. The city of Bamenda has witnessed an increase in the number of fuel filling stations and auto-mobile repair impacts of these activities on the surface water sources are yet to be investigated. It is against the backdrop of this knowledge gap that this study is conceived. In this research, the impacts of oil spills from fuel filling stations and auto-mobile repair workshops on the physico-chemical properties of surface water systems in some selected sites in the Bemanda city were investigated. The findings can then be used as a basis for improving the management of fuel filling stations and autho-mobile repair shops as well as guide environmental lanners on the suitable location of these activities in urban areas in Cameroon and other developing countries.

Study area

This study was carried out in Mezam division in the Bamenda highlands (17,300 km^2) in the North West Region of Cameroon. The area is located within latitude 5°40’ and 7° North of the equator and within longitudes 9°45 and 11°10’ East of the Meridian (Law, 2010).

MATERIALS AND METHODS

Sampling criteria and sample collection

Study sites selected for this study were based on their proximity to surface water resources to auto mobile repair workshops and fuel filling stations (Figure 1). Using this criterion, ten surface water sources which were located within a 10 to 20 m distance from the auto-mobile repair workshops and fuel filling stations were selected. Ten water samples were collected from five surface water resources (two fuel filling stations and three auto-mobile repair workshops) in the month of August 2017. Two samples were collected from each surface water system within a 100 m spacing. These samples were collected in 250 ml polythene bottles pre-washed with non-ionic detergents, rinsed with distilled water three times. Before sampling of water, the bottles were rinsed three times with the sampled water.

Sample analysis

Parameters like pH, temperature and electrical conductivity were tested in the field using, a Bluelab pH meter, Mercury in glass thermometer, and a WTW LF 91 meter, respectively. Samples were put in an ice cooler and transported to the chemistry laboratory of the University of Buea, Cameroon for further analysis of other physicochemical parameters.

The total hardness of water was measured using Ethylene Diamine Tetra Acid (EDTA) as titrant with Ammonium Chloride and Ammonium Hydroxide buffer solution (pH-10) and erichrome black T as the indicator. Alkalinity was determined using titrimetric method using standard solution of 0.01 M concentration of HCl and methyl orange used as indicator. Concentrations of Calcium, Magnesium and Chlorine were measured using complexometric

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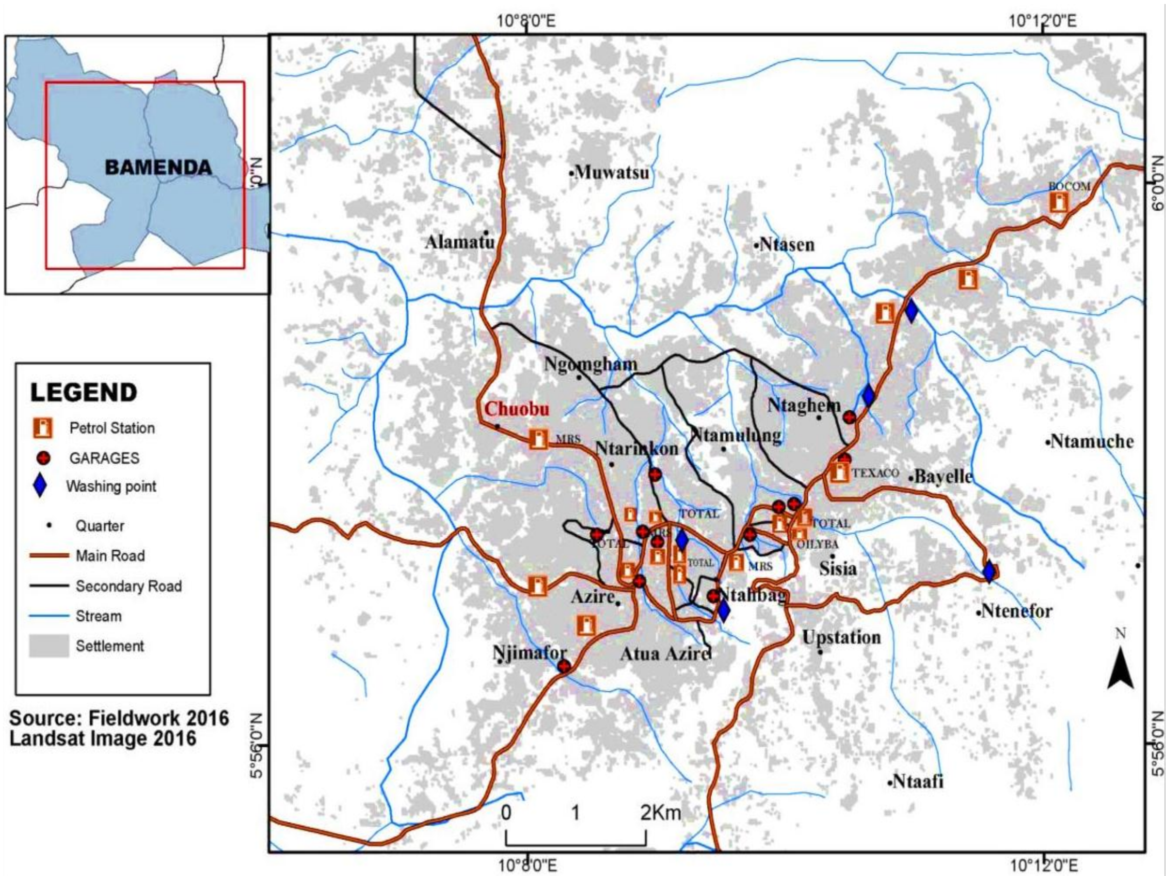

Figure 1. Map of Bamenda– North West Region showing sample points.
Source: Authors

titration. For Calcium concentration, EDTA was used alongside Patton's and Reeder's indicator with Sodium Hydroxide as buffer solution (pH-12). The concentration of Magnesium ion was determined using a standard solution of EDTA and Erichrome Black T as indicator with Ammonium Chloride and Ammonium Hydroxide as buffer solutions (pH 10).

RESULTS AND DISCUSSION

The results obtained from analysis of water samples are presented in Table 1 and statistical analysis presented in Tables 2 and 3 for fuel filling stations and auto-mobile repair workshops, respectively.

Potential hydrogen (pH)

pH is referred to as "potential hydrogen" and is the measure of the acidic or basic state of the water. It is calculated as the logarithm of the reciprocal of the concentration of hydrogen ion ($pH = Log\ 1/H^+$). The results obtained shows that pH values ranged from 5.62 to 6.24 for auto mobile repair workshops, and 6.15 to 6.70 for fuel filling stations (Figure 2). pH values are considered optimum for water and aquatic species in the range of 6.5 and 8.5 (WHO, 2008).

The presence of hydrocarbons and heavy metals from spilled oil may be an indication for the reduced pH level of water. The values of pH lower than 6.5 can cause the corrosion of metal pipes and subsequent release of toxic metals such as lead, cadmium, and zinc (Buridi and Gedala, 2014). The pH values thus indicated that the water within the selected study areas is not suitable for domestic use or consumption. In a similar study conducted by Vincent-Akpu et al. (2015) in Delta State Nigeria, it was noted that the pH values of surface water resources near spilled sites were within permissible limits which is not in line with the findings of the study. The differences in pH values of surface water resources in the spilled sites may have resulted from the differences in the quantity of spilled oil discharged in the nearby surface water resources.

Conductivity

Conductivity is the measure of the ionic concentration in the water. In other words, it is the ability of water to

Table 1. Physical and chemical parameters of water.

Sample	pH	Temperature (°C)	Conductivity (µS/cm)	Hardness (mg/L)	Alkalinity (mg/L)	$[Ca^{2+}]$ (mg/L)	$[Mg^{2+}]$ (mg/L)	$[Cl^{-}]$ (mg/L)
PS1A	6.70	28.9	167	39.11	150.33	11.1	1.05	15.61
PS1B	6.69	27.3	140	19.92	149.00	11.1	3.10	14.81
PS2A	6.15	28.8	101	10.01	190.00	10.8	3.12	22.18
PS2B	6.24	29.1	110	29.41	188.33	11.8	3.11	22.13
GR1A	5.62	30.8	120	28.01	133.67	5.0	0.04	3.10
GR1B	5.91	29.9	120	26.56	130.00	6.7	0.05	4.19
GR2A	6.14	28.5	107	7.49	141.33	4.8	1.81	17.80
GR2B	6.24	28.2	101	9.00	142.67	8.3	1.70	17.00
GR3A	6.11	29.0	118	18.80	160.33	3.5	0.11	4.17
GR3B	6.08	30.1	120	19.10	171.67	3.4	0.12	4.11

PS = Fuel filling station, GR = auto-mobile repair workshops.
Source: Authors

Table 2. Descriptive statistics for results of physicochemical parameters for Water samples collected around fuel filling stations.

Parameter	pH	Temp (°C)	EC (µS/cm)	Hardness (mg/l)	Alkalinity (mg/l)	$[Ca^{2+}]$ (mg/l)	$[Mg^{2+}]$ (mg/l)	$[Cl^{-}]$ (mg/l)
Max	6.70	29.1	167	39.11	190.00	11.8	3.12	22.18
Min	6.15	27.3	101	10.01	149.00	10.8	1.06	14.81
Mean	6.45	28.5	129.5	24.61	169.42	11.2	2.60	18.68
SD	0.29	0.80	30.05	12.50	22.82	042	1.03	4.02
WHO range	6.5 - 8.8	27.3-30	400-600	75	20-200	100	50	5

Source: Authors

Table 3. Descriptive statistics for results of physicochemical parameters for water samples collected around auto-mobile repair workshops.

Parameter	pH	Temp (°C)	EC (µS/cm)	Hardness (mg/l)	Alkalinity (mg/l)	$[Ca^{2+}]$ (mg/l)	$[Mg^{2+}]$ (mg/l)	$[Cl^{-}]$ (mg/l)
Max	6.24	30.80	120	28.01	171.67	8.30	0.04	17.8
Min	5.62	28.23	101	7.49	130.00	3.40	1.81	3.1
Mean	6.02	29.43	114.3	18.16	146.61	5.28	0.64	8.39
SD	0.22	1.01	8.26	8.56	16.14	1.91	0.87	6.99
WHO range	6.5-8.5	27.3-30	400-600	75	20-200	100	50	5

Source: Authors

conduct electrical current due to its ionic content.

Increasing the salt content in water increases its conductivity (Oyem and Oyem, 2013). The mean electrical conductivity recorded for fuel filling stations was 129.5±15.03 while that for auto-mobile repair workshops stood at 114.3±3.37 (Figure 3). The electrical conductivity values of samples were generally lower than WHO range (400-600 µS/cm).

The low values recorded within the study area may be attributed to the increased intensity of rainfall thus rainwater runoffs causing reduction of salts in water. However, an excessive increase of the surface water electrical conductivity will generate modifications of the bacterial ecosystem and also influence the survival of aquatic fauna and flora (Demakoye et al., 2017). The findings of this study are similar to the findings of Odipe et al. (2020) on the effects of filling stations and auto mobile repair workshops on groundwater quality in Ilorin metropolis where authors noted that the conductivity values were within permissible limits in their study area.

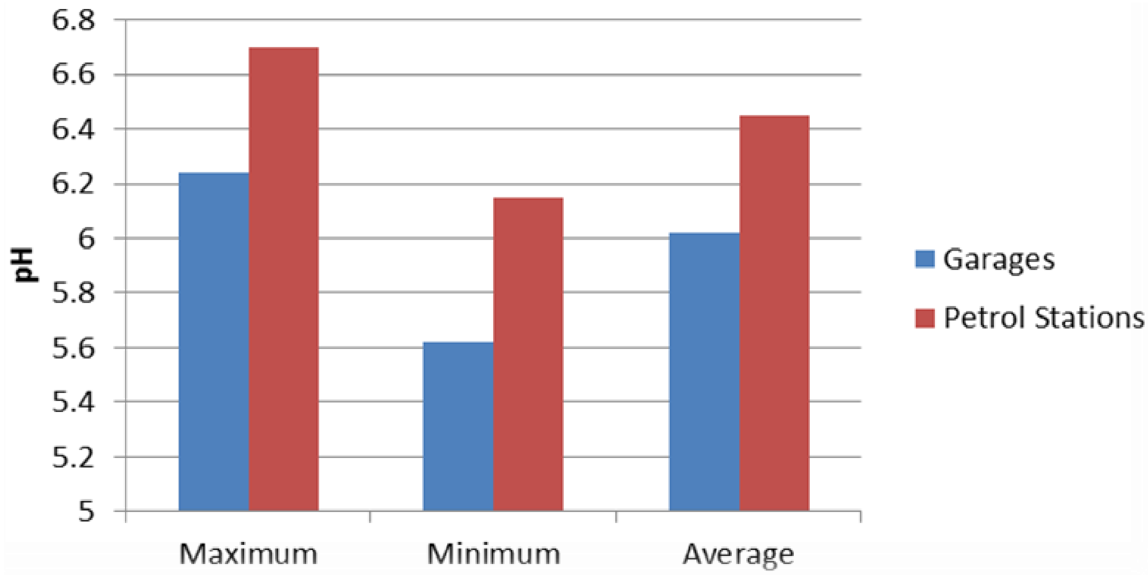

Figure 2. pH values for Fuel filling stations and auto-mobile repair workshops.
Source: Authors

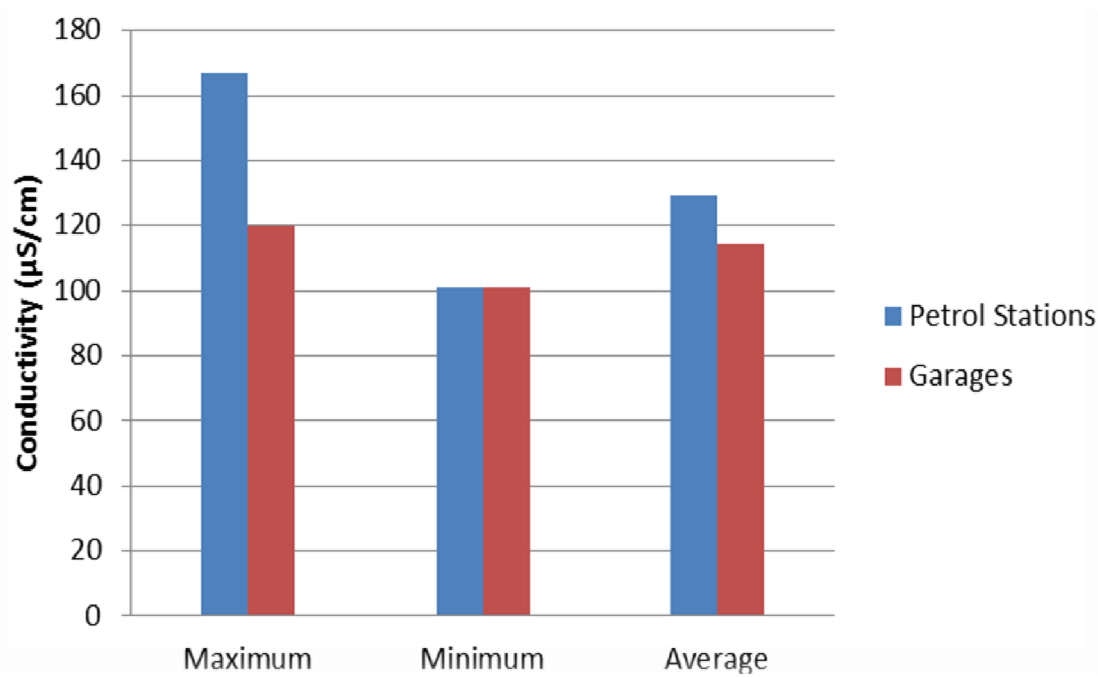

Figure 3. Electrical conductivity values for fuel filling stations and auto-mobile repair garages.
Source: Authors

Temperature

The mean value of temperature recorded for fuel filling stations was 28.5°C±0.40, and that of auto-mobile repair workshops stood at 29.43°C±0.41 (Figure 4).

However, acceptable temperature values range from 27.3 to 30.0°C for portable water (WHO, 2008). This indicates that temperature values were all within the acceptable limit. The high temperature values recorded may be attributed to high atmospheric temperature within the study area. It should be noted that temperature of water controls the rate of all biological process and thus

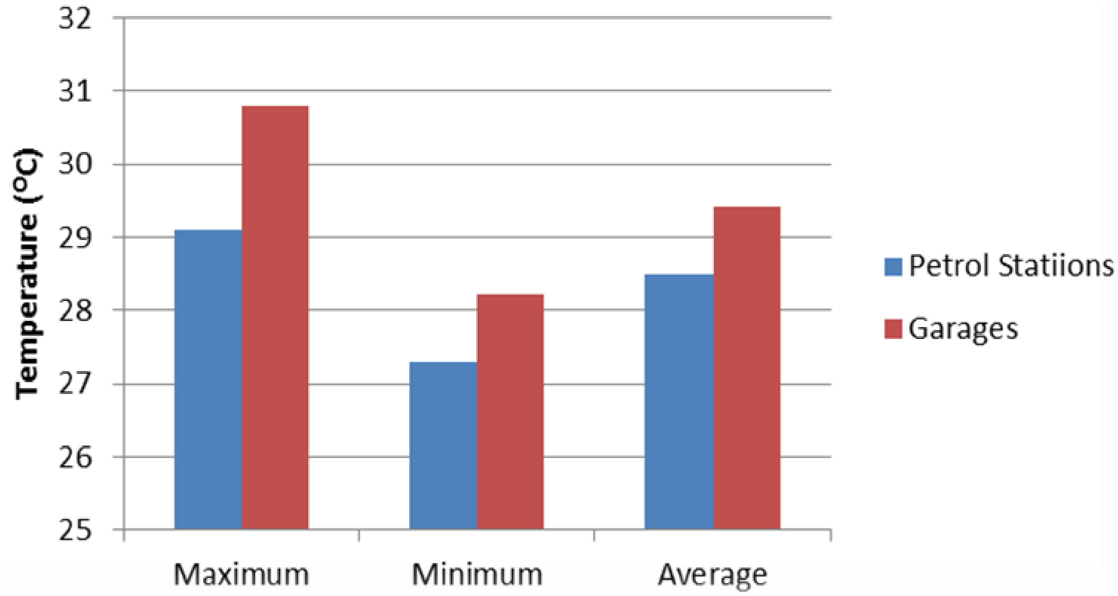

Figure 4. Temperature values for fuel filling stations and auto-mobile repair workshops.
Source: Authors

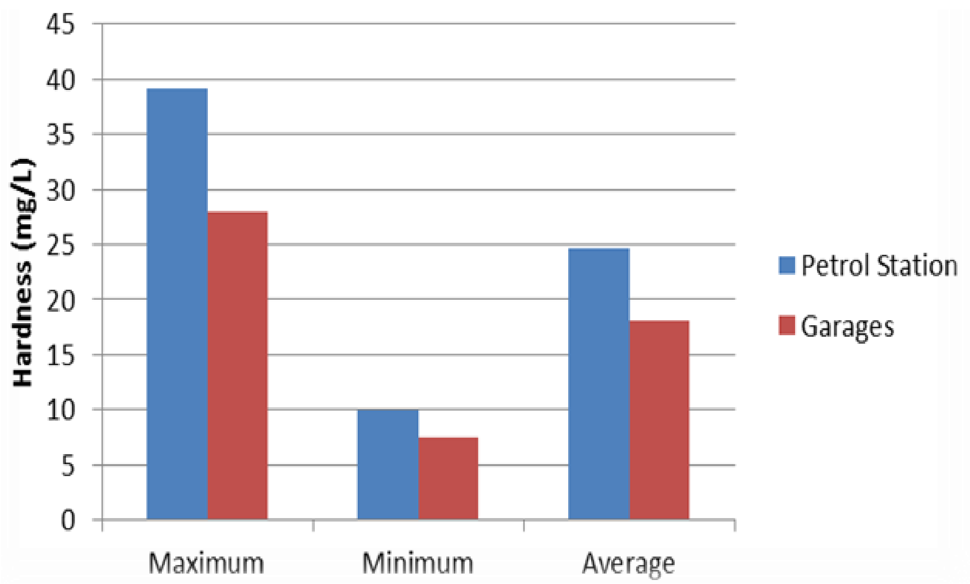

Figure 5. Hardness of Water for fuel filling station and auto-mobile repair workshops.
Source: Authors

affect aquatic systems.

Hardness

The mean value for water hardness was 24.62 mg/L ±12.50 for fuel filling station samples and 18.16 mg/L ± 8.56 for auto-mobile repair workshops (Figure 5).

Hardness of water is a function of the concentrations of magnesium and calcium ions present in the samples as well as other ions like sulphate, chloride and hydrocarbonate ions. The presence of very high concentrations of anions in water indicates the water may either be permanently or temporally hard. However, concentrations in the samples collected did not exceed the maximum allowable concentration of 75 mg/L as recommended by the WHO. The results of the present study are similar to the findings of Vincent-Akpu et al.

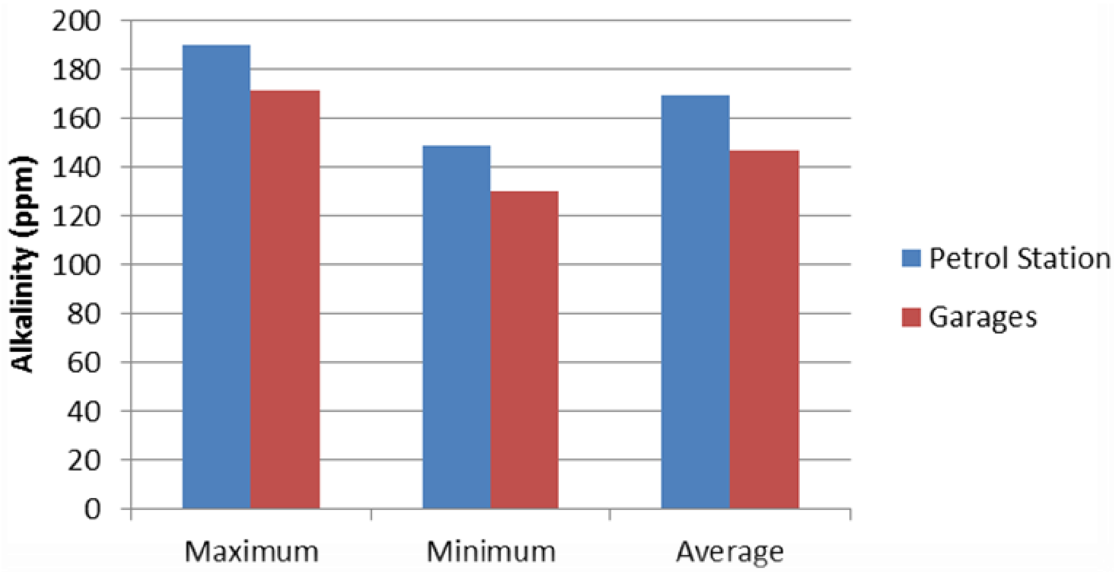

Figure 6. Alkalinity of water samples for fuel filling stations and auto-mobile repair workshops.
Source: Authors

(2015) who noted that hardness of surface water near fuel filling stations in Delta State Nigeria were within permissible limits.

Alkalinity

Alkalinity is water acid-neutralizing capacity and is influenced by the presence of carbonate, hydroxide and bicarbonate ions in water. Alkalinity acts as a stabilizer for water (Patil et al., 2012). Alkalinity values concentration recorded mean values of 169.42 ppm ± 11.41 for fuel filling stations and 146.61 ppm ± 6.95 for auto-mobile repair workshops (Figure 6).

High values of alkalinity will cause a bitter taste of water and adversely affects the human digestive system. It will also lead to scale formation in water due to conjunction of bicarbonate and calcium. The extremely low alkalinity of water may be the reason for the low pH values of water. It should be noted that, alkalinity values are however lower for auto-mobile repair workshops compared to fuel filling stations in this study.

Ionic concentration

Concentration of Ca^{+} had a mean value of 11.64 mg/L ± 0.04 and 5.28± 1.91 values for fuel filling stations and auto-mobile repair workshops, respectively. With a MAC of 100 mg/L, the results indicate that these values were within limits in both sites. Mg^{2+} values were recorded at 2.06± 1.03 mg/l and 06.4± 0.87 mg/l while Cl was recorded at 18.68 ± 4.02 mg/l and 8.39 ± 6.99 for fuel filling stations and auto-mobile repair workshops, respectively. With a MAC value of 50 mg/l for Mg^{2+}, the present results show that Mg^{2+} were within permissible limits for both sides. However, Cl concentration was out of MAC in both sides since the mean values for these sites were above 5 mg/l (Table 4).

High concentration values of chloride may render water unsuitable for consumption and will affect the aesthetic properties of water. It may equally cause body irritation in humans, stomach discomfort and increase the corrosiveness of water (Adefemi and Awokunmi, 2010). The concentration of chlorine is the study area requires attention as the values are above WHO allowable limits (5 mg/l).

Conclusion

The findings of this study noted that temperature, alkalinity, conductivity and hardness were within the WHO acceptable ranges for surface water sources around fuel filling stations and auto-mobile repair workshops. pH values were however lower than expected thus causing the alteration of other parameters like conductivity of surface water resources in both sites. The pH of water affects other parameters in water thus “out-of-limit” values of these parameters indicate that the water is not suitable for domestic use. Ca^{+} and Mg^{2+} concentration was within limits while Cl was above WHO recommended limits. It was concluded that the amount of waste oil generated at fuel filling stations and auto mobile repair workshops is significant to cause negative effects on the environment. This study also suggests proper waste

Table 4. Descriptive Analysis for Ionic for concentration (Max, Min, Mean, SD and WHO standards).

Area of sampling	Statistical parameter	[Ca^{2+}] (mg/l)	[Mg^{2+}] (mg/l)	[Cl^{-}] (mg/l)
Fuel filling stations	Max	11.8	3.12	22.18
	Min	10.8	1.06	14.81
	Mean	11.2	2.60	18.68
	SD	0.42	1.03	4.02
Auto-mobile repair workshops	Max	8.30	0.04	17.8
	Min	3.40	1.81	3.1
	Mean	5.28	0.64	8.39
	SD	1.91	0.87	6.99
WHO standards		100	50	5

Source: Authors

management of used oil and the relocation of these facilities from environmentally sensitive areas such as surface water systems to prevent the harmful effects of spilled oil on environment and human health.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Status of the cheetah (*Acinonyx jubatus*) in Ethiopia: A review

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Cheetah (Acinonyx jubatus), one of the wide-ranging scarce carnivores, was widespread some decades back in Ethiopia's wild lands. However, its natural habitats are currently fragmented and shrinking due to anthropogenic factors. Regardless of this general overview, there appears to be a lack of up-to-date information which reveals the past and existing status of cheetahs in Ethiopia since they are relatively understudied compared to other large carnivores. Available published and unpublished reports, manuscripts, and policy-focused documents on the target species were reviewed to explore and document the status of the cheetah in Ethiopia. Based on our review, we concluded that the cheetah population size is extremely small (below 500) while large ranges (65% of projected habitat area) have been identified through field assessments and sightings undertaken since 2015. Besides, the incidence and extent of its threats are increasing and changing over time. It is therefore recommended that there is a need to conduct a countrywide assessment to examine the status of the existing populations and review the developed national action plan based on up-to-date information on the potential threats to the populations of the cheetah.

Key words: Trends, distribution, range, estimates, density, abundance, threats, conservation.

INTRODUCTION

The cheetah (*Acinonyx jubatus,* Schreber, 1775) is one of the most unique and specialized members of the cat family. As predators, cheetahs have evolved the ability to run at speed to capture their prey. Cheetah is the fastest land mammal capable of running with a speed of 100 km per hour for short distance run (Sharp, 1997). Cheetahs, unlike many other African predators, rarely scavenge (Durant et al., 2015). They take a wide variety of prey, depending on habitat and geographic location, but they prefer prey of 15 to 30 kg (Durant, 2000; Durant et al., 2015).

Cheetahs appear to show relatively low habitat selectivity and occur at relatively low densities compared with other carnivores (Durant et al., 2015). Cheetahs are adaptable to various types of habitats ranging from desert through grassland savannahs to thick bush (Myers, 1975; Caro, 1994; Kingdon, 1997; EWCA, 2012). Cheetah males are often social, forming permanent coalitions of two or three animals, usually brothers, which stay together for life while females are solitary or accompanied by dependent young (Caro, 1994; Kingdon, 1997; Durant et al., 2015).

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In areas where prey is migratory, female cheetahs go along with the herds, while male coalitions establish small territories of about 30 km^2 on average (Caro, 1994). However, in areas where prey is non-migratory, both cheetah sexes may have overlapping and very large range (average 1,642 km^2) (Caro, 1994; Marker 2002; Durant et al., 2015).

About five decades back, cheetah was quite widespread in the wild lands of Ethiopia, and it has been an essential element in the ecosystems that range from open savannah grassland to arid/semiarid lowland and thick bushland (Myers, 1973; EWCA, 2012; Kebede and Gebretensae, 2018). However, the present distribution of the species is limited to some wild habitats of the country. The distribution of the species has contracted noticeably from its historical range and the declines have been largely attributed to habitat loss and fragmentation. These have been the over-arching threats to cheetah populations since cheetahs require much larger areas of land than do other carnivore species (Myers, 1975; EWCA, 2012, Kebede and Gebretensae, 2018).

Despite this general truth, it is evident that there is a lack of up-to-date information which reveal the past and present status of cheetahs in Ethiopia since the species is relatively understudied compared to other large carnivores, and thus little is known about the species in question in most of its ranges (Marker, 2002; Durant et al., 2015; Kebede and Gebretensae, 2018). Therefore, this review aims to examine and document the past and current status of the distribution and population size of cheetahs in Ethiopia.

METHODOLOGY

Study area

Ethiopia is located in the Horn of Africa, bordering Eritrea in the North, Djibouti, and Somalia in the East, Kenya in the South, and Sudan and South Sudan in the West. The country stretches from 3°N of the equator to 15°N latitude and from 33°E to 48°E longitude and has an area of 1,127,127 km^2. Ethiopia has great geographic diversity with high and rugged mountains, flat-topped plateaus, deep gorges, incised river valleys, and rolling plains. The climate pattern of Ethiopia is mainly determined by the alternations of the inter-tropical convergence zone and the influence of the Indian Monsoon throughout the year. The differences in altitude, topography, and climate have created the different ecosystem types of Ethiopia, which range from cool afro-alpine to evergreen montane forests, to dry desert scrubland (Hussein, 2021). Ethiopia is consequently endowed with a diverse suite of biological resources and the isolation of its mountain and desert areas has given rise to numerous endemic species of flora and fauna found nowhere else on Earth (IBC, 2005; Biodiversity Indicators Development National Task Force, 2010).

Literature sources

Numerous scholarly sources, published and unpublished reports, and policy and strategy documents related to cheetah are the primary sources for the review. This review used a total of twenty-four articles and books published in the past fifty years. Moreover, five unpublished reports of wildlife assessment submitted since 2015 to the concerned global and national offices were used as crucial sources for the review. The strategy documents that were considered to undertake this review are the regional and national action plans for the conservation of the cheetah and African wild dog (IUCN SSC, 2007; EWCA, 2012). Google Scholar (http://scholar.google.com), Science Gate (https://www.sciencegate.app) and Science Direct (https://www.sciencedirect.com) were the academic search engines used to get the review material that is not found in local libraries and archives. Conservation status, abundance and distribution of cheetah were the keywords used to search for available information on the target species.

Extrapolations of trend in distribution and abundance

The trends in distribution and abundance of cheetah in Ethiopia for the past 50 years are presented chronologically from the past to the present. In most cases, density estimates were conservative since expert-based information was not available. Consequently, the population estimates were derived from applying density estimates from comparable areas to resident ranges as mapped during conservation strategy workshops and related studies (IUCN SSC, 2007; Durant et al., 2015; Durant et al., 2017). For this review, the following density estimates were used: (1) for well managed protected areas density was estimated at one individual per 100 km^2 as applied by Durant et al. (2011); and (2) for areas that are largely unprotected or are under threat, density was estimated at 0.25 individuals per 100 km^2 following Marker (2002) and Durant et al. (2017).

The maps and Global Positioning System (GPS) readings indicated in the published and unpublished reports were used mainly to assess distributions of the species in question.

RESULTS AND DISCUSSION

Trend in distribution of cheetah in Ethiopia

Historical distribution of cheetah in Ethiopia was probably determined by geographical features more than anything else due to the existence of the high altitude of the central highlands (EWCA, 2012). The first status survey for cheetahs was conducted in the early 1970s (Myers, 1973, 1975). Later surveys of selected countries were conducted in the 1980s (Gros, 1996, 1998, 2002; Gros and Rejmanek, 1999). The summary of the then knowledge of global status was also collated in 1998, although accurate information is complicated to collect for cheetah, which is shy and rarely seen across most of its ranges (Durant et al., 2007; EWCA, 2012).

In the 1960s, cheetahs were quite widespread in the wild lands of Ethiopia. They had been widely seen in the Somali border area of the then Harerghe province (eastern part of Ethiopia), in the then Ghemu Gofa province, and in the Borana area of the then Sidamo province (southern Ethiopia). There were also considerable numbers in the Omo River area, and relict populations in the Ogaden, southern Bale province, and Danakil Depression (Myers, 1973, 1975). However, like the case of other African countries, cheetah in Ethiopia has experienced significant reductions in its range over

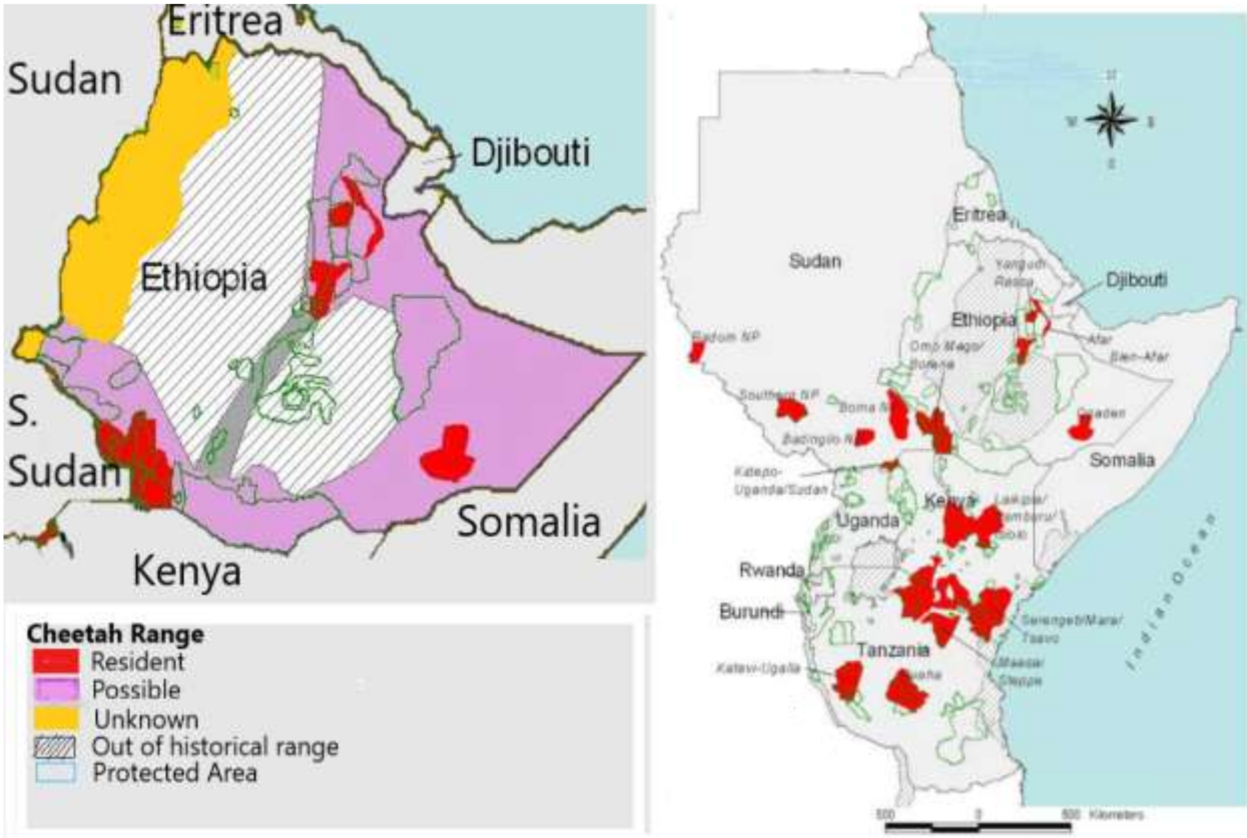

Figure 1. Range of Cheetah in Ethiopia (R) and distribution of cheetah in range states within eastern Africa in 2007 (L) as mapped by participants at the regional conservation strategy workshop.
Source: (IUCN SSC, 2007).

the last century (CITES, 2019) in which its historical ranges have been fragmented and shrinking over time due to mainly habitat conversion for different land use types like expansion of cultivation and urbanization (EWCA, 2012).

Before the national workshop, the eastern Africa regional meeting on conservation planning for cheetahs and wild dogs was held in 2007, at Mpala Research Centre in Kenya. Following the regional workshop, some limited areas in the Great Rift Valley (Omo and Awash Valleys) and Ogaden area in the Somali region (Figure 1) were identified as locations for resident populations of cheetah (IUCN SSC, 2007).

During the 2010 workshop in Addis Ababa to develop a national action plan for the conservation of cheetahs and African wild dogs (EWCA, 2012), additional information about the then status of cheetahs was gathered. Based on this, the following map of distribution for cheetah including additional areas of Gambella, Borena, Geralle, and Afder was developed (Figure 2).

A series of recent reports have indicated that there are more ranges for cheetah. For example, Wendim et al. (2015, 2018) have confirmed the existence of considerable number of cheetahs in the western part of the country, indicating a total of 23 and 6 individuals were directly spotted in the Mao-Komo proposed protected area and Dedessa proposed National Park, respectively. The fact that cheetahs were observed in all transects during the assessment in Moa-Komo shows that the cheetahs are evenly distributed throughout the area. There is also a new sighting in 2022 at Midega-Tolla, south of Babile Elephant Sanctuary (Perscomm). This shows that there are still relict populations of cheetah around Babile, which was also confirmed by previous work (EWCA and WSD, 2010), although this was debated by the results of the recent survey (Bauer et al., 2019). Therefore, considering the aforementioned reports, some areas indicated earlier as unknown and possible ranges (Figure 2) are currently taken as confirmed ranges for the cheetah population in Ethiopia (Figure 3).

Trend in the abundance of cheetah in Ethiopia

There is lack of data that show the current status of the population of Cheetah. In areas where there are sightings, data on the existing population in the specific habitats

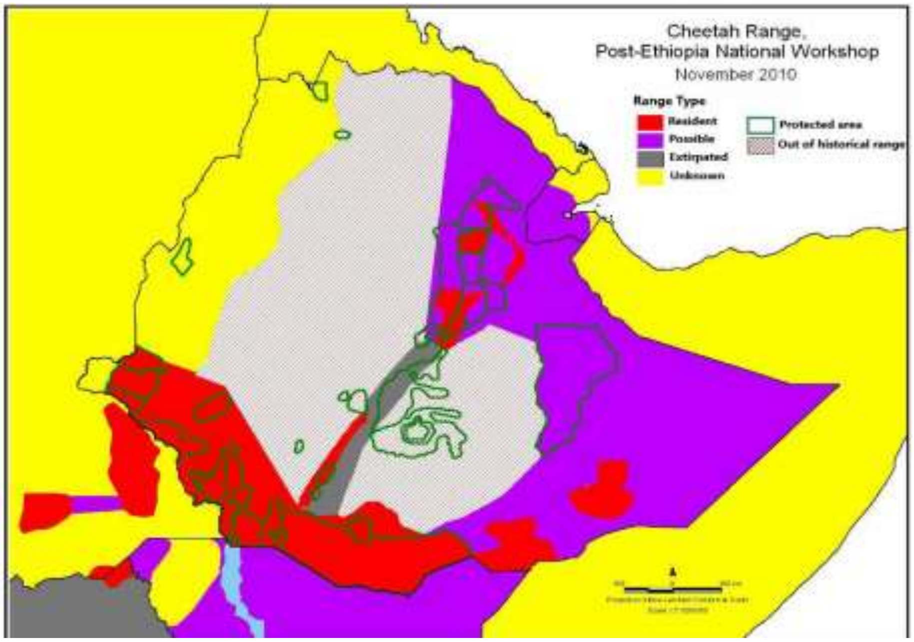

Figure 2. Cheetah distribution and ranges in Ethiopia (taken from National Action Plan for the conservation of Cheetah and African Wild Dog in Ethiopia, 2010)
Source: Authority (2012).

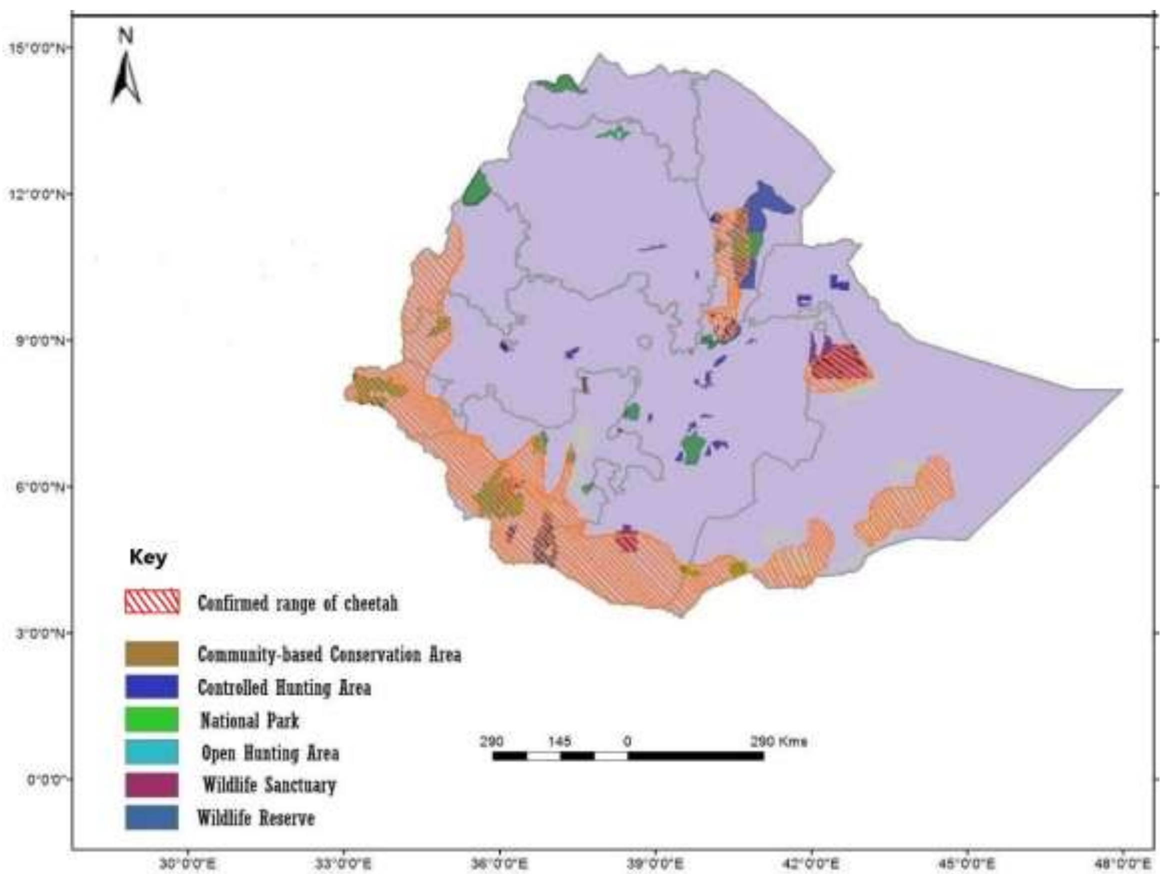

Figure 3. Present conformed distribution of Africa Cheetah in Ethiopia (based on the result of this review).
Source: Authors

Table 1. Previously known cheetah areas, habitat size and population estimate in Ethiopia (IUCN SSC, 2007).

Area name	Total area of habitat (km^2)	Estimated population
Afar	4,702	40
Bilen-Afar	7,342	70
Ogaden	11,095	110
Omo-Mago/Borena	25,010	250
Yangudi-Rasa	2,768	30
Total population estimate	-	500

Source: (IUCN SSC, 2007).

are not available, and in most cases, the population estimates, including the expert-based ones, need to be treated with extreme caution and are provided as an indication only (Myers, 1973; Marker, 2002; IUCN SSC, 2007; Durant et al., 2015).

The regional conservation strategy for the cheetah and African wild dog in Eastern Africa (IUCN SSC, 2007) suggested five locations for cheetah populations in Ethiopia and estimated the population was 500 (Table 1).

The estimate was made from the size of the polygon using a conservative density of 1 adult per 100 km^2 as adopted by Durant et al. (2011) which is derived from applying density estimates from comparable ranges of well managed protected areas. However, the estimate considers a conservative density of 1 adult per 100 km^2 which is proposed for ranges of well managed protected areas (Durant et al., 2011, 2015), nevertheless most of the areas are unprotected and under threat (Kebede and Gebretensae, 2018). Moreover, this estimate of population sizes does not take into account the Gambella, Mao-komo and Dedessa areas which were recently reported as the significant ranges in the western part of Ethiopia (Wendim et al., 2015, 2018).

The latest study and report on range states (Durant et al., 2017; CITES, 2019) argue that the previous conservative way of estimating density at 1 adult per 100 km^2 in unprotected areas needs to be revised to address the scarce distribution of cheetah across its ranges. Consequently, the recent study by Durant et al. (2017) considers 0.25 adults/100 km^2 as well as one individual per 1,000 km^2, and estimated 11, 20, 32, 8, and 191 adult cheetahs for Afar, Blen-Afar, Ogaden, Yangudi-Rassa, and Kenya/Ethiopia/South Sudan, border areas, respectively. This study also appears to have some gaps since it estimated the density of cheetah in the border ranges (Omo and Gambella) at 1 individual per 1,000 km^2. Because it seems unjustifiable to use this density estimation for populations of relatively intact areas of Ethiopia as it was proposed earlier for areas under elevated pressures and direct threat (Durant et al., 2015). Moreover, the report does not consider Babile and the newly explored stronghold sites of Mao-komo and Dedessa areas.

Therefore, there is a need to take into account the gaps encountered in the previous estimations and consequently, the current population estimate of cheetahs in Ethiopia has been extrapolated (Table 2).

Considering the result of the previous assessments (Wendim et al., 2015, 2018) and the intactness of the areas, the current estimate based on the result of this review assumes a conservative density of 1 individual per 100 km^2 for Moa-Komo and Dedessa, as adopted by Durant et al. (2011). For the other ranges largely under threat, density is estimated at 0.25 individuals per 100 km^2, following Marker (2002).

Based on the results presented by various studies, especially the recent surveys and sightings indicated in this review, it is possible to recognize that there is an increase in habitat, and this indicates that cheetahs are still found in a wide range of habitats in Ethiopia but in low population densities. This has also been explored by prior reports (Durant et al., 2015, 2017 Belbachir et al., 2015) which also indicated that cheetahs' low density throughout their range means that their populations require much larger areas of land to survive than do those of other carnivore species.

There is a decline in population size compared to 2007 even though contrasting the population estimates undertaken by the researchers has its own pitfalls since the assessments used different assumptions for estimating the density of cheetah. For example, the 2007 extrapolation (IUCN SSG, 2007) estimated the density at 1 individual per 100 km^2 and this is much larger as compared to 0.25 individuals per 100 km^2 used by Durant et al. (2017) and this study. As a result, a sizable cheetah population was estimated in 2007 even though the projected habitat area was 35% of the current estimate (Figure 4).

Potential threats

Globally, the cheetah is classified as 'Vulnerable' by the IUCN (Durant et al., 2015), having disappeared

Table 2. The present areas, habitat size, and population estimate of cheetahs in Ethiopia.

Area name	Total area of habitat (km^2)	Estimated population
Mao-Komo and Dedessa Areas & their surroundings	9,000	90*
Gambella	18,061	45**
Omo Valley, Borena and Geralle	72,245	180**
Middle and Lower Awash Valley	14,812	37**
Afder and Ogaden	22,190	55**
Babile and its surroundings	8,982	22**
Total population estimate		429

*Density estimated at 1 individual per $100km^2$ as applied by Durant et al. (2011); **Density estimated at 0.25 individuals per $100km^2$ following Marker (2002) and Durant et al. (2017).
Source: (Durant et al. (2011); Marker (2002) and Durant et al. (2017))

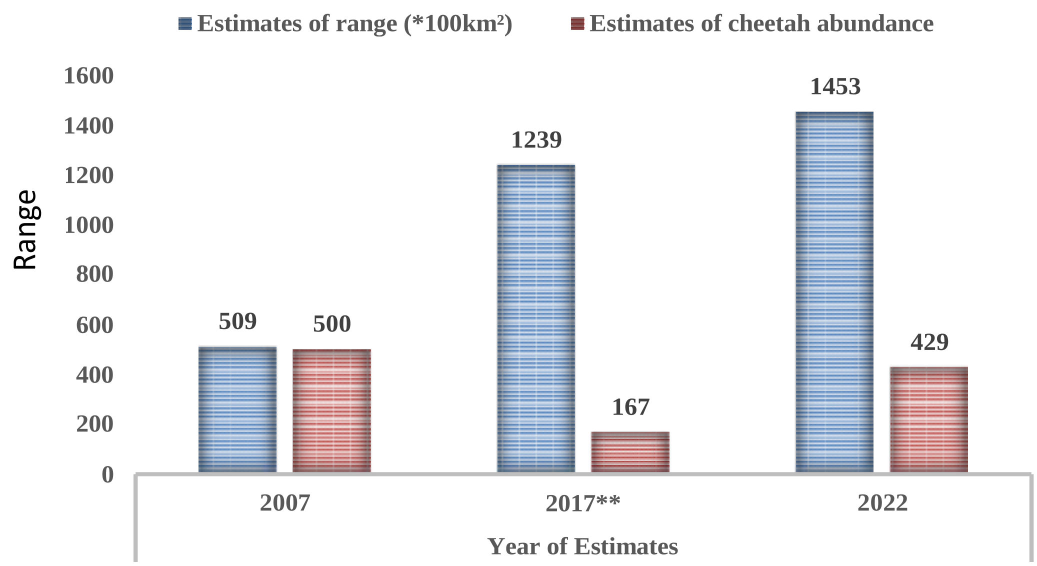

Figure 4. Estimates of cheetah range and abundance by IUCN SSC (2007), Durant et al. (2017), and the current estimate.
**For 2017, only 50% of the estimated population and habitat were considered in the case of Ethiopia/Kenya/South Sudan ranges
Source: IUCN SSC (2007); Durant et al. (2017) and authors.

from 20 countries and confined to 9% of its historical distributional range (Durant et al., 2017). According to the global assessment on threats to cheetah populations, the type and extent of the threats vary between regions (Woodroffe et al., 2007; EWCA, 2012).

Evaluation of threats conducted during the development of the national conservation action plan shows that habitat loss and fragmentation together represent the over-arching threat to cheetah populations in Ethiopia, which contribute to several of the other proximate threats (IUCN SSC, 2007; EWCA, 2012; Durant et al., 2015). Cheetahs are also threatened by conflict with livestock herders, reduced prey scarcity, and illegal live trade (EWCA, 2012; Nowell, 2014; Durant et al., 2017; CITES, 2019). Moreover, cheetahs are killed to use their skins for traditional ceremonies, especially in the southern part of Ethiopia where dozens of skins were counted across two years ceremonies of the Daasanach community (Torrents-Ticó et al., 2022).

Overall, the incidence and extent of the threats to cheetahs in Ethiopia are increasing and changing over time. For example, since the recent past, illegal trade in cheetahs, which is mainly driven by the demand for exotic pets in the Middle East, has been identified as a potential threat to cheetah populations in Ethiopia, and this threat is increasing over time (Nowell, 2014; CITES, 2019; Tricorache and Stiles, 2021; Tessema et al., 2021). The data collected by Tessema (2017) and Tricorache and Stiles (2021) clearly show that Somaliland and Ethiopia are the primary sources and transit areas for smuggling cheetahs to the Arabian Peninsula. According to Tricorache and Stiles (2021), the number of illegally trafficked live cheetahs in Ethiopia for ten years (2005-2015) was 103 while Tessema (2017) reported that an estimated 98 cheetah cubs were smuggled from Ethiopia to the Middle East in 2016. This trend is also supported by the recent report of a top officer from EWCA who addressed the media mentioning that every month, at least four cheetahs were smuggled to the Gulf nations (BBC, 2020).

Conservation action

Cheetahs are protected by national law and even licensed hunting of this species is not allowed in Ethiopia. It is evident that legal protection of the species alone is not sufficient, if the ever- increasing threats to cheetah are not taken into consideration. To this end, a national action plan for the conservation of cheetahs and African wild dogs was endorsed in 2012 and this strategic plan was developed using participatory process involving as many stakeholders as was practicable (EWCA, 2012).

Like the case of other species-specific action plans, there have been considerable limitations in delivering the outputs to meet the objectives of the action plan. One of the reasons for this is that the main conservation approach in Ethiopia is ecosystem-based, which focuses on safeguarding key biodiversity areas using the limited resources (Kebede and Gebretensae, 2018). As a result, few components of the cheetah and wild dog conservation strategy (e.g. management of human-cheetah conflict and establishing networking and collaboration) were partially addressed. Moreover, this species-specific conservation action plan was developed using logical framework methodology, based on the information on potential threats and associated problems by then and thus there is a need to review the plan based on the existing conditions on the ground as the severity of threats to cheetah is increasing and changing over time.

CONCLUSION AND RECOMMENDATIONS

It is noticeable that there is a lack of data on the status of cheetah, particularly in Ethiopia. However, the information gathered from the field assessment, literature, and supporting policy documents presented over the last five decades indicate that cheetahs are still found in a wide range of habitats in Ethiopia but in low population densities. In spite of the wider range and increase in area of the projected habitat, the population size of the cheetah is still extremely small and the incidence and extent of its threats is increasing and changing over time. It is therefore recommended that there is a need to: (1) conduct a countrywide assessment to examine the status of the existing populations; (2) review the developed national action plan based on up-to-date information on the potential threats to the populations of cheetahs; and (3) strengthen partnerships to curb the ever-increasing illegal trade of cheetahs.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Phenotypic characterization of sorghum accessions on farmers' fields in northern and eastern Uganda

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Sorghum is one of the most important cereal crops grown in arid/semi-arid regions of the world. Understanding and utilising the genetic variation in sorghum accessions is essential for improving the crop to adapt to abiotic and biotic constraints. Several authors have reported the loss of sorghum diversity, but there is limited available information on on-farm sorghum diversity in the major sorghum growing areas in Uganda hence limiting the utilization of diversity for improvement of the crop. This study was carried out to determine sorghum diversity on farmers' fields in Uganda. Phenotypic data was used to assess diversity in 100 sorghum accessions collected from Northern and Eastern regions of Uganda. The accessions were phenotyped using qualitative and quantitative morphological characteristics. Phenotypic evaluation was done using 10×10 Alpha lattice design with two replications at Pakor village in Agago district. Analysis of variance revealed highly significant ($p \leq 0.01$) differences for all quantitative traits measured indicating the existence of a wide genetic variation among accessions. The 100 accessions were grouped into two major clusters which were further subdivided into five sub clusters. The largest cluster had 30 accessions and the smallest cluster had five accessions. The five clusters varied with respect to plant height (202.8 to 379.9 cm), days to 50% flowering (77.3 to 163), number of leaves per plant (10.9 to 24.6), 100 grain weight (2.5 to 4.6 g) and yield (1977.4 to 3475.6 kg ha^{-1}). The clustering patterns of accessions was not entirely based on geographic origin and/or breeding status, probably due to gene flow. This study showed the existence of wide genetic diversity within the sorghum accessions, which could be exploited in the improvement of the crop through breeding for high yielding, pest and disease resistant varieties.

Key words: Sorghum bicolor, ward clustering, morphological traits, diversity.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important cereal crop following wheat, rice, maize, and barley in both total production and acreage in the world (FAOSTAT, 2022). Sorghum is a staple food crop for millions of the most food-insecure poorest people in the semi-arid tropics of Africa, South Asia and Central America (Abreha et al., 2022; Girma et al., 2019). Sorghum is predominantly grown in marginal environments which are prone to water scarcity. These regions are often too dry for the cultivation of most of the other important cereal crops.

For instance, 60% of the land in Sub-Saharan Africa where sorghum is commonly grown is considered vulnerable to recurrent droughts (Hadebe et al., 2017) and 80% of sorghum cultivated in the US is grown under non-irrigated conditions, where water is a major limiting factor, which substantially reduces yield (Abreha et al., 2022). Therefore, sorghum is important for addressing the current and future food security needs for marginal environments, especially with the looming effect of climate change. In Uganda, sorghum is the third most important staple cereal crop after maize and rice mainly grown by the resource poor farmers in arid and semi-arid regions of the North and East (Olupot, 2011). The crop has multiple uses including but not limited to human consumption in form of bread, porridge and boiled grain, beer production, sugar and biofuel production (stems), feeds (leaves and stems) and as a building material (Mathur et al., 2017; Kigozi et al., 2011). High genetic diversity is vital for the development of climate resilient crop varieties to mitigate the impact of climate change and to meet the multiple uses of the crop.

Most of sorghum diversity both at phenotypic and genotypic level is concentrated from where sorghum was first domesticated (Reddy et al., 2008). Much of the genetic variability is available in Africa and Asia, which are areas of the first domestication and early introduction of the crop respectively (Reddy et al., 2008). Species and varietal diversities in smallholder farming systems are valuable for coping with environmental variability and for specific uses (Altieri, 2004). The study of these processes at the community scale is complementary to large time-space approaches and contributes to the general understanding of the *in situ* genesis of crop genetic patterns (Labeyrie et al., 2014). Therefore, in the search for diverse breeding materials, farmers' cultivars or landraces are usually the major sources of genetic variation (Ghebru et al., 2002). Genetic diversity is important because it is useful in breeding programmes to produce superior varieties or hybrids with resistance to abiotic and biotic stresses (Sinha and Kumaravadivel, 2016).

The major cereals including sorghum have experienced significant reduction in genetic diversity due to the introduction of improved varieties (Petrović and Dimitrijevic, 2012). Other causes of genetic erosion include: emergence of new pests, weeds and diseases, environmental degradation, urbanization, conflicts and land clearing through deforestation and bush fires (Govindaraj et al., 2015). The impact of such genetic reduction has occasionally been witnessed when calamities strike such as the ug99 virus (*Puccinia graminis* tritici) that is threatening wheat production globally following a breakdown in resistance to stem rust (Joshi et al., 2008).

Crop genetic diversity forms a foundation for sustainable agriculture and global food security, now and in future, whether crops are used in traditional farming systems, conventional breeding or in new biotechnologies (FAO,1998). If not well understood and managed, crop genetic diversity of most crops like sorghum most especially on farmers' fields will be vulnerable to genetic erosion (FAO, 1998). Erosion of these resources results in a severe threat to the world's long-term food security (Hammer et al., 1999). Since the crop is an important cereal and is cultivated in marginal environments, genetic diversity is very important for crop improvement (Westengen et al., 2014). A good understanding of genetic variability among the accessions on farmers' fields will allow for selection of desirable parents for breeding programmes, systematic collections, characterisation, documentation and conservation in the national gene bank (Sinha and Kumaravadivel, 2016).

Deliberate efforts therefore, need to be put in place to prevent further loss of genetic diversity. However, to be able to put in appropriate conservation strategies, knowledge of existing diversity on the farmers' fields is paramount. While knowledge of sorghum diversity remains a key asset for effective implementation of on-farm conservation strategies and for development of new varieties. There is no available information on the status of on-farm sorghum diversity on farmers' fields in Uganda. Previous studies have reported the existence of significant diversity of sorghum at regional level (Andiku et al., 2021; Akatwijuka et al., 2016; Mbeyegala et al., 2012). Past studies revealed the existence of sorghum diversity at regional level by Mbeyagala et al. (2012) and Akatwijuka et al. (2016). However, in these studies the method of determining sorghum diversity was insufficient, for example Mbeyagala et al. (2012) picked only two panicles per field leaving probably other sorghum types while Akatwijuka et al. (2016) focused only in south western Uganda which is not a major sorghum producing region in Uganda. Relatedly, Andiku et al. (2021), looked at genetic diversity analysis of East African sorghum germplasm collections for agronomic and nutritional quality traits. There are however, no farm level studies that have been done to determine phenotypic diversity of sorghum. In addition, crop genetic diversity on the farmers' fields varies from time to time. This has limited the use and conservation of sorghum diversity hence increasing the risk of losing them. A good and complete understanding of the genetic basis of target traits, in any crop, is critical to design integral breeding strategies and to implement the necessary steps for the development and release of new improved varieties.

Over the years, a number of studies have dealt with estimating genetic diversity in cultivated sorghum using

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morphological traits (Adugna, 2014). Measurement of morphological variation is the most easily obtained indicator of genetic diversity and does not require expensive technology (Govindaraj et al., 2015; Ngugi and Maswali, 2010). In this study, an attempt was made to determine phenotypic relationship among sorghum accessions in Northern and Eastern Uganda using both the quantitative and qualitative traits.

MATERIALS AND METHODS

Description of the experimental sites

The evaluation of sorghum accessions was carried out at Makerere University, Agricultural Research Institute, Kabanyolo (MUARIK) in Wakiso district and Pakor village in Agago district in Northern Uganda. MUARIK is located at 0°28'N and 32°37'E, and at an elevation of 1,150 m above sea level, about 17 km north of Kampala city in Wakiso district (Arnold, 1993). The area experiences bi-modal rainfall pattern with two wet seasons, one running from April to May and the other from October to November. However, for 2016, the area experienced a very long dry spell. The dry months are often January to February and July to August although there is variability. The mean annual rainfall of Wakiso district was 1320 mm per annum. The soils are generally sandy clays of high productivity. The dominant soils types are red gravely loams with occasional marram reddish brown sandy loam on red clay loam and yellowish sands with quartz gravel (Yost and Estwaran, 1990). Agago is situated at latitudes 2^o 50'N and longitudes 33^o 20'E, at an elevation of 1060 m above sea level in Northern Uganda.

The dominant types of soils are sandy loam, clay and clay loam which vary in colour from one location to another. Agago has annual rainfall of 1145 mm (https://en.climate-data.org as accessed on 04/08/2017). The area receives bi-modal type of rainfall with the wet season starting from March to May and a second wet season (September-November). Agago has savannah type of vegetation dominated by short grass with dotted tall trees and shrubs. The dominant grass species are Guinea, star and thatching grasses (*Hyparrhenia rufa*).

Agago was selected as the site of the field evaluation because of the high diversity observed during the preliminary surveys. In addition, the interest was also to use the field evaluation to learn more from farmers about diversity of sorghum. Field evaluations could not be performed in all the districts due to the resource limitation.

Materials (accessions evaluated)

One hundred accessions were collected from Northern (Agago and Apac) and Eastern (Serere) Uganda during a survey conducted in December, 2015 to January, 2016. The accessions were collected based on grain colour, type of inflorescence, glume colour and plant height using sorghum descriptor guides (IBPGR and ICRISAT, 1993). Each sample was labelled indicating the district, field number and other characteristics like inflorescence type, glume colour and grain colour. The samples were properly dried, threshed and packed in paper bags before evaluation.

Experimental set up

To determine the relationships among accessions from the different districts, field evaluation was done in Agago district and Makerere University, Agricultural Research Institute, Kabanyolo. The evaluation trials were established on 20/03/2016 and 15/03/2016 during the first rain season, respectively. The evaluation was setup using 10 × 10 alpha lattice design replicated twice during the first rainy season on 15/03/2016. The field was first sprayed with glyphosate to kill the weeds. The land was ploughed and then later harrowed. Each of the plots measuring 3 m by 2 m was planted with an accession allocated to it at random at spacing of 60 cm by 20 cm between rows and plants, respectively. Three to four seeds were sown per hill and each stand was later thinned at two weeks after emergence to one plant per hill. Weeding was done twice using hand hoes in both locations.

Data collection

Phenotypic data on various morphological traits were recorded during crop growth. Data on qualitative traits such as midrib, grain and glume colours were collected by observing the help of sorghum descriptor guides (IBGR and ICRISAT, 1993). Data on quantitative traits such as flag leaf length (FL/cm) was determined by measuring the length of the flag leaf from the sheath to the apex, flag leaf width (FW/cm) was determined by measuring the width of the flag leaf from the broadest part. Panicle length (PL/cm) and width (PW/cm) were determined by measuring the length of the panicle from the base where the branches originate up to the tip whereas width was determined by determining the width from the broadest part of the panicle. Number of leaves (No. L) and nodes were determined by counting the leaves and nodes (No. N) from each plant sampled from the base up to the last leaf or flag leaf. Internode length (IL/cm) was determined by measuring the distance between the different internodes. Three internodes were measured from both the bottom and upper most parts of each plant. Days to 50% flowering (DFL/days) was determined by counting the number of days taken by plants in a given plot from the time of planting to when half of them had flowered. Plant height (PHT/cm) was determined both at 50%flowering and at physiological maturity. Height at 50% flowering was determined by measuring the height from the base of the plant to the tip of the panicle when it has just emerged or when half of the plants had flowered whereas height at maturity was taken from the base up to the tip of the panicle at physiological maturity. For the accessions with goose neck panicles (Head shape 10), the height was measured for the straight part and added to the length of the curved part to get overall plant height at maturity. Panicle weight (PWt/g) was determined by weighing 10 panicles that were dried under sunshine for 6 days and 100 grain weight was determined by counting 100 grains and they were then weighed at 13% moisture content. Yield (kg/ha) was determined by weighing the total amount of grains harvested per plot divided by the size of the plot and multiplying it by 10000 m^2

Data analysis

Data collected on both quantitative and qualitative traits during phenotypic evaluation was entered into excel and subjected to various types of analyses. Both descriptive and inferential statistical analytical tools were used in the study. Summary statistics (means, variances) were used to compare sorghum accessions from different geographical locations based on quantitative and qualitative traits. Analysis of variance was performed on quantitative traits such as plant height, flag leaf length and width, days to 50% flowering and yield using GenStat 14^{th} Edition statistical package; and significant means were separated using Least Significant Difference (LSD) at the 0.05 probability level. Gower's distances were used to compare the relationship among the accessions from different areas. Gower's distance was chosen because of its ability

Table 1. Descriptive statistics of quantitative traits for MUARIK and Agago experimental sites.

MUARIK	DFL	PHT FL	PHT MT	No.L	No.N	IL	FL	FW	PL	PW	PWt	PGWt	100 gwt	Yield
Mean	97.0	186.5	219.4	14.1	13.1	13.0	35.7	6.1	25.2	6.6	71.7	53.3	2.4	2012.0
Minimum	48.0	85.6	115.0	7.0	6.0	7.7	20.7	2.8	9.4	3.5	26.0	15.6	1.3	585.0
Maximum	183.0	365.0	430.0	24.0	23.0	22.5	54.2	9.0	45.4	10.6	145.8	100.0	5.0	4381.0
Range	133.0	279.4	315.0	17.0	17.0	14.7	33.5	6.3	36.0	7.1	119.8	84.5	3.7	3796.0
Variance	1134.0	3909.0	5595.0	18.9	19.1	9.7	63.4	2.4	60.0	2.4	643.7	392.7	0.5	595206.0
P-values	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.011	0.002	0.001	0.001	0.001
CV	34.9	33.5	34.1	30.9	33.4	24.1	22.3	25.1	30.8	23.5	35.4	37.2	29.7	38.4
AGAGO														
Mean	110.0	245.0	285.3	15.4	14.4	15.1	37.6	6.1	29.4	7.1	82.7	59.6	2.7	2233.0
Minimum	55.0	76.2	120.0	7.0	6.0	5.5	17.9	2.8	11.2	3.3	27.3	16.5	1.6	618.8
Maximum	191.0	450.7	510.2	30.0	29.0	25.7	66.8	9.2	46.6	14.0	161.4	116.8	5.5	4381.0
Range	136.0	374.5	390.2	23.0	23.0	20.2	48.9	6.5	35.5	10.7	134.1	100.3	3.9	3762.0
Variance	1236.0	7320.0	9363.0	28.6	28.5	15.1	59.5	1.7	65.1	2.6	720.8	401.0	0.4	555310.0
P-values	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.011	0.001	0.002	0.001	0.001

Source: Authors

to combine both quantitative and qualitative traits. Ward cluster analysis was performed using R-statistical software to determine the relationship among accessions from different geographical locations.

RESULTS

Quantitative traits

A wide range of variation ($p<0.05$) was observed for different quantitative traits. The results of the quantitative traits collected on the accessions such as days to 50% flowering ($p<0.001$), height at 50% flowering ($p<0.001$), height at maturity ($p<0.001$), number of leaves ($p<0.001$), number of nodes ($p<0.001$), internode length ($p=0.011$), flag leaf length ($p<0.001$) and width ($p<0.001$), panicle length and width, panicle weight, 100 grain weight ($p<0.001$) and yield ($p<0.001$) for the two locations are presented in Table 1.

The analysis for each experimental site showed that the accessions had relatively similar performance in most quantitative traits, although there were slight variations in traits such as days to 50% flowering, plant height at both 50% flowering and at maturity, panicle length, panicle width, one hundred grain weight and yield.

Qualitative traits

Morphological variation among sorghum accessions was high with regard to midrib colour, panicle compactness, glume and grain colour. Four different colours were observed for midrib ranging from white (87%), green (9%) tan (3%) and red (1%). In terms of glume colour, the majority of sorghum accessions had black (53.2%), red (46.9%) and brown (6.3%). There was wide variation in grain colour among the accessions where brown was predominant (51.7%), red (19%), white (16.8%), cream (4.2%), yellow (3.2%) and purplish-brown (3.2%). Panicle compactness (inflorescence type) varied greatly among sorghum accessions where majority had very loose drooping primary branches (40.8%) and compact elliptic type (23.5%). Other types of inflorescence observed included semi-loose drooping primary branches (12.2%), semi-compact elliptic (7.1%), half broom corn branches (7.1%), loose erect primary branches (4.1%), compact oval (2.04%), loose drooping primary branches (1%) semi-loose erect primary branches and broom corn (1%).

Phenotypic relationships and distances

Analysis using Gower's distance and Ward clustering methods grouped the 100 accessions into two major groups. The two groups were further sub divided into five sub groups/clusters (Figure 1). In general, sorghum accessions clustered according to geographical locations with some overlaps where accessions cut across all the locations.

Among the different clusters, the cluster size varied from 5 to 30 accessions. The maximum number of accessions was included in cluster V (30) and the minimum number of accessions was included in cluster III having five accessions (Figure 1).

Cluster I consisted of 23 accessions, 21 were from Agago and two from Apac and were characterized by late flowering and second tallest (Table 2). Furthermore, accessions in this cluster had panicles with very loose

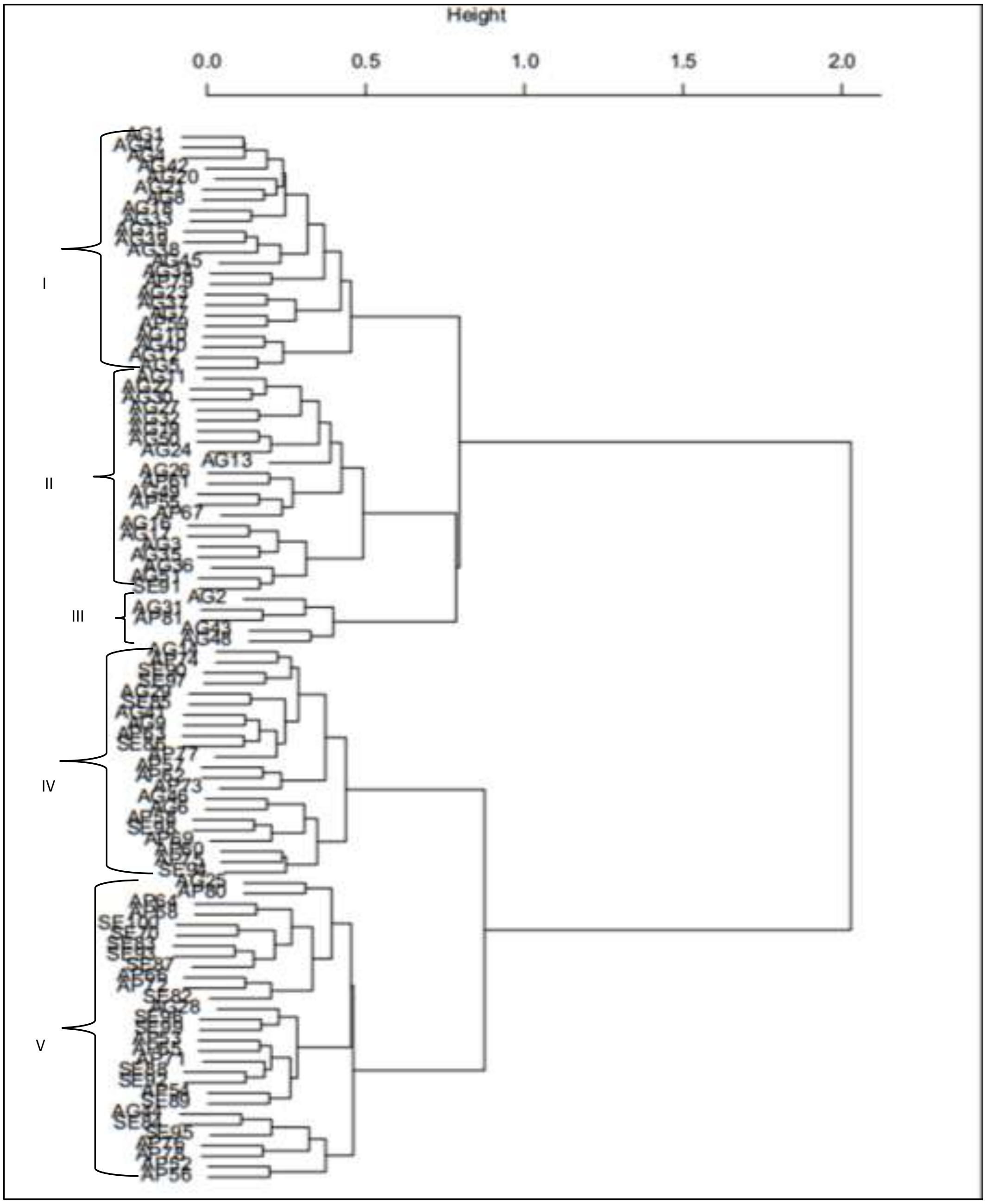

Figure 1. Dendrogram showing the grouping of 100 sorghum accessions.
Source: Authors

drooping primary branches and the grain colour varied from brown, red and white.

Cluster II had 21 accessions (Figure 1) out of which 17 were from Agago, three from Apac and one from Serere with varied morphological characters. All accessions in this cluster were characterized by late flowering, medium plant height, varied grain shape and colour, and very loose drooping primary branches type of panicles.

Cluster III consisted of five accessions, four were from Agago, one was from Apac and six were from Serere (Figure 1). All accessions in this cluster were characterized by early flowering, moderate height and less number of leaves (Table 2).

Cluster IV consisted of 21 accessions from all the three study areas almost in equal proportions (Figure 1) out of which seven were from Agago, six were from Serere and eight were from Apac. The cluster was characterized by moderate days to 50% flowering, largest flag leaves and

Table 2. Characteristic Means of five similarity cluster groups of sorghum accessions.

Trait	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
Days to 50%flowering	142.8	128.8	163.2	85.0	77.3
Ht. at 50% flowering	325.1	293.0	338.7	185.2	172.8
Ht. at maturity	374.1	346.9	379.9	217.5	202.8
No. of leaves	20.1	20.2	24.2	11.6	10.9
No. of nodes	19.1	19.2	23.2	10.6	9.9
Internode length	16.7	16.1	11.7	14.5	14.3
Flag leaf length	37.4	35.2	32.8	40.0	38.3
Flag leaf width	5.6	5.6	5.2	6.9	6.6
Panicle length	37.8	32.4	29.7	25.2	22.8
Panicle width	6.9	6.7	8.8	7.9	6.9
Panicle weight	84.9	74.2	124.4	90.2	75.5
Panicle grain weight.	63.4	53.0	92.7	61.0	52.6
100 grain weight	2.8	2.7	4.6	2.5	2.5
Yield (kg)	2366.9	1988.1	3475.6	2285.9	1977.4
No. of accessions	23.0	21.0	5.0	21.0	30.0

Source: Authors

lowest 100-grain weight (Table 2). Cluster V consisted of the largest number of accessions (30) out of which two were from Agago, 12 were from Apac and 16 were from Serere. The cluster was characterized by early flowering, shortest plant height and lowest number of leaves.

The cluster mean of the five similarity cluster groups in the 100 sorghum accessions are presented in Table 2. Sub cluster V had the lowest mean values for height at maturity (202.8), days to 50% flowering (77.3), lowest number of leaves per plant (10.9) and yield (1977.4). Sub clusters I, II and IV showed moderate mean values for leaf length, leaf width, height, yield, days to 50% flowering, and 100-grain weight. Sub cluster III had the highest mean values for plant height (379.9), panicle weight (124.4), panicle width (8.8), grain weight per panicle (92.7), 100-grain weight (4.6) and yield (3475.6). Based on the cluster means, the important cluster is cluster III that had the highest mean values for 100-grain weight and yield. Hence, the accessions falling under these clusters could be used as the parents for hybridization program. However, other clusters also had special attributes that can be explored in the improvement of the crop for example early flowering observed in sub clusters IV and V.

DISCUSSION

The objective of this study was to determine the phenotypic relationship among the accessions. There was wide variability in both quantitative and qualitative traits across all the sites. Ward clustering using Gower's distances grouped accessions into two main clusters that were further sub divided into five sub clusters with the cluster sizes ranging from five to thirty accessions.

Overall, the cluster analysis confirmed the presence of variation among accessions both in quantitative and qualitative traits. Qualitative traits such as pigmentation are very useful in differentiating accessions and selection for different breeding purposes. High significant differences, hence, high phenotypic diversity among accessions in all the traits tested have also been reported in Kenya (Ngugi and Maswili, 2010). Sinha and Kumaravadivel (2016) reported significant variation for all 14 quantitative traits investigated on 40 accessions in Tamil Nadu, India. The Agago accessions were tallest, had the highest number of leaves and they took too long to reach to 50% flowering and they formed the biggest number of sub clusters I, II, III, IV, whereas sub cluster V was dominated by accessions from Apac and Serere and were mostly short, had lowest number of leaves and also reached 50% flowering early. Ngugi and Maswili (2010) observed that the Turkana accessions that were tallest had more leaves, nodes and took longest to mature.

The significant mean values for quantitative traits such as plant height, 100 grain weight, yield and panicle weight obtained in Agago were generally much higher than at MUARIK although the accessions that performed well or poorly maintained the same performance across the two experimental sites. The differences for some of the characters indicated that the conditions in the two locations were not similar in many cases. For example, differences in rainfall, fertility of the soil as well as pests such as birds that could have reduced the yield of the accessions at MUARIK. Flowering is largely influenced by prevailing temperature and it occurs soon after panicle emergence (booting stage). However, despite the influence of the environment on the quantitative traits, the qualitative traits such as glume colour, colour of the seed, midrib colour and type of inflorescence remained the same throughout the two locations indicating that the environment less affects the qualitative traits. Therefore, the expressions for most of these characters such as yield, days to 50% flowering, height, panicle weight and pigmentation were genetic which can be explored in the improvement of sorghum through breeding.

The higher variance values obtained in both locations on the measurement of the quantitative traits can be attributed to high variability among the accessions. The large difference in quantitative characters among sorghum accessions in two locations is attributed to the differences in rainfall recorded in the growing seasons. Water demand is high for plants at germination, booting and flowering compared to during grain filling and ripening. Dry spells at the beginning and during the growing season are usually detrimental on sorghum and millet (Kudadjie et al., 2007). Bello et al. (2007) observed that high error or environmental variance estimate for some characters similar to what was obtained similar to this study. One way of increasing precision and reducing error could be by increasing the sample size and performing multi-locational trials, although this may be costly. Comparative performance among the sorghum accessions across two experimental sites proved that some accessions were superior to others in some attributes such as yield, 100-grain weight but other accessions were also more superior as far as attaining 50% flowering was concerned. Good scope exists among the accessions ranging from high yielding, early maturing as well as for forage. Depending on the breeding objectives, there was a wide range of accessions/ cultivars to choose from.

The clustering pattern of 100 accessions showed the existence of significant amount of variability among the sorghum accessions grown on farmers' fields in northern and Eastern Uganda. The wide variability exhibited by the accessions in both quantitative and qualitative traits on farmers' fields in Northern and Eastern Uganda is an indication of wide opportunities for improvement of sorghum in Uganda. The results in this study suggest that diversity of the sorghum accessions were structured more on geographical locations and based on quantitative traits like plant height, days to 50% flowering, yield, panicle length, width and 100 grain weight and qualitative traits like grain colouration than agro-ecological conditions. For example, sorghum accessions from Agago were grouped together in cluster I, while cluster V had a majority of accessions from Serere and Apac, which was an indication of their similarity in characteristics. The clustering of sorghum accessions based on geographical locations was distinct with some overlaps where accessions cut across the locations. These overlaps among sorghum accessions during clustering indicate that, there was relatedness among these accessions. Several factors could have contributed to the detected patterns for example seed exchanges among farmers and on-farm participatory trials conducted by National Agricultural Research Organisation. The predominantly autogamous breeding system can contribute towards explaining patterns of genetic diversity and structure observed. Secondly, environmental, biological, cultural, and socio-economic factors all play a role in farmer's decisions to choose or keep a particular sorghum cultivar at any given time. Farmers make decisions on how much of each accession to plant, the percentage of seed or germplasm to save and the percentage to buy or exchange from other sources. Each of these decisions affects the genetic diversity of crop cultivars and is linked to a complex set of environmental and socio-economic influence.

There was a close relationship among the Agago accessions that can be attributed to sharing of accessions. This pattern of genetic relationships where accessions from the same region were genetically similar could also be attributed to existence of variety exchange patterns of such accessions between relatives or friends in the communities. Reports of other studies in sorghum accessions have shown grouping primarily on the basis of origin and clustering within groups as driven by racial classification (Sharma et al., 2010). The morphological diversity was also observed within each region and was distributed with geographical origin using Sudanese sorghum landraces (Grenier et al., 2004). The main evolutionary forces responsible for producing genetic structure in plant populations are gene flow, selection associated with environmental heterogeneity and/or farmer preferences and random genetic drift (Muui, 2014).

Sorghum is primarily a self-pollinated crop resulting in a low level of observed heterozygosity, but the gene pool as a whole maintains a high level allelic variation. The low heterozygosity was a clear indication that the accessions were homozygous and thus high level of stability within the population. Although sorghum is self-pollinated, it also out crosses 7 to 30%, cross pollination could have occurred between different accessions within farmers' fields resulting into crosses that have related similarities in different locations. The accessions within a certain region also showed variability within themselves, for example accessions from Agago, Serere and Apac were clustered into more than one group. This is an indication of variability among the accessions. According to Sinha and Kumaravadivel (2016) citing Geleta and Labuschagne (2005), morphological variation was found among sorghum accessions collected from Eastern parts of Ethiopia using 10 morphological traits and variation among the sorghum germplasm.

In general, the findings of this study reveal the existence of great diversity among the sorghum accessions grown on farmers' fields in Northern and Eastern Uganda. Introduction of new sorghum varieties and landraces through breeding and human transportation may have caused higher sorghum diversity in Northern and Eastern Uganda. This is particularly true as more diversity was observed among Agago accessions and Agago being located closer to the border with South Sudan that is one of centers of domestication of Sorghum, there is a possibility that, through human movement some landraces were introduced into the country hence contributing to high variability. On the other hand, Serere being close to the National Research Station, less variability of sorghum accessions was observed and this can be attributed to replacement of traditional varieties with improved varieties.

Conclusion

High levels of diversity were observed which provide farmers and plant breeders with options to develop, through selection and breeding, new and more productive varieties that are adapted to changing environments.

Sorghum accessions generally clustered based on their geographical regions. Most of the diversity resided in individuals within a population. The results from this study suggest need for collection strategies of accessions for conservation with possible focus on the Agago and Serere accessions because of the high levels of diversity and uniqueness.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Human-wildlife conflict in the Campo-Ma'an Technical Operational Unit, Southern Cameroon

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Human-Wildlife Conflict (HWC) is increasing in the Campo-Ma'an Conservation Area located in the southern region of Cameroon, thus threatening human livelihoods and wildlife; yet the sources and consequences of HWC in this region remain poorly understood. 127 households from three subdivisions were interviewed to investigate the extent of wildlife crop damage and identify humans' impact on wildlife. Most surveyed households (98%) reported wildlife crop damage, mainly by eighteen species. The severity level's distribution differed among subdivisions. Out of 23 plant species grown, 14 suffered damage, five being staple foods; suggesting that HWC can threaten food security. Elephants (*Loxodonta cyclotis*) were the second most cited crop raiders, after cane rats (*Thryonomys swinderianus*), causing the greatest economic loss. None of the mitigation measures implemented effectively reduced crop raiding. The main human effects on wildlife were poaching and habitat loss, threatening biodiversity. Crop damage and illegal activities must be monitored and mitigations established, to reduce human-wildlife interferences. This requires setting up adaptive land-use systems and modifying and empowering wildlife legislation.

Key words: Forest elephants, Crop raiding, Campo-Ma'an National Park, mitigation, wildlife policy.

INTRODUCTION

Human-Wildlife Conflict (HWC) is a situation that occurs when the presence or behaviour of wildlife poses an actual or perceived, direct and recurring threat to human interests or needs, leading to disagreements between groups of people and negative impacts on people and wildlife (International Union for Conservation of Nature [IUCN], 2020). The negative consequences on human's livelihood may involve wildlife damage to crops (Torres et al., 2018; Granados and Weladji, 2012 Pant et al. 2016), livestock (Weladji and Tchamba, 2003; Karanth et al. 2013a; Torres et al., 2018), or attacks on humans (Karanth et al., 2013b; Karanth and Kudalkar, 2017). Conflicts also occur when people retaliate against the species blamed or compete with wildlife for resources such as space, water and food (Hoare, 2015; Mariki et al., 2015; Conover et al., 2018). Humans have lived alongside and interacted with wild animals throughout the evolutionary history and HWC with its long historical existence is receiving increasing attention from conservation biologists across the globe (Messmer, 2000;

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Barua et al., 2013; Anand and Radhakrishna, 2017). Despite these efforts, HWC remains a global phenomenon, with nearly 90% of the countries currently affected (Messmer, 2000; Anand and Radhakrishna, 2017). Most of Africa's protected areas (PAs) were created by colonial administrators without considering the concerns of local communities, and in most cases, people were displaced or deprived of the traditional use of resources, causing them to suffer economic hardship (Weladji and Tchamba, 2003; Matseketsa et al., 2019). On the other hand, the animals that are to be considered "protected", mostly abundant in the PAs (Ole, 2011), often find themselves roaming outside PAs, creating further damages to crops and livestock (Granados and Weladji, 2012; Karanth and Vanamamalai, 2020). This generates conflicts around PAs, where land has become a scarce resource. Yet, the human population adjacent to wildlife habitats is generally growing, and with it, the demand for more farming lands and more resources from the PAs (Mekonen, 2020). Moreover, local communities illegally herd and graze livestock into PAs (Bobo and Weladji, 2011; Karanth et al., 2013b), and have engaged in poaching, often also killing species listed as threatened (Mwakatobe et al., 2014; Mariki et al., 2015). For humans living adjacent to PAs, crop raiding is one of the most reported forms of HWC (Granados and Weladji, 2012; Karanth and Vanamamalai, 2020; Govind and Jayson, 2021), and a variety of species groups are the culprits including, but not limited to, elephants (*Loxodonta spp*), primates, rodents and birds (Mwakatobe et al., 2014; IUCN, 2020). Among the many wildlife species involved in HWC, elephants are the most reported (Naughton-Treves, 1998; Granados and Weladji, 2012; Anand and Radhakrishna, 2017) and generally have a bad reputation among local people as they damage a lot in a single raiding event (Naughton-Treves, 1998; King, 2010; Ngama et al., 2018). Indeed, although being currently listed as Endangered or Critically Endangered in Africa (IUCN, 2021), conflict with humans is one of the major causes of the decline of elephant populations, hampering their long-term conservation (Granados and Weladji, 2012; Pant et al., 2016).

HWC is widespread, unevenly distributed, and complex in nature, making it a central issue in biodiversity conservation and wildlife management (Dickman, 2010; Anand and Radhakrishna, 2017; Mekonen, 2020). Different species are involved, causing different types of damage at different times of the year (Conover et al., 2018; Mekonen, 2020). This may be because of animal preferences or may be a consequence of the dominant crop types grown in each area (Weladji and Tchamba, 2003). Also, crop damages and the resulting retaliations are the only visible impacts of HWC, as there are hidden or poorly documented social impacts not often reported (Dickman, 2010; Barua et al., 2013; Redpath et al., 2015). For example, people have given up some of their rights because of having proximity to wild animals or conservation areas (Thirgood et al., 2005; Dickman, 2010) on which they are dependent for fuelwood, thatch, fish, bushmeat, medicinal plants, and pasture (Weladji and Tchamba, 2003; Granados and Weladji, 2012). Furthermore, various mitigation strategies developed against wildlife damages are limited with different levels of efficiency depending on the target species (Hoare, 2015; King, 2010; Nelson et al., 2003). HWC is exacerbated in Central Africa, where wildlife is often considered state property (Naughton-Treves 1998; Ole, 2011), with dramatic consequences on both wildlife and local communities (Weladji and Tchamba, 2003; Granados and Weladji, 2012; Ngama et al., 2018). Despite recent efforts to involve local people and other stakeholders, frustrations remain (Bobo and Weladji, 2011). In the Democratic Republic of Congo, elephant damage to crops was reported to decrease farmers' annual revenues by 77% (Inogwabini et al., 2013). In Northern Cameroon, 87% of households complained of crop damage with 31% of crop income lost to wildlife around the Bénoué Wildlife Conservation Area (Weladji and Tchamba, 2003), whereas elephant damages to crops have been estimated between US$40,000 to US$75,000 per year (Tchamba, 1996). On the other hand, 62% of the forest elephant population of the Congo basin was decimated because of the illegal ivory trade between 2002 and 2011 (Maisels et al., 2013). The negative reputation local people have for wildlife could also be present in the Campo-Ma'an region where local people heavily rely on the nearby forest for their livelihood and HWC is reported, mostly from large and medium size mammals including elephants (Ole, 2011, Eyebe et al., 2012), and effective mitigation strategies are lacking. Indeed, Eyebe et al. (2012) reported a couple of villages facing damage from elephants in Campo-Ma'an. Human population has increased in the Campo-Ma'an region in recent years in response to the development and establishment of agro-industrial and logging companies (Tiani et al., 2005), and major development projects such as the dam and port constructions (Ministère des Forêts et de la Faune [MINFOF], (2014). Moreover, the recent creation of an industrial oil palm plantation in the region has resulted in the reclassification of about 60,000 ha and the slash of all the trees in the logging concession n°09025, situated in the west of the National Park. These may increase the frustration by imposing greater restrictions on the use of resources on which local peoples rely, thereby increasing HWC. Accordingly, this study aims to identify the main source of conflicts between people and wildlife, as a prerequisite to framing an adaptive management policy through the development of effective mitigation techniques to alleviate potential problems. More specifically, the study assess: the crop damage experience and severity level; the types and stages of growth of crop raided; the wildlife species involved; the factors influencing crop damage occurrence and mitigation strategies used by farmers; the

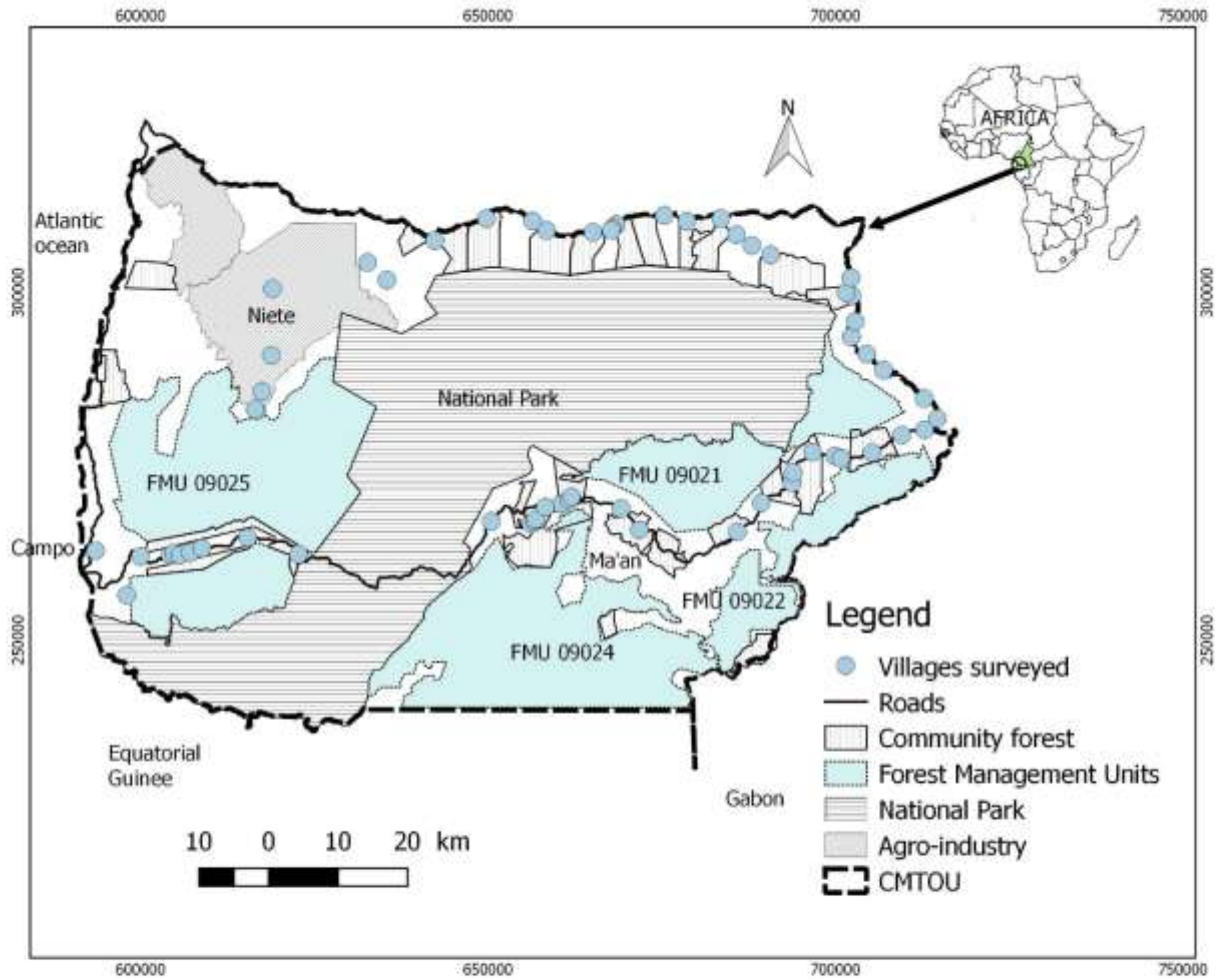

Figure 1. Location of study site and different land use types in the Campo-Ma'an Technical Operational Unit (CMTOU), Southern Cameroon.
Source: Authors

economic impact of crop raiding on farmers' livelihood; and the potential influence of humans on wildlife. Furthermore, the study evaluates whether there were differences in the effects among subdivisions.

MATERIALS AND METHODS

Study area

The Campo-Ma'an National Park (CMNP) and its peripheral zone known as Campo-Ma'an Technical Operational Unit (hereafter designated CMTOU), represents 16% (770 000 ha) of the South region of Cameroon with nine subdivisions and about 111,000 inhabitants. The CMNP is located between 2°10'N, 9°50'E and 2°25'N, 10°48'E (Figure 1) and is surrounded by 162 villages and hamlets along the main road. In addition to the park with 264,064 ha, the CMTOU includes three other land use systems, the Forest Management Units (FMU) for logging (235,485 ha), a state maritime estate (320 ha), and a multipurpose area (275,033 ha) devoted to community forests and human activities (Tiani et al., 2005). This research includes three subdivisions: Campo, Niete, and Ma'an with different socio-cultural backgrounds (MINFOF, 2014). The mean annual precipitation is about 2500 mm (MINFOF, 2014). The mean annual temperature is 25°C and the climatic conditions are favorable for agriculture all year round. There are about 80 species of mammals, including a critically endangered forest elephant (*Loxodonta cyclotis*) having a population of about 544 individuals and 2200 great apes (Nzooh-Dongmo et al., 2015). Table 1 includes most crops grown in the region (Tiani et al., 2005). Figure 1 shows the location of study site and different land use types in the Campo-Ma'an Technical Operational Unit (CMTOU), Southern Cameroon.

Data collection

Data for the human impacts on wildlife were obtained from the park's annual reports (2014-2017) and images from 19 Bushnell camera traps (Trophy Cam HD Essential E3 Trail Brown 16 MP 119837C Model, Bushnell, Kansas) deployed in southwestern Campo-Ma'an. Camera traps data were collected between May and December 2019. Deployment was stratified to have 6 cameras stations in the logging concession, 4 in the community land and 7 in the park. Camera placement was chosen based on expert

Table 1. The distribution of the percentage of reported wildlife incident by crop types.

Types of crops	Overall N=125	Campo n=68	Ma'an n=14	Niete n=43
Cassava: *Manihot esculenta*	89	91	100	81
Maize: *Zea mays*	61	54	71	67
Banana: *Musa paradisiaca*	50	60	64	30
Groundnuts: *Arachis hypogaea*	48	44	86	42
Cocoyam*: Colocasia esculenta*	38	26	50	51
Sweet potatoes*: Ipomea batatas*	19	22	7	19
Squash: *Cucurbita spp*	16	13	43	12
Yam: *Dioscorea spp*	12	12	0	16
Cocoa: *Theobroma cacao*	9	6	36	5
Sugar cane: *Saccharum spp*	10	6	21	12
Palm tree: *Alaeis guineensis*	4	3	0	7
Pepper: *Capsicum frutescens*	1	2	0	0
Okra: *Abelmoschus esculentus*	1	2	0	0
African pear: *Dacryodes edulis*	1	0	0	2

A total of 125 respondents were surveyed in Campo, Ma'an and Niete subdivision from May through August 2018.
Source: Authors

knowledge of a team of field assistants (hunters and wood logging workers) with the goal of maximizing detection of forest elephants when present at camera trap location. No human image from the camera traps would be shared or be published as they may be used for prosecution against them. In fact, community members were informed about the purpose of our work, and that their privacy would be respected (that is, no image would be shared with park authorities), and they helped identify the locations of the cameras (Sandbrook et al., 2018; Sharma et al., 2020). From the images, we extracted those with human presence, and subsequently identified and classified them as hunters (with a hunting device or animal carcasses), forest loggers (with a logging device or with wood products), or others when known (such as park staff or researchers with their crew, Deith and Brodie, 2020). Data on wildlife influence on local communities were collected from May through August 2018 in the CMTOU. We visited 54 communities within the CMTOU based on the availability of their leaders and informed them about the purpose of the research. Among them, 23 (42%) villages, from the above-mentioned three administrative subdivisions (12 villages in Campo, 4 in Ma'an, and 7 in Niete), were selected opportunistically for interviews. Within a village, households were also selected opportunistically based on their presence at the time we were present for the actual interview and willingness to take part in the research, which they confirmed by reading and signing the consent form (Supplementary material 1; Ngama et al., 2019; Mouafo et al., 2021). households heads, their wives, or any adults male or female (≥18 years old) present because adulthood starts at 18 years old in Cameroon were interviewed (Patrice, 2019; Hariohay et al., 2020; Mouafo et al., 2021; Mwakatobe et al., 2014). Overall, 127 households were interviewed, 25% being females. Interviews were conducted in French wherever possible, as most people were fluent in French (Granados and Weladji, 2012; Fopa et al., 2020). In one instance, the respondent, from a *Bagyeli* household, did not speak French, and we used a local interpreter. Following Granados and Weladji (2012) and, Weladji and Tchamba (2003) methods, the interview consisted of a semi-structured questionnaire during which the respondent had to answer several crop damages-related questions (Supplementary material 2).

The extent of crop damage was obtained using the respondents' declarations on the estimated area reported damaged by wildlife (Hariohay et al., 2020; Neupane et al., 2017). We intended to visit all farms where crop damages were reported, but due to logistical reasons, and the difficulty to estimate the extent of the damage for most animals (since most damages had occurred several months prior to our visit), we decided to only visit farms that experienced elephant crop-raiding recently (< 4 months) knowing that elephants signs may last about three months (Nzooh-Dongmo et al., 2015). Accordingly, we visited twelve farms and used data on some previously reported crop raiding events, assessed and compiled by the conservation office, to validate the responses received, thereby minimizing the risk of exaggeration from the responses received. Cassava and bananas are staple foods commonly grown in a slash-and-burn agriculture system in our study area (MINFOF, 2014). Growing these plants require farmers to use the same land for about two years allow it for fallow period for many years (Breuer and Ngama, 2020). Therefore, respondents were asked whether they were victims of crop raiding during the last three years, and if yes, to identify the growth stage of the damaged crops (Supplementary material 2) and to provide an estimate of the farm distance from the village and park boundary (Mwakatobe et al., 2014; Breuer and Ngama, 2020). Most of the respondents were aware of the distance of their villages to the entry of the CMNP by road but ignored the distance to the closest border of the CMNP or FMU. CMNP and FMU are considered wildlife habitats and the presence of wildlife in these two land use types is ideal for coexistence with farmers. Since farmers ignored the distance from their location to the park border, QGIS software (QGIS Development Team, 2020) was used to estimate the linear distances from the closest park border or FMU to each village. We considered the raiding events within the last three years in terms of the estimated percentage of crops damaged by wildlife (Karidozo and Osborn, 2005). Crop losses caused by different animal species were assessed for each cropping season. Following Granados and Weladji (2012), these percentages were grouped into four categories (Supplementary material 2): Moderate (0 to 25%), severe (25 to 50%), more severe (50 to 75%) and extremely severe

(75 to 100%). Other household members were present during the interview and could confirm or refute the information provided, to account for possible loss of information. Multi-cropping system is used for agricultural production in our study area. Therefore, several crops could be damaged simultaneously. In addition, a crop could be subject to multiple raiding events by different wildlife species. To assess the level of involvement of each animal in crop damage, we counted the number of incidents involving each crop type and attributed it to each animal species. The economical assessment of crop damages to people's livelihood was determined by estimating the actual total annual harvest by type of crops for each farmer, the proportion sold as well as the price per unit for each type of crop (Equation 1). This helped to overcome the problem of different units used to measure different types of crops. For example, cocoas are sold in bags of 100kg while cassavas are sold in baskets. Knowing the annual income from agriculture for each farmer, we deducted the monetary loss by dividing the current sale by the average percentage of losses in fields. For this purpose, we considered the mid values of the interval used to classify the extent of damage (12.5 for moderate, 37.5 for severe, 67.5 for more severe, and 87.5 for extremely severe) for all the calculations.

$$\text{Economic losses} = \sum (H_i \times P_i)/\%\text{loss} \quad (1)$$

Where H_i represents the total annual harvest of crop type i and P_i the price of unit sale for crop type i on the local market. This research was performed in accordance with the Certification of Ethical Acceptability for Research Involving Human Subjects n°30009480 delivered by the Concordia University Human Research Ethics Committee. Locally, the research protocol was reviewed and approved by the CMNP manager, and the regional administrative authority (authorization n°025/AR/L/SG/DAAJ/SDAT issued on June 19th, 2018, by the South Region Governor).

Statistical analysis

Questionnaire responses were summarized and cross tabulated for statistical analysis. A Generalized Linear Models (GLMs) was used with a binomial distribution and logit link to test the occurrence of crop raiding experienced by households across the three subdivisions and by severity level. The response variable in this model had two levels (whether the respondent experienced crop damage or not) and therefore binomial. In the second model, we assessed the impact of crop raiding on individual crop types, the response variable being the total count of raiding events on each crop species grown by the farmers. GLM with a Poisson distribution and a log link function was used to identify whether crop specie and the severity level predicted the frequency of reported damage experienced by a given crop type across the subdivisions. A quasi-Poisson distribution was used instead to account for over-dispersion, and only included data for known crop species in the analysis. For the third model, GLM with Poisson distribution was used to identify whether the wildlife species and the level of severity in crop damage across subdivisions could explain variation in the frequency of reported events caused by a given wildlife species. The total count of wildlife involvement in crop raiding incidents was used as a response variable whereas the severity level of farm damage, the wildlife species, and subdivisions were used as predictors. A quasi-Poisson distribution was also used here to account for over-dispersion. For all GLM, the log-transformed number of respondents per subdivision was used as an offset to account for differences in the statistical population between subdivisions (Agresti, 1996). We also ran separate ANOVA models to compare the mean size of reported land area affected by crop loss caused by wildlife, mean distance to FMU or National Park and average economic loss within each subdivision. Pairwise comparisons were performed using Tukey-Kramer corrections for the difference between the means. We used Pearson chi-squares to compute the difference between the subdivisions in the distribution of the severity level and stages of growth of the crops damaged. Pearson chi-squares were also used to assess the difference between mitigation methods, the differences in elephant's involvement in crop raiding incidents between subdivisions, and the distribution of human presence (total number of independent observations of poachers and loggers from photos) across three land use types (the National Park, the FMU and the community land) and the stage of growth of damaged crops. Unless otherwise specified, we reported means with their standard deviations and estimated difference with their 95% confidence intervals. Statistical analyses were performed using R statistical software (R Core Team 2020) with a significance level set at 0.05.

RESULTS

Crop raiding

From the 12 farms visited 9 (75%) were consistently in accord with the questionnaire responses, while the rest had lower actual damage than reported during the interview. Of the respondents, 98% (n = 127) reported crop damage by wildlife with no significant differences between subdivisions (GLM test, $\chi^2_2 = 1.61$, $p = 0.450$). All respondents from Campo (n = 68), representing 54% of the total, and Ma'an (n = 14) with 11%, suffered crop damages. In contrast, from Niete, only 2% respondents were not affected by crop damage. Across subdivisions, there was no difference among the levels of severity (GLM test, $\chi^2_3 = 6.07$, $p = 0.110$). Overall, 29% (n=36) of the respondents experienced extremely severe crop damages, 22% (n = 27) was more severe, 26% (n = 32) severe and 23% moderately severe. However, the severity level distribution differed significantly between subdivisions (Chi-square test, $\chi^2_6 = 14.85$, $p = 0.021$; Figure 2). Significant differences were observed for households experiencing extremely severe damages between Campo with 35% and Ma'an with 14% ($\chi^2_1 = 8.89$, $p = 0.003$). In comparison, Campo and Niete (with 24%) as well as Ma'an and Niete, were comparable (all $p > 0.1$). Figure 2 shows relative distribution of damages to crops by severity level in three subdivisions of the Campo-Ma'an region, southern Cameroon.

Types of crops damaged, and wildlife involved

Overall, of the 23 types of crops grown by the respondents, 14 (Table 1) were reported damaged by wildlife. The distribution of incidents reported varied significantly with respect to crop types (GLM test, $\chi^2_{13} = 115.93$, $p < 0.001$) and subdivisions (GLM test, $\chi^2_2 = 134.23$, $p < 0.001$), with a model $R^2 = 0.23$. The five most damaged crops reported (79% of raiding events) were also staple crops, namely cassava, maize, banana, groundnut, and cocoyam. Forty respondents (31%) reported damage to all their crops on farms with 21 in Campo and 19 in Niete. The level of severity did not differ

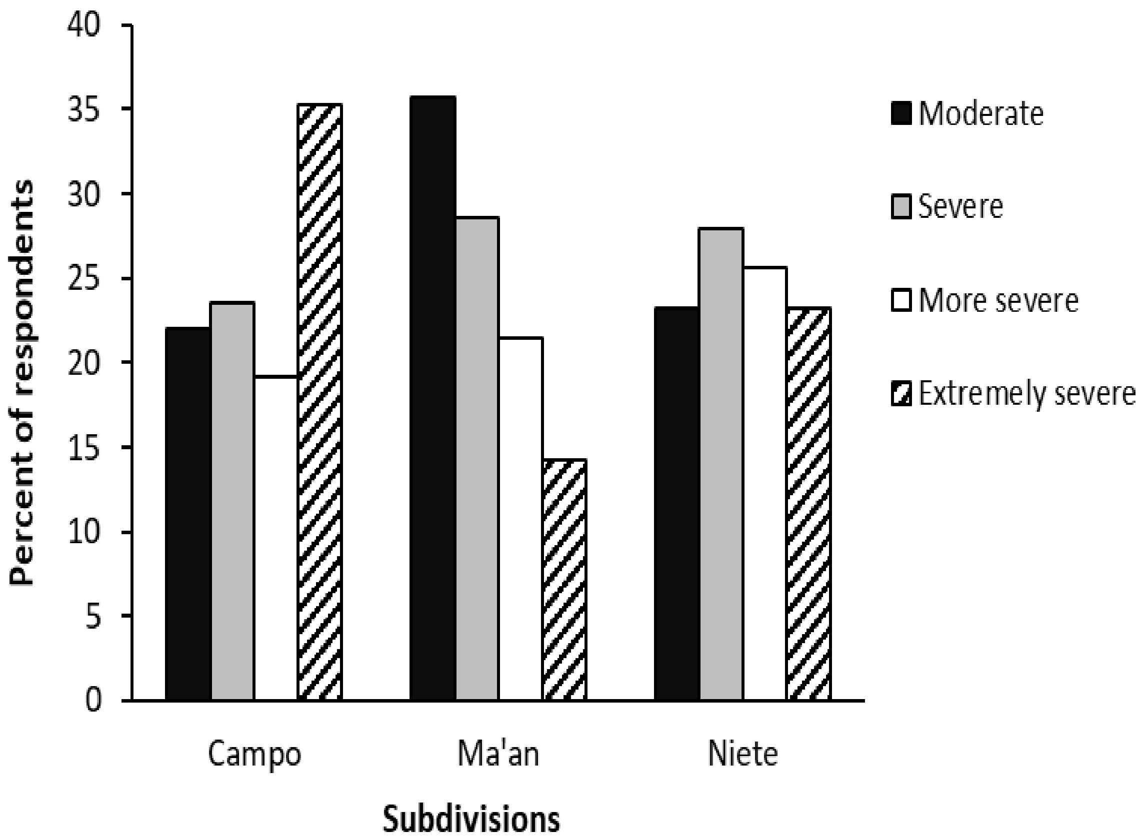

Figure 2. Relative distribution of damages to crops by severity level in three subdivisions of the Campo-Ma’an region, southern Cameroon.
Source: Authors

with respect to crop type (GLM test, χ^2_3 = 4.76, p = 0.314). The distribution of the stages of growth at which incidents generally occur did not differ between the subdivisions (χ^2_4 = 7.07, p = 0.132). Within subdivisions however, mature crops were more affected than both intermediate (χ^2_1 = 35.64, p < 0.001) and young (χ^2_1 = 40.95, p < 0.001) stages (Figure 3). Overall, 71% of damages reported happened at a mature stage, 16% at the intermediate stage, and 13% at the young stage of crops within subdivisions. Figure 3 displays the percent distribution of crop raiding incidents by growth stages of the crops in three subdivisions of the Campo Ma’an region, southern Cameroon, while Table 1 shows the distribution of the percentage of reported wildlife incidents by crop type. Table 2 displays the distribution of the crop raiders by subdivision, from which, five were reported more often reported [Cane rat (28%), elephant (19%), talapoin (14%), porcupine (11%) and rat (9%)]. Overall, although the model fit was not high (R^2=0.13), the distribution of crop raiding incidents was significantly different with respect to wildlife species (GLM test, χ^2_{17} = 58.44, p = 0.021) and the involvement of various species in crop damage differed among subdivisions (GLM test, χ^2_2 = 131.13, p < 0.001). Elephants were more destructive to crops in Niete (28%) and Campo (20%) as compared to Ma’an with only 1% (Chi-square test, χ^2_2 = 23.99, p < 0.001).

Factors influencing crop damage occurrence and mitigation measures used

The severity of crop damage did not vary according to the average distance of households from the park border (ANOVA test, $F_{3, 119}$ = 0.62, p = 0.603). Although not significant (ANOVA test, $F_{2, 119}$ = 2.17, p = 0.119), households in Ma’an seemed on average closer to the park (Mean ± SD = 4.5 ± 3.6 km) than those in Campo (7.25 ± 4.2 km) and Niete (6.3 ± 4.5 km). Most respondents (97%, n = 123) were settled on national domain and only 3% (n = 4) owned their land. Most farm plots (72%, n = 74) were at least 5 km from the nearest border of the National Park, but still were victims of wildlife damages regardless of subdivisions. The average distance of households from FMU did not vary with the severity of crop damage (p = 0.321) but was significantly

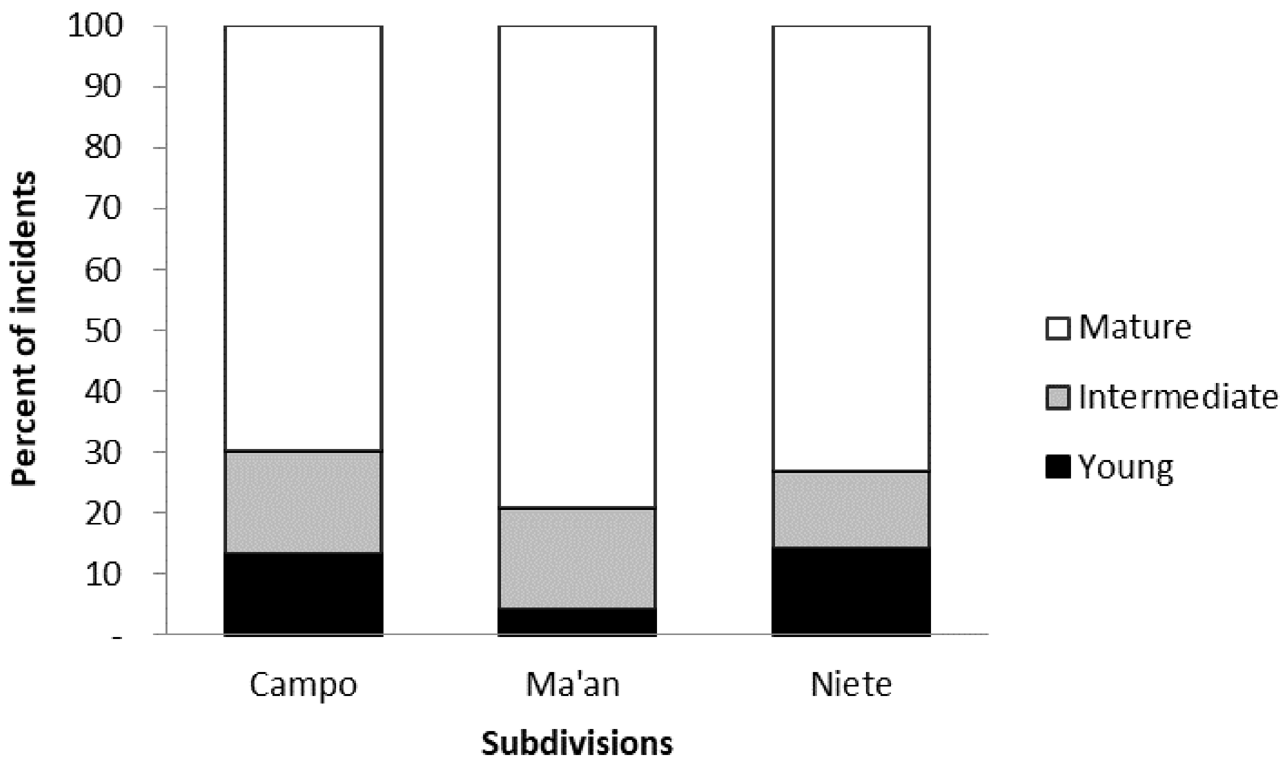

Figure 3. Percent distribution of crop raiding incidents by growth stages of the crops in three subdivisions of the Campo Ma'an region, southern Cameroon.
Source: Authors

Table 2. Distribution of crop raiding incidents reported per animal taxon in Campo (N = 450), Ma'an (N = 131) and Niete (N = 219).

Animal species	Total	Campo		Ma'an		Niete	
		n	%	n	%	n	%
Cane rat: *Thryonomys swinderianus*	225	120	27	33	25	72	33
Elephant: *Loxodonta cyclotis*	151	89	20	1	1	61	28
Talapoin: *Miopithecus talapoin*	113	71	16	14	11	28	13
Porcupine: *Atherurus africanus*	86	37	8	27	21	22	10
Rat: *Cricetomys gambianus*	75	24	5	27	21	24	11
Bush pig: *Potamochoerus porcus*	41	36	8	5	4	0	0
Sitatunga: *Tragelaphus spekei*	22	19	4	3	2	0	0
Gorilla: *Gorilla gorilla*	24	17	4	7	5	0	0
African buffalo: *Syncerus caffer*	18	13	3	2	2	3	1
Mandrill: *Mandrillus sphinx*	11	11	2	0	0	0	0
Snakes	7	3	1	2	2	2	1
African small-grain lizard: *Varanus sp*	4	3	1	1	1	0	0
Chimpanzee: *Pan troglodytes*	5	3	1	2	2	0	0
Squirrel: *Xerus erythopus*	9		0	6	5	3	1
Pangolin: *Uromanis tetradactyla*	2	2	0	0	0	0	0
Birds*	4	1	0	0	0	3	1
African civet: *Vivera civetta*	2	1	0	0	0	1	1
Daman tree*: Dendrohyrax arboreus*	1	0	0	1	1	0	0

*Birds refer to Grey parrot (Psitacus eritacus) and Village Weaver (Ploceus cucullatus).
Source: Authors

Table 3. Frequency and percentage distribution of mitigation techniques per subdivision.

Methods	Total	Campo		Ma'an		Niete	
	N	n	%	n	%	n	%
Fencing	54	35	52	8	57	11	24
Trapping	45	30	44	8	57	7	16
Noise making	22	15	22	2	14	5	11
Fire around the farm	20	15	22	1	7	4	9
Camping in the farm	13	12	18	0	0	1	2
Abandon the plot	6	2	3	0	0	4	9
Killing problem animal	4	2	3	1	7	1	2
Lighting farm at night	1	1	2	0	0	0	0
Raising bees	1	1	2	0	0	0	0
Scarecrows	4	1	2	1	7	2	4
Pepper crops	1	1	2	0	0	0	0
Clearing farms' edge	4	0	0	1	7	3	7
Shifting land	2	0	0	0	0	2	4
Growing sweet potatoes	1	0	0	0	0	1	2
Early harvest	1	0	0	0	0	1	2
Selecting crop	1	0	0	0	0	1	2
None	14	5	7	1	7	8	18

A total of 127 respondents were surveyed in Campo, Ma'an and Niete from May through August 2018.
Source: Authors

different between subdivisions (ANOVA test, $F_{2,\ 119}$ = 21.35, $p < 0.001$), with model $R^2 = 0.28$. On average farms from Ma'an (3.3 ± 2.1 km) were farther to FMU border than those from Campo (2.2 ± 0.8 km; Estimated difference 1.17, [0.17, 2.18]); while farms from Ma'an were on average farther than those from Niete (3.95 ± 1.9 km; Estimated difference 1.79, [1.12, 2.45]). Sixteen methods were identified as commonly used by locals to protect their crops from wildlife damage (Table 3). Overall, mitigation techniques used by respondents differed significantly in proportion for the five most used methods (Table 3) regardless of the subdivisions (χ^2_4 = 39.81, $p < 0.001$). While noise making was equally used among subdivisions (χ^2_2 = 2.77, p = 0.251), use of traps (16%, χ^2_2 = 23.23, $p < 0.001$) and fencing (24%, χ^2_2 = 13.77, p = 0.001) were less used in Niete as compared to Campo and Ma'an (Table 3).

Economic impact of human wildlife conflict

Average agricultural income losses did not vary between the subdivisions (ANOVA test, $F_{2,\ 90}$ = .05, p = 0.950), but varied significantly with severity level (ANOVA test, $F_{3,\ 90}$ = 3.39, p = 0.021), with model $R^2 = 0.10$). The average losses of agricultural income were estimated for Campo, Ma'an and Niete (Table 4). The average loss of income for households experiencing moderate losses (Mean ± SD = 189,080 ± 248,615 FCFA or US$ 315 ± 415, n = 14) were lower (Estimated difference with 95% CI = -1174180.2, [-2,266,542.61, -81,817.84]) compared to the average income loss of those with extremely severe crop losses (1,462,763 ± 2,686,825 FCFA or US $2,437 ± 4,478, n = 25). Households with more severe income losses (522,840 ± 870 FCFA or US $ 871 ± 1,096, n = 21) and those with severe losses (376,910 ± 390,015 FCFA or US $ 628 ± 650, n = 19) were comparable (All p > 0.05). The average agricultural incomes were estimated respectively for Campo, Ma'an and Niete (Table 4). All calculations are done at a rate of US $ 1 = 600 FCFA.

Human influence on wildlife

Data were presented from the anti-poaching unit for the period 2014-2017 from the CMTOU in Table 5. It appears that a variety of evidence exists confirming the real impact of humans on wildlife including actual gun seized to poachers. Between May and December 2019, 19 cameras deployed in the conservation area took 20,325 photos. From these images, 10,681 humans were seen on 4,376 photos (22%) and included 428 (4%) hunters, 9,531 (89%) loggers, 28 (1%) antipoaching patrols staff and 694 (6%) research assistants. Human occurrence differed between land use types (n= 9,959, χ^2_2 = 18,64, $p < 0.001$; Figure 4). The majority were filmed in the community area as compared to the park (χ^2_1 = 9721, $p < 0.001$) and the FMU (χ^2_1 = 9,129.70, $p < 0.001$). In addition, more persons were filmed in the FMU compared to the park (χ^2_1 = 189.90, $p < 0.001$). The distribution of

Table 4. Summary (mean ± standard deviation) of the average agricultural income and average agricultural income losses by farmers in Campo, Ma'an and Niete subdivisions.

Subdivisions	Average agricultural income (mean ± SD)		Average loss of agricultural income (mean ± SD)	
	CFA	USD	CFA	USD
Campo	945,235 ± 1,196,515	1,575.5 ± 1,994	644,480 ± 1,003,630 (68%)	1,075 ± 1672.7
Ma'an	1,794,135 ± 2,153,780	2,990 ± 3,590	420,265 ± 267,200 (23%)	700.5 ± 445.3
Niete	1,327,660 ± 3,051,700	2,212 ± 5,086	1,075,800 ± 2,801,530 (74%)	1,793 ± 4,667

The values are given in the local currency in Franc CFA (Communauté Financière Africaine) and in US$ (1 USD ~ 600 CFAF). The percentage of income losses are given in brackets.
Source: Authors

Table 5. Summary of the results from the antipoaching unit between 2014 and 2017 in the Campo-Ma'an Technical Operational Unit.

Poaching indices	2014	2015	2016	2017
Gun seized	19	11	15	23
Sockets	159	282	177	230
Traps destroyed	578	319	819	607
Ammunition seized	243	101	138	119
Camps destroyed	35	52	57	66
Animal remains	466	211	135	149
Earing report	6	7	20	14
Ivory seized	0	2	0	2
Elephant carcasses	0	1	3	4
Complaints against wildlife (elephants, gorilla, mandrill)	16	2	3	3

Gun seized, traps destroyed, firearms cartridges, ammunition seized, camps destroyed, animal remains seized, ivory seized, and elephant carcasses are all related to illegal actions of humans against wildlife. Hearing reports refer to humans suspected of conducting illegal activity related to wildlife and transferred to the court for prosecution. Complaints against wildlife refer to a limited number of farmers who reported their crop damages to the conservation office.
Source: Authors

the hunters differed significantly between land use types (χ^2_2 = 403.88, $p < 0.001$; Figure 4). Overall, more hunters (78%, n = 333) were observed in the community area as compared to the park (2%, n = 7, χ^2_1 = 312.58, $p < 0.001$ and FMU (21%, n = 88, χ^2_1 = 142.58, $p < 0.001$). There were also more hunters in the FMU than in the park (χ^2_1 = 69.06, $p < 0.001$). Of the 9,531 images of loggers, the majority (99%, n = 9,409) were filmed in community area as compared to the FMU (1%, n = 122, χ^2_1 = 9,049.20, $p < 0.001$; Figure 4). No tree logging activity was observed in the park.

DISCUSSION

The findings confirm the reportedly increasing HWC worldwide, with evidence of wildlife damaging crops and humans poaching and destroying wildlife habitat. We also show that level of conflict varies among subdivisions and therefore can be site-specific, causing the abandonment of farms and the dependence of the populations of Campo on the food crops that are no longer cultivated locally. Finally, the study provides evidence of humans' influence on wildlife using human photos from 19 camera traps. That 98% of the respondents reported being a victim of damage by wildlife is symptomatic of people living close to PAs and may be the result of the increase in population in this area; from 60,338 inhabitants in 2002 to 111,000 in 2011 (MINFOF, 2014). This result is consistent with several studies with more than 80% of households experiencing wildlife crop raiding (Weladji and Tchamba, 2003; Karanth et al., 2013b; Gontse et al., 2018). Many wildlife species from various taxa were identified as responsible for crop damage, including elephants and rodents (King, 2010; Ole, 2011; Conover et al., 2018). We found the level of damage to differ between the subdivisions, being less severe in Ma'an where elephant density is lowest (Matthews and Matthews, 2006; Nzooh-Dongmo et al., 2015). The observed pattern matched elephant's distribution in the CMTOU; as Ma'an was the less affected by elephant damages. In contrast, Niete, previously problem-free (Eyebe et al., 2012; MINFOF, 2014), became a new elephant conflict area since the start or major project in

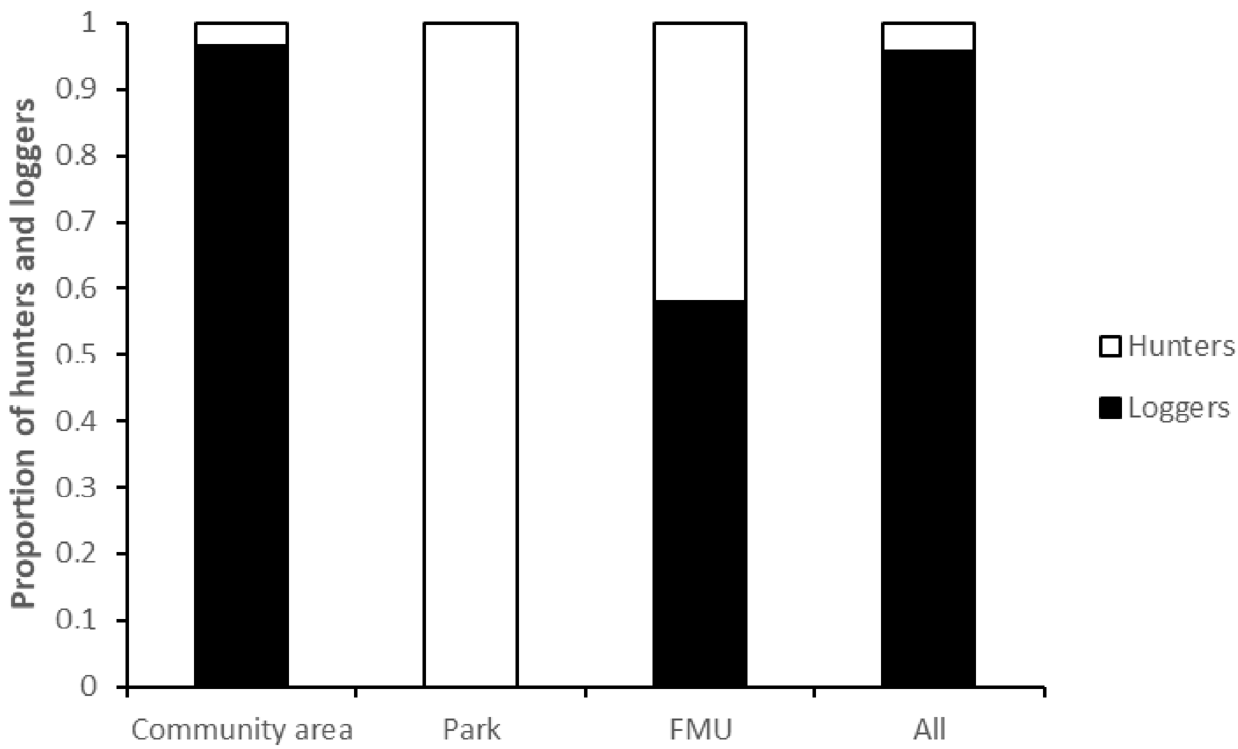

Figure 4. Proportion distribution of the number of images of hunters and loggers across Community Land, National Park, and Forest Management Unit (FMU). Hunters occurring in the National Park or FMU are considered poachers.
Source: Authors

the conservation area. Elephants were the animals causing the most losses in Campo and Niete with their single raiding event surpassing the cumulative raiding of all other crop raiders. This result is consistent with the broad idea of extreme severity associated with elephant damages (; Anand and Radhakrishna, 2017; Gontse et al., 2018; Ngama et al., 2018). Selective damage to staple food crops by wildlife lowers the yield (Eyebe et al., 2012; Nyirenda et al., 2018; Breuer and Ngama, 2020). Although crop damage occurs at all stages of plant growth, it worsens when crops mature and are ready for harvest by farmers. This result is consistent with other findings (Granados and Weladji, 2012; Mwakatobe et al., 2014; Pant et al., 2016; Breuer and Ngama, 2020). Forest elephants might consider farms with mature crops as part of their seasonal food. Indeed, mature crops are of high nutritional value providing necessary calories needed by wild animals while reducing their movement and feeding time**.** We observed in the field that the creation of plantations opens the canopy and creates attractive spots surrounded by fruit trees consumed by wildlife, including elephants. Such disturbed areas create secondary forests that are attractive to wildlife because it concentrates good quality food in a small area (Mwakatobe et al., 2014; Breuer and Ngama, 2020). Distance to the PA is an important predictor of the severity level of damages to crops (Naughton-Treves, 1997; Mwakatobe et al., 2014). Most damage occurred within 500 m of villages, far from the park border but often close to the logging concessions considered PAs, and, therefore, part of wildlife habitat (MINFOF, 2014; Nzooh-Dongmo et al., 2015). Contrary to observations elsewhere (Naughton-Treves, 1997; Mwakatobe et al., 2014; Pant et al., 2016), we found that proximity to park border did not explain the level of damage. Wildlife in the conservation area takes advantage of the contiguous forest cover despite a variety of land use systems being applied. Indeed, the 2015 inventory of wildlife shown that elephants as many other wildlife reside permanently in the FMU to which villages are closer than to the park (MINFOF, 2014; Nzooh-Dongmo et al., 2015).

Farmers mostly make cash income from the sale of their crops. Crop destructions by wildlife influenced household economic stability as elsewhere (Weladji and Tchamba, 2003;; Mwakatobe et al., 2014; Gontse et al., 2018; Terada et al., 2021). The average agricultural income lost per year per household were lower in Ma'an (23%) than in Campo (68%) and Niete (74%), and this corroborates the distribution of the elephant populations likely to raid farms unfortunately with no direct aid from the conservation authorities. This indicates that despite the diversity of crop raiders, the imprint of the forest elephants on people's income is particularly noticeable (Nyirenda et al., 2018; Breuer and Ngama, 2020;

Compaore et al., 2020; Terada et al., 2021). Several studies have documented the detrimental effects of human activities on wildlife (Fa et al., 2015; Kouassi et al., 2017; Lata et al., 2018), which may well also be occurring in the CMTOU where we found evidence of poaching and logging attributed to local communities. Bushmeat is a staple food for people living in the vicinity of PAs (Fa et al., 2015; Kouassi et al., 2017; Martin et al., 2020). Because of the restrictions on hunting, poaching is often the only way people can have access to the much-needed bushmeat, although one can hunt in the community area as per the domestic use right. In fact, the hunting and consumption of species with high growth rate is tolerated to improve cohabitation between forest wardens and farmers, and to minimize the risk of human–human conflict (*sensu* Dickman, 2010; Breuer and Ngama, 2020; Martin et al., 2020). That local communities do not have access to the species causing them the more losses can trigger negative attitudes toward wildlife and conservation (Weladji and Tchamba, 2003; Granados and Weladji, 2012). Based on this, one may consider some of their actions as retaliations, justifying to some extent their resentment towards wildlife as seen by the many proofs reported by the law enforcement unit (amount of poachers' camps and traps destroyed, ammunitions collected, firearms and ivories seized, poachers arrested, etc. (Table 5) (Tiani et al., 2005). Local communities were also involved in "illegal" logging in the CMTOU. These activities impose the opening of roads and removal of trees some of which provide fruit food to forest elephants. Consistent to other findings, this will lead to the fragmentation and loss of wildlife habitat, the movement of animals to other sites where they may become vulnerable, and ease the access to the park for poachers (Lata et al., 2018; Breuer and Ngama, 2020). Even though our images displayed illegal hunters and loggers, we did not denunciate them to park authorities, fulfilling our obligation of respecting their privacy, a guarantee for the acceptance by the populations of the introduction of camera traps for research (Sandbrook et al., 2018, Sharma et al., 2020). Disturbances in the park's eastern side from dam construction (2012–2017) might have forced large mammals, including elephants, to move away (MINFOF, 2014; Nzooh-Dongmo et al., 2015).

Severe damages to different crop species threaten the food security of the populations. This may build resentment in them, as no alternative food source exist, making it challenging to resolve HWC (Dickman, 2010; Barua et al., 2013). Local resentment is often intensified by conservation regulations that impede local communities' capacity to cope with losses to wildlife (Dickman, 2010). Consequently, they turn to illegal activities in the conservation area, which put pressure on wildlife habitat and threatens biodiversity. This calls for an urgent need for a broad enough solution to accommodate both parties, which is not easy to achieve. Indeed, although several mitigation strategies have been proposed and even tested in several places, most have limitations suggesting that conflict requires original and comprehensive approaches for long-term resolution (Dickman, 2010; Anand and Radhakrishna, 2017; Karanth and Kudalkar, 2017). HWC is complex because of involvement of many factors (Dickman, 2010; Anand and Radhakrishna, 2017; Torres et al., 2018). Conflict situations in the CMTOU are all about crop damages by wildlife in search of nutritious and palatable foods, and poaching, making coexistence difficult for communities and conservationists (Torres et al., 2018; Breuer and Ngama, 2020; Terada et al., 2021). This situation induced direct costs for farmers in terms of time and money (Barua et al., 2013, Nyirenda et al., 2018). There are also indirect costs, such as the psychological effects associated with the risk of starvation, injury or even death (Barua et al., 2013; Hoare, 2015; Breuer and Ngama, 2020; Terada et al., 2021). HWC is shaped by actual and past interactions with wildlife. Considering such hidden aspects that shape conflict situations can be a significant step toward a lasting solution (Dickman, 2010; Barua et al., 2013; Hoare, 2015; IUCN, 2020).

The construction of fences and traps around fields was used against small fauna. In contrast, noise production by any means possible was used to repel problem animals such as elephants, great apes, and other animals considered dangerous (Ole, 2011; MINFOF, 2014). Fencing is often associated with camping in the forest near the farms around large fires, producing smoke that may keep animals away. These methods, taken individually or in combination, unfortunately, require a physical presence which has repercussions on the organization of the family, their livelihood, and the children's education, especially during the harvest period (King, 2010; Mwakatobe et al., 2014). Sometimes, farmers use scarecrows or call for culling from the wildlife authorities, which does not occur often. A compensation scheme existed in the early period of the creation of the CMNP, including setting up revolving funds with women's associations and a micro-credit system to help local people develop economic activities, but it has since disappeared because of the insolvency of the first beneficiaries (MINFOF 2014). Other less-widely used techniques have also been implemented, such as night lighting of fields with flares and cultivation of chili at the edge of the field, but as we know, smart elephants get habituated when repeatedly exposed to new methods (King 2010; Nelson et al. 2003). Compensation schemes have been also proposed elsewhere and used as mitigation strategies, but results are not always conclusive (Nelson et al., 2003; Karanth et al., 2013a).

Economic losses in agriculture (Table 4) could justify the intensity of alternative activities such as hunting, fishing, gathering or picking of non-wood forest products that provide financial support to households (Tiani et al., 2005). In addition, we noticed the lack of enthusiasm for the creation of new agricultural plots by some respondents in Campo, arguing that the presence of the elephant in their vicinity is forcing them to switch their feeding habits favoring imported products, to be purchased and for which they are not used to. At the subdivision level, the direct impacts of the conflict in the western side of the park (Campo and Niete, Table 4) could be the lack of locally produced foodstuffs, which would have helped to lower the cost of living. Unfortunately, almost all the products consumed are imported from areas less exposed to HWC including Ma'an. Such impacts have been described in northern Congo leading to an increased price of staple food products (Breuer and Ngama, 2020). Although we validated crop raiding data with those compiled for the conservation of large and medium size mammals, we acknowledge several limitations to the study. We used recall type questionnaires whereby the data are obtained based mainly on the declarations of farmers. Therefore, they present the risk that people may differ in their ability to recall and may not be accurate in their answers because of poor memory. Also, they may have overestimated the loss hoping to receive some sort of compensation at one point. The interview took place in private for some households. In contrast, some respondents were interviewed in the presence of their relatives who could have influenced their answers to questions, depending on how information was being shared within a household. Despite our efforts to validate the extent of damages reported by the respondents, we could only visit 12 farms from which recent elephant damages could still be visible in the field. Although signs may be less visible, we could have visited other farms damaged by other wildlife species as well.

Conclusion

We reported evidence of HWC in the CMTOU, the subdivisions with higher elephant density suffering higher economic losses. As agriculture is the main source of food and income for these populations, we need to understand elephant movement patterns better to inform the development of appropriate mitigation measures. It is imperative that we rethink conservation policies for large mammals in this densely populated area. This will imply revisiting land use planning and the choice of sites allocated for the creation of large-scale plantations in this landscape. We acknowledge that HWC is complex in nature and that mitigation strategies do not always work. Therefore, we recommend using holistic and adaptive solutions, which consider direct and indirect costs while satisfying wildlife and human needs. This will require setting up adaptive land use systems, modifying and empowering wildlife legislation. For example, the creation of a community hunting area on the FMU as proposed by the management plan of the CMNP (MINFOF, 2014), and the facilitation of the use rights by allowing locals more access to natural resources from the CMTOU to favor tolerance and coexistence of both protagonists. Also, it may be important to set up a permanent crop damage monitoring process in different villages close to farmers to estimate the actual level of loss.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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SUPPLEMENTARY MATERIALS

Supplementary material 1: Consent form

Human-wildlife conflict in the Campo-Ma'an Technical Operational Unit, southern Cameroon

By:______________, PhD student,___________ University. Contact:__________
Preamble:

This questionnaire is designed for research on "the human-wildlife conflicts" in your community, carried out by me, ________________________. The research aims are to: (1) assess the socio-economic impact of the human-wildlife interactions around CMNP; (2) study the relationship between different stakeholders that is park staff, local people, the private organizations as well as the non governmental organizations operating in the area; (3) Assess people's attitudes and perceptions towards wildlife, the park and the wildlife legislation; (4) Study some ecological aspects of the elephants including testing some mitigation measures; and finally (5) Propose plans to mitigate conflicts and promote ecosystem-based management for the park.

If you accept to participate, you will be asked several questions (see questionnaire), and eventually we will visit your farm to assess the level of damage caused by elephants to your crops. The answers that you will provide us on the following questionnaire, which lasts approximately 45 minutes, will remain confidential and will be used exclusively by the researchers for the study.

There is no risk in participating in this study. However, by providing your name, we may use this information in the events of a compensation program that is retroactive. There is no guaranty for this, however. You are free to decline or accept that your name be disclosed for this purpose.

It remains at your discretion to determine whether you wish to answer the questionnaire in whole or in part, or if you do not wish to participate at all. If this study is published, the anonymity and confidentiality of this questionnaire will always apply. You must also be at least 18 years old to participate.

If you have any questions, please do not hesitate to ask me during the interview or later by email at "_____________________"or by phone at"_______________________".

Do you agree to participate in the study under the conditions described above?
If yes, say YES
If no, say NO

Thank you!"

Supplementary material 2: Subset of the Household questionnaire

Name: _______________________ Age _______________ Sex____________

Education level:

Primary:	Lower secondary:	Upper secondary:	Higher education:

(1) Did you experience crop damage by wildlife anytime the last 3 years? Y___ N___
(2) If yes, list crop types by area cultivated and the expected income/sale from each.

	Area	**Crop types**	**Total output (tons/bags)**	**Sale (in Franc CFA)**
1 2 3 4				

(3) How far is your farm from the village?

01 : 0-500 m	02 : 0.5-1 km	03 : more than 1 km	04: Estimate (from the village)

(4) How far is your farm from the CMNP?

01: 0-2 km	02: 2-5 km	03: > 5 km (give an estimate)

(5) What proportion of your field was damaged?

01: a little bit (0 - 25%) moderate	03: more than half (50% - 75%) more severe
02: just under half (25% - 50%) Severe	04: the whole field (75% - 100%) extremely severe

(6) What animals are responsible for the damage (by crop type and by crop stage of growth)

		Stage of growth		
Species	Type of crop damaged	Young	Intermediate	Mature
1				
2				
3				
4				
5				
…				

(7) What are the methods you have used to deter wildlife from causing crop damage? Name and describe each, including to what extent it was effective.

1:_______________________________________
2: _______________________________________
3:_______________________________________
4:_______________________________________

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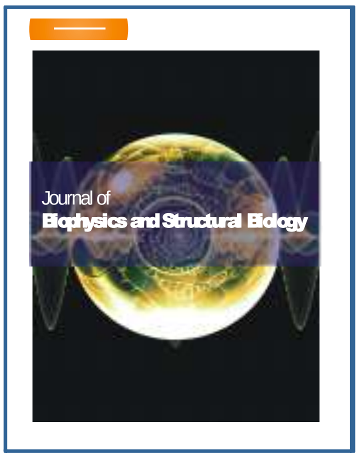

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