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Population density of elephants and other key large herbivores in the Amboseli ecosystem of Kenya in relation to droughts

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ABSTRACT

Kenya/Tanzania borderland is a critical area for conservation of biodiversity. This study was done to establish the effects of 2007 and 2009 droughts through aerial counts. Findings indicate that large mammal population collapsed, but some species crashed more than others. Total large mammal density declined over three times (−207.43%), recovering modestly (+41.59%) between 2010 and 2013. Over that time, the most abundant species was zebra (10,466.3 ± 2860.5 animals), followed by wildebeest (8921.0 ± 4897.9), Grant's gazelle (3447.0 ± 303.7), Maasai giraffe (1381.3 ± 132.7), African elephant (990.67 ± 12.60), eland (544.0 ± 311.4), Thomson's gazelle (495.3 ± 232.3), buffalo (331.3 ± 128.8) and impala (354.3 ± 61.0). The species affected most by drought was lesser kudu, followed by African buffalo, Maasai giraffe, kongoni, common eland, common wildebeest, common zebra, Grant's gazelle, gerenuk, impala, African elephant, Thomson's gazelle and fringe - eared Oryx respectively. Further, large mammal species numbers were dependent on location ($\chi 2 = 13,647.35$, df = 15, $p < 0.001$), with numbers being higher near protected areas. Animals with low numbers, specific diets, water - dependent and limited range were most affected by the drought. This provides a baseline for future comparisons and also future effects of droughts.

1. Introduction

Wildlife conservation in Kenya began during the British colonial rule and continued after independence in 1963. This has seen nearly 8% of the country set aside for biodiversity conservation purposes, and plans are underway to have additional landscapes designated as wildlife conservation areas. This is in recognition of the key role played by tourism in foreign revenue generation. Although numerous strategies and financial resources have been used to enhance wildlife conservation, there is rampant population decline of numerous species throughout the country such as the African elephant (*Loxodonta africana*), black rhino (*Diceros bicornis*), gravy zebra (*Equus grevyi*), and large carnivores especially lion (*Panthera leo*) and cheetah (*Acynonix jubatus*), various species of monkeys, hilora antelope among others (Western et al., 2009a).

Numerous studies have examined the causes of decline of wildlife populations in different parts of Kenya (e.g. Ottichilo et al., 2000, 2001; Okello and Kiringe, 2004; Western et al., 2009a; b; Primack, 1998). Collectively, these studies reveal that a myriad of anthropogenic factors such as; human-wildlife conflicts, illegal wildlife poaching, bush meat activities, increase in human population, alienation or inadequate involvement of locals in conservation initiatives and programs, proliferation of inappropriate land uses like agriculture which compromise wildlife survival and its conservation are responsible for the decline of wildlife. However, the contribution of drought to wildlife decline has not been fully evaluated yet its effects on populations can be devastating just like

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human related impacts. This article therefore focusses on the impact of the 2007 to 2009 drought on elephants and other key large mammalian wildlife species in the Amboseli Ecosystem of Kenya.

In the last century, most parts of Kenya more so the high potential and heavily human populated have seen tremendous decline and loss of large mammalian wildlife species. However, the Amboseli Ecosystem, a semi-arid region, which until recently was characterized by relatively low and sparse human population (although now increasing because of immigrants and high birth rates) is still endowed with diverse free ranging wildlife species. Two major factors have interactively contributed to preservation of wildlife in the ecosystem, elephants included; a semi-arid environment which acts as an ecological limitation to land use especially proliferation of rain-fed agriculture, lifestyle, culture and traditions of the Maasai people who are the main inhabitants. The foundation of the Maasai lifestyle is pastoralism which thrives in relatively dry areas and allows livestock and wildlife to co-exist which makes it compatible with wildlife conservation (Berger, 1993; Ntiati, 2002). Further, overtime, various taboos and traditional beliefs which abhors eating and indiscriminate killing of wildlife among the Maasai has equally contributed to wildlife preservation over the years (Seno and Shaw, 2002; Kangwana, 2011).

In the context of the Amboseli Ecosystem, the Amboseli National Park which is the ecological lifeline of herbivorous wildlife species is an important dry season concentration area for elephants and other large wildlife species like common wildebeest (*Connochaetes taurinus*), buffalo (*Sycerus caffer*) and common zebra (*Equus burchelli*) (Western, 1975; Western and Maitumo, 2004; Croze and Lindsay, 2011; Kangwana and Browne-Nunez, 2011). These species also tend to spend nearly 80% of their time outside the park and use a landscape about 20 times bigger than the park (Croze and Moss, 2011). Studies have therefore demonstrated that these species move seasonally in and out of the park (Western, 1975; Esikuri, 1998; Kioko, 2005; Croze and Lindsay, 2011), but are currently living in a rapidly evolving human matrix characterized by enormous land use, tenure and increasing human population growth as a result of immigrants overflowing from fertlile arable lands, and increasing local birth rates (Okello and Kioko, 2010; Kangwana and Browne-Nunez, 2011). This poses an immediate and future threat to the survival and conservation of wildlife in the entire ecosystem (Western, 1982; Kangwana and Browne-Nunez, 2011).

The population of elephants in the ecosystem which is currently estimated at nearly 1500 individuals (Croze and Lindsay, 2011) was nearly exterminated in the 1980s due to poaching. Moss (2011) estimated that in the early 1970's, the elephant population in the entire ecosystem was about 600 individuals and due to the relative safety accorded to them, the population rapidly increased, and by the end of 2002, it stood at nearly 1225 individuals. It's one of the best-studied wild elephants in Kenya and the world, as a result of work of Cynthia Moss and her collaborators over the last 30 years. The population once extended from Ol Donyo Orok in the west to the Chyulu Hills in the east, near the town of Emali in the north, and to the slopes of Mt. Kilimanjaro in the south (Western and Lindsay, 1984). During the 1990s and into the last century, the range has begun to expand again. Consequently, considerable efforts have gone into encouraging the Amboseli elephants to disperse more widely outside the park by working towards greater tolerance amongst local communities.

The future and long term conservation of elephants and other wildlife types in the Amboseli region depends not only on maintaining the ecological integrity of Amboseli National Park and adjoining areas but also enlisting the support of the Maasai who live beyond the park boundaries. However, there are concerns that the park's integrity and consequently its ability to support elephants and populations of other large herbivores like zebra and wildebeest has increasingly been compromised by long term vegetation changes. For the last 50 years or so, the yellow acacia woodlands have significantly declined and are nearly absent in most parts of the park, and this has created a lot of concern among conservationists and wildlife management authorities in the country (Western and Maitumo, 2004; Western, 2006).

In their 20 years research work in the park, Western and Maitumo (2004) demonstrated that loss and impaired regeneration of Acacia woodlands in the park was largely attributed to impacts associated with elephants. Subsequent studies (Western, 2006) further revealed tremendous changes in vegetation within the park characterized by decline and loss of woody vegetation communities and expansion of grassland and scrubland. This has in turn put a lot of ecological pressure on the swamps through herbivory and trampling effects of large aggregations of elephants, zebra and wildebeest particularly during the dry season when their dispersal is reduced. Another concern regarding the future of the park is the effects if climate change and rainfall variability (Fig. 1). Thompson et al. (2009) noted that the glaciers and relief rainfall of Mt. Kilimanjaro are the major source of water for the Amboseli swamps, but climate change effects on water sources are affecting the volume of these swamps. This is also being accelerated by the logging and general deforestation on Mt. Kilimanjaro. The short and long term ecological damage associated with environmental change can't be underestimated, and calls for crafting of well thought and sound management strategies that will reduce significant deterioration of the park. Thus, every effort should be made to ensure the landscape adjoining the park is secured and both elephants and other migratory species are able to use them as has been the tradition.

Another concern in the borderland is the emergence of agriculture especially in the Amboseli Ecosystem, which was introduced in the last century by immigrants from other parts of Kenya plus the Chagga people from Tanzania (Esikuri, 1998; Ntiati, 2002; Okello, 2005; Okello and D'Amour, 2008). The ecological ramifications and threats posed by this new land use continues to cause a lot of concern among conservationists and wildlife conservation NGOs working in the region. Seno and Shaw (2002) have described the emergence of a diverse community of farmers, ranchers, and entrepreneurs in areas like the Amboseli as the biggest challenge to the future of wildlife conservation. Further, the push and general clamor for sub-division of the group ranches will have irreversible negative impacts on elephants and other species alike and will negatively affect wildlife survival and conservation efforts, and this

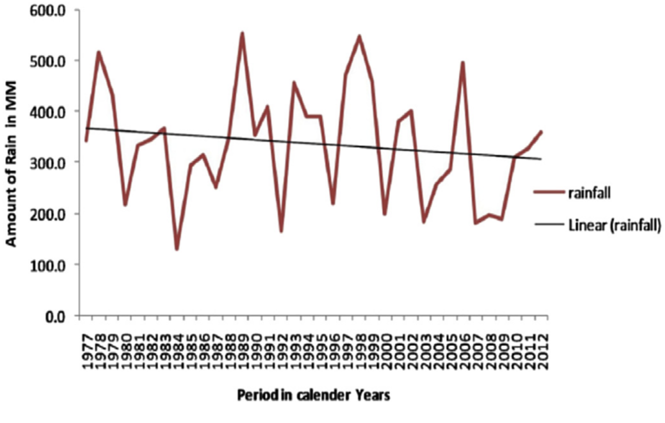

Fig. 1. Rainfall trends in the Amboseli Ecosystem (1977–2012). Source.Kenana et al., 2013

has become the single most important threat to wildlife, elephants included (Croze et al., 2006).

Globally, the percentage of land under drought has risen dramatically in the last 25 years, and the incidents of drought, both short and long term, has been rising in Africa (Conway, 2008), including the Amboseli region (Thompson et al., 2009). Given the arid to semi-arid nature of the region, droughts can lead to massive mortality of wildlife especially water dependent species and those which require large amounts of daily food intake. In this regard, during the 2007 to 2009 there were two severe droughts in the Kenya/Tanzania borderland (land encompassing Kilimanjaro, West Kilimanjaro, Lake Natron and Lake Magadi area) that had one of the most severe effects in history because of their proximity and impacts on large mammals and livestock. The Kenya/Tanzania borderland represents one of the most important conservation areas in the world, having large free wild mammals roaming between Kenya and Tanzania and having renowned national parks (Amboseli, Kilimanjaro, Maasai Mara and Serengeti). It therefore represents an important conservation area in the world. The two droughts in the region may have been some of the most severe in history due to impact and proximity, and so provided an opportunity to examine the influence of droughts on elephants and other key large herbivorous wildlife species, based on data collected during the dry season and within two droughts between 2007 and 2009.

The overall objective was to estimate the changes in elephant and other large herbivore density associated with droughts and make inferences about this for large mammal conservation. Specifically, we addressed the following objectives:-

i. Determine the population status elephants and key large herbivorous wildlife species in the Amboseli Ecosystem
ii. Assess the effects of the 2007 to 2009 drought on the population of elephants and key large herbivorous wildlife species in the Amboseli Ecosystem
ii. Establish the distribution pattern of elephants and other large wildlife species in the Amboseli Ecosystem
iv. Make appropriate recommendation for management

2. Materials and methods

2.1. The 2008 to 2011 drought and its impacts in Kenya

According to NOAA (2008), drought is a deficiency in precipitation over an extended period, usually a season or more, resulting in a water shortage causing adverse impacts on vegetation, animals, and/or people. It is a normal, recurrent feature of climate that occurs in virtually all climate zones, from very wet to very dry. Drought is a temporary aberration from normal climatic conditions, thus it can vary significantly from one region to another. Drought is different than aridity, which is a permanent feature of climate in regions where low precipitation is the norm, as in a desert.

This large mammal count was done at a time when there were two severe droughts in the Kenya/Tanzania borderland (PDNA, 2011). For the entire country, rainfall fell below the monthly average in 8 months out of 12, or 67 percent of the time in 2008. In 2009, the number of months showing less rainfall than the long-term monthly average increased to 9 or 75 per cent of the time. In 2010, the number of rainfall deficit months decreased to 7.5 months (62 percent of the time); and in the first half of 2011, the number of months rose significantly to 5 out of 7 months (72 percent of the time) (PDNA, 2011).

The overall impact of the 2008–2011 droughts in Kenya is estimated at Ksh 968.6 billion (US$12.1 billion). This includes Ksh 64.4 billion (US$805.6 million) for the destruction of physical and durable assets, and Ksh 904.1 billion (US$11.3 billion) for losses in the flows of the economy. The most affected sector was livestock (Ksh 699.3 billion), followed by agriculture (Ksh 121.1 billion). The highest values of per capita damage and losses occurred in provinces where the HDI is lowest. The economic impact of the drought is estimated to have slowed down the growth of the country's economy by an average of 2.8 percent per year across Kenya (PDNA, 2011; NOAA, 2008).

2.2. Study area

Amboseli region is situated in the Southern part of Kenya, and covers an area of approximately 8797 Km^2 (Fig. 2). It's made up of several blocks of land, mainly; Amboseli National Park, and Maasai owned group ranches (Olgulului/Olararashi, Eselenkei/lengisim, Mbirikani, Kuku, Kaputei, Osilalei, Mailua and the former Kimana/Tikondo Group Ranch. It also includes former 48 former ranches, located on the lower slopes of Mt. Kilimanjaro along the international border with Tanzania, that are currently subdivided and under rain-fed agriculture (Fig. 2). The region consists of basement plains, saline plains with fresh water swamps and the volcanic slopes of Mt. Kilimanjaro. Quaternary volcanic soils on the north-eastern Kilimanjaro slope dominate around the southeast, which favors crop production while the southeast part of Ilkisongo is covered by basement rock soils making it largely suitable for pastoralism (Pratt and Gwynne (1977).

The Amboseli area lies in ecological zone VI, and is generally arid to semi-arid savanna environment with low agricultural potential (Pratt and Gwynne, 1977; Croze et al., 2006). It's characterized by spatial and temporal variation in hydrology, and surface water is only found in few permanent streams and rivers (Fig. 1). The streams, rivers and existing water resources are predominantly a result of the hydrological influence of Mt. Kilimanjaro, where water flows underground and emerges elsewhere in the form of streams, rivers or swamps (Ntiati, 2002). These springs together with rainfall, feed the rivers, streams and swamps in the area.

Rainfall in the Amboseli region is mostly bimodal, but its unpredictable and unreliable in amount and timing (Ntiati, 2002). The short rains occur between the end of October and mid-December, while the long rains fall between March and May (Okello and D'Amour, 2008), and the mean annual rainfall across the area ranges from 400 to 1000 mm (Reid et al., 2004). The October–December rainfall accounts for 45%, and the March–May for 30% of the total rainfall received. Therefore, the amount of rainfall is the single most important factor influencing land use practices, which currently include agriculture, pastoralism and wildlife conservation (Ntiati, 2002). Human population growth in the region especially within the group ranches and along the slopes of Mt. Kilimanjaro has been rapid, and population in the area more than doubled between 1979 and 1999 (Reid et al., 2004). Over the past 15 years the number of registered members within the Kimana, Kuku, and Mbirikani Group Ranches has increased by 505%, 1323%, and 497%, respectively (Ntiati, 2002). This rapid population increase is due to the immigration of non-pastoral people seeking access to more productive land within the group ranches (Ntiati, 2002). At the same time, the land within the group ranches has experienced extensive changes over the past 30 years in response to a variety of economic, cultural, political, institutional, and demographic processes (Reid et al., 2004). Pastoralism, which was once the backbone of the Maasai livelihood, has declined tremendously, partly as a result of increased agricultural activities that have become widespread in the entire region (Ntiati, 2002).

The vegetation of the region is typical of a semi-arid environment. Dominant vegetation types are: open grasslands towards the

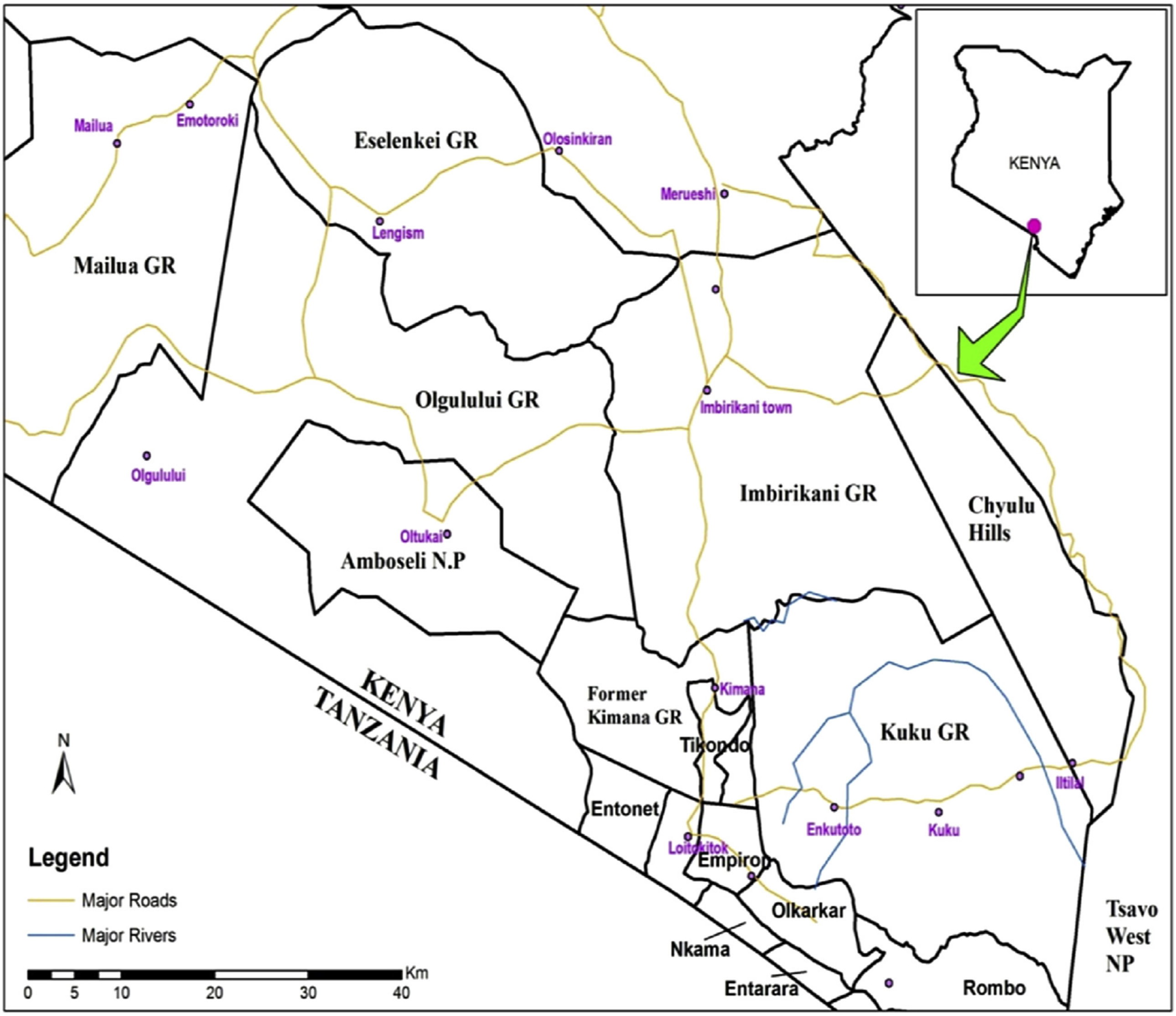

Fig. 2. Location and outline of the Amboseli Ecosystem.

north and northeast to the Chyulu Hills, Acacia dominated bushland southward to the forest belt of Mt. Kilimanjaro. In these main types, there are patches of swamps and swamp-edge grasslands and Acacia woodlands.

3. Methods

Total aerial counts of elephants and key large herbivorous wildlife species were conducted during the dry season in 2007 (24th to 29th May at the start of rain season), 2010 (11th to 16th October at the end of dry season) and 2013 (6th to 12th October) based on the technique described by Norton-Griffiths (1978). The count therefore employed the Global Positioning System (GPS) technique with Arc View software used for plotting species distribution maps. Counts were done within blocks demarcated based on well-defined ground features such as; roads, rivers, hills etc. (Fig. 3), in an average area of 7852 km^2. These features were meant to make it easier for pilots to navigate the blocks, thus the counting blocks design was demarcated so as to conform to the following rules; i) rivers were not used as boundaries of the blocks. Rivers are normally areas of concentration of animals hence not suitable as boundaries for counting blocks owing to the necessity to turn over this area and begin a new transect and the high possibility animals would move from one side of the river to the other, resulting in double counts, ii) blocks were made rectangular or square in shape, which eased navigation for the pilots and Front Seat Observer (FSO) using GPS and allowed more time for observations, iii) blocks were made small enough to be counted within a maximum of 6 h a day, and an area of 900 km^2 was deemed a suitable average size of a block, and, iv) block boundaries did not cut across areas of high wildlife density as determined by kernel densities from previous surveys.

To improve the quality of data collected on wildlife populations, the crew was trained in the use of various counting and estimation techniques, use of GPS equipment, voice recorders and cameras), species identification and estimation, data handling and processing. Practical training sessions and test flights were included as rehearsal for the actual census. The test flights involved the different flight crews flying the same mock transects at different intervals while maintaining same orientation in order to assess inter observer variability in species detection, estimation and identification. Thereafter, each block was systematically searched

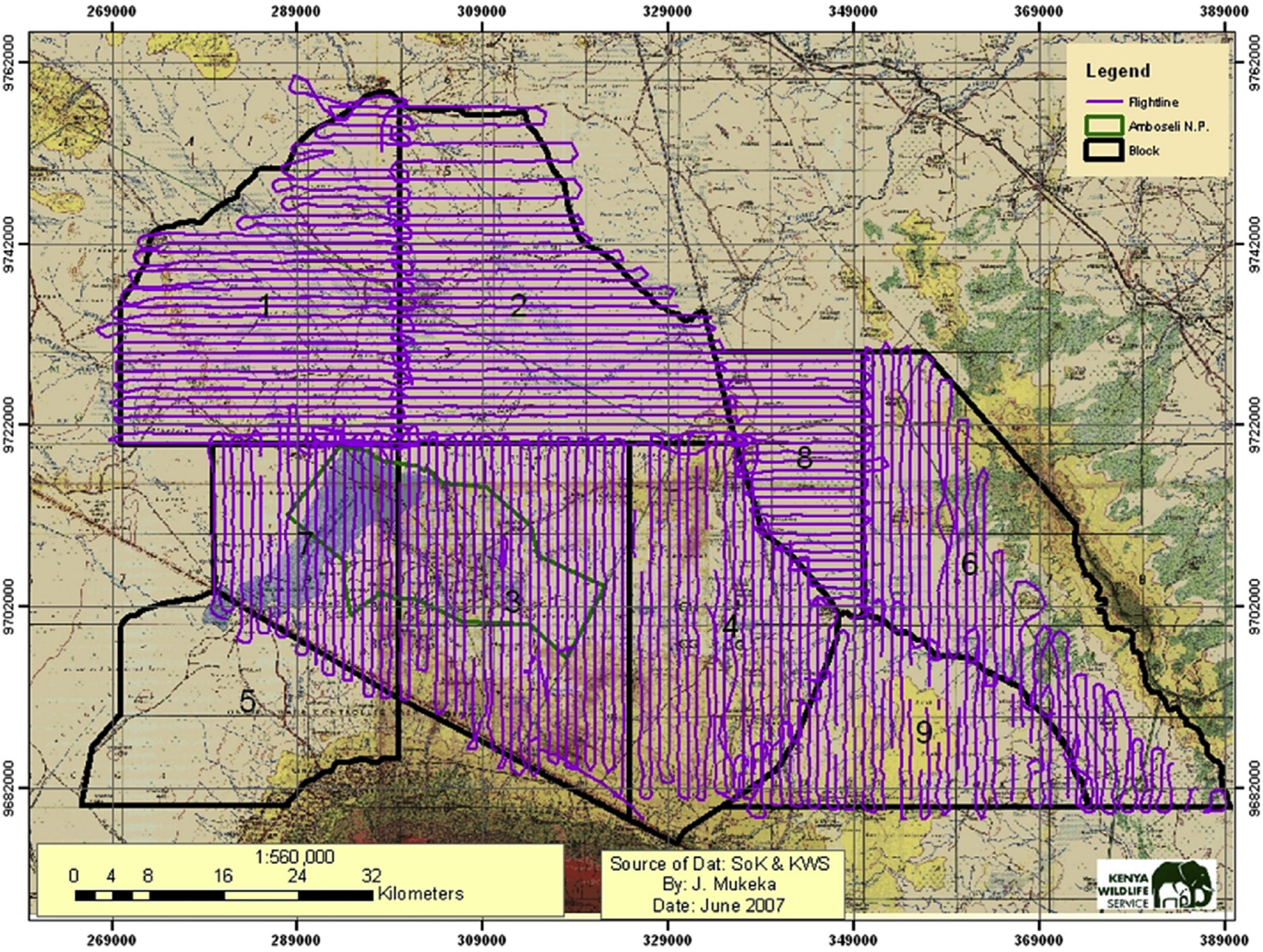

Fig. 3. Counting blocks and flight paths used during census.

using light air-crafts flying either North South or East West directions along transects of 1–2 km width depending on visibility and terrain (Fig. 3). The aircraft crew consisted of a pilot, Front Seat Observer (FSO) and Rear Seat Observer (RSO). The aircraft crew systematically searched for and made observations and recording of elephants and key large wildlife species and their number along the flight transects. For each observation a waypoint was marked using a hand held Global Positioning System (GPS) and the observation recorded on a data sheet. Tape recorders were also used to aid in data capture and data were transcribed into the datasheet after every survey session. Large herds of more than 10 individuals were photographed unless the view was obstructed by thick vegetation, in order to establish the correct count (Douglas-Hamilton, 1996). At the end of each count session, the GPS flight paths and waypoints were downloaded using DNR-Garmin/MapSource software (Minesota Department of Natural Resources), and the FSO did a summary table of each block. Any double counts in neighboring blocks were also validated worked out and eliminated during these sessions. Voice recordings were processed digitally to remove background noises and improve clarity. A team of data handlers transcribed the voice records onto datasheets and entered these into a digital database. The exercise started every morning at around 7:30 a.m. and ended in the afternoon. End time was variable because it depended on the size of the blocks, and rest breaks were taken during refueling of the aircrafts at lunch time. Flight path and way point data were processed using ArcGIS 9.3 (ESRI, Redlands California) program, while the observation data sheets were cleaned and entered into Microsoft Excel 2003/2007 for further analysis.

3.1. *Data analysis*

Data for the dry period of 2007 (during the drought, which ended in 2009 in Amboseli area) and then after droughts (2010 and 2013) were used. Tallies, percentages, means and standard errors for the data were calculated using standard statistical methods (Zar, 1999) using PASW version 18 (SPSS Inc.). CJhanges in population numbers were expressed as percent change in 2007 and 2013 relative to 2010 population counts. Chi – square cross – tabulations were done to establish the association between species numbers and the counting areas (group ranch locations), and between species numbers and years (association to drought periods) using PASW statistical software. Even though the dry season census area of the year 2007 was 5542 km^2 mainly in Amboseli Ecosystem, the census area increased to 8797 km^2 in 2010 and further to 9212 km^2 in 2013 to cover the entire Kenya/Tanzania borderland. The total numbers may therefore be affected by the size, but the density and proportions of each species of the large mammals seen were reliable measures for comparison due to weighting per unit area and as a proportion. Even though the cross − tabulations may be affected because of the slight study site size differences especially between 2010 and 2013, in our view, this was deemed not to greatly alter the general conclusions of that test. However, the same study area size would be most appropriate for comparisons especially for cross tabulations. However, we recognize that this could be a limitation of the chi − square cross − tabulation comparisons.

4. Results

Changes in numbers of elephants in between 2007 and 2010, and between 2010 and 2013 was expressed as percent to calculate the percent changes in density between the years. The general overall large mammal average density declined more than three times (−207.45%) between 2007 and 2010, and recovered only modestly between 2010 and 2013 (Table 1). The common large mammal species numbers were dependent ($\chi^2 = 5988.60$, df = 10, $p < 0.001$) on the period in relation to the drought (during the drought in 2007, just after the drought in 2010, and well after the drought in 2013). Generally, large mammal numbers declined during the drought until after the drought ended, with most of them recovering in post drought period. Further, the numbers of large mammal species was dependent ($\chi^2 = 13{,}647.35$, df = 15, $p < 0.001$) on relative location from protected areas, with numbers being higher to areas close to a protected area (Amboseli, Tsavo West, Chyulu Hills), but lower in areas further away from protected areas (like Eselenkei and parts of Olgulului/Ololorashi Group Ranch).

The African elephant (*Loxodonta Africana*) was the fifth most abundant species in overall density (Table 1) over the three years (Fig. 4). It had an average number comprising about 4% of all the counted large mammal species (Table 1). The drought was associated with declining elephant density and numbers from 2007.

The most abundant large mammal species (based on overall density) over this period (Table 1) were common zebra (*Equus burchelli*) followed by common wildebeest (*Chonochaetus taurinus*), Grant's gazelle (*Gazella granti*), Maasai giraffe (*Giraffa carmelopardalis*), African elephant, common eland (*Taurotragus Oryx*), Thomson's gazelle (*Gazella thomsoni*), impala (*Aepyceros melampus*), African buffalo (*Cyncerus caffer*) and lesser kudu (*Tragelophus imberbis*) respectively.

Based on overall density, the most abundant wildlife species among those surveyed was the common zebra (Table 1). It comprised about 38% of all the counted large mammals over that time (Fig. 5). Zebra density also declined during the drought from 2007 to 2010, but recovered in density between 2010 and 2013 (Table 1).

The second abundant large mammal species in overall density was the common wildebeest (Fig. 6). It comprised about 27% of large mammals counted (Table 1). During the drought, the common wildebeest declined sharply between 2007 and 2010. However, its population recovered remarkably from 2010.

Grant's gazelle was the third most abundant large mammal species in overall density. It comprised about 14% of counted large mammals (Table 1). The species declined also during the drought as well as after drought ended. Its population declined sharply in population density between 2007 and 2010, and continued to decline still after drought between 2010 and 2013.

The fourth abundant large mammal species in overall density was the Maasai giraffe. It comprised about 5% of large mammals counted (Table 1). During the drought, the Maasai giraffe declined in density in 2010, but had a positive increase in density after the drought between 2010 and 2013.

The sixth abundant large mammal in overall density was the common eland. It comprised about 2% of all large mammals seen (Table 1). The eland declined sharply in density between 2007 and 2010. However, the species started making positive recovery after this time.

The seventh abundant large mammal species in overall density was the Thomson's gazelle. It comprised only about 2% of large mammal counted (Table 1). The Thomson's gazelle density declined during the drought between 2007 and 2010, but recovered between 2010 and 2013.

Impala comprised only 1% of all the large mammals counted between 2007 and 2013 (Table 1). They declined in between 2007 and 2010, but recovered between 2010 and 2013. Similarly, African buffalo, which had a low density (Table 1) declined sharply during the drought between 2007 and 2010. The decline continued even after drought ended.

Lesser kudu had also a low density (Table 1) as it comprised less than 1% of large mammals counted (Table 1). They declined sharply in density during the drought. But after the drought, the density had a positive recovery. Similarly, Kongoni (Coke's hartebeest, *Alcelaphus buselaphus*) had a low density (Table 1). Its density declined during the drought, and further continued to decline in density even after the drought ended (Table 1).

Lastly, two species with eve low population densities were gerenuk (*Litocranius walleri*) and fringe − eared Oryx (*Oryx buselaphus*). Gerenuk declined during the drought, but made a very modest positive recovery in density after the drought ended. Similarly, the Fringe − eared Oryx also declined in density during the drought, but had a positive recovery in density by almost the same amount as the Oryx after the drought ended (Table 1).

In terms of the most drastic decline in overall density during the drought, the species order with most decline in density was lesser kudu followed by Maasai giraffe, common wildebeest, common eland, common zebra, African buffalo, Thomson's gazelle, impala, fringe − eared Oryx, kongoni, gerenuk, Grant's gazelle and African elephant respectively. Looking at the rate of recovery in density between 2010 and 2013, the poorest recovery in density was in kongoni density followed by African buffalo, African elephant, Grant's gazelle, gerenuk, lesser kudu, Maasai giraffe, impala, common eland, common zebra, wildebeest and lastly fringe − eared Oryx respectively. Based on a combined rate of decline during the drought (between 2007 and 2010) and recovery after droughts (between 2010 and 2013), the species with lowest overall rate was lesser kudu, followed by African buffalo, Maasai giraffe, kongoni, common eland, common wildebeest, common zebra, Grant's gazelle, gerenuk, impala, African elephant, Thomson's gazelle and lastly fringe − eared orxy respectively. But one species that seemed not affected by drought of 2007–2009 was the African hippopotamus (*Hippopotamus amphibius*) which maintained a low density but increased in density during the drought as well as after the drought between 2010 and 2013.

Some carnivores were also seen in the 2007 and 2013 census, albeit smaller numbers and low densities. These included the African lion (*Panthera leo*), the spotted hyena (*Crocuta crocuta*) and the cheetah (*Acinonyx jubatus*). The spotted hyena seemed to be the relatively most abundant followed by the lion and lastly the cheetah (Table 1).

5. Discussion

The African elephant is an important ecological keystone for the African Savanna. It has been ranked as “Vulnerable” by the International Union for Conservation of Nature (IUCN) (Blanc, 2008) although individual population segments are ranked as “Endangered” (central Africa), “Vulnerable” (western Africa, eastern Africa) and “Least Concern” (southern Africa). Other than poaching,

Table 1
Population size and density of elephants and other wildlife species from 2007 to 2013.

Large mammal	Year	Census area (km^2)	Number	Percent abundance in area	Density per km^2 (Mean ± SE)	Abundance rank based on overall density (and % change before and after drought)
African elephant	2007	5542	967	2.18	0.17	5 (−35.29, 0.00)
	2010	8797	1010	6.83	0.11	
	2013	9214	995	4.02	0.11	
	Overall (Mean)		990.67 ± 12.60	4.34 ± 1.35	0.13 ± 0.02	
African buffalo	2007	5542	588	1.33	0.11	9 (−72.73, −33.33)
	2010	8797	222	1.50	0.03	
	2013	9214	184	0.74	0.02	
	Overall (Mean)		331.33 ± 128.90	1.19 ± 0.23	0.05 ± 0.03	
Maasai giraffe	2007	5542	1458	3.29	0.26	4 (−53.85, +33.33)
	2010	8797	1053	7.12	0.12	
	2013	9214	1444	5.84	0.16	
	Overall (Mean)		1318.33 ± 132.73	5.41 ± 1.12	0.18 ± 0.04	
Common eland	2007	5542	1161	2.62	0.21	6 (−90.48, +50.00)
	2010	8797	162	1.09	0.02	
	2013	9214	309	1.25	0.03	
	Overall (Mean)		544.00 ± 311.40	1.65 ± 0.48	0.09 ± 0.06	
Common zebra	2007	5542	15,328	34.61	2.77	1 (−77.62, +87.11)
	2010	8797	5424	36.66	0.62	
	2013	9214	10,647	43.03	1.16	
	Overall (Mean)		10,466.33 ± 2860.47	38.10 ± 2.54	1.51 ± 0.65	
Common wildebeest	2007	5542	18,538	41.86	3.35	2 (−91.64, +121.43)
	2010	8797	2499	16.89	0.28	
	2013	9214	5726	23.14	0.62	
	Overall (Mean)		8921.00 ± 4897.90	27.30 ± 7.50	1.42 ± 0.97	
Coke's hartebeest (kongoni)	2007	5542	102	0.23	0.02	12 (-50.00, −100.00
	2010	8797	71	0.48	0.01	
	2013	9214	27	0.11	0.00	
	Overall (Mean)		66.67 ± 21.76	0.27 ± 0.11	0.01 ± 0.00	
Fringe – eared Oryx	2007	5542	84	0.19	0.02	12 (−50.00, +50.00)
	2010	8797	49	0.33	0.01	
	2013	9214	139	0.56	0.02	
	Overall (Mean)		90.67 ± 26.19	0.36 ± 0.11	0.01 ± 0.00	
Lesser kudu	2007	5542	220	0.50	0.04	11 (−100.00, 0.00)
	2010	8797	21	0.14	0.00	
	2013	9214	35	0.14	0.00	
	Overall (Mean)		92.00 ± 64.13	0.26 ± 0.12	0.02 ± 0.01	
African hippopotamus	2007	5542	10	0.02	0.00	15 (0.00, +infinity)
	2010	8797	43	0.29	0.00	
	2013	9214	70	0.28	0.01	
	Overall (Mean)		41.00 ± 17.35	0.20 ± 0.09	0.00 ± 0.00	
Maasai Ostrich (game bird)	2007	5542	736	1.66	0.13	6 (-46.15, −28.57
	2010	8797	630	4.26	0.07	
	2013	9214	488	1.97	0.05	
	Overall (Mean)		618.00 ± 71.84	2.63 ± 0.82	0.09 ± 0.02	
Grant's gazelle	2007	5542	4054	9.15	0.73	3 (+50.68, −5.56)
	2010	8797	3126	21.13	0.36	
	2013	9214	3161	12.78	0.34	
	Overall (Mean)		3447.00 ± 303.67	14.35 ± 3.55	0.48 ± 0.13	
Thomson's gazelle	2007	5542	396	0.89	0.07	8 (−71.43, +50.00)
	2010	8797	152	1.03	0.02	
	2013	9214	938	3.79	0.10	
	Overall (Mean)		495.33 ± 232.27	1.90 ± 0.94	0.06 ± 0.02	
Impala	2007	5542	426	0.96	0.08	9 (−62.50, +33.33)
	2010	8797	233	1.57	0.03	
	2013	9214	404	1.63	0.04	
	Overall (Mean)		354.33 ± 61.00	1.39 ± 0.21	0.05 ± 0.01	
Gerenuk	2007	5542	112	0.25	0.02	12 (+50.00, 0.00)
	2010	8797	84	0.57	0.01	
	2013	9214	90	0.36	0.01	
	Overall (Mean)		95.33 ± 8.51	0.39 ± 0.09	0.01 ± 0.00	
Olive baboon	2007	5542	60	0.14	0.01	15 (−100.00, +infinity)
	2010	8797	0	0.00	0.00	
	2013	9214	13	0.05	0.00	
	Overall (Mean)		24.33 ± 18.22	0.06 ± 0.04	0.00 ± 0.00	
African lion	2007	5542	1	0.00	0.00	15
	2010	8797	–	–	–	
	2013	9214	5	0.02	0.00	
	Overall (Mean)		3.00 ± 1.63	0.01 ± 0.01	0.00 ± 0.00	
Spotted hyena	2007	5542	12	0.00	0.00	15
	2010	8797	–	–	–	

Table 1 (*continued*)

Large mammal	Year	Census area (km^2)	Number	Percent abundance in area	Density per km^2 (Mean ± SE)	Abundance rank based on overall density (and % change before and after drought)
	2013	9214	3	0.01	0.00	
	Overall (Mean)		7.50 ± 3.67	0.01 ± 0.01	0.00 ± 0.00	
Cheetah	2007	5542	2	0.00	0.00	15
	2010	8797	–	–	–	
	2013	9214	1	0.00	0.00	
	Overall (Mean)		1.50 ± 0.41	0.00 ± 0.00	0.00 ± 0.00	
Total for only large mammals between 2007 and 2013						Percent change in density
	2007	5542	43,550	7.86	53.13	–
	2010	8797	14,165	1.61	17.28	−67.47
	2013	9214	24,253	2.63	29.59	+12.64
	Overall (Mean)		27,322.45 ± 8620.45	4.03 ± 1.93	33.33 ± 10.52	

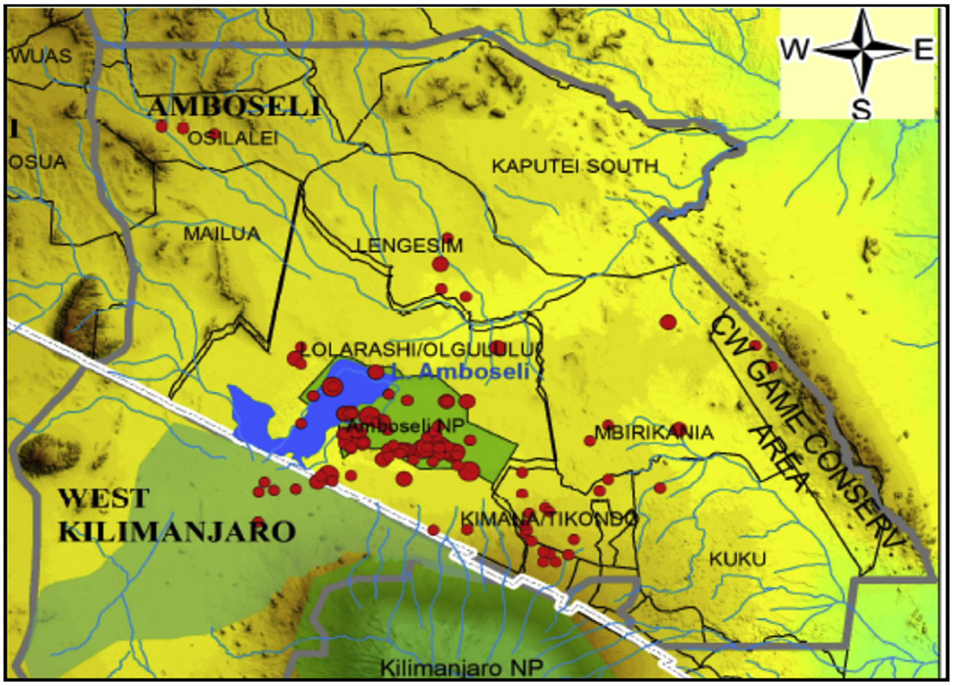

Fig. 4. Distribution of the African elephant during the dry season of 2013.

droughts are one of the most significant mortality factors for elephants. Droughts, especially if frequent and intense, are always accompanied by reduced access to water and vegetation and also face relatively higher heat load from increased temperature. All these affect the survival and reproduction of elephants, and eventually its population status. This drought was also accompanied by elephant mortality as well as decline in numbers and density. Droughts have caused significant mortality in elephant populations in historic times, such as in Tsavo National Park from 1960 to 1961 and from 1970 to 1975 (Spinage, 1994). All these factors reduce elephant population and affect rate of recovery of the population after droughts.

The African elephant is a water-dependent species, with requirements of 150–300 L of water per animal per day for drinking, with additional amounts required for bathing (Du Toit, 2002a,b; Garai, 2005). Therefore acquisition of water is a significant part of their daily activity, although they may go for three days without drinking in wet season (Spinage, 1994). Elephants can walk up to 30–50 km or more in search of water (Spinage, 1994; Garai, 2005). They readily dig for water in dry riverbeds if surface water is not available (Garai, 2005). Further, under drought conditions, competition for forage and water with people and livestock increased human-elephant conflicts leading to both human and elephant mortality (Muruthi, 2005). Poaching, crop raiding, water use and other conflicts with humans will increase as elephant forage and water resources reduce during drought.

Elephants are heat-sensitive animals and individual elephants are susceptible to heat stress and sunburn generated from between 1 and 2 °C in temperature change (Du Toit, 2002b; Garai, 2005). Elephants manage their body temperature through physiological mechanism such as heat dissipation through their ears; behavioral mechanisms such as mud baths, water baths, spraying of water through the trunk onto the body and seeking shade (Spinage, 1994; Garai, 2005). Climate change such as droughts may also be associated with elephant diseases that reduce their body condition. Elephants are sensitive to diseases such as anthrax, trypanosomiasis, encephalo-myocarditis, salmonellosis, endotheliotropic herpes, foot-and-mouth disease and floppy trunk disease (Du Toit, 2002b; Garai, 2005), which are exacerbated by drought and heat stress.

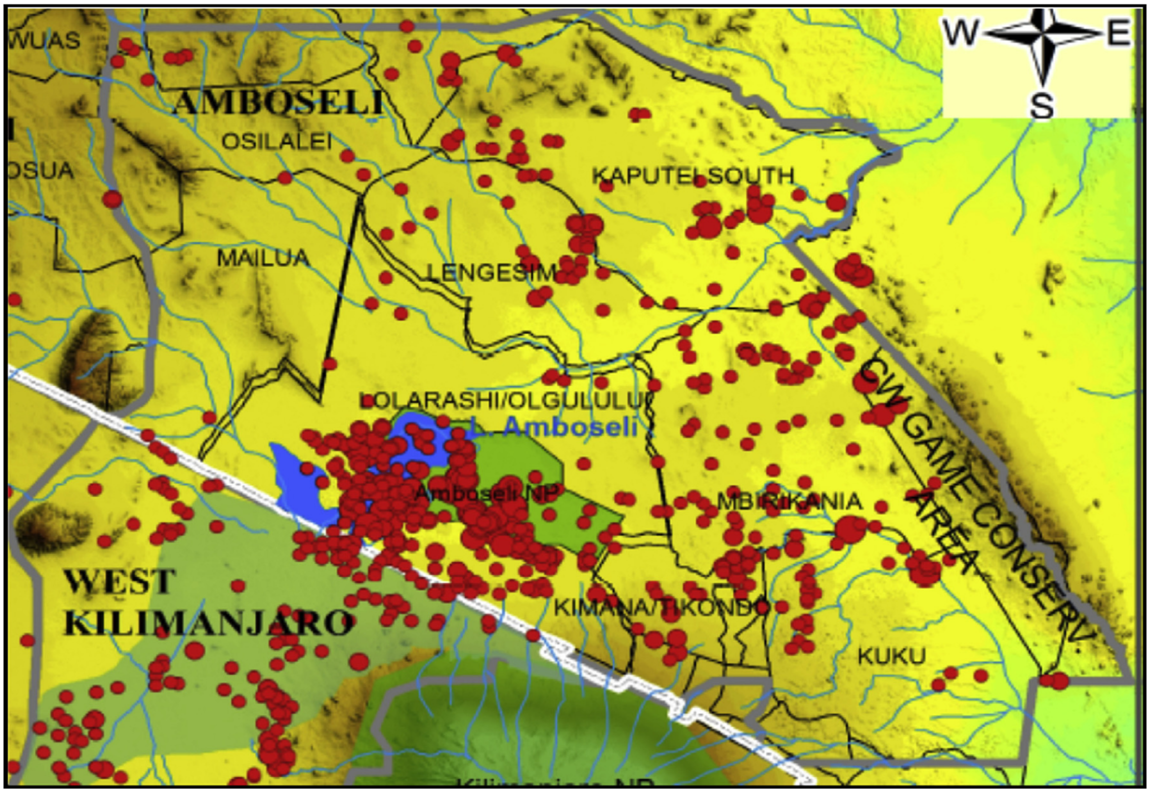

Fig. 5. Distribution of common zebra during the dry season of 2013.

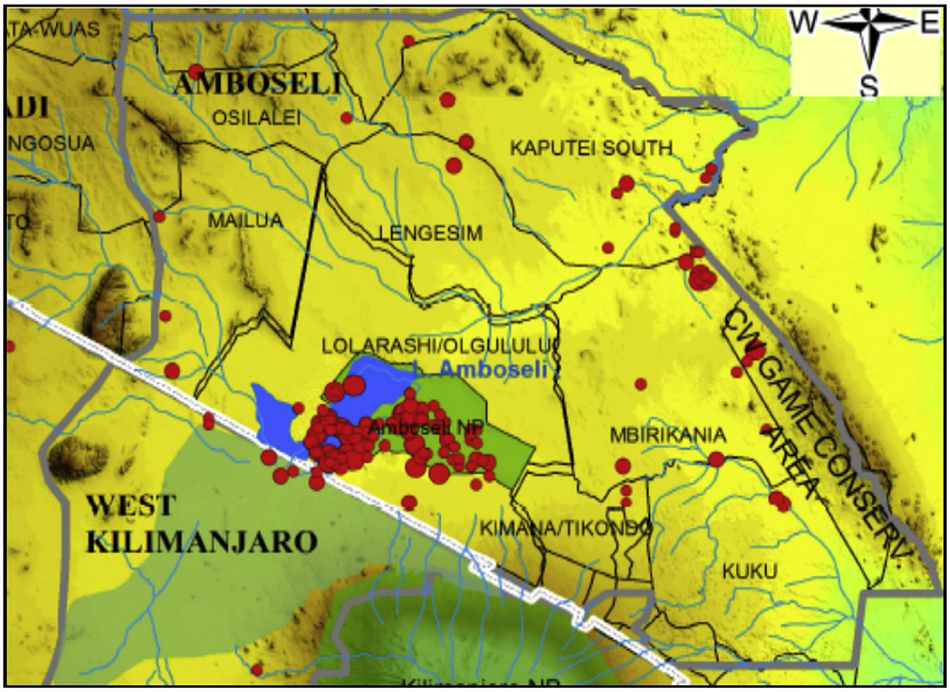

Fig. 6. Distribution of common wildebeest during the dry season of 2013.

However, elephants are extremely adaptable, occupying a variety of habitats from desert to savanna to gallery forest (Lausen and Bekoff, 1978). In savanna ecosystems, they also tend to select where and what to feed on in order to maximize rate of nutrient intake which enhances their survival and reproduction chances in times of limited food quantity and quality (Lindsay, 2011). Further, they normally spend more time browsing during dry spells (Jachmann, 1989; Kangwana, 1993; Lindsay, 2011). Their forage also tends to be diverse and may include herbs bark, fruits, tree forage and grass (Kangwana, 1993; Western, 1975; Estes, 1992; Croze and Lindsay, 2011; Kioko, 2005). Thus, the feeding behavior of elephants confers them a significant amount of ecological survival advantage over many other wildlife species when faced by prolonged drought conditions.

All wild large mammals (and equally livestock from observation on the ground) were affected by the 2007 to 2009 droughts, leading to declines in their density. Large mammal numbers underwent drastic population decline in the study area during 2007 and 2009. Two of the most abundant grazing species in the area: zebra and wildebeest showed the highest declines, but also the highest recovery rates after the droughts. The degree of decline and recovery was dependent on large mammal abilities to migrate, vary feeding patterns, ability to cope with heat and rise in temperature, ability to change forage preference and the population size maintained during and before the droughts. Understanding the factors influencing the recovery rates of these different species after a major population decline is vital to predicting whether species will persist in the future, in the face of anthropogenic pressures and climate change.

Differential response of animals to droughts can also arise because of their social behavior and foraging strategies. Duncan et al. (2012) suggested that the species most at risk from drought are those relatively sedentary, and those wholly or partially dependent on plants less resistant to droughts. This is further compounded by intense intra and inter-species competition for reduced forage during droughts with other species (Estes, 1992). Grazers may survive droughts better than browsers because browse declines during droughts faster than grass (Western, 1975). And this confers grazers an ecological advantage over bowsers when faced by food shortages during the dry season or in times of drought. Lesser kudu and Maasai giraffe are pure browsers (Estes, 1992), but also had very low density in the study area, which makes them extremely vulnerable to droughts because of initial low numbers and dependence on browse that rapidly declines during droughts.

The common zebra is a bulk feeder and a hind-gut fermenter, and can therefore utilize grass forage of low quality (Rubenstein, 2010) unlike other grazers like the common wildebeest. Further, its grass forage tends to have more stem than leaf material unlike the wildebeest (Estes, 1992), conferring it some ecological advantage in utilizing grass forage. Rubenstein (2010) noted that abundant food and water supply normally reduces competition between different reproductive groups of common zebra females.

Animals who are already too low in number are likely to continue to decline even though conditions (of plenty of water and pasture) improve due to demographic *Allee' effect* (a depressed population condition due to few breeding numbers in the population) (Allee et al., 1949; Berec et al., 2001). The lesser kudu, gerenuk, hartebeest, and oryx had very low population numbers and so they are likely to decline further due to their population being generally lower than minimum viable size to allow for a more rapid population increase once drought conditions improve. So whether a large mammal population has high fecundity, natality and generally reproductive potential, the level to which populations are reduced by droughts will affect their ability to cope with droughts (Gandiwa et al., 2016).

However, this study didn't evaluate other key factors such as range degradation, livestock overgrazing and competition with wild large mammals and human persecution such as poaching and snaring for bush meat that may have contributed to wildlife mortality and population decline. However, numerous studies in semi-arid savannas of Africa including the Amboseli region have reported wildlife decline commonly attributed to growth of agro-pastoral populations, livestock and subsistence and commercial agriculture (Homewood et al., 2001). In this regard, it's probable that such factors may have contributed significantly to mortality and associated decline of wildlife besides actual drought effects in the 2007 to 2009 drought in the borderland. For hundreds of years, the human population in the ecosystem remained quite low but from the middle of the last century, and at the beginning of the new one, the population escalated drastically. This has been accompanied by all manner of changes including sedentarization and associated infrastructure development, group ranch subdivision land use changes such as farming and land privatization (Kimani and Pickard, 1998; Ntiati, 2002; Western et al., 2009b) which negatively affects wildlife. Western et al. (2009a) revealed a significant decline and loss of wildlife inside and outside Kenya's protected areas which they attributed to a combination of factors including loss of range and migratory routes due to human activities. Ottichillo et al. (2000) examined the population trends of large non-migratory wildlife herbivores in the Maasai Mara Ecosystem between 1977 and 1997, and their findings showed that they had declined by 58%. They attributed this to a combination of poaching, drought, vegetation and land use changes.

Another factor that may have equally contributed to the observed mortality is high stocking rate for livestock and as associated deterioration in range condition in the Amboseli Ecosystem. Recent studies (Kiringe and Okello, 2010, 2012) have revealed widespread poor state of the rangelands in the ecosystem characterized by decline and loss of Decreaser grasses, prevalence of forbs, Increaser II grasses and soil erosion, decline in herbaceous vegetation cover, and poor forage potential. These changes could be as a result of a various factors but ecologically they indicate that the ability to produce sufficient food resources that can support large populations of herbivores has declined over the years. Consequently, in the event of a prolonged drought, food quantity and variety available to animals will become very scarce leading to starvation and death.

While land use changes, habitat loss and degradation have been identified as key threats to wildlife in the Amboseli Ecosystem, climate variability and associated occurrence of drought present a major environmental challenge to wildlife conservation. This calls for sustained monitoring of the status and trends of wildlife populations whilst isolating the underlying causes for the observed patterns so as to help formulate appropriate strategies for better conservation practices. Drought is also a threat to Maasai pastoral lifestyle which is the backbone of their livelihood and similarly, appropriate interventions that will help them sustain this practice amidst a dry and rapidly changing landscape are urgently needed.

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References

Allee, W.C., Park, O., Emerson, A.E., Park, T., Schmidt, K.P., 1949. Principles of Animal Ecology, first ed. Missouri: WB Saundere Company, St. Louis.

Berger, D., 1993. Wildlife extension: participatory conservation by the Maasai of

Kenya. ACTS Environ. Policy Ser. 4, 5–45.

Berec, L., Boukal, D., Berec, M., 2001. Linking the Allee effect, sexual reproduction, and temperature-dependent sex determination via spatial dynamics. Am. Nat. 57 (2), 217–230. http://dx.doi.org/10.1086/318626 pmid:18707273.

Blanc, J., 2008. Loxodonta africana. In: IUCN 2011. IUCN Red List of Threatened Species. Version 2011.2. www.iucnredlist.org. Downloaded on 13 June 2012.

Conway, G., 2008. The Science of Climate Change in Africa: Impacts and Adaptations. Department for International Development (United Kingdom).

Croze, H., Sayialel, S., Sitonic, D., 2006. What's on in the Ecosystem: Amboseli as a Biosphere Reserve; a Compendium of Conservation and Management Activities in the Amboseli Ecosystem. ATE/AERP. UNESCO/MAB, Nairobi, p. 28.

Croze, H., Lindsay, W.K., 2011. Amboseli ecosystem context: past and present. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), The Amboseli Elephants; a Long-term Perspective on a Long-lived Mammal. The University of Chicago Press, Chicago and London, pp. 11–28.

Croze, H., Moss, C.J., 2011. Patterns of occupancy in time and space. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), The Amboseli Elephants; a Long-term Perspective on a Long-lived Mammal. The University of Chicago Press, Chicago and London, pp. 89–105.

Douglas-Hamilton, I., 1996. Counting elephants from the air; total counts. Chapter 4. In: Kangwana, K. (Ed.), Studying Elephants, AWF Series of Handbooks #7, African Wildlife Foundation Nairobi, Kenya, pp. 28–37.

Duncan, C., Chauvenet, A.L.M., McRae, L.M., Pettorelli, N., 2012. Predicting the future impacts of droughts in ungulate populations in arid and semi arid areas. PLoS One 7 (12), e51490. http://dx.doi.org/10.1371/journal.pone.0051490.

Du Toit, J.G., 2002a. Water requirements. In: du P Bothma, J. (Ed.), Game Ranch Management, Fourth Edition. Van Schaik Publishers, Pretoria, South Africa, pp. 98–102.

Du Toit, J.G., 2002b. The elephant. In: du P Bothma, J. (Ed.), Game Ranch Management, Fourth Edition. Van Schaik Publishers, Pretoria, South Africa, pp. 176–182.

Estes, R.D., 1992. The Behaviour Guide to African Mammals; Including Hoofed Mammals, Carnivores and Primates (The University of California Press).

Esikuri, E.E., 1998. Spatio-temporal Effects of Land Use Changes in a Savanna Wildlife Area of Kenya. Ph.D. Thesis Dissertation. Virginia Polytechnic Institute and State University, Blacksburg, Virginia. United States of America.

Garai, M.E., 2005. The elephant. In: du P Bothma, J., Van Rooyen, N. (Eds.), Intensive Wildlife Production in Southern Africa. Van Schaik Publishers, Pretoria, South Africa, pp. 2–24.

Gandiwa, E., Heitkonig, I.A., Eilers, P.H., Prins, H.H., 2016. Rainfall variability and its impact on large mammal populations in a complex of semi-arid African savanna protected areas. Trop. Ecol. 57 (2), 163–180.

Homewood, K., Lambin, E.F., Coast, E., Kariuki, A., Kikulai, I., Kiveliai, J., Said, M., Serneels, S.M., Thompson, M., 2001. Long-term changes in Serengeti-Mara wildebeest and land cover: pastoralism, population, or policies? PNAS 98 (22), 12544–12549. www.pnas.orgycgiydoiy10.1073ypnas.221053998.

Jachmann, H., 1989. Food selection by elephants in the “miombo” biome, in relation to leaf chemistry. Biochem. Syst. Ecol. 17, 15–24.

Kangwana, K., 1993. Elephants and Maasai: Conflicts and Conservation in Amboseli, Kenya. Ph.D. Thesis (University of Cambridge).

Kangwana, K., 2011. The behavioral responses of elephants to the Maasai in Amboseli. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), The Amboseli Elephants; a Long-term Perspective on a Long-lived Mammal. The University of Chicago Press, Chicago and London, pp. 307–317.

Kangwana, K., Browne-Nunex, C., 2011. The human context of the Amboseli elephants. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), The Amboseli Elephants; a Long-term Perspective on a Long-lived Mammal. The University of Chicago Press, Chicago and London, pp. 29–36.

Kenana, L.M., Bakari, S.K., Bitok, E., Machoke, N.M., Hamza, K., Mukeka, J., Chepkwony, R.K., Mwiu, S.N., 2013. Total Aerial Count for Amboseli – West Kilimanjaro and Magadi- Natron Cross Border Landscape, April 2013. A Technical Report for KWS, Kenya and TAWIRI, Tanzania Kenya Wildlife Service (KWS) (1990, pp. 1991–1996. Amboseli National Park management plan.

Kimani, K., Pickard, J., 1998. Recent trends and implications of group ranch subdivision and fragmentation in Kajiado District, Kenya. Geogr. J. 164, 202–218.

Kioko, J.M., 2005. Spatial - Temporal Distribution of African Elephants (*Loxodonta africana Africana*, Blumenbach) and Their Interaction with Humans in Kuku - Kimana Area of Tsavo - Amboseli Ecosystem, Kenya. M.Sc., Thesis. The University of Greenwich and the International Centre for Protected Landscapes, United Kingdom.

Kiringe, J.W., Okello, M.M., 2010. Degradation of rangelands: causes, ecological, wildlife conservation and socio-economic implications. In: Veress, B., Szigethy, J. (Eds.), Horizons in Earth Science Research, Volume1. Nova Science Publishers, Inc, pp. 1–76.

Kiringe, J.W., Okello, M.M., 2012. Land Use and Land Tenure Changes and Their Impact on the Kitenden Wildlife Corridor between the Amboseli & West Kilimanjaro Ecosystems. Final Report for African Wildlife Foundation (AWF). Kenya, Nairobi.

Lausen, L., Bekoff, M., 1978. *Loxodonta Africana.* Mammalian species, 92, 1–8.

Lindsay, W.K., 2011. Habitat use, diet choice, and nutritional status in female and male Amboseli elephants. In: Moss, C.J., Croze, H., Lee, P.C. (Eds.), The Amboseli Elephants; a Long-term Perspective on a Long-lived Mammal. The University of Chicago Press, Chicago and London, pp. 51–73.

Muruthi, P., 2005. Human Wildlife Conflict: Lessons Learned from AWF's African Heartlands. African Wildlife Foundation, Washington, DC, p. 16.

NOAA, 2008. DROUGHTS: public fact sheet. Natl. Weather Serv. accessed 11 03 16 http://www.nws.noaa.gov/os/brochures/climate/DroughtPublic2.pdf, 23 pp.

Norton–Griffiths, 1978. Counting Animals. Handbook 1, second ed. African Wildlife Foundation, Nairobi, Kenya.

Ntiati, P., 2002. Group Ranches Subdivision Study in Loitokitok Division of Kajiado District. Land Use Change Impacts and Dynamics (LUCID) Working Paper 7. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Okello, M.M., Kiringe, J.W., 2004. Threats to biodiversity and their implications in protected and adjacent dispersal areas of Kenya. J. Sustain. Tour. 12 (1), 55–69.

Okello, M.M., 2005. Land use changes and human-wildlife conflict in the Amboseli Area, Kenya. Hum. Dimensions Wildl. 10, 19–28.

Okello, M.M., D'Amour, D.E., 2008. Agricultural expansion within Kimana electric fences and implications for natural resource conservation around Amboseli National Park, Kenya. J. Arid Environ. 72, 2179–2192.

Okello, M.M., Kioko, J.M., 2010. Contraction of wildlife dispersal area in Olgulului – ololorashi group ranch around Amboseli national park, Kenya. Open Conservation Biol. J. 4, 28–39.

Ottichilo, W.K., de Leeuw, J., Skidmore, A.K., Prins, H.H.T., Said, M.Y., 2000. Population trends of large non-migratory wild herbivores and livestock in the Maasai Mara ecosystem, Kenya, between 1977 and1997. Afr. J. Ecol. 38, 202–216.

Ottichilo, W.K., de Leeuw, J., Prins, H.H.T., 2001. Population trends of resident wildebeest [*Connochaetes taurinus hecki* (Neumann)] and factors influencing them in the Maasai Mara ecosystem, Kenya. Biol. Conserv. 97, 271–282.

PDNA, 2011. Kenya post-disaster needs assessment (PDNA) 2008-2011 drought. Government of Kenya, Nairobi, Kenya.

Pratt, D.J., Gwynne, M.D., 1977. Rangeland Management and Ecology in East Africa. Hodder and Stoughton, London, England.

Primack, R.B., 1998. Essentials of conservation biology, second ed, pp. 47–304. Sinauer Assoc. Inc.

Reid, R., Gachimbi, L., Worden, J., Wangui, S., Mathai, S., 2004. Linkages between Changes in Land Use, Biodiversity and Land Degradation in the Loitokitok Area of Kenya. Land Use Change Impacts and Dynamics (LUCID) Working Paper Series, 49, pp. 1–29.

Rubenstein, D.I., 2010. Ecology, social behavior, and conservation in zebras. Adv. study Behav. 42, 231–258. http://dx.doi.org/10.1016/S0065-3454(10)42007-0.

Seno, S.K., Shaw, W.W., 2002. Land tenure policies, Maasai traditions, and wildlife conservation in Kenya. Soc. Nat. Resour. 15, 79–88.

Spinage, C.A., 1994. Elephants. T & AD Poyser Natural History, p. 319. Norfolk, UK. xvi +.

Thompson, L.G., Brecher, H.H., Mosley-Thompson, E., Hardy, D.R., Mark, B.G., 2009. Glacier loss on Kilimanjaro continues unabated. PNAS 1–6. Available. http://www.pnas.org/cgi/doi/10.1073/pnas.0906029106. Accessed 11 09 14.

Western, D., 1975. Water availability and its influence on the structure and dynamics of a savannah large mammal community. East Afr. Wildl. J. 13, 265–285.

Western, D., 1982. Amboseli National Park: enlisting landowners to conserve migratory wildlife. Ambio 11 (5), 302–308.

Western, D., Lindsay, W.K., 1984. Seasonal herd dynamics of a savanna elephant population. Afr. J. Ecol. 22, 229–244.

Western, D., Maitumo, D., 2004. Woodland loss and restoration in a savanna park: a 20-year experiment. Afr. J. Ecol. 42, 111–121.

Western, D., 2006. A half a century of habitat change in Amboseli National Park, Kenya. Afr. J. Ecol. 45, 302–310.

Western, D., Russell, S., Cuthill, I., 2009a. The status of wildlife in protected areas compared to non-protected areas of Kenya. PLoS ONE 4 (7), e6140. http://dx.doi.org/10.1371/journal.pone.0006140.

Western, D., Groom, R., Worden, J., 2009b. The Impact of Subdivision and Sedentarization of Pastoral Lands on Wildlife in an African Savanna Ecosystem Biological Conservation, vol. 142, pp. 2538–2546.

Zar, J.H., 1999. Biostatistical Analysis 4th Edition. Prentice Hall, Upper Saddle, River, New Jersey.