**Seasonal variation in home range sizes and distance to the nearest ephemeral surface water for African savannah elephant (*Loxodonta africana*) in semi-arid eastern Okavango panhandle, northern Botswana**

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**Conflicts of Interest**

The authors acknowledge that there is no conflict of interest associated with this work.

**Author Contributions**

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**Data Availability Statement**

Data are stored at Ecoexist Trust offices in Maun and deposited at MOVEBANK; <https://datarepository.movebank.org/home>.

**Abstract**

African elephants (*Loxodonta africana*) are megaherbivores of the African savannas requiring extensive ranges that can provide key resources critical for their survival and reproduction, both at spatial and temporal scales. We studied seasonal differences in home range sizes and distance to the nearest ephemeral surface water sources by five male and ten female African elephants in the eastern Okavango Panhandle in northern Botswana between 2014-2017. We hypothesized that (*i*) elephant home ranges would be larger in the wet season than in the dry season (because forage and water sources tend to be more plentiful and widely distributed in the wet season than in the dry season, and elephants would not be restricted to localized resource areas), and that (*ii*) the distance of the elephants to the nearest ephemeral surface water sources would be larger in the dry season than in the wet as these ephemeral water sources successively dry up. Our findings supported the hypotheses of the study. Elephants had larger home ranges in the wet season than in the dry season and the distance to the nearest ephemeral surface water sources was larger in the dry season than in the wet season. The findings indicate the need to consider seasonal variations in elephant space use in land use planning and protected area management to minimize restricting elephant access to critical resources as seasons change or droughts intensify due to climate change.

**Keywords:** *Climate variability, ephemeral surface water forage, kernel density, resource availability, space use.*

# **Introduction**

Large African herbivore species such as the African elephant (*Loxodonta africana*), blue wildebeest (*Connochaetus taurinus*) and plains zebra (*Equus quagga*) are known for their long-distance seasonal movements undertaken to access essential minerals, forage, and water sources, which often are sparsely distributed over time and space due to seasonally erratic rainfall (Chamaille-Jammes et al., 2007, Duffy et al., 2011). However, the seasonal movements of these herbivores are gradually being restricted or diverted as human developments and activities around and between wildlife areas increase (Naidoo et al., 2022a). Examples of such anthropogenic activities include expansion of human settlements (Ngene et al., 2017), extensive agriculture, and erection of cordon fences (Naidoo et al., 2022b). Because of the dire need to access critical resources between seasons, large herbivore species and often the most feared by humans such as the African elephant finds itself coming into serious conflict with man, hence increasing calls to reduce its numbers through hunting or removal from agroecosystems (Öhman, 2015). In terms of the human-wildlife conflict, the African elephant is the most problematic species causing huge losses in crop production, farm implements and human lives, and consequently high poverty and resentment in the form of poaching by local communities (Songhurst, 2017, Schlossberg et al., 2018). The increasing elephant populations across its ranges and associated human-elephant conflict incidents outside protected areas calls for regular and empirical information on how elephants use their space within and between seasons. The intensification of climate change, which is manifesting in the form of increasing droughts (van Beest et al., 2011), frequent fires (Nunes et al., 2021) and increasing dispersal especially by elephants (Dejene et al., 2021) will require wildlife managers and land use planners to have regular and adequate information on wildlife movements and distribution to effect pro-active adaptive wildlife management strategies.

Local movements of an animal species within a range in a particular time period defines its home range, which is simply defined as “an area used by an animal in its daily activities of foraging, mating, and caring for young” (Burt, 1943: 351, Powell and Boitani, 2012). Because of the need to meet their physiological requirements animals must move from one location to another or between seasonal ranges (Parker et al., 2009). For large herbivores such as the African elephant, which consumes about 150-400 kg of forage and drinks between 50-200 litres of water a day (Sukumar, 2003), space availability and the ability to move over a wide landscape to utilize supplementary and complementary resources is crucial. However, the availability of large and open landscapes to elephant populations, and hence their homes ranges are increasingly getting smaller across the elephant historical ranges in Asia and Africa. There is therefore a need to monitor these changes in home range sizes and area covered by elephant as their conduct their daily search for food and mates for social interaction, including reproduction. Continued research will improve the amount and quality of data on elephant home ranges that is currently limited (Shaffer et al., 2019). Despite the huge declines in elephant numbers in some of their historical ranges in some parts of Africa and provisioning of artificial waterpoints which might have limited their physiological need to move large distances within and between seasons (Chase et al., 2016) there still exist some extensive ranges in the world that still allow for large home ranges and access to seasonal ranges. Such large landscapes still exist in Botswana which also holds a large populations of elephants (Hunter, 1996, Gross and Heinsohn, 2023), elephants still move widely across the wild landscape to forage and drink from both ephemeral and permanent surface water sources (Tsalyuk et al., 2019, Pandraud, 2022).

African elephants are water dependent and need access to drinking water on a daily or regular basis (Gaugris and Van Rooyen, 2010, Dunkin et al., 2013). In environments where water resources are uniformly distributed within the landscape, elephant distribution assumes a similar uniform distribution pattern (Dzinotizei et al., 2018). Where water sources are skewed towards one side of the range, elephants tend to congregate in areas with water (Skarpe et al., 2000). Thus, surface water availability can be a critical factor influencing elephant home range sizes and distance travelled to access resources such as water within and between seasonal ranges (De Beer and Van Aarde, 2008). In some elephant conservation areas, especially in semi-arid countries, artificial provisioning of water to wildlife through pumping out underground water has become a necessary elephant management strategy (Tshipa et al., 2017). It is not only the distribution of waterholes that is critical for elephant space use and distribution but also the quantity and length of time the waterholes continue to provide sufficient water to elephants (Chamaille-Jammes et al., 2007, Branco et al., 2019).

Elephant are heavy consumers of plant matter, taking up to 400kg of forage (Kohi, 2013). Although elephants also need nitrogen-rich plant tissues such as grasses and tree leaves (Mattson Jr, 1980), much of their food comprise carbohydrates and specific-nutrient sources such as bushes, twigs, tree barks, and roots (Ben-Shahar and Macdonald, 2002, Prajapati, 2008). It is therefore necessary that an elephant range should be able to provide these diverse sources of nutrients to elephants within and between seasons, as well as at separate times of the day. Elephants may need more carbohydrates at certain times of the day to fill up their stomachs and enhance food digestion (Owen-Smith, 1988), and may need protein-rich or mineral-rich food at other times of the day or season depending on their physiological requirements (Sach et al., 2019). Female elephant may need more mineral rich foods during pregnancy and breast-feeding for bone development of their inborn and born calves (Takatsu et al., 2017). Therefore, home ranges may differ between seasons and between sexes of elephants.

This study examines the difference in home range sizes between 15 African elephants (5 male and 10 female) in the eastern Okavango Panhandle in northern Botswana across wet and dry seasons between 2014 – 2017. The eastern Okavango Panhandle presents a wide and large landscape which elephant can move around with ease and access key critical resources needed in different seasons. Botswana has the largest contiguous population of elephants in the world with about 130,000 individuals (Bussière and Potgieter, 2023) ranging across the northern part of the country, which falls within the Kavango–Zambezi Trans-frontier Conservation Area (KAZA TFCA). The KAZA TFCA is one of the largest conservation areas in Southern Africa transcending the borders of Angola, Botswana, Namibia, Zambia, and Zimbabwe (Songhurst et al., 2015). Pozo et al. (2017), (Matsika et al., 2023) indicated that in the eastern Okavango panhandle, there are about 18000 elephants in the area occupying over 80% of the area. The human population is low (16300 people) (Central Statistics Office, 2021) and is largely and linearly distributed along the Okavango River which also provides permanent surface water to elephants and people (Pozo et al., 2018).

In this study, we hypothesized that (*i*) elephant home ranges would be larger in the wet season than in the dry season (because forage and water sources tend to be more plentiful and widely distributed in the wet season than in the dry season, and elephants would not be restricted to localized resource areas) and that female elephants would have larger home ranges than males. We also hypothesized that (*ii*) the distance of elephants to the nearest ephemeral surface water sources would be larger in the dry season than in the wet season as these ephemeral water sources successively dry up. Because elephants need forage and water regularly, they must commute between foraging sites and ephemeral water pools to satisfy their daily requirements. The distance between foraging sites and water sources would steadily increase as dry conditions intensify and water pools successively dry up.

# **Materials and Methods**

## *Study area*

The study was conducted in the eastern Okavango Panhandle, northern Botswana from April 2014 to December 2017 (Fig. 1). The study area covers an area of 8,732 km2 and includes three wildlife management areas, NG/11, NG/12, and NG/13. These areas are not fenced and therefore they allow free movement of wildlife across their boundaries. The climate is semi-arid savanna with strictly seasonal and erratic rainfall falling between November and April. The dry season starts in May-October with the minimum temperatures around 17oC in July, and maximum temperatures reaching 37oC in September and October (Songhurst and Coulson, 2014).

The soils in the study area are sandy (arenosols) and support deciduous dry savanna woodlands, open-tree savannas, shrublands and grasslands on the fossil sand dunes (Hartemink and Huting, 2008, Cao, 2017). Towards the Okavango River in the west and south, the vegetation is mostly riverine with dense woodlands and floodplain grasslands (Thomas, 1991, Ringrose et al., 2003). The topography is generally flat with a slightly higher elevation of 1068m in the north, and slopes in the south-west and south-east towards the Okavango River which is at 937 m above the sea level. Towards the north and central parts of the eastern Okavango panhandle are gently undulating and longitudinal east-west fossil sand dunes characteristic of the Kalahari sand region (Gumbricht et al., 2001). The area also has numerous ephemeral pans scattered across the landscape that dry at different times after the rainfall season, although some can hold water for a long duration into the late dry season or into the next rainfall season. Some pans can hold water until August, with some larger pans able to hold until the next rainy season (Chase et al., 2018). Much of the inner and further parts in the north and east have few and no seasonal water pans and are rarely used by water-dependent animals in the dry season. The Okavango River in the panhandle of the Okavango Delta is the only source of permanent surface water in the area and is heavily used by water-dependent wildlife in the dry season, which includes elephants (Songhurst et al., 2016, Pozo et al., 2018, Chase et al., 2018, Buchholtz et al., 2019).

There are about 18,000 elephants in the eastern Okavango Panhandle as well as large populations of plains zebra (*Equus quagga*), sable antelope (*Hippotragus niger*), roan antelope (*Hippotragus equinus*), greater kudu (*Tragelaphus strepsiceros*), and giraffe *(Giraffa camelopardalis).* The area also has a good number of wild carnivores such as the Africanlion (*Panthera leo*) and leopard (*Panthera pardus*) (Bothma and Walker, 2013). Human settlements numbering 14 main villages and supporting 16,300 people are lined along the stretch of the Okavango River (Central Statistics Office, 2021). Sources of livelihoods are tourism, pastoral and arable farming (Songhurst et al., 2015). Human-elephant conflict is intense in NG11 where there is high interaction between agricultural activities and elephants that are accessing water and resources in the Okavango River and Okavango Delta, and consequently raid farmers’ crops, damage property, and threaten people’s lives (Songhurst, 2023).

### *Elephant collaring and tracking*

We used the Global Positioning System (GPS) collar (Iridium Vectronics) data from 15 elephants (5 males, 10 females) collared in Wildlife Management Areas (NG11, 12 and NG13) in the eastern Okavango Panhandle in April 2014. Each collar was set to give hourly GPS fixes. Individuals were selected using a spotter plane and darted and immobilized from a helicopter. All collaring procedures were supervised by a veterinarian and performed under the research permit EWT 8/36/4 XVII (79) and immobilization permits issued to Ecoexist Trust. To reduce bias towards any specific area within the eastern Panhandle individual elephants were selected from independent herds. Females were selected based on their body size and age of their calves (>3 years) if any. Larger individuals were preferred as they were considered mature adults and highly likely to be matriarch. All collared males were older than 20 years (Songhurst, 2014). For this study, we used data from April 2014 – December 2017, and a total of 10518 –30609 fixes per elephant were analysed (see Table 1).

### *Drought estimates*

To identify drought conditions, we used the Standardized Precipitation Evapotranspiration Index (SPEI) drought index (<https://spei.csic.es/>) for grid cells and covered the period from 1950-2017. The drought conditions were classified using the SPEI indices and five qualitative drought severity categories (Table 2). The SPEI indices range from 2 to -2 and the range from –2 to 0 reflects the occurrence of drought and the range from 0-2 depicts non-drought conditions. SPEI values less than −1.5 indicate severe to extreme drought conditions. In this study, we used SPEI 48, which is an indicator of prolonged drought conditions impacting the state of hydrological systems.

## Data Analysis

### *Home range size*

The elephant fixes totalling 333,319, were downloaded using the Vectronic GPS PLUS X Collar Manager and compiled into Microsoft Excel. This dataset was then imported into R statistics version 4.0.1 for subsequent visualization and statistical analysis (R Core Team, 2013). To ensure data quality, a cleaning process was undertaken. Initially, rows lacking XY coordinates and data falling outside the study period (Songhurst, 2014) were removed. To eliminate duplicate fixes, the *'getDuplicatedTimestamps'* function from the 'Move' package, in R version 4.0.3 (Kranstauber et al., 2020), was employed. This rigorous data processing resulted in a final dataset encompassing 333,319 fixes related to the 15 collared elephants.

The 95 % kernel utilisation distribution (UD) for each elephant was derived with the kernel density estimation (KDE) method (Van Winkle, 1975, Fieberg and Kochanny, 2005), from the ‘*adehabitat*’ package in R version 4.0.3 (Calenge, 2006) to allow a comparison of home range sizes between seasons and sex (Benhamou, 2011). The reference smoothing parameter (*h\_ref)* (Worton, 1987, Viana et al., 2018) was used to calculate home ranges and 95% contours (Börger et al., 2006). The smoothing parameter *h\_ref* was chosen over Least Square Cross Validation (LSCV) which is widely used because the latter did not converge with the dataset used. Kernel home range estimators were selected over Minimum Convex Polygon (MCP) estimators since the MCP do not reveal the real outline of the home range but consider areas that are infrequently visited identically to those that are often visited. Kernels differentiate intensively used locations more precisely (Worton, 1987). From these home range, seasonal home range sizes were extracted for every collared individual elephant. To be able to generate complete seasonal home range sizes we used data from the collars that had consistently recorded GPS fixes throughout the entire season.

The data did not satisfy the assumptions of normality after a Shapiro-Wilk test. The data were then log-transformed, after which they followed a normal distribution (W= 0.99191; p value = 0.2977). The effects of season on home range size were analysed using a linear mixed-effects model (LMM) in R (*lmer* package; (Bates et al., 2015) with the log of home range size as the dependent variable, fixed effects predictors variables were two-way interaction between season and sex, and individual animal and year as the random effect. The dredge function in the ‘*MuMIn*’ package was used to run models with all combinations of the predictors and identified the most parsimonious models based on AIC values (Akaike, 1974).

### *Distance to the nearest ephemeral surface waterpoint*

Distance was measured using the daily distance between the elephant location and the ephemeral waterpoint. The GPS collar data were downloaded at an hourly rate. However, we transformed the data to 1 point per day and took a midnight point to account for all 24 hours in a day. We used the ‘*Near Analysis*’ tool in ArcGIS Pro 3.3 to calculate the daily distances to ephemeral surface water in the wet and dry seasons (Environmental Systems Research Institute, 2023). The effect of season on the distance of elephants to ephemeral surface water was analysed using linear mixed models (LMMs) in R (lme4 package after (Bates et al., 2015) using a log link function for the data (Bates et al., 2015). Distance to ephemeral surface water was used as the dependent variable. Fixed effect predictors included a two-way interaction between season, sex, and year, with an individual animal as a random effect to account for repeated observations and allow for variation among individuals. Year was converted into a factor in R to assess its influence on the distance to ephemeral surface water. The *anova* function from the ‘*stats*’ package was used to calculate p-values for significant variables. The dredge function in the ‘*MuMIn*’ package was also used to run the model with all combinations of the predictors and identified the most parsimonious global models based on AICc values (Akaike, 1974, Barton, 2009).

# **Results**

### *Home range size*

The mean seasonal home range size from the collared elephants recorded over 4 years was 1246.80 km2 (sd 1050.901) and ranged from 800 to 4000 km2. The most parsimonious model explaining significant variations in home range sizes included season only (AICc = 396.5, AICw = 0.817). No other models were competitive (Table 3 and 4). The home range sizes were consistently smaller in the dry season (800-1800 km2) than in the wet season (1850-4000 km2) (Supplementary: Figure 4. A-D).

### *Distance to the nearest ephemeral surface water source*

There was a significant difference in seasonal daily distance from ephemeral surface water between seasons, sex, and year (AICc= 16227.7, AICw =1; Table 5,6 and 7). The most parsimonious model included an interaction between season and sex; season, year and was significant (see Table 5 and 7), and no other model was competitive. Elephants were found near ephemeral surface water sources in the wet season (6000-6250m) compared to the dry season (12000-1875m) for all sexes (Figure 3, and Figure 4 in the supplementary section). Female elephants stayed closer to ephemeral water sources than male elephants. Annually, elephants were closer to ephemeral surface water in 2014 and 2017, but in 2015 and 2016, they travelled farther from ephemeral water sources (Figure 6).

### *Climate*

There was a drought in the study area throughout the study period (Figure 7). When using a Standardized Precipitation Evapotranspiration Index (SPEI) on a 48-month time scale (SPEI 48), we found that the period from 2015-2017 had an extremely severe drought compared to 2014 which was less dry. We assume that rains were low but increased towards the end of the study in 2017 (Figure 7).

# **Discussion**

*Home range sizes*

This study hypothesized that *(i)* elephant home ranges would be larger in the wet season than in the dry season on the basis that critical resources are abundant and widely distributed over a larger area in the wet season than in the dry season and that elephants would not be restricted to small localities that offer the much-needed resources. Our study found that elephants had larger home range sizes in the wet season than in the dry season. Generally, resource availability is critical in determining the distribution and abundance of megaherbivore populations in the African savannas (McNaughton, 1985, Fryxell, 1991, Fynn and Bonyongo, 2011). Surface water and forage availability in particular are key determinants of elephant movement and home-range size (De Beer and Van Aarde, 2008, Loarie et al., 2009, Cushman et al., 2005, Cushman, 2010). African elephants are water-dependent and must drink regularly usually every 2-3 days to maintain their body water requirements and facilitate thermoregulation (Hidden, 2009). Elephants are also heavy carbohydrate consumers and can ingest over 400 kg of forage daily (Ben-Shahar and Macdonald, 2002, Prajapati, 2008, Kohi, 2013). Where this quantity of food and surface water sources are widely and abundantly available, elephants can move around and cover a larger area in a day without finding the need to go back to the original location (Adams et al., 2021), and this may explain why in this study the home ranges were larger in the wet season than in the dry season. Our findings are similar to those found in Chobe in north-eastern Botswana (Chase, 2007, Adams, 2016), and other semi-arid countries where elephant home ranges were consistently larger in the wet season than in the dry season (Western and Lindsay, 1984, Osborn and Parker, 2003, Galanti et al., 2006, Kikoti, 2009, Ngene et al., 2017, Mlambo et al., 2021). However, the home range sizes in our study were much larger than those observed in Kwando and Chobe National Park in north-eastern Botswana (149.68-685.81 km2 and 800-4000 km2) (Chase, 2007). Although the large difference in home ranges for elephants between the study area and Kwando and Chobe National Park is not known, the intense cross-border elephant poaching that is happening within and around Chobe and Kwando areas(Chase and Griffin, 2009, Spinage, 2024) could be the cause of this difference. The other possible explanation could be the presence of Chobe, Zambezi, and Kwando-Linyanti rivers that offer permanent sources of water and forage-rich habitats which many elephants would hang around throughout the year, hence limiting their home ranges (Adams et al., 2021). The eastern Okavango Panhandle area is a vast area with limited human presence and has numerous and widely distributed ephemeral pans that can offer enough water during the wet season and allow elephants to move freely and without fear for humans within the wet season range (Adams et al., 2021, Naidoo et al., 2022b). Although forage availability (Stokke and Du Toit, 2002), habitat type (Thouless, 1995, Schulte, 2000, Bohrer et al., 2014, Adams et al., 2021), and terrain (Schulte, 2000, Nellemann et al., 2002) can influence wildlife movements and home ranges, there is limited information that could be used to explain the differences in home ranges observed for elephants in north-eastern and in the eastern Okavango Panhandle. The eastern and northern boundaries of our study area are marked by a veterinary cordon fence which is less than 1.4m in height and is not electrified. This fence does not pose any serious hindrance to elephant movement into and out of the study area as the short height and flexibility of the fence allow the elephants to cross with impunity, even when crossing as family herds with calves. Therefore, the study area can be considered to have semi-permeable boundaries that do not limit cross-boundary movements. In this study we recorded transboundary movements of some collared male elephants from the study area into Namibia and Angola, and back, which indicated the permeability of the study area boundaries despite the presence of the cordon fence, and possible explanation for the larger home range sizes observed in eastern Okavango panhandle compared to those found in Kwando and Chobe in northeastern Botswana which may be restricted by increasing anthropogenic activities around the Chobe National Park and forest reserves (Adams et al., 2021).

*Distance to the nearest ephemeral surface waterpoint*

We hypothesized that the distance of elephants to the nearest ephemeral surface water sources would be larger in the dry season than in the wet season. Our findings indicated a significant difference in the distance of the collared elephants to the nearest ephemeral surface water between seasons, years, and sex. Distance to the nearest ephemeral surface water was larger in the dry season (12-18 km) than in the wet season (6 km), with female elephants found closer to ephemeral water sources than male counterparts. The results indicate that as the dry conditions set in during the dry season and ephemeral water sources progressively dry up, elephants would travel longer distances from their foraging sites to the nearest ephemeral water source which would still have some water in the dry season. The distance between the foraging sites and seasonal water pools would increase as more water pools dry up, leaving a few that often are distant apart. The distance increases because elephants need water and forage regularly and need to travel between foraging sites and water sources to satisfy their food and water intake. The larger distances found in the dry season suggest that critical resources were depleted in the wet season range and were only available further away, hence forcing the elephants to travel long distances to reach pools that still had water. As the dry season conditions intensify, the high density of the elephant distribution shifts towards the Okavango River which offers a permanent water source (Buchholtz et al., 2021). The elephants usually start moving towards the Okavango River from the core area of the eastern Okavango panhandle between April-June (Songhurst, 2012, Songhurst et al., 2015, Pozo et al., 2018). In Chobe National Park, studies found that elephants congest around Chobe River which provides permanent water sources in the dry season and move some daily distance of up to 10km further from the river to browse in the woodlands (Skarpe et al., 2004). Elephants can travel over 70 km every 2-4th day from a wet season range to a dry season range to drink from a permanent water source, and those that are frequent drinkers can reside within 10-40 km from the water source (Viljoen, 1989, Skarpe et al., 2004, Wato et al., 2018). Similar observations were found in the forest elephants in the tropical forests of Gabon (Mills et al., 2018). Our study found that in the dry season elephants covered a large daily distance of 6-6.2 km, indicating the need for elephants to commute between water sources and forage to satisfy their physiological needs. Resource availability, especially water, is the main determinant of the home-range size and movement patterns of large African herbivores (Leggett, 2006). Desiccation of water pools or the arrival of light showers signalling water availability and the subsequent emergence of flush vegetation can trigger long-distance and cross-border movements (Viljoen and Bothma, 1990), hence changes in home range sizes and distance to water.

Sex was also a key determinant of the distance to ephemeral water for the collared elephants in this study. Female elephants were found closer to ephemeral water sources than their male counterparts. This could be because female elephants move in family groups comprising different age groups including lactating mothers and juveniles that need to forage and drink more frequently. With that higher affinity for water, they need to hang around waterholes more than their male counterparts. Furthermore, female elephants often walk young calves that move slowly, are vulnerable to predation, and need to be in a safer place compared to male elephants who are often solitary, risk takers, and exploratory (Ngene et al., 2010, Lee, 2011, Mills et al., 2018, Wato et al., 2018).

A high affinity for water by elephants (Mills et al., 2018, Wato et al., 2018) was evident when the effect of year was assessed. The results indicated that elephants occurred closer to ephemeral water in 2014 and 2017 when the drought was not so severe, but further away in 2015 and 2016 when the drought was extremely severe. The much drier period in 2015 and 2016 resulted in many ephemeral water pools drying up and forcing elephants to move further from the ephemeral water pools. Dispersal distances of over 40km from ephemeral waters were recorded during the extreme drought periods compared to the average distance of 15km recorded in the less dry years. Elephants likely moved to the Okavango River in the eastern and southern boundary and Kwando River in the far eastern side of the study area which provide permanent surface water throughout the period. It is possible that the dispersal of elephants away from the dry ephemeral water pools to permanent water sources as the drought intensified in 2016 and 2017 contributed to an increase in human-wildlife interactions and conflict in the study area. For elephants in the study area to reach the Okavango River they are forced to navigate through a cluster of human settlements, which are also linearly distributed along the river to access the water (Songhurst, 2023). This creates a challenge as elephants pass between these settlements and exacerbates human-wildlife conflict which can occur in the form of damage to crops and property, human mortality, and revenge killing of offending elephants by farmers and wildlife authorities (Songhurst, 2017).

# **Conclusion**

Elephant home ranges were larger in the wet season than in the dry season and the distance of elephants to the nearest ephemeral waterpoints was larger in the dry season than in the wet season. Season regulated the home range sizes and distance to ephemeral water sources. We believe seasonal variations in food and water resources were important determinants of space use and distance to ephemeral water sources by elephants in the eastern Okavango Panhandle. Informed and integrated land use planning that considers seasonal variations in elephant home range sizes and access to critical seasonal ranges at a landscape scale should be a priority when developments are planned in elephant conservation areas. We recommend that priorities be also given to conservation initiatives such as the Kavango Zambezi Trans-frontier Conservation Area that was established to provide more area for conservation of elephants, especially in the face of climate change when high temperatures and droughts would exacerbate forage and water shortage and intensify human-elephant conflict.

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# **Appendix**

**Figure Captions**

**Figure 1.** Map of the study area, within Area NG11, where the 12 sampled villages are illustrated according to population size.

**Figure 2.** Seasonal home range sizes for male and female elephants in the eastern Okavango Panhandle, Botswana between 2014-2017. Home ranges derived from Kernel density estimation using R Statistics version 4.2.1.

**Figure 3**. Elephant daily distance to ephemeral surface water and sex in the eastern Okavango Panhandle, Botswana from 2014-2017. Error bars represent ± 1 standard error. Distances derived using *'near analysis tool*’ in ArcGIS Pro 3.0.

**Figure 4 A-D.** Seasonal home ranges for African elephant (Year 2014-2017) in the eastern Okavango Panhandle, northern Botswana

**Figure 5.** Season and distance to the nearest ephemeral surface water

**Figure 6.** Year and distance to the nearest ephemeral surface water

**Figure 7.** SPEI 48 – representing hydrological droughts. SGlobal Drought Monitor online portal; https://spei.csic.es/map/maps.html and is available at a one-degree spatial resolution for the period 2014-2017 covering time series at cell -18.25 degrees south and 23.75 degrees east

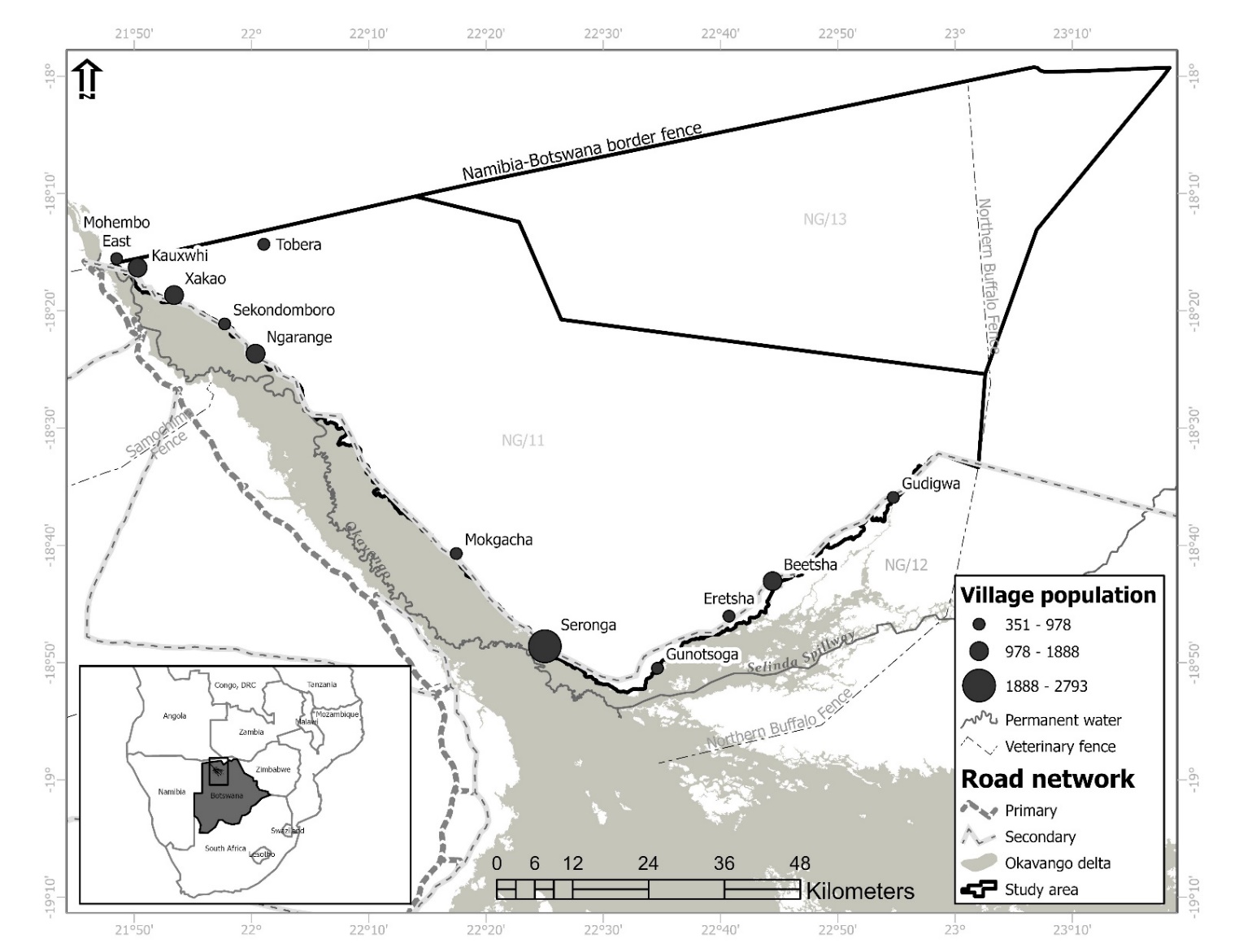
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Figure 1.

**A graph showing different types of data

Description automatically generated with medium confidence**

Figure 2.

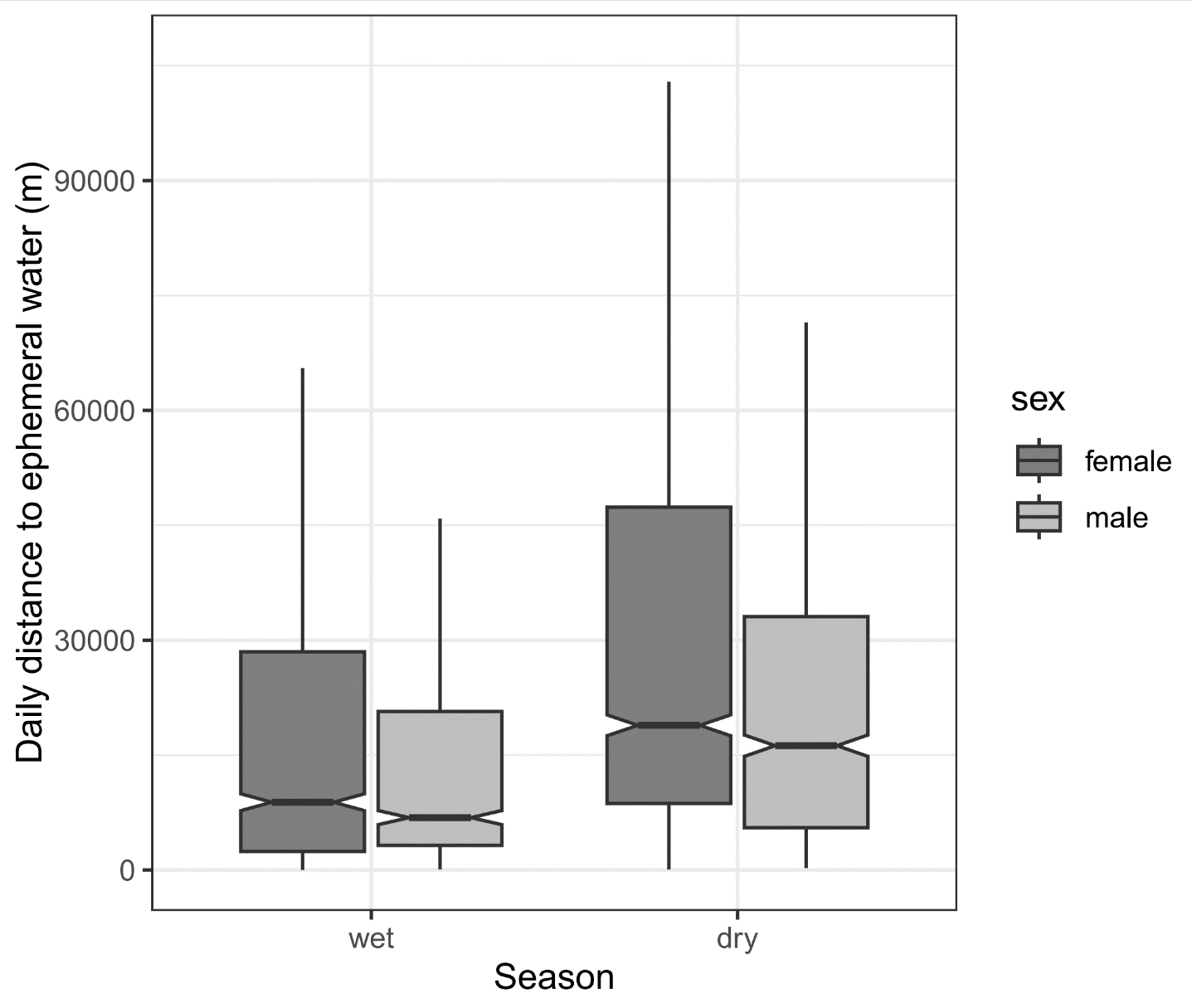
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Figure 3

**Table Captions**

**Table 1.** Identity and biodata of the 15 collared African elephants and the number of the GPS location fixes obtained between 22 April 2014 – April 2017 in the eastern Okavango panhandle, northern Botswana.

**Table 2.** Drought classification based on SPEI values.

**Table 3.** Type III Analysis of variance table with Satterthwaite method for home range sizes

**Table 4.** Candidate models of the effects of season and sex on home range size in African elephants in the eastern Panhandle, northern Botswana, between 2014-2017Drought classification based on SPEI values.

**Table 5.** Type III Analysis of variance table with Satterthwaite method for distance traveled to ephemeral water

**Table 6.** Candidate models of the effects of season, sex, year on distance travelled in African elephants in the eastern Panhandle, northern Botswana, between 2014-2017.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Elephant**  **name** | **ID** | **Deployment / Tracking period** | **Sex** | **Age** | **No. fixes** |
| Pille | 14648 | 22 Apr. 2014 – April 2017 | Female | 20+ | 30609 |
| Nare | 14649 | 22 Apr. 2014 – April 2017 | Female | 25 | 18361 |
| Mpule | 14650 | 24 Apr. 2014 – April 2017 | Female | 25 | 27791 |
| Mbamba | 14653 | 25 Apr. 2014 – April 2017 | Female | 20+ | 30260 |
| Rain | 14654 | 24 Apr. 2014 – April 2017 | Female | 20 | 17395 |
| Ann | 14656 | 23 Apr. 2014 – April 2017 | Female | 20 | 14861 |
| Ebby | 14659 | 24 Apr. 2014 – April 2017 | Female | 16-20 | 29977 |
| Koo | 14660 | 23 Apr. 2014 – April 2017 | Female | 20 | 29492 |
| Whisper | 14661 | 25 Apr. 2014 – April 2017 | Female | 25 | 11866 |
| Amantle | 14664 | 23 Apr. 2014 – April 2017 | Female | 20 | 10518 |
| Howard | 14646 | 23 Apr. 2014 – April 2017 | Male | 40+ | 21543 |
| Chan | 14652 | 25 Apr. 2014 – April 2017 | Male | 36+ | 20734 |
| G | 14657 | 23 Apr. 2014 – April 2017 | Male | 40 | 19266 |
| The Bachelor | 14658 | 24 Apr. 2014 – April 2017 | Male | 30 | 20502 |
| Whiskey | 14662 | 25 Apr. 2014 – April 2017 | Male | 30 | 30144 |

Table 1. Datasets used.

Table 2.

|  |  |  |
| --- | --- | --- |
| Level | Drought Category | SPEI values |
| 0 | Non drought | 0 ≤ index |
| 1 | Mild drought | -1.0 < index < 0 |
| 2 | Moderate drought | -1.5 < Index ≤ -1.0 |
| 3 | Severe drought | -2.0 < Index ≤ -1.5 |
| 4 | Extreme drought | Index ≤ -2.0 |

(*Source:* (Tan et al., 2015)

Table 3. Home ranges - Analysis of Variance Table with Satterthwaite's method

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | Significance |
| Season | 47.814 | 47.814 | 1 | 162.760 | 151.0063 | <2e-16 | \*\*\* |
| sex | 0.000 | 0.000 | 1 | 13.081 | 0.0000 | 0.9953 |  |
| Season: sex | 0.315 | 0.315 | 1 | 190.550 | 0.9955 | 0.3197 |  |

Table 4. Candidate models of the effects of season, sex and their interaction on home range size in African elephants in the eastern Panhandle, northern Botswana, between 2014-2017

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | (int) | Season | Sex | Season: sex | df | LogLik | AICc | Delta | Weight |
| 2 | 7.381 | + |  |  | 5 | -193.103 | 396.5 | 0.00 | 0.817 |

Table 5. Analysis of Variance Table with Satterthwaite's method – daily distance to ephemeral surface water

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Sum Sq | Mean Sq | NumDF | DenDF | F value | Pr(>F) | Significance |
| Season | 867.41 | 867.41 | 1 | 5289.4 | 702.6569 | < 2.2e-16 | \*\*\* |
| Sex | 2.00 | 2.00 | 1 | 13.1 | 1.6232 | 0.22e--16 |  |
| Year | 1867.40 | 622.47 | 3 | 5285.2 | 504.2368 | < 2.2e-16 | \*\*\* |
| Season: sex | 39.70 | 39.70 | 1 | 5289.6 | 32.1609 | 1.494e-08 | \*\*\* |

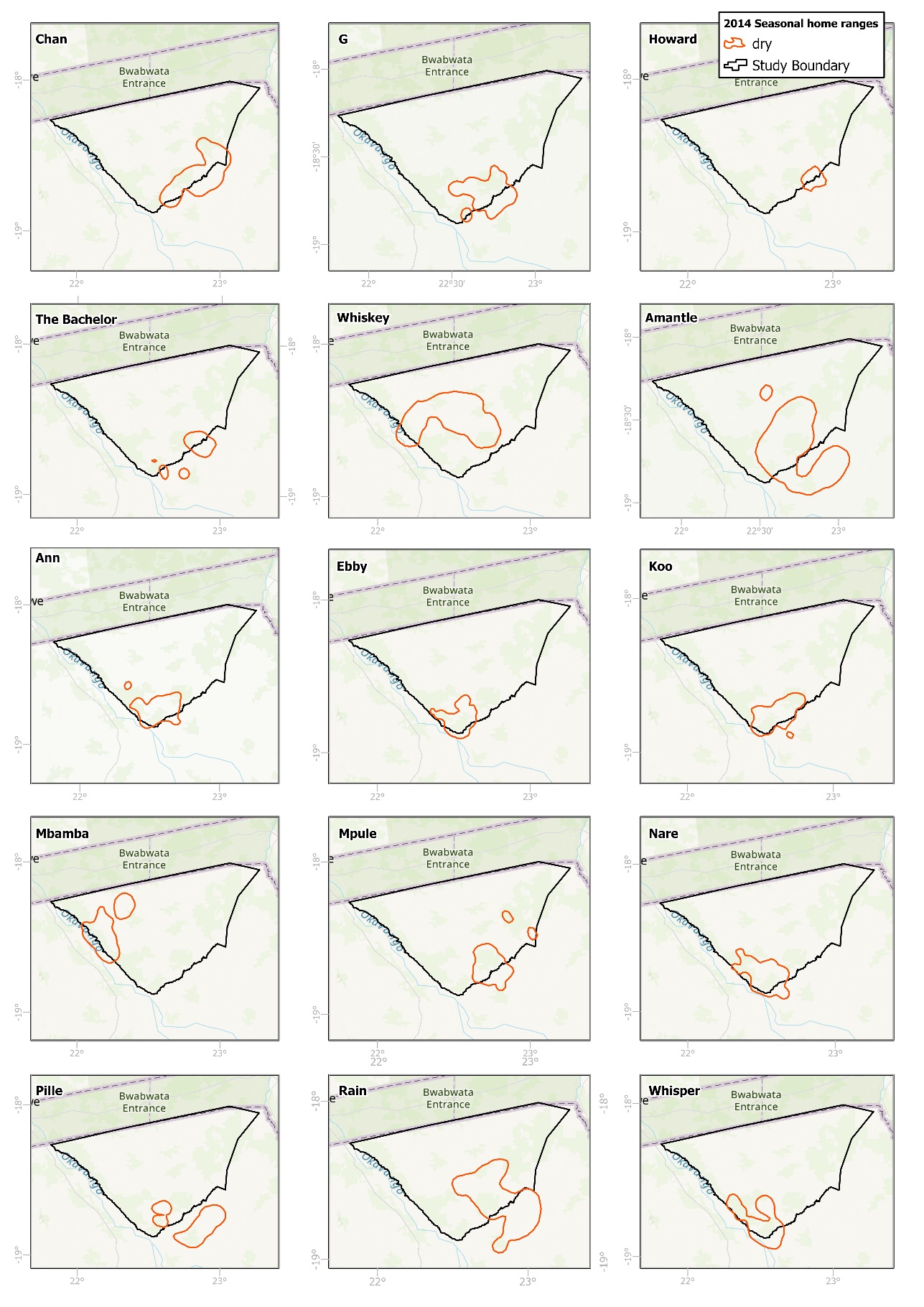
Table 6 Type III Analysis of variance table with Satterthwaite method for distance traveled to ephemeral water

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Estimate Std. | error | df | T value | Pr(>|t|) | Significance |
| (Intercept) | 9.12682 | 0.07549 | 24.09028 | 120.901 | < 2e-16 | \*\*\* |
| Season [wet] | -1.05014 | 0.03947 | 5290.44379 | -26.606 | < 2e-16 | \*\*\* |
| Sex [male] | -0.32727 | 0.11596 | 14.94794 | -2.822 | 0.0129 | \* |
| Year [2015] | 1.26329 | 0.04808 | 5290.95720 | 26.275 | < 2e-16 | \*\*\* |
| Year [2016] | 1.22026 | 0.04848 | 5289.52783 | 25.173 | < 2e-16 | \*\*\* |
| Year [2017] | 0.02515 | 0.04972 | 5271.47497 | 0.506 | 0.6129 |  |
| Season [wet]: sex [male] | 0.36891 | 0.06505 | 5289.64879 | 5.671 | 1.49e-08 | \*\*\* |

Table 7. Candidate models of the effects of season, sex, year and their interaction on home range size in African elephants in the eastern Panhandle, northern Botswana, between 2014-2017

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Model | Int | Season | Sex | Year | Season: sex | Df | logLik | AICc | delta | weight |
| 16 | 9.127 | + | + | + | + | 9 | -8104.854 | 16227.7 | 0.00 | 1 |
|  |  |  |  |  |  |  |  |  |  |  |

# **Supporting Information**

Seasonal home ranges for African elephant (Year 2014-2017) in the eastern Okavango Panhandle, northern Botswana

**A**

A collage of images of a map

Description automatically generated

**B**

A collage of maps of different countries/regions

Description automatically generated

**C**

A collage of images of different maps

Description automatically generated

Figure 4

**D**

A graph with a number of squares

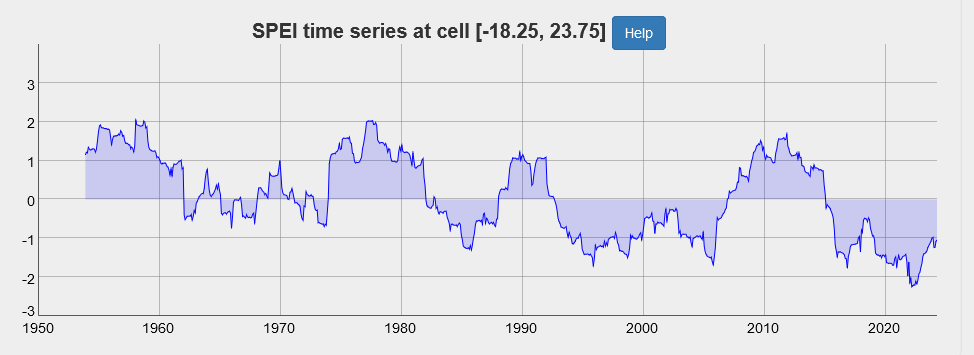
Description automatically generated with medium confidence

Figure 5

A graph with a number of squares

Description automatically generated

Figure 6



**SPEI**

**Year**

Figure 7