ASSESSMENT OF HOME RANGE ESTIMATES FOR NAMIBIAN ELEPHANTS USING GIS AND REMOTE SENSING

A Thesis

by

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ABSTRACT

In the region of northwestern Namibia, the desert elephants' population has been reduced to a total of 81 remaining as of 2019. Their population has been on a steady decline due to poaching, wars in the region, increasing human settlements, and various environmental factors that have affected the region for decades. There is a lack of information regarding the Namibian elephants, their migration patterns, and areas in which they reside. Efforts to assess the optimal home ranges for these elephants are important for the conservation of one of the last populations of desert-dwelling elephants. This research tracks the movement of nine Namibian elephants over an approximately five-year period, and introduces a new method for quantifying their home ranges. Given elephants' ability to communicate over great distances using low-frequency sound, a sound-based home range estimate is proposed and compared to traditional minimum convex polygon (MCP) estimates. The size of these two home range estimates is first compared, and remotely sensed vegetation and slope data are then extracted from the home ranges. The resulting values were compared statistically to determine which home range estimate is most representative of the Namibian elephants' preferred environment. The traditional MCP home range ultimately proved to be more effective in quantifying the elephants' home range environment. This information not only contributes to improving the knowledge base regarding the Namibian elephant sub-population, but also develops a simple and effective methodology to study other elephant populations, thereby aiding in the conservation of the species.

DEDICATION

This thesis is dedicated to my family, friends, and relatives. I am grateful to have reached this point in my education and know that none of this would have been possible without their prayers and constant support, and God's help. I have thoroughly enjoyed my graduate school journey and am proud to be a part of a group of students who persevered through the COVID-19 pandemic and a myriad of tumultuous challenges, all while combating the natural stresses that come with pursuing higher education.

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CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Frauenfeld (advisor), and Professor Casellas Connors of the Department of Geography and Professor Gao of the Department of Civil Engineering. All other work conducted for the thesis was completed by the student independently.

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NOMENCLATURE

EKF-1	Eastern Kunene Female #1
EKM-1	Eastern Kunene Male #1
EKM-2	Eastern Kunene Male #2
EKM-3	Eastern Kunene Male #3
EKM-6	Eastern Kunene Male #6
EVI	Enhanced Vegetation Indices
MCP	Minimum Convex Polygon
MODIS	Moderate Resolution Imaging Spectroradiometer
MYD13Q1v006	MODIS/ Aqua Vegetation Indices 16-Day L3 Global 250m SIN Grid
NASA	National Aeronautics and Space Administration
SCNP	Skeleton Coast National Park
SR	Sound Radius
SRTM	Shuttle Radar Topography Mission
WKF-16	Western Kunene Female #16
WKF-18	Western Kunene Female #18
WKM-10	Western Kunene Male #10
WOM-4	Western Omusati Male #4

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INTRODUCTION AND LITERATURE REVIEW

1.1 Overview

The African continent, one of the largest in the world, includes over 45 countries that span over 30 million km^2 of land. The majority of the continent is located between the tropical and sub-tropical latitudes where there is more diurnal variation in temperatures than there is throughout the year. Covering as large of an expanse of land as it does, Africa also contains a diverse range of climates. The continent has a fairly sub-humid climate, but also experiences prolonged dry seasons over a year (Nicholson et al., 2001). Africa hosts a wide variety of flora and fauna, and remains an ecosystem rich in wildlife (Sibanda & Omwega, 1996). Specifically, the country of Namibia in Southern Africa has been a home to an elephant sub-population known as the Namibian desert-dwelling elephants. The knowledge, data, and history regarding their species is limited (Viljoen 1987, Viljoen et al., 1988, 1989a, b; Viljoen & Bothma, 1990; Lindeque & Lindeque, 1991, Leggett 2006, Leggett et al., 2003, Leggett et al., 2011).

The country of Namibia used to host a large population of the *Loxondonta Africana* meaning African desert elephants (Viljoen, 1989). Although there is limited concrete information available on these elephants during the time period of 1962–1982, it was noted that the elephants living in the desert conditions within the Kaokoland (now Kunene) region were severely threatened (Douglas-Hamilton, 1987). Some of the numbers showed that the population went from 3000 elephants in 1962 to 220 elephants remaining in 1982 (Douglas-Hamilton, 1987). This dramatic change took place in the 1970s which was within this 20-year period, and it reveals the rapid rate at which this sub-population declined. The factors that reduced the elephant populations included the high demand and price of ivory (Parker, 1979), an arms race and military actions (Garstang et al., 2014), and the increase of human population (Douglas-Hamilton, 1987). Prior to the 1970s, ivory would have averaged at about $5.45 per kg. However, after the 1970s the price of ivory fluctuated between $7.44 to over $100 per kg, which reflects the high demand. Additionally, the arms race introduced automatic rifles to the continent which sped up the decline of elephants, and resulted in excessive poaching continent-wide (Douglas-Hamilton, 1983). Given the very traumatic past these Namibian elephants have experienced due to intensive poaching and hunting occurring during a period of wars, the species has become endangered. The population of the desert-dwelling elephants has reduced to 81 remaining as of 2019 (Brown et al., 2020; Ramey II et al., 2019). However, the remaining population in 2020 is unknown as of now.

In this study, the movement of nine desert-dwelling elephants is tracked over a 5-year time period. The 9 elephants include one Eastern Kunene female (EKF-1), four Eastern Kunene males (EKM-1, EKM-2, EKM-3 & EKM-6), two Western Kunene females (WKF-16 & WKF-18), one Western Kunene male (WKM-10), and one Western Omusati male (WOM-4). The current status of the majority of these elephants is unknown, but a few are known to have meanwhile been killed or died of natural causes.

The history of desert elephants and documentation of their movement is very scarce, and accurately quantifying the Namibian elephants' home ranges is challenging. In previous studies, Fixed Kernel Densities (FKDEs) and Minimum Convex Polygons

(MCPs) have been used in identifying home ranges (Spencer & Barrett, 1984). The MCPs have been the most widely-used method to date, but they also have significant drawbacks. An MCP creates a tight-fit polygon around a set of points. Typically, by using this method, significant outliers are encompassed into the creation of an MCP or, in other words, an elephant's home range. This skews the areas through which elephants migrated, and may exaggerate their movement range. In this study, the use of a sound-based home range estimate is proposed. Using low frequency sound (Garstang et al., 2004), elephants can communicate with each other up to a ~10 km distance. Creating an equidistant, 10 km sound radius (SR) around the elephants' tracking points introduces a new way of assessing the elephants' movement and accounts for the preferences they have regarding where they choose to move, reside, and access their resources. This method also accounts for communication that occurs between the elephants, thus further increasing accuracy in home range identification by including a major factor that can influence movement.

To assess which estimation is more representative of an elephant's home range, both MCPs and SRs will be created for each elephant's tracking points during each 2002–2007 wet and dry season, and the average environmental characteristics will be established. The two estimates will be compared to determine whether there is a significant difference between the two methods, but each will also be compared to the average environmental characteristics at each known elephant tracking location. If the SR characteristics prove to be significantly different from the tracking locations' means, the MCPs will prove to be better home range estimators. However, if the MCPs means are more different from the tracking locations' means in comparison to the SRs, then the SRs will prove to be the more suitable estimator. When studying elephants and their migration patterns, it is vital to assess the distribution of two basic variables, vegetation and terrain slope (within the produced home range estimates), because these variables likely impact the decision-making process driving elephant movement. The distribution of these variables could then be useful for establishing wildlife corridors that allow elephants access to their resources.

Literature Review

1.2 Environment in Namibia, Africa

The country of Namibia is located in the southern region of Africa alongside the southern Atlantic Ocean (Figure 1). It is bordered by the five neighboring countries of Angola, Zambia, Zimbabwe, Botswana, and South Africa. The human population in Namibia, currently estimated at 2,678,191 (Central Intelligence Agency, 2021), has some of the lowest densities in the world (Hauptefleisch et al., 2021; World Population Review 2019). The Namibian capital city of Windhoek (located in the central region of Namibia) has a smaller, but fast-growing, population because of urbanization in the country (Hauptefleisch et al., 2021; Nickanor and Kazembe 2016). The Windhoek population had a 40% growth rate from 2001–2011 (Namibia Statistics Agency 2011), with a population of ~350,000 individuals in 2011 (Hauptefleisch et al., 2021). As of 2014, over 60% of Windhoek's population in the north and northwestern parts of the city lives on 25% of land in crowded formal and informal settlements (Pendleton et al., 2014). The Kunene region, the focus of this study, had a population of 86,856 in 2011, with 75% of people living in rural areas (Namibia Statistics Agency, 2011). The largest town in the study area is Kunene's capital of Opuwo (Figure 1), which had a population of 5,101 and 7,657 at the time of the 2001 and 2011 census, respectively, with most recent estimates of 20,000 people (Namibia Statistics Agency, 2011). Other populated places in the study area (Figure 1) include the settlement of Sesfontain (7,358 people), and the village of Kamanjab (1,795 people).

Namibia has a relatively dry and arid climate with mostly drought-like conditions throughout the year, and is commonly known as being a semi-desert, high-plateau country. Precipitation is variable and occurs mostly in the wet seasons of the year (Leggett et al., 2011). To determine the wet and dry seasons in Namibia and their transition times, daily rainfall measurements by Garstang et al. (2014) were used. Namibia's wet/dry seasons shift slightly from year to year, but typically last from September to November. The wet season tends to start in October (sometimes September) and lasts until November, while the dry season starts approximately in September (sometimes August) and ends in October. Namibia is comprised of a variety of topographic and landscape features which include: the Namib desert, the Great Escarpment, the Central Plateau, the Kalahari Desert, and the Kavango-Caprivi region. The terrain in Namibia consists of plateaus with mountainous regions along the coastline. The terrain ranges from −45 m to 2559 m across the northwestern Namibian region. Some of the main terrain features in the area are around 689, 1118, 1172, 1759 and 1918 m. Although the terrain is relatively flatter throughout much of the country, there are mountainous areas in proximity to the coastline which contain steep slopes and rougher terrain. Climate change has exacerbated the already arid region to be extremely dry, thus resulting in conditions such as minimal precipitation, severe water shortages, and reduced vegetation growth in the region. Agricultural production in Namibia has suffered due to impacts from climate change, and locals typically sustain themselves through rain-fed subsistence cropping and pastoralism (on communally owned land). On average, less than 10% of land in the region is used for cropping, and 75% is used for grazing (Government of Namibia, 2002). Agricultural land in the country is already marginal, and large changes in rainfall will cause more difficulty in its production (Reid, 2006).

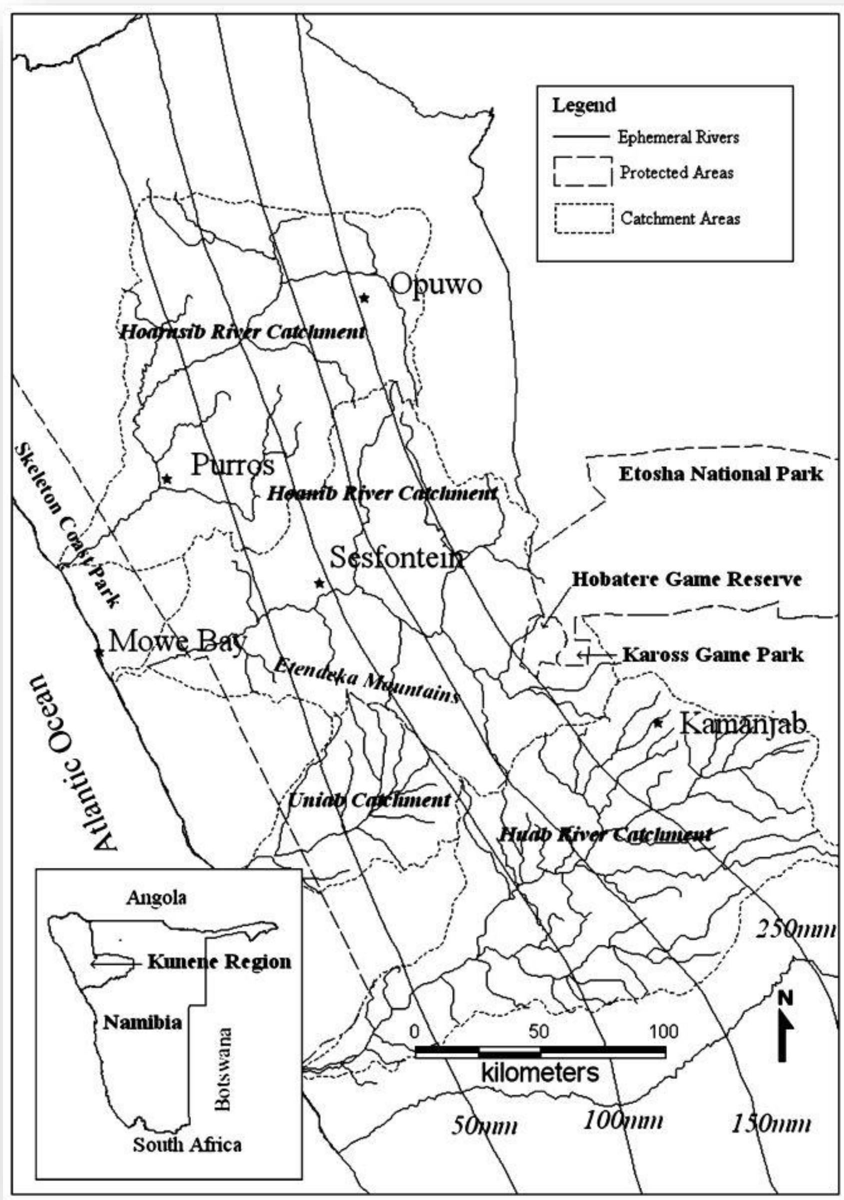

Figure 1: Study Area (Leggett, 2006).

1.3 History of the Desert Elephants in Namibia, Africa

The history of Namibian desert-dwelling elephants is quite unknown due to the remote environment and overall ruggedness of the area (Leggett et al., 2011). During a period of wars, the Namibian elephants were exposed to various high-stress conditions that severely affected their population. The elephants experienced severe drought and heavy ivory poaching (Viljoen et al., 1988), and human settlements increasing in proximity to the elephants' home ranges which severely worsened environmental conditions over time (Owen-Smith, 1970). Trophy hunting of elephants has a long history in northwestern Namibia, and commercial elephant hunting (for their ivory and other benefits) ushered in a major shift in prioritizing global networks of trade and desire-driven poaching activities. Poaching became a leisurely sport which ultimately diminished many elephant subpopulations in northwestern Nambia (Bollig & Olwage, 2016). The global demand for ivory, being a highly priced commodity, drove extreme amounts of illicit poaching activities for political gains (Bollig & Olwage, 2016). According to Viljoen (1987), the Namibian elephant population before the year 1900 was estimated to be somewhere between 2500 and 3500 elephants. Towards the end of the 19th century, this population was extensively hunted, but there was not any evidence that there was a decrease in the elephants' numbers (Viljoen, 1987). However, by the 1960s, there was a noticeable decline in the elephant population, and their numbers ranged somewhere between 600 to 800. By 1983, the number of elephants further decreased to around 360 (Viljoen, 1987) due to consistently poor conditions in the area. At this point in the 1980s, the elephant population in the northwestern region of Namibia had split into three separate populations, without maintaining any contact with either the eastern or western population (Viljoen, 1987). There may have been some genetic exchange occurring between the eastern and western populations due to a transitional elephant group that moved between the eastern and western elephants, however there was low calving recorded for the elephant population due to the human disturbance and increased poaching in Namibia (Viljoen, 1987). According to the Specialist Support Services (1999), the number of elephants slightly recovered to about 760 by 1999. Although there is information on elephant interactions, little is known of the elephants' social structure, interactions between the eastern and western populations, or the reasons driving their movement. Although poaching and culling still occur in the region, the intensity has dramatically diminished due to an ivory ban. However, the effects of extreme poaching have lasted over time, and resulted in only few remnants of the desert-dwelling elephants still existing (Leggett et al., 2011).

There are a few studies that focus on the subpopulations of desert-dwelling elephants within the Kunene region of northwestern Namibia. The remaining subpopulation has been identified as a remnant since the oldest members are survivors of the war-related poaching in the 1970s and 1980s. One of the first systematic surveys conducted to assess the number of elephants in the Kunene region was by Owen-Smith (1970) who estimated a total of 70 elephants occupying the Hoarusib river, from the upper Hoarusib gorge to the coast (Owen-Smith, 1970). Aerial surveys of the land during wars (1975–1989) revealed the possible large-scale displacement of elephants in the western Kunene, which included the loss and re-colonization of elephants in the lower

Hoarusib River. Another subpopulation in the western end of the Kunene River used to make annual migrations south of the Hoarusib River, but it was wiped out due to poaching by the 1980s (Viljoen, 1988). The current number of elephants has not recovered to pre-war levels, and has remained disturbed due to the excessive poaching in the past (Leggett et al., 2011).

1.4 African Elephant Social Structure & Behavior

The social structure of African elephants is typically based on groups of related females and their dependent offspring, led by the eldest female elephant (Buss, 1961; Buss & Smith, 1966; Moss, 1982). An individual female and her dependent offspring are considered a "family unit," which is defined as the basic unit of elephant society (Leggett et al., 2011; Moss and Poole, 1983; Poole, 1996). Additionally, "family groups" are related adult females with dependent offspring who associate with each other to some degree. These family groups play a tremendous role in forming defensive units, and kin-based allegiances that aid in protecting all elephants within the family group. This bond, naturally, is said to have a positive effect on the calf survival rate (Leggett et al., 2011; McComb et al., 2001; Archie et al., 2006). Bond or kinship groups are made of several closely related family groups, and are essentially formed when individual family groups are too large and split up based on family lines. Bond groups can be identified when they are reunited with their families by extravagant behavioral mannerisms (Leggett et al. 2011; Douglas-Hamilton, 1972, Douglas-Hamilton & Douglas-Hamilton, 1975; Moss, 1982). Another extremely important characteristic of elephants is that they can communicate with each other, using low-frequency sounds, up to a ~10 km distance (Garstang, 2004). These sounds, that humans cannot hear, impact the decision-making process and movement patterns of other elephants. Lastly, if families and bond groups have similar seasonal ranges, they are classified as “clans.” The term “clans” is used to define a level of association regarding habitat usage if it is unclear whether the elephants are a functioning social unit (Leggett et al., 2011; Poole, 1996). The Namibian elephant subpopulation, unlike others, lacks strong multi-tiered, matrilineal associations. Rather, previous studies suggested that elephant associations within the Kunene subpopulation are loosely affiliated, and lack strong social bonds (Leggett et al., 2011). This could also contribute to a faster decline in the remnant subpopulation.

1.5 Elephant Home Range Preferences

To better understand how the elephant population decreased over time and where the elephants prefer to reside, it is vital to study the elephants’ movements. Leggett (2006) determined the home ranges of elephants and their seasonal movement in the Kunene region of northwestern Namibia. Leggett (2006) expands on earlier work (Leggett et al., 2003) which was not conclusive because it focused on elephants within a specific river basin, thus not allowing for understanding their large-scale movement patterns. As noted in older literature, the elephants range from being sedentary (Douglas-Hamilton, 1971; De Villiers & Kok, 1997) to more semi-nomadic and seasonally dispersive (Leuthold 1977, Viljoen 1989a; Lindeque & Lindeque 1991; Thouless 1995). The home ranges tended to differ based on the elephant’s gender, age, and level of sexual activity (Leggett, 2006). It is known that rainfall plays a vital role in the seasonal movements of elephants, their differential habitat uses, as well as forage preferences and availability. In an area like Namibia, precipitation is scarce, inconsistent and both spatially and temporally variable, and averages less than 100 mm annually (Leggett et al., 2011; Viljoen, 1988). During the wet season of the year, rainfall occurring in the upper reaches of the Hoarusib and Hoanib River catchments tends to produce short-lived flooding regardless of whether or not it rains in the immediate area (Leggett et al., 2011; Viljoen, 1988). Ephemeral rivers carry small amounts of surface water (except in canyons where the bedrock naturally forces it to the surface), but for most of the year the water flows underground (Leggett et al., 2011; Jacobson et al., 1995). The patterns of water flow are crucial to understand because water ultimately leads to the production of healthy vegetation across certain areas in Namibia. After water nourishes land in the region, ribbons of vegetation form alongside the ephemeral rivers creating ‘linear oases’ which become sources of forage and water for elephants and other wildlife. The elephants’ predicted home ranges show that they occupy the ephemeral rivers for much of the year (Leggett et al., 2011; Viljoen, 1988; Leggett et al., 2003; Leggett, 2006). Leggett et al. (2011) note that the female elephants travel up and down the tributaries and surrounding riverbeds, and occasionally to the ocean, periodically migrating ~70 km between the two rivers. The abundant ripening of *Faidherbia albida* (Jacobson et al. 1995; Fennessy et al. 2001) tree pods, a highly preferable protein source amongst elephants and other herbivores, often triggers the migration of elephants. These particular trees are abundant in the western region of the Hoanib River, and tend to bear fruits/pods towards the end of a hot, dry season which lasts from September through December (Leggett, 2006). Additionally, during the wet season, elephants migrate past river drainages specifically to find the *Commiphora spp.* bushes, and the greener vegetation that grows from the rainfall in the area. Elephants make the effort to seek out greener vegetation, especially landscapes with vegetation that is greener than its surroundings (Loarie et al., 2009; Viljoen, 1987, 1988, 1989a, 1989b; Viljoen & Bothma, 1990; Leggett, 2006, 2011). Throughout the year, these preference patterns are visible even when elephants are constrained to a location because of seasonally available water. Elephants prefer seasonally variable landscapes in the wet seasons which include open woodlands, shrublands, and grasslands because these landscapes, besides having an overall lower average annual greenness, become very green for the few months within wet seasons. In contrast, during the dry seasons, elephants prefer less variable and more consistently green landscapes which are in closed woodlands and well-wooded areas (Loarie et al., 2009). Elephants have slightly different preferences in vegetation throughout the year, restricting them to small, homogenous protected areas that would not be suitable for permanent residence. Although elephants prefer areas of water and vegetation, in most cases they steer clear of areas with excessive human habitation. Humans are more populous in the town of Purros (Figure 1), located upstream along the Hoarusib and Hoanib rivers. That area also includes some tourist camps that are distributed between the towns and Skeleton Coast National Park (SCNP). Although access into the SCNP (which extends from the coastline to around 30 km inland) is mostly restricted, self-driving tourists roam up and down rivers during the dry season. Elephants also prefer to dig wells adjacent to free-flowing surface water, as opposed to drinking directly from water sources that are readily available, so they can access clean water (Ramey et al., 2013). Artificially introducing water availability in certain areas within Namibia could also have detrimental elephant impacts on the biodiversity and vegetation in the region (Loarie et al., 2009). Another factor that plays a large role in which areas elephants can migrate is the slope of hilly or mountainous areas in Namibia. While elephants try to go after greener vegetation, steep slopes hinder them from accessing and residing in certain areas. Energy calculations for elephants reveal that even minor hills are quite large energy barriers for these heavy animals, and elephant density decreases exponentially on increasingly steep hill-slopes (Wall et al., 2006). When all these factors are collectively assessed, the findings support that elephants prefer green vegetation, more water sources, flatter terrain, and fewer human populations within their home ranges.

1.6 Desert-Dwelling Elephants in the Kunene Region, Namibia

Viljoen (1988) conducted a study over the period of 1980–1983 in the western Kunene, a time of severe drought and heavy poaching due to the Namibian War of Independence (1966–1989) occurring concurrently with the Angolan War (1975–2002). One of Viljoen’s (1988) subpopulations included the desert-dwelling elephants in the northwestern Kunene region, where he discovered that, based on the age structures of many family groups, it was likely that the older adult females (matriarchs) leading the groups had been poached (Leggett et al., 2011; Viljoen, 1988). Additionally, he found an increase in the average group sizes of the elephants during the wet season as a result of feeding aggregations (Leggett et al., 2011). Lindeque and Lindeque (1991) suggested that the remaining elephants resembled a core remnant elephant society, reduced due to wars and associated poaching activities. At the time, all elephants were aged by their size when identified (Laws, 1966). Traditional photographic techniques, similar to those described in previous studies (Altmann, 1974; Douglas-Hamilton and Douglas-Hamilton, 1975; Moss, 1982; Sukumar, 1989), were used to photograph each individual elephant. Once an elephant's offspring reached sexual maturity, they were each assigned an adult number. For females, sexual maturity is shown when they give birth to their first offspring. For males, sexual maturity is when they depart from their original family unit. Each group is classified based on the eldest female elephant within the group (Leggett et al., 2011). Being located in an area such as Namibia where both rainfall and resources are scarce, the African desert elephants have low calving intervals and resulting rates of population increase. Additionally, although it is common in other African savannah and dry bush dwelling elephants to have family groups that consist of 8–12 elephants on average (Leggett et al., 2011; Moss & Poole, 1983), the desert-dwelling Kunene elephants' group sizes range from 4–8 individuals (Leggett et al., 2011; Viljoen, 1988; Leggett, 2003). Usually, in the wild, it is uncommon to find lone female elephants roaming for an extended period of time, however, in the western Kunene region this would be a normal occurrence (Poole, 1994, Leggett et al., 2011). It is also noted that female desert-dwelling elephants typically live in first-tier/family units or small second-tier/family groups, in which there are at least two unrelated females (Leggett et al., 2011). Interestingly, this pattern can be seen in other elephant subpopulations that have experienced poaching or culling (Leggett et al., 2011; Nyakaana et al., 2001; Charif et al., 2005; Gobush et al., 2009). These elephants have shown a strong attachment to their original home ranges despite having been displaced and moved in various directions throughout time. Even if they were driven out of their home ranges or temporarily moved out in the past, they would always return to their original home ranges (Viljoen, 1988). These elephants have a unique herd structure which is unlike any of the other elephant populations. Heavy poaching and a low reproductive rate, as a result of the desert environment, may have permanently disturbed the stability after having experienced drastic trauma (Leggett et al., 2011). The desert-dwelling elephants that reside in a marginal environment such as the Kunene region have a lower reproduction rate, reduced defecation rate, longer movements, and naturally larger home ranges as a result (Leggett et al., 2003; Leggett, 2006; Leggett, 2008, Leggett et al., 2011). With fewer and fewer elephants remaining from the original subpopulation it is vital to preserve what is left, especially the females. The different factors discussed earlier highlight the need to reduce female elephant mortality from diseases, poaching or further human-elephant conflict (Leggett et al., 2011).

1.7 Studying Elephant Migration Patterns Using Remote Sensing Technology

Leggett (2006) assessed home range estimates for each of the elephants described in section 1.1. The data for his study was first collected beginning 2002 using GPS/telemetry collars which were placed onto 8 elephants. The GPS system used a Vistar MT2000 Satellite Terminal which was specifically adapted to be used on the GPS collars by Africa Wildlife Tracking, Pretoria, South Africa (Startrack, 2002). These collars were able to collect 3600 timestamps of the elephants' locations (which equates to 3 readings a day for approximately 2 years). Additionally, these special units were designed to enable two-way data satellite communication with the GPS systems. The system simultaneously communicated with the geostationary Inmarsat-3 F1 Satellite, and there was a navigation transponder attached to the tracking device which enhanced the accuracy of readings by ±5 m (Leggett, 2006). It also enhanced the integrity and availability of the GPS (3.5 –7.8 m accuracy) and GLONASS (5–10 m accuracy) satellite navigation systems. Using this system, the first 24 months of the elephants' movement were captured with their locations recorded every 8 hours (3 points per day), followed by one point recorded per day for the rest of the time period (Leggett, 2006). After all the data was collected, the tracking locations were projected. Leggett (2006) used MCPs and FKDEs with fixed kernels of 25, 80, and 90 percent of loci, which correspond to the 'core,' 'activity,' and 'areal' distributions of the data from Spencer & Barrett (1984) (Leggett, 2006). To overcome the previously mentioned limitations of MCPs, the FKDE method instead describes the elephants' home ranges by placing a kernel (probability density) over each observation point. A rectangular grid is superimposed onto the data, and an estimate of density is calculated at each grid intersection based on the entire sample, which reveals where the elephants spent most of their time (Worton 1989; Seaman & Powell, 1996). MCPs yielded very different results than the FKDEs (Leggett 2006). MCPs account for peripheral points which are often biased by extraordinary movements beyond the typical ranges, and are therefore likely not the best way to describe elephants' home ranges in an arid environment (Leggett, 2006). On the other hand, FKDEs identify home ranges based on where the greatest number of loci occur, which show where an elephant spent most of its time. Leggett (2006) focused on the MCPs (Figure 2) for further analysis and to discuss the seasonal ranges of the elephants as opposed to FKDEs since they do not account for the movement paths used by elephants between their seasonal ranges.

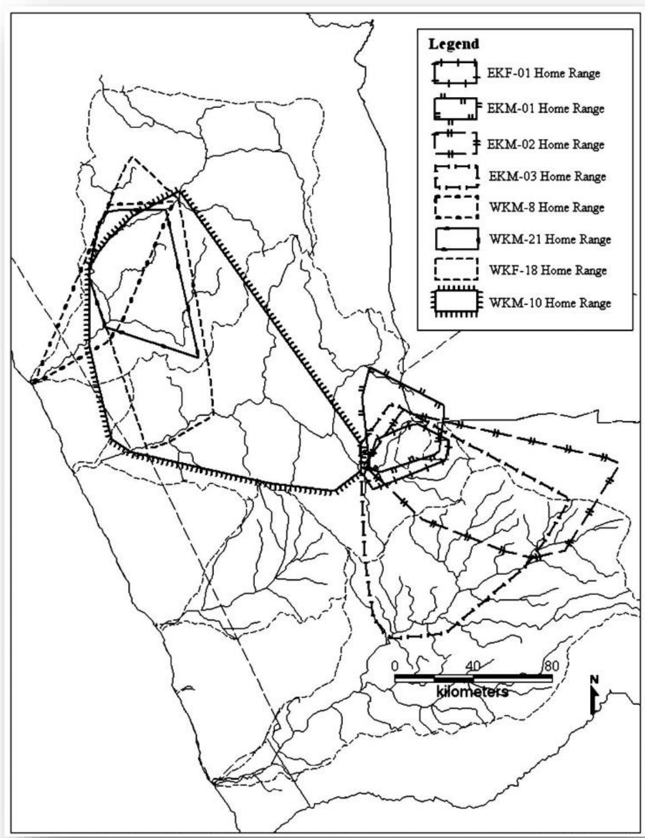

Figure 2: MCPs of eight GPS collared elephants' home ranges in the Kunene Region, Namibia (Leggett, 2006).

Leggett (2006) shares that northwestern Namibia's elephants had the largest home ranges ever recorded. However, Leggett (2006) doubted whether MCPs were the optimal method for describing the home ranges of elephants in an arid environment, because elephants tend to migrate along pathways between seasonal ranges, as opposed to equally over the MCPs area (Leggett, 2006). These findings reveal the obvious need for an accurate home range estimation method that properly accounts for the complexities in determining and defining what an elephant's home range may be based on their movement, behavior, and home range preferences.

1.8 Research Goals & Objectives

Although research efforts have been made in the past to understand the elephant home ranges, a robust method that provides an accurate representation of the elephants' home range environment has yet to be identified. Using a radius based on the communication range between elephants is a new way of estimating the elephants' home ranges. The variables assessed include vegetation and terrain. Elephants seek vegetation, particularly vegetation that is greener than the surroundings, and will make significant effort to acquire it (Loarie et al., 2009; Viljoen, 1987, 1988, 1989a, 1989b; Viljoen & Bothma, 1990; Leggett, 2006, 2011). However, slope determines if elephants can physically access an area. This research may help interpret the behavior of elephants and what influences the decision-making process regarding their seasonal migrations. It will contribute to understanding how the environment in Namibia has changed over the five-year time period, and what the elephants home range preferences are.

The main research goal of this study is to determine if a physically-based estimation using elephants' unique ability to communicate via low-frequency sound more accurately quantifies Namibian elephants' home range environments in comparison to a purely statistical estimation based on MCPs. The first objective is to quantify home ranges based on MCPs and SRs using tracking data for nine elephants from 2002–2007. The second objective is to calculate the distribution of vegetation and slope in both home range estimations, and at the actual tracking locations of each elephant. To determine the most representative home range estimation, the third objective compares the two home ranges' slope and vegetation characteristics to those corresponding to the tracking locations. Because elephants' behavior varies seasonally, all comparisons are also separately evaluated during wet versus dry seasons.

DATA AND METHODS

2.1 Characteristics of the Nine Namibian Elephants

The movement of nine elephants is studied from 2002 to 2007 over the northwestern Namibian region. As described in section 1.1, there are 2 female elephants and 1 male from the western Kunene, 1 female and 4 males from the eastern Kunene, and 1 male elephant from the western Omusati region. WKF-16 was assumed to be in the 35–45-year age range, and mainly spent her time in the western region of the Hoarusib river. She gave birth to two offspring who were at sub-adult, and juvenile stages during the time period. WKF-16 was not a very social animal, but did have loose associations with most of the Hoarusib females since family units frequently met in that river system. WKF-18 was also a predominantly western Hoarusib female who was between 45 –50 years of age. She was occasionally seen, but had the most interesting migration patterns which ranged widely in the rivers. She also had two calves during this time period, and had loose associations with most tier family units, but generally stayed within the Hoarusib area, occasionally making trips to the Hoanib river region. WKM-10 was a large, single male that was collared in his early to mid 40s. He was identified as a rather aggressive, wide-ranging dominant male who sired most of the generation of new calves in the Kunene region from 1997–2007. He had loose associations with all female groups, and did not spend a lot of time with any particular one. Most of his migration range fell within the western Kunene region, but he did return to Etosha National Park in one of the years within the study. There was one eastern Kunene female, EKF-1, who mainly spent her time in the Hobatere Game Reserve, and occasionally moved into either Kaross

(Etosha National Park) or the eastern Kunene (beyond Hobatere's borders). There were high densities of people to the west of Hobatere, and elephants were reluctant to go there. EKF-1 was part of a group that consisted of 8 adult females, and only had one calf. Her travel range was very small, and she did not have a healthy fear of people. EKM-1 was an old solitary male who was approximately 50–55 years of age, and was collared on the Hobatere Game Reserve in northwestern Namibia. When collared, he did not associate with any other males, but later associated with younger bulls for varying time periods. EKM-2 was also a ~50-year-old male who showed little movement for the majority of the study, but when he did move he traveled long distances. He showed a few associations with other males in the Hobatere Game Reserve. EKM-3 was a relatively young, immature 20–25-year-old male who was quite aggressive, and traveled wide ranges. He only had known associations with EKM-6 (based on tracking locations), but even this was tenuous, and he had no known associations with females at all. EKM-6 was a 35–45-year-old male that occupied a large home range, but was not as wide ranging as EKM-3. He was shot by farmers on a trophy hunt near Kamanjab (Figure 1). He was also an aggressive, large male with no other known associations apart from EKM-3. Lastly, WOM-4 was a large dominant male ~45 years of age. He ranged widely from Etosha National Park almost to the Kunene river in the north, but spent the majority of his time in the Omusati region of Namibia. Little information was noted about this male, but he was thought to have loose contact with other males, and no interactions with family units were observed. Surveys were conducted monthly to properly record each elephant, their location within the study area, numbers, and behavior (Pers. Comm.). If elephants were noted to be within 500 m of each other, they were presumably associated (Wittemyer et al., 2005; Pinter-Wollman et al., 2008). Most of the observations, however, showed elephant interactions at distances much shorter than 500 m, and only one observation of interaction was recorded per day for any pair of elephants (Leggett et al., 2011).

2.2 Elephant Tracking Data

The elephant tracking data was acquired from Keith Leggett. The elephants were tracked using a GPS/Telemetry collar from 2002–2007. For the first year, the location of each elephant was noted 3 times a day, but after the first year their locations were recorded once a day. There is at least one period of missing data per elephant over the ~5-year time period, presumably due to the GPS collars malfunctioning. ArcGIS software was used to process and manipulate all of the elephant tracking data. The tracking points for each elephant were first re-projected into the *Africa Albers Equal Area* projection, and the data was checked for any errors or missing observations.

2.2.1 Namibia's Wet and Dry Seasons

To account for elephants' different seasonal movement patterns, the tracking data was broken into 5 different wet and dry seasons (10 total). The wet season date ranges include: 10/6/2002 to 4/18/2003 (wet season 1), 10/23/2003 to 4/22/2004 (wet season 2), 9/13/2004 to 5/18/2005 (wet season 3), 9/30/2005 to 6/11/2006 (wet season 4), and 8/30/2006 to 5/22/2007 (wet season 5). Alternating with the wet season dates, the dry seasons I determined include the date ranges: 4/19/2003 to 10/22/2003 (dry season 1), 4/23/2004 to 9/12/2004 (dry season 2), 5/19/2005 to 9/29/2005 (dry season 3), 6/12/2006 to 8/29/2006 (dry season 4), and 5/23/2007 to 9/20/2007 (dry season 5). These wet/dry season delineations are based on the daily precipitation analysis presented in Garstang et al. (2014).

2.2.2 Minimum Convex Polygons

The first home range estimation method is to create a tight-fit polygon (convex hull) that encompasses all the tracking points per season for each elephant. The "Minimum Bounding Geometry" tool in ArcMap was used to create this convex hull for the points which represents the range of an elephant's movement during a wet/dry season. The tracking points in the format of a shapefile were used as input features, and the geometry type was a convex hull.

2.2.3 Sound Radii

The SR is a new idea proposed here to identify home ranges for elephants. In ArcMap, the "buffer" tool was used to create a 10 km equidistant radius around each of the elephants' tracking points. The input features were the tracking points, the side type was "full" which creates a radius around each point, and a "round" end type which creates radii with a rounded, half circle end instead of being flat. The radius method was "geodesic" which ensures that all created radii are shape-preserving, and the "dissolve type" was "ALL" which dissolved all the radii into one tube-like shape that merged all the tracking points' radii for that season. Depending on the distribution of tracking points, some of the SRs are not single tubes, but instead have 2 or 3 tubes generated for a season of elephant tracking data.

2.3 Vegetation Data

Vegetation plays a key role in discerning where elephants will migrate. The Enhanced Vegetation Indices (EVI) from the MODIS/ Aqua Vegetation Indices 16-Day L3 Global 250 m SIN Grid (MYD13Q1 v006) data was used to assess vegetation distribution within the home ranges over the ~5-year period. This imagery is available through the United States Geological Survey NASA Earth Data portal and is produced as 16-day averages at a spatial resolution of 250 meters, and a has a 16-bit signed integer data type. The motivation for using MODIS EVI data is that it has improved sensitivity in detecting vegetation presence and type while correcting for some atmospheric conditions, canopy background noise, and saturation. Using EVI data to analyze vegetation distribution in Namibia, a country severely lacking biomass, provides a significant improvement in analysis, as opposed to using MODIS normalized difference vegetation indices. The MODIS data were downloaded as four main tiles that cover the study region, and were mosaicked to seamlessly cover the expanse of Namibia. After each 16-day period imagery was mosaicked, the mosaicked raster was converted to tag image file format and multiplied by a scale factor of 0.0001 through the "raster calculator" tool, to display the correct EVI value range of −1 (lack of green vegetation) to 1 (abundance of green vegetation). There were some months that were missing EVI imagery in the region which included: April 2003, May 2004, April 2005, April 2006 and April 2007. These months were not factored into calculating the monthly EVI values.

2.4 Slope Data

Slope data is derived from a digital elevation model (DEM) of Namibia. The data was acquired from the NASA Shuttle Radar Topography Mission (SRTM) at a spatial resolution of 30 m. While elevation is critical in understanding the terrain distribution in an area, slope determines whether an elephant will be able to physically overcome and pass through an area. The data product used was the SRTM 1 Arc-Second Global dataset which contains rasters for download in 1° tiles of ~30 m resolution. These tiles were mosaicked to cover the northwestern region of Namibia, and the resulting DEM was used to create a slope raster. The "slope" spatial analyst tool was used to create a geodesic, percent slope (percent rise) raster of the study region.

2.5 Data Extraction

The area was calculated for the MCPs and SR polygons, and the size for the two home range estimates was compared. Similarly, vegetation and slopes were compared between the two estimates. The "zonal statistics as table" tool was used to extract the values from each of the home range estimations for all elephants' ten wet and dry seasons. After the MCPs and SRs were used as parameters, the actual elephant tracking location points were also used to extract slope and vegetation values per location using the "extract values to points tool."

2.6 Comparing MCPs and SRs

To understand if the new physically-based home range method (SRs) is significantly different from the older statistically-based method (MCPs), t-tests were conducted to compare the mean EVI and slope values for all elephants' ranges. T-tests were also used to compare the average home range EVI and slope values to those at the actual tracking locations.

2.7 Suitable Habitat Estimates

After determining which home range estimate better reflects the elephants' preferred habitat, the corresponding slope and EVI values were used to delineate suitable areas for elephants in northwestern Namibia. The "mosaic to new raster" tool was used to merge all wet/dry season rasters of EVI data into two separate maps, and input values from those two EVI rasters and slope raster were used in the "raster calculator" tool to highlight areas that are suitable and unsuitable for elephants.

RESULTS

3.1 MCP and SR Home Ranges

The maps below (Figures 3–12) visualize the distribution of all the elephants corresponding to where they were generally located during a specific wet/dry season. Each polygon represents the seasonal range of one elephant, and is assigned a unique color to be easily distinguishable in all maps. This method follows the elephants’ tracking points more closely, and includes outliers in a different manner while simultaneously accounting for elephant communication which could also influence an elephant’s migration pattern.

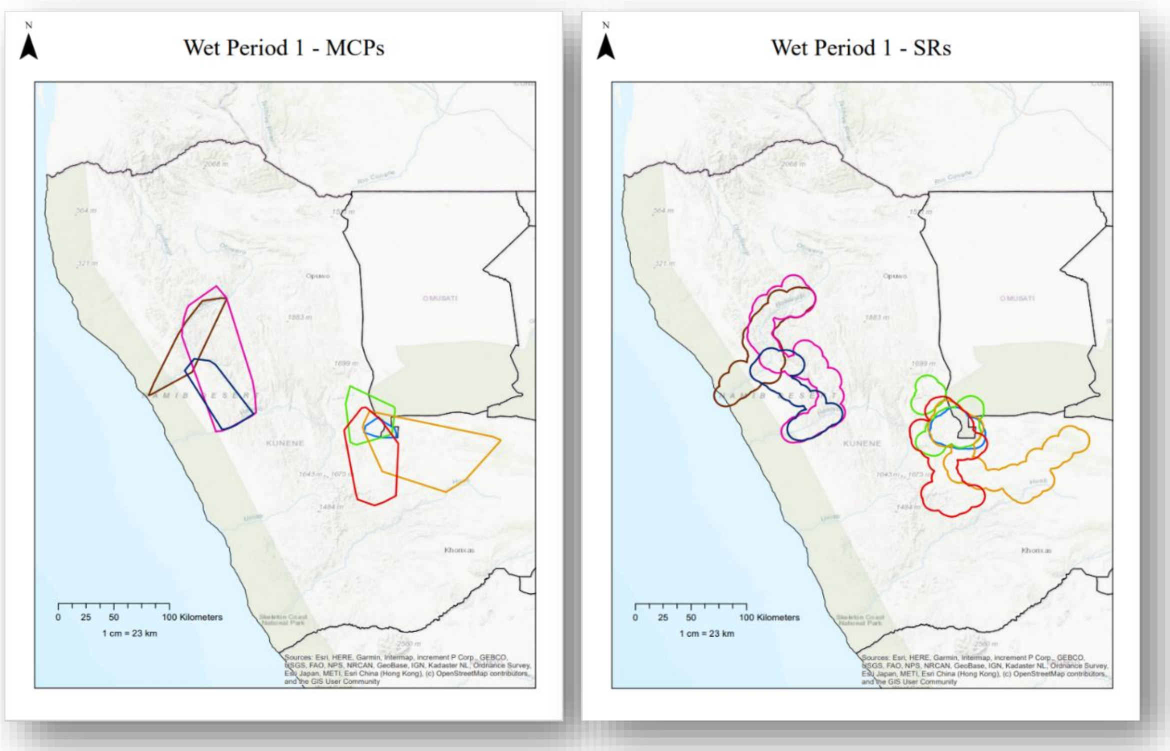

Figure 3: MCPs (left) and SRs (right) of Namibian elephants in wet season 1. Elephants: EKF-1 (blue), EKM-1 (green), EKM-2 (orange), EKM-3 (red), WKF-16 (brown), WKF-18 (magenta), WKM-10 (navy).

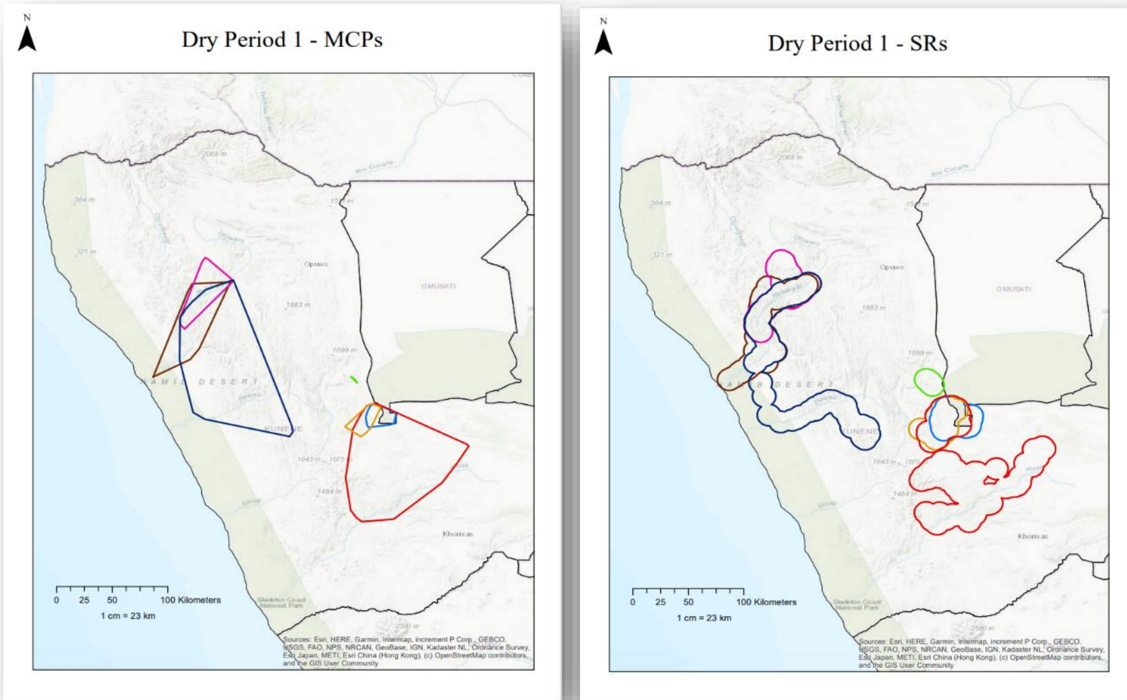

Figure 4: MCPs (left) and SRs (right) of Namibian elephants in dry season 1. Elephants: EKF-1 (blue), EKM-1 (green), EKM-2 (orange), EKM-3 (red), WKF-16 (brown), WKF-18 (magenta), WKM-10 (navy).

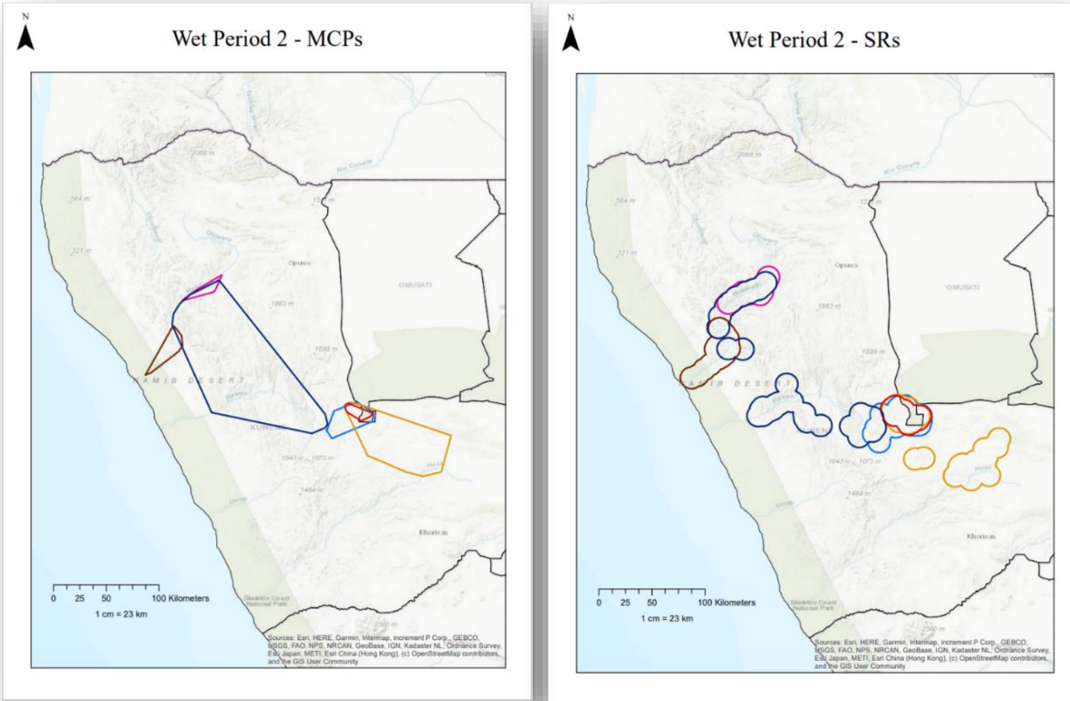

Figure 5: MCPs (left) and SRs (right) of Namibian elephants in wet season 2. Elephants: EKF-1 (blue), EKM-2 (orange), EKM-3 (red), WKF-16 (brown), WKF-18 (magenta), WKM-10 (navy).

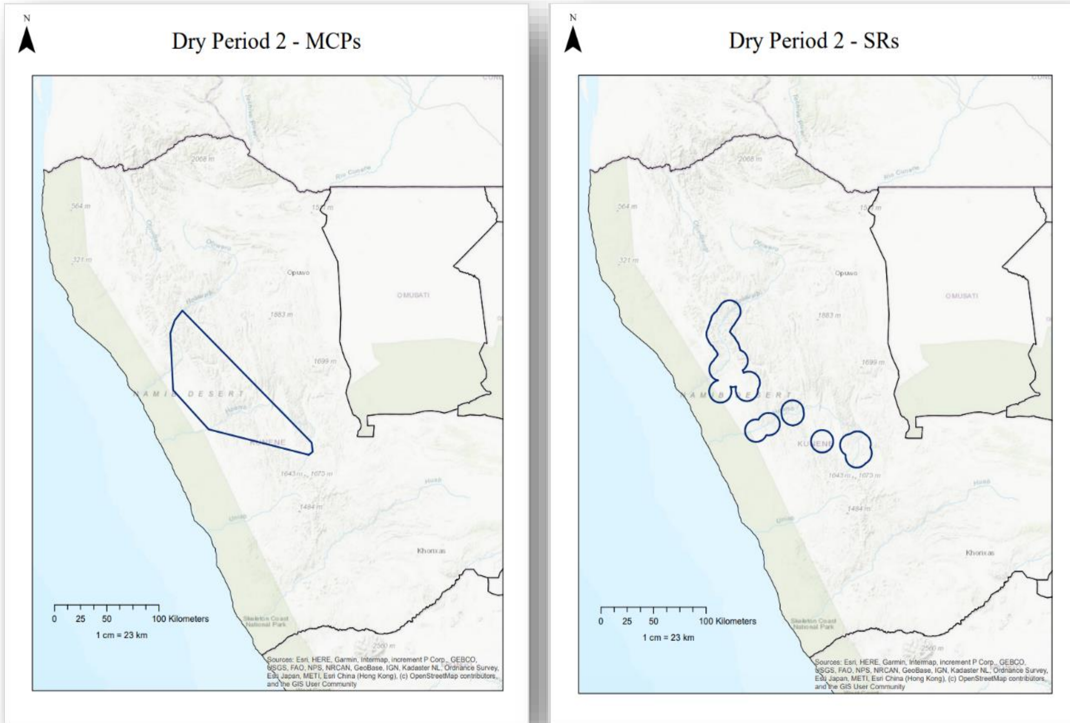

Figure 6: MCPs (left) and SRs (right) of Namibian elephant in dry season 2.
Elephant: WKM-10 (navy).

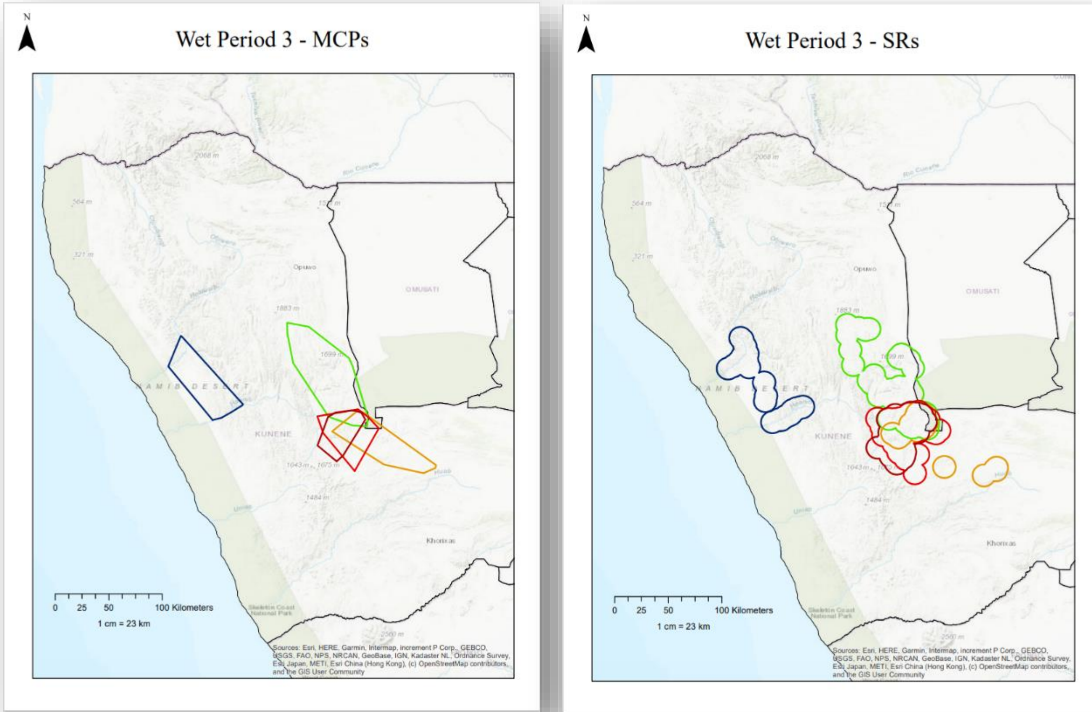

Figure 7: MCPs (left) and SRs (right) of Namibian elephants in wet season 3. Elephants: EKM-1 (green), EKM-2 (orange), EKM-3 (red), EKM-6 (dark red), WKM-10 (navy).

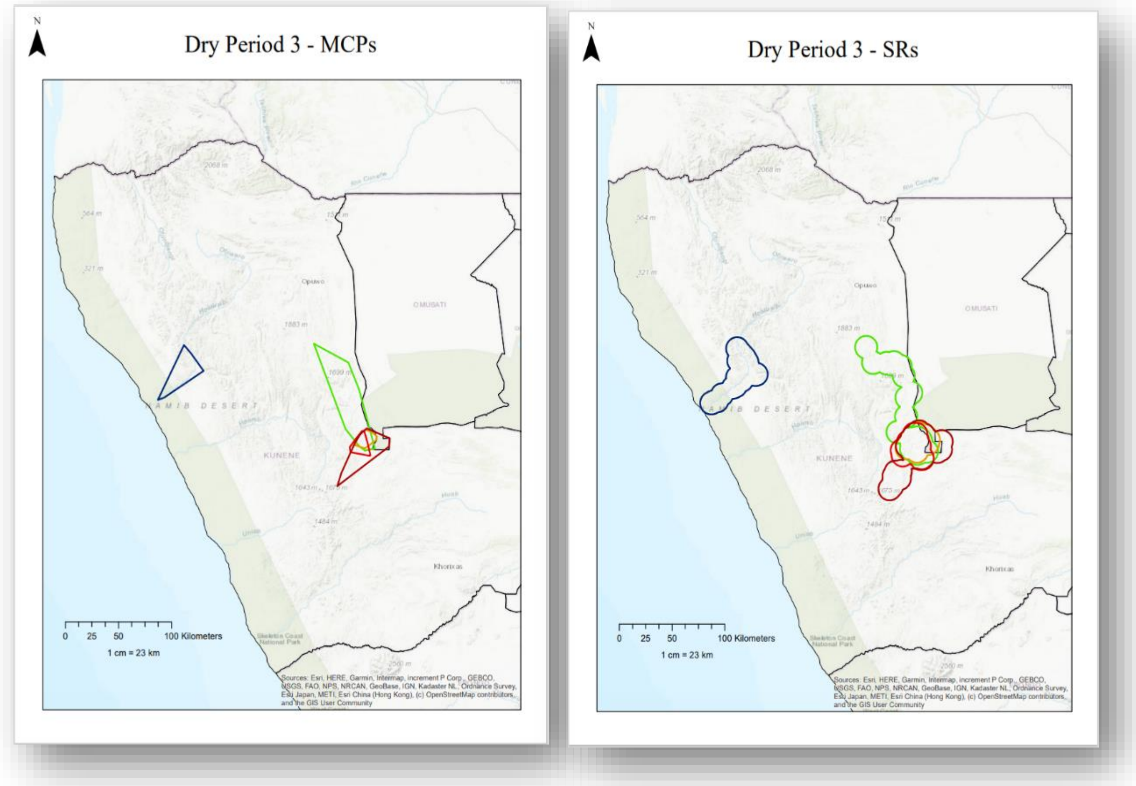

Figure 8: MCPs (left) and SRs (right) of Namibian elephants in dry season 3. Elephants: EKM-1 (green), EKM-2 (orange), EKM-3 (red), EKM-6 (dark red), WKM-10 (navy).

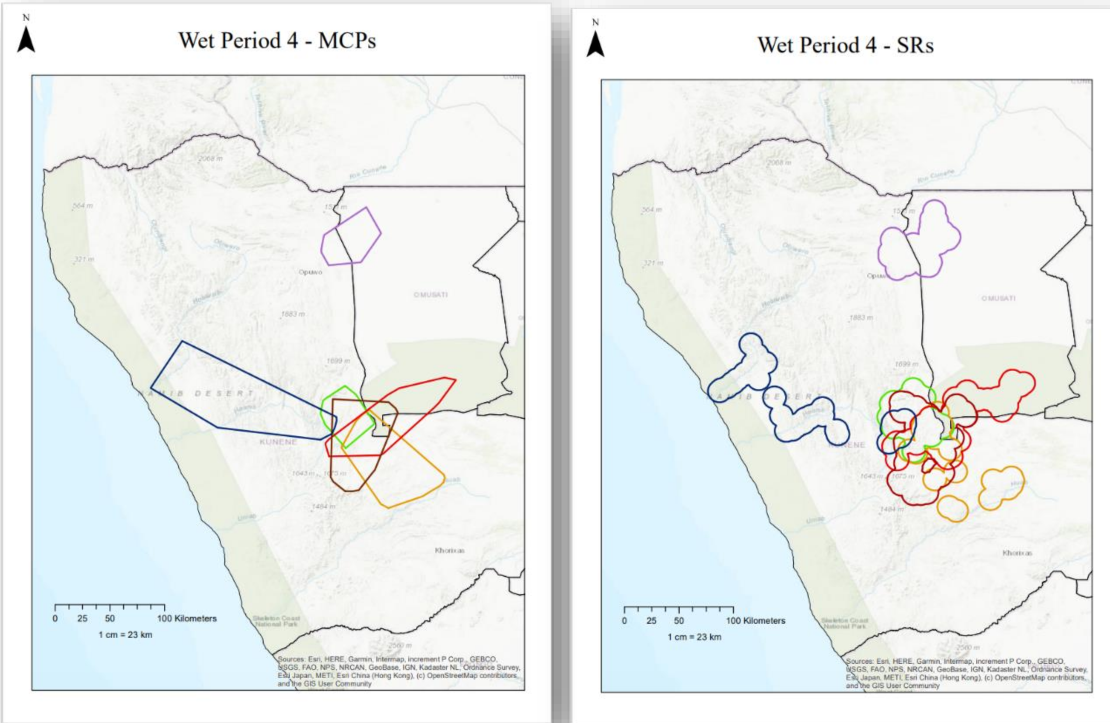

Figure 9: MCPs (left) and SRs (right) of Namibian elephants in wet season 4. Elephants: EKM-1 (green), EKM-2 (orange), EKM-3 (red), EKM-6 (dark red), WKM-10 (navy), WOM-4 (bright purple).

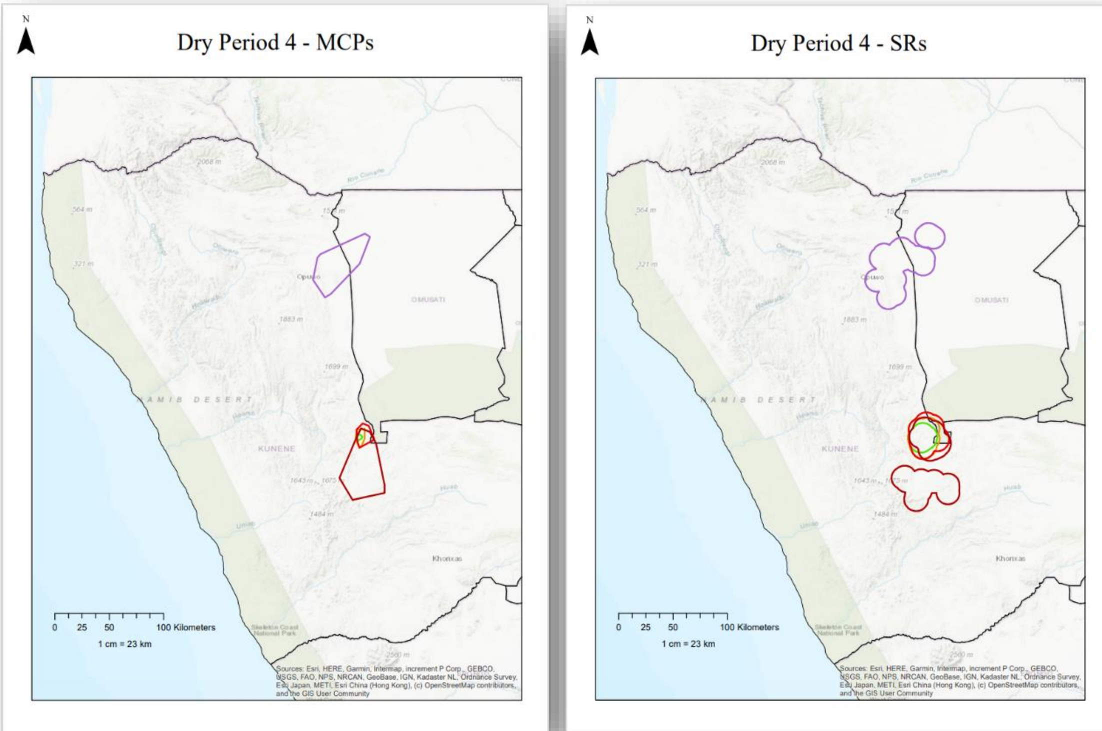

Figure 10: MCPs (left) and SRs (right) of Namibian elephants in dry season 4. Elephants: EKM-1 (green), EKM-2 (orange), EKM-3 (red), EKM-6 (dark red), WOM-4 (bright purple).

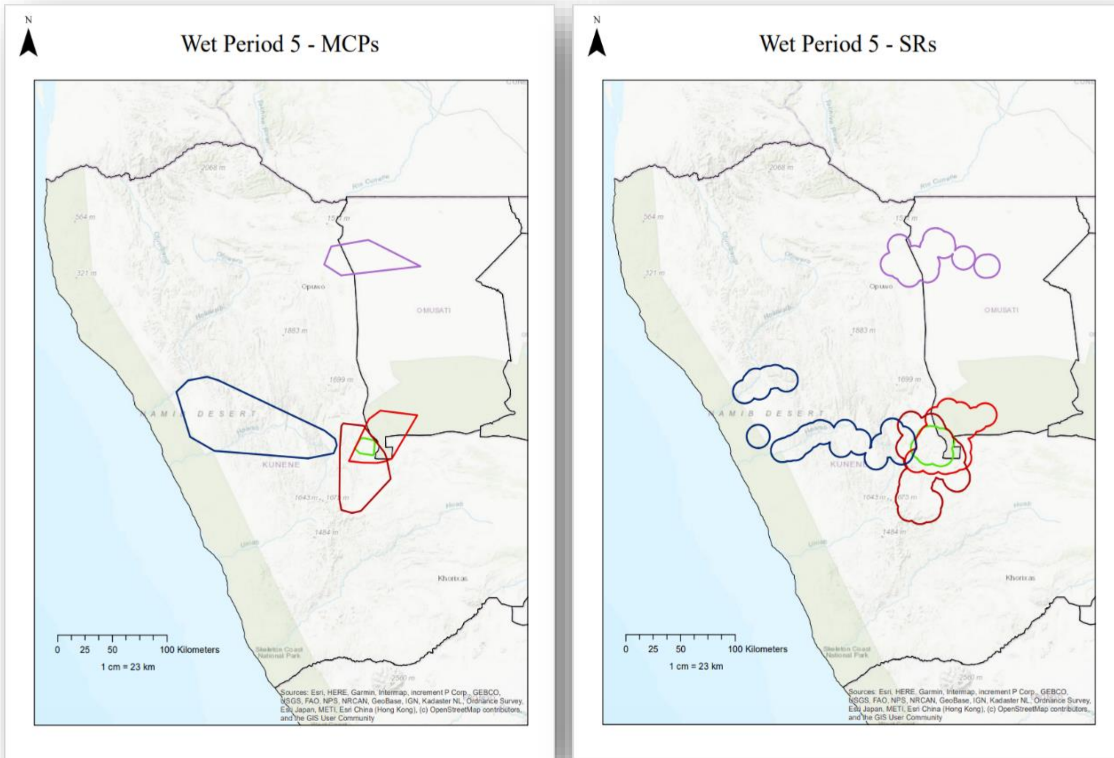

Figure 11: MCPs (left) and SRs (right) of Namibian elephants in wet season 5. Elephants: EKM-1 (green), EKM-3 (red), EKM-6 (dark red), WKM-10 (navy), WOM-4 (bright purple).

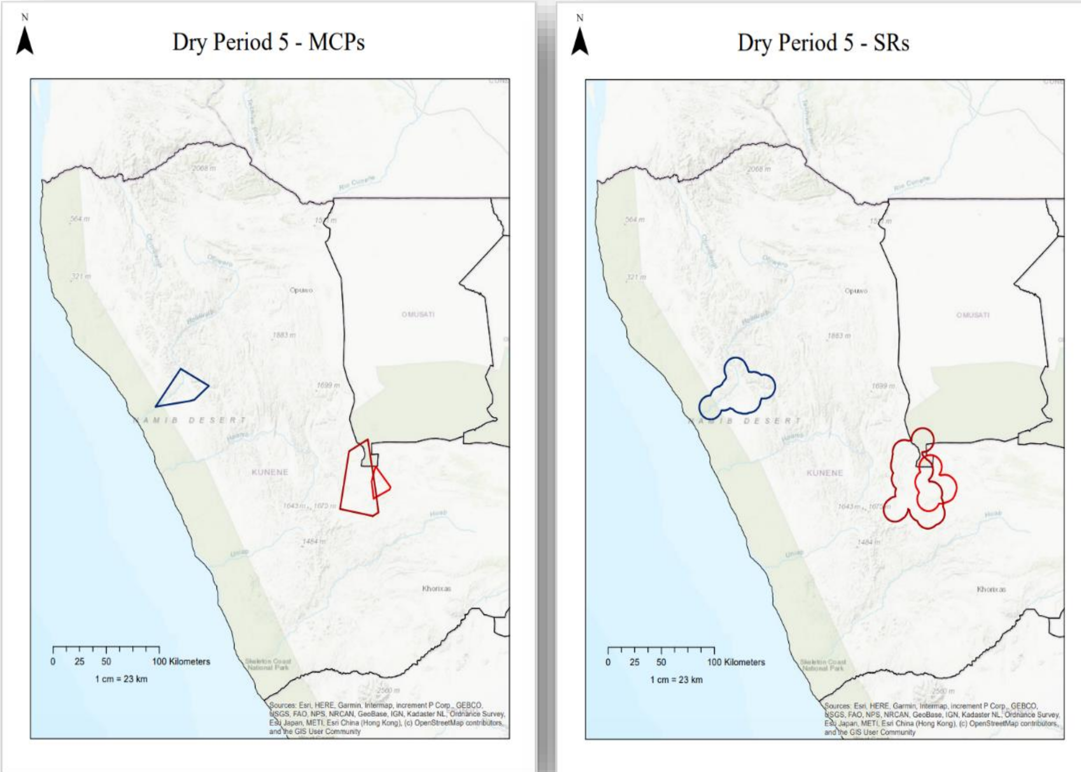

Figure 12: MCPs (left) and SRs (right) of Namibian elephants in dry season 5. Elephants: EKM-3 (red), EKM-6 (dark red), WKM-10 (navy).

3.2.1 Seasonal Elephant Movements

The movement of elephants during each wet and dry season reveals different locational preferences about where an elephant resided (depending on tracking data availability for an elephant during the season), and how long they chose to reside in an area. During wet season 1 (Figure 3), three elephants (WKF-16, WKF-18, and WKM-10) resided along the coastline in the Namib desert area, whereas four of the other elephants (EKM-1, EKF-1, EKM-2, and EKM-3) stayed further inland in between the Kunene and

Omusati regions. In dry season 1 (Figure 4) the three elephants near the coast stayed in relatively the same area, but the WKM-10 elephant moved further south and inland. The EKM-3 elephant also moved further inland, and the EKM-1 elephant moved around much less than during wet season 1. The EKM-2 and WKM-10 made the largest movements in comparison to the other elephants, which stayed in the same area during wet season 2 (Figure 5). The WKM-10, the only elephant recorded during dry season 2, stayed in proximity to the coastline (Figure 6). In wet season 3 (Figure 7), the EKM-1, EKM-2, EKM-3, and EKM-6 all moved a great amount which expanded their ranges, whereas the WKM-10's range decreased slightly. Interestingly, in dry season 3 (Figure 8), all of the elephants' ranges retracted back to the corner of the Kunene and Omusati regions, and the EKM-1 and EKM-6 moved further out than the others. In wet season 4 (Figure 9), all the elephants moved towards the area where both regions (Kunene and Omusati) meet, and their respective ranges also enlarged. This was also the first season where movement for WOM-4 was documented, and he resided in the northwestern region of the study area. A similar trend is observed in dry season 4 (Figure 10). The WOM-4 remained in the northern area, and the other elephants remained in the corner of the regions. In wet season 5 (Figure 11), the WOM-4 moved further east into the Omusati region and expanded his range. The WKM-10 also moved east towards the corner of the regions, but the other elephants remained in their original area. Lastly, in dry season 5 (Figure 12) the WKM-10 retreated to the coastal areas, whereas the EKM-3 and EKM-6 remained in place.

The MCP and SR estimates are incredibly unique in the way they identify an elephant’s home range. To determine if the SR method better represents an elephant’s home range than the MCP, various comparisons are made to better understand each method.

3.2.2 Home Range Area Estimates

Elephants (9 total)	Period	Start - End (MM/DD/YEAR)	Area in MCPs (SQ. KM)	Area in SRs (SQ. KM)
EKF-1 (Eastern Kunene Female #1)	Wet 1	10/6/2002 - 4/18/2003	321	1333
Map color: Blue	Dry 1	4/19/2003 - 10/22/2003	407	1451
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	820	2065
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	n/a	n/a
	Dry 3	5/19/2005 - 9/29/2005	n/a	n/a
	Wet 4	9/30/2005 - 6/11/2006	n/a	n/a
	Dry 4	6/12/2006 - 8/29/2006	n/a	n/a
	Wet 5	8/30/2006 - 5/22/2007	n/a	n/a
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a
EKM-1 (Eastern Kunene Male #1)	Wet 1	10/6/2002 - 4/18/2003	1560	2696
Map color: Green	Dry 1	4/19/2003 - 10/22/2003	4	471
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	n/a	n/a
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	3592	4989
	Dry 3	5/19/2005 - 9/29/2005	1906	3048
	Wet 4	9/30/2005 - 6/11/2006	1517	2989
	Dry 4	6/12/2006 - 8/29/2006	17	496
	Wet 5	8/30/2006 - 5/22/2007	190	1013
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a
EKM-2 (Eastern Kunene Male #2)	Wet 1	10/6/2002 - 4/18/2003	5120	5143
Map color: Orange	Dry 1	4/19/2003 - 10/22/2003	447	1549
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	3683	3600
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	2150	2205
	Dry 3	5/19/2005 - 9/29/2005	199	1041
	Wet 4	9/30/2005 - 6/11/2006	4138	3982
	Dry 4	6/12/2006 - 8/29/2006	98	818
	Wet 5	8/30/2006 - 5/22/2007	n/a	n/a
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a
EKM-3 (Eastern Kunene Male #3)	Wet 1	10/6/2002 - 4/18/2003	2973	4396
Map color: Red	Dry 1	4/19/2003 - 10/22/2003	7317	7437
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	206	1105
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	1680	3241
	Dry 3	5/19/2005 - 9/29/2005	238	1161
	Wet 4	9/30/2005 - 6/11/2006	3580	5114
	Dry 4	6/12/2006 - 8/29/2006	213	1074
	Wet 5	8/30/2006 - 5/22/2007	1590	3155
	Dry 5	5/23/2007 - 9/20/2007	243	1150
EKM-6 (Eastern Kunene Male #6)	Wet 1	10/6/2002 - 4/18/2003	n/a	n/a
Map color: Dark Red	Dry 1	4/19/2003 - 10/22/2003	n/a	n/a
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	n/a	n/a
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	1156	2596
	Dry 3	5/19/2005 - 9/29/2005	916	2310
	Wet 4	9/30/2005 - 6/11/2006	3522	5166
	Dry 4	6/12/2006 - 8/29/2006	1589	2558
	Wet 5	8/30/2006 - 5/22/2007	2484	4217
	Dry 5	5/23/2007 - 9/20/2007	1459	2891
WKF-16 (Western Kunene Female #16)	Wet 1	10/6/2002 - 4/18/2003	2027	3658
Map color: Brown	Dry 1	4/19/2003 - 10/22/2003	2387	3636
Status: Dead (Shot, 2018)	Wet 2	10/23/2003 - 4/22/2004	522	1700
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	n/a	n/a
	Dry 3	5/19/2005 - 9/29/2005	n/a	n/a
	Wet 4	9/30/2005 - 6/11/2006	n/a	n/a
	Dry 4	6/12/2006 - 8/29/2006	n/a	n/a
	Wet 5	8/30/2006 - 5/22/2007	n/a	n/a
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a
WKF-18 (Western Kunene Female #18)	Wet 1	10/6/2002 - 4/18/2003	5101	5326
Map color: Magenta	Dry 1	4/19/2003 - 10/22/2003	1260	2581
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	231	1326
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	n/a	n/a
	Dry 3	5/19/2005 - 9/29/2005	n/a	n/a
	Wet 4	9/30/2005 - 6/11/2006	n/a	n/a
	Dry 4	6/12/2006 - 8/29/2006	n/a	n/a
	Wet 5	8/30/2006 - 5/22/2007	n/a	n/a
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a
WKM-10 (Western Kunene Male #10)	Wet 1	10/6/2002 - 4/18/2003	1797	2901
Map color: Navy	Dry 1	4/19/2003 - 10/22/2003	8631	5830
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	10058	5352
	Dry 2	4/23/2004 - 9/12/2004	7002	4466
	Wet 3	9/13/2004 - 5/18/2005	2101	2828
	Dry 3	5/19/2005 - 9/29/2005	721	1889
	Wet 4	9/30/2005 - 6/11/2006	6929	4897
	Dry 4	6/12/2006 - 8/29/2006	n/a	n/a
	Wet 5	8/30/2006 - 5/22/2007	5739	4725
	Dry 5	5/23/2007 - 9/20/2007	732	1917
WOM-4 (Western Omusati Male #4)	Wet 1	10/6/2002 - 4/18/2003	n/a	n/a
Map color: Bright Purple	Dry 1	4/19/2003 - 10/22/2003	n/a	n/a
Status: Unknown	Wet 2	10/23/2003 - 4/22/2004	n/a	n/a
	Dry 2	4/23/2004 - 9/12/2004	n/a	n/a
	Wet 3	9/13/2004 - 5/18/2005	n/a	n/a
	Dry 3	5/19/2005 - 9/29/2005	n/a	n/a
	Wet 4	9/30/2005 - 6/11/2006	1676	3024
	Dry 4	6/12/2006 - 8/29/2006	1404	2749
	Wet 5	8/30/2006 - 5/22/2007	1532	2760
	Dry 5	5/23/2007 - 9/20/2007	n/a	n/a

Table 1: Comparison of elephants' home range areas (between MCPs and SRs) per season.

Average Area In All Wet/Dry Seasons Per Elephant			
Elephants (9 total)	Periods	Average Area in MCPs (SQ. KM)	Average Area in SRs (KM)
EKF-1	All Wet	570.5	1699
	All Dry	407	1451
EKM-1	All Wet	1714.75	2921.75
	All Dry	642.33	1338.33
EKM-2	All Wet	3772.75	3732.5
	All Dry	248	1136
EKM-3	All Wet	2005.8	3402.2
	All Dry	2002.75	2705.5
EKM-6	All Wet	2387.33	3993
	All Dry	1321.33	2586.33
WKF-16	All Wet	1274.5	2679
	All Dry	2387	3636
WKF-18	All Wet	2666	3326
	All Dry	1260	2581
WKM-10	All Wet	5324.8	4140.6
	All Dry	4271.5	3525.5
WOM-4	All Wet	1604	2892
	All Dry	1404	2749

Table 2: Average area in all wet/dry seasons per elephant

Average Area In All Combined Wet/Dry Seasons Per Elephant			
Elephants	Periods	Average Area in MCPs (SQ. KM)	Average Area in SRs (KM)
All Elephants	All Wet Periods	2368.94	3198.45
	All Dry Periods	1549.32	2412.07

Table 3: Average area in all combined wet/dry seasons per elephant

Average Area In All Wet/Dry Seasons Per Male/Female Elephant			
Elephants	Periods	Average Area in MCPs (SQ. KM)	Average Area in SRs (KM)
All Male Elephants	All Wet Periods	2801.57	3513.675
	All Dry Periods	1648.32	2340.11
All Female Elephants	All Wet Periods	1503.67	2568
	All Dry Periods	1351.33	2556.00

Table 4: Average area in all wet/dry seasons per male/female elephant

The area calculations for both home range estimates (Table 1) reveal large differences in what is identified as a home range. While MCPs appear to cover a larger area at first glance, the area calculations reveal that in most cases, the SRs are much larger, and therefore likely encompass more environmental variability into their estimation of an elephant's home range. The areas in MCPs are mainly larger during the wet season, apart from the WKF-16 elephant's home range, and are smaller during the dry seasons (Table 2). The area calculations showed the EKM-3 elephant had an overall similar areal average in both wet and dry seasons in MCPs, but the SRs' averages show a much larger difference between the two (Table 2). The majority of elephants have larger home range areas during the wet seasons in the SR area calculations, but the WKF-16 elephant covered a smaller area during the wet season and a larger area in the dry season. In all cases, on average, male elephants have larger home ranges than female elephants (Table 4). The area calculations show interesting differences between the MCPs and SRs. In some cases, the SRs are lower than the MCPs, and other times they are relatively equal or much greater than the MCPs. The reason behind these areal disparities is the unique distribution of tracking points for each elephant. If an elephant was migrating through a much smaller area for the majority of a season, but had a few outliers (farther tracking points) then their home ranges would be created quite differently between the two methods. An MCP would create a polygon around those outliers, but the SR would include the outliers in its estimate while also encompassing the surrounding 314 km^2 area around it, thus likely increasing the size of the identified home range.

3.3 Vegetation Comparison

The vegetation distribution in Namibia varies between wet and dry seasons. During the wet seasons, there is typically an overall increase in green vegetation (EVI values closer to 1). However, in the dry seasons there is an overall lack of green vegetation (EVI values closer to −1), and the region contains drought-like conditions. The collective wet and dry season averages (Figure 13) show the average vegetation distribution of the two seasons within the study's period.

The EVI distribution during all the combined wet and dry seasons (Figure 13) reveals interesting patterns regarding where vegetation was abundant or sparse throughout the two seasons (Tables 5, 6, 7 and 8). EVI values range from −0.2 to 1 (−1 represents the lowest amount of greenness, and therefore no vegetation, whereas 1 represents a high amount of greenness, thus an abundance of green vegetation). During the wet seasons, the entire western coastline of Namibia had minimal to no vegetation. Moving further inland, there is slightly greener vegetation available however, vegetation amount overall was extremely low. In the dry seasons, the areas closer to the western coastline had more severe drought-like conditions and less vegetation, but the areas inland had more vegetation than the wet seasons did. Overall, there is a severe lack of vegetation throughout the country as a whole. The average EVI values within both home range estimates were compared to determine which method better represents the elephants' preferred habitat (Tables 5 and 6). Roughly half of the average EVIs per season were significantly different between the MCPs and SRs. Also, the average location-EVIs per season did not exceed 0.25 for any elephant. However, there were some cases where the maximum location-EVI values for an elephant ranged from 0.30–0.40, while minimum values ranged from 0.01–0.02. These values confirm that the elephants sought out the greenest vegetation they could find (in most cases), without compromising their metabolic costs.

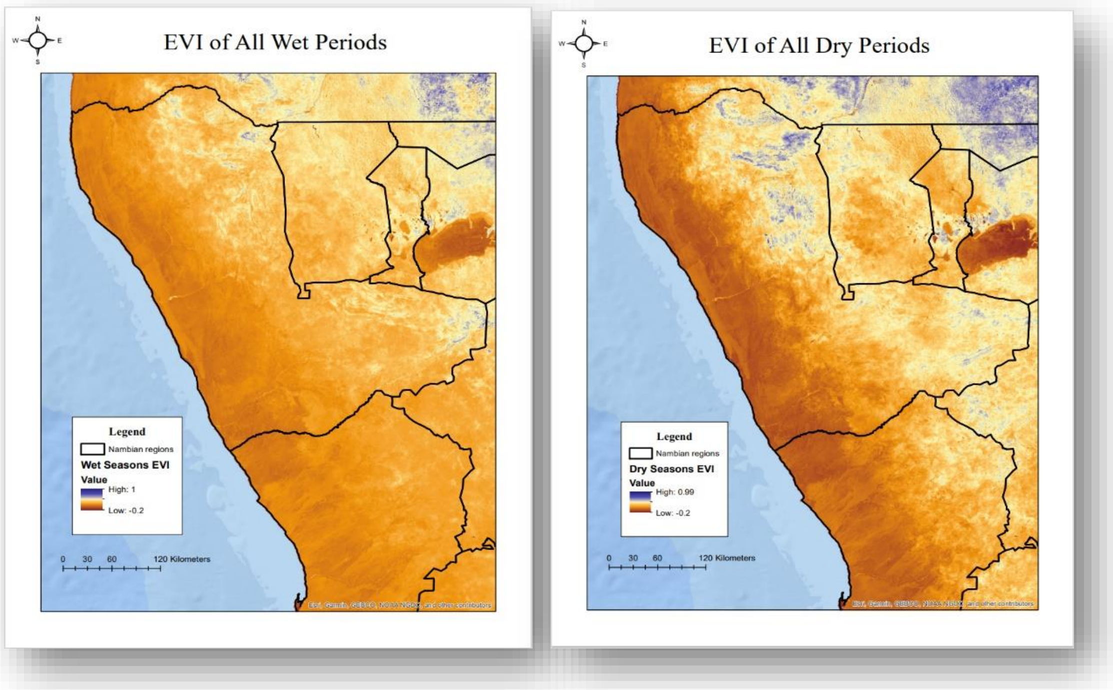

Figure 13: Vegetation distribution of all wet (left) and dry (right) seasons (from 2002-2007) in northwestern Namibia using MODIS EVI.

T-tests were conducted between all wet and dry seasons separately, but also for the combined wet/dry seasons (Tables 7 and 8) which revealed that there are slightly more significant differences in between the SRs and locational averages in comparison to the MCPs, since there was one more significantly different SR EVI observation than the MCP EVIs (Table 7). In some cases, when there were significant differences between the home range values and locations, there were also significant differences between the home ranges themselves. However, there were also many cases where significant locational differences did not correlate to significant differences between the home ranges (Tables 5, 6, 7 and 8).

There were not any significant differences observed when comparing the wet and dry seasons for each elephants' EVI values. The wet seasons had higher EVI values overall, whereas the dry seasons had slightly lower EVI values. Average EVIs of MCPs and SRs were quite close to the locational EVI values for each season, and this was observed for each elephants' EVI values. While most EVI values fell within the 0.10–0.20 range, there were three elephants that were significant outliers. The WKF-16, WKF-18, and WKM-10 had some of the lowest EVI averages, and their values ranged from 0.04–0.12 (including the locational EVI values). On the other hand, the wide-ranging, 45-year-old, WOM-4 elephant had some of the highest EVI values which ranged from 0.17–0.23 (including the locational EVI values). On average, the eastern elephants sought out greener vegetation than the western elephant population, but the WOM-4 sought out the greenest vegetation amongst the three.

MODIS EVI Averages In Home Ranges By Individual Period				
Period	**Elephant**	**MCPs**	**SRs**	**Averages of locational EVI values per period**
Wet 1	EKF-1	0.18	0.15	0.16
	EKM-1	0.15	0.15	0.16
	EKM-2	**0.17**	**0.16**	0.17
	EKM-3	**0.14**	**0.14**	0.15
	EKM-6	n/a	n/a	n/a
	WKF-16	****0.06**	****0.07**	0.09
	WKF-18	**0.08	**0.08	0.1
	WKM-10	**0.06	**0.06	0.09
	WOM-4	n/a	n/a	n/a
Dry 1	EKF-1	0.13	0.13	0.13
	EKM-1	**0.14**	****0.13**	0.14
	EKM-2	0.12	0.12	0.13
	EKM-3	**0.12**	****0.12**	0.13
	EKM-6	n/a	n/a	n/a
	WKF-16	**0.06	**0.06	0.11
	WKF-18	**0.08	**0.09	0.12
	WKM-10	****0.07**	****0.06**	0.11
	WOM-4	n/a	n/a	n/a
Wet 2	EKF-1	**0.14	**0.15	0.17
	EKM-1	n/a	n/a	n/a
	EKM-2	0.17	0.17	0.17
	EKM-3	0.16	0.16	0.17
	EKM-6	n/a	n/a	n/a
	WKF-16	****0.04**	****0.04**	0.07
	WKF-18	****0.10**	****0.11**	0.12
	WKM-10	**0.09**	****0.08**	0.1
	WOM-4	n/a	n/a	n/a
Dry 2	EKF-1	n/a	n/a	n/a
	EKM-1	n/a	n/a	n/a
	EKM-2	n/a	n/a	n/a
	EKM-3	n/a	n/a	n/a
	EKM-6	n/a	n/a	n/a
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	**0.06**	****0.06**	0.09
	WOM-4	n/a	n/a	n/a
Wet 3	EKF-1	n/a	n/a	n/a
	EKM-1	0.19	0.18	0.19
	EKM-2	**0.18**	**0.18**	0.19
	EKM-3	**0.17**	**0.17**	0.18
	EKM-6	**0.17**	**0.16**	0.18
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	****0.05**	****0.05**	0.09
	WOM-4	n/a	n/a	n/a
Dry 3	EKF-1	n/a	n/a	n/a
	EKM-1	0.13	0.13	0.13
	EKM-2	0.13	0.13	0.13
	EKM-3	0.13	0.13	0.13
	EKM-6	**0.12	**0.12	0.13
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	****0.04**	****0.05**	0.09
	WOM-4	n/a	n/a	n/a
Wet 4	EKF-1	n/a	n/a	n/a
	EKM-1	0.18	0.18	0.19
	EKM-2	**0.19**	**0.19**	0.2
	EKM-3	**0.20**	**0.19**	0.19
	EKM-6	**0.18**	**0.18**	0.19
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	**0.08	**0.08	0.12
	WOM-4	0.22	0.22	0.23
Dry 4	EKF-1	n/a	n/a	n/a
	EKM-1	0.13	0.13	0.14
	EKM-2	0.13	0.13	0.14
	EKM-3	0.13	0.13	0.13
	EKM-6	0.13	0.13	0.14
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	n/a	n/a	n/a
	WOM-4	0.17	0.17	0.18
Wet 5	EKF-1	n/a	n/a	n/a
	EKM-1	0.13	0.13	0.13
	EKM-2	n/a	n/a	n/a
	EKM-3	**0.14**	**0.14**	0.14
	EKM-6	**0.13	**0.13	0.14
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	**0.07	**0.07	0.09
	WOM-4	0.19	0.19	0.21
Dry 5	EKF-1	n/a	n/a	n/a
	EKM-1	n/a	n/a	n/a
	EKM-2	n/a	n/a	n/a
	EKM-3	0.13	0.12	0.13
	EKM-6	**0.11	**0.11	0.12
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	****0.04**	**0.05**	0.08
	WOM-4	n/a	n/a	n/a

Table 5: MODIS EVI comparison between MCPs, SRs, and location-averaged values per season. Bolded values indicate a significant difference (p-value < 0.05) between the MCPs and SRs EVI averages, and "**" denote significant differences with location-averaged EVI (p-value < 0.05).

Average of Points' EVI Values Per Period				
Elephant	**Period**	**MCPs**	**SRs**	**Average of elephants' locational EVI Values Per Period**
EKF-1	Wet 1	0.18	0.15	0.16
	Dry 1	0.13	0.13	0.13
	Wet 2	**0.14	**0.15	0.17
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
EKM-1	Wet 1	0.15	0.15	0.16
	Dry 1	**0.14**	****0.13**	0.14
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	0.19	0.18	0.19
	Dry 3	0.13	0.13	0.13
	Wet 4	0.18	0.18	0.19
	Dry 4	0.13	0.13	0.14
	Wet 5	0.13	0.13	0.13
	Dry 5	n/a	n/a	n/a
EKM-2	**Wet 1**	**0.17**	**0.16**	0.17
	Dry 1	0.12	0.12	0.13
	Wet 2	0.17	0.17	0.17
	Dry 2	n/a	n/a	n/a
	Wet 3	**0.18**	**0.18**	0.19
	Dry 3	0.13	0.13	0.13
	Wet 4	**0.19**	**0.19**	0.2
	Dry 4	0.13	0.13	0.14
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
EKM-3	**Wet 1**	**0.14**	**0.14**	0.15
	Dry 1	**0.12**	****0.12**	0.13
	Wet 2	0.16	0.16	0.17
	Dry 2	n/a	n/a	n/a
	Wet 3	**0.17**	**0.17**	0.18
	Dry 3	0.13	0.13	0.13
	Wet 4	**0.20**	**0.19**	0.19
	Dry 4	0.13	0.13	0.13
	Wet 5	**0.14**	**0.14**	0.14
	Dry 5	0.13	0.12	0.13
EKM-6	Wet 1	n/a	n/a	n/a
	Dry 1	n/a	n/a	n/a
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	**0.17**	**0.16**	0.18
	Dry 3	**0.12	**0.12	0.13
	Wet 4	**0.18**	**0.18**	0.19
	Dry 4	0.13	0.13	0.14
	Wet 5	**0.13	**0.13	0.14
	Dry 5	**0.11	**0.11	0.12
WKF-16	**Wet 1**	****0.06**	****0.07**	0.09
	Dry 1	**0.06	**0.06	0.11
	Wet 2	****0.04**	****0.04**	0.07
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
WKF-18	Wet 1	**0.08	**0.08	0.1
	Dry 1	**0.08	**0.09	0.12
	Wet 2	****0.10**	****0.11**	0.12
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
WKM-10	Wet 1	**0.06	**0.06	0.09
	Dry 1	****0.07**	****0.06**	0.11
	Wet 2	**0.09**	****0.08**	0.1
	Dry 2	**0.06**	****0.06**	0.09
	Wet 3	****0.05**	****0.05**	0.09
	Dry 3	****0.04**	****0.05**	0.09
	Wet 4	**0.08	**0.08	0.12
	Dry 4	n/a	n/a	n/a
	Wet 5	**0.07	**0.07	0.09
	Dry 5	****0.04**	**0.05**	0.08
WOM-4	Wet 1	n/a	n/a	n/a
	Dry 1	n/a	n/a	n/a
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	0.22	0.22	0.23
	Dry 4	0.17	0.17	0.18
	Wet 5	0.19	0.19	0.21
	Dry 5	n/a	n/a	n/a

Table 6: Average of elephants' locational EVI values per period. Bolded values indicate a significant difference (p-value < 0.05) between the MCPs and SRs EVI averages, and "**" denote significant differences with location-averaged EVI (p-value < 0.05).

MODIS EVI Averages In Home Ranges By All Wet/Dry Periods Per Elephant				
Elephant	**Period**	**MCPs**	**SRs**	**Average EVI of all locations per period**
EKF-1	All Wet Periods	0.17	**0.15	0.17
	All Dry Periods	0.13	0.13	0.13
EKM-1	All Wet Periods	**0.16	**0.16	0.17
	All Dry Periods	****0.14**	****0.13**	0.14
EKM-2	All Wet Periods	****0.18**	****0.18**	0.18
	All Dry Periods	**0.13	**0.13	0.13
EKM-3	All Wet Periods	**0.16**	**0.16**	0.17
	All Dry Periods	****0.13**	****0.12**	0.13
EKM-6	All Wet Periods	****0.16**	****0.16**	0.17
	All Dry Periods	**0.12	**0.12	0.13
WKF-16	All Wet Periods	****0.05**	****0.06**	0.08
	All Dry Periods	**0.06	**0.06	0.11
WKF-18	All Wet Periods	****0.09**	****0.09**	0.11
	All Dry Periods	**0.08	**0.09	0.12
WKM-10	All Wet Periods	****0.07**	****0.07**	0.10
	All Dry Periods	**0.06	**0.06	0.09
WOM-4	All Wet Periods	**0.21	**0.21	0.22
	All Dry Periods	**0.17	**0.17	0.18

Table 8: Comparison of average EVI for locations per season with MCP and SR averages. Bolded values indicate MCPs are significantly different from SRs values (p-value < 0.05), and "**" denote significant differences with location-averaged EVI (p-value < 0.05).

Comparing Average MCPs and SRs EVI Values with Average of Points' EVI Per Period				
Elephant	**Period**	**MCP Average**	**SR Average**	**Average of Points' EVI Per Period**
EKF-1	Both wet/dry combined	0.15	0.14	0.15
EKM-1	Both wet/dry combined	0.15	0.15	0.15
EKM-2	Both wet/dry combined	0.16	0.16	0.16
EKM-3	Both wet/dry combined	0.15	0.14	0.15
EKM-6	Both wet/dry combined	0.14	0.14	0.15
WKF-16	Both wet/dry combined	**0.06	**0.06	0.10
WKF-18	Both wet/dry combined	**0.09	0.09	0.12
WKM-10	Both wet/dry combined	**0.07	**0.07	0.10
WOM-4	Both wet/dry combined	0.19	0.19	0.2

Table 7: Average EVI of MCPs and SRs with the location-averages per elephant. Bolded values indicate MCP EVI values are significantly different from SR EVI values (p-value < 0.05), and "**" mean the EVI value is significantly different from its corresponding location-average EVI (percent rise; p-value < 0.05).

3.4 Slope Comparison

The terrain in Namibia varies throughout the country. The elevation (Figure 14), and the slope derived from the elevation DEM (Figure 15) are shown below. The elevation in Namibia (Figure 14) ranges from a low of −45 m to a high of 2559 m throughout the study region. The elevation is lower towards the coastline, and moving further inland there are peak elevation values followed by lower values. The DEM of Namibia was used to extract a slope map (Figure 15) which visualizes all the flat and steep areas. This data is crucial to understand what inhibits the movement of an elephant and restricts them from traversing an area. Slopes are a better metric than elevation because an area that is higher in elevation does not necessarily correspond to steep slopes.

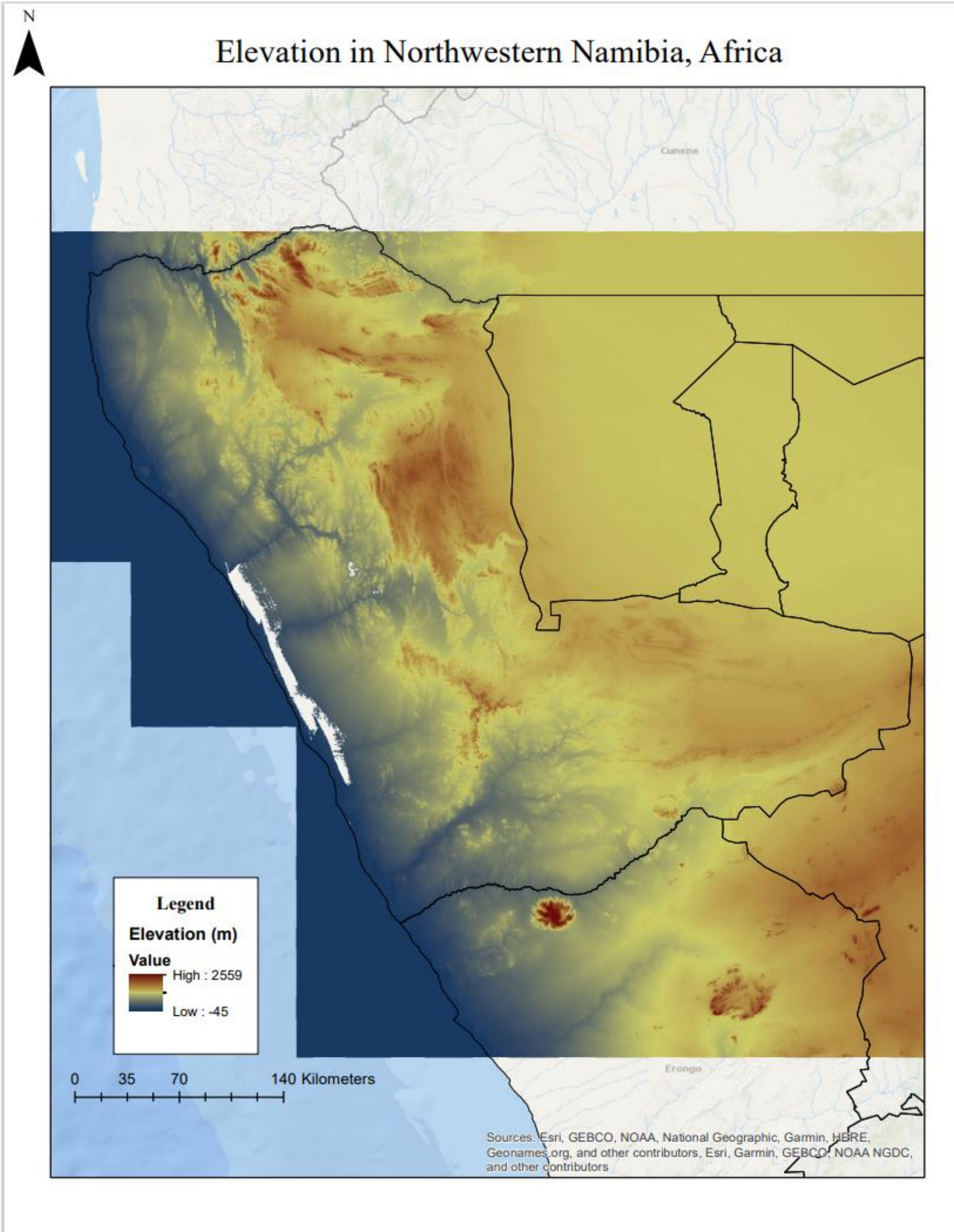

Figure 14: Elevation (m) in Northwestern Namibia, Africa.

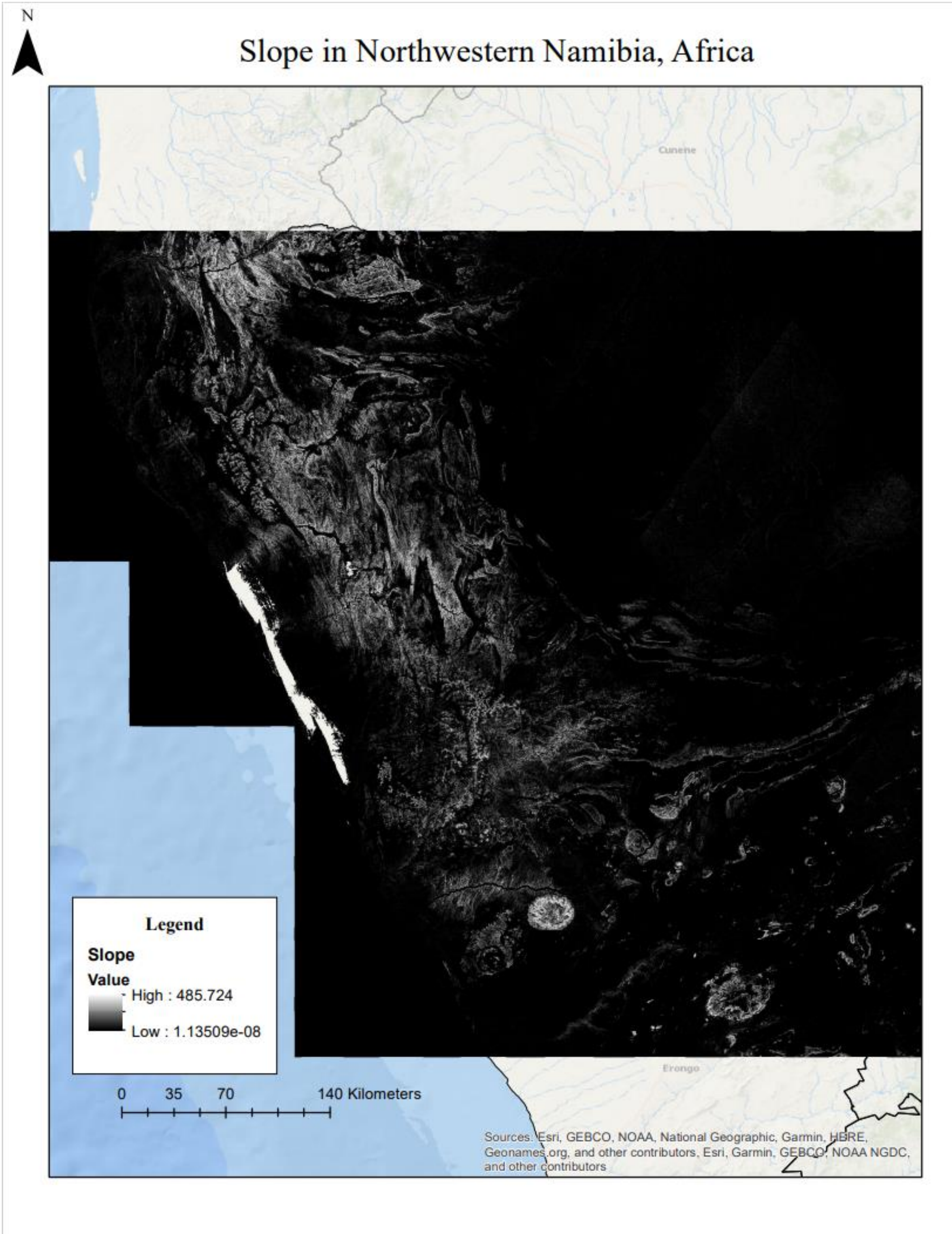

Figure 15: Slope (percent rise) in Northwestern Namibia, Africa.

The slope data is calculated as percent rise for all the elephants' MCPs, SRs, and actual locations per season (Tables 9, 10, 11, and 12). The highest slope value in an MCP home range was 27.2%, and the lowest was 3.5%. In the SRs, 25.8% was the steepest slope value and the lowest was 3.8%. On average, most of the slope values for the home ranges fell somewhere in the middle of each of the mentioned ranges. For the location-average slopes per season, the values stayed under 17% rise (Table 9). On average, most elephants pursued areas with lower slope percentages during the wet seasons and stayed relatively close to those same slope percentages during the dry seasons as well. However, the WKF-16, WKF-18, and WKM-10 elephants migrated through the steepest areas during the wet seasons, and even steeper areas during the dry season. Interestingly, the WOM-4 elephant climbed the least steep slopes in both wet and dry seasons. Since WOM-4 spent most of his time in the northern region of Namibia, he likely had access to greener vegetation in much flatter areas, so he did not have to migrate through steep slopes, and/or higher elevation areas, for better vegetation.

Mean slopes were compared using t-tests between all wet and dry seasons separately (Table 10), but also combined (Tables 11 and 12). Results revealed that the SRs are more frequently significantly different from the location averages than the MCPs. There were a few elephants that stood out based on slope percentages during various wet/dry seasons. The WKF-16, WKF-18, and WKM-10 elephants were in steeper terrain compared to the rest of the elephants, regardless of the wet or dry seasons (Table 10). While the three western Kunene elephants' location-slopes were similar to those for the rest of the elephants, the average slopes within both the MCPs and SRs were much larger than for the rest of the elephants. This could be due to terrain differences in the Western Kunene or that the three elephants primarily occupied areas that lacked green vegetation, which ultimately could have driven them to migrate through areas with steeper slopes in pursuit of greener vegetation. Since the eastern Kunene elephants mainly resided in the flatter areas of northwestern Namibia, they also had access to greener vegetation without having to climb very steep slopes. Whereas, the western Kunene elephants had to overcome steeper slopes to access the greener vegetation, but still did not acquire vegetation as green as that of the western Kunene and Omusati elephants. The Omusati elephant resided in a relatively flatter area for most of the time.

Slope (Percent Rise) Average Per Period				
Period	Elephant	MCPs	SRs	Average slope of all elephants per period
Wet 1	EKF-1	7.68	8.12	6.52
	EKM-1	10.47	10.82	5.97
	EKM-2	7.17	7.88	6.44
	EKM-3	10.87	11.42	7.13
	EKM-6	n/a	n/a	n/a
	WKF-16	24.34	20.52	n/a
	WKF-18	23.07	24.8	7.8
	WKM-10	17.89	20.97	7.4
	WOM-4	n/a	n/a	n/a
Dry 1	EKF-1	6.9	8.02	6.22
	EKM-1	7.67	12.66	9.76
	EKM-2	12.91	12.17	5.31
	EKM-3	11.33	12.62	6.72
	EKM-6	n/a	n/a	n/a
	WKF-16	25.42	22.53	14.98
	WKF-18	27.23	23.26	7.48
	WKM-10	21.05	20.75	7.05
	WOM-4	n/a	n/a	n/a
Wet 2	EKF-1	11.75	11.5	6.26
	EKM-1	n/a	n/a	n/a
	EKM-2	6.93	7.71	6.52
	EKM-3	7.56	7.93	6.38
	EKM-6	n/a	n/a	n/a
	WKF-16	19	19.2	12.08
	WKF-18	23.94	25.8	9.28
	WKM-10	22.81	23.28	7.53
	WOM-4	n/a	n/a	n/a
Dry 2	EKF-1	n/a	n/a	n/a
	EKM-1	n/a	n/a	n/a
	EKM-2	n/a	n/a	n/a
	EKM-3	n/a	n/a	n/a
	EKM-6	n/a	n/a	n/a
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	20.78	20.25	6.35
	WOM-4	n/a	n/a	n/a
Wet 3	EKF-1	n/a	n/a	n/a
	EKM-1	13.09	12	5.95
	EKM-2	8.24	10.46	7.94
	EKM-3	11.75	11.76	5.13
	EKM-6	15.44	12.54	7.52
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	16.08	19.82	8.03
	WOM-4	n/a	n/a	n/a
Dry 3	EKF-1	n/a	n/a	n/a
	EKM-1	11.7	9.94	9
	EKM-2	9.53	9.56	6.87
	EKM-3	11.42	11.8	7.02
	EKM-6	10.56	10.38	8.07
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	19.18	20.15	5.55
	WOM-4	n/a	n/a	n/a
Wet 4	EKF-1	n/a	n/a	n/a
	EKM-1	14.02	14.01	11.36
	EKM-2	8.93	10.61	8.73
	EKM-3	7.41	7.57	7.19
	EKM-6	10.26	11.39	7.95
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	19.6	19.33	7.97
	WOM-4	3.52	4	3.31
Dry 4	EKF-1	n/a	n/a	n/a
	EKM-1	12.34	10.46	12.45
	EKM-2	10.03	10.22	9.81
	EKM-3	8.62	9.06	4.64
	EKM-6	8.5	9.49	6.89
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	n/a	n/a	n/a
	WOM-4	4.51	4.7	2.57
Wet 5	EKF-1	n/a	n/a	n/a
	EKM-1	10.46	10.27	16.73
	EKM-2	n/a	n/a	n/a
	EKM-3	6.02	7.22	4.53
	EKM-6	11.21	11.37	6.95
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	19.66	20.06	13.08
	WOM-4	3.64	3.81	3.06
Dry 5	EKF-1	n/a	n/a	n/a
	EKM-1	n/a	n/a	n/a
	EKM-2	n/a	n/a	n/a
	EKM-3	9.35	7.72	3.13
	EKM-6	7.74	8.56	5.54
	WKF-16	n/a	n/a	n/a
	WKF-18	n/a	n/a	n/a
	WKM-10	21.61	20.97	8.25
	WOM-4	n/a	n/a	n/a

Table 9: Slope (percent rise) average per season.

Average of Points' Slopes Per Period				
Elephant	Period	MCPs	SRs	Average of Points' Slopes Per Period
EKF-1	Wet 1	7.68	8.12	6.52
	Dry 1	6.9	8.02	6.22
	Wet 2	11.75	11.5	6.26
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
EKM-1	Wet 1	10.47	10.82	5.97
	Dry 1	7.67	12.66	9.76
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	13.09	12	5.95
	Dry 3	11.7	9.94	9
	Wet 4	14.02	14.01	11.36
	Dry 4	12.34	10.46	12.45
	Wet 5	10.46	10.27	16.73
	Dry 5	n/a	n/a	n/a
EKM-2	Wet 1	7.17	7.88	6.44
	Dry 1	12.91	12.17	5.31
	Wet 2	6.93	7.71	6.52
	Dry 2	n/a	n/a	n/a
	Wet 3	8.24	10.46	7.94
	Dry 3	9.53	9.56	6.87
	Wet 4	8.93	10.61	8.73
	Dry 4	10.03	10.22	9.81
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
EKM-3	Wet 1	10.87	11.42	7.13
	Dry 1	11.33	12.62	6.72
	Wet 2	7.56	7.93	6.38
	Dry 2	n/a	n/a	n/a
	Wet 3	11.75	11.76	5.13
	Dry 3	11.42	11.8	7.02
	Wet 4	7.41	7.57	7.19
	Dry 4	8.62	9.06	4.64
	Wet 5	6.02	7.22	4.53
	Dry 5	9.35	7.72	3.13
EKM-6	Wet 1	n/a	n/a	n/a
	Dry 1	n/a	n/a	n/a
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	15.44	12.54	7.52
	Dry 3	10.56	10.38	8.07
	Wet 4	10.26	11.39	7.95
	Dry 4	8.5	9.49	6.89
	Wet 5	11.21	11.37	6.95
	Dry 5	7.74	8.56	5.54
WKF-16	Wet 1	24.34	20.52	9.97
	Dry 1	25.42	22.53	14.98
	Wet 2	19	19.2	12.08
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
WKF-18	Wet 1	23.07	24.8	7.8
	Dry 1	27.23	23.26	7.48
	Wet 2	23.94	25.8	9.28
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	n/a	n/a	n/a
	Dry 4	n/a	n/a	n/a
	Wet 5	n/a	n/a	n/a
	Dry 5	n/a	n/a	n/a
WKM-10	Wet 1	17.89	20.97	7.4
	Dry 1	21.05	20.75	7.05
	Wet 2	22.81	23.28	7.53
	Dry 2	20.78	20.25	6.35
	Wet 3	16.08	19.82	8.03
	Dry 3	19.18	20.15	5.55
	Wet 4	19.6	19.33	7.97
	Dry 4	n/a	n/a	n/a
	Wet 5	19.66	20.06	13.08
	Dry 5	21.61	20.97	8.25
WOM-4	Wet 1	n/a	n/a	n/a
	Dry 1	n/a	n/a	n/a
	Wet 2	n/a	n/a	n/a
	Dry 2	n/a	n/a	n/a
	Wet 3	n/a	n/a	n/a
	Dry 3	n/a	n/a	n/a
	Wet 4	3.52	4	3.31
	Dry 4	4.51	4.7	2.57
	Wet 5	3.64	3.81	3.06
	Dry 5	n/a	n/a	n/a

Table 10: Average of points' slopes per season

Slope Averages In Home Ranges - Wet/Dry Periods Per Elephant				
Elephant	**Period**	**MCPs**	**SRs**	**Average slope of all locations per period**
EKF-1	All Wet Periods	9.72	9.81	6.39
	All Dry Periods	6.90	8.02	6.22
EKM-1	All Wet Periods	12.01	11.78	11.35
	All Dry Periods	10.57	11.02	10.40
EKM-2	All Wet Periods	**7.82**	**9.17**	7.41
	All Dry Periods	10.82	10.65	7.33
EKM-3	All Wet Periods	8.72	**9.18	6.07
	All Dry Periods	**10.18	**10.3	5.38
EKM-6	All Wet Periods	12.30	**11.77	7.47
	All Dry Periods	8.93	**9.47	6.83
WKF-16	All Wet Periods	21.67	**19.86	11.03
	All Dry Periods	25.42	22.53	14.98
WKF-18	All Wet Periods	****23.50**	****25.3**	8.54
	All Dry Periods	27.23	23.26	7.48
WKM-10	All Wet Periods	**19.20	**20.69	7.34
	All Dry Periods	**20.65	**20.53	6.8
WOM-4	All Wet Periods	3.58	3.91	3.19
	All Dry Periods	4.51	4.70	2.57

Table 11: Average location-slope (percent rise) comparison per season with MCP and SR averages. Bolded values indicate MCP slopes are significantly different from SR slopes (p-value < 0.05), and "**" mean the slope is significantly different from its corresponding location-average slope (percent rise; p-value < 0.05).

Comparing Average MCPs and SRs Slope Values with Average of Points' Slopes Per Period				
Elephant	**Period**	**MCP Average**	**SR Average**	**Average of Points' Slopes Per Period**
EKF-1	Both wet/dry combined	8.78	9.21	6.33
EKM-1	Both wet/dry combined	11.39	11.45	10.17
EKM-2	Both wet/dry combined	9.11	**9.80	7.37
EKM-3	Both wet/dry combined	**9.37	**9.68	5.76
EKM-6	Both wet/dry combined	**10.62	**10.62	7.15
WKF-16	Both wet/dry combined	**22.92	**20.75	12.34
WKF-18	Both wet/dry combined	**24.75	**24.62	8.19
WKM-10	Both wet/dry combined	**19.85	**20.62	7.91
WOM-4	Both wet/dry combined	3.89	4.17	2.98

Table 12: Average slopes (percent rise) of MCPs and SRs with the location-averages (percent rise) per elephant. Bolded values indicate MCP slopes are significantly different from SR slopes (p-value < 0.05), and "**" mean the slope is significantly different from its corresponding location-average slope (percent rise; p-value < 0.05).

3.5 Namibian Habitat Suitability

Using the data produced in previous sections, the EVI and slope values corresponding to each elephant in different wet and dry seasons were used to create habitat suitability maps for the overall wet (Figure 16) and dry (Figure 17) seasons. For the wet season map, suitable areas were considered to be those with EVI values greater than or equal to 0.15, and areas with slopes that were less than or equal to 24.34% rise. In the dry season, areas considered suitable had greater than or equal to 0.12 EVI values, and contained slopes that were less than or equal to 27.23% rise. These values represent the median EVI for areas traversed by elephants during the respective 2002–2007 wet and dry seasons, and also delineate areas that are accessible for elephants by setting the thresholds to be less than the steepest terrain accessed by an elephant. Thresholds were applied to EVI data based on the lowest EVI average for all the elephants. All vegetated areas that were equal to or had a higher EVI value than that average minimum were highlighted in the map. For slope, the steepest slope value by an elephant was used to locate areas that were equal to or lower than that slope value, highlighting more easily accessible areas in the maps. Areas that were higher in vegetation and lower in slope were marked as "suitable," and areas that were lower in vegetation and higher in slope were marked as "unsuitable." Regardless of which season is being assessed, the main determinant of habitat suitability is slope since it directly hinders the movement of elephants through steeper areas, and second would be vegetation since it drives the elephants' movement to seek greener vegetation.

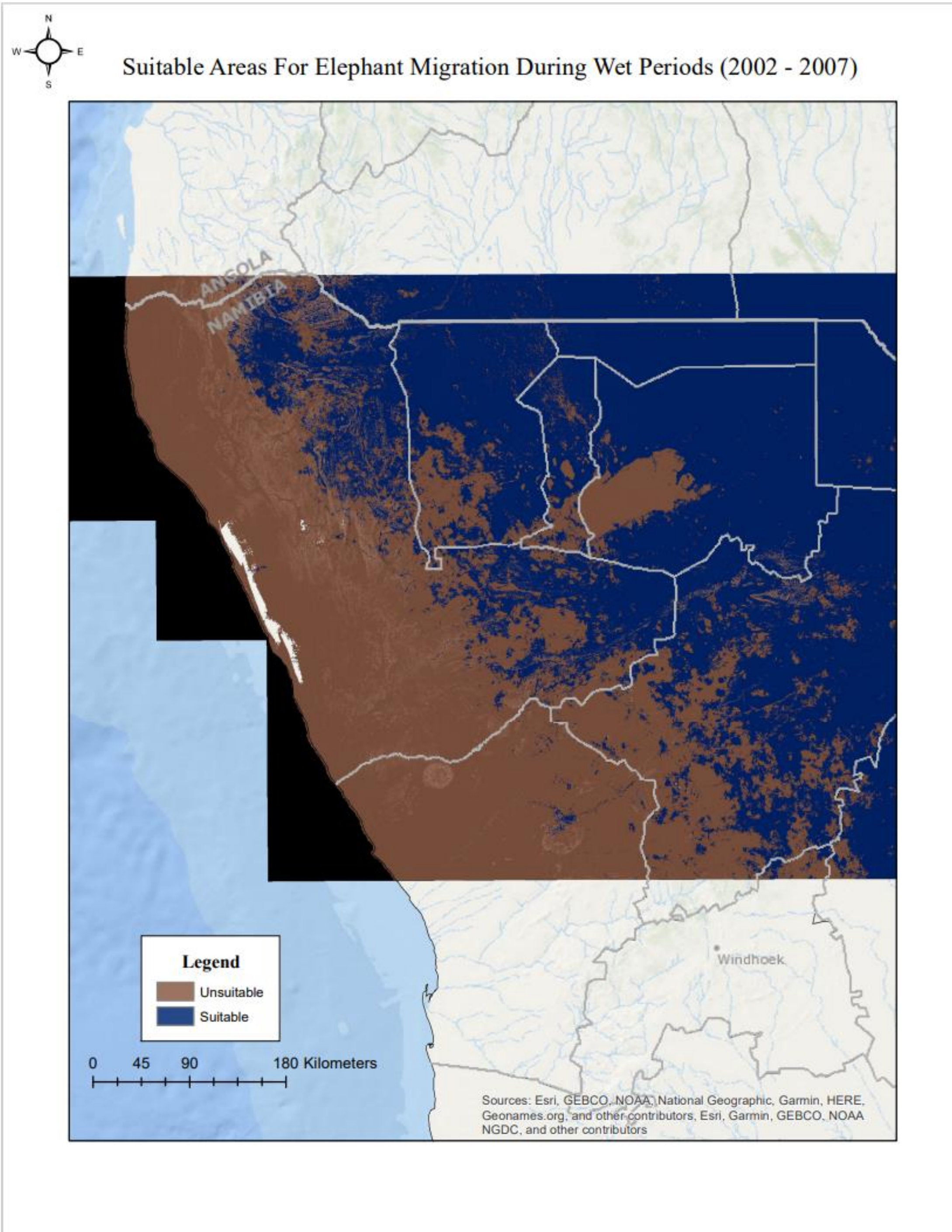

Figure 16: Suitable and unsuitable areas for elephant migration during wet seasons (2002–2007).

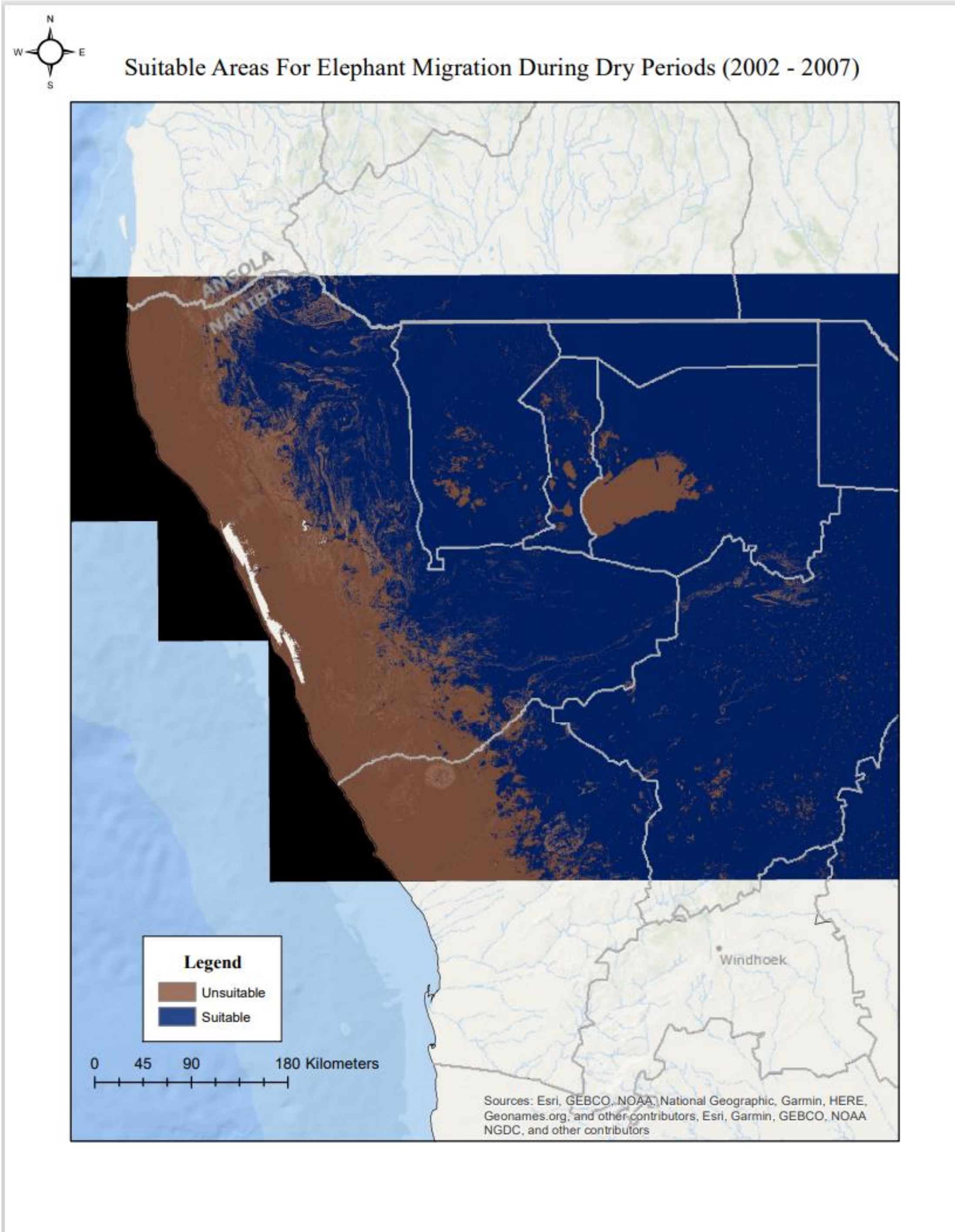

Figure 17: Suitable and unsuitable areas for elephant migration during dry seasons (2002–2007).

DISCUSSION

4.1 Most Effective Home Range Estimation Method

Using the tracking data of nine Namibian elephants, two different home range estimates (MCPs and SRs) were created for each wet and dry season that occurred within the ~5 years of study. Those home ranges were then used as regions for which areas were calculated and vegetation (EVI) and slope data were extracted and compared. The calculated areas within home ranges were larger in SRs during the wet seasons, and usually smallest in MCPs during dry seasons. The EVI and slope values within the home ranges and at each tracking location of the elephant also revealed interesting information about the elephants' migration patterns. Two separate vegetation distributions were created (one for all wet seasons and one for all dry seasons), which showed the average variability of low and high vegetation per season. Overall, there is a lack of vegetation throughout most of the country, especially in areas near the coastline. There is more green vegetation in the northern region of the country, and less in the southern region (in both wet/dry seasons). The majority of high slope and high elevation areas in Namibia are also concentrated in proximity to the coastline, and the terrain gets relatively flatter moving inland. Multiple comparisons were used to quantify the differences in between the MCPs, SRs, and tracking location values of the two variables. T-tests to compare EVI averages showed that more of the SR observations, for EVI and slope, were significantly different from the location-EVIs than the MCPs, and t-tests for slope had many more significant location differences relative to the SRs than the MCPs. After comparing various values of vegetation (EVI), slope, and locational point value averages, the t-tests revealed that the MCP is a more representative method for quantifying a Namibian elephant's home range environment.

There are a few reasons why the MCP may be a more representative method than the SR. When an MCP is created, it accounts for significant outliers which typically broadens the area that is defined as a home range. This potentially causes more environmental variability to be captured in an MCP as opposed to an SR, and could represent more variable conditions in the environment that an elephant could be drawn to. Secondly, the two variables (vegetation and slopes) evaluated in the elephants' home ranges do not exhibit extreme values throughout the region, which could explain why MCPs adequately capture the home range environment. For example, the vegetation distribution in Namibia shows that there are no areas that have an abundance of vegetation. Mostly, the land is either barren or slightly vegetated throughout northwestern Namibia. Similarly, the terrain in Namibia is relatively flat, apart from the mountainous region near the coastline. Had there been more variability in areas through which elephants migrated, a SR may have been a more useful method in quantifying the elephants' home ranges.

4.2 Limitations and Future Work

Since this research is a case study working with elephant movement data during a time period in the early 2000s, the biodiversity within the study region may have changed greatly since then due to factors such as climate change, fluctuating poaching activities, increasing human population, etc. The elephants in this study have either been poached or otherwise killed, or have an unknown status since 2007. Therefore, this research cannot be extended to further study the specific sub-population. Additionally, the technology used to acquire elephant tracking locations at the time malfunctioned randomly throughout the five-year period, thus resulting in a lot of missing observations for some of the elephants' wet/dry seasons. While MCP and SR calculations are based on the same tracking locations and can reliably be compared to each other, it is much more difficult to make definitive conclusions regarding differences between seasons and between elephants. Technology is advancing rapidly, and acquiring high-quality observations for research such as this should be easier than before. Using advanced, higher quality tracking technology and data with even better spatial resolution would greatly improve the results. If there were more consistent observations and timestamps of when and where the elephants migrated, the conclusions based on their tracking locations would likely be of better quality, and more accurate. Lastly, assessing water sources and human settlements in the study region, in addition to vegetation and slope, would also improve the quality of the analysis and account for two more especially important factors that influence elephant migration patterns that then also determine elephants' home ranges.

Reliable data for water sources and human settlements was not available for the time period of this study, but would be very useful to include if this study were to be repeated.

This case study could be applied to study elephants that are currently in the region, as well as other desert elephant sub-populations. While MCPs visualize collective locations where and when an elephant migrated, they do not visualize the duration of time an elephant spent in a specific location. Including this temporal component with the MCPs could significantly increase the conclusions that can be drawn from the home range estimates, and improve our understanding about the elephants' home ranges. Additionally, knowing the type of vegetation available within an MCP can also further clarify the elephants' preferences regarding the type of vegetation they went after at each of their tracking locations. If there were data available for all four variables mentioned earlier—vegetation, slope, water sources, and human settlements—their distribution could be assessed in a similar way using the MCP home range estimates to understand the characteristics within a home range based on each of the variables. Those values could be used for a least-cost path analysis for all the elephants and determine suitable corridors for the elephant population. The discovered routes and characteristics could then be shared with conservancies and other agencies that manage the elephants in the region to aid in the conservation of the species.

CONCLUSIONS

The overarching research goal of this study was to determine if a physically-based home range estimate using sound more accurately quantifies the Namibian elephants' home range environments in comparison to a purely statistical estimate such as minimum convex polygons. The first objective was to create the two home range estimates (MCPs and SRs) based on elephant tracking locations for nine elephants from 2002–2007. These estimates were successfully created using tools available in ArcGIS software for the elephants during Namibia's wet and dry seasons. After the home range estimates were generated, area calculations assessed and compared the size differences between the MCP and SR home range estimates. The second objective was to assess the distribution of vegetation and slope in both home range estimates, and at the tracking locations of each elephant per season. The two datasets used for this objective included 250 m resolution MODIS EVI data to represent vegetation distribution in the region, and the 30 m resolution NASA SRTM data to assess the slope distribution. The home range areas were used as parameters from which to extract the slope and vegetation data. The resulting values were then used to gauge their variability in the elephants' home ranges for a particular season. To determine the most effective home range estimation method, the third objective was to compare the means using t-tests of the slope and vegetation data corresponding to the tracking locations, MCPs, and SRs, for the elephants individual and collective wet/dry seasons. The results showed that the MCP estimation was more effective than a SR in quantifying the elephants' home ranges.

These findings can contribute to determining a process based on GIS technology that will allow the remaining elephants from this sub-population to be studied more effectively. By assessing the distribution of slope and vegetation in the home ranges and at each of the elephants' tracking locations, valuable information is now available on elephant migration patterns and home range preferences throughout northwestern Namibia.

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