Assessing patterns of spatial occurrence and human-carnivore conflict for African lions (*Panthera leo*) in and around Etosha National Park, Namibia

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Submitted in partial fulfillment of the requirements for the degree of Master of Arts in Conservation Biology under the Executive Committee of the Graduate School of Arts and Sciences

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ABSTRACT

Carnivore populations face threats from increasing human populations and rapidly diminishing, suitable habitat. Large carnivores such as African lions (*Panthera leo*) commonly range outside of their protected areas and attack livestock on adjacent farmlands. This can lead to human-carnivore conflict (HCC) events often resulting in retaliatory lion killings. HCC retaliation by poisoning the offending animals is highly costly to lions due to the species’ group hunting and feeding habits. Conflict has thus been identified as a primary driver of wild lion population declines, estimated to have globally decreased by 43% in the last 20 years. Etosha National Park (ENP) in Namibia is an IUCN designated Lion Conservation Unit and is home to the country's largest surviving and only stable lion population. Lions frequently cross onto farmlands bordering ENP causing HCC, leading to ~30 to 50 HCC lion mortalities annually; ~10% of Etosha’s lion population is lost to HCC each year. Park officials are further concerned with the recent, simultaneous increase in HCC events and decrease in communication from farmers regarding problem animals. The aim of this dissertation was to (1) develop a baseline understanding of the spatial ecology of the resident lion population in Etosha National Park using GPS location data from lion satellite collars and (2) to analyze patterns of HCC involving Etosha lions in relation to farm types and land use practices around Etosha’s boundaries. Twenty-one
GPS satellite collars were fitted to lions in the Southern and Western boundaries of ENP where the most conflict is occurring. Analyses showed considerable variation in lion home range size and ranging behavior outside of park boundaries between individuals, but no significant difference between seasons. Home range utilization distributions showed a consistent, frequent use of the landscape around known annual waterpoints suggesting that lion landscape use is driven by water availability inside ENP. Analyses of historical HCC records showed a steady increase in HCC resulting in lion mortalities from 1975-2017 with the majority (~70%) of events occurring on commercial livestock and game farms. Large data gaps from 2005-2017 were consistent with park management’s concerns of underreporting. Changes in dominant land use and farm type caused by Namibian land reform initiatives passed in 2003 may be to blame. Human landscape level changes around ENP are altering the social, political, and physical landscape impacting HCC and Etosha lion survival. Further assessments should use combined-spatial-statistical modeling techniques to examine how specific landscape attributes and land use types influence lion distribution, home range, HCC, and subsequent lion mortalities around ENP.
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1.0 Introduction

1.1 Human-Carnivore Conflict with African lions

Carnivore conservation presents a global challenge as human population increase and suitable habitat for carnivores decreases (Winterbach et al. 2013, Bauer et al. 2015). Wild carnivore populations face increased risks along the borders of, and inside, protected areas (PAs) where wildlife and communities increasingly overlap (Woodroffe & Ginsberg 1998). Threats include the pressures of habitat loss and fragmentation and declining natural prey populations, as well as more direct threats such as commercial exploitation, disease epidemics from increased contact between domestic animals and wildlife, and mortalities resulting from human-carnivore conflict (HCC; Treves & Karanth 2009, Bauer et al. 2015). Conflict is considered one of the most serious threats to carnivore survival with the most common cause being livestock depredation (Winterbach et al. 2013). This occurs when carnivores range outside of PAs, carnivores prey on livestock, and conflict subsequently arises between farmers and wild animals. Retaliatory killings of offending animals by poisoning or shooting is a common result (Inskip & Zimmerman 2009). Livestock depredation conflicts are one of the most serious threats to large carnivore populations today (Woodroffe et al. 2005).

African lions (*Panthera leo*) are an iconic carnivore species suffering from rapid global population decline, having decreased by ~43% in the last 2 decades (Bauer et al. 2015). Lions are more frequently blamed in livestock depredation HCC than any other carnivore species (Winterbach et al. 2013). Retaliatory killings are highly costly to lion conservation due to the species’ group hunting and feeding habits; if a farmer retaliates for a lost cow by baiting a lion with a poisoned carcass, multiple mortalities can occur when a group of lions feeds on it (Linnell et al. 2012). People who rely on livestock for their livelihood have been found to be the least
tolerant of lions and the risk of lion mortalities is markedly higher in PA boundary areas with high human and livestock density (Winterbach et al. 2013, Miller 2015). Conflict has thus been identified as a primary driver of wild lion population declines and is of the utmost concern along the boundaries of protected areas (Bauer et al. 2016).

Sub-Saharan Africa has many protected areas that serve as the last strongholds for dwindling lion populations and are priority landscapes for the species’ conservation. Etosha National Park (ENP) in Namibia is an IUCN designated Lion Conservation Unit (Bauer et al. 2016) and is home to the country’s largest surviving, and only stable, lion population (est. ~435 individuals, Etosha Lion Survey Report 2014). Etosha is one of the top tourism destinations in Namibia for wildlife viewing and has been a “fully fenced” since 1973. However, the quality and type of fence around ENP varies considerably and has proven ineffective for keeping lions in, since they often use holes that other species dig (such as warthogs and porcupines) to cross under the fence (Stander 1991). Lions frequently cross outside of ENP’s borders (est. ~50–80 lions annually) leading to HCC resulting from livestock depredation, causing ~30–50 lion mortalities in park boundary areas annually (Trinkel et al. 2016). The well-established relationship between human-carnivore conflict and the boundaries of protected areas and Etosha’s effective lack of a hard barrier between ENP and adjacent lands makes it necessary to understand the landscape along Etosha’s boundary to understand its HCC risk and protect ENP’s lions (Lindsey et al. 2013).

1.2 The Importance of Namibian Land Tenure and Land Reform to Conflict

Since establishing Independence in 1990, Namibia has undergone several major changes to their land tenure system, resulting in land reform initiatives and many subsequent changes to the dominant land use types in the areas surrounding ENP. Land tenure systems in both
industrialized and developing countries often consist of a patchwork of government/state, communal/private, and individual/private property rights and occupancy arrangements (Mendelsohn 2006; LandLink 2013). Many younger, developing countries in Africa, Asia, and Latin America struggle to balance “statutory tenure” systems established by colonial rule (i.e. tenure based on titled, private property rights) with “customary tenure” systems based on “traditional” land and resource rights (Christenson 2005). Customary tenure is often associated with indigenous communities where informal or unwritten rules and norms govern community allocation, use, access, and transfer of land (LandLink 2013). The development or enforcement of statutory tenure systems in and around newly established protected areas- particularly in areas which have traditionally following customary tenure- can produce land conflicts and confusion on overlapping rights, contradictory rules, and competing authorities (Mendelsohn et al. 2012). In Namibia, this tenure system issue is a major contributing factor to the many complexities surrounding human-wildlife conflict incidences when animals cross outside of protected area borders (Schumann et al. 2012; Lindsey et al. 2013). The established relationships between HCC, land use, and conflict risk factors for lions makes it likely that these political, social, and legal changes accompanying land tenure and altering land use practices around ENP may be contributing to increased HCC risk for Etosha’s lions (Woodroffe & Ginsberg 1998; Inskip & Zimmerman 2009; Lindsey et al. 2013; Miller 2015).

Today, Namibia juggles the complexities of integrating customary and statutory tenure systems balancing two land allocation systems: 1. Freehold, defined by formal title of private lands under a statutory tenure system and 2. Communal, defined by informal occupancy of state-owned lands by groups of individuals who traditionally occupied said lands under a customary tenure system (prior to “establishment” of state ownership) (Mendelsohn et al. 2012). At
Independence, Namibia’s central government resolved that all land not held as private, titled property (i.e. Freehold\(^1\) land) was re-designated as State-owned, “Communal Land” (Malan 2003). The Communal Land Reform Act (CLRA Act No. 5, 2002) took effect in 2003 and spawned a land reform initiative to re-allocate these newly designated, State-owned, “Communal” lands as registered\(^2\), Communal farms to individuals and groups based on the state’s acknowledgment of prior occupancy under customary land rights (Malan 2003). Almost two thirds of Namibians live on Communal areas today, all of which is rural land and constitute \(~41\%\) of Namibia’s land (CIA World Factbook 2018). In contrast, Commercial farms account for \(~44\%\) of Namibia’s landmass and are owned by only 8-10\% of the population (FAOSTAT 2017). The Namibian government has therefore also made a strong push to re-allocate commercial (freehold) land to previously disadvantaged Namibians who do not have property rights in the form of registered or leased Communal lands (still owned by the State) (The National Resettlement Policy est. 2001).

An additional 15 million hectares of commercial agricultural land are to be acquired by the State, one third for allocation under resettlement purposes and two thirds for agriculture/conservancies and tourism, within the next decade (Ministry of Land Reform National Policy, Namibia 2017/2018). This will involve acquiring commercial agricultural property (i.e. land previously held only by Freehold farmers) for re-allocation as Communal Resettlement land for Communal farming, facilitating individual loans for previously disadvantaged Namibians to purchase and establish new Communal, commercial-scale farms,

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\(^1\) Prior to Independence, only white Namibians were able to own freehold property thus all commercial farms were freehold properties, and the terms are often used interchangeably today (BDO Namibia 2018).

\(^2\) This “registration” is not ownership in the sense that freehold property is owned, Communal land registration only includes rights to leasehold and occupational land rights for those who occupy “commonage” areas and do not own, or do not desire to own, the title to property outright (Muduva 2015).
and helping support the establishment of Communal Conservancies. “Communal Conservancies” is a registered coalition of community members occupying a state-owned, Communally allocated area who have agreed to a fixed boundary within their farming lands to establish integrated space to protect wildlife and natural resources (NACSO 2018). Communal conservancies usually encompass a mixture of land use types, integrating traditional resource uses with new income sources: small-scale agriculture and livestock/game grazing, eco-tourism, sustainable trophy hunting, fishing and fishery protection areas, and exclusive wildlife conservation areas. Game guards from the community are often employed by the conservancy to patrol the area, deter poachers and assist the MET to monitor wildlife within its borders (NACSO 2018).

An oversight of all the land registration, reform, and resettlement acts has been state silence regarding designation or management of different land-use practices common in Communal areas (Muduva 2015). Practices such as migrant pastoralism, shifting agriculture, seasonal crop fields and shifting cattle posts that use grazing areas communally are potential contributing factors to the occurrence HCC events (Abade et al. 2014), and none of these are currently regulated during the registration or re-allocation of Communal lands (CLRA Act No. 5, 2002; Malan 2003). The complexities of multiple, shifting Namibian land tenure systems contribute to many actively changing landscape and land use practices in rural areas today, exacerbating human-wildlife conflicts for many species around Namibian protected areas including between farmers and carnivores (i.e. HCC) (Schuman et al. 2012, Lindsey et al. 2013).

3 “In 1996 an amendment was made to the Nature Conservation Ordinance of 1975, which devolved rights to communities over natural resources, which includes wildlife, and established rights for communities to set up tourism enterprises. These rights were to be exercised through communal conservancies. The first four communal conservancies were formed in 1998. To date, there are 82, covering almost 20% of Namibia.” (NACSO 2018).
1.3 Contextualizing HCC in Namibia’s Land Tenure System and Etosha’s Landscape

Etosha National Park is positioned at the juncture of five regions in north-central Namibia, four of which (Omusati, Oshana, Ohangwena and Oshikoto) host 40% of the country’s human population, despite only occupying about 10% of the country's land mass (CIA World Factbook). Nearly all of ENP’s boundary abuts agricultural areas. These agricultural areas are used as either (1) livestock and/or game farms or (2) conservation areas for tourism and wildlife and operate at two varying scales: (1) Commercial (i.e. large-scale private farms or operations) and (2) Communal (i.e. small-scale, subsistence farming) and are regionally distributed in the following structure (Namibian Environmental Information Service 2018):

- The southern and eastern boundaries of ENP exclusively neighbor Freehold properties that are most often commercial-scale livestock and/or game farms used for meat production or grazing. Some game farms are also registered as game hunting operations or grouped together as “Game Reserves” (see further explanation in text below) (Namibian Environmental Information Service, 2018).

- The northern and western boundaries of ENP are conversely surrounded exclusively by state-owned, Communal allocated areas, used predominately for small-scale subsistence farming (livestock grazing) and/or registered as Communal conservancies) (Namibian Environmental Information Service, 2018).

In the last few years, many commercial livestock farms on the southern boundary have begun capitalizing on eco-tourism operations by increasing the amount of commercialized, free-ranging game on their farms and establishing tourist guest lodges for game viewing (Outjo MET office, pers. comm.). These grouped commercial game farms refer to themselves as “Game Reserves” and consider themselves to be “ENP lion friendly” in the interest of attracting tourists, but they are usually not registered conservation areas and are grouped freehold farms. This has subsequently decreased the amount of domesticated livestock (cattle, sheep, goats) on ENP
adjacent lands in the southern areas and many farmers have removed game-proof fences to allow for influx of wild game from ENP onto their properties (ENP-MET office, pers. comm.).

Historically, conflict has received the most negative attention in southern boundary areas with commercial livestock farms and HCC has been less frequent along the northern and western borders (Stander 2004, Stander 2005, Trinkel 2012). Generally, MET believes this is because patrolling by game guards in Communal Conservancies and the greater value Communal area communities place on wildlife to support their conservancy economies prevents lions crossing onto northern and western boundary properties from escalating to HCC and mortalities (ENP-MET office, pers. comm.) However, communal conservancies also have small-scale, subsistence cattle farmers on their lands, and protected conserved areas for wildlife do not make up the majority of ENP-Communal Conservancy boundary areas. Conflicts resulting in lion mortalities in the last 3-5 years are most frequently occurring in the southern and western boundary areas (Pierre DuPreez, MET, pers. comm.)

1.4 Etosha Lion Population Monitoring

Despite their importance to conservation and tourism, there has not been regular, park-wide monitoring of the lion population in Etosha National Park for over 40 years. In 2010 and 2014 park rangers from the Ministry of Environment and Tourism (MET) conducted a calibration exercise to develop a call-up (play back) population survey method for ENP. Although this lion population survey method was developed in Kruger National Park, South Africa (Ferreira and Funston 2010), it was determined by MET to be suitable for estimating lion numbers within Etosha’s large land mass and difficult terrain. The two completed surveys show the lion population has nearly doubled in the last 30 years from an estimate of 271 individuals

Although Etosha lion populations are currently stable, they still face increasing risks that accompany human and lion coexistence in and around protected areas. In addition to increased retaliatory killings driven by HCC, an increase in poaching has been a growing concern for MET staff, given the presence of multiple “high-value” species within the park, including lions themselves (ENP- MET office, pers. comm.). Beginning in 2016, MET collaborated with researchers at WWF-Namibia and Etosha Ecological Institute to support the initiation of a Large Carnivore Monitoring Program in and around Etosha National Park. The project seeks to better monitor carnivore populations within the park and on neighboring farms and communal conservancies in the surrounding area using GPS satellite collar data. Given the relationship between environmental variables, land tenure, land use, and HCC, it is critical to contextualize lion location data and HCC events using the landscape variables of ENP’s immediately adjacent lands, particularly in southern and western boundary areas where HCC is increasingly occurring.

1.5 Thesis Outline

The aim of this dissertation is to: 1) develop a baseline understanding of the spatial ecology of the resident lion population in Etosha National Park and 2) analyze patterns of HCC as it relates to land use in and round the Etosha boundaries.

Chapter 2 provides an introduction the landscape of Etosha National Park and outlines general methods related to the GPS satellite collars that were used to collect data on the movement, and mortality of lions. These data are used in other chapters in the thesis.
Chapter 3 uses GPS location data from lion satellite collars to assess seasonal variation in home range size and landscape use for lions in the southern and western regions of Etosha along core and park boundary areas where conflict is most frequent.

Chapter 4 uses home range estimates to determine a standardized, economical sampling frequency interval for future satellite collars that will inform future analyses of GPS collar data.

Chapter 5 analyzes historical human-carnivore conflict data to determine patterns related to landscape features and land use types.
2.0 An overview of the landscape of Etosha National Park and general methods used in this study.

2.1 Study Area

Etosha National Park (ENP) is a 22,270 km\(^2\) state protected area located in northern Namibia. Established in 1907, the park has experienced changing boundaries and varying levels and categories of protection status over time (MET 2015). Etosha provides protected habitat for an abundant array of flora and fauna native to Africa plains habitats. The main landscape feature of the reserve is a large, seasonally flooded saltpan covering 4,590 km\(^2\) in the central and northeast quadrants of the park. The remainder of the park is characterized by temperate open plain savannah, with Mopane and Acacia woodlands (Figure 1).

Historically, the area experiences three distinct seasons: the cold-dry season from May to September, the hot-dry season from October to December and the hot-wet season from January to April (Trinkel 2012). The majority of the park’s yearly rainfall occurs during the latter period, but the timing of the rainfall within this period is unpredictable. Recent changes in seasonal rainfall and prolonged periods of drought make a 2-season classification of hot-wet and cool-dry seasons more appropriate for the last 5-10 years (ENP-MET staff, pers. comm.). The landscape is dotted with natural and artificial waterholes, around which ungulate species and predators congregate in the dry season (Stander 1991, Trinkel 2012). During periods of higher rainfall, wildlife species disperse from their close residency to annual waterpoints and disperse across the park’s territories for grazing and access to seasonal waterpoints (Tsalyuk et al. 2017).

It is a rarity for protected areas of comparably large size to be completely enclosed by a fence and many believe Etosha’s “fully fenced” status makes Etosha a “stable”, “protected” habitat. However, the Etosha fence varies considerably in quality as well as type of fence (i.e.
game proof fences vs stock proof fences, above ground vs below ground reinforced, electric vs stick/wire etc.), affecting its ability to keep Etosha lions inside ENP borders. Park staff struggle to maintain a hard barrier to surrounding areas against general maintenance demands (i.e. deterioration, elephant damage) as well as damage (i.e. fence cutting) from the increased poaching presence in recent years.

2.2 Lion GPS Satellite Collars

2.2.1 Lion Capture and GPS Collaring

While the fence does not constitute a firm barrier for lions in ENP, the Etosha saltpan does creates a natural barrier to lion movement. No lions live on the Etosha Pan and thus lions rarely cross onto communal lands in the northeast of ENP. To study lion movements on park borders, the park was divided into three major areas study areas delineated by the East-West boundaries of the following waterpoints: 1) Eastern area from Namutoni/Andoni until Homob; 2) Central/Southern area from Homob until Duiwelsvuur; and 3) Western area from Duiwelsvuur up to the western fence boundary (Figure 1).

Due to the constraints of Etosha’s large size and difficult terrain, GPS Satellite collars were initially deployed on lions in the most easily accessible park boundary areas which, conveniently, is also where the most conflict is occurring (predominantly South and West areas, delineated above). During the wet season, the park is largely inaccessible by vehicle, collaring operations were therefore limited to the months December to May and most collars were placed on lions from June-November in 2016 and not again until June-October 2017.
Figure 1. Map of Etosha National Park showing the saltpan, waterholes, roads and surrounding lands.
To date, 21 lions have been opportunistically located, darted, and fitted with GPS-satellite collars fabricated by African Wildlife Tracking (AWT: https://www.awt.co.za); 12 lion collars are currently functioning and operational across the park, 6 lion collars have been removed or retrieved due to failure resulting from conflict or mortality situations, and 4 collars are currently nonfunctional (Table 1). Individual collars were set to various sampling interval frequencies. Intervals used include hourly, every 3 hours, every 4 hours and every 5 hours. These intervals produce a range of 6-24 location fixes per day. The rationale for sampling intervals is further discussed in Chapter 5.

### 2.2.2 GPS Satellite Collar Location Data

Various environmental and technological factors influence the satellite signals received by a GPS collar, potentially deteriorating accuracy of position (Stark et al. 2017). To improve the quality of the datasets, raw data for individual lion collars were downloaded from the AWT “Telemetry Tracker Portal” into .csv format and imported into RStudio statistical software for data exploration and cleaning prior to analysis. Inaccurate outlier locations were filtered and excluded under the following conditions including: (1) the first 48 hours after the subject was captured and collared (noted potential high levels of fix inaccuracy while collar is calibrated to satellite signal in new locale, AWT pers. comm.); (2) DOP$^4$ values $\geq$ 30 m; (3) “duplicate” fixes as determined by fixes recorded $\leq$ 120 seconds apart; and (4) fixes with “missing” or null values for latitude, longitude, DOP value, timestamp or date. The majority of excluded data points occurred at high speeds, during nighttime hours (when lions are frequently more active i.e.

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$^4$ All GPS fixes also record a dilution of precision (DOP) value indicating the range (in meters) that a recorded point is expected to fall within of the animal’s actual location. As per Pebsworth et al. (2012), DOP values greater than 30 were considered unreliable and excluded from further analyses. It is notable that $<5\%$ of collar fixes were removed for DOP exclusion, indicating a relatively high level of location fix accuracy compared to other lion collaring studies (Elliot et al. 2014).
moving at higher speeds), and at high DOP values when nearby locations occurred in known areas of dense vegetation. GPS locations for remaining records were re-projected to Universal Transverse Mercator Zone 33S coordinates and subset for further analyses as needed.

It is necessary for collars to transmit for at least one full dry and one full wet season cycle to accurately estimate the home range of a lion reliably (Wayne Getz, UCBerkeley, pers. comm.). To date, only seven of the 21 collars have a “complete” dataset, six of which are analyzed in Chapter 4 to determine potential seasonal variation in home range size and utilization distribution (Table 1). Seasons were determined by averaging monthly rainfall during the time satellite collars were active (2016-2018) from daily rainfall data collected at Okaukuejo Research station by MET staff in ENP (Claudine Cloete, MET, pers. comm.).

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5 Raw location data were recorded in decimal degrees (WGS 1984) and time/date stamps according to standard UTC Time. Etosha National Park and surrounding areas used in these analyses fall within UTM Zone 33S.

6 It should be noted that the sample period for some collars were less than 365 days, but were included in these analyses having recorded ~85% of a full wet and dry season respectively prior to collar loss or failure.
Table 1. Lion GPS Satellite collars deployed in Etosha National Park from June 2016-April 2018 (n=21). Collar ID in red means the collar was lost to conflict or mortality (n=6), in orange means collar failure (location unknown, n=4) and in green means active (n=11).

<table>
<thead>
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<th>Date Collared</th>
<th>Sex</th>
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<th>Area</th>
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<td>F</td>
<td>Adult</td>
<td>Gaseb</td>
</tr>
<tr>
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<td>17/07/2016</td>
<td>M</td>
<td>Adult</td>
<td>Ombika</td>
</tr>
<tr>
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<td>19/09/2016</td>
<td>F</td>
<td>Adult</td>
<td>Gemsbokvlakte</td>
</tr>
<tr>
<td>1821</td>
<td>26/12/2016</td>
<td>M</td>
<td>Adult</td>
<td>Aus to main road</td>
</tr>
<tr>
<td>1823</td>
<td>26/12/2016</td>
<td>F</td>
<td>Adult</td>
<td>Aus to main road</td>
</tr>
<tr>
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<td>Adult</td>
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3.0 Estimating seasonal variation in lion home range and space use patterns using GPS-Satellite collar data

3.1 Introduction

The edge effects documented along protected area (PA) boundaries are well-known to impact carnivore population dynamics, movement, home range and population demographics (Woodroffe & Ginsberg 1998). African lions (*Panthera leo*) are among carnivore species negatively affected by PA edge effects in several ways (Winterbach et al. 2013). Lion home ranges can be widely variable for individuals along park boundaries and may be significantly constricted compared to those that live in park core areas (Loveridge et al. 2010), and these differences can result in different patterns of mortality for different sub-populations of lions along PAs (Woodroffe & Ginsberg 1998). Lion mortalities in PA edges are often a result of human-carnivore conflict (HCC) and subsequent retaliatory killings, making HCC along PA boundaries a primary driver of wild lion population declines (Bauer et al. 2016). However, not all lions living at the edge of a park experience the same level of threat from HCC as many land use and landscape level variables also pose differing threat levels to lions and HCC (Loveridge et al. 2010; Davidson et al. 2012; Loveridge et al. 2016).

Patterns determining how animal space use intersects with human land use to drive patterns of conflict has been well studied, and land use patterns along PA boundaries often vary considerably (Winterbach et al. 2013; Davidson et al. 2012; Miller 2015). Determining lion space use along protected area edges -where conflict most often occurs- is hence particularly important to understanding potential conflict risk (Loveridge et al. 2010). Understanding the combined interactions of lion home range and human landscape use can even further help to identify landscape risk factors affecting HCC that coincide with lion space use, and subsequently
identify areas with these features in which HCC is most likely to occur in the future (Miller 2015). This will help to focus conflict mitigation and management strategies on identifying priority locations for current conflict mitigation as well as better understand land use changes driving HCC that will reduce conflict in the future.

Sub-Saharan Africa is one of the last strongholds for dwindling lion populations and a priority landscape for mitigating and managing HCC events. Etosha National Park (ENP) in Namibia is an IUCN designated Lion Conservation Unit and is home to the country’s largest surviving and only stable lion population (IUCN 2006; Etosha Lion Survey Report 2014). Etosha’s lions are increasingly important to the general survival of African lions and it is therefore of the utmost importance to monitor and protect this population in face of declines across the rest of Africa. Despite ENP’s lion population holding stable in the last decade (Etosha Lion Survey Report 2014) it is not immune to negative edge effects driven by HCC along the park’s borders. An annual estimated 50-80 lion are reported to cross park boundaries into neighboring farmlands and approximately 30-50 of these lions are subsequently killed from HCC events (Trinkel et al. 2016). Conflict is responsible for a loss of ~10% of ENP’s lion population annually. While this level of direct mortality is already alarming, park researchers and MET staff believe that lion mortalities from HCC have been increasing for the past decade and will continue to rise (Michelle Moeller, WWF-Namibia; Werner Kilian, MET, pers. comm.). The Namibian Ministry of Environment and Tourism (MET) has recently supported the Etosha Carnivore Monitoring Project to better monitor lion populations within the park and better understand risk factors of HCC on farms in the surrounding area. The project has deployed a total of 21 GPS satellite collars on lions across ENP since the Fall of 2016 to examine lion distribution and dispersal patterns. It is the aim of this section to assess GPS location data of
Etosha’s collared lions to determine home range size and variation in space use. This will help management staff to better understand the spatial ecology of Etosha’s lion population, both in- and outside the park boundary, that can be further applied to analyses determining factors affecting lion space use and HCC occurrence across Etosha’s surrounding landscape.

3.2 Methods

Datasets for individual lions containing all available records of GPS location fixes were downloaded from the AWT Telemetry Tracker Portal into .csv format and imported into RStudio statistical software for cleaning prior to being subset and analyzed. Data were cleaned for inaccuracies and missed fixes using the methodology previously outlined in section 2.2. To determine seasonal variation in lion home ranges, GPS data points were subset by “dry” and “wet” seasons for the periods of June-November and December-May respectively. Home range estimation analyses were conducted using a fixed kernel density estimation (KDE) method in the Home Range Tools (HRT) 2.0 extension package for Esri ArcGIS 10.5.1 Geographic Information System (GIS) mapping software (Walter et al. 2015). All home range estimations were conducted using a fixed kernel KDE model with Gaussian (bivariate normal) kernel format. Smoothing bandwidth \( h \) was determined using an adhoc selection method (i.e. “plug-in”; Gitzen et al. 2006, Walter et al. 2011) for each individual animal dataset which determined an appropriate \( h \) to produce the smallest, continuous or almost continuous (with minimal fragmenting i.e. <3 polygons) 95% isopleth contour (lion home range) without oversmoothing for each KDE (HRT 2.0 Tutorial, Walter et al. 2015, Fieberg and Borger 2012). Scaling and buffer factor were auto-determined by HRT software individual to each dataset.

All KDEs were analyzed using two model outputs, 1. isopleth contours representing animal range areas as follows: 99.99%= full/total animal range, 95%=animal “home range” and
50% = animal “core range” (Fieberg and Borger 2012) and 2. A raster image utilization
distribution surface (100 m resolution) clipped to the extent of the 99.99% KDE isopleth contour
for each individual animal’s total range. Calculation of the percent overlap of seasonal ranges
was determined for the total extent of overlapped area at each isopleth for each animal and is
expressed here as the percentage of dry season range overlapping the wet season range.

3.3 Results

Home range contours and utilization distributions (UD) are shown for the full dataset and
by season for each individual lion in Figures 2-7. The color heat map visually represents the
output values of the kernel density function where the color ramp indicates varying probability of
a lion’s use of space across ENP’s landscape. Home range area (km²) was calculated from UDs
for 3 isopleth contours indicative of an animal’s true range: 99.99% contour, i.e. “Total Range”
indicating the total extent of the data points; 95% contour, i.e. “Home Range”, indicating the
animal’s realistic home range; and 50% contour, i.e. “Core Range”, indicating the core area of an
animal’s home range it most frequently uses (Table 2).

Home range size in wet season (mean = 637±393 km², range 297-1336 km²) was higher
than home range size in dry season (mean = 474±274 km², range 181-835 km²) however total,
home and core range size did not significantly differ between wet and dry seasons across all
animals respectively (Wilcoxon signed rank test; W=20,20,16; n=6,6,6, p=0.0625, 0.0625,
0.3125 respectively) (Table 2).

Lion annual home range size (95% isopleth) varied greatly for all individuals (mean = 632
± 406 km², range 254 -1331 km²) but annual “total range” size (99.99% isopleth) varied the most
(mean = 1497 ±832 km², range 616-3002 km² (Table 2). Core areas with the highest fix density
are represented by “high UD” values (represented by red areas in Figures 2-7) and were visibly concentrated around waterholes for all subjects.

3.4 Discussion

The application of kernel density estimation methods (KDE) was used to assess home range area size and use of 6 lions with “complete” datasets, encompassing full wet and dry seasons during late 2016 to present (Fig 2-7). Differences in lion home range size and shape were compared for data subsets of wet vs. dry seasons to determine seasonal variation in home range extent and landscape use. Lion home range size and utilization distribution showed insignificant variation between individuals and between seasons (Table 2, Figures 8-13).

The influence of water points and subsequent prey availability on lion home range and movement patterns has been well documented in other habitats (Loveridge et al. 2012; Valeix et al. 2012). Previous research in Etosha has suggested lion population dynamics were driven by water availability and seasonal prey dynamics (Trinkel 2012; Elliot et al. 2014). Strong associations exist between lion home range and landscape use and varying land-use practices, livestock husbandry techniques, seasonal variation in water points and the risk of HCC events (Borger et al. 2006; Valeix et al. 2010; Linnell et al. 2012; Miller 2015). Climate change risk predictions for Namibia predicts a warming of 2°C over the coming 50 years producing a more variable and extreme climate with continual regional reductions in rainfall (Ziedler 2010). True to these predictions, ENP has already experienced seasonal drought and shifts in rainfall in the last five years contributing to a new seasonal classification of a hot-wet season from November-April and a cool-dry season from May-September. Given that ~85% of Etosha’s waterpoints are man-made and man-maintained boreholes, the steady decline in rainfall is negatively affecting the few available natural, year-round waterpoints (Trinkel 2012). Lion core range areas
(represented by 50% isopleths) where animals were most frequently found, were noticeably
concentrated around waterholes (Fig 2-7). This pattern also suggests the importance of
vegetation or land use classes commonly surrounding waterpoints to lion space use patterns in
Etosha, and that changes to water availability would significantly affect lion home range
distribution and subsequently affect HCC risk across their range. The influence of changes in
annual waterhole availability may be reflected in analysis with a larger sample size (i.e. using
more collars to compare where lions using the same waterholes are in relation to each other if
water is becoming a limiting resource) or across a longer sampling duration (if drought
conditions persist and water becomes scarcer from 2018 forward). Further research should
investigate the influence of individual environmental variables on lion space use to better
understand lion home range and habitat selection (i.e. vegetation cover, land use type, distance to
water points, seasonal variation).
Table 2. Lion home range sizes (km$^2$) for KDE Analysis by season. Analysis performed in HRT 2.0 for ArcGIS 10.2, Kernel Density Estimation, smoothing bandwidth (h)= adhoc selection method, 100 m$^2$ resolution. Percent overlap is expressed as % of dry season area overlapping matched wet season area per individual.

<table>
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<th>Lion</th>
<th>Sample Period</th>
<th>N_wet(N_dry)</th>
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<th>%Overlap(dry over wet)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Wet Season</td>
<td>Dry Season</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td>99.99% 95% 50%</td>
</tr>
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<td>1226.79 563.85 122.90</td>
<td>1187.97 568.60 108.24</td>
</tr>
<tr>
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<td>12/26/16-04/29/18</td>
<td>1362(833)</td>
<td>2944.92 1335.52 218.50</td>
<td>1799.49 834.84 124.21</td>
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<tr>
<td>1679</td>
<td>07/20/16-05/03/17</td>
<td>3657(3203)</td>
<td>1108.02 439.46 84.67</td>
<td>597.11 235.62 40.26</td>
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<tr>
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<tr>
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<td>432.60 181.24 38.61</td>
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<tr>
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<td>14.38 14.02 16.88</td>
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Figure 2. Seasonal variation in location and home range of Lion 1820 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 3. Seasonal variation in location and home range of Lion 1679 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 4. Seasonal variation in location and home range of Lion 1822 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 5. Seasonal variation in location and home range of Lion 1821 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 6. Seasonal variation in location and home range of Lion 2069 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 7. Seasonal variation in location and home range of Lion 2118 depicting (a) all GPS location data subset by wet and dry season and kernel density estimation home range estimates for isopleth contours 99.99% Total Range, 95% Home Range, and 50% Core habitat for (b) all data in the annual extent dataset (c) dry season and (d) wet season respectively.
Figure 8. Seasonal variation in location and home range of Lion 1820 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.

Figure 9. Seasonal variation in location and home range of Lion 1822 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.
Figure 10. Seasonal variation in location and home range of Lion 1821 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.

Figure 11. Seasonal variation in location and home range of Lion 2069 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.
Figure 12. Seasonal variation in location and home range of Lion 1679 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.

Figure 13. Seasonal variation in location and home range of Lion 2118 depicting isopleth contours by wet (red lines) vs. dry (black lines) season at 99.99% Total Range, 95% Home Range and 50% Core for individual animal.
4.0 Assessing the effect of varied sampling interval frequencies on lion home range estimates in Etosha National Park

4.1 Introduction

There are numerous technical and logistical constraints to GPS satellite collar operations which can limit the quality and quantity of location data. Major concerns involve field durability and battery life of collars, accuracy of location fixes occurring at high speeds or in dense vegetation cover, frequency of missed fixes, timeliness and cost of capturing operations and the high costs of collars themselves. These constraints can limit or restrict the ability to obtain a representative sample necessary for accurate analyses and applications of location data (Powell and Mitchell 2012). Management teams using GPS location data must consider the tricky tradeoff off between sampling frequency (the number of fixes per day) and sampling duration (how long the battery life of a collar in the field will last) and its effect on project costs and analytical results. The best approach to determining “ideal” or “correct” location data sampling interval for animal space use questions will depend on the needs of individual research questions (Fieberg and Borger 2012). However, the costs of purchasing and operating satellite collar monitoring programs are substantial. It is beneficial to use a unified sampling approach applicable to a range of down-stream analytical approaches, however, identifying the “best” sampling interval can be difficult.

Battery life limits the frequency of samples or the time frame over which sampling occurs, or both. When designing studies dependent on analyzing GPS location data, the time between successive location fixes is a critical component to consider dependent on the scale of your analyses (Walter et al. 2011, Fieberg and Borger 2012). Sampling interval frequency subsequently affects sampling duration; a higher sampling frequency means more fixes are
recorded and transmitted per day, decreasing potential sampling duration by depleting a collar’s battery life faster. The process of tracking, capturing, collaring and retrieving collars is costly and challenging to a project’s finances and timeline. Although more data may always seem better, if a sampling interval is so frequent that little to no movement occurs between fixes it may be an unnecessary expenditure of battery life for non-useful data in illuminating broad-scale space use patterns. Prolonging collar battery life is therefore desirable to management schemes to optimize project costs by maximizing sample duration, but only if it does not compromise the integrity or usefulness of the dataset for future analyses. For many broader-scale, animal space use research questions, lower sampling interval frequencies are less of a concern than inadequate sampling durations (Fieberg and Borger 2012). The goals of ENP’s Carnivore Monitoring Program are to use lion satellite collar data to assess broad-scale, spatial and temporal patterns of lion distribution and landscape use. It is preferable for ENP to determine a standardized sampling interval that will transmit a minimum number of fixes per day to prolong collar battery life and increase sampling duration, while still producing a dataset with a representative sample to ensure the accuracy of future analyses.

4.2 Methods

Sampling interval frequencies used in broad-scale, spatial ecological analyses of lion movement data include several equal sampling intervals (i.e. fixes every 1, 3 or 4 hours) and a more varied “Dusk to Dawn” (DD) interval based on lion behavior and life history qualities. This “DD” sampling interval uses hourly fixes from dusk to dawn (when lions are most active and large variation between fix locations is more likely) plus 2 set fixes during daylight hours (when lions are typically sleeping/inactive and movement between fix locations is less likely) (Loveridge et al. 2016). To date, collars deployed on Etosha lions have read at several sampling
frequencies including hourly, every 3 hours, every 4 hours and every 5 hours. These intervals produce a range of 6-24 location fixes per day and have dramatically different effects on collar battery life. To determine a standardized sample frequency interval that would be optimal for both future analyses of lion space-use patterns and project operation costs I compared the effects of 4 sampling intervals (1 hour, 3 hours, 4 hours, and “DD” as described above) on similarity of lion home range estimation. These sampling intervals were selected for analysis based on the available datasets for ENP’s collared lions as well as for their varied history of applicability to many methodologies used to assess lion space-time use patterns that may be of interest to ENP and MET in the future (home range analysis, landscape resistance surfaces, habitat connectivity, utilization distribution etc.).

For this initial analysis, I used the available dataset for Lion 1679 which provided a consistent record of hourly readings for an extended period (288 days) and was used to compare home range analyses of an individual lion by subsampling data fixes at 3 and 4 hour and DD intervals. The full dataset was imported into RStudio and cleaned prior to home range analyses using the methods described in Chapter 2 apart from the cleaned dataset being subset by season. After cleaning, data were subset into 4 new datasets containing: 1. all fixes (at 1-hour interval i.e. 24 fixes/day) 2. fixes at 3-hour intervals (8 fixes/day), 3. fixes at 4-hour intervals (6 fixes/day), and 4. “DD” interval (hourly dusk-dawn fixes +2 midday fixes i.e. 16 fixes/day). Home range analysis for each sampling interval subset was run using the same fixed KDE method and model specifications for estimating home range isopleths and utilization distributions as described above in Chapter 2. Average home range size was calculated for 99.99% total range, 95% home range, and 50% core isopleth contours (area in km²). Home range overlap between sampling interval models was assessed for the 3 data subsets (3 hr., 4 hr., and DD) compared to the full
(hourly fix) dataset to determine “Percent Overlap” and is expressed as the percentage of the latter overlapped by the former. A one-way, repeated measures ANOVA was used to determine significant difference between HR size across sampling intervals (k=4, n=3).

4.3 Results

Lion 1679’s total range, home range, and core area size was similar for all four data sampling frequencies (Table 3). There was no significant difference between home range size calculated between different sampling intervals for Lion 1679 (ANOVA, F (3,6) =1.99, p=0.217010) Percent overlap was >99% for all models and minimally differed between models (range) (Table 3). Isopleth contours and UD surfaces for sampling interval subsets showed little, visible variation between high and low value UD areas across the 99.99% total range (Figure 14). Core range areas closely correspond with the highest fix density-i.e. “high UD” values shown in red -and were visibly concentrated around the same waterhole for all sampling interval UDs (Figure 14).

4.4 Discussion

There were no significant differences to HR size estimates found between various collar fix intervals for any range isopleth (Table 3). There was also a visible lack of differences in lion landscape use as demonstrated by utilization distributions and home range isopleths (Figure 14-15). The lack of significant difference in total range extent, home range and core areas, and UD for lion 1679’s KDE between 4 various sampling frequencies indicates that the minimum number of fixes per day (i.e. 6 fixes per day using a 4 hour sampling interval) is suitable for home range estimations using sampling intervals designated in literature, and the most efficient in terms of project costs. Setting additional collars that will be placed on lions in the future and changing the fix times of already active collars to the minimum number of 6 fixes a day, will
prolong collar battery life and subsequently increase the overall sampling duration. Sampling duration is more critical to standardize across subject animals than sampling frequency to obtain an accurate, representative sample to model broad scale animal time-space use patterns from a population of individuals (Fieberg and Borger 2012). This practice would be economically beneficial to project operations, present and future, while still maintaining data integrity and accuracy for future analysis.

Table 3. Lion home range sizes (km²) for Lion 1679 KDE Analysis for varied sampling intervals  Analysis performed in HRT 2.0 for ArcGIS 10.2, Kernel Density Estimation, smoothing bandwidth (h)=reference value, 1800. 100 m² resolution. Percent overlap is expressed as % of variable frequency interval overlapping respective KDE contours for all data (1HR) dataset

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<th>Isopleth %</th>
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Figure 14. Home range extents (% Isopleth Contours) and UD surfaces for Lion 1679 for varied sampling intervals at (a) all GPS location data sampled at 1 HR intervals (N=24/day) (b) ‘Dusk-Dawn’ sampling interval (N=16/day) (c) 3 hour interval (N=8/day) and (d) 4 hour interval (N=6/day).
Figure 15. Comparison of isopleth contours for Lion 1679 KDE home ranges for varied sampling intervals
5.0 Examining patterns of landscape use human-carnivore conflict around Etosha National Park’s boundary

5.1 Introduction

Protected areas (PAs) are widely viewed as an effective solution to combat the negative impacts of habitat fragmentation and loss affecting many global wildlife populations. Large carnivore species have benefitted from the successful protection afforded by the establishment of intensively managed, fenced, and well-funded reserves (Bauer et al. 2015). However, “edge effects” resulting from the juxtaposition of PA and boundary environments have been demonstrated to negatively impact the capacity of PAs to fully protect wildlife populations along its boundaries for many large vertebrate species, including carnivores (Loveridge et al. 2010). For example, an almost ironic consequence of successful PA establishment is that protection of wildlife leads to population rises inside PAs which, by definition, have limited space and resources and may not be able to support increasing numbers (Woodroffe et al. 2005). A surplus of individuals may disperse out of PA habitats into inhospitable areas leading to mortalities, thus PA boundaries often become population sinks (Woodroffe & Ginsberg 1998). The large home range requirement typical of large carnivore species make them particularly vulnerable to edge effects such as the environmental pressures from human encroachment and development along PA borders (Woodroffe & Ginsberg 1998). Human-carnivore conflict (HCC) events commonly occur when this ranging behavior results in contact between humans and carnivores at PA edges and is the single most important cause of carnivore mortalities outside of parks (Woodroffe & Ginsberg 1998).

Species such as African lions (Panthera leo) are a primary example of a carnivore species where populations with home ranges near park boundaries experience negative impacts of edge
effects compared to those who live in the protected area’s core (Loveridge et al. 2010). Threats to lion populations include poorly managed, legal trophy hunting, illegal poaching, vehicle collisions, and mortalities resulting from HCC (Winterbach et al. 2013). While some HCC incidents are caused by simple public fear of wild predators, very few are from attacks on people; most HCCs involving lions are a result of retaliatory killing of lions by farmers after lions have killed livestock i.e. depredation (Inskip & Zimmerman 2009). A pattern exists where carnivores attack livestock on PA-adjacent farmlands, conflict arises between farmers and animals, and farmers respond with retaliatory killings of the offending animals by poisoning or shooting. Retaliatory killings are particularly costly to African lion conservation because of the species’ social hunting and feeding habits; if a farmer retaliates for a lost cow by baiting a lion with a poisoned carcass, multiple mortalities can occur when a group of lions feeds on it (Linnell et al. 2012). Conflict has thus been identified as a primary driver of wild lion population declines, estimated to have globally decreased by 43% in the last 20 years (Bauer et al. 2016).

Etosha National Park (ENP) is home to the largest surviving lion population in Namibia and the International Union for Conservation of Nature has designated it as a Lion Conservation Unit (IUCN 2006). In ENP, lions crossing onto farmland bordering the park and are reported to park officials and rangers at ENP’s Ministry of Environment and Tourism (MET) office. These HCC events and lion mortalities have been recorded by MET from 1975 to present date, ranging from ~50-80 reports of lions exiting the park and ~30-50 resultant lion mortalities annually. In the 1980s and 1990s, commercial livestock farmers in the area around ENP killed an average of 30 lions each year (Stander 2004; Stander 2005). From 2000-2010, this number increased to ~40 lions killed annually (Trinkel et al. 2016) but the records indicate a sharp decline in HCC after 2010. Park researchers and MET staff believe that reported declines in the numbers of lion HCC
issues is artificial and reflects changes in monitoring and reporting and that human-lion conflict, and the resultant lion mortalities, is dramatically escalating (M. Moeller, WWF-Namibia; W. Kilian, MET, pers. comm.).

Negative attitudes and actions towards lions often persist once depredation events have occurred, regardless of conflict management or resolution. Conservationists therefore agree it is far more critical to prevent conflict from occurring via pre-emptive mitigation strategies rather than just focusing efforts on retroactive management (Abade et al. 2014). Given the urgency and importance of resolving and preventing HCC and resulting wild lion population declines, many researchers are focusing on identifying priority locations for conflict mitigation around landscape features with known increased risk of HCC (Miller 2015). For example, there is a greater risk of conflict and subsequent mortality occurring at sites where lions, PAs, humans, and livestock intersect, this is most common along PA boundaries (Woodroffe & Ginsberg 1998; Loveridge et al. 2010; Abade et al. 2014). Factors associated with HCC risk along PA boundaries include variable land-use zones and livestock husbandry techniques as well as differences in farming industry and capacity (Abade et al. 2014). For example, some PAs are completely contained within hard boundaries such as fences, whereas some exist without fences and have land use restrictions limiting anthropogenic influence in “buffer zones” surrounding the protected area (Miller et al. 2016). These open transitional areas have varying regulations for human use activities, such as seasonal livestock grazing, and can affect the occurrence of conflict surrounding PAs (Abade et al. 2014; Cushman et al. 2016). Livestock grazing sites along PA boundaries that are near areas with high carnivore occurrence or distribution probability (based on landcover variables and species distribution modeling (SDM)) have also shown an increased risk of HCC (Miller 2015).
Practices along boundaries and in buffer zones around ENP often differ based on the density and type of farm animals (i.e. commercial scale vs small scale farms, livestock vs. game animals) as well as land use “type” (i.e. subsistence livestock farming/free grazing, livestock farming for meat, game farming for meat, game farming for hunting, game farming for eco-tourism “Game Reserves”, Communal conservancies with game and livestock) and can therefore fall under overlapping categories; Example A- a commercial-scale livestock meat operation and commercial-scale game meat operation on the same farm, Example B- a Communal conservancy area with free-ranging game for conservation and small-scale subsistence farming/livestock grazing for inhabitants (Schumann et al. 2012). I examined all MET historical records of human-lion conflict incidents and lion mortalities resultant from HCC within a 25 km buffer7 of ENP from 1975 to 2018 to examine patterns of HCC occurrence around ENP related to land use types and farming practices. This will serve to identify conflict “hotspots” indicating risky areas and factors linked with HCC occurrence, such as land use types and farming practices.

5.2 Methods

5.2.1 Data Collection

To examine the frequency of lion-human conflict around ENP, archived paper records related to HCC and lion mortalities- referred to as human-wildlife conflict (HWC) events8 by MET- were accumulated and digitized from multiple MET resources and locations during the fall of 2017 and fall of 2018. Documents were obtained directly from ENP-MET offices which

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7 Buffer size was selected to encompass all feasible areas which ENP lions may encounter outside ENP boundaries based on home range size, if lion is positioned at the border, determined by taking the ~radius in km of avg. ENP lion HR size (km²) in section 3 above
8 MET “HWC event” records may include incidents with non-carnivore animal species, such as elephant or hippopotamus crop raiding, as well as with non-lion carnivores, including Spotted hyaena, leopard, or cheetah. All HWC records were examined and filtered for confirmed HCC events only with lions for these analyses (ENP-MET Office 2018).
included HCC reports from all PA boundary regions. Additional documents were compiled from MET regional office archives in the southern and eastern boundary areas of ENP (regions of Outjo, Otjiwarango, and Grootfontein). Reports of HCC were also compiled from the national MET Archives headquartered in Windhoek by searching archives for any reports/claims to MET head office from 1975-present day involving wildlife complaints, conflict, killings, trophy hunting, illegal poaching and lion skin/bones sales/permits. Summary reports collated by month for Regional and National MET activities and updates were also reviewed from 2015-2017 for mentions of HWC and livestock depredations involving lions.

Documented HCC event records from 1975-2002 consisted of separate annotation for a conflict event and a subsequent lion mortality event; separate records with separate dates for “type 1” records= an initial conflict event and “type 2” records= a lion mortality corresponding to a prior (type 1) conflict event record. All records of lion conflict events from 1975-2002 had a corresponding lion mortality record (i.e. a 1:1 ratio of type1:type 2 records). HCC record annotation changed from 2003-2017 and HCC events were documented in a combined conflict/mortality event record with a single date; “type 3” record= a initial conflict event+ any resultant lion mortality corresponding to that event. However, type 3 HCC event records from 2003-2017 did not always specifically reference a mortality following a conflict event and lion mortalities in 2003-2017 could therefore not be individually verified from the national/regional summary records and we can only assert that documented HCC event records after 2002 suggest but do not necessarily document a 1:1 ratio of a known lion mortality resulting from each conflict event as seen between type 2:type 1 records from 1975-2002. All HCC event and lion mortality records from 1975-2017 were thus synthesized such that type 1 conflict event records with corresponding type 2 lion mortality records were counted as 1 individual “HCC event” in order
to equally represent conflict events documented in the two different annotation styles. For 1975-2002: 1 (type 1) conflict record + 1 (type 2) mortality record = 1 HCC event with known lion mortality. For 2002-2017: 1 (type 3) HCC record specifically noting a subsequent lion mortality OR 1 (type 3) HCC record not specifically referencing mortality = 1 HCC event with suggested lion mortality.

5.2.2 HCC Data Analysis

All paper documents were scanned using Adobe PDF Scanner for iPad Air and converted to grayscale PDFs before data was digitized, input and analyzed in the statistical software package R. HCC incidents were categorized by land use/ farm type based on the reported location for each event by either corresponding farm name where the event occurred with the national “Farms” and “Land Use” databases (farm names, ownership, land use and locations publicly available shapefiles cc 2005 from Namibian Environmental Info Services (http://www.the-eis.com/); metadata available upon request c/o Ministry of Land Reform-Directorate of Survey and Mapping (MLR-DSM) office in Windhoek, Namibia).

Conflict events and mortalities were classified by the land use type (which also reflects tenure structure) of each recorded farm name or location. Categories were determined based on Namibia’s current land tenure systems for Freehold tenure/Commercial property and Customary Tenure/Communal land. Categories were as follows: (1) “Communal Areas”: small-scale subsistence farming on state-owned, “communal” occupied land, including Resettlement Farms (2) “Communal Conservancies”: mixture of agriculture (small-scale livestock farming and wild game farms) and tourism on state-owned, “communal” occupied land (3) “Commercial Farms”: large-scale agriculture and tourism operations on freehold (private) land, mostly livestock and game farms, with subcategories of (4) “Commercial Hunting” farms for registered, sustainable
trophy hunting, and (5) “Game Reserves” which are grouped coalitions of private game farms with conservation/tourism use. Some records contained geographic descriptors that we were unable to identify an exact or even approximate location from to accurately assign a land use type and were thus left as (6) “Unknown”.

5.3 Results

Examination of historical records from MET offices in ENP and Outjo for human-wildlife conflict events with lions indicate that an average of ~50 lions per year were reported on surrounding farms from the 1980s to early 2000s and about 30 lions were subsequently reported shot or poisoned per year following HCC (Figure 16). In 2005, the number of mortalities jumped to 55 lions reported killed annually, however, this increase coincided with many recording gaps in the following years. After 2005, there was a noticeable sharp decline of documented HCC in MET regional records up through 2010, and little to no documentation or synthesized record keeping of HWC afterwards. The total number of lions killed per year of all kills currently known from 1975-present are shown in Figure 16 and Table 4. These HCC events are broken down by current farm/land use type in Table 5. Examination of records 2005-present showed huge data gaps and inconsistencies, particularly when compared to park officials’ knowledge of events as well as compared to the number of HWC noted ad libitum in the media since 2015. HCC numbers since 2004 should therefore to be viewed as potentially incomplete, and numbers since 2010 are considered unreliable as full HCC estimates per year. Years with incomplete records require additional data collection sources to accurately assess HCC locations and patterns.

Confirmed HWC numbers show a fit to a steadily increasing curve for number of HWC events over the past 40+ years, despite the data gaps (Figure 16). Average number of lions killed
per year = 21.8, ~22 lions/year, ranging from 2-71 HCC events annually during 1975-2017. Almost 70% of HWC incidents in the last 40 years have occurred on “Commercial Farm” game and/or livestock farms. Almost 35% of recorded incidents lacked the geographic specificity to determine the HWC event’s location or follow up with involved parties to confirm lion mortalities stemming from HWC.

5.4 Discussion

Prior reports by Trinkel et al. (2016) estimated an average of 50-80 Etosha lions per year reported on farms around ENP from the 1980s to early 2000s, with ~30 lions a year subsequently shot or poisoned. This number increased to around 40 lions reported killed per year by 2004 and has nearly doubled in the decade since (Table 4, Figure 16). The lower reported numbers and data gaps for certain years from 2005-2017 indicate that written records dramatically underrepresent the level of conflict at present (Figure 16). Historical data indicated a lack of accurate reporting to MET in ENP and regional offices beginning in 2005, making HCC estimates unreliable from the end of 2004-2010, absent from 2011-2014, and severely underpopulated with confirmed HCC events alone vs HCC events also resulting in subsequent lion mortalities from 2015 to present date. This is particularly evident when comparing official reports of HCC from MET correspondences from 2017-2018 with HCC events noted ad libitum in media occurrences and known, “unofficial” conversations between farmers and MET staff/local officials (W. Kilian, MET, pers. comm.). Conflict with lions, and the incidence of lion mortality, was believed to be increasing each year and is confirmed in these analyses (Figure 16). Discussion with regional and national MET staff indicated that recent land use changes may be affecting the landscape and altering the frequency of lions leaving the park itself, and social/political changes accompanying these land use changes may be affecting the frequency
with which HCC is reported (M. Moeller, WWF-Namibia; W. Kilian, P. DuPreez, MET, pers. comm.).

Changing land use patterns in portions of southern Africa have demonstrated the potential to exacerbate HCC and alter survival prospects for lions on PA adjacent farms (Lindsey et al. 2013). During examination of historical records and the process of determining the category of farm “type” for HCC incidents, it became evident that there have been two re-occurring, recent transitions of land use on various ENP adjacent farms since 2003: 1. from Freehold/commercial livestock to commercial game farming and 2. From small-scale, Communal farms to Communal conservancy areas (MLR-DSM; MET2018). Native wildlife species are extremely well adapted to the harsh climate of northern Namibia and given the increasing environmental stressors of habitat degradation, vegetation changes, water availability and temperature in the face of climate change, have proved to fare better than cattle and sheep in recent decades, particularly farmed game species (Ministry of Agriculture, Water and Forestry (MAWF), Namibia 2017; Ziedler 2010). Game farming on commercial and communal lands is now widely considered the most appropriate and environmentally sound land use for Namibia (Ziedler 2010). At the same time, the central government’s land reform initiatives are pushing the resettlement and new registration of Communal area farms and the acquisition of commercial farms for large-scale agriculture operations run by previously disadvantaged Namibians (Muduva 2015). This may explain why these two, frequent land use transitions are occurring: farmers and communities, freehold and Communal alike, have transitioned to game farming and conservancy land uses in the last 5-10 years to capitalize on the economic benefits, environmental stability, and sustainability success of ecotourism and wildlife (i.e. game) viewing/farming operations (Ziedler 2010, MET 2018). This has caused a shift from commercial livestock farming and small-scale subsistence
farming/livestock grazing, which dominated the landscape around ENP from 1975-2010, to more registered commercial game farming, “game reserves” and communal conservancies dependent on game species survival today (MLR-DSM, pers. comm. 2018). Large carnivore predation of commercially farmed game species, or wild game species in conservation areas, is difficult to mitigate (Winterbach et al. 2013). Game depredation by lions is particularly difficult if not impossible to solve compared to livestock depredation, since farmers cannot alter their practices to protect free-ranging game (as opposed to protective measures for livestock against depredation, such as kraaling cattle at night) (Inskip & Zimmerman 2009; Abade et al. 2014) (Table 5). These land use changes may be contributing to the increase of HCC in recent years.

Many of these land use shifts related to land tenure and changing demands of the landscape also coincide with changes to the legalities of conflict animal reporting and livestock loss compensations. Historically, Namibian government policy allowed individuals to report “problem animals” to MET who would then investigate, monitor and potentially relocate a problem lion to prevent further conflict. MET did not provide compensation for damages or losses caused by HWC to any individuals (Stander 2005). Changes to land use designations and wildlife management policies accompanied the enforcement and changes outlined by the Communal Lands Registration Act in 2003. This allows individuals who are “Communal” farmers to apply for HWC compensation⁹ for acts of crop damage by elephants or livestock loss by predators like lion, leopard, and cheetah (MET 2018). The policy only allows payment up to N$1500 for livestock killed by lions, even though replacing a single head of cattle can cost N$10,000 on average. Commercial livestock and game farmers living on “freehold” property

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⁹ This can include: 1. individuals resettled by the government onto federally-owned properties inhabited by and operated under communal farming practices as part of the “National Resettlement Initiative” under the “Agricultural (Commercial) Land Reform Act of 1995” or 2. Individuals living on traditionally recognized communal land registered under the “Communal Land Reform Act of 2002”.
cannot claim compensation for HWC Loss at all. However, these individuals can legally kill a lion on their property if they can prove it “presented a threat to their life or livelihood” and retroactively apply for a permit to sell its skin and bones (Stander 2005; The Controlled Wildlife Products and Trade Act (Act No. 9 of 2008)). While this “lion skin sale permit” is an unofficial means of self-compensation for private livestock losses, officials suspect many lions are killed on commercial farms that don’t result in permit applications. Presumably this is due to lack of evidence to support the “threat” claim or because farmers find the application process burdensome (Outjo MET office, pers. comm.). Compensation applications and skin/bone sale permits can be filed directly with national MET offices whereas traditional “problem animal complaints” often went through local/regional MET staff. This difference in procedure also potentially explains why documentation of HWC on the local/regional level shows a decrease in numbers.

These land use changes, and subsequent shifts in HCC policy regarding reporting and compensation, coincide with the recent data gaps and drop in “problem animal complaints” I found in the ENP- MET database beginning in 2005 (Figure 16). Inadequate institutional incentives to officially report HCC instead of retaliating via lion killings is likely contributing to institutional breakdown and the escalating conflict cycle between lions and farmers outside ENP. This is perhaps particularly true for commercial capacity livestock and game farms as is indicated by the disproportionately higher incidence of lion mortalities occurring on commercial/private farms in the last four decades (Table 5). This pattern of increasing HCC coupled with decreasing transparency necessitates utilizing alternative methods for understanding and identifying HWC risk for lion mortalities within ENP’s unique political and ecological landscape.
It should also be noted that a high percentage of HCC events lacked the geographic specificity to determine a farm location or type (~35%, Table 5). Given the lack of formal documentation or registration of land within Communal Areas is it likely that many these unknown locations are on Communal Area land. Further HCC analysis requires further document acquisition and review of additional data sources as well as confirmation of regional geofeature data via GPS point collection to confirm HCC incidences and corresponding locations in the last decade.

Figure 16. Number of HCC events per year around Etosha National Park, 1975-2017. Data from 1975-2010 represents known lion mortality HCC events only, data from 2011-2017 represent documented HCC events suggesting mortality, further confirmation from additional data sources is required.
Table 4. Summary Statistics of HCC events form all HWC records around ENP 1975-2017

<table>
<thead>
<tr>
<th></th>
<th>ALL HWC RECORDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL NUMBER EVENTS</td>
<td>815</td>
</tr>
<tr>
<td>ANNUAL AVERAGE</td>
<td>21.8</td>
</tr>
<tr>
<td>STDEV</td>
<td>18.12</td>
</tr>
<tr>
<td>KNOWN MORTALITY VS. HWC EVENT</td>
<td>742</td>
</tr>
<tr>
<td>% OF HWC EVENTS KNOWN MORTALITY EVENTS</td>
<td>91.04%</td>
</tr>
<tr>
<td>ANNUAL RANGE</td>
<td>2 - 71</td>
</tr>
</tbody>
</table>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NUMBER OF YEARS WITHOUT DATA</td>
<td>7</td>
</tr>
<tr>
<td>NUMBER OF YEARS WITH DATA</td>
<td>35</td>
</tr>
<tr>
<td>DATE RANGE</td>
<td>1975-2017</td>
</tr>
</tbody>
</table>

Table 5. HCC events around ENP (1975-2017) by farm type/land use type, based on farm type designated in 2017. Note that some farms are both “Commercial Farms” and “Game Reserve”.

<table>
<thead>
<tr>
<th>Farm Type</th>
<th>Description</th>
<th>Code</th>
<th>Total Number HWC Events (1975-2017)</th>
<th>Number of Farms where HWC has occurred</th>
<th>% of Total HWC Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communal Areas</td>
<td>Communal allocation, includes resettlement and small-scale farming, livestock only</td>
<td>CA</td>
<td>82</td>
<td>46</td>
<td>10%</td>
</tr>
<tr>
<td>Commercial Farm</td>
<td>Freehold(private), Livestock/Game, No Hunting</td>
<td>CF</td>
<td>570</td>
<td>98</td>
<td>70%</td>
</tr>
<tr>
<td>Commercial Hunting</td>
<td>Freehold, game only</td>
<td>CH</td>
<td>115</td>
<td>6</td>
<td>14%</td>
</tr>
<tr>
<td>Communal Conservancy</td>
<td>Communal, game, wild</td>
<td>CC</td>
<td>16</td>
<td>8</td>
<td>2%</td>
</tr>
<tr>
<td>Game Reserve</td>
<td>Freehold, commercial, Grouped CF Farms, no CH</td>
<td>GR</td>
<td>50</td>
<td>1</td>
<td>6%</td>
</tr>
<tr>
<td>Unknown</td>
<td>Unable to determine geographic location from logged info</td>
<td>UK</td>
<td>283</td>
<td>72</td>
<td>35%</td>
</tr>
</tbody>
</table>
6.0 Discussion

6.1 Environmental risks affecting ENP lions

Landscape feature and land use changes are naturally taking place across the harsh, arid environment that characterizes Etosha National Park in Namibia. Etosha’s lion populations have shown a general adaptability and resilience for this habitat, persisting when other populations across Africa are rapidly declining. However, despite the protection that Etosha’s boundary provides for the wildlife it hosts, fencing cannot halt the continued and accelerating risks of anthropogenic impacts like climate change along park boundaries. Soil degradation leading to nutrient and organic matter loss, erosion, vegetation changes and habitat conversion, and fire are all major concerns across Namibia’s wildlands that also threaten ENP (Tsalyuk et al. 2017). Perhaps the most important among these risks are that changing seasonal weather patterns and rainfall will affect permanent and ephemeral water resources, both in terms of availability and quality (Ziedler 2010). The impacts of climate change on seasonal water availability can already be seen across Etosha’s landscape, contributing to limited resource availability, changing vegetation cover and habitat degradation both inside the park and along its boundary (Tsalyuk et al. 2017; W. Kilian, MET, pers. comm.). Home range analyses of ENP’s lions showed a high usage of areas surrounding waterholes (Section 3). This suggests that lion landscape use is driven by the availability of water, an already scarce resource now being affected by rising temperatures, changing seasonal rainfall patterns, and periods of drought.

The areas surrounding ENP’s borders contain the highest human density regions in the country (CIA World Factbook 2018) and support almost half of the country’s agricultural industry, in the form of permanent grazing lands for game and livestock farming (FAOSTAT 2017). These neighboring landscapes and communities will also be impacted by climate change
and competition for changing and potentially limited resources, such as water, and their conflicting needs will likely negatively affect Etosha’s wildlife in the coming decade. Many of these environmental variables and landscape attributes are also known to affect risk factors for HCC and resultant lion mortalities (Winterbach et al. 2013; Abade et al. 2014; Miller 2015). Etosha lions are at high risk for HCC to continue increasing based on these expected changes in resource availability and landscape makeup in coming years.

6.2 The risks of land use change for ENP lions

Historically, the differences in land use and rights associated with Namibian land tenure between Freehold farms/Commercial “Game Reserves” and Communal Area farms/Conservancies (i.e. variation in compensation policies for lost livestock/game, the legal right to kill a lion etc based on farm type, as discussed in Section 5) has led to far fewer incidences of HCC in communal area and conservancy communities, and more HCC in commercial farms (Stander 2004; Trinkel et al. 2016; NACSO 2018). My examination of historical data from Etosha National Park show a greater frequency of HCC resulting lion mortalities occurring on a small number of commercial livestock farms outside the park compared to the number of smaller, communal areas/farms that surround it (see Discussion, Section 5). Strong associations exist between differing land-use practices, livestock husbandry techniques, and risk of HCC/HWC events that are supported by these findings (Linnell et al. 2012, Miller 2015). However, Commercial/freehold farms and Communal areas adjacent to Etosha’s wildlife resources have recently shifted land use practices to capitalize on eco-tourism opportunities in Etosha’s greater landscape, increasing the amount of game farming and conservancies and shifting away from livestock farming in doing so (MLR-DSM, 2018). Both Freehold and Communal farmers have altered several of their practices regarding perceptions
and reporting of “problem” wildlife because of farm type changes and have also altered farming practices and fencing types adjacent to ENP to support influx of wild game in/out of the park onto their own farms during this transition (W. Kilian, MET, pers. comm.). Presumably many factors differ between commercialized livestock and game farms in the area and even more differences may occur as these commercial and communal level farms shift their land use practices; secondary shifts in the variables affecting land use-HCC occurrence in ENP may also be occurring. Public perception and attitudes on wildlife and wild lands, fencing types, prey availability and potentially even environmental changes such as increased manmade waterholes to support increased game numbers in the surrounding ENP area may all impact the spatial occurrence of HCC around ENP in the near future. Specifics of landscape level variables on adjacent lands, including number of waterpoints, grazing practices, livestock abundances and fencing types or quality., should be further investigated and analyzed for co-occurrence with HCC to better understand landscape level risk.

6.3 Future Directions

There are numerous and significant landscape level concerns affecting Etosha’s lion population that are linked to the variability of ENP’s surrounding landscape, such as land cover, land use, and farming practices. Recent advances in statistical analysis and spatial modeling techniques allow us to assess how these factors are correlated with subsequent HWC events, creating highly accurate predictive models for where HWC may occur in the future and could be useful in future assessment of HCC risk determined by land use around ENP (Abade et al. 2014; Loveridge et al. 2016). Geostatistical modeling of lion GPS location data can be modeled alongside changes in landscape-level resource distribution and environmental threats to provide a powerful analysis tool to determine the impact of environmental change on the conservation and
management strategies of this species. In the previous chapters, I conducted several analyses exploring the space use patterns of lions in ENP that contribute to the base of such analyses. GPS-Satellite telemetry enables tracking of an individual animal over a long period of time and can provide accurate information on both broad and fine scale animal movement patterns. Home range analyses were limited due to the small sample size of collared lions with “complete” datasets for wet and dry seasons at the time of discussion; almost 50% of the collars placed on lions in the first 2 years were lost to conflict issues before a usable data period was collected (Table 1). However, conducting fine-scale movement assessments on the existing collar “partial” datasets (as well as future datasets) may be helpful to illuminate lion-landscape-conflict relationships on smaller temporal scales in ENP’s landscape. For example, “time Local convex Hull” (t-LoCoH) home range estimation is a home range analysis method showing how animals use areas both spatially and temporally (t-LoCoH package, R statistical software). This method allows researchers to understand estimates the amount of time an animal spends in subregions within its established home range rather than just using the frequency/density of GPS locations in an area not only the areas where animals are visiting but also the frequency with which they visit those areas (Getz et al. 2007, Lyons et al. 2013). This in turn can show habitat selection and use for certain well-established behaviors (t-LoCoH R package). For example, areas visited less often but for longer periods of time have been shown to be used for feeding sites whereas areas that are often visited but only for short periods of time often indicate use of waterholes (Lyons, et al. 2013). Using time sensitive home range estimates for future collar analysis would better illuminate factors (both temporal and spatial) like available prey and water resources on adjacent, private lands that may be affecting lion movements in and out of ENP’s boundary areas.
Analyses of animal movements can also be used to develop models of species distribution across a greater area by incorporating landscape feature variables (such as landcover and land use types) into species distribution models. Programs such as the species habitat modeling software MaxEnt use a comparison of landscape features and species presence points (GPS collar data, aerial surveys, camera-traps etc.) to create algorithms that predict areas with increased likelihood of species presence. Extrapolating species distribution across a landscape by modeling known species presence under variable landscape features could allow for a better understanding of wildlife distributions and movement over a highly variable and difficult to traverse landscape like ENP’s (Abade et al. 2014). Future studies examining lion landscape use using this GPS location data would be helpful in identifying conflict risk factors corresponding with the present-day movements/occurrence of ENP’s collared lions. Analyzing these models for conflict and lion co-occurrence based on landscape features as well as land use factors (such as commercial livestock farming vs communal subsistence farming) would be particularly helpful for management schemes.

Lastly, it is also important to consider that while edge effects impact the incidence of human-lion conflict events based on ecological principles such as increased risk of depredation in certain areas, an increased HCC risk is also a result of the increased, negative perception of lions by communities in PA boundary areas (Loveridge et al. 2016); people who rely on livestock for their livelihood commonly border PAs, and are the least tolerant of large carnivore species (Winterbach et al. 2013). In many African communities, livestock are a source of food, income, social standing, and security, and lions are vilified for attacks on livestock well outside the economic cost of a lost cow (Treves & Karanth 2009). The conceptual threat of lions to livestock combines with any history of prior HCC events to create persistent, deleterious image
of lions in many communities bordering PAs. These negative attitudes and perceptions towards lions are so entrenched in many Namibian communities that any lion crossing onto farmlands outside PAs is at a high risk for HCC, regardless of direct predation events (Schumann et al. 2012; Lindsey et al. 2013). It will also be important to gain a better understanding of how this economically attractive land use change from commercial livestock to game farming, and small scale, Communal farming to Conservancies is affecting the perceptions and attitudes of individuals on adjacent farmlands in order to understand the link between lions, environmental variables, land use, and HCC.
7.0 Conclusion

Since its Independence in 1990, Namibia has pursued one of the most progressive wildlife and natural resources management approaches throughout the world. It was the first country to include environmental protection in its constitution and ~14% of its total land mass today is a designated protected area (CIA World Factbook). Nearly 44% of all Namibian land is under conservation management, made up of a web of protected areas (~14%), community forests (~8%) and conservation areas across communal and freehold(commercial) lands dedicated to and designated for the protection of wildlife and their habitats (MET 2015). The Namibian government has also dedicated vast resources towards Commercial and Communal land reform initiatives aimed at restructuring agricultural areas for a more equal distribution of land amongst all Namibians (Mendelsohn et al. 2012). These initiatives, combined with the growing availability of protected and conserved areas, has paved the way for a rapidly developing eco-tourism industry for wildland and wildlife viewing in Namibia in the last 20 years.

Etosha National Park, is perhaps the country’s most popular and ecologically important protected area, and is home to a wide array of wildlife, including the largest and only stable lion population in Namibia (IUCN 2016). It is presently a major concern to Etosha conservationists that the frequency of human carnivore conflict events resulting in lion mortalities is increasing and is a major threat to Etosha lion population persistence. The Namibian government determined game farming a more sustainable land use practice compared to the livestock farming practices that historically dominated ENP’s boundary (Ziedler 2010). Game farming around ENP has the added economic benefit of eco-tourism income (from hunting or game viewing, game lodges etc). Many of ENP’s surrounding livestock farms (of commercial and communal scale)
have subsequently transitioned to game farms, “game reserves” and conservation areas in the last 10-15 years. Even though there is an increase in “lion friendly” properties (game farms and reserves invested in lion conservation for eco-tourism purposes) bordering the park, the frequency of conflict animal reporting seems to be decreasing and the frequency of HCC is increasing.

Analyses of GPS satellite collars fitted to lions in the Southern and Western boundaries where the most conflict is occurring show considerable variation in home range size and ranging behavior outside of park boundaries. Home range utilization distributions showed a consistent, frequent use of the landscape around known annual waterpoints by all collared lions. This suggests that lion landscape use is driven by the availability of water, an already scarce resource now being affected by rising temperatures, changing seasonal rainfall patterns, and periods of drought. Analyses of historical, paper documents from Ministry of Environment and Tourism records regarding human-carnivore conflict events with lions showed a steady increase in HCC resulting in lion mortalities since 1975. The majority (~70%) of HCC occurred on commercial livestock and game farms from 1975-2017. These records also showed large data gaps in records from 2005, consistent with park management’s concerns regarding underreporting. The changes in land use and farm type also began with land reform in 2003 and may be creating secondary shifts in land use practices like fencing types and waterhole presence and community attitudes such as farmer willingness to report problems animals.

The concerns over environmental pressures are combining with a governmental push for Land Reform to affect agricultural industry and land use decisions for areas immediately outside of the park, resulting in downstream effects of land use change that may be increasing the frequency of HCC events. These landscape level changes for humans are also altering the
landscape for Etosha’s lions, effectively creating a new, manmade “barrier” to carnivore survival across ENP’s surrounding landscape. Further assessments should use combined spatial-statistical modeling techniques to examine how specific landscape attributes and land use types influence lion distribution, home range, HCC, and subsequent lion mortalities around ENP. Answering these questions will help to 1) identify high-priority areas for targeting lion conservation and conflict mitigation efforts/funds and 2) design more effective conflict mitigation strategies based on landscape features and land use practices particular to ENP and its surrounding areas.
8.0 References


The Controlled Wildlife Products and Trade Act, Namibia. (Act No. 9 of 2008).


The Nature Conservation Ordinance, Namibia. (Act No. 4 of 1975).


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