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DIET AND SPACE USE OF THE MARTIAL EAGLE (*POLEMAETUS BELLICOSUS*) IN THE MAASAI MARA REGION OF KENYA

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DIET AND SPACE USE OF THE
MARTIAL EAGLE (*POLEMAETUS BELLICOSUS*)
IN THE MAASAI MARA REGION OF KENYA

THESIS

A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Forest and Natural Resource Sciences in the
College of Agriculture, Food and Environment
at the University of Kentucky

By

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Lexington, Kentucky

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Lexington, Kentucky

2018

ABSTRACT OF THESIS

DIET AND SPACE USE OF THE
MARTIAL EAGLE (*POLEMAETUS BELLICOSUS*)
IN THE MAASAI MARA REGION OF KENYA

The martial eagle (*Polemaetus bellicosus*) is a vulnerable species that is declining throughout large portions of its range. There is an urgent need to improve understanding of this species' ecology to inform its conservation. I equipped 20 adult martial eagles with global positioning system backpack transmitters to characterize diet and space use of the species in the Maasai Mara region of Kenya. The resulting high-resolution transmitter data sets allowed for the rapid location of kills and provided a means to estimate home range size. From November 2016 to April 2018, 191 kills were identified from 206 kill location visits. Martial eagle diet comprised 26 prey species of which hares (two *Lepus* species, 17.3%), impala fawns (*Aepyceros melampus*, 13.6%) and helmeted guineafowl (*Numida meleagris*, 12%) were the most numerous. Sex-based differences in diet were found, with females selecting for heavier prey items ($p < 0.001$). The average 95% kernel density estimated home range for the duration-of-transmitter-placement (average of 372 days) was 174.5 ± 83.2 km^2, a much larger estimate than previously reported. This study is the most extensive to date on martial eagle diet and spatial ecology in eastern Africa, and the first to show dietary differences between the sexes.

KEYWORDS: diet, home range, Maasai Mara, martial eagle, *Polemaetus bellicosus*

Richard S. Hatfield

10/17/2018

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This thesis is dedicated to my parents, Mark and Susan Hatfield. I couldn't have done this without you. Thank you for always supporting my passions and teaching me to think critically.

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CHAPTER 1

DIET OF THE MARTIAL EAGLE (*POLEMAETUS BELLICOSUS*) IN THE MAASAI MARA REGION OF KENYA

Abstract

Detailed knowledge of dietary requirements and preferences for apex predators can help develop effective conservation strategies. Studies on the diets of many of Africa's threatened raptors are lacking. I studied the diet of 19 transmitter-equipped adult martial eagles (*Polemaetus bellicosus*) in the Maasai Mara region of Kenya to document the species' diet and assess dietary differences between the sexes. High resolution global positioning system (GPS) transmitter location data were used to rapidly identify kill locations that were subsequently visited to identify prey remains. From 14 November 2016 to 7 April 2018, 191 kills were identified from 206 kill location visits. Martial eagle diet comprised 26 species of which hares (two *Lepus* species) (17.3%), impala fawns (*Aepyceros melampus*) (13.6%) and helmeted guineafowl (*Numida meleagris*) (12%) were the most common. Female martial eagles, which had greater body mass than males ($p < 0.001$), selected larger prey items than males ($p < 0.001$), an intraspecific dietary difference that provides supporting evidence for the food niche hypothesis as an evolutionary driver of reversed sexual dimorphism in martial eagles. This study presents the largest dataset on martial eagle diet in east Africa and is the first to show a significant dietary difference between the sexes.

Introduction

Detailed knowledge of dietary requirements for apex predators can inform the development of effective conservation strategies (Ontiveros et al. 2005, Jachowski et al. 2011, Wolf and Ripple 2016). Unfortunately, qualitative and quantitative dietary data for many apex predator species is often limited and difficult to obtain because of secretive behaviors and low population densities (Ripple et al. 2014). This is particularly true for many African avian apex predators (raptors) that are understudied (Amar et al. 2018) as compared to terrestrial mammals.

Intraspecific sexual size dimorphism is common (Fairbairn et al. 2007) and often attributed to niche partitioning between the sexes (Shine 1989, Shine et al. 2002, Krüger 2005). Raptors frequently exhibit reversed sexual size dimorphism (RSD), in which females are considerably larger than their male counterparts (Amadon 1975, Newton 1979). Numerous hypotheses have been proposed to explain the origin and maintenance of RSD within raptor species, but many have at least partially attributed it to food niche partitioning between the sexes (Amadon 1975, Krüger 2005, Slagsvold and A. Sonerud 2007, Sonerud et al. 2014). Accounting for intraspecific prey preferences in raptors with RSD is important for understanding a species' diet.

The martial eagle (*Polemaetus bellicosus*) is an apex predator distributed throughout sub-Saharan Africa in savanna-grassland, thorn brush, and semi-desert habitats (Brown and Amadon 1968). The species is increasingly threatened and is listed as vulnerable by the International Union for Conservation of Nature (IUCN); (Birdlife International 2017). The martial eagle is known to exhibit RSD (Chittenden et al. 2016), but studies providing large morphometric datasets from single populations are lacking.

Very little is also known about martial eagle diet. A literature search resulted in only four studies to date that attempted some form of quantitative analysis: Smeenk (1974) in Tsavo East National Park, Kenya, and Boshoff and Palmer (1980), Steyn (1980) and Boshoff et al. (1990) in the Cape provinces of South Africa. These studies relied on the identification of prey remains and castings found at or near nest sites and found hares (*Lepus* species), hyrax (family *Procaviidae*), mongoose (family *Herpestidae*), monitor lizards (*Varanus* species), francolin and spurfowl (*Peliperdix*, *Dendroperdix*, *Scleroptila,* and *Pternistis* species), guineafowl (family *Numididae*), bustards (family *Otididae*), and small/young antelopes (family *Bovidae*) to be important prey items. Although these studies were valuable in providing a basic understanding of martial eagle diet, reliance on the use of prey remains at or near nests to characterize diet is inherently biased and limited because it: (1) underestimates prey diversity, as small species' are either eaten entirely or decompose and are overlooked, (2) underestimates the number of prey items consumed because only multiples of bones or feathers can be counted as different individuals, (3) only considers prey items consumed during the breeding period when birds are at a nest, and (4) does not allow the attribution of kills to individuals, and therefore dietary differences between the sexes cannot be assessed (Boshoff and Palmer 1980, Redpath et al. 2001, Marti et al. 2007, Bakaloudis et al. 2012).

Recent advances in telemetry technology provides a means to accurately describe a species' diet. Using high resolution global positioning system (GPS) transmitter datasets, cluster analyses have been employed to identify the kill locations of apex predators (Elbroch et al. 2018, Kermish-Wells et al. 2018). Visiting kill site locations enables prey remain identification and kill association with a specific individual.

Applying this technique to the study of raptors allows for the identification of prey remains during both the breeding and non-breeding periods.

Herein, I describe the use of high resolution GPS data to rapidly identify and locate martial eagle kill sites to identify prey remains and characterize martial eagle diet in the Maasai Mara region of Kenya. Using this diet dataset, I tested for sex-based differences in diet based on prey body mass class. Additionally, I tested for body mass differences between tagged male and female martial eagles to confirm RSD within this population. I hypothesized that martial eagles would exhibit RSD in the Maasai Mara, and predicted that females would catch heavier prey items.

Study Area

The Maasai Mara region (henceforth, Mara) of southwest Kenya (1° S and 34° – 35° east, altitude ~1400 -~1800 meters) forms part of the greater Mara-Serengeti savannah ecosystem. My study area was approximately 2500 km^2 and comprised of protected areas under both private and local government management (Figure 1.1).

Habitats on this landscape include tall and short grassland, scrubland, woodland grassland, forest, and rocky hillsides (Oindo et al. 2003). The climate is characterized by a bimodal rainy season that occurs from November to June, peaking between November and December (short rains) and then again between March and May (long rains); (Ogutu et al. 2008). Annual rainfall varies, but is typically between 700 mm and 900 mm (Ogutu et al. 2007). The combination of a bimodal rainy season, deep nutrient-rich soils, and equatorial location makes the Mara one of the most ecologically productive and biodiverse savannah ecosystems in the world (Reid 2012). Thus, it is home to a diverse and densely populated fauna that is highlighted by the annual wildebeest migration. The region is inhabited by the pastoral Maasai people who engage in several economic activities including wildlife-based ecotourism, livestock husbandry and agriculture. This landscape is undergoing rapid change as human populations expand and alter natural habitats (Løvschal et al. 2017). Approximately 3200 km^2 of the Mara is considered protected, but these areas are managed differently with human influence ranging from no human presence to communities living and grazing their livestock among wildlife.

Methods

Nineteen adult (determined by plumage) martial eagles, representing 15 pairs, were captured using a Bal Chatri trap (Berger and Mueller 1959, S. Thomsett personal communication) baited with live chickens (*Gallus gallus*); (University of Kentucky Institution for Animal Care and Use Committee protocol #2016-2394). Individual adult eagles with known nest sites were specifically targeted for capture and tagging. All eagles were fitted with a 27 g GPS global system for mobile (GSM) solar-powered transmitter equipped with an accelerometer (madebytheo©, Nijmegen, NL). All units were attached with custom backpack harnesses made with Teflon™ ribbon supplied by KoEco© (Yuseong-gu, SKR). All harnesses had a leather weak link included in their design to facilitate transmitter drop off. The weak link was a leather doughnut placed below the crop and was attached to all four Teflon™ straps that secured the transmitter (S. Kapila personal communication). Transmitters were programmed to collect location data throughout the full 24-hour period on a dynamic interval based on the movement of the eagle. The maximum location collection interval was once per hour, but decreased to as little as every 30 s based on increased movement determined by the accelerometer and calculated using a proprietary algorithm developed by madebytheo©. The algorithm was programmed specifically for this study to increase the sampling rate to better discriminate among behaviors, such as flying, feeding and plucking. Location errors were removed based on a ratio of satellite number and transmitter error thresholds determined by myself and the transmitter developer: all locations were removed that were recorded with satellite count of < 3, location error of > 30, satellite count of 3 or 4 and location error of > 10, and satellite count of ≥ 5 and location error of > 20.

GPS location clusters were visited opportunistically from 14 November 2016 – 7 April 2018 to identify martial eagle kill sites. I defined a location cluster as a minimum of four consecutive stationary locations separated by intervals of ≤ 5 minutes, a pattern that I identified as possible feeding and plucking behavior based on field observations of tagged eagles engaged in these behaviors. Clusters were visited within 48 hours of the presumed kill time. When a cluster was visited, prey remains were identified to genus or species level. Hare remains were difficult to identify to species level and were assumed to be either scrub hare (*Lepus saxatilis*) or cape hare (*Lepus capensis*), the two most common *Lepus* species in the Mara (Kennedy and Kennedy 2012). Hyrax prey remains were also difficult to identify to species level and were assumed to be either southern tree hyrax (*Dendrohyrax arboreus*) or bush hyrax (*Heterohyrax brucei*), the two most common hyrax species in the Mara (Kennedy and Kennedy 2012). Ungulate prey remains that consisted only of hair pluckings were collected. Guard hairs from each sample were prepared and mounted on slides following Twigg (1975). Using a stereomicroscope, these samples were classified to species level based on macroscopic properties (hair shape, size and color) and microscopic properties (cuticle scale patterns) compared to the reference collection reported by Beveridge and van den Hoogen (2013). A rarefaction curve for all prey items was created prior to analysis using package "vegan" in R (Oksanen et al. 2018) to ensure a prey diversity asymptote had been met.

Sex of captured eagles was based on body mass at capture (F = ≥ 4 kg, M = < 4 kg), as measured by a digital scale (Dr. Meter ES-PS01, CHN) to the nearest 10 g (Table 1.1). Sex of eagles was later confirmed via behavioral observations at nest sites when pairs were copulating, courting or incubating (Steyn 1973). Body mass difference between males and females was tested using a Student's t-test.

Diet summaries were created by calculating the species composition and niche breadth of recorded prey items. Species composition was calculated by determining the proportion of each prey species and category in relation to the total sample size. Niche breadth was calculated using the standardized Levin's index (Levins 1968, Hurlbert 1978, Krebs 1999), where n is the number of prey species and p_i is the relative proportion of category i. Values closer to zero indicate a more specialized diet while values closer to one indicate a more diverse diet (Levins 1968).

Prey body mass was estimated using available literature. Because of a lack of study-site-specific prey body mass values, prey species were placed in four body mass categories: small (0-999 g), medium (1000-2999 g), large (3000-4999 g), and very large (≥5000 g) to account for geographical variation in prey body mass (Table 1.2). All prey species recorded were assumed to be adults except for Grant's gazelle (*Nanger granti*), impala (*Aepyceros melampus*), bohor reedbuck (*Redunca redunca*), Thomson's gazelle (*Eudorcas thomsonii*), common warthog (*Phacochoerus africanus*) and domestic goat

(*Capra hircus*), all of which were neonates when found; therefore, for these prey items, body masses were estimated by multiplying birth body mass or emergence body mass by 1.5 (Table 1.2). This method was chosen because the resulting body masses closely approximated opportunistically collected carcass weights. The average body mass for a domestic cat (*Felis catus*) was assumed to be approximately that of an African wildcat (*Felis sylvestris*). Domestic cats in the Mara are rarely kept as pets. Owners provide food and medication infrequently and their movements are not restricted, resulting in frequent hybridization with the African Wildcat (personal observation).

I used ordinal logistic regression and the cumulative linked mixed model (clmm) provided by the package "ordinal" in R (Christensen 2018) to test for dietary differences between the sexes, using prey body mass data in the four described body mass categories as the response (dependent) variable and sex as the explanatory (independent) variable. Pair and individual eagle nested within pair were included as random effects in the model. Individual eagles with < 5 identified kills were excluded from this portion of my analysis. Kills ≤ 300 meters from observed nest sites for the individual eagle were also excluded from this section of the analysis, because I could not be certain whether the individual eagle had killed the prey, or if it had been delivered by the opposite sex as part of courtship.

All statistical analyses were performed using the program R (R Core Team 2018). Results were considered significant if p-values were ≤ 0.05.

Results

I captured 19 adult martial eagles (7F, 12M) from 15 July 2016 to 31 August 2017. Of the 19 eagles captured, 12 exhibited some form of breeding behavior during the study (Table 1.1). Male (n = 12; x = 3453 ± 151 g) and female (n = 7; x = 4679 ± 115 g) martial eagles (Table 1.1) differed in body mass (t =18.5, p < 0.001).

From 14 November 2016 to 7 April 2018, I identified prey remains at 191 of 206 (92.7%) kill sites. Only one kill was located within 300 meters of a nest and could not be assigned a sex. Six kills were removed from the dataset that belonged to individuals with < 5 identified kills, thus reducing the dataset to 184 kills (F = 73, M = 111) from 15 (7F, 8M) individuals (Table 1.1) that were assigned body mass categories. The rarefaction curve approached an asymptote (Figure 1.2) indicating sampling had almost approached maximum prey species diversity in the diet.

In total, 26 prey species and categories were recorded with hares (17.3%), impala (13.6%), and helmeted guineafowl (*Numida meleagris*) (12%) being the most numerous (Table 1.3). Male martial eagles preyed on 19 species and categories with hares (23.9%), helmeted guineafowl (17.9%), black-bellied bustard (*Lissotis melanogaster*) (10.3%), and red-necked spurfowl (*Pternistis afer*) (9.4%) being the most frequent (Table 1.3). The standardized Levin's index for adult male martial eagle diet in the Mara was 0.39, indicating a partially specialized diet. Female martial eagles preyed on 17 species and categories with impala (34.2%), and Thomson's gazelle (15.1%) being the most frequent (Table 1.3). The standardized Levin's index for adult female martial eagle diet in the Mara was 0.31, indicating a more specialized diet than their male counterparts. The cumulative linked mixed model indicated a significant difference between male and female diets in the Mara based on prey body mass category, whereby males selected for smaller prey items than females (coefficient = -2.64, $z = -5.96$, $p < 0.001$; Figure 1.3, Table 1.4).

Discussion

In this study of martial eagle diet in the Mara, I observed significant RSD and associated dietary differences between males and females. My hypothesis was supported; larger female martial eagles preyed on larger species than smaller males. I recorded 26 different prey species and categories for martial eagles in this region. This diverse prey base, while difficult to compare directly to previous work due to methodological and habitat differences among study sites, shows similarities and confirms the importance of hares, hyrax, mongoose, francolin and spurfowl, guineafowl, bustards, and small/young antelopes to martial eagle diet across eastern and southern Africa (Smeenk 1974, Boshoff and Palmer 1980, Steyn 1980, Boshoff et al. 1990).

Sex-based dietary differences in my study indicated food niche partitioning between the sexes. Similar dietary differences have been documented in numerous raptor species including male and female Eurasian sparrowhawks (*Accipter nisus*) during the breeding period (Newton and Marquiss 1982), and between male and female harpy eagles (*Harpia harpyja*); (Miranda et al. 2018). This division of food resources reduces direct competition between pair mates and age classes that hunt limited prey populations within similar areas. There are significant fitness benefits to reducing competition between individuals that occupy the same area (Bolnick et al. 2007, Svanbäck and Bolnick 2007); however, these benefits do not directly explain the evolution of RSD within raptors, specifically why females evolved as the larger sex (Krüger 2005). Other possible evolutionary drivers of RSD in martial eagles that need to be explored are behavioral and role differences between the sexes observed during breeding and courtship (Krüger 2005).

The characterization of animal food habits from sampling regimes that do not consider all biologically relevant seasons can be biased. For example, other studies have found dietary differences in breeding and non-breeding periods for several raptor species (Barrows 1987, Morrison et al. 2008, Watson 2010). Previous dietary studies on martial eagles and other large raptor species have focused on breeding diet because these data are easier to collect when birds are delivering prey and feeding at a nest (Smeenk 1974, Boshoff and Palmer 1980, Steyn 1980, Boshoff et al. 1990, Herholdt and Kemp 1997, McPherson et al. 2016, Murgatroyd et al. 2016). Additionally, studying breeding dietary data in isolation with species that exhibit significant RSD likely underestimates prey diversity and size as males are often the primary food providers during the breeding period (Steyn 1973, Newton 1979). My results reduce these potential biases as data from males and females from both breeding and non-breeding periods were used to describe martial eagle diet.

Livestock and poultry depredation by large eagles is an increasingly common occurrence in Africa as human populations continue to expand into eagle habitat (Brown 1952, Boshoff and Palmer 1980, Hatfield et al. unpublished data). Despite this, I recorded only four human-wildlife conflict incidences in my dataset despite increasing human development in the Mara region (Lamprey and Reid 2004, Løvschal et al. 2017) . I attribute this to the protected conservation status of my study area and the more cautious hunting behaviors of experienced adult eagles (S. Thomsett personal communication). Of the 19 eagles followed during this study, 11 had home ranges that extended outside of my study area into non-protected areas. Receiving the required permission to visit GPS clusters on these small private land holdings would not only have been a logistical challenge, but could have proven detrimental to martial eagle populations as I might have drawn attention to livestock and poultry losses that local community members might not have attributed to martial eagles. This bias in my dataset likely underestimates the amount of poultry and livestock in the diet of martial eagles in the Mara. Evidence of this bias was provided by community members that frequently reported livestock losses attributed to martial eagles. During my study, at least one adult martial eagle was intentionally poisoned due to frequent livestock predation on the boundary of my study area.

In pastoral regions where high levels of human-martial eagle conflict occur, intraspecific dietary differences observed between martial eagle sexes could lead to increased human persecution rates of adult females, as communities rely on livestock as a significant source of income and food. This is a conservation concern as large eagles can show male-biased sex ratios (Hunt et al. 2017). Increasing this biased sex ratio further, through retaliatory killings of females, could have significant population level effects, more severe than if retaliatory killings were evenly distributed between the sexes. More work needs to be done investigating the diet and demographics of both adult and juvenile martial eagles outside of protected areas where increased human-eagle conflict is likely.

An additional source of bias in my study may be that small prey items consumed in under 15 min were overlooked (Elbroch et al. 2018). The smallest prey item recorded, using the method described in this study, had an estimated body mass of 220 g. Based on personal field observations, unpublished camera trap data and previous work (Smeenk 1974, Boshoff and Palmer 1980, Steyn 1980, Boshoff et al. 1990), kills smaller than this are unlikely for martial eagles, but not impossible. For example, during this study male martial eagle ME22 was observed delivering a helmeted guineafowl chick (estimated body mass of 25 g) to its nest (Nobo et al. 2012). This potential bias against small prey could lead to my results underestimating martial eagle diet diversity in the Mara. Accounting for this bias in future studies will be challenging and will require improvements to transmitter technology or a large sample of martial eagle castings collected during both the breeding and non-breeding periods.

Previous work on raptor species' diets have shown how prey density and, more importantly, prey availability influence diet (Preston 1990, Bennetts and McClelland 1997). My work did not account for prey density or availability and how it might have influenced my results, a difficult task given the diverse prey base, inaccessibility of terrain, and inherent human risks of conducting ground surveys where large carnivores and herbivores are present. The short sampling window of my work also inherently limited examination of possible differences in diet caused by prey responses to habitat-altering forces, such as overgrazing, climate and fire. However, because francolin, spurfowl and guineafowl seem to be a critical food source during the incubation and chick period (S. Hatfield unpublished data), I hypothesize that martial eagle breeding is triggered by significant rainfall that in turn causes insect eruptions and results in synchronized gamebird breeding. Much more data are required to test this and other hypotheses related to martial eagle diet and prey selection patterns/trends.

Recent dietary studies on the crowned eagle (*Stephanoaetus cornatus*) and Verreaux's eagle (*Aquila verreaxii*) in South Africa show some diet similarities with martial eagles from the Mara (McPherson et al. 2016, Murgatroyd et al. 2016). In my study area, there are three locations where these three species nest in close proximity, providing a promising future study site to investigate how Africa's three largest eagles partition limited resources whilst occupying a similar area. Carrying out this study would build upon the work of Brown (1952) at Eagle Hill and would begin to answer some of his questions regarding the interspecific gregariousness of Africa's diverse raptor community (S. Thomsett personal communication).

To my knowledge, this study presents the largest dataset on martial eagle diet in east Africa and is the first study to show significant dietary differences between martial eagle sexes. This dietary dataset provides conservation managers with an informed understanding of what prey species are important for martial eagles in the Mara region and it may be broadly informative across the species range. Livestock grazing and grass management is a current and complex issue in the Mara. Different land management plans affect average grass height across the protected areas and likely influence martial eagle prey species' abundance and availability. I hope my findings encourage further research on how livestock and habitat management influences the diet and feeding ecology of the martial eagle, informing this vulnerable species conservation.

Table 1.1: Body mass, number of kills identified and the breeding status of all adult martial eagles captured and fitted with GPS transmitters, Maasai Mara, Kenya, 2016-18.

Individual	**Sex**	**Body mass (g)**	**Number of kills**	**Breeding status**
ME01	F	4510	13	NB
ME19	F	4560	9	B + NB
ME12	F	4650	12	NB
ME15	F	4710	7	B + NB
ME16	F	4710	5	B + NB
ME13	F	4770	17	B + NB
ME10	F	4840	10	B + NB
ME08	M	3210	31	B + NB
ME22	M	3290	2	B
ME18	M	3360	2	NB
ME05	M	3370	5	B + NB
ME03	M	3390	1	NB
ME06	M	3390	25	B + NB
ME17	M	3450	6	NB
ME14	M	3480	8	B + NB
ME07	M	3510	6	NB
ME20	M	3610	18	NB
ME21	M	3680	1	B
ME11	M	3700	12	B + NB
Totals	7F 12M	-	**190**	**-**

Breeding status**:** B (Breeding) and NB (Non-Breeding)

Table 1.2: Summary of all prey species, their assumed ages, their estimated body mass (BM) and their designated BM category, Maasai Mara, Kenya, 2016-18.

Species	Age of BM estimation	Average BM in grams	Prey BM classification
Falco tinnunculus (Common Kestrel)	Adult	220 (del Hoyo et al. 2018)	S
Peliperdix coqui (Coqui Francolin)	Adult	250 (del Hoyo et al. 2018)	S
Asio capensis (Marsh Owl)	Adult	310 (del Hoyo et al. 2018)	S
Galerella sanguinea (Slender Mongoose)	Adult	580 (Kingdon 2015)	S
Pternistis afer (Red-necked Spurfowl)	Adult	640 (del Hoyo et al. 2018)	S
Ardea melanocephala (Black-headed Heron)	Adult	1180 (del Hoyo et al. 2018)	M
Eupodotis senegalensis (White-bellied Bustard)	Adult	1450 (del Hoyo et al. 2018)	M
Numida meleagris (Helmeted Guineafowl)	Adult	1480 (del Hoyo et al. 2018)	M
Phacochoerus africanus (Common Warthog)	Emergence BM*1.5	1800 (Roth 1965, Melletti and Meijaard 2018)	M
Gallus gallus (Domestic Chicken)	Adult	1800 (Magothe et al. 2012)	M
Lissotis melanogaster (Black-bellied Bustard)	Adult	1830 (del Hoyo et al. 2018)	M
Mungos mungo (Banded Mongoose)	Adult	1890 (Kingdon 2015)	M
Alopochen aegyptiaca (Egyptian Goose)	Adult	1920 (del Hoyo et al. 2018)	M
Varanus niloticus (Nile Monitor)	Adult	1950 (Ciliberti et al. 2011)	M
Heterohyrax brucei/ Dendrohyrax validus (Bush/Tree Hyrax)	Adult	2080 (Kingdon 2015)	M
Lepus saxatilis/ Lepus capensis (Scrub/Cape Hare)	Adult	2540 (Kingdon 2015)	M
Capra hircus (Goat)	Birth BM*1.5	3000 (Hary and Schwartz 2002)	L
Ciconia ciconia (White Stork)	Adult	3340 (del Hoyo et al. 2018)	L
Ichneumia albicauda (White-tailed Mongoose)	Adult	3600 (Kingdon 2015)	L
Eudorcas thomsonii (Thomson’s Gazelle)	Birth BM*1.5	3750 (Robinette and Archer 1971)	L
Otocyon megalotis (Bat-eared Fox)	Adult	4150 (Kingdon 2015)	L
Felis catus (Domestic Cat)	Adult	4450 (Kingdon 2015)	L
Madoqua kirkii (Kirk's DikDik)	Adult	4600 (Maloiy et al. 1988, Kingdon 2015)	L
Redunca redunca (Bohor Reedbuck)	Birth BM*1.5	7050 (Dittrich 1968, Kingdon 2015)	VL
Aepyceros melampus (Impala)	Birth BM*1.5	7500 (Fairall 1969, Jarman and Jarman 1973)	VL
Nanger granti (Grant's Gazelle)	Birth BM*1.5	9020 (Dittrich 1968)	VL

Prey BM Classifications**:** S = Small (0-999 g), M = Medium (1000-2999 g), L = Large = (3000-4999 g), VL = Very Large (≥5000 g)

Table 1.3: Diet summary for male and female adult martial eagles, Maasai Mara, Kenya, 2016-18.

Species	Female Martial Eagles	Male Martial Eagles	Total
Falco tinnunculus (Common Kestrel)	0 (0%)	1 (0.9%)	1 (0.5%)
Peliperdix coqui (Coqui Francolin)	0 (0%)	6 (5.1%)	6 (3.1%)
Asio capensis (Marsh Owl)	0 (0%)	1 (0.9%)	1 (0.5%)
Galerella sanguinea (Slender Mongoose)	1 (1.4%)	0 (0%)	2 (1%)
Pternistis afer (Red-necked Spurfowl)	0 (0%)	11 (9.4%)	11 (5.8%)
Ardea melanocephala (Black-headed Heron)	0 (0%)	6 (5.1%)	6 (3.1%)
Eupodotis senegalensis (White-bellied Bustard)	0 (0%)	2 (1.7%)	2 (1%)
Numida meleagris (Helmeted Guineafowl)	2 (2.7%)	21 (17.9%)	23 (12%)
Phacochoerus africanus (Common Warthog)	1 (1.4%)	0 (0%)	1 (0.5%)
Gallus gallus (Domestic Chicken)	1 (1.4%)	1 (0.9%)	2 (1%)
Lissotis melanogaster (Black-bellied Bustard)	1 (1.4%)	12 (10.3%)	13 (6.8%)
Mungos mungo (Banded Mongoose)	6 (8.2%)	6 (5.1%)	12 (6.3%)
Alopochen aegyptiaca (Egyptian Goose)	1 (1.4%)	0 (0%)	1 (0.5%)
Varanus niloticus (Nile Monitor)	4 (5.5%)	1 (0.9%)	5 (2.6%)
Heterohyrax brucei/ Dendrohyrax validus (Bush/Tree Hyrax)	6 (8.2%)	2 (1.7%)	8 (4.2%)
Lepus saxatilis/ Lepus capensis (Scrub/Cape Hare)	5 (6.8%)	28 (23.9%)	33 (17.3%
Capra hircus (Goat)	2 (2.7%)	0 (0%)	2 (1%)
Ciconia ciconia (White Stork)	3 (4.4%)	0 (0%)	3 (1.6%)
Ichneumia albicauda (White-tailed Mongoose)	0 (0%)	2 (1.7%)	2 (1%)
Eudorcas thomsonii (Thomson's Gazelle)	11 (15.1%)	9 (7.7%)	20 (10.5%)
Otocyon megalotis (Bat-eared Fox)	0 (0%)	1 (0.9%)	1 (0.5%)
Felis catus (Domestic Cat)	1 (1.4%)	0 (0%)	1 (0.5%)
Madoqua kirkii (Kirk's DikDik)	0 (0%)	5 (4.3%)	5 (2.6%)
Redunca redunca (Bohor Reedbuck)	1 (1.4%)	0 (0%)	1 (0.5%)
Aepyceros melampus (Impala)	25 (34.2%)	1 (0.9%)	26 (13.6%)
Nanger granti (Grant's Gazelle)	2 (2.7%)	1 (0.9%)	3 (1.6%)
Total Kills	73	117	191
Standardized Levin's Index	0.31	0.39	0.39

Table 1.4: Prey body mass classification for male and female adult martial eagle prey items in the Maasai Mara, Kenya, 2016-18.

	S (small)	**M (medium)**	**L (large)**	**VL (very large)**	**Total**
Male	19 (17%)	74 (67%)	16 (14%)	2 (2%)	111
Female	1 (1%)	27 (37%)	17 (23%)	28 (38%)	73

Prey body mass classifications: S = Small (0-999 g), M = Medium (1000-2999 g), L = Large = (3000-4999 g), VL = Very Large (≥5000 g)

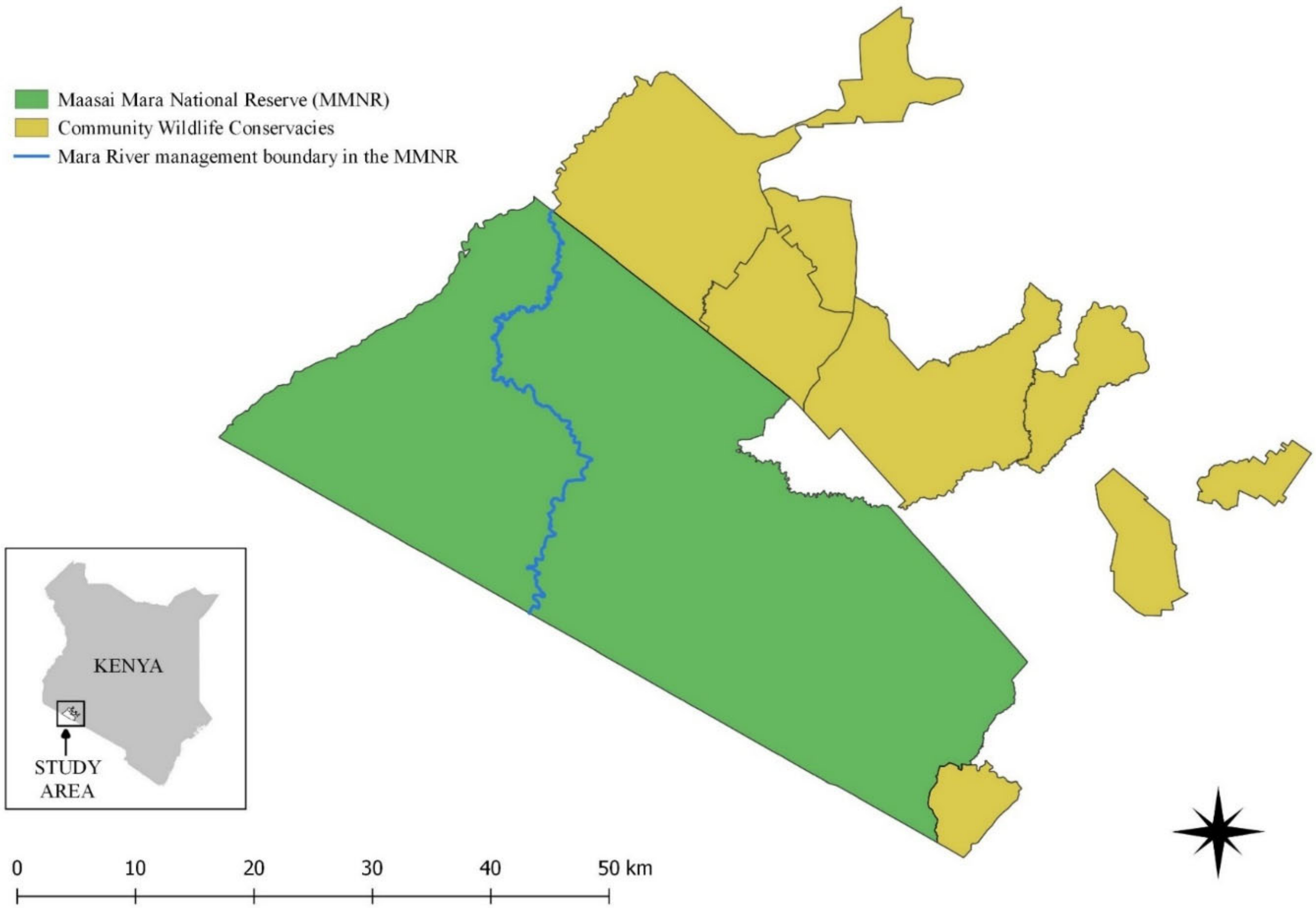

Figure 1.1: The 2500 km^2 martial eagle study area, Maasai Mara, Kenya, 2016-18.

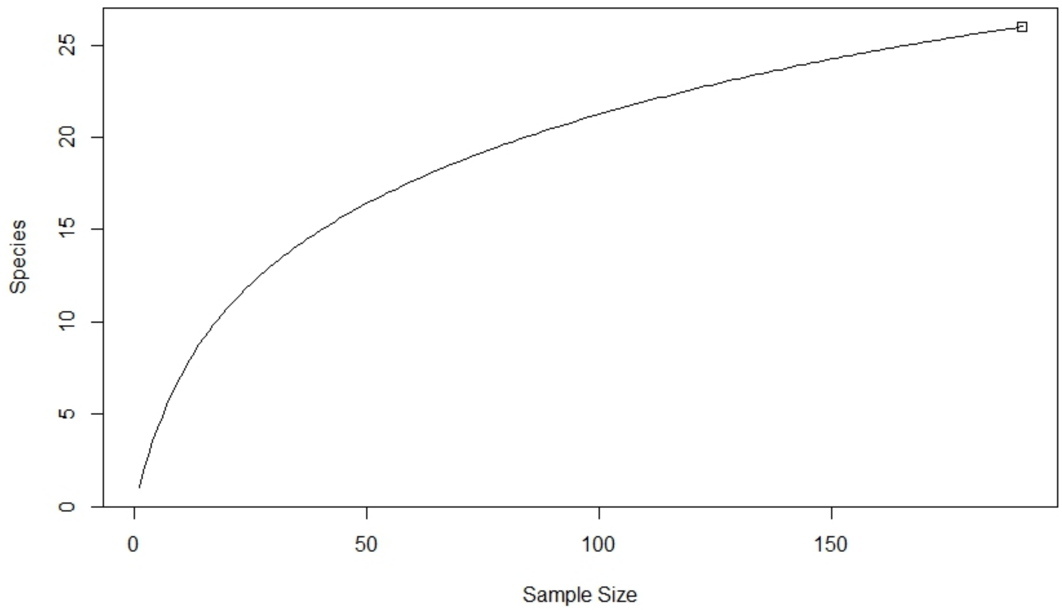

Figure 1.2: Rarefaction curve generated from 191 adult martial eagle kills of 26 different species and categories, Maasai Mara, Kenya, 2016-18.

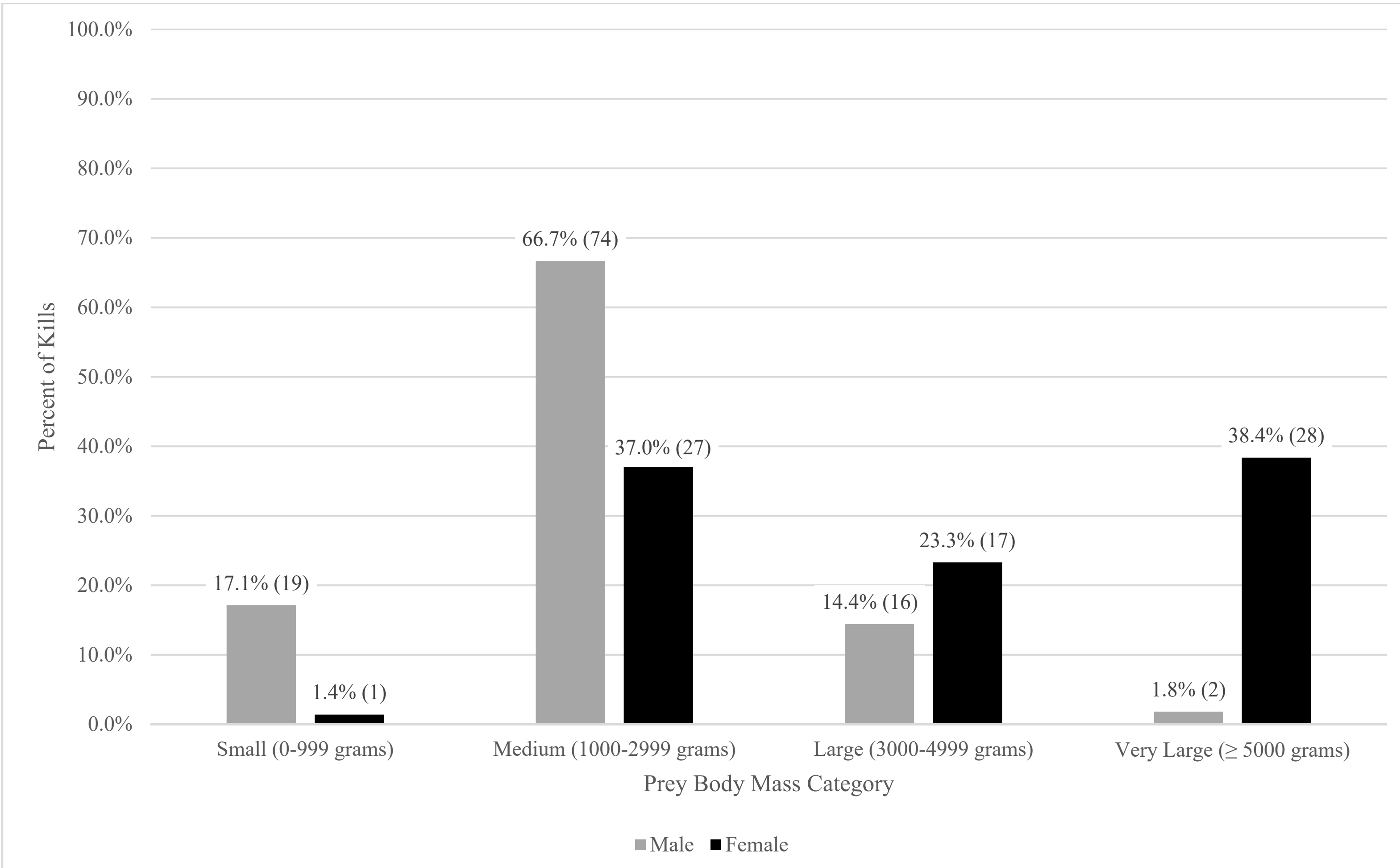

Figure 1.3: Male and female adult martial eagle diets based on prey body mass category, Maasai Mara, Kenya, 2016-18.

CHAPTER 2

SPACE USE PATTERNS OF THE MARTIAL EAGLE (*POLEMAETUS BELLICOSUS*) IN THE MAASAI MARA REGION OF KENYA

Abstract

Understanding the spatial requirements of animals is fundamental for their management and conservation. Several raptor species are experiencing rapid population declines in Africa, yet the spatial ecology of most are poorly understood. The martial eagle (*Polemaetus bellicosus*) is understudied, vulnerable and in rapid decline throughout its range. To increase our understanding of this species space use patterns, 20 adult martial eagles in the Maasai Mara region of Kenya were fitted with global positioning system (GPS) transmitters. Annual, monthly, breeding period, and duration-of-transmitter-placement home ranges were calculated using minimum convex polygons (MCPs) and fixed kernel density estimates (KDEs). Composite 95% KDE utilization distribution (UD) or home range, was 174.5 ± 83.2 km^2 and composite 95% MCP home range was 187.1 ± 123.7 km^2, much larger home range estimates than previously reported for the species. Annual martial eagle home range overlap at the 50% and 75% contours (core home ranges) were minimal, providing evidence of territoriality between neighboring conspecifics. Annual 95% KDE home ranges differed by sex (t = -2.87, p = 0.014), with male home ranges (233.7 ± 119.4 km^2) larger than females (100.6 ± 29 km^2). A visual inspection of 95% monthly KDE home ranges from the Olare Motorogi Conservancy pair showed the male with a larger home range during both breeding and non-breeding months. Male and female home ranges were largest during the non-

breeding and fledgling provisioning periods, and contracted during the nest-building, incubation and chick periods. My findings present the largest study of martial eagle spatial ecology in eastern Africa, and suggest that extensive protected areas are required for this species' survival.

Introduction

Understanding the spatial needs of animal species is fundamental to their conservation and management. The most common metric of animal space use is the home range, which can be defined as the area traversed by an individual during a defined period while carrying out activities such as feeding or breeding (Burt 1943). Apex predator home range requirements are particularly important to understand because of their status as keystone species and their recent rapid population declines (Sergio et al. 2006, Ripple et al. 2014). Raptors occupy high trophic positions in many terrestrial communities and are considered apex predators. Their large home ranges and occasional sallies often extend outside of protected areas, making their conservation a unique challenge (Woodroffe and Ginsberg 1998, Van Eeden et al. 2017). Large eagles are raptors of particular concern because of their low population densities and k-selected life history strategies (Newton 1979).

Some eagle species are known to exhibit territoriality, defending exclusive areas of their home range from other adult eagles of the same species (Pérez-García et al. 2013, Tapia and Zubergoitia 2018). This behavior reduces home range overlap between neighboring birds and results in lower population densities. The social and breeding structure of eagles typically consists of breeding pairs that occupy home ranges in suitable habitat (Newton 1979). Males and females assume different behavioral roles within the pair and therefore utilize space differently within the pair's home range (Newton 1979). These differences are especially pronounced during breeding when females typically incubate and care for eggs and chicks, while males defend the home range and provide the female and chicks with food (Steyn 1973, Newton 1979). Understanding and accounting for these home range size differences is important when building a complete understanding of a species' home range requirements.

The martial eagle (*Polemaetus bellicosus*) inhabits savannah grassland, thorn brush, and semi-desert habitats throughout sub-Saharan Africa (Brown and Amadon 1968). They are one of the largest eagle species in Africa (Brown and Amadon 1968) and are among the most vulnerable to human disturbance because of their sensitive behavior and propensity to prey on livestock and poultry (Brown 1952, 1991). The current population size and status of martial eagles is largely unknown, but numbers are considered to be declining in South Africa, Namibia, Niger, Burkina Faso and Kenya (Brown 1991, Thiollay 2006, Amar and Cloete 2017, S. Thomsett personal communication); consequently, the martial eagle has been listed as vulnerable by the International Union for Conservation of Nature (IUCN), and is a candidate for up-listing to endangered (Birdlife International 2017).

Declining martial eagle populations have created an urgent need to increase our understanding of this species' ecology to better understand population decline and enact effective conservation measures. Very little is known about adult martial eagle space use patterns, such as home range size and overlap. Two previous studies have explored martial eagle spatial ecology using transmitters and their results were limited by either a small sample size ($n = 4$ and $n = 8$) or a sex-biased sample (Ong 2000, Van Eeden et al. 2017).

Herein, I used GPS satellite transmitter-equipped Martial Eagles to characterize their space use patterns in the Maasai Mara region of Kenya. Specifically, I (1) estimated home range size, (2) determined whether home range overlap occurred among individuals at the core home range scale, (3) tested for sex-based differences in home range size, and (4) determined if home range size contracted during the breeding season.

Study Area

The Maasai Mara region (henceforth, Mara) in southwest Kenya (1° S and 34° – 35° east, altitude ~1400 -~1800 meters) forms part of the greater Mara-Serengeti ecosystem. My study area was approximately 2500 km^2 and comprised of protected areas under both private and local government management (Figure 1.1).

The Mara is characterized by a dynamic rainy season that occurs from November to June, peaking between November and December (short rains) and then again between March and May (long rains); (Ogutu et al. 2008). Annual rainfall varies widely, but is typically between 700-900 mm (Ogutu et al. 2007). Habitats in this landscape include tall and short grassland, scrubland, woodland grassland, forest, and rocky hillsides (Oindo et al. 2003). The combination of a bimodal rainy season, deep nutrient-rich soils, and equatorial location makes the Mara one of the most ecologically productive and biodiverse savannah ecosystems in the world (Reid 2012). Thus, it is home to an incredibly diverse and densely populated fauna that is highlighted by the annual wildebeest migration. Over 60 species of diurnal raptors have been observed in the Mara (eBird 2012). This unique assemblage of avian predators and scavengers represents one of the world's most diverse raptor communities. The pastoral Maasai people inhabit the Mara and engage in several economic activities including wildlife-based ecotourism, livestock husbandry and agriculture.

Methods

From 15 July 2016 - 31 August 2017, 20 adult martial eagles (determined by plumage), representing 15 pairs, were captured using a Bal Chatri trap (Berger and Mueller 1959, S. Thomsett personal communication) baited with live chickens (*Gallus gallus*); (University of Kentucky Institution for Animal Care and Use Committee protocol #2016-2394). Adult eagles with known nest sites were specifically targeted for capture. All individuals captured were fitted with a 27 g GPS-global system for mobile (GSM) solar powered transmitter equipped with an accelerometer (madebytheo©, Nijmegen, NL). All transmitter units were attached with a backpack harness made with Teflon™ ribbon supplied by KoEco© (Yuseong-gu, SKR). All harnesses included a leather weak link in their design to facilitate transmitter drop off. The weak link was a leather doughnut placed below the crop and was attached to all four Teflon™ straps that secured the transmitter (S. Kapila personal communication). Transmitters were programmed to collect data on a dynamic interval based on the activity of the eagle. The maximum data collection interval was once per hour, but decreased to as little as every 30 s based on increased movement determined by the accelerometer and calculated using a proprietary algorithm developed by madebytheo©. Transmitters were programmed to collect data throughout the full 24-hour period. Errors were removed based on a ratio of satellite number and transmitter error thresholds determined by myself and the transmitter developer: all locations were removed that were recorded with satellite count of < 3, location error of > 30, satellite count of 3 or 4 and location error of > 10, and satellite count of ≥ 5 and location error of > 20.

Sex of captured martial eagles was based on body mass at capture (F = ≥4 kg, M = <4 kg), as measured by a digital scale (Dr. Meter ES-PS01, CHN) to the nearest 10 g. Sex of eagles was later confirmed via behavioral observations at nest sites while pairs were copulating, courting or incubating (Steyn 1973).

Minimum convex polygons (MCPs; Mohr 1947) and fixed kernel density estimates (KDEs; Worton 1989) of individual martial eagle utilization distributions (UDs) or home ranges were calculated using the adehabitatHR package in program R (Calenge 2006). The KDE and MCP approaches represent the most common method of estimating home ranges using telemetry data (Laver and Kelly 2008) and are, therefore, more comparable to other findings (e.g. including the only published martial eagle home range studies that used transmitter data; Ong 2000, Van Eeden et al. 2017). All KDE home ranges were calculated using the bandwidth parameter h_{ref} with a standardized grid size of 200. I calculated the 50% and 75% (core home ranges; Auffenberg 1978, Hodder et al. 1998), 95% (traditional home range; Laver and Kelly 2008) and 99% home range contours in km^2. These contour sizes were chosen as they are biologically relevant and directly comparable to GPS transmitter home range estimates provided by Van Eeden et al. (2017). I calculated the 95% home range contour for MCPs, as this size is roughly comparable to the martial eagle home range estimate reported in Ong (2000). Prior to home range creation, each transmitter dataset was subsampled by selecting the location recorded nearest to every hour during daylight hours beginning at sunrise the day after an eagle was tagged and ending either at transmitter cessation or at sunset on 28 February 2018. In rare instances where duplicate locations were selected, the location with the time farthest from the selected hour was removed. This subsampling regimen was chosen to reduce spatial autocorrelation between locations (Swihart and Slade 1985). At times, because of cloudy weather conditions, transmitter power levels were not high enough to collect data dynamically as described above. During these periods, transmitters reverted to collecting four locations per day at six hour intervals (05:00, 11:00, 17:00 and 23:00). These periods were included in my analysis as their removal did not change my results significantly and two or three locations per day has been shown to adequately represent an organisms movements for home range estimation (Girard et al. 2002, Börger et al. 2006).

Kernel density estimated home ranges were created for individuals based on the duration of transmitter placement, month, year, and breeding period. Minimum convex polygons were only created for individuals based on the duration of transmitter placement and year as the MCP method is generally considered a less reliable home range estimator and was only utilized in this study for comparison with past work (Nilsen et al. 2008). Monthly home ranges were created for each month that a bird was tagged for ≥50% of the month. Annual home ranges were created for individuals tagged throughout the year beginning on 1 March 2017 and ending on 28 February 2018. Annual 95% KDE home range area overlap was calculated using the “raster” package in program R (Hijmans 2016). Differences in male and female home range size were compared with a Student’s t-test using the 95% annual home ranges. To assess within pair differences in home range size, I visually compared the size of the annual and monthly 95% KDE home ranges of male ME08 with female ME13. ME08 and ME13 form the Olare Motorogi Conservancy (OMC) pair and were the only complete pair with at least a year of data collected over the same period. All other complete pairs had at least one member of the pair with only a few months of data or data that was only collected during the breeding period. Breeding period home ranges were created based on periods when a bird was nest building (PB), incubating (I), provisioning a chick (C), provisioning a fledgling (F) or exhibiting no breeding behavior (NB). Direct and camera trap (Bushnell Trophy Camera 119736C) observations aided in identifying incubation and chick provisioning time periods. The nest building period was set at 30 days prior to incubation (S. Thomsett personal communication, Brown 1952) and the fledgling provisioning period was set at 240 days post fledging (Brown 1952, Van Eeden 2016). Fledging was defined as the chick's first confirmed flight and was determined by camera traps placed at nests. When camera trap and direct observations were insufficient in providing the exact incubation and chick provisioning time periods, these were set to 50 days for incubation and 95 days for chick provisioning (Brown 1952, Steyn 1973). Breeding period home ranges from four adult females (ME10, ME13, ME15, ME19) and two adult males (ME08, ME11) were visually compared to one another since the small sample size prevented any statistical analyses. These individuals were selected for comparison as their data includes either a complete (NB, PB, I, C and F) or near-complete breeding cycle (NB, PB, I, C).

All computations were performed using program R (R Core Team 2018). Results were considered significant if p-values were ≤ 0.05.

Results

Twenty adult martial eagles (13M, 7M, complete pairs = 4) were tagged and monitored for an average of 372 days (range = 59 - 594, Table 2.1). Breeding behavior was observed by 13 of these eagles (8M, 5F, complete pairs = 3, Table 2.1).

The average 95% KDE home range size for the duration of transmitter placement was 174.5 ± 83.2 km^2 (range = 61.7 – 423.7 km^2, Figure 2.1, Table 2.1). The average 95% MCP home range size for the duration of transmitter placement was 187.1 ± 123.7 km^2 (range = 72.8 – 654.9 km^2, Table 2.2). The average 95% annual KDE home range size was 167.2 ± 108.3 km^2 (range = 61.0 – 471.1 km^2, Table 2.3). The average 95% annual MCP home range size was 186.1 ± 142.8 km^2 (range = 72.2 – 635.1 km^2, Table 2.4).

Home range overlap analysis showed no 50% annual core home range overlap between adult martial eagles of different pairs, and minimal 75% annual core home range overlap (Figure 2.2, Table 2.5, Table 2.6). The only unpaired individuals that overlapped at the 75% contour were female ME01 and male ME07 (ME01: 5.4% overlap, ME07: 1.5% overlap) and female ME12 and female ME15 (ME12: 7.7% overlap, ME15: 9.5% overlap; Table 2.6). The largest 95% annual home range overlap for two tagged, unpaired martial eagles, was between female ME19 and male ME06 (ME19: 18.2% overlap; Table 2.7). Within pair annual home range overlap between female ME13 and male ME08 was estimated at 99.7% at the 75% contour and 87.5% at the 99% contour (Table 2.6, Table 2.8)

Males (n = 7) had larger 95% annual home ranges (233.7 ± 119.4 km^2) than females (n = 7, 100.6 km^2 ± 29 km^2; t = -2.87, p = 0.014; Table 2.3). My small sample size prevented any statistical analysis of within-pair home range size differences, but a visual inspection of 95% annual and monthly home ranges for the OMC pair male ME08 and female ME13 showed that the male from this pair had a larger home range during most breeding and non-breeding months (Figure 2.3, Table 2.3).

The small sample size prevented any statistical analysis of breeding status's effect on home range size. A visual inspection of spatially plotted data indicated home ranges for both males and females contracted during the breeding period, with the smallest home range for females observed during incubation and for males during nest building (Figure 2.4, Figure 2.5, Table 2.9). Home ranges for females were largest during the non-breeding and fledgling periods and for males during non-breeding, chick provisioning and fledgling provisioning periods (Figure 2.4, Figure 2.5, Table 2.9).

Discussion

Very little is known about martial eagle spatial ecology in Africa, and my findings increase this knowledge. I found home range size (KDE 95%: 174.5 ± 83.2 km^2, MCP 95%: 187.1 ± 123.7 km^2) to be much larger than previous estimates for the species (Ong 2000, Van Eeden et al. 2017). In Ong (2000), four adult martial eagles (2M, 2F, complete pairs = 2) in the Athi Kapiti region of south central Kenya were equipped with tail-mounted radio transmitters, and were tracked for between 6-12 months. Average MCP home range size during this period was estimated at 120 km^2. Van Eeden et al. (2017) tagged eight adults (2M, 6F, complete pairs = 0) with GPS backpack transmitters and monitored them over a three-year period. Of the eight birds tracked, four were classed as only territory holders, two were classed as floaters, and two birds switched from a territory holder to a floater during the study. Average 95% KDE home range size for the territory holders was 108 km^2, and floater 95% KDE home range size ranged from 10,830 km^2 to 45,337km^2. My larger home range estimates might be explained by the methodological differences between Ong (2000) and my work, the female-biased sample for Van Eeden et al. (2017), or the possibility that martial eagle habitat was higher quality in these previous study sites and, therefore, could hold a higher density of martial eagles. In the Kruger National Park (NP) in South Africa, Van Eeden et al. (2017) found that martial eagles selected for areas with high canopy cover. A large proportion of the Mara is dominated by open grasslands (Oindo et al. 2003). The prevalence of less optimal habitat in the Mara could explain the larger home ranges in this region.

Territoriality is known for many raptor species (Pérez-García et al. 2013, Tapia and Zubergoitia 2018), and my results suggest this behavior for martial eagles. Van Eeden et al. (2017) tagged two martial eagles that abandoned their territories and became floaters, ranging vast distances far beyond their former territory boundaries. All eagles tagged on this project remained on territory. Larger and more long-term studies are required to better understand martial eagle territory defense, maintenance and inheritance and how these factors influence the health of regional populations.

The sex-based difference in home range size supports previous findings that indicate male martial eagles have larger home ranges than females (Ong 2000 and Van Eeden et al. 2017). While the results of my t-test showed a statistically significant difference between male and female annual home ranges, the most convincing evidence of this size difference was shown by the OMC pair. Between-pair home ranges are difficult to compare directly with one another due to home range habitat quality differences. Comparing within-pair home range size differences is a way to remove this bias. Future work investigating home range size differences and overlap between martial eagle sexes should include more complete pairs.

Home range contraction during breeding is typical for many raptor species, including martial eagles (Braham et al. 2015, Van Eeden et al. 2017). I found a similar reduction in home range size for both sexes during the breeding period. Martial eagles have very low reproductive rates, producing on average one chick every two years (Steyn 1973, Hustler and Howells 1987). Therefore, focusing conservation efforts on protecting identified core breeding home ranges is essential for ensuring reproductive success.

The sedentary and territorial nature of the Mara martial eagle population presents a unique opportunity for active conservation management. It is my hope that the results of this study will begin to inform conservation managers about the basic spatial requirements of these raptors. The close approximation of martial eagle core home ranges to that of protected area boundaries suggests a selection for these relatively intact natural areas within an increasingly pastured and denatured landscape; however, we cannot rule out the possibility of sampling bias given our extremely limited access to trapping outside protected areas. Juvenile martial eagles exhibit different movement patterns than adults during their post-fledging dispersal period (Van Eeden 2016). Future studies should include juvenile martial eagles to better understand dispersal behavior and the inherent risks incurred when on non-protected land (Runge et al. 2014).

Table 2.1: Adult martial eagle KDE home ranges (HR) in km^2 for the duration-of-transmitter-placement, Maasai Mara, Kenya 2016-18.

Individual	Pair	Sex	Breeding Behavior	Start Date	End Date	Days Monitored	Locations	50% HR	75% HR	95% HR	99% HR
ME01	Naboisho	F	N	7/15/2016	2/28/2018	594	8793	24.1	53.4	134.5	210.9
ME09	Naboisho	M	N	11/26/2016	1/23/2017	59	910	43.6	92.0	201.1	291.8
ME10	Cottar's	F	Y	12/1/2016	2/28/2018	455	7203	12.3	43.6	153.5	310.7
ME05	Cottar's	M	Y	9/15/2016 8/30/2017	2/23/2017 2/28/2018	345	4573	42.2	84.7	181.9	263.1
ME13	OMC	F	Y	12/6/2016	2/28/2018	450	6287	13.0	46.5	141.7	332.0
ME08	OMC	M	Y	12/6/2016	2/28/2018	450	7135	46.5	97.1	253.8	441.9
ME19	Sekero	F	Y	1/26/2017	2/28/2018	399	6353	8.6	32.7	89.4	144.7
ME22	Sekero	M	Y	8/31/2017	2/28/2018	182	2245	24.6	53.0	119.1	185.6
ME03	Esirwa	M	N	11/18/2016	2/28/2017	107	1663	61.6	119.9	231.0	325.8
ME20	Esirwa	M	N	4/13/2017	2/28/2018	322	5095	36.0	74.3	160.7	253.0
ME12	Musiara	F	N	12/10/2016	2/28/2018	446	7029	11.2	25.2	82.8	155.6
ME15	River	F	Y	1/31/2017	2/28/2018	394	6089	3.1	23.1	114.7	250.4
ME16	KWS	F	Y	2/2/2017	2/28/2018	392	5539	6.0	19.6	61.7	122.9
ME06	Olive	M	Y	11/10/2016	2/28/2018	476	7548	67.8	135.8	282.5	424.0
ME07	Ol Kinyei	M	N	9/21/2016	2/28/2018	526	8083	73.8	177.2	423.7	663.9
ME11	Inselberg	M	Y	12/9/2016	2/28/2018	447	7016	39.3	87.4	195.8	287.3
ME14	MNC	M	Y	1/29/2017	2/28/2018	396	5562	14.4	36.3	92.1	156.5
ME17	Sand	M	N	2/8/2017	2/28/2018	386	5811	65.9	120.7	219.2	321.7
ME18	Transmara	M	Y	2/9/2017	2/28/2018	385	5915	16.5	55.7	169.8	315.7
ME21	Ngiro-are	M	Y	7/12/2017	2/28/2018	232	3167	37.2	78.6	181.9	307.3
Average	-	-	-	-	-	**372.2**	**5600.8**	**32.4**	**72.8**	**174.5**	**288.2**
ST Deviation	-	-	-	-	-	**134.5**	**2134.1**	**22.4**	**42.2**	**83.2**	**124.0**

Table 2.2: Adult martial eagle 95% MCP home ranges in km^2 for the duration-of-transmitter-placement, Maasai Mara, Kenya 2016-18.

Individual	Pair	Sex	Breeding Behavior	Start Date	End Date	Days Monitored	Locations	95% MCP
ME01	Naboisho	F	N	7/15/2016	2/28/2018	594	8793	150.4
ME09	Naboisho	M	N	11/26/2016	1/23/2017	59	910	162.1
ME10	Cottar's	F	Y	12/1/2016	2/28/2018	455	7203	138.3
ME05	Cottar's	M	Y	9/15/2016 8/30/2017	2/23/2017 2/28/2018	345	4573	181.0
ME13	OMC	F	Y	12/6/2016	2/28/2018	450	6287	164.4
ME08	OMC	M	Y	12/6/2016	2/28/2018	450	7135	241.4
ME19	Sekero	F	Y	1/26/2017	2/28/2018	399	6353	99.5
ME22	Sekero	M	Y	8/31/2017	2/28/2018	182	2245	108.9
ME03	Esirwa	M	N	11/18/2016	2/28/2017	107	1663	215.0
ME20	Esirwa	M	N	4/13/2017	2/28/2018	322	5095	168.4
ME12	Musiara	F	N	12/10/2016	2/28/2018	446	7029	89.3
ME15	River	F	Y	1/31/2017	2/28/2018	394	6089	155.1
ME16	KWS	F	Y	2/2/2017	2/28/2018	392	5539	72.8
ME06	Olive	M	Y	11/10/2016	2/28/2018	476	7548	310.5
ME07	Ol Kinyei	M	N	9/21/2016	2/28/2018	526	8083	654.9
ME11	Inselberg	M	Y	12/9/2016	2/28/2018	447	7016	188.6
ME14	MNC	M	Y	1/29/2017	2/28/2018	396	5562	89.1
ME17	Sand	M	N	2/8/2017	2/28/2018	386	5811	201.4
ME18	Transmara	M	Y	2/9/2017	2/28/2018	385	5915	178.6
ME21	Ngiro-are	M	Y	7/12/2017	2/28/2018	232	3167	172.7
Average	-	-	-	-	-	**372.2**	**5600.8**	**187.1**
ST Deviation	-	-	-	-	-	**134.5**	**2134.1**	**123.7**

Table 2.3: Adult martial eagle annual KDE home ranges (HR) in km^2, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018.

Individual	**Pair**	**Sex**	**Breeding Behavior**	**Locations**	**50% HR**	**75% HR**	**95% HR**	**99% HR**
ME01	Naboisho	F	N	5642	26.2	56.9	136.2	216.8
ME10	Cottar's	F	Y	5782	3.2	18.2	87.0	168.6
ME12	Musiara	F	N	5751	11.1	25.7	85.5	157.7
ME15	River	F	Y	5632	2.7	20.8	112.0	235.5
ME16	KWS	F	Y	5120	5.9	19.6	61.0	122.3
ME19	Sekero	F	Y	5812	6.9	28.8	84.6	139.7
ME13	OMC	F	Y	5155	9.2	41.2	138.1	297.2
ME08	OMC	M	Y	5795	41.8	88.7	220.6	404.4
ME06	Olive	M	Y	5796	63.0	131.4	276.0	420.5
ME07	Ol Kinyei	M	N	5711	84.0	199.4	471.1	711.6
ME11	Inselberg	M	Y	5731	32.8	77.6	186.9	277.9
ME14	MNC	M	Y	5081	13.0	33.9	89.2	152.5
ME17	Sand	M	N	5486	65.8	121.6	221.9	324.2
ME18	Transmara	M	Y	5613	17.1	56.4	170.3	315.7
Average	-	-	-	**5579.1**	**27.3**	**65.7**	**167.2**	**281.8**
ST Deviation	-	-	-	**265.2**	**26.6**	**53.4**	**108.3**	**156.7**

Table 2.4: Adult martial eagle annual 95% MCP home ranges in km^2, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018.

Individual	Pair	Sex	Breeding Behavior	Locations	95% MCP
ME01	Naboisho	F	N	5642	141.4
ME10	Cottar's	F	Y	5782	102.5
ME12	Musiara	F	N	5751	93.7
ME15	River	F	Y	5632	152.8
ME16	KWS	F	Y	5120	72.2
ME19	Sekero	F	Y	5812	95.7
ME13	OMC	F	Y	5155	158.8
ME08	OMC	M	Y	5795	208.8
ME06	Olive	M	Y	5796	295.4
ME07	Ol Kinyei	M	N	5711	635.1
ME11	Inselberg	M	Y	5731	182.1
ME14	MNC	M	Y	5081	84.8
ME17	Sand	M	N	5486	201.7
ME18	Transmara	M	Y	5613	179.9
Average	-	-	-	**5579.1**	**186.1**
ST Deviation	-	-	-	**265.2**	**142.8**

Table 2.5: Annual KDE home range percent area overlap at the 50% contour for adult martial eagles, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018. Home ranges that overlap are highlighted in grey.

	ME01	**ME06**	**ME07**	**ME08**	**ME10**	**ME11**	**ME12**	**ME13**	**ME14**	**ME15**	**ME16**	**ME17**	**ME18**	**ME19**
ME01	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME06	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME07	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME08	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	22.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME10	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME11	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME13	0.0%	0.0%	0.0%	100%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%
ME15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%
ME16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%
ME17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%
ME18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%
ME19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**

Table 2.6: Annual KDE home range percent area overlap at the 75% contour for adult martial eagles, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018. Home ranges that overlap are highlighted in grey.

	ME01	ME06	ME07	ME08	ME10	ME11	ME12	ME13	ME14	ME15	ME16	ME17	ME18	ME19
ME01	**100%**	0.0%	5.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME06	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME07	1.5%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME08	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	46.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME10	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME11	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	7.7%	0.0%	0.0%	0.0%	0.0%
ME13	0.0%	0.0%	0.0%	99.7%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	1.4%	0.0%
ME15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	9.5%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%
ME16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%
ME17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%
ME18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.8%	0.0%	0.0%	0.0%	**100%**	0.0%
ME19	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**

Table 2.7: Annual KDE home range percent area overlap at the 95% contour for adult martial eagles, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018. Home ranges that overlap are highlighted in grey.

	ME01	**ME06**	**ME07**	**ME08**	**ME10**	**ME11**	**ME12**	**ME13**	**ME14**	**ME15**	**ME16**	**ME17**	**ME18**	**ME19**
ME01	**100%**	0.0%	17.2%	1.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME06	0.0%	**100%**	0.0%	0.0%	0.0%	8.7%	0.0%	0.0%	0.0%	3.5%	0.0%	6.8%	0.0%	5.6%
ME07	5.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME08	1.2%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	59.2%	4.6%	0.0%	0.0%	0.0%	0.0%	0.0%
ME10	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.9%	0.0%	0.0%	0.0%
ME11	0.0%	12.8%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%
ME12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.7%	16.6%	0.0%	0.0%	0.0%	0.0%
ME13	0.0%	0.0%	0.0%	94.6%	0.0%	0.0%	0.0%	**100%**	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%
ME14	0.0%	0.0%	0.0%	11.4%	0.0%	0.0%	0.7%	12.9%	**100%**	0.0%	0.0%	0.0%	6.5%	0.0%
ME15	0.0%	8.7%	0.0%	0.0%	0.0%	0.9%	12.7%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%
ME16	0.0%	0.0%	0.0%	0.0%	1.2%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%
ME17	0.0%	8.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	2.5%
ME18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%	**100%**	0.0%
ME19	0.0%	18.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.6%	0.0%	**100%**

Table 2.8: Annual KDE home range percent area overlap at the 99% contour for adult martial eagles, Maasai Mara, Kenya, 1 March 2017 – 28 February 2018. Home ranges that overlap are highlighted in grey.

	ME01	**ME06**	**ME07**	**ME08**	**ME10**	**ME11**	**ME12**	**ME13**	**ME14**	**ME15**	**ME16**	**ME17**	**ME18**	**ME19**
ME01	**100%**	0.0%	20.1%	13.6%	0.0%	0.0%	0.0%	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME06	0.0%	**100%**	0.0%	0.0%	0.0%	19.5%	0.0%	0.0%	0.0%	14.8%	0.6%	17.2%	0.0%	11.9%
ME07	6.1%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
ME08	7.3%	0.0%	0.0%	**100%**	0.0%	0.0%	1.8%	64.3%	13.2%	1.8%	0.0%	0.0%	4.7%	0.0%
ME10	0.0%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	0.8%	0.0%	0.0%
ME11	0.0%	29.5%	0.0%	0.0%	0.0%	**100%**	0.0%	0.0%	0.0%	9.2%	0.0%	0.0%	0.0%	1.4%
ME12	0.0%	0.0%	0.0%	4.7%	0.0%	0.0%	**100%**	2.7%	8.3%	24.6%	0.0%	0.0%	2.4%	0.0%
ME13	2.1%	0.0%	0.0%	87.5%	0.0%	0.0%	1.4%	**100%**	17.9%	2.2%	0.0%	0.0%	1.0%	0.0%
ME14	0.0%	0.0%	0.0%	34.9%	0.0%	0.0%	8.6%	34.8%	**100%**	0.0%	0.0%	0.0%	33.1%	0.0%
ME15	0.0%	26.4%	0.0%	3.1%	0.0%	10.9%	16.5%	2.8%	0.0%	**100%**	0.0%	0.0%	0.0%	0.0%
ME16	0.0%	2.1%	0.0%	0.0%	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	**100%**	2.6%	0.0%	0.0%
ME17	0.0%	22.3%	0.0%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	**100%**	0.0%	11.1%
ME18	0.0%	0.0%	0.0%	6.1%	0.0%	0.0%	1.2%	0.9%	16.0%	0.0%	0.0%	0.0%	**100%**	0.0%
ME19	0.0%	35.9%	0.0%	0.0%	0.0%	2.8%	0.0%	0.0%	0.0%	0.0%	0.0%	25.8%	0.0%	**100%**

Table 2.9: Adult martial eagle KDE breeding period home ranges (HR) in km^2, Maasai Mara, Kenya 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Individual	**Pair**	**Sex**	**Breeding Period**	**Start Date**	**End Date**	**Days Monitored**	**Locations**	**50% HR**	**75% HR**	**95% HR**	**99% HR**
ME11	Inselberg	M	NB	12/9/2016	4/5/2017	118	1830	49.0	97.2	199.6	300.0
			PB	4/6/2017	5/5/2017	30	459	10.8	39.6	108.6	164.5
			I	5/6/2017	6/24/2017	50	769	31.2	79.8	167.6	243.0
			C	6/25/2017	9/28/2017	96	1502	37.4	95.5	207.1	305.6
			F	9/29/2017	2/28/2018	153	2392	36.8	74.9	179.9	256.5
ME08	OMC	M	NB	12/6/2016	4/27/2017	143	2249	62.9	130.1	328.3	513.0
			PB	4/28/2017	5/27/2017	30	461	7.8	25.9	79.7	149.5
			I	5/28/2017	7/16/2017	50	781	21.7	56.0	130.9	193.4
			C	7/17/2017	9/27/2017	73	1140	19.5	46.2	107.6	179.4
			NB2	9/28/2017	2/28/2018	154	2440	60.1	131.7	293.1	466.0
ME13	OMC	F	NB	12/6/2016	4/27/2017	143	2008	29.2	65.6	209.0	445.6
			PB	4/28/2017	5/27/2017	30	442	5.1	15.9	48.4	85.6
			I	5/28/2017	7/16/2017	50	772	1.0	2.5	32.4	78.0
			C	7/17/2017	9/27/2017	73	1135	1.6	5.3	50.8	118.8
			NB2	9/28/2017	2/28/2018	154	1879	37.9	77.0	168.0	316.9
ME10	Cottar’s	F	NB	12/1/2016	4/16/2017	137	2152	61.8	129.6	352.1	932.9
			PB	4/17/2017	5/16/2017	30	459	2.1	7.1	41.1	77.3
			I	5/17/2017	7/5/2017	50	770	0.2	0.4	2.5	13.1
			C	7/6/2017	10/13/2017	100	1580	1.2	4.0	31.9	66.9
			F	10/14/2017	2/28/2018	138	2178	9.6	29.4	111.7	177.0
ME15	River	F	NB	1/31/2017	3/12/2017	41	629	9.8	22.4	69.4	132.6
			PB	3/13/2017	4/11/2017	30	435	6.5	18.1	75.5	130.8
			I	4/12/2017	5/31/2017	50	749	1.5	5.5	29.2	102.5
			C	6/1/2017	7/1/2017	31	462	0.9	2.4	8.1	38.4
			NB2	7/2/2017	8/7/2017	37	563	11.0	43.6	142.0	224.6
			PB2	8/8/2017	9/6/2017	30	457	2.3	6.0	40.3	91.5
			I2	9/7/2017	10/26/2017	50	776	1.7	4.5	44.5	126.2
			C2	10/27/2017	10/30/2017	4	48	0.9	2.0	8.6	15.8
			NB3	10/31/2017	2/28/2018	121	1843	27.1	67.1	157.2	260.7
ME19	Sekero	F	NB	1/26/2017	5/18/2017	113	1786	23.4	52.0	102.3	154.3
			PB	5/19/2017	6/17/2017	30	463	1.1	3.4	19.7	38.5
			I	6/18/2017	8/6/2017	50	784	0.4	1.0	6.9	29.3
			C	8/7/2017	11/9/2017	95	1500	2.2	10.7	53.6	117.7
			F	11/10/2017	2/28/2018	111	1756	22.8	46.3	98.3	154.9

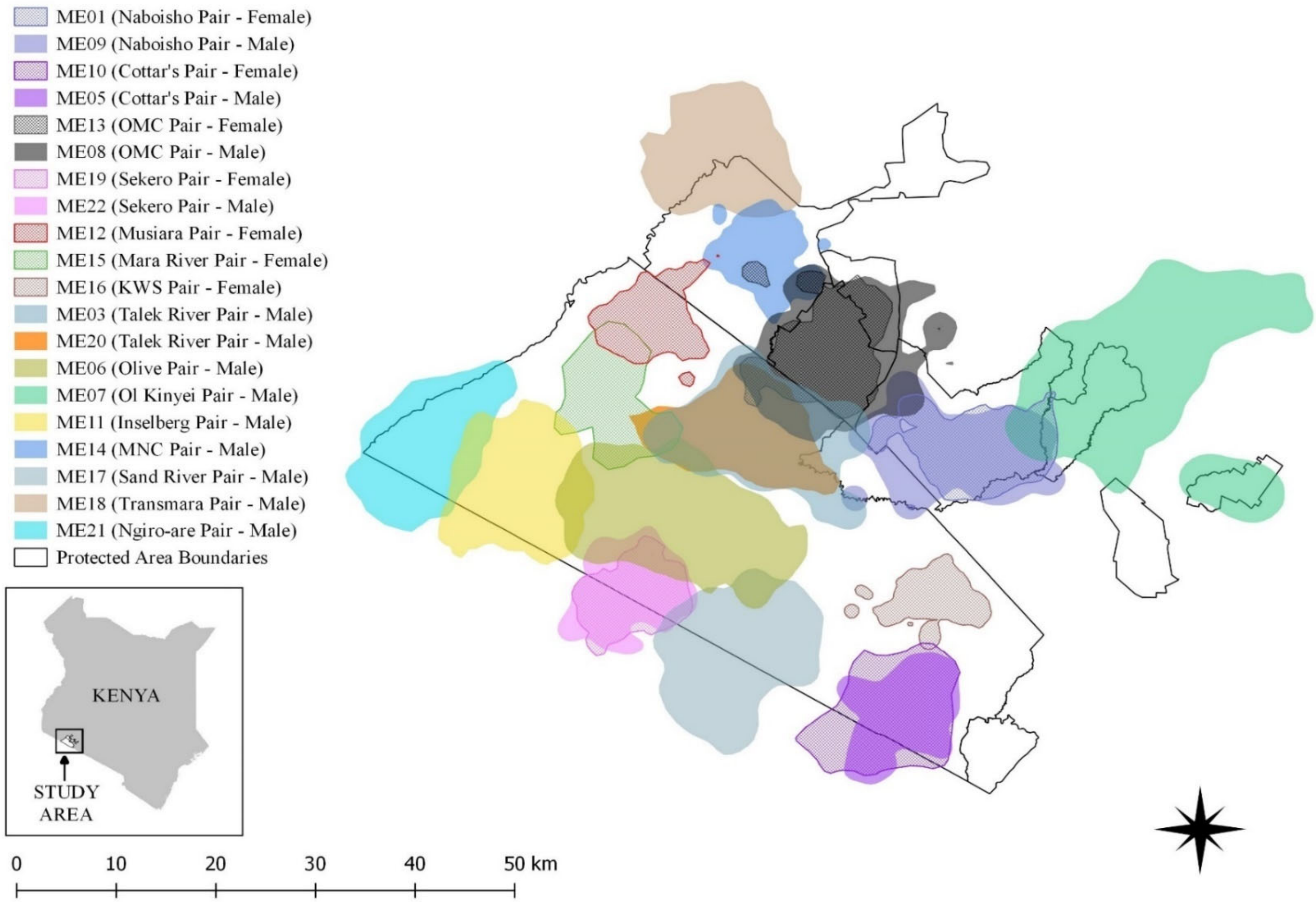

Figure 2.1: Estimated adult martial eagle 95% KDE home ranges for duration-of-transmitter-placement, Maasai Mara, Kenya, ~2016-18 (Table 2.1 for exact dates of transmitter placement). Black outlined boundaries represent public and private protected area boundaries, and filled, colored polygons represent individual martial eagle home ranges.

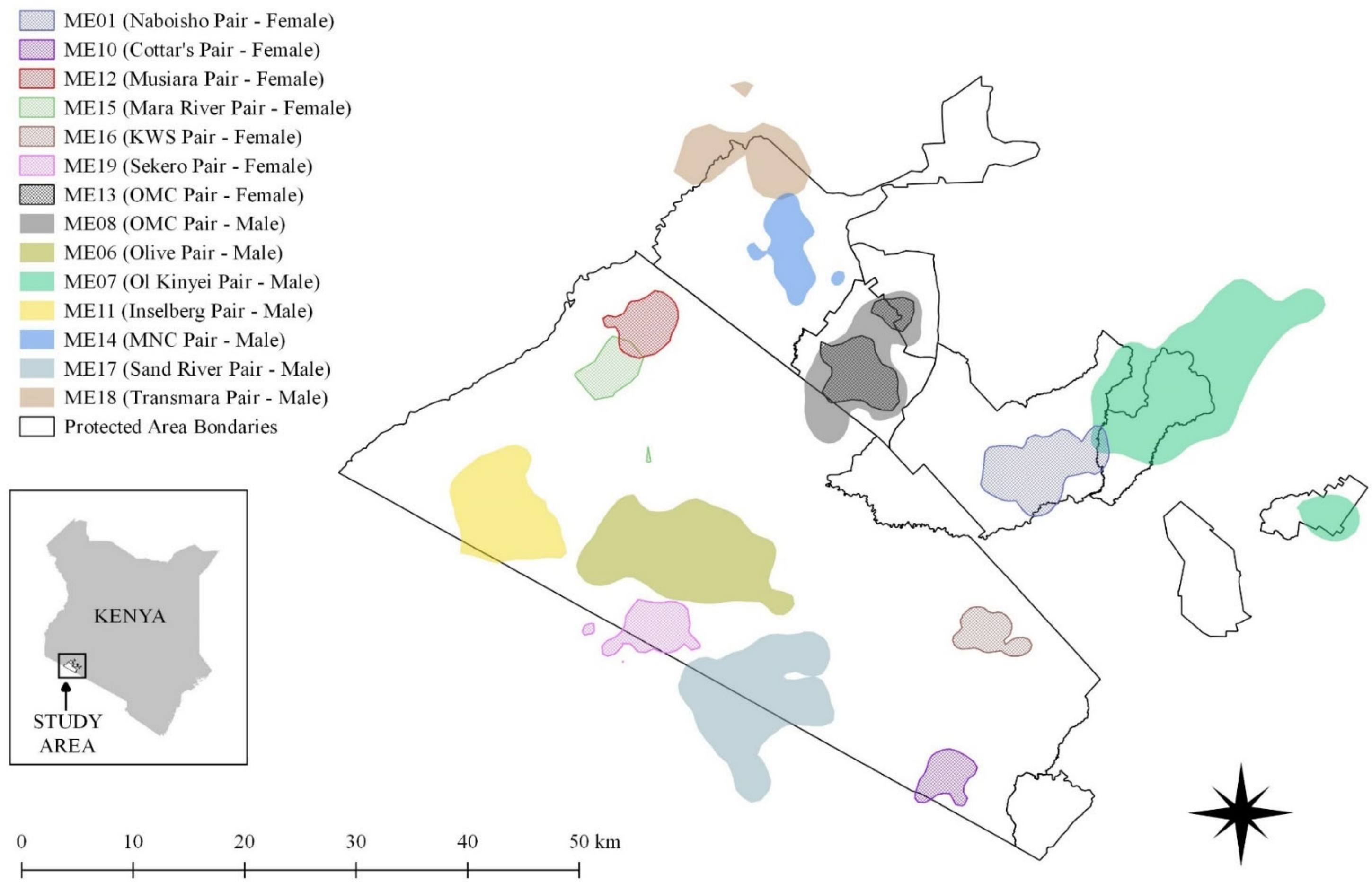

Figure 2.2: Adult martial eagle 75% KDE home ranges using transmitter data gathered continuously from 1 March 2017 – 28 February 2018, Maasai Mara, Kenya. Black outlined boundaries represent public and private protected area boundaries, and filled, colored polygons represent individual martial eagle home ranges.

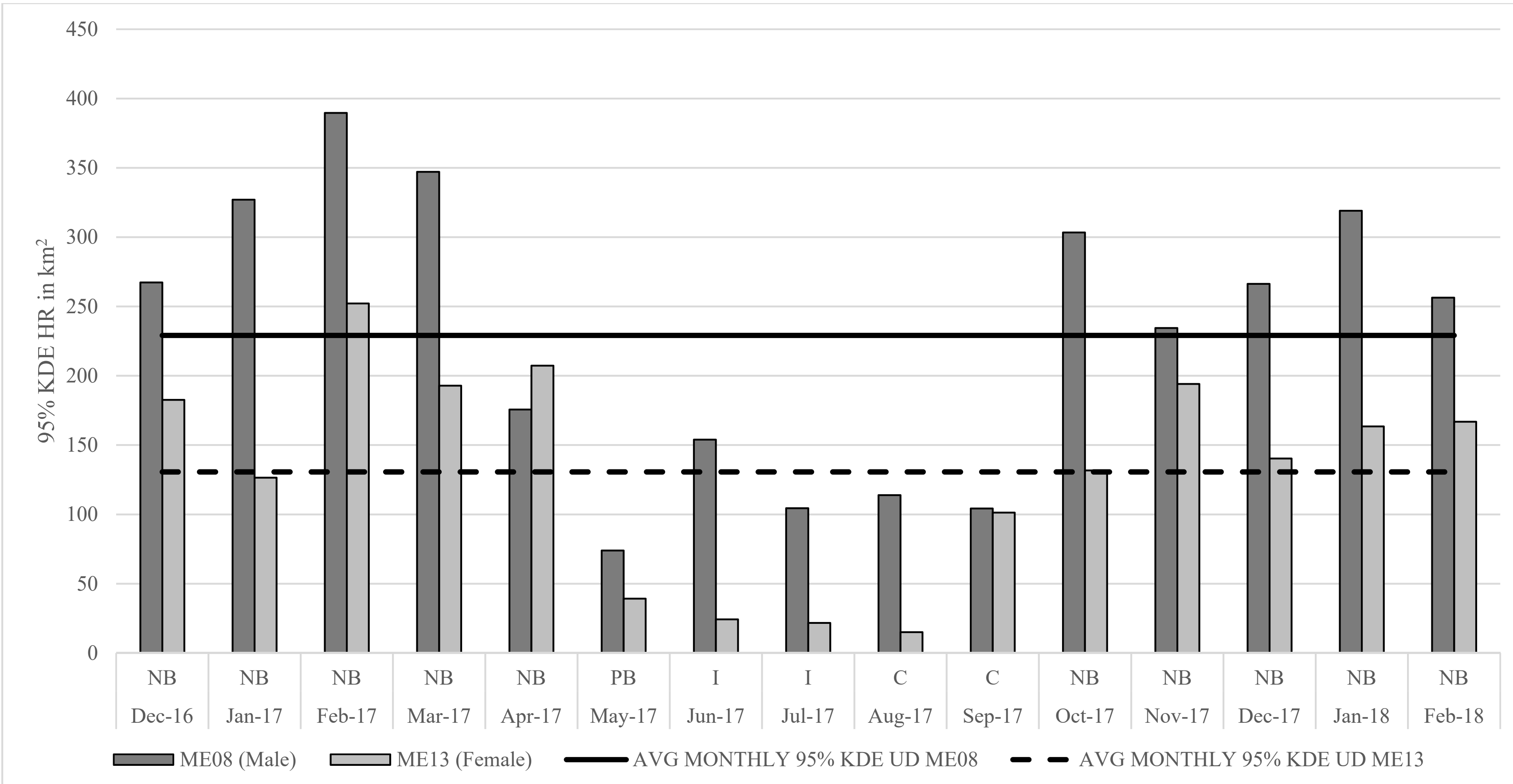

Figure 2.3: Olare Motorogi Conservancy (OMC) pair male (ME08) and female (ME13) martial eagle 95% KDE monthly home range (HR) sizes, Maasai Mara, Kenya, December 2016 – February 2018. The pair's breeding status for each month is indicated by the following: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick).

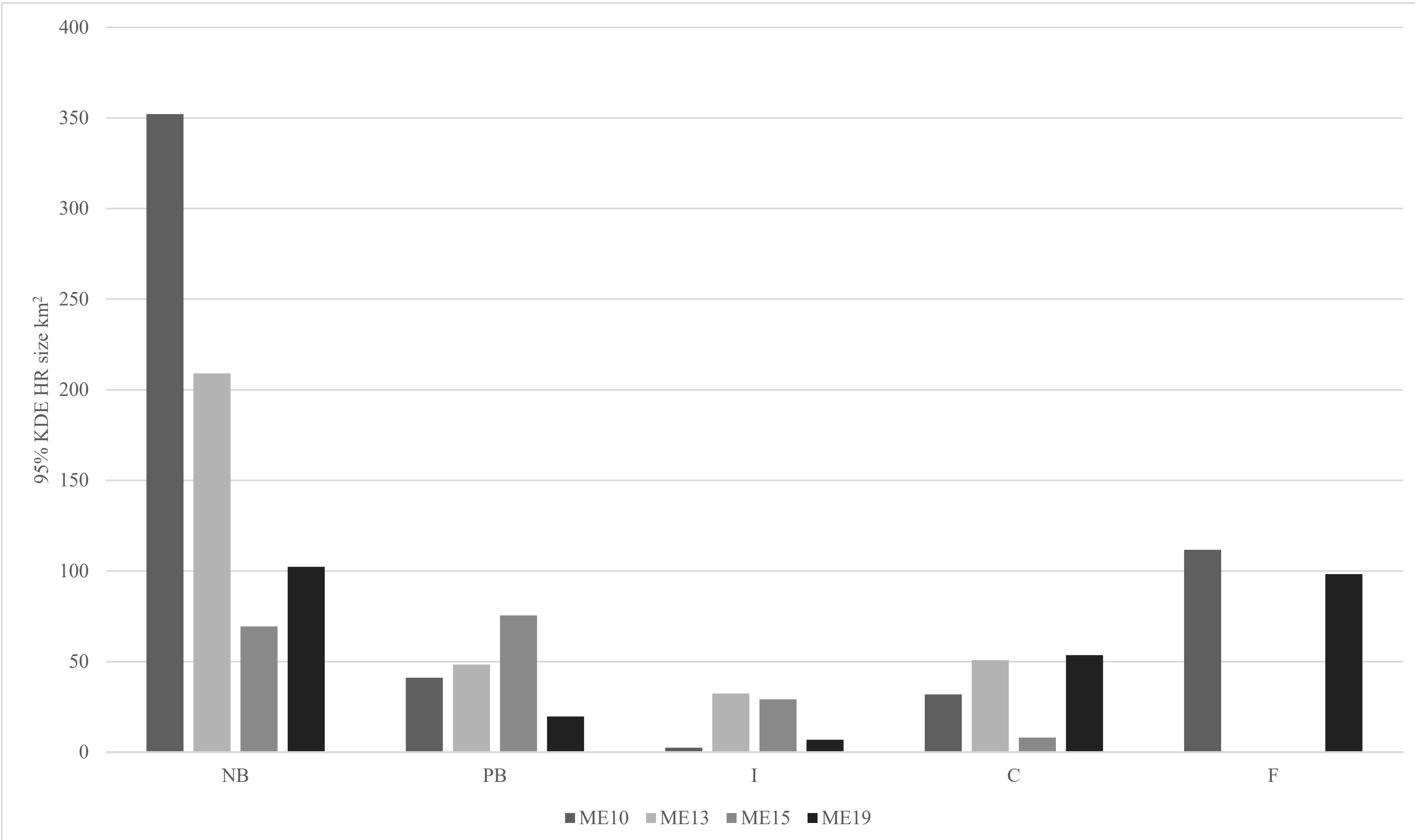

Figure 2.4: Adult female martial eagle 95% KDE home range (HR) sizes during the breeding period, Maasai Mara, Kenya, ~2016-18 (Table 2.3 for exact dates of breeding periods for individual eagles). Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

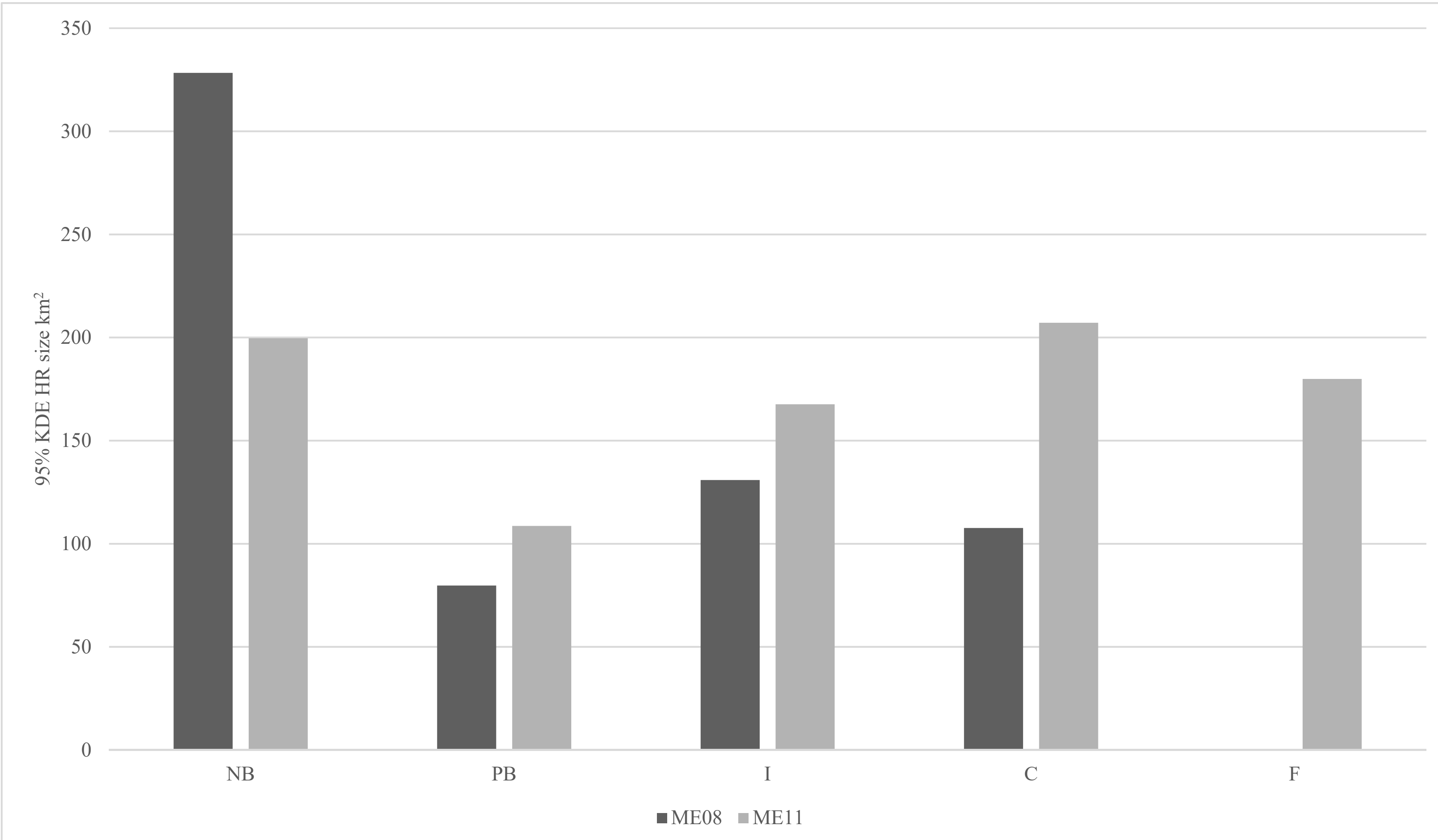

Figure 2.5: Adult male martial eagle 95% KDE home range (HR) sizes during the breeding season, Maasai Mara, Kenya, ~2016-18 (Table 2.3 for exact dates of breeding periods for individual eagles). Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

APPENDICES

Appendix A: Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
July 2016	ME01	Naboisho	F	NB	236	11.9	33.8	90.0	134.1
August 2016	ME01	Naboisho	F	NB	421	15.7	34.7	85.1	132.2
September 2016	ME01	Naboisho	F	NB	465	19.5	43.6	99.7	164.0
	ME05	Cottar's	M	NB	247	47.6	87.9	169.4	247.7
October 2016	ME01	Naboisho	F	NB	445	20.6	47.7	109.3	174.9
	ME05	Cottar's	M	NB	478	44.1	77.4	143.8	211.0
	ME07	Ol Kinyei	M	NB	467	48.5	115.3	261.0	393.5
November 2016	ME01	Naboisho	F	NB	458	21.9	50.1	140.2	230.4
	ME03	Esirwa	M	NB	350	52.8	104.7	195.1	265.6
	ME05	Cottar's	M	NB	462	32.7	69.0	152.7	243.3
	ME06	Olive	M	F	320	67.0	139.8	282.0	398.9
	ME07	Ol Kinyei	M	NB	436	41.0	85.6	174.7	249.9
December 2016	ME01	Naboisho	F	NB	487	19.6	43.6	110.5	192.7
	ME03	Esirwa	M	NB	486	52.0	95.7	177.5	244.4
	ME05	Cottar's	M	NB	478	36.0	81.6	161.8	252.9
	ME06	Olive	M	F	492	88.6	167.1	315.6	472.8
	ME07	Ol Kinyei	M	NB	452	69.7	135.6	248.4	342.0
	ME08	OMC	M	NB	398	62.8	122.5	267.3	427.3
	ME09	Naboisho	M	NB	479	47.9	104.1	225.1	310.9
	ME10	Cottar's	F	NB	493	85.8	176.7	491.6	1255.8
	ME11	Inselberg	M	NB	360	52.5	100.7	218.1	323.0
	ME12	Musiara	F	NB	335	10.9	23.5	60.5	93.7
	ME13	OMC	F	NB	299	40.4	84.2	182.6	310.1
January 2017	ME01	Naboisho	F	NB	219	16.0	36.1	92.6	141.0
	ME03	Esirwa	M	NB	479	74.5	134.2	258.8	375.3
	ME05	Cottar's	M	NB	472	51.8	104.2	195.0	275.7
	ME06	Olive	M	F	493	87.7	171.9	355.0	496.2
	ME07	Ol Kinyei	M	NB	457	47.4	109.0	229.8	327.0
	ME08	OMC	M	NB	494	72.5	155.3	327.1	471.7
	ME09	Naboisho	M	NB	367	43.6	92.7	199.9	307.6

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
January 2017	ME10	Cottar's	F	NB	492	49.2	91.5	187.5	274.1
	ME11	Inselberg	M	NB	486	43.4	88.7	192.8	280.2
	ME12	Musiara	F	NB	495	11.5	25.0	59.9	96.4
	ME13	OMC	F	NB	419	25.0	54.8	126.4	216.5
February 2017	ME01	Naboisho	F	NB	420	29.3	59.1	137.1	198.9
	ME03	Esirwa	M	NB	348	75.2	143.2	280.0	386.7
	ME05	Cottar's	M	NB	361	43.6	90.1	181.9	262.3
	ME06	Olive	M	F	447	61.3	125.2	255.3	389.6
	ME07	Ol Kinyei	M	NB	434	56.1	118.5	250.8	366.5
	ME08	OMC	M	NB	448	90.4	187.7	389.6	563.2
	ME10	Cottar's	F	NB	436	147.4	323.0	1211.9	2974.8
	ME11	Inselberg	M	NB	439	47.7	95.5	201.9	299.4
	ME12	Musiara	F	NB	448	14.2	28.0	75.3	131.9
	ME13	OMC	F	NB	414	45.2	91.5	252.2	602.4
	ME14	MNC	M	NB	439	25.6	51.8	109.6	166.6
	ME15	River	F	NB	441	12.7	29.1	82.6	138.3
	ME16	KWS	F	NB	419	8.4	20.4	53.9	90.8
	ME17	Sand	M	NB	325	50.1	96.3	184.4	277.7
	ME18	Transmara	M	I	302	12.3	37.6	143.6	238.3
	ME19	Sekero	F	NB	446	27.0	54.7	110.1	151.1
March 2017	ME01	Naboisho	F	NB	487	24.4	50.9	135.0	210.9
	ME06	Olive	M	F	493	54.0	111.6	230.0	328.9
	ME07	Ol Kinyei	M	NB	477	71.7	154.0	288.8	407.1
	ME08	OMC	M	NB	494	64.2	142.4	347.1	548.9
	ME10	Cottar's	F	NB	493	39.1	81.2	212.2	347.2
	ME11	Inselberg	M	NB	482	35.9	72.8	158.4	233.3
	ME12	Musiara	F	NB	496	13.3	30.3	87.5	159.9
	ME13	OMC	F	NB	477	20.4	59.3	192.9	339.2
	ME14	MNC	M	NB	481	26.6	50.3	118.1	199.7
	ME15	River	F	PB	474	6.7	15.0	49.4	99.1
	ME16	KWS	F	NB	486	9.8	21.7	54.9	109.3
	ME17	Sand	M	NB	462	44.4	91.1	200.2	294.5

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
March 2017	ME18	Transmara	M	I	489	14.6	51.0	163.2	284.6
	ME19	Sekero	F	NB	493	15.9	36.6	79.4	118.3
April 2017	ME01	Naboisho	F	NB	464	33.7	66.4	134.7	188.7
	ME06	Olive	M	F	480	42.5	98.5	227.4	327.0
	ME07	Ol Kinyei	M	NB	464	55.3	131.0	306.9	459.8
	ME08	OMC	M	NB	479	29.3	77.2	175.6	267.0
	ME10	Cottar’s	F	NB	477	4.8	19.5	73.2	125.3
	ME11	Inselberg	M	PB	474	11.1	41.9	116.9	178.1
	ME12	Musiara	F	NB	480	19.4	43.1	103.2	156.3
	ME13	OMC	F	NB	458	24.3	66.8	207.3	351.8
	ME14	MNC	M	NB	402	6.0	21.5	80.4	131.5
	ME15	River	F	I	454	1.5	3.9	36.1	77.1
	ME16	KWS	F	PB	472	4.9	14.2	39.7	71.7
	ME17	Sand	M	NB	446	61.1	117.4	224.6	315.1
	ME18	Transmara	M	NB	470	41.9	104.1	232.5	407.1
	ME19	Sekero	F	NB	480	29.4	63.8	127.5	185.7
	ME20	Esirwa	M	NB	287	29.6	64.7	135.4	188.5
May 2017	ME01	Naboisho	F	NB	485	17.2	41.7	98.7	154.1
	ME06	Olive	M	F	495	53.1	112.4	227.4	325.2
	ME07	Ol Kinyei	M	NB	488	89.1	175.6	368.2	611.6
	ME08	OMC	M	PB	493	6.3	21.4	74.0	139.8
	ME10	Cottar’s	F	PB	492	0.6	1.3	13.7	34.8
	ME11	Inselberg	M	I	491	24.4	63.7	147.9	210.1
	ME12	Musiara	F	NB	496	20.0	47.1	121.1	203.7
	ME13	OMC	F	PB	469	3.0	10.3	39.2	75.1
	ME14	MNC	M	Unknown	426	2.2	6.6	28.6	50.9
	ME15	River	F	I	475	3.6	9.5	41.6	142.9
	ME16	KWS	F	I	415	0.5	1.4	7.4	16.1
	ME17	Sand	M	NB	455	71.3	140.3	264.0	380.6
	ME18	Transmara	M	NB	489	27.6	68.1	186.6	298.1
	ME19	Sekero	F	NB	496	9.3	25.7	59.1	88.9
	ME20	Esirwa	M	NB	495	36.5	78.4	167.6	243.9

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
June 2017	ME01	Naboisho	F	NB	454	31.3	73.4	166.9	291.2
	ME06	Olive	M	NB	469	59.9	125.5	262.4	387.7
	ME07	Ol Kinyei	M	NB	472	43.6	121.6	333.8	586.0
	ME08	OMC	M	I	478	30.4	69.4	153.9	218.6
	ME10	Cottar's	F	I	466	0.2	0.4	1.5	8.7
	ME11	Inselberg	M	I	469	36.5	95.6	200.0	275.8
	ME12	Musiara	F	NB	480	16.7	38.2	88.8	142.8
	ME13	OMC	F	I	474	1.1	2.5	24.3	66.3
	ME14	MNC	M	Unknown	400	2.5	8.1	49.5	83.8
	ME15	River	F	C	462	0.9	2.4	8.1	38.4
	ME16	KWS	F	I	315	0.5	1.2	7.7	20.4
	ME17	Sand	M	NB	459	72.2	132.5	261.3	384.6
	ME18	Transmara	M	NB	471	34.5	79.2	195.2	337.6
	ME19	Sekero	F	PB	479	0.2	0.5	3.1	10.3
	ME20	Esirwa	M	NB	478	37.4	78.4	191.7	307.7
July 2017	ME01	Naboisho	F	NB	477	21.9	45.7	102.0	157.6
	ME06	Olive	M	NB	493	63.2	126.2	268.6	407.3
	ME07	Ol Kinyei	M	NB	491	68.7	166.4	404.5	623.2
	ME08	OMC	M	I	494	17.4	42.1	104.5	158.7
	ME10	Cottar's	F	C	495	0.2	0.4	2.9	12.3
	ME11	Inselberg	M	C	485	25.7	67.8	176.0	262.2
	ME12	Musiara	F	NB	491	6.3	14.2	39.4	69.2
	ME13	OMC	F	I	490	0.8	2.1	21.7	51.0
	ME14	MNC	M	Unknown	468	8.5	27.2	77.3	131.2
	ME15	River	F	NB	486	10.1	39.0	135.8	222.2
	ME16	KWS	F	I	336	0.9	1.9	13.7	42.7
	ME17	Sand	M	NB	472	67.2	129.3	244.5	343.8
	ME18	Transmara	M	NB	475	27.8	64.9	180.2	271.6
	ME19	Sekero	F	I	496	0.3	0.7	4.5	17.6
	ME20	Esirwa	M	NB	493	40.1	80.1	160.6	229.8
	ME21	Ngiro-are	M	C	312	35.3	81.7	208.9	331.5

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
August 2017	ME01	Naboisho	F	NB	474	32.9	64.2	131.8	185.4
	ME06	Olive	M	NB	496	55.6	112.8	251.5	385.8
	ME07	Ol Kinyei	M	NB	492	91.1	217.3	468.2	772.3
	ME08	OMC	M	C	489	20.0	48.3	113.9	200.4
	ME10	Cottar's	F	C	495	0.6	1.6	16.2	34.5
	ME11	Inselberg	M	C	491	47.1	103.2	234.4	351.5
	ME12	Musiara	F	NB	493	14.3	34.6	102.3	182.9
	ME13	OMC	F	C	486	0.5	1.4	15.0	35.2
	ME14	MNC	M	NB	478	13.5	27.5	67.0	119.6
	ME15	River	F	PB	487	4.9	13.5	79.1	143.6
	ME16	KWS	F	NB	441	12.6	34.9	109.1	192.7
	ME17	Sand	M	NB	473	46.1	87.0	204.1	336.2
	ME18	Transmara	M	NB	480	18.1	56.0	162.0	265.2
	ME19	Sekero	F	C	495	0.6	1.4	7.2	27.8
	ME20	Esirwa	M	NB	494	38.2	75.6	159.2	230.8
	ME21	Ngiro-are	M	C	488	41.4	90.5	220.7	414.7
September 2017	ME01	Naboisho	F	NB	450	17.8	35.2	71.0	105.5
	ME05	Cottar's	M	C	383	36.4	72.3	142.5	208.4
	ME06	Olive	M	NB	480	77.0	143.7	306.4	488.2
	ME07	Ol Kinyei	M	NB	470	121.0	230.5	496.7	813.8
	ME08	OMC	M	C	475	23.5	50.3	104.3	149.4
	ME10	Cottar's	F	C	478	6.9	20.1	57.2	99.3
	ME11	Inselberg	M	C	477	47.5	94.7	175.2	248.6
	ME12	Musiara	F	NB	467	5.3	12.6	38.9	71.0
	ME13	OMC	F	C	464	7.9	27.1	101.3	199.4
	ME14	MNC	M	NB	469	17.1	35.4	86.5	145.3
	ME15	River	F	I	471	1.8	4.7	41.1	109.5
	ME16	KWS	F	NB	464	19.5	43.3	88.7	132.2
	ME17	Sand	M	NB	460	45.1	84.5	184.5	291.4
	ME18	Transmara	M	NB	469	29.7	75.0	187.1	283.5
	ME19	Sekero	F	C	480	3.3	9.9	71.8	139.5
	ME20	Esirwa	M	NB	473	45.0	85.3	161.3	225.3

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
September 2017	ME21	Ngiro-are	M	C	454	39.0	90.1	193.3	291.2
	ME22	Sekero	M	C	479	28.5	60.2	131.7	198.9
October 2017	ME01	Naboisho	F	NB	479	29.9	55.7	108.9	168.2
	ME05	Cottar’s	M	F	405	65.5	121.8	217.5	291.1
	ME06	Olive	M	NB	496	60.2	123.6	267.1	404.0
	ME07	Ol Kinyei	M	NB	484	100.6	212.6	454.5	672.4
	ME08	OMC	M	NB	492	59.8	119.9	303.3	491.5
	ME10	Cottar’s	F	F	493	7.9	23.7	114.2	181.4
	ME11	Inselberg	M	F	494	34.7	71.4	157.0	234.3
	ME12	Musiara	F	NB	480	7.5	15.2	39.7	75.8
	ME13	OMC	F	NB	467	30.4	58.8	131.7	221.9
	ME14	MNC	M	NB	483	16.1	35.7	77.6	122.0
	ME15	River	F	I	495	1.8	4.8	35.8	98.8
	ME16	KWS	F	NB	493	23.1	44.4	88.9	131.9
	ME17	Sand	M	NB	474	63.4	115.7	200.4	276.2
	ME18	Transmara	M	NB	483	26.8	56.1	120.4	185.8
	ME19	Sekero	F	C	496	6.2	18.4	58.0	97.6
	ME20	Esirwa	M	NB	489	46.9	91.5	182.5	257.4
	ME21	Ngiro-are	M	F	479	38.3	75.0	165.4	253.5
	ME22	Sekero	M	C	495	22.9	47.7	99.4	149.5
November 2017	ME01	Naboisho	F	NB	472	32.7	72.1	180.6	269.6
	ME05	Cottar’s	M	F	346	53.5	104.0	203.3	273.8
	ME06	Olive	M	NB	477	77.6	165.3	339.4	490.7
	ME07	Ol Kinyei	M	NB	474	62.5	145.1	348.1	524.2
	ME08	OMC	M	NB	480	35.2	97.9	234.4	347.6
	ME10	Cottar’s	F	F	478	10.8	31.3	108.2	171.7
	ME11	Inselberg	M	F	473	32.6	75.2	168.2	234.1
	ME12	Musiara	F	NB	471	12.6	27.3	59.9	94.1
	ME13	OMC	F	NB	446	51.0	96.1	194.1	326.7
	ME14	MNC	M	NB	402	21.2	39.7	78.1	133.8
	ME15	River	F	NB	474	29.0	80.5	167.9	252.5

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	Individual	Pair	Sex	Breeding Period	Locations	50% HR	75% HR	95% HR	99% HR
November 2017	ME16	KWS	F	NB	468	12.0	26.6	57.9	98.0
	ME17	Sand	M	NB	442	42.7	86.2	178.3	271.0
	ME18	Transmara	M	NB	465	12.2	43.3	105.6	164.1
	ME19	Sekero	F	F	477	22.0	45.7	94.0	145.8
	ME20	Esirwa	M	NB	469	47.8	96.1	199.1	287.5
	ME21	Ngiro-are	M	F	457	30.6	58.7	119.3	183.2
	ME22	Sekero	M	F	386	21.2	45.4	93.9	134.7
December 2017	ME01	Naboisho	F	NB	487	30.2	63.3	141.4	209.5
	ME05	Cottar’s	M	F	334	59.8	116.8	215.3	297.4
	ME06	Olive	M	NB	495	66.5	131.5	284.8	440.6
	ME07	Ol Kinyei	M	NB	493	136.3	272.8	568.5	868.6
	ME08	OMC	M	NB	495	61.7	138.4	266.2	369.0
	ME10	Cottar’s	F	F	496	5.2	14.3	48.5	83.9
	ME11	Inselberg	M	F	491	44.2	94.6	194.4	270.5
	ME12	Musiara	F	NB	494	13.4	27.3	67.0	107.5
	ME13	OMC	F	NB	370	34.8	66.7	140.3	258.0
	ME14	MNC	M	NB	297	28.1	54.8	99.9	135.9
	ME15	River	F	NB	475	22.0	49.6	110.3	190.8
	ME16	KWS	F	NB	388	4.6	10.6	27.2	51.1
	ME17	Sand	M	NB	455	34.2	82.2	191.5	280.0
	ME18	Transmara	M	NB	457	16.0	45.4	111.8	167.4
	ME19	Sekero	F	F	494	15.6	31.2	65.2	99.4
	ME20	Esirwa	M	NB	494	34.8	65.9	131.6	183.7
	ME21	Ngiro-are	M	F	478	40.5	79.1	162.6	233.6
	ME22	Sekero	M	F	458	27.3	52.5	105.6	158.0
January 2017	ME01	Naboisho	F	NB	494	26.4	51.1	95.6	147.6
	ME05	Cottar’s	M	F	292	39.9	80.5	166.2	254.0
	ME06	Olive	M	NB	493	67.2	144.6	290.5	407.0
	ME07	Ol Kinyei	M	NB	476	77.5	183.6	415.5	606.0
	ME08	OMC	M	NB	495	74.9	157.7	319.0	471.1

Appendix A (continued): Adult martial eagle KDE monthly home ranges (HR) in km^2, Maasai Mara, Kenya, 2016-18. Breeding periods are abbreviated as follows: NB (Non-Breeding), PB (Nest Building), I (Incubation), C (Chick) and F (Fledgling).

Month	**Individual**	**Pair**	**Sex**	**Breeding Period**	**Locations**	**50% HR**	**75% HR**	**95% HR**	**99% HR**
January 2017	ME10	Cottar's	F	F	491	9.3	22.7	65.7	103.0
	ME11	Inselberg	M	F	492	31.7	58.6	112.9	160.7
	ME12	Musiara	F	NB	489	11.0	26.1	68.2	111.9
	ME13	OMC	F	NB	276	43.6	85.9	163.5	234.0
	ME14	MNC	M	NB	382	28.2	57.2	109.7	153.9
	ME15	River	F	NB	483	45.4	84.2	174.8	284.4
	ME16	KWS	F	NB	416	3.8	8.0	19.7	33.1
	ME17	Sand	M	NB	478	55.1	115.7	222.8	309.6
	ME18	Transmara	M	NB	475	8.3	32.9	104.3	167.0
	ME19	Sekero	F	F	496	21.7	44.2	94.7	146.0
	ME20	Esirwa	M	NB	494	32.7	74.4	153.3	228.2
	ME21	Ngiro-are	M	F	277	42.3	84.4	165.2	228.6
	ME22	Sekero	M	F	176	21.9	44.9	114.3	177.8
February 2017	ME01	Naboisho	F	NB	435	26.0	53.7	111.0	178.3
	ME05	Cottar's	M	F	297	52.8	94.0	168.2	235.4
	ME06	Olive	M	NB	445	33.6	99.0	231.8	336.5
	ME07	Ol Kinyei	M	NB	446	87.2	229.2	520.9	799.2
	ME08	OMC	M	NB	447	60.1	122.8	256.4	398.6
	ME10	Cottar's	F	F	444	17.9	42.4	102.0	150.5
	ME11	Inselberg	M	F	428	43.1	81.5	164.0	230.8
	ME12	Musiara	F	NB	430	5.4	15.7	69.9	129.9
	ME13	OMC	F	NB	282	34.1	70.6	166.9	328.7
	ME14	MNC	M	NB	409	11.0	25.6	69.2	123.8
	ME15	River	F	NB	412	26.3	62.8	148.5	242.3
	ME16	KWS	F	PB	445	3.9	9.6	26.9	48.4
	ME17	Sand	M	NB	428	66.2	144.0	300.6	451.3
	ME18	Transmara	M	PB	405	25.6	75.2	180.9	310.9
	ME19	Sekero	F	F	446	21.0	43.9	101.5	161.6
	ME20	Esirwa	M	NB	445	20.2	65.8	153.2	250.5
	ME21	Ngiro-are	M	F	226	71.6	140.3	300.9	522.1
	ME22	Sekero	M	F	239	41.9	82.9	160.5	232.6

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"The ecology of the martial eagle in the Maasai Mara region of southern Kenya"
Student Sustainability Council: $8525

Hatfield, Richard S., Ralph Buij and John J. Cox. November 2017.
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Peregrine Fund: $5000

Hatfield, Richard S. Fall 2017.
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