EXAMINING THE EFFECTS OF HOME RANGE ESTIMATION TECHNIQUES ON ELEPHANT HABITAT USE ANALYSIS

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ABSTRACT

This study examined the effects of six different home range estimation techniques on the proportions of habitats located therein. The study utilized the GPS point dataset collected for nine individual elephants in the Amboseli ecosystem, Kenya. Each dataset was used to create home ranges using the following techniques: (1) Minimum Convex Polygon (MCP); (2) Characteristic Hull Polygon (CHP); (3) k-Local Convex Hulls (LoCoH; (4) Fixed Kernel Density Estimation (KDE); (5) Brownian Bridge Movement Model (BBMM); and (6) Dynamic Brownian Bridge Movement Model (dBBMM). This study also compared the difference in mean annual as well as mean seasonal home ranges among nine different elephants estimated from the dBBMM home range estimator. Two land cover products (20 m resolution and 300 m resolution) were used to analyze habitat use by elephants. Mann-Whitney-Wilcoxon tests were used to determine whether the six home range estimation techniques produced significantly different areas and proportions of each habitat type. These results were then evaluated to determine whether the method of home range estimators has an effect on which land cover types are most utilized by elephants and, therefore, which habitats are considered preferable. The result revealed that the annual and wet season home range sizes estimated by the MCP method were significantly larger than other estimators. While the home range size estimated by the CHP method was significantly smaller than the one estimated by other techniques. However, the dry season home range estimated by LoCoH method showed the smallest home range size. In addition, the study results showed that the dominant land cover type used by the elephant in study area in most of case is the shrub land, and the second dominance habitat is the grassland. While the choice of home range estimation did not have an effect on which land cover types were determined to be the most frequently visited, it did affect the proportion and amount of each land cover type found within each home range.

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LIST OF ABBREVIATION

BBMM	Brownian Bridge Movement Model
BRB	Biased Random Bridge Kernel Method
CCI	ESA Climate Change Initiative
CHP	Characteristic Hull Polygon
dBBMM	Dynamic Brownian Bridge Movement Model
ESA	European Space Agency
FAO	Food and Agriculture Organization
GPS	Global Position System
IFAW	International Fund for Animal Welfare
JRC/EC	Joint Research Centre
KDE	Kernel Density Estimation
KWS	Kenya Wildlife Service
LC	Land Cover
LCCS	Land Cover Classification System
LoCoH	Local Convex Hulls
MCP	Minimum Convex Polygon
SLKDE	Scaled Line Kernel Density
TGDE	Time-Geographic Density Estimation
UD	Utilization Distribution
UTM	Universal Transverse Mercator
UN	United Nations

1. INTRODUCTION

1.1. Background

The concept of the home range is proposed by Seton (1909) who noticed that animals restrict their movements to a specific area. Burt (1943) defines the home range as: "the area in which an animal spends most of its time during normal activities as growth, survival, and reproduction". He indicates that the territory, as a property right, never overlay with other individual's territory, but home range area can overlay with two or three different individual's home range (Burt, 1943). Several studies have compared the home range estimators for quantifying animal home range size (Johnson, 1980; Van Winkle, 1975). The mostly used method for home range estimation is the minimum convex polygon (MCP). On the basis of the MCP method, a statistical definition of the home range—"stationary space use distribution" is outlined by Blackwell (1997). A number of studies also reviewed the development of home range estimators (Worton, 1987; Powell, 2000; Laver & Kelly, 2008). Using the biological concept, the home range is defined as "an emergent space use pattern that results from animals restricting their movements within a certain area while attempting to meet their needs for growth, survival, and reproduction" (Moorcroft & Lewis, 2006). An animal's "home range" and "territory" are a totally different concept. The territory refers to the area that is defended with tooth and claw (Burt, 1943). Home range is associated with the concept of utilization distribution (UD), which is a probability offending an animal in a defined area within home range relating to space and time (Van Winkle, 1975). Since the uneven distribution of foods, water, and other resources within an animal's home range, some areas used by animals must be more important than other parts.

Several concepts are also important for home range study. Core area can be defined as the 50 percent of area of total home range area (Barg *et al.,* 2005; Boitani & Fuller, 2000). The root of home range definition focuses on mammals only; however, it is universal for animal shaping the home range because the home range is shaped considering the resources distribution (Mitchell & Powell, 2004, 2012) and risk of natural enemy. Thus, Burt's home range definition beyond mammals (Powell & Mitchell, 2012). For example, home range research applied not only on mammals (Black Bear-Powell, 1987) but also on the bird (Boobooks-Olsen *et al.,* 2011), reptiles (Bog Turtles-Smith, & Cherry, 2016), amphibians and fish (Ebersole, 1980).

The wildlife managers need information about the home range for in-situ conservation of particular animal. Without knowing the habitat and mobility of the animal, it is difficult to manage conservation area. The animal has large home range can access the distant food, but that has the small home range can only access food of nearby (Devigne & Detrain, 2006). Therefore, wildlife conservationists need to understand the home range of wild animal to manage the food as well as the overall habitat of the animal.

Reasons for quantifying home range is that knowing it can provides a profound insight of mating and reproduction patterns, interactions to the environment, social organization, water and food choices, important components of habitat, and limited resources (Powell *et al.,* 2000). There are many techniques for studying home ranges. Due to the limitation of radio tracking technology, most of home range estimators are based on the minimum convex polygon (MCP). Home range estimation is at the beginning stage of mammals research, according to the review of different home range models of Worton (1987).

After that, a more advance estimator—kernel density estimation (KDE) was optimized by Worton (1989) using extensive data set. According to the treatment of time and the track data as geometric or probabilistic, these estimators are divided into four categories. The point-based methods use geometric approach only include GPS point location, for instance, minimum convex polygon (MCP, Mohr, 1947), characteristic hull polygon (CHP, Downs & Horner, 2009) and time local convex hull (LoCoH, Getz *et al.,* 2007). Lyons *et al.,* (2013) takes time into account and developed time local convex hull (T-LoCoH). Also, some estimators use a probabilistic approach like KDE (Worton, 1989). The Brownian Bridge Movement Model (BBMM-Bullard, 1999; Horne *et al.,* 2007) ignores the time information. The scaled line kernel density (SLKDE-Steiniger & Hunter, 2013) is on the basis of previous estimators. The time-geographic density estimation (TGDE-Downs *et al.,* 2011) and the Biased Random Bridge Kernel Method (BRB, Benhamou & Cornélis, 2010; Benhamou, 2011) consider the time information. In addition, estimators like BBMM, dBBMM, SLKDE estimators are the line-based methods.

Elephants in Kenya and Tanzania roam freely outside the protected areas. These areas are critical for long-term elephant survival. Understanding the ecological conditions in these landscapes and threats to elephants is critical in elephant management. Using Global Position System (GPS) collared elephants, the habitat use and selection was studied intensively in the past few decades. For example, previous studies shows that the home range of 21 collared elephants varied from 191 to 3,698 km^2 in northern Tanzania (Kikoti, 2009) and 102 to 5,527 km^2 in northern Kenya (Thouless, 1996). While Douglas-Hamilton *et al.,* (2005) reported that home range size of 11 elephants varied from 11 to 5,520 km^2 in southern and central Kenya. In addition, previous studies also found that the home range size of elephants are bigger in winter and smaller in summer. The summer home range size of elephants range from 33 to 40 km^2. while winter home range sizes of elephants range from 61 to 71 km^2 (Shannon *et al.,* 2006). The dominant land cover types in the home range of the Sumatran elephant are natural forest and pulpwood plantation (Moßbrucker, Fleming, Imron, Pudyatmoko, & Sumardi, 2016). However, it was found that the dominant land cover types used by African elephants are riverine forests (Shannon *et al.,* 2006).

1.2. Problem statement

Although there are many methods that can be used to simulate the home range of an animal. It is hard to say which estimator is the best. Several home range estimators such as the Minimum Convex Polygon (MCP) and the Kernel Density Estimation (KDE) have been commonly used in previous studies. Among these home rang estimators the MCP is the easiest technique. However, this method ignores landscape features like physical barriers and does not allow concave polygon and holes which lead to over-estimate. The CHP creates a Delaunay triangulation based on GPS tracking points, then remove minimum triangles (Downs & Horner, 2009). This method allows concave polygon and holes happen within the home range area, also tends to underestimate the home range (Downs & Horner, 2009). Methods mentioned above use the actual boundary according to GPS tracking points. Based on moving track object, the Brownian Bridge Movement Model (BBMM) and the Dynamic Brownian Bridge Movement Model (dBBMM) takes time geography analysis into account, similar to the KDE method, the BBMM and the dBBMM also creates a probability density surface (Downs *et al.* 2011). The Kernel density methods is based on the probability surface. Both of them use a calculated boundary and have a tendency of over-estimate. The methods, BBMM, dBBMM are all based on kernel density to develop a time-aware methods. Several studies have been carried out to determine a single best estimator (Walter *et al.,* 2015; Walter *et al.,* 2011). However, it turns out that there is no single estimator best for every situation.

The population of the African elephant significantly reduced in the past few decades. The illegal hunting, habitat loss and fragmentation are believed to be the main reasons causing the decline of African elephant populations. Elephants roam the landscapes utilizing different habitats and its resources that meet their needs and enhance their survival. Within the landscape, habitat patches vary in their composition and spatial arrangement. Therefore, habitat characteristics and resources within their home ranges can determine the level of preference and use of different habitats. By identifying how land cover distribution affects the spatial dynamics of elephants, one may be able to predict how elephants will respond to areas in which they do not occur. This may facilitate initiatives to improve conservation management plans.

For this semiarid area like Amboseli, water is a vital resource for both human and animals. Not all surface water is permanent on Africa, during the wet season, seasonal rivers are essential to water resources, however, on dry season local people rely on hand hug wells and boreholes (BurnSilver *et al.* 2008). Those human-wildlife conflicts compel elephant to live in the gap between agricultural land and human residential land(Kioki, 2006).

1.3. Research objectives

The overall objective of this study is to exam the effects of home range estimation techniques on the assessment of habitat utilization by elephants in the Amboseli ecosystem, Kenya. The specific objectives of this study are as follows:

- To compare the differences in mean annual as well as mean seasonal (i.e., dry and wet season) home ranges of elephants estimated from six different home range estimators.
- To compare the differences in mean annual as well as mean seasonal home ranges among nine different elephants estimated from the Dynamic Brownian Bridge Movement Model (dBBMM) home range estimator.
- To compare the differences in the proportion of each land cover type within the mean annual as well as mean seasonal home ranges of elephants estimated from six different home range estimators.
- To determine the most utilized land cover types within the mean annual as well as mean seasonal home ranges estimated from six different home range estimators.

1.4. Research questions

- Are there significant differences in the mean annual as well as mean seasonal home ranges of elephants estimated from the six different home range estimators?
- Are there significant differences in mean annual as well as mean seasonal home ranges among nine different elephants estimated from the dBBMM home range estimator?
- Are there significant differences in the proportion of each land cover type within the mean annual as well as mean seasonal home ranges of elephants estimated from six different home range estimators?
- Do the six home range estimators have a significant effect on the determination of the most utilized (i.e., the most frequently visited or preferable) land cover types by elephants at the annual and seasonal scale?

1.5. Research hypotheses

Hypothesis 1

H_0: There are no significant differences in the mean annual as well as mean seasonal home ranges of elephants estimated from the six different home range estimators?

H_1: There are significant differences in the mean annual as well as mean seasonal home ranges of elephants estimated from the six different home range estimators?

Hypothesis 2

H_0: There are no significant differences in the mean annual as well as mean seasonal home ranges among nine different elephants estimated from the dBBMM home range estimator?

H_1: There are significant differences in the mean annual as well as mean seasonal home ranges among nine different elephants estimated from the dBBMM home range estimator?

Hypothesis 3

H_0: There are no significant differences in the proportion of each land cover type within the mean annual as well as mean seasonal home ranges of elephants estimated from six different home range estimators?

H_1: There are significant differences in the proportion of each land cover type within the mean annual as well as mean seasonal home ranges of elephants estimated from six different home range estimators?

Hypothesis 4

H_0: The choice of home range estimators does not affect the determination of the most utilized land cover types by elephants at the annual and seasonal scales.

H_1: The choice of home range estimators has a significant effect on the determination of the most utilized land cover types by elephants at the annual and seasonal scale.

2. MATERIALS AND METHODS

2.1. Study area

The Amboseli ecosystem is mainly located in Loitoktok District, Kajidao County, Rify Valley Province in Kenya and lies immediately north-west of Mount Kilimanjaro, on the border with Tanzania (see Figure 1). This savannah is called Kenya's "conservation jewels" since human, domesticated and wild animals live together on this land (BurnSilver *et al.,* 2008). The Amboseli ecosystem covers an area of approximately 8,500 km² and surrounded by six group ranches: Kimana/Tikondo, Olgulului/Olararashi, Selengei, Mbirikani, Kuku, and Rombo (S. Ngene *et al.,* 2017). The temperature of the Amboseli ranges between 20℃ and 30℃(Altmann *et al.,* 2002), and annual rain fall ranges from 500-600 mm in the north to 250-300 mm in Amboseli National Park (Gara, 2014). This area has warm and dry climate which classified as semi-arid climate and agro-climatic zoon VI (Pratt *et al.,* 1977). The rainy pattern in Amboseli is predictable and generally can be described as two rain (short wet season from Nov. to Dec. and long wet season from (Feb. to May) seasons and two dry seasons (see Figure 2) (Altmann *et al.,* 2002; Kioki *et al.,* 2006; Gara, 2014).

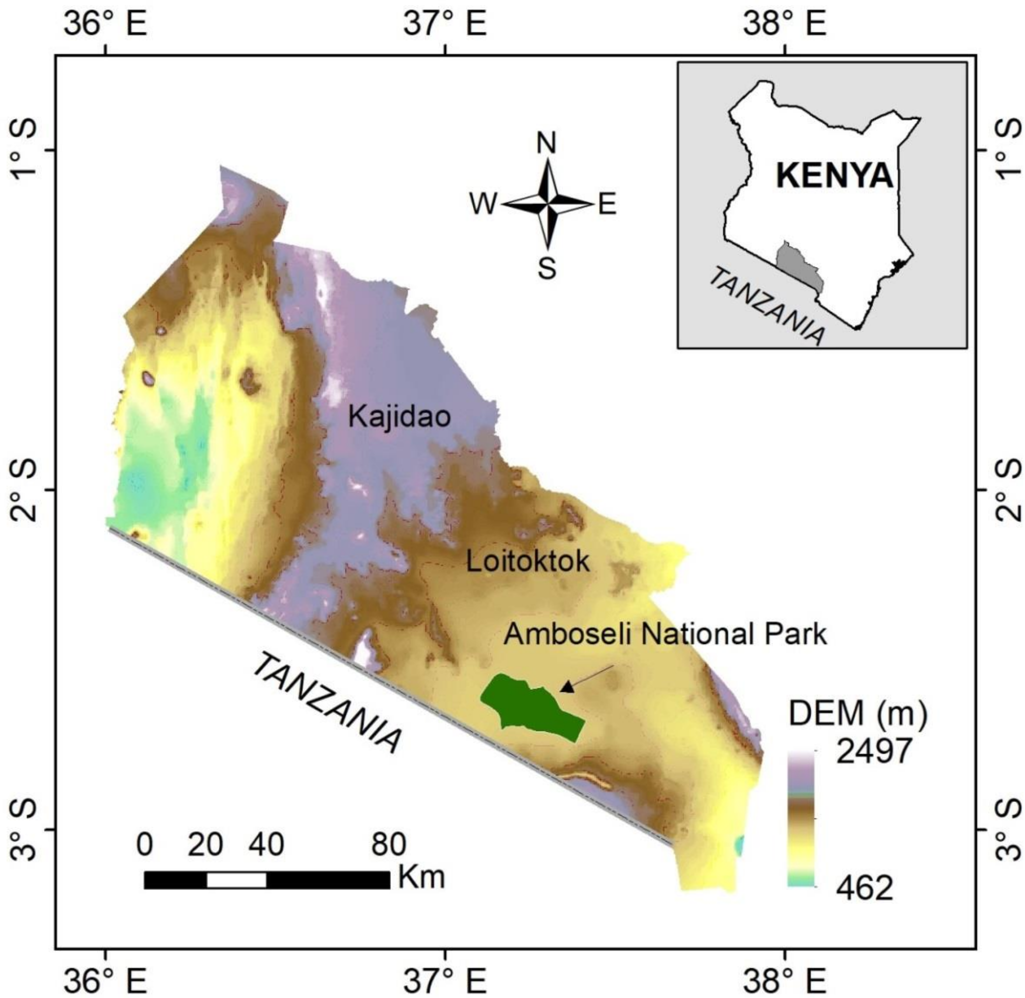

Figure 1: The location of the study area and the Amboseli Ecosystem

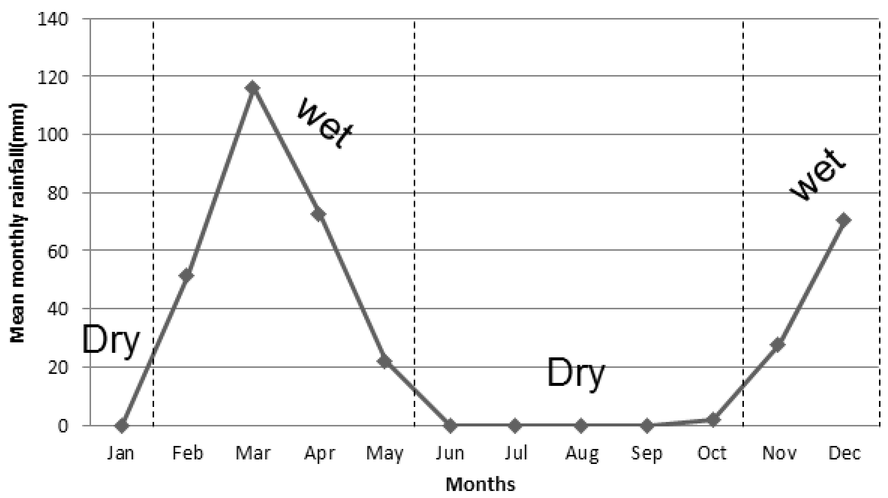

Figure 2: Mean monthly rainfall variations in Amboseli National Park of the year 2014

2.2. Elephant GPS tracking data

The Kenya Wildlife Service (KWS) and the International Fund for Animal Welfare (IFAW) fitted three females and nine male elephants with GPS collars in the Amboseli ecosystem between 2013 and 2014.. The collars were supplied by African wildlife Tracking, South Africa. The age of collared elephants ranges between approximately 15 and 40 years old. The size of elephant herds ranges between 3 and 13 individuals. The tracked elephants belong to different families. The GPS collars were configured to acquire one GPS fix every four hours. The GPS collars provide coordinates (x, y) at an accuracy of 10 m and the time (GMT +3) (Ngene *et al.,* 2017; Gara, 2014). The GPS fixes were re-projected to Universal Transverse Mercator (UTM) WGS-84 reference system (Zone 37M) in ArcGIS 10.4 (ESRI, 2011). The tracking duration of these elephants ranges between 235 and 1218 days (Figure 3). GPS tracking point data of elephants ELM, KIM and MAF were not used in this study since the time duration did not cover the whole year of 2014 as other elephants. Table 1 details the characteristics of the 12 collared elephants.

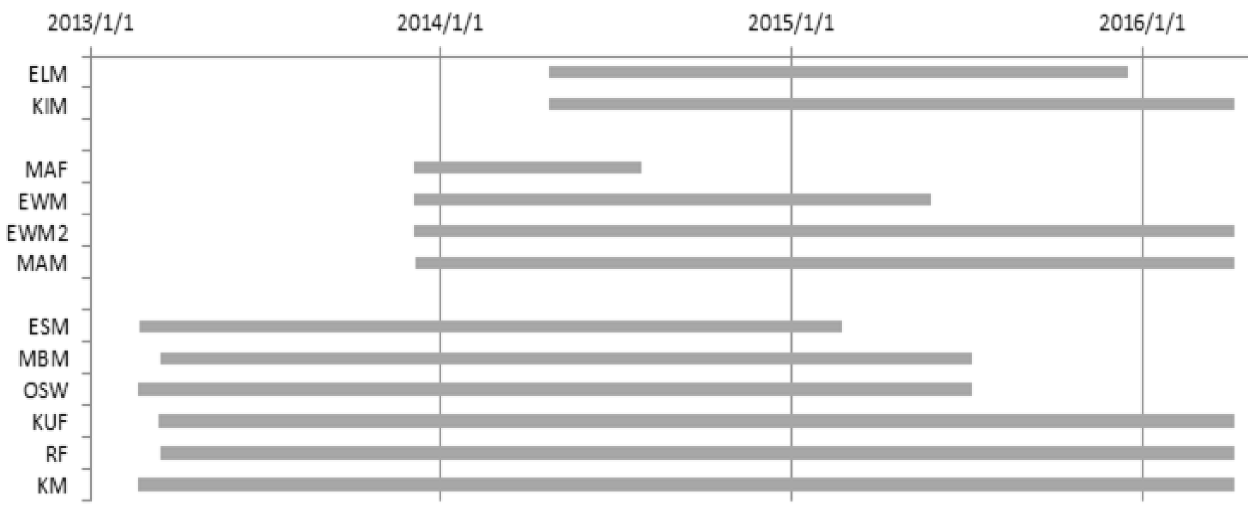

Figure 3: Time duration of tracking 12 collared elephants in Amboseli ecosystem

Table 1: Description of the 12 collared elephants in Amboseli ecosystem

Name	ID	Age	Gender	Group size	Tracking period	Tracking days	Number of points
KUF	**F1**	26	Female	10	2013/3/14 - 2016/4/6	1102	6031
RF	**F2**	15	Female	13	2013/3/14 - 2016/4/6	1102	5410
EWM	**M1**	40	Male	Not available	2013/12/3 - 2015/5/26	533	2587
EWM2	**M2**	30	Male	Not available	2013/12/3 - 2016/4/6	843	4250
ESM	**M3**	33	Male	6	2013/2/20 - 2015/2/22	1082	3778
KM	**M4**	26	Male	5	2013/2/19 - 2016/4/6	1127	6254
MAM	**M5**	25	Male	3	2013/12/4 - 2016/4/6	842	4171
MBM	**M6**	22	Male	9	2013/3/15 - 2015/7/8	1193	4278
OSW	**M7**	30	Male	3	2013/2/20 - 2015/7/8	1218	4646
MAF	**F0**	25	Female	7	2013/12/4 - 2014/7/29	235	1247
ELM	**M0**	20	Male	Not available	2014/4/23 - 2015/12/17	594	3285
KIM	**M00**	22	Male	Not available	2014/4/23 - 2016/4/6	703	2933

The GPS collar dataset was pre-processed by the Kenya Wildlife Service and all the GPS fixes with errors (missing coordinates) were eliminated from the dataset. In this study, only nine collared elephants tracked for one entire year between 1st January 2014 and 31st December 2014 (were considered for further analysis. The distribution of GPS points of the nine collared elephants was shown in Figure 4.

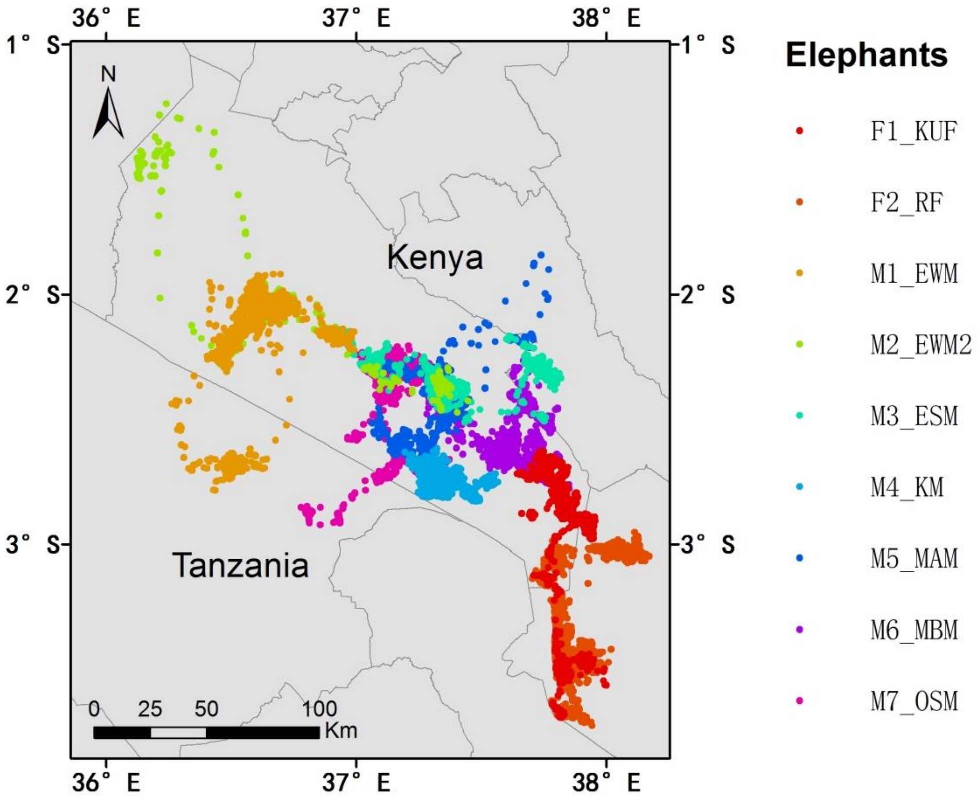

Figure 4: Study area and elephants GPS tracking points used in this study

2.3. Home range estimators

2.3.1. Minimum Convex Polygon (MCP)

The MCP method is the most popular and the most straightforward estimator which provides a basic range of animal's home range area (Mohr, 1947). As the name suggests, the estimator consists in the calculation of the smallest convex polygon enclosing all the GPS tracking points of the collared animal. This polygon is considered as the home range of the animal. The minimum convex polygons delineate outline of home range. As a consequence, this method is highly sensitive to the extreme points. Since the home range has been defined as the area traversed by the animal during its normal activities of foraging, mating and caring for young (Burt, 1943). A conventional operation consists to first remove a small percentage of the relocations farthest from the centroid of the cloud of relocations before the estimation (Calenge, 2015). Sometimes the animal may make occasional moves to unusual places and this result in outliers that cannot be considered as "normal activities". One major limitation of the MCP method is that it ignores physical characteristic of habitat, which can lead to the tendency of overestimating home range. For example, hard boundary such as wall, fences, and rivers would be disregarded by the MCP method. Also, significant water source would be included by the MCP as a home range of terrestrial animal *(Barg et al.,* 2005).

However, Barg (2005) also suggested that this smallest area convex polygon can be an origin point for comparison with otherhome range estimation techniques, and Schoener (1981) indicated that the MCP method is highly correlated with sample size for estimate home range with few relocations.

2.3.2. Characteristic Hull Polygon (CHP)

The CHP method was developed by Downs and Horner (2009), which calculates the Delaunay triangulation of relocations data set. This method estimates home range with creating characteristic hull polygons using a set of relocations, then orders triangles from smallest to largest. The smaller the triangles the area is more intensively used by the animals (Calenge, 2015). A conventional operation consists of moving a percentage of triangles away which with large perimeter (5% removed in the study of Downs and Horner, 2009), are removed and the remaining polygons are considered the estimated home range. If no triangles are removed from Delaunay triangulation result, it can be extended to an MCP home range from the same points data set. The CHP method was developed to overcome the drawback of the Kernel Density Estimation (KDE) and the Minimum Convex Polygon (MCP) methods. The CHP produces estimates of home range allows for concavity and holes, unlike the MCP which all edges of the polygon are convex which encompasses fewer regions of space not used the by the animal. Downs and Horner (2009) indicates that the CHP method tends to slightly underestimate home range by reduced the seemingly unused areas compared with other methods such as the MCP and the KDE estimators.

2.3.3. Local Convex Hulls (LoCoH)

The LoCoH estimator is a nonparametric kernel method. The principle of this methods is to create convex hull for relocation points, and then merge the convex hull based on the area into isopleths *(Getz et al.,* 2007). The isopleth contains 10% of the points and represents a higher utilization than the 100% isopleth that contains all the points (Calenge, 2015). The LoCoH family includs three algorithms: fixed k LoCoH, fixed r LoCoH, and adaptive LoCoH. The fixed k LoCoH method is known as k-NNCH which discussed in Getz and Willmers (2004). Each point of the convex hull is constructed from the nearest neighbors to that point, then merged together sort by the area of each convex hull from small to large (Calenge, 2015). The fixed r LoCoH method creates hulls based on a root point and points around it the distance within r. It fristly sorts ebery hull by the value of k generated, then sorts it by the area of the hull (Calenge, 2015). The adaptive LoCoH is another method that the hulls are created out of the maximum nearest neighbors, such that the sum of the distances from the nearest neighbors is less than or equal to d, which uses the same hull sorting as the Fixed r LoCoH (Calenge, 2015). In conclusion, sort those hulls of algorithms above sorted by area, ordered, and gradually merged to construct a utilization distribution without hard bound such as rivers, lakes wall, and fences. Home range estimators should not contain landscape features like hard bounaries as is often the case extend beyond by parametric kernel density methods as a home range. As the reason of consistency across different estimators, only fixed k LoCoH was used in this study and the value of k value calculated from a number of tracking points of each data set.

2.3.4. Kernel Density Estimation (KDE)

The KDE estimator is believed as one of the best methods to estimate Utility Distribution *(UD, Powell et al.,* 2000). The method develops a probabilistic function to create a smooth density surface which become the isopleth contours for home range (Van Winkle, 1975). This method produces a probability surface to estimate the areas that are more frequently used by the animal. Kernels, probabilistic functions fitted to each point, provide the values for a smooth density surface. Calculated values from this surface are used to create the isopleth contours used for home range and core area delineations. Generally, the 95% contour is considered the entire home range and the 50% contour is considered the core area. The areas visited by animals outside of the 95% contour may be considered exploratory in nature (Burt 1943). An important parameter of the KDE is the band width "h", which refers to smoothing parameter monitoring placed of every point (Worton, 1989).

The fixed-KDE method was used to estimate utilization distribution because fixed kernel was considered most accurate compared with adaptive kernel. A location-based estimator was selected using KDE with smoothing determined by the reference bandwidth (LKDE). Bandwidth for the KDE is generally chosen by either least-squares cross-validation (LSCV), plug-in (PI), solve the equation (STE) or likelihood cross-validation (LCV) methods (Worton, 1989). The LSCV method determines bandwidth by reducing the squares of the errors between estimated and actual distributions and has been determined to be more appropriate for large sample sizes. The LCV method minimizes the Kullback-Leiber distance between these values and is considered more appropriate for datasets with smaller (<50) sample sizes and when finding areas of high utilization, rather than the full extent of the home range. The bandwidth is the extent to which values are grouped to determine how they are grouped in the density estimation. For example, in a spatial dataset, for the values of 1, 3 and 7, if assigned a bandwidth of 4, the values of 1 and 3 would be grouped in the first band (0 – 4) and the value of 7 would be in its own band (4 – 8). If the bandwidth is reduced to 2, each would be in a separate band, with 1 falling between 0 and 2, 3 falling between 2 and 4, and 7 falling between 6 and 8. The choice of bandwidth will affect the smoothness of the distribution. Choosing too small a bandwidth will separate values into too many bands, nullifying any trend in the distribution. A bandwidth that is too large will cause too much smoothing, again losing any trends in distribution. The KDE method removes the limitation of the convex polygon containing unused areas. However, it has been shown to generate large spaces in the interior of the home range (Lyons et al., 2013) and overestimate home ranges, regardless of the method by which the bandwidth was chosen(Downs & Horner, 2009). Furthermore, the KDE method evaluates the presence points as stationary, independent events which is not appropriate when evaluating animal tracking data, in which points are sequential(Downs & Horner, 2008).

2.3.5. Brownian Bridge Movement Model (BBMM)

The BBMM estimator is based on the kernel method and make it time aware methods. Compare to kernel density estimator, the BBMM puts the kernel method on each trajectory instead of on each relocation points (Bullard, 1999). Location of relocation points and travel path are contained by this method. The Brownian bridge estimation relies on two smoothing parameters, sig1 and sig2. The parameter sig1 is related to the speed of the animal, and describes how far from the line joining two successive relocations the animal can go during one time unit.. The larger this parameter is, and the more wiggly the trajectory is likely to be (Bullard, 1999). It is related to the inaccuracy of the relocations, and is supposed known (Horne et al., 2007). The concept of BBMM is based on a Brownian bridge with the probability of being in an area dependent upon the elapsed time between the starting and ending locations(Bullard, 1999; Horne et al., 2007). The BBMM "fills in" the space between sequential locations irrespective of the density of locations where the width of the Brownian bridge is conditioned only on the time duration between the beginning and ending locations for each pair of locations and GPS location error. As such, BBMM is able to predict movement paths that otherwise would not be observed with KDE methods. While some authors have suggested using ≤90% home range contours (Getz et al., 2007)to remove outliers or exploratory movements for KDE, increasing size of home range from 95% to 99% for BBMM does not over-smooth the utilization distribution but rather serves to more accurately define the area of use for some species. Therefore, BBMM intuitively appears better suited for mammalian and avian species that migrate or travel long distances (Walter et al., 2011).

2.3.6. Dynamic Brownian Bridge Movement Model (dBBMM)

A new method also based on trajectories analysis as the BBMM called biased random bridge kernel method (dBBMM) was developed by Benhamou and Cornélis (2010). This method includes several sub-steps, for example add new points between original two neighbour points. The next step is to use kernel function to estimate relocation points. At the last stage it takes biased random walk model into account, the steps with speed, angle, direction can be estimated. Dynamic approach to space and habitat use based on biased random bridges (Benhamou, 2011). Incorporating movement behaviour and barriers to improve kernel home range space use estimates (Benhamou & Cornélis, 2010). With the wide-spread use of GPS technology to track animals in near real time, estimators of home range and movement have developed concurrently. Unlike the traditional point-based estimators that only incorporate density of locations into home range estimation, newer estimators incorporate more data provided by GPS technology. While BBMM incorporates a temporal component and GPS error into estimates, dynamic Brownian Bridge Movement Models (dBBMM) incorporate temporal and behavioural characteristics of movement paths into estimation of home range. However, estimating a movement path over the entire trajectory of data should be separated into behavorial movement patterns prior to estimating the variance of the Brownian motion.

2.4. Land cover data

Two land cover products were used in this study (see Figure 5). The two products were both released by the European Space Agency (ESA) CCI projects. The first product is 300m annual global land cover time series from 1992-2015 (https://www.esa-landcover-cci.org/?q=node/175), after data manipulation, this study extracted the land cover map of the year 2014 to match the time duration of elephants tracking data. The other land cover product is ESA CCI prototype land cover map at 20m resolution over Africa for the year 2016 (http://2016africalandcover20m.esrin.esa.int/), this latest high-resolution map released in September 2017 used to detect water bodies spots and build up area. Both land cover map 300m for the year 2014 and 20m for the year 2016 were projected to Universal Transverse Mercator (UTM) WGS-84 reference system (zone 37M).

The prototype land cover map of the year 2016 (Dec.2015 to Dec.2016) at 20m resolution over Africa was based on Sentinel-2A images (CCI Land Cover (LC) team, n.d.). The legend of this product was built into ten generic classes after reviewing popular typologies such as LCCS, GLC-share, GlobeLand30, Africover, and SERVIR-RMCD(CCI Land Cover (LC) team, n.d.). For the "open water" class and "urban areas" class were identified with the external dataset. The former one based on Global Surface Water product delivered by JRC/EC and the later based on the Global Human Settlement Layer by JRC/EC and Global Urban Footprint by DLR. Accuracy assessment relied on two independent validation datasets of this product was processed by two different approaches indicated the accuracy level is around 65% (Lesiv et al., 2017).

The 300 m annual global land cover map which time series from 1992 to 2015 was using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO). From 2014 to 2015 land cover map ten year's global land cover map was used as a baseline of remote sensing classification also PROBA-V global SR composites at 1 km was used as updating the baseline. What's more PROBA-V time series at 300m was used to delineate the identified changes the LC map spatial resolution(ESA Climate Change Initiative - Land Cover project, 2017). The user guide of CCI product provides accuracy assessments of the CCI-LC map year 2015 using GlobCover 2009 validation dataset. Overall accuracies found out to be 71.45% using "certain" whether "homogeneous" or "heterogeneous" points what's more 75.4% was found using only "homogeneous" and "certain" points(ESA Climate Change Initiative - Land Cover project, 2017).

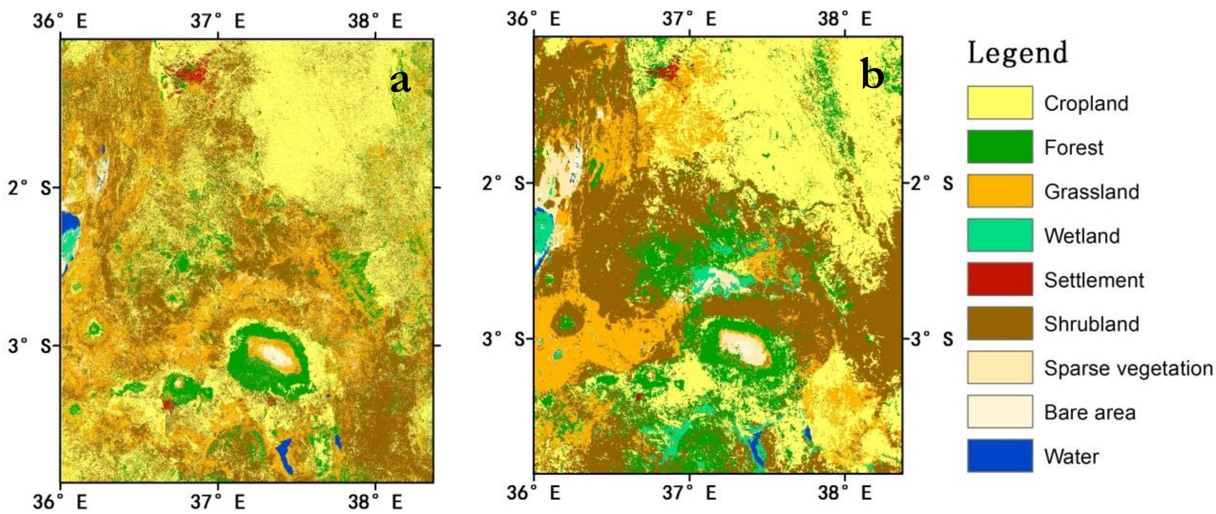

Figure 5 : Land cover map of the study area: a) The prototype land cover map of year 2016 at 20m b) The 300 m land cover map of the year 2014

As this is a habitat study and to ensure two land cover products can be comparable in habitat analysis. The land cover map at 300m resolution of the year 2014 was reclassified into appropriate habitat types after reviewing user guide of two products (CCI Land Cover (LC) team, n.d.; Lesiv et al., 2017). The correspondence between land categories used by prototype land cover 20m map of Africa 2016 and the LCCS legend used in 300 m annual global land cover map of the year 2014 was defined in Table 2: which was based on the user guide and data description (CCI Land Cover (LC) team, n.d.; Lesiv et al., 2017). Land categories used by prototype land cover 20m map of Africa 2016

Table 2: Description of the two land cover products used in this study

Land cover	Land categories used by prototype land cover 20m map of Africa 2016		LCCS legend used in 300 m annual global land cover map of the year 2014	
Cropland	4	Cropland	10,11,12	Rained cropland
			20	Irrigated cropland
			30	Mosaic cropland (>50%)/natural vegetation (tree, shrub, herbaceous cover) (<50%)
			40	Mosaic natural vegetation (tree, shrub, herbaceous cover) (>50%)/cropland (<50%)
Forest	1	Tree cover areas	50	Tree cover, broadleaved, evergreen, closed to open (>15%)
			60,61,61	Tree cover, broadleaved, deciduous, closed to open (>15%)
			70,71,72	Tree cover, needleleaved, evergreen, open (>15%)
			80,81,82	Tree cover, needleleaved, deciduous, open (>15%)
			90	Tree cover, mixed leaf type(broadleaved and needleleaved)
			100	Mosaic tree and shrub (>50%)/herbaceous cover (<50%)
			160	Tree cover, flooded, fresh or brakish water
			170	Tree cover, flooded, saline water
Grassland	3	Grassland	110	Mosaic herbaceous cover (>50%)/tree and shrub (<50%)
			130	Grassland
Wetland	5	Vegetation aquatic or regularly flooded	180	Shrub or herbaceous cover, flooded, fresh-saline or brakish water
Settlement	8	Built up areas	190	Urban
Shrubland	2	Shrubs cover areas	120,121,122	Scrubland
Sparse vegetation	6	Lichens Mosses / Sparse vegetation	140	Lichens and mosses
			150,151,152,153	Sparse vegetation(tree, shrub, herbaceous cover)
Bare area	7	Bare areas	200,201,202	Bare areas
water	10	Open Water	210	Water
-	9	Snow and/or Ice	220	Permanent snow and ice

2.5. Statistical analysis

For each individual and each estimator, the areas of the home range were calculated. After the land cover data was clipped using each home range, the proportion of each habitat type was recalculated. These areas were grouped according to the reclassification system mentioned above and summarized by mean and standard deviation. Kruskal-Wallis tests were used to determine whether the area changes from one home range to the next were a result of random chance or whether the changes were significant enough to be caused by the different home ranges. Each estimator analysis was set up with the nine home ranges as six groups, each with an n value of 9, corresponding to the nine individual point sets used. The Mann-Whitney-Wilcoxon tests were used to determine the significant differences between a pair of each estimator. The means values and standard deviations were input for each habitat type. Analyses were performed for the areas of each habitat. Then resulted in 9 total chi-square analyses: two for each of the six habitat types.

3. RESULTS

3.1. Differences in the mean annual home ranges of elephants estimated from the six different home range estimators

Figure 6 shows the annual home range of nine elephants estimated from six different home range estimators.

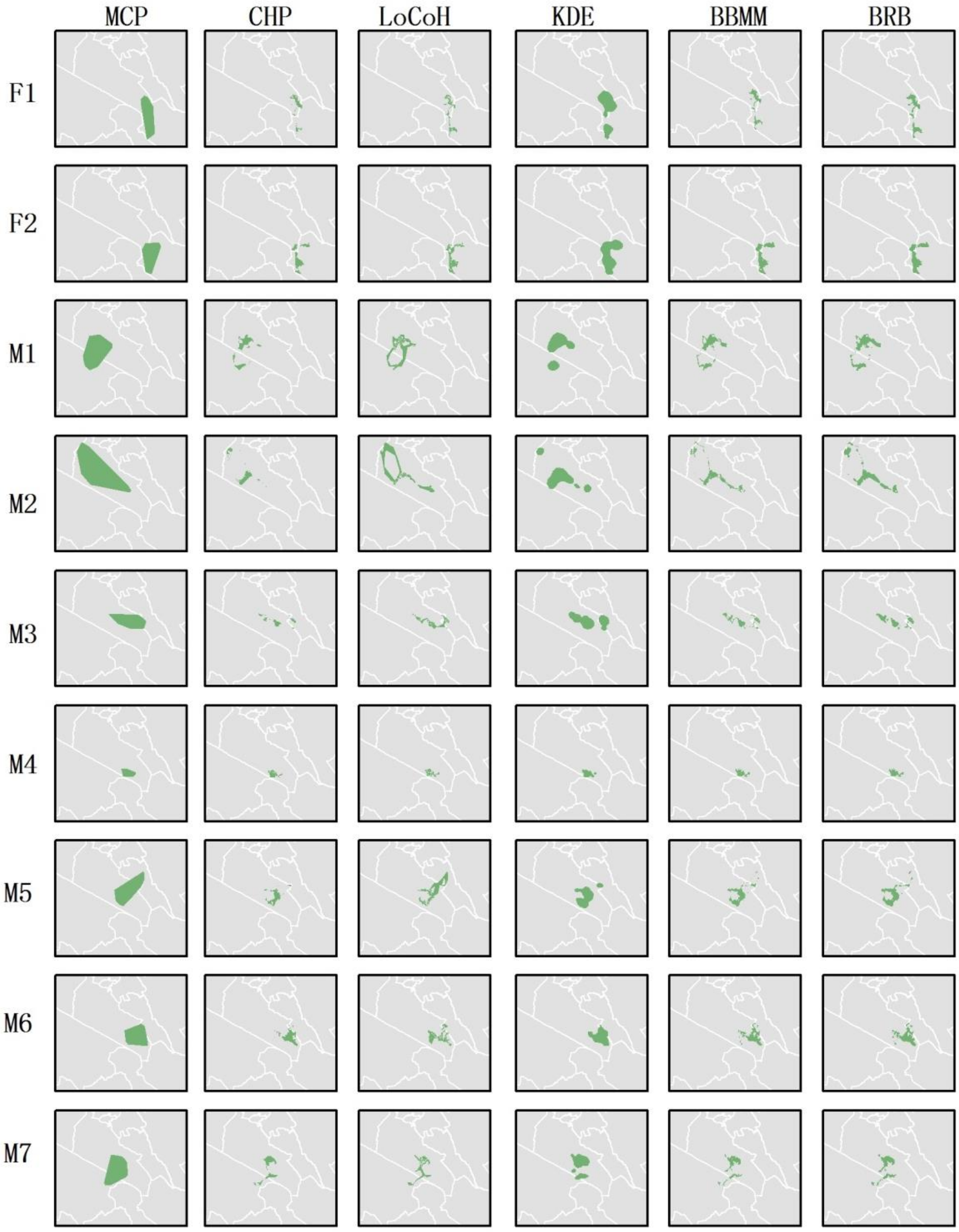

Figure 6: Annual home range of nine elephants estimated from the six different home range estimators

Table 3: Annual home range sizes (km²) of the nine collared elephants estimated from the six different home range estimators

	MCP	CHP	LOCOH	KDE	BBMM	dBBMM
F1	3039.86[2]	567.55[1]	624.85	2781.31	912.50	1138.27
F2	2899.60	912.75[1]	1041.82	3075.60[2]	1378.00	1464.41
M1	5023.92[2]	946.29[1]	1937.93	2968.96	1526.00	1780.35
M2	9177.09[2]	2237.76	2463.67	3246.92	1444.75[1]	2036.65
M3	2867.46[2]	434.33[1]	794.86	2529.71	789.00	968.67
M4	655.00[2]	282.76[1]	311.31	490.33	401.75	417.90
M5	3683.62[2]	740.83[1]	1569.84	1941.21	1181.50	1346.77
M6	2914.68[2]	926.78[1]	1060.16	1690.11	1135.00	1238.34
M7	3719.71[2]	790.84[1]	870.68	1825.74	972.25	1129.97
MEAN	3775.66	871.10	1186.12	2283.32	1082.31	1280.15
SD	2328.06	562.44	681.38	882.34	356.79	467.15

1: Smallest home range area per individual.

2: Largest home range area per individual.

The annual home range sizes for the nine elephants ranged between 282.76 km² and 9177.09 km². The average home range was1746.44 ±1592.85 km² (Table 3). The MCP and CHP estimators produced the largest (mean=3775.66 ±2328.06 km²) and the smallest (mean=871.10 ±562.44 km²) home ranges, respectively. The estimated mean annual home ranges were significant different among the six different estimators (Kruskal-wallis, p<0.001). The pairwise test (Figure 7) showed that the home range estimated by the MCP method and KDE method (mean=2283.32±882.34 km²) were significantly larger than other methods While the home range size estimated by the CHP method was much smaller than other methods.

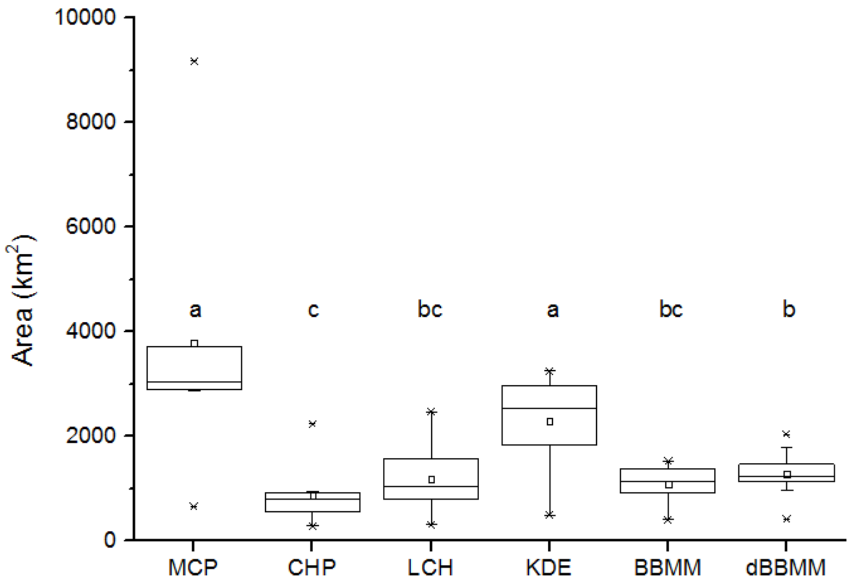

Figure 7: Comparison of the mean annual home range size between the six estimators. Different superscript letters indicate statistical differences ($p < 0.05$)

3.2. Differences in the seasonal home ranges of elephants estimated from the six different home range estimators

Figure 8 shows the wet season home range sizes of the nine elephants estimated by the six different home range estimators.

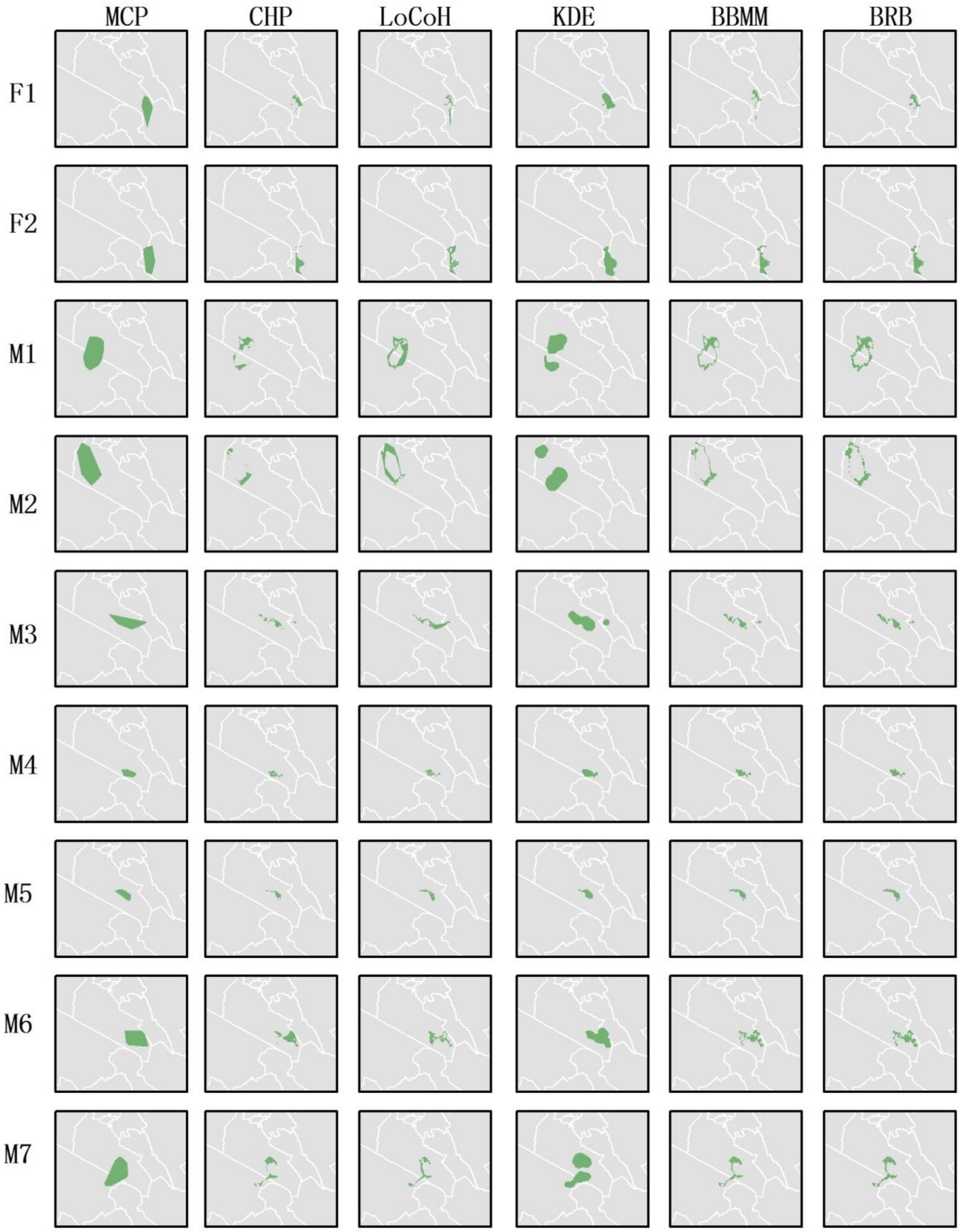

Figure 8: Wet season home range sizes of the nine elephants estimated by the six different home range estimators.

Table 4: The wet season home range sizes (km²) of the nine elephants estimated by the six different home range estimators.

	MCP	CHP	LOCOH	KDE	BBMM	dBBMM
F1	1500.77[2]	355.16[1]	373.69	909.56	443.25	434.74
F2	1857.43[2]	721.79[1]	828.69	1666.76	1024.75	1071.83
M1	3889.71[2]	1016.33[1]	1809.49	3044.80	1356.50	1792.50
M2	4505.77[2]	649.51[1]	1740.63	3561.77	966.50	1360.24
M3	1947.77[2]	414.86[1]	755.70	2296.46	647.00	721.73
M4	611.53[2]	171.09[1]	271.51	598.57	385.25	403.36
M5	692.02[2]	247.01[1]	330.76	463.54	411.00	460.77
M6	2260.56[2]	936.67	792.86[1]	2024.22	913.75	1003.93
M7	3102.06	724.44[1]	699.39	3233.60[2]	869.25	1008.93
MEAN	2263.07	581.87	844.75	1977.70	779.69	917.56
SD	1342.59	299.85	567.89	1159.81	330.90	467.12

1: Smallest home range area per individual.
2: Largest home range area per individual.

The wet season home range sizes for the nine elephants estimated by the six home range estimators ranged between 171.09 km² and 4505.77 km². The average home range size in wet season was 1227.44 ± 980.71 km²(Table 4) The MCP and CHP produced the largest (mean=2263.07±1342.59 km²)and the smallest (mean=581.87±299.85 km²) home range sizes, respectively. The estimated mean wet season home ranges for the six elephants were significantly different among the six different estimators (Kruskal-Wallis, $p<0.001$). The pairwise difference tests (Figure 9) showed that the home range sizes estimated by the MCP method and KDE method were larger than other methods. However only MCP method was significantly larger. While the CHP method (mean=581.87±299.85 km²), LoCoH method (mean=844.75 ±567.89 km²), BBMM method (mean=779.69±330.90 km²) and dBBMM method (mean=917.56± 467.12 km²) produced sizes similar to each other and no significant difference.

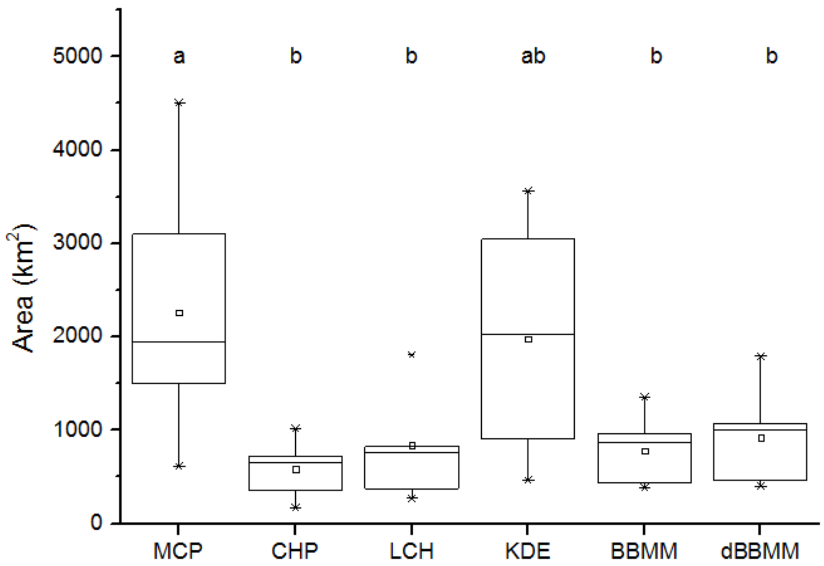

Figure 9: Comparison of the mean wet season home range sizes between the six different home range estimators. Different superscript letters indicate statistical differences ($p < 0.05$)

Figure 10 shows the dry season home range sizes of the nine elephants estimated by the six different range estimators.

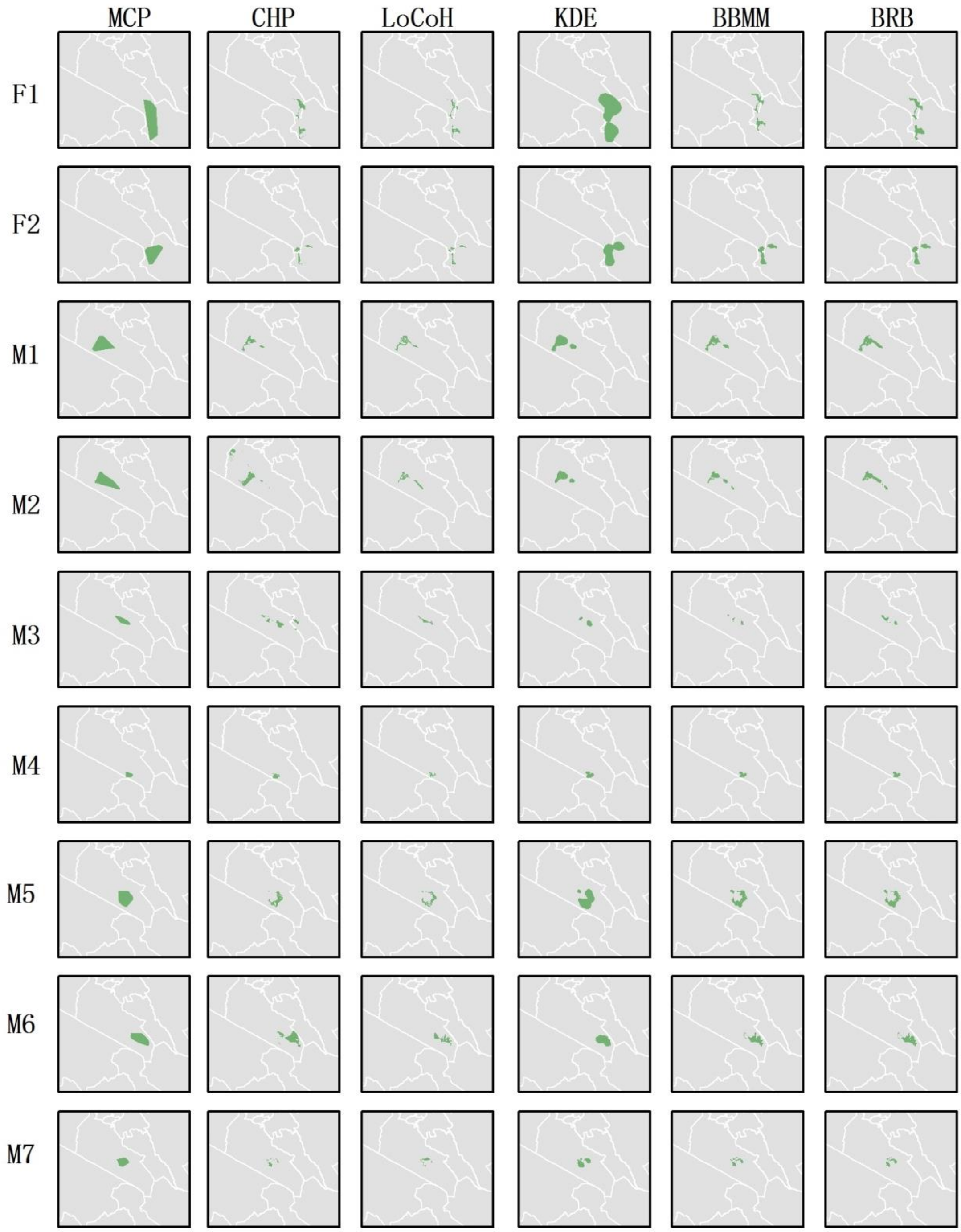

Figure 10: The dry season home range sizes of the nine elephants estimated by the six different home range estimators.

Table 5: The dry season range (km²) of the nine elephants estimated from the six different home range estimators

dry	MCP	CHP	LoCoH	KDE	BBMM	dBBMM
F1	2824.55[2]	586.17	463.63[1]	4538.52	818.00	982.32
F2	1540.03	314.80	277.44[1]	1938.54[2]	734.25	881.74
M1	1520.42[2]	423.16[1]	462.30	1173.40	711.00	801.79
M2	1507.23[2]	277.34[1]	375.08	777.40	521.00	659.76
M3	453.76[2]	48.13[1]	185.35	255.84	110.00	226.55
M4	219.22	171.09	112.59[1]	267.53[2]	202.50	243.18
M5	1346.06	552.41	452.67[1]	1455.92[2]	863.75	820.37
M6	1078.14[2]	936.67	470.99[1]	840.04	612.50	644.62
M7	543.98[2]	124.95[1]	181.69	479.01	250.75	261.14
MEAN	1225.93	381.64	331.31	1302.91	535.97	613.50
SD	785.11	277.84	143.72	1334.68	282.18	295.88

1: Smallest home range area per individual.
2: Largest home range area per individual.

The areas of dry season home range for the nine elephants estimated by the six different estimators ranged from 112.59 km² to 2824.55 km²(see Table 5). The average home range size in the dry season was 731.88±745.47 km². Again, the MCP produced the largest home ranges size (mean=1225.93±785.11 km²) for most of the elephants. The estimated mean dry season home range sizes were significantly different among the six different estimators (Kruskal-Wallis, $p<0.001$). The pairwise test (Figure 12) showed that that the home range sizes estimated by the MCP method and KDE method (mean=1302.91 ±1334.68 km²) were significantly larger than the CHP method (mean=381.64±277.84 km²) and LoCoH method (mean=331.31±143.72 km²).

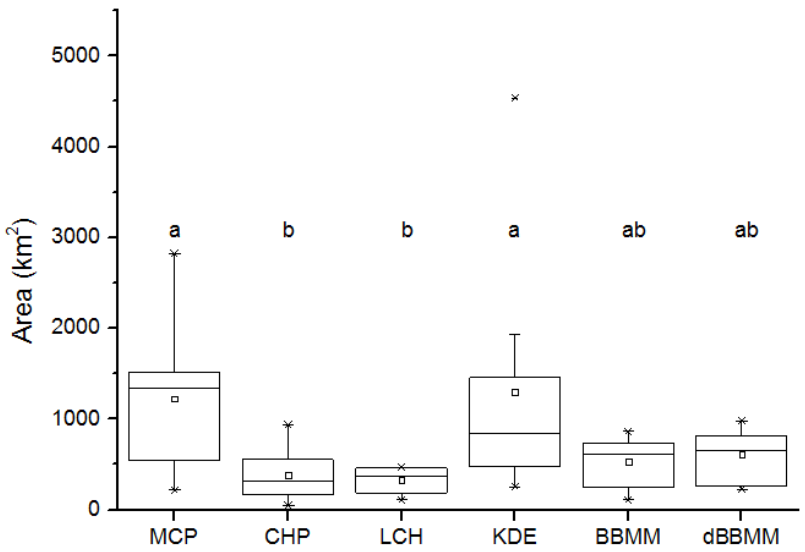

Figure 12: Comparison of the mean dry season home range sizes between the six different home range estimators. Different superscript letters indicate statistical differences ($p < 0.05$)

3.3. Differences in mean annual as well as mean seasonal home ranges among 12 different elephants estimated from the dBBMM

Figure 13 shows the annual as well as the seasonal (wet and dry season) home range sizes of the nine elephants estimated by the dBBMM method.

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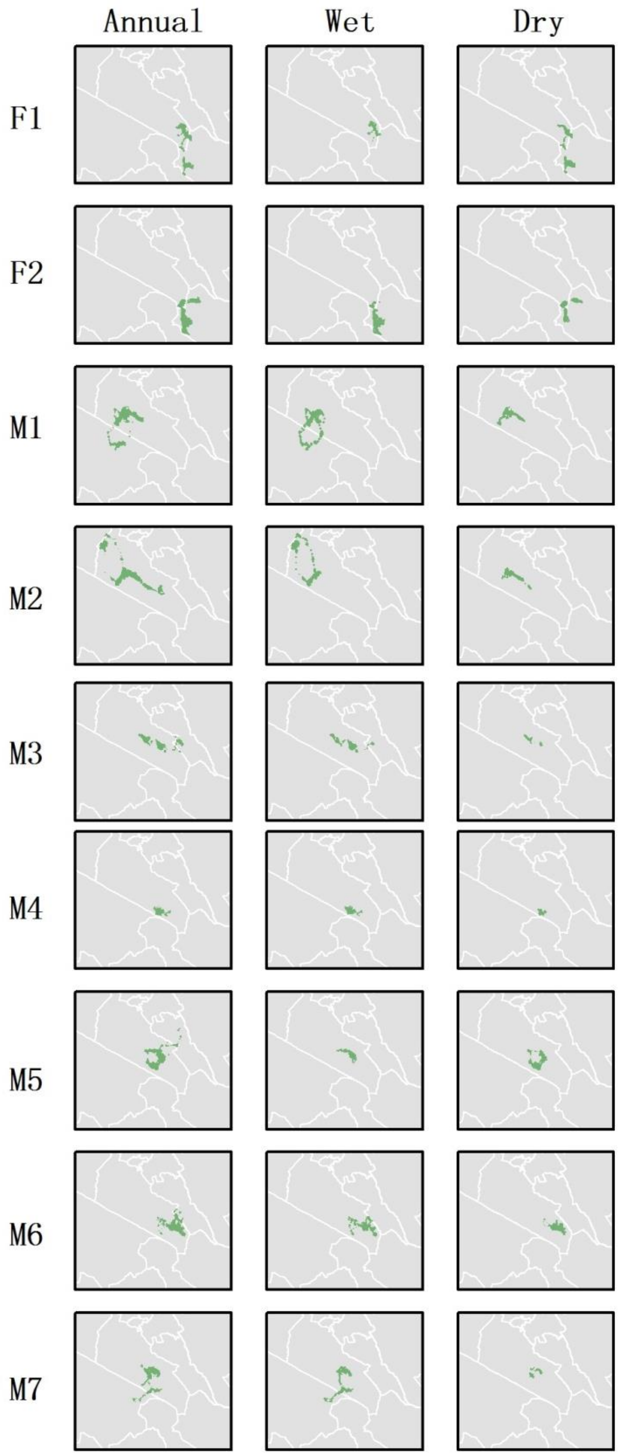

Figure 13: The annual, dry season and wet season home range sizes of the nine elephants estimated by the dBBMM estimators.

Table 6: The annual and seasonal home (dry and wet seasons) range sizes estimated by the dBBMM estimator

	ANNUAL	WET	DRY
F1	1138.27	434.74	982.32
F2	1464.41	1071.83	881.74
M1	1780.35	1792.50	801.79
M2	2036.65	1360.24	659.76
M3	968.67	721.73	226.55
M4	417.90	403.36	243.18
M5	1346.77	460.77	820.37
M6	1238.34	1003.93	644.62
M7	1129.97	1008.93	261.14
MEAN	1280.15	917.56	613.50
SD	467.15	467.12	295.88

The covered a range of 917.56±467.12 km² during wet season covered a range of 613.50±295.88 km² during the during the dry season, what's more, covered a range of 1280.15±467.15 km² annually (

Table 6). The estimated mean home range by individuals significantly among annual and season (Kruskal-Wallis, p=0.0092). With pairwise difference testing (Figure 14) the significant difference of annual home range and seasonal home range during the dry season was found.

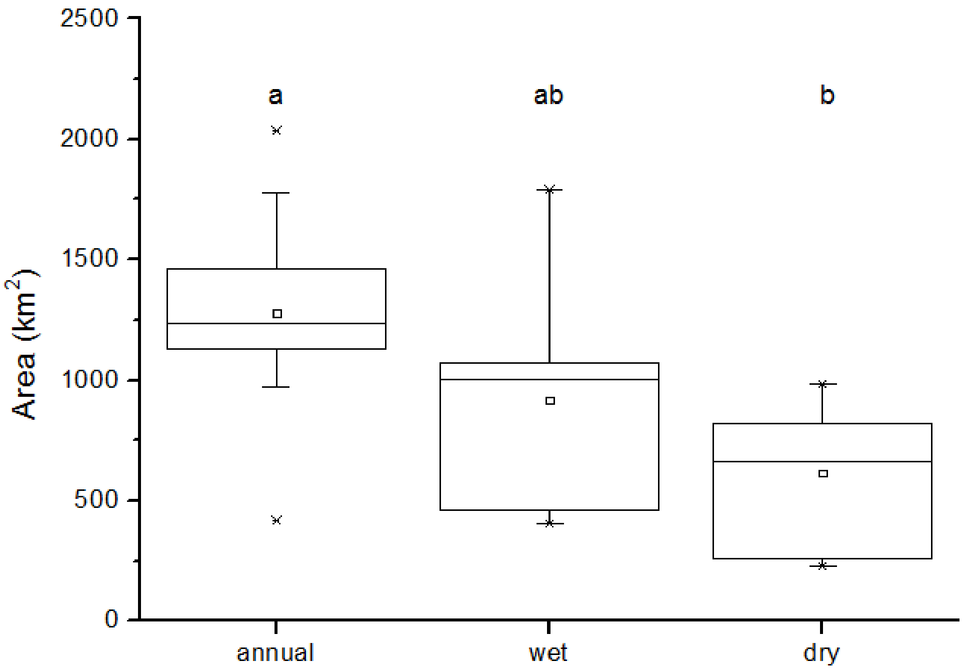

Figure 14: Comparison of home range sizes between the annual, the wet and dry seasons estimated by the dBBMM home range estimator. Different superscript letters indicate statistical differences ($p < 0.05$)

3.4. Differences in the proportion of each land cover type within the mean annual as well as mean seasonal home ranges of elephants estimated from six different home range estimators

Proportion of individual habitat type within each home range ranged from 0.01% to 64.48% for MCP, 0.01% to 59.68% for CHP, 0.01% to 59.71% for LoCoH, 0.01% to 53.56% for KDE, 0.01% to 58.15% for BBMM, 0.01% to 58.50% for dBBMM using the prototype land cover map of year 2016 at 20m (see Table 7. to Table.12).

Table 7: Habitat type proportion by the 100% MCP - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	9.72	3.43	34.47	0.02	0.01	48.30	3.20	0.83	-
F2	10.54	3.01	19.68	-	-	64.48	1.85	0.44	-
M1	31.28	9.37	20.57	-	0.03	38.70	0.01	0.02	0.02
M2	26.01	4.56	24.17	0.07	0.05	43.28	0.63	0.95	0.27
M3	12.09	5.81	30.24	-	-	51.21	0.55	0.10	-
M4	11.64	1.29	46.76	0.11	0.04	34.70	3.59	1.73	0.14
M5	17.64	6.12	30.98	0.02	-	43.39	0.59	1.24	0.03
M6	5.26	5.62	43.84	0.01	0.01	41.43	2.90	0.94	-
M7	17.64	6.12	30.98	0.02	-	43.39	0.59	1.24	0.03
MEAN	15.76	5.04	31.30	0.04	0.03	45.43	1.55	0.83	0.10
SD	8.35	2.32	9.41	0.04	0.02	8.62	1.36	0.56	0.11

Table 8: Habitat type proportion by the 95% CHP - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	3.62	5.78	47.33	-	-	39.40	3.11	0.76	-
F2	10.55	4.93	22.60	-	-	59.68	1.97	0.26	0.00
M1	35.98	2.57	16.24	-	-	45.10	0.01	0.01	0.09
M2	26.01	4.56	24.17	0.07	0.05	43.28	0.63	0.95	0.27
M3	16.82	6.36	23.42	-	-	53.35	0.03	0.02	-
M4	13.38	1.35	45.43	0.07	0.05	36.22	1.64	1.86	0.01
M5	11.36	3.82	29.56	0.08	0.02	52.53	0.30	2.21	0.12
M6	4.62	4.91	46.82	0.01	-	39.44	2.72	1.48	-
M7	15.30	4.50	31.20	0.04	0.02	47.65	0.41	0.81	0.08
MEAN	15.29	4.31	31.86	0.05	0.03	46.29	1.20	0.93	0.10
SD	10.23	1.55	11.80	0.03	0.02	7.72	1.19	0.79	0.10

Table 9: Habitat type proportion by the k-LoCoH - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	5.08	4.37	40.15	-	-	46.75	2.99	0.66	-
F2	9.83	3.72	23.69	-	-	59.71	2.53	0.52	-
M1	34.34	6.46	16.66	-	0.04	42.40	0.01	0.03	0.06
M2	40.91	2.57	15.10	-	-	41.37	0.02	0.01	0.02
M3	12.63	4.05	30.64	-	-	52.47	0.17	0.03	-
M4	13.26	1.72	45.62	0.07	0.06	35.58	1.68	1.99	0.01
M5	29.86	3.24	21.49	0.04	0.04	43.89	0.52	0.87	0.06
M6	5.03	2.58	41.02	-	-	47.00	3.01	1.35	-
M7	17.21	4.60	31.62	0.03	0.01	44.10	0.59	1.75	0.07
MEAN	18.68	3.70	29.56	0.05	0.04	45.92	1.28	0.80	0.04
SD	13.14	1.40	11.08	0.02	0.02	6.91	1.28	0.75	0.03

Table 10: Habitat type proportion by the 95% KDE - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	5.45	8.26	44.03	0.02	-	37.29	3.19	1.05	0.72
F2	14.18	4.61	24.50	0.04	0.02	53.56	2.03	0.53	0.54
M1	33.97	5.51	21.40	-	0.04	39.01	0.01	0.02	0.04
M2	21.53	2.42	24.79	0.09	-	48.00	1.17	1.56	0.43
M3	16.63	9.13	22.34	-	0.05	51.72	0.12	0.02	-
M4	13.12	1.67	46.11	0.01	0.04	37.51	0.58	0.83	0.12
M5	12.23	4.65	28.97	0.03	0.01	51.80	0.63	1.62	0.05
M6	4.19	8.53	44.09	0.01	0.00	39.68	2.48	1.01	-
M7	17.54	6.90	24.64	0.03	0.01	49.78	0.44	0.61	0.04
MEAN	15.43	5.74	31.21	0.03	0.03	45.37	1.18	0.81	0.28
SD	8.88	2.67	10.38	0.03	0.02	6.85	1.13	0.58	0.28

Table 11: Habitat type proportion by the 99% BBMM - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	4.25	5.45	43.08	-	-	43.72	2.71	0.69	0.09
F2	11.00	4.57	23.90	0.01	-	58.15	1.91	0.35	0.12
M1	35.56	4.55	15.91	-	0.01	43.88	0.01	0.01	0.07
M2	32.20	5.74	22.85	-	0.03	39.09	0.01	0.03	0.03
M3	16.87	6.09	23.92	-	-	52.99	0.10	0.02	-
M4	13.62	1.60	44.40	0.06	0.02	38.46	0.79	0.88	0.17
M5	14.31	5.04	27.50	0.05	0.02	50.73	0.30	1.97	0.08
M6	4.86	4.86	43.79	0.01	-	42.82	2.47	1.20	-
M7	16.96	6.07	26.64	0.01	-	49.33	0.37	0.55	0.06
MEAN	16.63	4.88	30.22	0.03	0.02	46.58	0.96	0.63	0.09
SD	10.83	1.37	10.66	0.03	0.01	6.63	1.10	0.65	0.04

Table 12: Habitat type proportion by the 99% dBBMM - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	4.72	5.01	40.60	0.01	-	46.36	2.48	0.68	0.13
F2	11.42	4.52	23.27	0.01	-	58.50	1.83	0.37	0.10
M1	35.32	4.93	16.17	-	0.05	43.45	0.01	0.01	0.06
M2	31.62	5.54	18.28	-	0.04	44.27	0.21	0.03	-
M3	18.44	6.02	24.08	-	-	51.34	0.10	0.02	-
M4	13.83	1.54	44.35	0.09	0.03	37.96	1.00	1.05	0.16
M5	15.17	5.22	26.97	0.05	0.02	50.12	0.38	2.01	0.07
M6	5.07	4.62	43.25	0.01	-	43.42	2.48	1.16	-
M7	16.97	5.60	28.33	0.01	0.01	47.86	0.52	0.65	0.05
MEAN	16.95	4.78	29.48	0.03	0.03	47.03	1.00	0.66	0.10
SD	10.54	1.31	10.68	0.03	0.02	5.88	1.00	0.67	0.04

Table 13: Mean proportion of habitat type using the 20 m land cover map of the year 2016

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
BBMM	16.86	4.86	29.57	0.02	0.01	47.02	0.97	0.63	0.08
BRB	16.95	4.78	29.48	0.02	0.02	47.03	1.00	0.66	0.08
CHP	16.95	4.09	30.86	0.02	0.01	46.08	1.13	0.82	0.05
KDE	16.61	6.11	30.99	0.02	0.02	44.38	1.05	0.64	0.22
LoCoH	16.53	3.68	30.63	0.03	0.02	46.66	1.41	0.97	0.13
MCP	15.76	5.04	31.30	0.03	0.02	45.43	1.55	0.83	0.07
MEAN	16.61	4.76	30.47	0.02	0.02	46.10	1.19	0.76	0.11
SD	0.45	0.84	0.77	0.01	0.01	1.04	0.24	0.14	0.06

Calculations of the areas of individual habitat types with in each home range ranged from 0% to 47.03%. The habitat type shrub land and settlement provided the largest (mean=46.10 ± 1.04, Table.13 and smallest (mean=0.02 ± 0.01, Table.13) proportion for each estimator. With pairwise difference test (Figure 15) indicating that the shrub land and grass land (mean=30.47 ± 0.77, Table.13) produced proportion significantly larger than another habitat type.

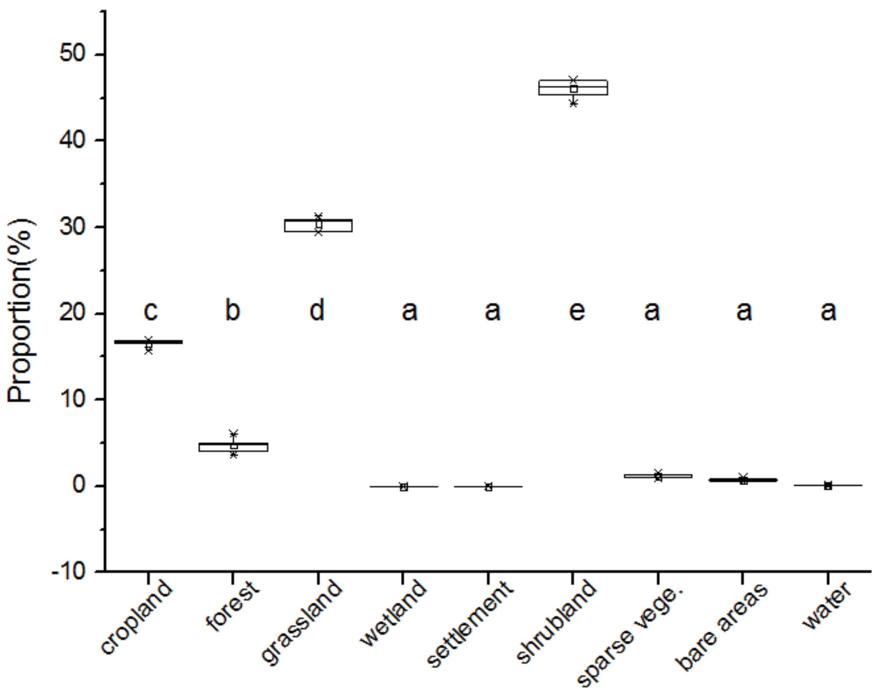

Figure 15: Comparison of the mean proportions of habitat types based on the 20 m land cover map . Different superscript letters indicate statistical differences ($p < 0.05$)

Proportion of individual habitat type with in each home range ranged from 0.02% to 81.68% for MCP, 0.02% to 87.12% for CHP, 0.01% to 81.95% for LoCoH, 0.01% to 83.66% for KDE, 0.07% to 84.96% for BBMM, 0.07% to 85.35% for dBBMM using the 300 m land cover map of the year 2014 (see Table 14. to Table.19).

Table 14: Habitat type proportion by 100% MCP -300m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	58.08	1.33	38.74	0.62	-	-	1	0.24	-
F2	42.41	0.97	26.95	0.02	-	29.52	0.1	0.03	-
M1	5.62	8.74	3.92	0.04	-	81.68	-	-	-
M2	6.94	7.69	16.54	1	-	55.79	2.17	9.71	0.17
M3	10.27	22.35	10.49	6.49	-	50.41	-	-	-
M4	1.43	9.56	3.63	14.58	-	54.1	15.35	1.14	0.21
M5	29.61	24.82	6.38	8.1	-	26.56	3.49	0.99	0.05
M6	4.61	9.2	18.72	9.57	-	55.73	1.88	0.29	-
M7	6.56	40.18	8.65	9.73	-	24.31	10.08	0.38	0.11
MEAN	18.39	13.87	14.89	5.57	-	47.26	4.87	1.83	0.14
SD	20.17	12.81	11.78	5.34	-	19.48	5.67	3.50	0.07

Table 15: Habitat type proportion by the 95% CHP - 300m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	54.09	0.86	36	3.27	-	-	5.5	0.27	-
F2	42.73	0.78	22.14	0.04	-	34.18	0.12	-	-
M1	5.12	1.19	6.44	0.11	-	87.12	0.02	-	-
M2	6.59	1.81	5.87		-	85.65	0.07	-	-
M3	10.98	33.28	5.17	5.85	-	44.73	-	-	-
M4	1.44	10.83	4.78	15.16	-	51.94	14.85	1	-
M5	17.58	31.4	8.92	12.95	-	14.73	10.4	3.84	0.19
M6	1.42	5.89	18.69	8.48	-	63.28	1.84	0.4	-
M7	6.56	40.18	8.65	9.73	-	24.31	10.08	0.38	0.11
MEAN	16.28	14.02	12.96	6.95	-	50.74	5.36	1.18	0.15
SD	19.08	16.19	10.63	5.64	-	26.74	5.78	1.52	0.06

Table 16: Habitat type proportion by the k-LoCoH - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	53.08	0.72	41.16	1.53	-	-	3.1	0.41	-
F2	46.84	0.46	23.27	0.06	-	29.17	0.12	0.08	-
M1	6.43	7.51	3.87	0.23	-	81.95	-	0.01	-
M2	5.71	9.74	16.13	1.81	-	59.03	5.15	2.08	0.35
M3	10.2	24.35	13.02	5.82	-	46.62	-	-	-
M4	1.67	9.93	4.46	15.82	-	51.12	15.91	1.09	-
M5	33.61	18.54	7.85	9.01	-	25.37	3.98	1.53	0.1
M6	7.62	7.89	19.52	11.17	-	48.95	4.43	0.42	-
M7	7	36.77	10.61	13.29	-	20.58	9.74	1.86	0.14
MEAN	19.13	12.88	15.54	6.53	-	45.35	6.06	0.94	0.20
SD	19.80	11.77	11.62	6.01	-	20.17	5.20	0.82	0.13

Table 17: Habitat type proportion by the 95% KDE - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	19.73	5.08	13.83	2.58	-	56.84	1.03	0.2	0.72
F2	34.44	3.27	22.59	0.63	-	38.26	0.26	0.03	0.51
M1	7.49	1.16	7.63	0.04	-	83.66	0.01	0.01	-
M2	9.31	8.68	7.83	0.99	-	73.17	0.01	0.01	-
M3	13.65	25.5	5.72	4.7	-	50.43	-	-	-
M4	1.66	10.71	4.17	9.32	-	61.98	11.52	0.5	0.14
M5	15.55	31.63	8.4	14.73	-	17.51	9.28	2.8	0.1
M6	2.91	7.37	18.74	6.2	-	63.51	0.97	0.31	-
M7	7.15	38.73	1.6	10.63	-	34.12	6.55	1.17	0.05
MEAN	12.43	14.68	10.06	5.54	-	53.28	3.70	0.63	0.30
SD	10.11	13.66	6.94	5.12	-	20.59	4.69	0.96	0.30

Table 18: Habitat type proportion by the 99% BBMM - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	20.74	1.81	17.61	1.14	-	57.05	1.36	0.22	0.07
F2	39.15	1.38	22.94	0.43	-	35.87	0.11	0.1	-
M1	6.02	2.6	6.34	0.09	-	84.96	-	-	-
M2	8.44	10.35	7.84	1.29	-	71.94	0.14	-	-
M3	12.11	26.87	6.39	4.56	-	50.07	-	-	-
M4	1.95	11.53	5.07	11.6	-	57.82	11.74	0.12	0.17
M5	17.01	29.43	8.14	12.3	-	18.95	10.75	3.27	0.16
M6	3.02	6.42	18.24	7.78	-	62.36	1.86	0.32	-
M7	7.34	41.62	6.11	8.93	-	27.3	8.1	0.52	0.1
MEAN	12.86	14.67	10.96	5.35	-	51.81	4.87	0.76	0.13
SD	11.64	14.48	6.70	4.91	-	21.26	5.14	1.24	0.05

Table 19: Habitat type proportion by the 99% dBBMM - 20m resolution land cover map (%)

	Crop land	Forest	Grass land	Wet land	Settlement	Shrub land	Sparse vege.	Bare area	Water
F1	22.53	1.47	19.83	1.28	-	53.36	1.18	0.23	0.11
F2	40.49	1.33	24.2	0.4	-	33.38	0.1	-	0.1
M1	6.54	2.37	5.64	0.07	-	85.35	0.02	-	-
M2	8.84	10.81	7.81	1.71	-	70.5	0.33	-	-
M3	11.39	25.09	6.15	4.3	-	53.07	-	-	-
M4	2.46	14.55	6.57	16.66	-	41.98	17.1	0.47	0.21
M5	16.76	30.49	8.52	11.93	-	18.5	10.62	3.04	0.14
M6	3.78	6.52	19.06	7.84	-	60.89	1.62	0.31	-
M7	6.71	40.03	7.17	9.7	-	27.6	8.13	0.58	0.08
MEAN	13.28	14.74	11.66	5.99	-	49.40	4.89	0.93	0.13
SD	12.03	14.08	7.21	5.87	-	21.33	6.37	1.19	0.05

Table 20: Mean proportion of habitat type using the 300 m land cover map of the year 2014

	Crop land	forest	Grass land	Wet land	Settle ment	Shrub land	sparse vege.	Bare area	water
BRB	13.28	14.74	11.66	5.99	-	49.40	4.89	0.93	0.13
BBMM	12.86	14.67	10.97	5.35	-	51.81	4.87	0.76	0.12
KDE	12.43	14.68	10.06	5.54	-	53.28	3.70	0.63	0.30
LoCoH	19.13	12.88	15.54	6.53	-	45.35	6.06	0.94	0.20
CHP	16.28	14.02	12.96	6.95	-	50.74	5.36	1.18	0.15
MCP	18.39	13.87	14.89	5.57	-	47.26	4.26	1.60	0.13
MEAN	15.40	14.14	12.68	5.99	-	49.64	4.86	1.01	0.17
SD	2.95	0.72	2.19	0.63	-	2.94	0.82	0.35	0.07

Calculations of the areas of individual habitat types with in each home range ranged from 0.13% to 53.28%. The habitat type shrub land and water provided the largest (mean=49.64±2.94, Table.20) and smallest (mean=0.17 ± 0.07, Table.20) proportion for each estimator. With pairwise difference test (Figure.16) indicating that the Shrubland produced proportion significantly larger than another habitat type.

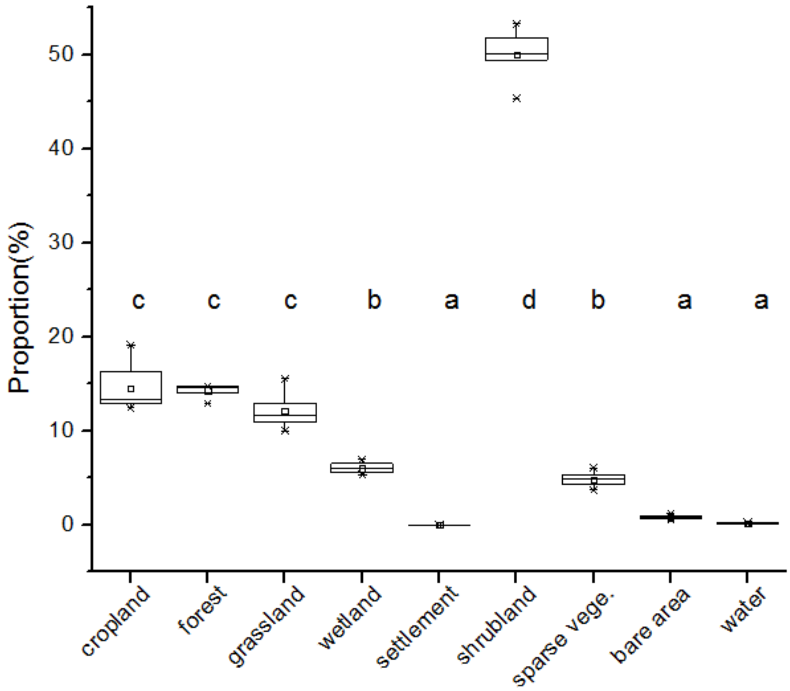

Figure 16: Comparison of the mean proportions of habitat types based on the 300 m land cover product. Different superscript letters indicate statistical differences ($p < 0.05$)

Table 21: Most utilized habitat with 20 m resolution land cover product

	MCP	CHP	LoCoH	KDE	BBMM	dBBMM
F1	Shrubland	Grassland	Shrubland	Grassland	Shrubland	Shrubland
F2	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M1	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M2	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M3	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M4	Grassland	Grassland	Grassland	Grassland	Grassland	Grassland
M5	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M6	Grassland	Grassland	Shrubland	Grassland	Grassland	Shrubland
M7	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland

Table 22: Most utilized habitat with 300 m resolution land cover product

	MCP	CHP	LoCoH	KDE	BBMM	dBBMM
F1	Cropland	Cropland	Cropland	Shrubland	Shrubland	Shrubland
F2	Cropland	Cropland	Cropland	Shrubland	Cropland	Cropland
M1	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M2	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M3	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M4	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M5	Cropland	Forest	Cropland	Forest	Forest	Forest
M6	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland	Shrubland
M7	Forest	Forest	Forest	Forest	Forest	Forest

Dominant habitat identified as shrub land in most of the case. When using the prototype land cover map of the year 2016 at 20m resolution (Table.21), elephants F1, M4 and M6 showing a different dominant habitat from the others which chose the glass land as most utilized habitat. When using the 300 m land cover map of the year 2014 (Table.22), elephants F1, F2, M5 and M7 giving a different dominant habitat type from the other elephant. F1 and F2 chose Cropland as dominant habitat and M5, and M7 chose forest as the dominant habitat.

4. DISCUSSION

4.1. The performance of six different home range estimators

There are currently six home range estimators available for use in these studies. Of the six home range estimators, the CHP method produced the smallest home ranges size with almost all individuals. Most of the largest home ranges size were delineated using the MCP and KDE methods. The MCP, the CHP, and the LoCoH methods delineate home range using the points themselves as vertices for the home range polygons. The CHP method excludes some areas and, therefore, produces smaller home ranges than other method. The KDE, BBMM and dBBMM methods predict movement past the points and calculated velocities. Since the points were taken at such infrequent intervals, the BBMM and dBBMM method predicted movement farther out from the points than did the KDE, in most cases.

This study uses open-source software Program R to determine the selection of an appropriate estimator for estimation of home range. There are many advances in using R package to estimate home range, for example, it is freely available and powerful at statistical analysis. However, drawing map and data management are not as user friendly as software like ArcGIS. Many researchers estimate home range base on the extension of ArcGIS or OpenJump. Combine estimator from R package and extension to some extent can increase the efficiency of data process, for example, calculating home range with the CHP and the LoCoH method consume a large amount of time for big tracking point data set.

4.2. Annual and seasonal home ranges of elephants

Kikoti and Griffin, (2009) reported a home range of 21 collared elephants varied from 191 to 3,698 k m^2 (100% MCP) in northern Tanzania. More or less similar to that study, Thouless (1996) reported the home range area of 20 collared female elephants varied from 102 to 5,527 km^2 (100% MCP) in northern Kenya. But Douglas-Hamilton et al. (2005) reported the home ranges area of 11 elephants varied from 11 to 5,520 km^2 in southern and central Kenya. Unlike than the previous findings, results of this species shows that annual home range of individual elephant is ranged from 282.76 km^2 (100% MCP) to 9177.09 km^2 (CHP) in the study area. Variation of home range studies gives more or less similar results. The elephants require space outside the protected areas within the larger Amboseli ecosystem. It is important to secure the space for elephants outside the protected areas for their continued use and future existence in the ecosystem. This can be achieved by direct purchase of land used by elephants outside the protected areas as well as the establishment of successful community and private conservancies on space utilized by elephants outside the protected areas.

Compare to seven bulls, only two females were used in this study. Results of this study did not show a clear pattern between females (3039.86 to 567.55 km^2) and bulls (282.769 to 177.09 km^2). However, Kikoti (2009) reported that on overall as well as seasonal time scales, bulls always had a larger home range than females using the MCP (100%) method and the KDE (95%) method which matches with previous studies (Stokke & du Toit, 2000). The reason is that females have higher nutritional needs due to body size and reproductive demands (Stokke & du Toit, 2000) and also female herds commonly consist of younger elephants which make it for the whole herd to cope with extensive movements (Ngene et al., 2009). However male herds consist of bulls on almost the same age, and they are able to roam around in larger areas as their movements are not interfered with by young individuals who cannot cope with rigorous movements like females (Douglas-Hamilton et al., 2005; Ngene et al., 2009). It is evident that bulls will, therefore, require more space than females, a factor critical for them to continue accessing females on estrous at different localities within the larger Amboseli landscape. Efforts to secure space outside the protected areas should be enhanced to ensure it is available to the bull elephants.

The previous study identified that the home range of the elephants are bigger in winter and smaller in summer the home range of bull elephant in summer is 33 to 40 km^2, and that of winter is 61 to 71 km^2 (Shannon et al., 2006). Unlikely In this study, the home range of the elephant is bigger in the wet season (February to May) and smaller in the dry season. (June to October). The elephants can find the water sources near to their habitats, so they don't move further for searching food and water.

4.3. Dominant land cover types utilized by elephants

These home ranges cannot claim to show where the animal has lived. Rather they are used to predict where the animal was likely to have traveled between the times at which the presence points were taken, giving an overall estimation of where the animal lived.

All estimators identified the shrublands as dominant cover in a home range of the elephant in the study area. The grasslands, croplands, and forests are other dominant land cover of the identified hope range of the elephants in the study area (Table 11 and 12). The dominant land cover of the Sumatran elephant is natural forest and pulpwood plantation (Moßbrucker et al., 2016). The African elephants prefer the riverine forests as habitats (Shannon et al., 2006). However, unlikely these findings this study identify the shrublands as major land cover support for the home range of African elephants in Kenya. The Elephants prefer to eat the lagers plants (trees and shrubs)(Koirala, Raubenheimer, Aryal, Pathak, & Ji, 2016) so The preference can be the shrubland rather than the other land cover in the study area of this study.

Result in two land cover products shown slight different. In 300m land cover map, habitat type settlement have not be detected among all individuals, however in 20m land cover map settlement (mean=0.02±0.01, Table 13) take a small proportion since high resolution product can detect fragment settlement what's more in the prototype land cover map of 20m resolution "urban areas" relied on the Global Human Settlement Layer from JRC/EC and on the Global Urban Footprint from DLR(http://2016africalandcover20m.esrin.esa.int/,CCI Land Cover (LC) team, n.d.). Elephant such a water-dependent species (S. Ngene et al., 2017; Western, 1975) water bodies should play a key role within elephant's home range. However, water availability is highly seasonal with in study area, also small area water pond can become a crucial parameter for elephant survival and movement pattern (Gara, 2014) even proportion of water body pretty small (20m land cover map water proportion: mean=0.11±0.06, Table 13; 300m land cover map water proportion mean=0.17±0.07, Table 20) this habitat type

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This study examed the effects of home range estimation techniques on the assessment of habitat utilization by elephants in the Amboseli ecosystem, Kenya. The following conclusions could be drawn from this study:

- There are significant differences in the mean annual as well as mean seasonal home ranges of elephants estimated from the six different home range estimators. Explicitly, the MCP and KDE methods were shown to estimate greater home range than other estimators. The CHP method is shown to estimate the smallest area in annual home range and the LoCoH, BBMM, dBBMM methods shows no significant differences in annual home range. What's more, the CHP, LoCoH, BBMM and dBBMM reveals similar home range area size according to statistical results.
- There are significant differences in mean annual as well as mean seasonal home ranges among 12 different elephants estimated from the dBBMM home range estimator. Annual home range and seasonal home range during dry season have detected significant different.
- There are significant differences in the proportion of each land cover type within the annual home ranges of elephants estimated from six different home range estimators.
- The dominant habitat type – shrub land was consistent between home range estimation techniques in most cases.

5.2. Recommendations

It is still difficult to say which is the single best home range estimators, however the methods MCP and the KDE can be a great start point of home range study. The CHP method and the LoCoH have silight tendency to unestimate home range size. The BBMM and the dBBMM reveal good Performance. In addition, the shrub land is the most important land cover type that was used by elephants in Amboseli ecosystem. We therefore suggest to protect and monitor this land cover type for the conservation of the elephant in this ecosystem.

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