Home-Range Analysis of the Endangered Roan Antelope (*Hippotragus equinus langheldi*) in Ruma National Park, Kenya

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Abstract

The roan antelope was formerly widely distributed in Africa but now its distribution range is so drastically reduced that the species is faced with the risk of extinction. In Kenya, only a remnant of less than 50 roans is left in Ruma National Park (RNP). Understanding the home range characteristics of this endangered species is a prerequisite for designing interventions for sustainable conservation. This study was carried out to investigate the differences and interactions of the home ranges of roan groups and lone males, determine the best home range estimator for the endangered roan antelope, assess various home range indices and characteristics of roan antelopes in different seasons and map the overlap of home ranges of roan groups and lone males in RNP. Data was collected on three roan groups and three lone males for six months using ground-tracking in RNP. Data analysis was done in the adehabitat package of the R statistical computing software using 3 home range estimators: minimum convex polygon (MCP), local convex hulls (LCH) and fixed kernel density (KDE_{href}). Results showed that mean ± S.E home-ranges (km^2) for 95% levels were 6.01 ± 0.14, 4.64 ± 0.13 and 4.64 ± 0.16 for the roan groups and 3.14 ± 0.50, 3.35 ± 0.47 and 4.72 ± 0.49 for the lone males using MCP, LCH and KDE_{href}, respectively. The LCH produced more realistic home-ranges that aligned with park fences and omitted inaccessible steep areas. Analysis of wet and dry seasonal variation in home range characteristics showed no significant difference in home-ranges sizes, the distance travelled daily and average speed of movement. However, during the dry season roan groups significantly spread less ($t = 4.399$, $df = 65$, $p < 0.0001$) and had larger herd sizes ($t = 5.073$, $df = 65$, $p < 0.0001$) than in the wet season. These findings can help formulate a roan recovery conservation strategy with clear guidelines on habitat management.

Key words: Adehabitat, home range analysis, roan antelopes, Ruma National Park,

INTRODUCTION

A home range can be defined as an area repeatedly occupied by an animal during a specified time period (Katajisto and Moilanen, 2006; Kenward, 2001; White and Garrot, 1990). Objective estimation of the size, shape and structure of the home range of a species is vital to understand that species' behavioural ecology and management requirements (Kenward, 2001; Swihart and Slade, 1985). Estimation of home range size is vital to estimate the minimum viable area of a recovery sanctuary for an endangered species. Home range shape is important to understand how the species home range is spatially placed in the park in relation to vital resources and infrastructure as well as how home ranges for different breeding groups fit together with those of lone males and bachelor herds. Study of home range structure can be used to predict the likelihood of encounter during population census (Kenward, 2001) or to reveal details of how individuals intensively use different parts of their home range.

Many techniques have been developed to estimate an animal's home range based on data collected using radio-tracking techniques or field observations (Katajisto and Moilanen, 2006; Kernohan *et al.*, 2001). Critical reviews of the existing techniques for home range analysis have been carried out by Worton (1987), Harris et al (1990), White and Garrott (1990), Kenward (2001), and Laver and Kelly (2008). However, there is still no consensus on the best home range estimators and no single best method for estimating all home range characteristics. As a result, many authors recommend the use of more than one home range estimator in any single study (Huck *et al.,* 2008 ; Wauters *et al.,* 2007 ; Hemson *et al.,* 2005), especially where there are different objectives to be achieved.

The selection of an appropriate method for home range analysis depends on four main factors (Getz and Wilmers, 2004; Kenward, 2001). First, the biological questions being asked and hence the particular home range indices required. For example, some estimators are good at estimating the home range size and shape whilst others give more details on the home range structure. Second, the choice is dependent on behavioural characteristics of the species being studied, that is, how the animals move in relation to resources. For example, if animals are foraging in habitats with abrupt boundaries, polygon methods may be the best (Kenward, 2001). Third, the sample size of collected data determines which estimator is valid. Some estimators such as ellipses can produce stable home ranges with less than 15 animal locations while others such as grid cells need at least 100 locations (Kenward, 2001). Fourth, the choice is also determined by the accuracy and detail required by the research. In practice a balance must be struck between the level of accuracy and the scope of details to be revealed by home range analysis. To achieve both high accuracy and greater detail, large numbers of locations that may not always be available or maybe too costly to collect are required.

Since the roan antelopes in RNP have not been studied in details, three commonly used home range estimators were used to obtain home range size, shape and structure for comparisons and also to form baseline information for future studies. The selected estimators were: (1) minimum convex polygon (MCP), (2) kernel density (KDE) and (3) local convex hull (LCH). Selection of these three estimators provided adequate variety of methods needed for analyzing the diverse nature of the available roan antelope data and answering various biological questions. The three selected home range estimators have particular advantages over other methods that make them more suitable for this study.

The MCP method still remains the most widely used technique for estimation of home range size and shape and for comparison of home ranges analysis between studies (Plotz *et al.,* 2016; Huck *et al.,* 2008; Simcharoen *et al.,* 2008; Wauters *et al.,* 2007; Franzreb, 2006; Harris *et al.,* 1990; White and Garrot, 1990). The MCP method is easily understood and can be computed using all available home range analysis computer software. Although the MCP method has been shown by many authors to yield overestimated home ranges (Katajisto and Moilanen, 2006; Ryan *et al.*, 2006; Burgman and Fox, 2003), it has also been shown to produce more realistic home range estimates when sample size is relatively small (Wauters *et al.,* 2007). The home range size and shape of MCP is greatly affected by outlying locations, which makes it yield overestimated home ranges covering large unused areas. However, these outliers can be excluded effectively before computing the home ranges using several techniques: (1) excluding 5% of all the outer locations in a home range (Ackerman *et al.,* 1990); (2) testing for discontinuity in frequency of locations in grid cells (Samuel *et al.,* 1985); (3) use of statistical outlier exclusion methods (Hodder *et al.*, 1998; Ackerman *et al.*, 1990), and (4) using utilization plots from incremental cluster analysis (Kenward, 2001; Hodder *et al.,* 1998; Clutton-Brock *et al.,* 1982).

The KDE method is mathematically robust, less-matrix-dependent, produces consistent results and it is also very good in highlighting areas of concentrated activity (Campbell *et al,* 2013; Worton, 1987). In agreement, Worton, (1989) also noted that the KDE method is often sufficient to make all the useful interpretations of an animal's movements from the home range data and that they have an intuitive appeal to biologists. Also the KDE method with relatively low smoothing can obtain stable home range sizes with 15-30 locations (Plotz, 2016; Seaman *et al.,* 1999; Powel *et al.*, 1997; Kenward, 2001).

The LCH method (Getz et al., 2007; Getz and Wilmers, 2004) is a generalization of the minimum convex polygon (MCP) method and is also essentially a nonparametric kernel method. The LCH has been shown to construct more appropriate and realistic home ranges and utilization distributions than the parametric kernel methods (Getz *et al.*, 2007; Huck, *et al*; Laver and Kelly, 2008), because of its ability to identify hard boundaries (such as park fence lines, rivers and cliffs) and irregular structures (such as rocky outcrops), its convergence to the true distribution as sample size increases, and capability to analyze sample data with replicates. The LCH method is relatively new and needs to be evaluated to ascertain its usefulness in comparison to the other established home range estimators.

This study was carried out to investigate the differences and interactions of the home ranges of roan groups and lone males, determine the best home range estimator for the endangered roan antelope, assess various home range indices and characteristics (distance travelled per day, speed of movement, spread of the group and herd size) of roan antelopes in different seasons and map the overlap of home ranges of roan groups and lone males in RNP. Since home range estimators differ in accuracy and performance, it was predicted that there would be varying accuracy and performance among the three home range estimators (MCP, KDE and LCH) used. It was also predicted that (i) roan groups would occupy larger home ranges as they require more resources than the individual lone males; (ii) the roan group home ranges would not overlap each other but that the lone males would track the roan groups in pursuit of females or with attempt to overthrow the dominant male; and (iii) the roan groups would be larger, spread less and travel longer distances at greater speed in the dry season than in the wet season, due to constraints of limited resources in the dry season.

MATERIALS AND METHODS

Collection of roan movement and distribution data

Data on roan movement and distribution in RNP were collected using the point location sampling methods as described by Kenward (2001). The roan locations were collected at an interval of 2 hours which was determined by Kimanzi (2012) to be the optimal interval for sampling roan antelope movement data. Data were collected for 3 roan groups and three lone males. For the roan groups, 6 locations were recorded per day (that is, at 0800, 1000, 1200, 1400, 1600 and 1800 hours) whereas only one location was recorded per day due to difficulties of locating and tracking lone males.

For each target roan individual, the following information was recorded: XY location coordinates of observer using a GPS, estimated distance to the animal, angle direction of the animal using a pair of binoculars with in-built compass. In addition, for each group, the number and spread of the group were recorded. For each target roan animal, data were collected once per week for 6 months. In total, there were 22 days of data for groups 1 and 2 each, and 7 days for group 3, which translated into 132 animal locations for group 1 and 2 each, and 42 locations for group 3. The third group had fewer locations because it was formed by females that split from group 1, midway through the fieldwork period. The three lone males had 20, 15, and 14 sample sizes, respectively.

Data analysis

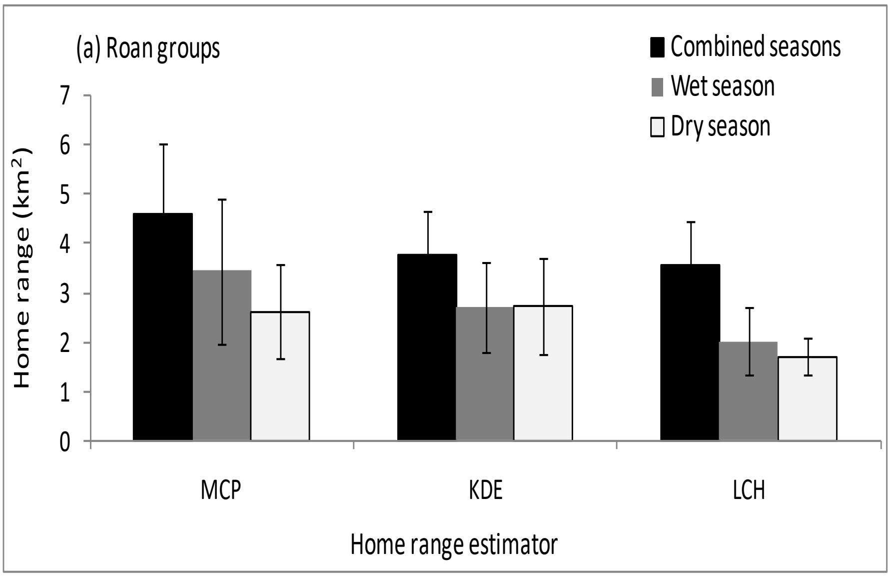
Home range analysis for roan groups and lone males was carried out using the three estimators (MCP, KDE and LCP) in Adehabitat package (Calenge, 2006) of the R statistical computing software (R Development Core Team, 2007). Home range sizes, shapes and overlap were compared for the roan groups and lone males using independent t-test. For the three roan groups, four home range indices were computed for the wet, dry and combined seasons. The four indices were: distance travelled per day, speed of movement, spread of the group and herd size. Comparison of home range sizes among the three estimators was done using Kruskal Wallis test.

RESULTS AND DISCUSSIONS

Comparison of home ranges for roan groups and lone males using three estimators

Estimation of home ranges for roan groups using three estimators (MCP, KDE and LCH) yielded insignificantly different estimates (Figure 1). For both the roan groups and lone males the three estimators showed that the combined season estimates were the largest whilst the dry season estimates were the smallest. However, all the three methods indicated that these seasonal differences in home ranges of roan groups and lone males were insignificant. For the combined season, the MCP estimator (Mean±SE = 4.58±1.43) had the largest estimates followed by KDE (3.79±0.86) whilst the LCH estimates (3.57±0.88) were the smallest (Figure 1a). Similarly, for the wet season, MCP (3.44±1.48) had the largest estimates followed by KDE (2.71±0.91) whilst the LCH estimates (2.02±0.67) were the smallest (Figure 1a). However, for the dry season, KDE (2.74±0.98) had the largest estimates followed by MCP (2.63±0.96) whilst the LCH estimates (1.71±0.36) were the smallest (Figure 1a). On the other hand, the KDE produced the highest estimates (3.85±0.94) followed by LCP (2.94±0.51) and MCP (2.81±0.49) for the combined season for lone males (Figure 1b). Contrary, the KDE produced the highest estimates (3.21±1.01; 2.03±0.44) followed by MCP (2.55±0.69; 1.34±0.08) and LCP (2.41±0.43; 0.78±0.13) for the wet and dry seasons, respectively (Figure 1b).

However, considering the home range shape, LCH estimates were more realistic and more accurate as they aligned well with sharp features like park fence that delineates the actual roan home ranges in RNP (Figure 2). Also, the core areas computed by LCH method represented the animals' locations more accurately than the other two methods. The LCH had 3 core areas; KDE had two core areas whereas MCP had a single mononuclear core area, which poorly represented the roans' locations. The home range and core area estimates computed by KDE and MCP spilled over the RNP boundary (Figure 2), implying that they were overestimates. Comparison of home ranges between roan groups and lone males showed no significant differences for all three estimators.



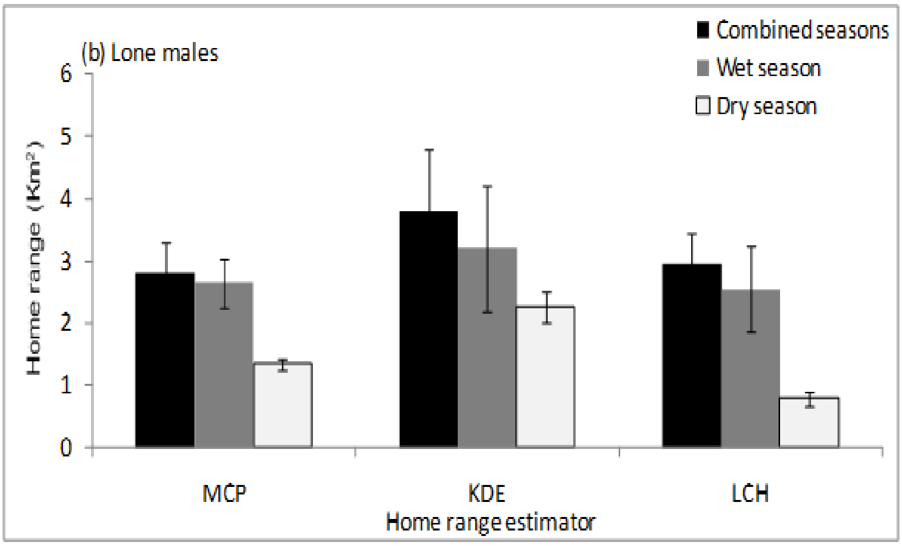


Figure 1: Comparison of home ranges estimates of (a) 3 roan groups and (b) 3 lone males in RNP in different seasons using 3 estimators

All the three home range estimators proved to be useful in characterizing different aspects of the roan home range, but overall the local convex hulls (LCH) method produced the most realistic home range and core area estimates. This is because the LCH home range estimates aligned well with sharp features in the RNP such as the park fence that marks the true roan home range boundary. The LCH method produced three core areas that accurately represent the three suitable patchy habitats near mineral salt lick, water dams and unburned breeding habitat for roan antelopes, respectively. The fixed kernel density (KDE) method produced a home range consisting of two separate portions that accurately represented the roan main habitat utilized most of the time and the breeding habitat. However, the LCH method yielded even a better home range by producing the two portions connected by a narrow corridor that indicates the route used by the roans to migrate to the breeding habitat. The only shortcoming of the LCH method is that its estimates were consistently smaller than those of other methods. This concurs with Getz *et al*, (2004) findings that LCH yields underestimated home ranges. Therefore, to estimate the total range size of roans, it is better to combine LCH with other methods as recommended by Huck *et al.*, (2008) and Laver and Kelly (2008).

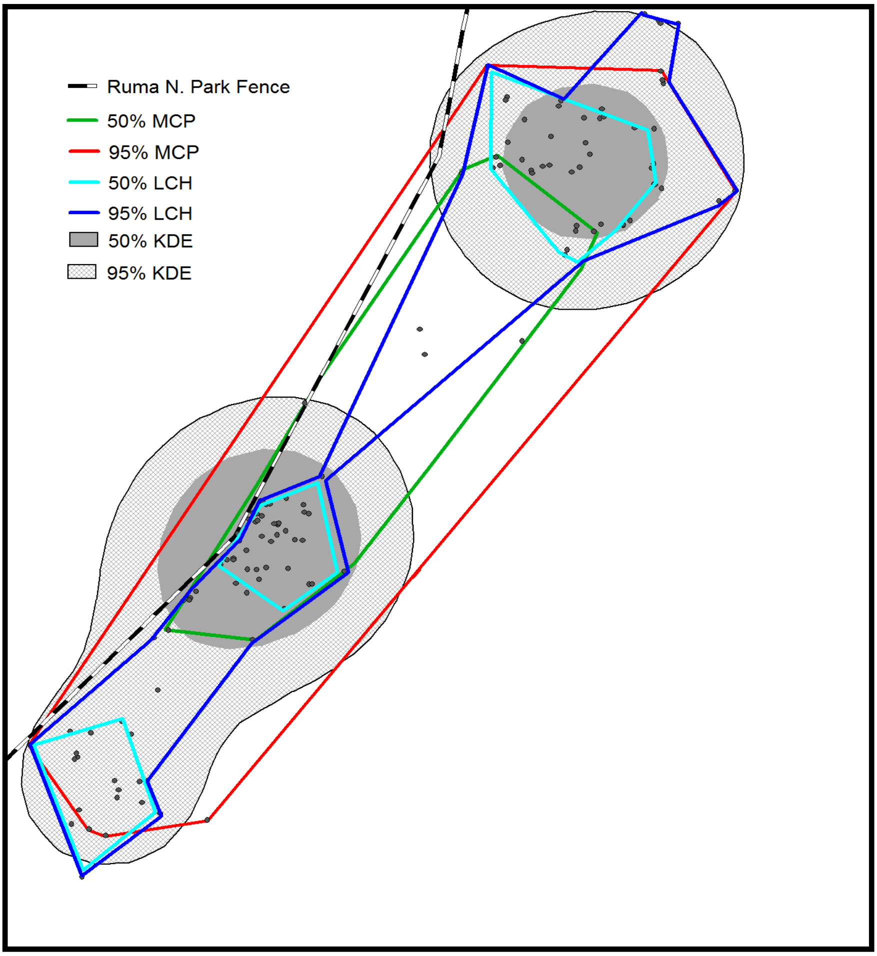


Figure 2: Comparison of home range and core area shapes of one roan group in RNP using three estimators (MCP, LCP and KDE). The black dots represent roan locations.

Home range indices and characteristics of roan antelopes in different seasons in RNP

Analysis of wet and dry seasonal variation in home range characteristics for the roan groups in RNP indicated no significant differences in the mean ± SE distance travelled daily (Dry =1.41±0.10; Wet=1.44±0.12) and average speed of movement (Dry=2.35±0.17, Wet=2.41±0.19) as shown in Table 1. However, during the dry season roan groups significantly spread less ($t = 4.399$, $df = 65$, $p < 0.0001$) and had significantly larger herd sizes ($t = 5.073$, $df = 65$, $p < 0.0001$) than in the wet season (Table 1).

Table 1: Comparison of mean ± SE of range indices in wet, dry and combined seasons for 3 roan groups in RNP. Technique

	Combined seasons		Wet season		Dry season	
Home range Index (units)	mean ± SE	n	mean ± SE	n	mean ± SE	n
Distance travelled per day (km)	1.43±0.08	67	1.41±0.10	41	1.44±0.12	26
Speed (m/min)	2.38±0.13	67	2.35±0.17	41	2.41±0.19	26
Spread of roan group (m)	80.91±6.38	67	147±19.50	41	59.37±4.16	26
Herd size (nos./group)	10.56±0.53	67	8.59±0.59	41	13.96±0.53	26

Note: * indicates statistical significance at p=0.05 for differences between wet and dry seasons; n is sample size; [the] home range estimates were based on the Local Convex Hull (LCH)

Assessment of seasonal variation in various roan home range characteristics showed significant differences in only two of them: group herd size and spread. All the other range characteristics (home range size, daily travel distance, and speed) were not statistically significant, probably due to the small sample size, the short period of data collection, and the use of data for only one year. Also, the roan daily behaviour (such as travel distance and speed) may have been altered by the occurrence of births in two roan groups during the wet season. The larger herd sizes that are spread less in the dry season imply the importance of group living in a harsh environment with limited resources. Dorst and Dandelot (1990) found that during the dry season many roan herds merge together into large groups as a result of food and water shortage. During the wet season there is no limitation of food and water and therefore the individual roans can afford to spread out and groups can split up. Wilson and Hirst (1977) noted that roans could be sedentary and occupy the same home range during the wet and dry season if there is plenty of food and water throughout the year.

Although further investigations are needed, these differences in home range characteristics suggest that in the dry season, the roans' habitat was limited by the availability of water. Roans are highly water-dependent and are always found near water sources (Dorst and Dandelot, 1990). They have been shown to be severely affected by droughts and to move a lot in search of water (Schuette *et al.*, 1998). However, roans in RNP cannot move far due to restrictions of the park fence and the surrounding farming communities.

Mapping the overlap of home ranges of roan groups and lone males in RNP

The KDE estimator was used to assess home range overlap because it was shown to be less sensitive to sample size variation (Kimanzi, 2012) and Kenward (2001) demonstrated that this method can yield stable estimates with small sample sizes. Mapping of home ranges showed more percentage overlap between roan groups and lone males' home ranges than within roan groups or lone males' home ranges (Figure 3). Only the home ranges of 2 roan groups overlapped slightly by 1% between each other whilst the home ranges of all the 3 lone males did not overlap between each other at all (Figure 4). However, the home ranges of all the 3 lone males overlapped substantially with those of their corresponding 3 roan groups. In particular, male 1 overlapped with group 1 by 46%, male 2 overlapped with group 2 by 67%, and male 3 overlapped with group 3 by 47% and with group 1 by 12%.

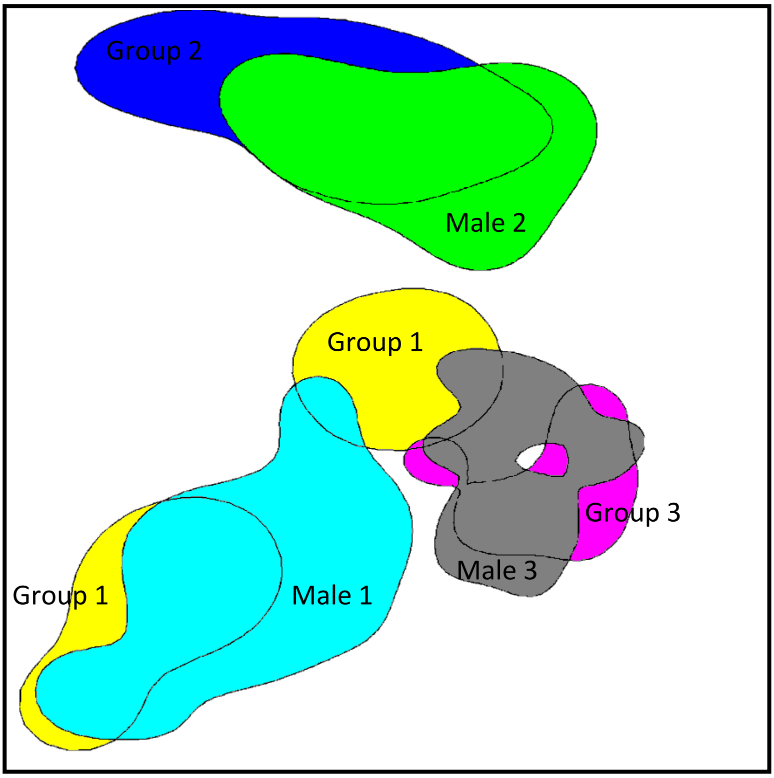


Figure 3: Overlap between home ranges for 3 roan groups and 3 lone males in RNP estimated using fixed kernel density (KDE).

The lack of home range overlap between different roan groups demonstrates that dominant roan bulls defend an area around their herds from intrusion by neighbouring bulls. This is what Joubert (1974) termed the intolerance zone, which differs from a true territory by lack of fixed boundaries. The lone male home ranges managed to overlap with the roan group home ranges by almost 50% because the defended area is not fixed and the lone males keep on tracking the roan groups at a far distance with the aim of accessing females or overthrowing the dominant bull. Joubert (1974) noted that the intruding lone males are not persecuted by the dominant bull as long as they keep a distance of at least 500m away from the female roan herd. Although, there is no evidence of the lone males occupying marginal habitats, in cases where resources are very limited, it is likely that the lone males will be forced by the dominant bulls to occupy marginal habitats most of the time.

	Group 1	Group 2	Group 3	Male 1	Male 2	Male 3
Group 1						
Group 2	0%					
Group 3	1%	0%				
Male 1	46%	0%	0%			
Male 2	0%	67%	0%	0%		
Male 3	12%	0%	47%	0%	0%	

Figure 4: Percentage overlap between and within home ranges of 3 roan groups and 3 lone males in RNP.

CONCLUSION AND RECOMMENDATIONS

The study concludes that the best home range estimator for roan antelopes is local convex hulls (LCH) which produced the most realistic home range and core area estimates. This is because the LCH home range estimates aligned well with the park fence that marks the true roan home range boundary whilst its three core areas accurately represented the three suitable patchy habitats near mineral salt lick, water dams and unburned breeding habitat for roan antelopes. The study revealed that roan group home ranges did not differ significantly from those of lone males. Also, roan group home ranges did not overlap each other but overlapped with that of the lone males by over 45% for all groups because the lone males tracked the roan groups in pursuit of females or with attempt to overthrow the dominant male. For the roan groups, there were no significant differences in home range size, daily travel distance and speed but during the dry season, roan groups significantly spread less and had significantly larger herd sizes than in the wet season.

For sustainable conservation of roans in RNP, it is necessary to employ various habitat management techniques to ensure that the park provides adequate suitable habitat for both roan groups and lone males. These habitat techniques can include prescribed burning and adequate supply of water especially during the dry season and periods of drought.

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Assessing the Economic Value and Credit Market Potential of Carbon Stock in South Nandi Forest, Kenya

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Abstract

Provision of information about carbon stock and potential carbon market for tropical forests ecosystem is an important knowledge base, which is scarce in developing countries, for decision making in carbon trade. Financial benefits of the carbon market, which has not been developed before, in which this study focuses would not only lead to poverty alleviation among local communities but also serve as an incentive for better management of the forest ecosystem. This study aimed at assessing the economic value of carbon stock in South Nandi forest towards securing its credit market for the forest adjacent communities. South Nandi forest is among the few remaining tropical rainforests in western Kenya, and it is a major source of livelihoods for forest adjacent communities. This protected ecosystem hosts a variety of endangered plants, animals and endemic bird species. This study comprised of two forest surveys: Participatory Forest Resource Assessment (PFRA) and carbon assessment survey. Results indicated a total carbon store of 2.8 ± 0.8 million tons of carbon (equivalent to 10.5 ± 2.9 million tons CO_2*). The findings showed that more open forest areas had lower carbon densities. The study found that there was potential for tree planting projects in and around the South Nandi Forest to attract carbon funding either through the regulated carbon credit market under the Clean Development Mechanism (CDM) or through the voluntary carbon market. One option would be to reforest degraded or cleared areas within the forest boundaries with indigenous species. Tree planting projects outside of the forest boundary, such as trees planted on farms, could apply for carbon based funding depending on their management. Activities that reduce deforestation in the South Nandi Forest could also attract REDD (Reduced Emissions from Deforestation and Degradation) project funding.*

Key words: Carbon credit market, Carbon emission, Carbon sequestration, Carbon stock, Poverty alleviation.