Title:

Ranging behaviour and habitat usage in black rhinoceros, *Diceros bicornis*

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Home ranges and habitat use in black rhino

Summary

Home range area and habitat utilsation by black rhinoceros *Diceros bicornis* were studied at Sweetwaters Rhino Sanctuary in the Laikipia district of Kenya, between June and September 1996. The 93 km2 sanctuary is fully fenced, and during the study period held 19 rhinoceros.

Home ranges were estimated from sightings and tracking data; home range area was very variable between individuals (range 225 - 1439 ha, minimum convex polygons), and was independent of age or sex. Groups of rhinoceros shared common home ranges, with little or no overlap between groups; each group consisted of one adult male, one or more adult females and their calves, and sometimes immature animals. All animals have occupied their present home ranges for at least 12 months, and adults of both sexes make occasional excursions outside their normal home range.

Rhinoceros utilise a variety of habitats, but within these show positive selection for certain habitats; home ranges generally included more *Euclea* bush, and less grassland and *Acacia* bush, than expected. Rhinoceros make use of regular resting places, or bedding sites, generally situated in bushland in secluded areas, often in dense thickets. Rhinoceros defecate at dung piles or middens. Middens are located throughout the range not just on the boundaries; the highest density of middens was found in riverine woodland; middens are generally located beside a path (80%), and often show clear signs of the animal scraping the feet through or kicking the deposit (87%). The likelihood of territorial behaviour in adult males is discussed.

***Key words*: habitat selection, home range, Kenya, social behaviour, territory**

Introduction

The black rhinoceros *Diceros bicornis L.* is endangered wherever it occurs in Africa, its numbers having been reduced from an estimated 65,000 in 1970, to about 3,400 in 1990 (Gakahu 1993, Anon. 1993). Population numbers are stable in only four countries, Zimbabwe, South Africa, Namibia and Kenya, which between them have over 90% of the remaining rhinoceros (Gakahu 1993).

Kenya has the only substantial breeding populations of the East African subspecies *D. b. michaeli*, estimated at over 400 animals in 1993 (Anon 1993). The majority of these animals have now been brought into protected sanctuaries, which are generally fenced, can be closely monitored and effectively guarded. The sanctuary policy, combined with intensive anti-poaching efforts, has had promising initial results - the longest established sanctuaries show a population increase of about 10% per year (Anon 1993). These gains offset losses of unprotected animals, and overall the population in Kenya is stable. The long-term management plan for black rhinoceros incorporates restocking historical ranges with surplus animals from the protected sanctuaries as populations increase (Anon 1993).

Despite the current conservation interest in the black rhinoceros, many aspects of its ecology and behaviour are relatively obscure. Most research into rhinoceros population biology and ecology was conducted when large numbers of free-ranging rhinoceros still existed (e.g. Schenkel & Schenkel-Hulliger 1969, Goddard 1967, 1970a, 1970b). From such studies it appears that optimum habitat is thick scrub and bushland, often with some woodland - this supports the highest densities (1.4 rhinoceros / km^2, Goddard 1970a; 1.6 rhinoceros / km^2, Conway & Goodman 1989) and the smallest home range size, as little as 100 ha (Goddard 1967). Open grassland appears the least favourable habitat, supporting densities as low as 0.04 rhinoceros / km^2 (Goddard 1970a) and home ranges up to 10,000 ha (Frame 1980) - the last is larger than some of the fenced rhinoceros sanctuaries (Anon 1993). The most important habitat features appear to be availability of water, food and cover, and absence of human disturbance

(Goddard 1967, Mukinya 1973, Frame 1980, Conway & Goodman 1989, Berger & Cunningham 1995). Leguminous plants form a large proportion of the diet (Goddard 1970b, Oloo, Brett & Young 1994), and legume availability may be a key factor in determining rhinoceros density (Goddard 1970b).

Black rhinoceros are generally thought to be solitary, with the only strong social bond being between a cow and her youngest calf (Schenkel & Schenkel-Hulliger 1969, Goddard 1966, Mukinya 1973, Frame 1980, Hitchins & Anderson 1983). Rhinoceros form other associations of varying duration. Bulls are known to have a consort relationship with oestrus cows (Schenkel & Schenkel-Hulliger 1969); and sub-adults and young adults frequently form loose associations with older individuals of either sex (Klingel & Klingel 1966, Schenkel & Schenkel-Hulliger 1969, Goddard 1967). Some authors have suggested that male black rhinoceros are territorial (e.g. Frame 1980, Hitchins & Anderson 1983), although this has not been demonstrated conclusively. However the home ranges of adjacent females generally overlap more than those of adjacent males, suggesting differences in behaviour between males and females (Mukinya 1973, Conway & Goodman 1989).

Relatively little ecological research has been carried out on small populations of rhinoceros confined to limited areas, although the majority of the remaining black rhinoceros are now confined to small isolated populations (Gakahu 1993). In this paper we describe the home range size and habitat utilisation of black rhinoceros in a fenced sanctuary, and from this determine essential habitat requirements.

Methods

Study area

Sweetwaters Rhinoceros Sanctuary is located in the Laikipia District of Kenya, between 0°00'N and 0°05'N, and between 36°53'E and 37°00'E. The terrain is gently undulating, between 1770m and 1820m altitude. Rainfall averages 800mm per year, concentrated into two rainy seasons, March to May and October to December (Anon 1993).

The 93km^2 sanctuary was created in 1989 as part of the Kenya Wildlife Services Kenya Rhinoceros Project. It is enclosed by an electrified fence, and is considered to be prime rhinoceros habitat, capable of supporting a high density, high productivity rhinoceros population, of great importance to the overall rhinoceros recovery plan in Kenya (Brett 1988, Anon 1993).

Between 1989 and 1993 a total of 21 black rhinoceros were introduced into the sanctuary. By June 1995 there had been 6 deaths, 1 export and 5 viable births, giving a total population of 19 wild rhinoceros. Rhinoceros were assigned to three age classes, similar to those used by Goddard (1967). Adults are full sized animals; immatures are less than full sized but have left their mothers, and calves are still dependent on their mothers. During the study period the population comprised four adult males, four adult females with dependent calves, three adult females without calves, three immature males and one immature female.

Data Collection

Data were collected between July and September 1995, and 165 hours observations recorded. We partitioned the reserve into geographical areas and census walks were conducted in each area in turn, so all areas were covered equally. The position of all sign and sightings of rhinoceros were recorded using a GPS Compass (Model XL1000, Silva (UK) Ltd, Egham, Surrey). Sign included footprints (spoor), dung middens, and bedding sites (rhinoceros frequently use the same place to rest, and through regular use these become bare of vegetation and clearly visible). Footprints of different animals were identified where possible by distinguishing characteristics and size.

In addition to these wider surveys, we made detailed measurements of a number of bedding sites and middens, and recorded details of the suronding vegetation. Efforts were made to sample middens in all the main habitat types and in all areas used by rhinoceros. For each midden the largest and smallest diameter were measured, and the surrounding habitat type, distance to the nearest path used by rhinoceros, and distance to the nearest shrub recorded. A number of bedding sites were also measured. Most bedding sites were regularly used and clearly defined, but any place where tracking indicated a rhinoceros had lain down was considered a bedding site. The area measured was either the limits of the clearly defined cleared area, or, where crushed grass showed where a rhinoceros had lain down, the outer limits of the body outline.

Home ranges

We calculated home ranges as minimum convex polygons (Mohr 1947, Southwood 1966), and harmonic mean 95% isopleth (Dixon & Chapman 1980), using all sign (sightings, spoor, middens and bedding sites). The minimum convex polygon is the oldest method available and widely used, despite its drawbacks - it gives no indication of how the range is utilised, and is sensitive to bias by both small sample sizes and extreme outlier locations. The harmonic mean is second only to minimum convex polygon in frequency of usage (Harris *et al* 1990). It gives a better fit to a number of different types of utilisation distribution than most other methods, including multiple-centre distributions (Boulanger & White 1990).

The software package Ranges IV for PC (Kenwood 1990) was used to calculate home range areas; harmonic means were calculated using a 40x40 grid, with fixes centred in each grid cell.

Many home range estimation methods can be significantly biased if the data is temporally autocorrelated (Swihart & Slade 1985, Harris *et al* 1990). To avoid this, when tracking a rhinoceros we recorded only the position where spoor could first be identified. Only one sighting or fresh spoor was recorded for an individual rhinoceros on any one day. When bedding sites or middens were encountered close together all were recorded, as these sites are visited repeatedly by rhinoceros, so indicate a genuine high usage of that area.

Core areas

Animals do not use their home ranges evenly - the area or areas used most intensively are generally known as the core area(s), although this is rarely defined precisely (Harris *et al* 1990). Cluster analysis indicated that most rhinoceros had several centres of activity, thus calculating core areas as mononuclear polygons was inappropriate. Instead two other methods of core area estimation were used. 70% cluster polygons (Kenwood 1990) were used as clusters show activity nucleii clearly, and the 70% polygon showed the lowest coefficient of variation between all animals. In addition, core area was estimated from the 70% isopleth of the harmonic mean range estimator.

Overlap between the home range and core area estimates for all pairs of animals were also calculated.

Habitat composition of home ranges

A number of habitat types were identified, based on the composition of the dominant plant species, as: (i) Grassland, with less than 20% shrub cover. (ii) *Acacia* bushland: grassland with 20-90% shrub cover, dominated by whistling thorn *Acacia drepanolobium*. (iii) *Euclea* bushland: grassland with 20-90% shrub cover, dominated by mukinyei *Euclea divinorum*. (iv) Mixed bushland: grassland with 20-90% shrub cover, with no one species dominant. (v) Dense *Euclea* bushland: >90% cover, dominated by *Euclea divinorum*. (vi) Riverine woodland:

dominated by Fever trees *Acacia xanthophloea*. and with an understorey dominated by *E. divinorum*. (vii) Marsh: characterised by low-growing vegetation and water-logged soil.

All habitat data were plotted onto a 1:50,000 map, and the area of each habitat type calculated. From this map the area of different habitat types within each home range and core area were calculated.

Patterns of habitat usage within home ranges

As varying amounts of time were spent searching different areas and habitats, intensity of rhinoceros usage was calculated on the basis of sign found per unit time. Census walks were carried out at a steady pace and so are a reliable estimate of distance covered. Amount of sign was analysed in respect to (i) different habitat types; (ii) proximity to water (as the dense bush near most permanent water makes direct estimation of distance difficult any sign within sight of or within 5 minutes walking of water was considered close to water); (iii) disturbance. (Sources of disturbance were considered to be human habitations inside the reserve and near the perimeter fences outside the reserve. Internal roads were not considered a source of disturbance as most wildlife is habituated to motor vehicles, and traffic is very light within the reserve).

In each case the amount of observed sign was compared to that expected if distribution is random using χ^2. To determine the effects of proximity to water and human disturbance, comparisons were made within in each habitat type - in some cases data from similar habitats was pooled due to low numbers.

Results

Home ranges

Home range estimates are often sensitive to small sample sizes (Harris *et al* 1990, Boulanger & White 1990). To determine whether the sample sizes collected were adequate to reliably estimate home ranges we plotted the total range area as convex polygons and 95% harmonic mean isopleths against increasing sample size for the animals with largest number of location fixes; this gave curves which reached an asymptote at between 20 and 30 fixes for both estimates. For 12 animals there were more than 25 location fixes, all subsequent analyses were carried out on those animals only; 3 animals had less than 20 locations, and were excluded from subsequent analyses. The four calves were never sighted away from their mothers and thus independent ranges were not calculated for these juveniles.

Minimum convex polygons and harmonic mean 95% isopleths gave similar home range sizes - average 765 hectares (range 225 - 1439 ha) for minimum convex polygons and average 768 ha (range 217 - 1582 ha) for the 95% harmonic mean isopleth (Table I).

Calculated home range areas were extremely variable between individuals. However there were no significant differences between the home ranges of males and females, or between adults and immatures, for both the minimum convex polygon and 95% isopleth areas (Mann-Whitney, U-test, $P > 0.05$ in all cases), indicating home range size is independent of both sex and age class.

Core Areas

Core areas calculated as 70% cluster polygons averaged 54.7 ha (range 13.9 - 185.2 ha), which is 7.1% (range 2.6% to 14.3%) of the minimum convex polygon range area. However cluster analysis also offers an estimate of the numbers of centers of activity nucleii. The 70% cluster polygons showed most animals to have more than 1 centre of activity (average 3.6, range 1 - 5). There was a strong negative correlation between core area size and number of nucleii (Pearson correlation coefficient $r = -0.700$, $df = 10$, $P < 0.01$). Thus animals with only a single nucleus of activity had much large core areas than those with a single nucleus.

Core areas calculated as 70% harmonic mean isopleths were larger, averaging 263 ha (range 73.6 to 493.5 ha) which is 43.4% (range 21.1 to 48.8%) of the harmonic mean 95% isopleth home range. As the harmonic mean method is an estimate of the probability of locating the animal in any part of its range, this can be translated as rhinoceros spending 70% of their time utilising less than half of their range.

70% isopleths showed a variable number of nucleii of activity (average 2.3, range 1 - 4), but this was not correlated with core area size (Pearson correlation coefficient $r = 0.296$, df = 10, $P > 0.10$). There was no sigificant difference in size of 70% isopleth core area between males and females and between adults and immatures (Mann-Whitney, U-test, $P > 0.05$ in all cases).

Habitat composition of home ranges

The total area covered by each habitat type, along with the average content of home ranges and core areas, is given in Table II. The habitat content of the home range of each rhinoceros was significantly different from that expected if they were using each habitat in proportion to its coverage in the whole reserve (Log-likelihood Chi-squared test (Sokal & Rohlf 1981) $P < 0.02$ in all cases). As some habitats are not evenly distributed, and some individuals did not use all habitats, some pooling of data was required; *Euclea* bush and dense *Euclea* bush were combined, as were riverine woodland and marsh. Ranges in general included more *Euclea* dominated bushlands than expected, and less grassland and *Acacia* bushland than expected.

Although home range areas contained less grassland than expected, the proportion of grassland in the home range (estimated by minimum convex polygon) is positively correlated with home range size ($r = 0.76$, df = 10, $P < 0.01$), this is also true for the proportion of dense Euclea ($r = 0.68$, df 10, $P < 0.01$). These positive correlations are also seen for the estimate of home range as 95% harmonic mean isopleths (grassland r = 0.66, df = 10, P < 0.01; dense Euclea bushland r = 0.67, df = 10, P < 0.01). Thus the smaller home ranges not only contain less grassland and dense Euclea bushland, they have smaller proportions of these habitats; so at least a part of the variation in home range size is accounted for by the proportions of grassland and dense Euclea they contain.

The habitat content of core areas also differed significantly from the surrounding home range, ($P < 0.05$ for all individuals, by both methods). As for the total range, there was more *Euclea* bush, and less *Acacia* bush and grassland, but there was also more mixed bush within the core area than in the surrounding home range.

Habitat usage within home ranges

Habitat usage as calculated from density of spoor, middens and bedding sites is given in Table III. Middens were not randomly distributed between the different habitats (χ^2=128.3, 5 df, $P < 0.001$), with fewer than expected in grassland, *Acacia* bushland and mixed bushland; and more than twice the expected number in riverine woodland. Bedding sites were not random (χ^2=66.8, 5 df, $P < 0.001$), being concentrated in mixed bushland, with fewer than expected in *Euclea* bushland, open grassland and riverine woodland. In particular, no bedding sites were found in open grassland, and the 2 bedding sites found in riverine woodland were places where a rhinoceros had rested once, rather than regularly used sites. Spoor were not randomly distributed (χ^2=36.7, 5 df, $P < 0.001$), with fewer than expected in mixed bushland, and more than expected in *Euclea* bushland and riverine woodland.

This shows that not only do rhino show preferences for certain habitats in locating their home ranges, but they use particular habitats in different ways. This is illustrated by the high incidence of bedding sites in mixed bush, and their low occurrence in *Acacia* bush and riverine woodland, while the latter habitat has the highest densities of middens and spoor.

Because of the differences in utilisation of different habitat types, the following comparisons were made by calculating the expected frequency of sign in each habitat type, assuming distribution is random within habitat type. In some cases low occurrence of sign necessitated pooling of data.

Proximity to water significantly affects the distribution of middens (χ^2=42.4, 2f, P < 0.001), bedding sites (χ^2=24.1, 1df, P < 0.001), and spoor (χ^2=25.1, 2 df, P < 0.001). More middens and fewer bedding sites were found close to water than far from water in all habitat types. Spoor showed less clear distinctions, with more spoor close to water in dense *Euclea* bush, *Euclea* bushland and mixed bushland, and more spoor far from water in *Acacia* bushland, open grassland and riverine woodland.

Disturbance affects sign distribution, with significantly fewer middens (χ^2=10.3, 1 df, P < 0.005) and no bedding sites (χ^2=5.69, 1 df, P < 0.02) in disturbed areas. Disturbance has no significant effect on spoor (χ^2=1.24, 1 df, P > 0.25).

Home Range and Core Area Overlap

Based on the home range data available here, we could determine no overlap between the home ranges of adult male rhinoceros (Fig.1). The other idividuals could be divided into four groups, with extensive overlap between animals in the same group, and little or no overlap between groups (Fig. 2). Each group consisted of one adult male, one or more adult females and their calves, and sometimes immatures.

The home ranges of all animals within each group overlapped with all the others, Table IV. The degree of overlap between male:female pairs within the same group (mean 65.9% for minimum convex polygons, 68.8% for 95% harmonic mean isopleths) was not significantly different from the overlap between pairs of females where there was more than one female in a group (mean 39.1%, students t-test, t = 2.02, 16df, $P > 0.5$ for minimum convex polygons; 41.0%, t = 1.86, $P > 0.5$ for 95% harmonic mean isopleths).

There was no overlap of core areas between any animals in different groups, but within groups all individuals core areas overlapped to some extent, an average 17.3% overlap with members of the same group for 70% clusters, and 45.2% for 70% harmonic mean isopleths.

Middens and Bedding sites

Overall 88.5% (n = 130) of dungpiles occupied well used sites, mean dimensions 3.62m long (range 1.0 - 7.8m) and 1.49m wide (range 0.3 - 4.0m), and appear to have been used many times. A few (11.5%) were smaller, mean dimensions 1.96m long (range 0.4 - 6.5m) and 0.63m wide (range 0.2 - 1.1m) and appeared to be the result of a single defacation. The multi-use sites were designated middens.

The elongated shape of most middens is due to the habit of kicking through the deposit with the hind legs, which can spread the dung greatly. This kicking leaves characteristic double scrape marks through the midden. 86.5% of middens showed clear scrapes through the most recent deposits. Rhinoceros use regular paths, and 79.6% of middens were found alongside (within 5m) such a path.

A typical bedding site is a clear space inside a dense thicket, with one or two ways through the thicket into the resting area, the average dimensions of these resting places were length 3.5m (range 2.0 - 5.0m, n = 42), width 1.9m (range 1.0 - 3.8m, n = 42). The majority (88%) were totally enclosed by tall vegetation, and in areas where dense thickets were separated by more open bushland rhinoceros bedding sites were always found in the thickets. 64% of bedding sites have full or partial shade at midday.

The position of middens within the home range was analysed to determine if middens are used as territorial boundary markers. To test for this, the arithmetic mean centre of all location fixes was calculated for each rhinoceros, and from this the distance from the mean centre to each location. If middens are located near territorial boundaries, this distance will be greater than for other types of location. Distances to spoor and sightings locations were pooled, and compared with middens and bedding sites for each rhinoceros using ANOVA (Table V). In each case where there was a significant difference, bedding sites were closest to the centre of the range, and spoor and sightings furthest away; middens being intermediate. These results may be due more to a tendency for bedding sites to be near the centre of the home range, than for other types of sign to be near the periphery. There was no apparent difference between males and females in midden or bedding site positioning behaviour.

Discussion

Home ranges

A number of studies of black rhinoceros have shown that the home range area is highly variable, and indicate that availability of water, food and shelter are the most important factors affecting area. In the forested parts of Ngorongoro crater Goddard (1967) found home ranges of no more than 100 ha, and Conway & Goodman (1989) recorded a group of 7 rhinoceros sharing 430 ha of moist woodland. In less favourable habitats home ranges are much larger - rhinoceros in the drier parts of the Serengeti had home ranges of 7,000 to 10,000 ha (Frame 1980), and home ranges may be even larger in Namibia (Berger & Cunningham 1995). However most studies have shown home ranges intermediate to these, 100 - 22400 ha at Ngorongoro crater and 140 - 3500 ha at Olduvai gorge (both Goddard 1967), 560 - 2270 ha in the Masai Mara (Mukinya 1973), and 1500 - 5400 ha in Laikipia plateau Kenya (Brett *et al* 1989). Home range areas at Sweetwaters of 225 to 1440 ha (minimum convex polygons) are smaller than many elsewhere, this may be an indication of the suitablity of the habitat for black rhinoceros; although the rhinoceros might roam more widely if the sanctuary were not fenced.

Some authors have found immatures have larger home ranges than adults (e.g. Goddard 1967, Mukinya 1973), and females with calves larger ranges than solitary females (e.g. Mukinya 1973). At Sweetwaters there were no significant differences in home range area between demographic groups.

Habitat usage

Habitat preferences are shown in two ways, the amount of sign found in the different habitats, and the habitat content of home ranges and core areas. The rhinoceros at Sweetwaters show a preference for the denser bushlands, with home ranges containing mostly mixed bush and *Euclea* bush. The highest densities of middens and spoor were in riverine woodland and *Euclea* bush, while most bedding sites were found in mixed bush and dense

Euclea bush. The high amount of spoor found in riverine woodland is partly due to rhino coming to drink, and may artificially high due to the ease of finding spoor at the rivers edge; but this does not account for the high numbers of middens and absence of bedding sites in riverine woodland. There was a general avoidance of open grass or *Acacia* bush, with a very low density of rhinoceros middens and spoor, and no bedding sites found in the open; these habitats are also under-represented in the habitat content of home ranges. These habitat preferences were further shown in the core areas, which had larger proportions of mixed bush and *Euclea* bush than the surrounding home ranges, and smaller proportions of more open habitats. The preference for dense bushland has been shown in other studies - Goddard (1970a) found the highest rhinoceros densities in bushland and mixed woodland habitats, and the lowest density in open grassland. Other studies have had similar results, e.g. Mukinya (1973), and Frame (1980). The selection of certain habitat types by the rhinoceros at Sweetwaters partially explains the wide variation in home range size.

The use of regular bedding sites by rhinoceros has not been previously described, possibly because a rhinoceros lying in a dense thicket is very hard to detect, even at close quarters. Bedding sites are always in the most secluded areas - the preferred habitat is mixed bush and bedding sites are frequently in dense thickets, and never close to human disturbance.

Social Organisation

The Kenyan rhinoceros sanctuaries will be managed as a metapopulation (Anon 1993), with movement of some animals between sanctuaries as part of the genetic management plan, yet almost nothing is known of how their social organisation is affected by translocation. Introducing new animals to an established population can increase intraspecific aggression, sometimes with fatal results (Anon 1993, also see Hall-Martin & Penzhorn 1977). Greater understanding of social interactions and behaviour is needed to reduce this mortality in the future.

At Sweetwaters groups of rhinoceros appear to share a common home range, each group consisting of one adult male, one or more adult females and their young calves, and sometimes immature animals. Not only do the home ranges of animals in the same group overlap extensively, their core areas also overlap - no animal has an exclusive core area. The clear separation into groups seen in this study has not been reported elsewhere, and may not be apparent at higher population densities or in more nomadic populations.

Are male rhinoceros territorial ?

The principal definitions of territorial behaviour involve defence of an area, exclusive use of an area and site specific dominance (Maher & Lott 1995). Defence of an area has never been observed directly in rhinoceros, but lack of overlap between the home ranges of the mature males at Sweetwaters indicates some form of resource defence. In other studies male home ranges do overlap, but to a lesser extent than females. In Conway & Goodman's (1989) study two males had home ranges overlapping by 12%, whereas female home ranges overlapped by 49% and 80%; in Goddard's (1967) study some male home ranges overlapped by up to 40%.

Most territorial animals demarcate their territory in some way. Rhinoceros may use middens as territorial markers - the ritualised behaviour associated with deposition of middens (Schenkel & Schenkel-Hulliger 1969) and the fact that they rarely defacate other than at a midden indicates an important role in intraspecific communication. Middens are distributed over the whole home range, not just around the perimeter. For an animal with a relatively large range and limited resources for marking this may be the most effective strategy to ensure intruders encounter a marker soon after entering the range (Mills & Gorman 1987). At Sweetwaters many middens are found close to paths, sometimes several were found along a few hundred meters of the same path; large numbers were also found close to the river, particularly near drinking places. This is consistent with middens being sited where they are most likely to be encountered by other rhinoceros and so is further evidence of middens being used in intraspecific communication, although the function of this communication remains uncertain.

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Table I.

Average home range and core area estimates for all rhino with more than 25 location fixes. Home ranges are estimated as minimum convex polygons and harmonic mean 95% isopleths. Core areas are estmated as 70% clusters and harmonic mean 70% isopleths, expressed as area and as percentage of total home range, using the previous estimates as totals. For 70% clusters the average number of cluster nucleii is also given. All areas in hectares (± S.E.).

		Home ranges		Core areas				
	Number of fixes	Minimum convex polygon	Harmonic Mean 95% isopleth	70 % Cluster Area	70 % Cluster no. nucleii	70 % Isopleth Area	% of total area 70% Cluster	% of total area 70% Isopleth
All rhino n=12	30.8 (1.4)	765.0 (125.0)	767.6 (127.0)	54.7 (13.8)	3.8 (0.4)	263.1 (43.4)	7.1 (1.2)	34.7 (2.3)
Adult males n=4	33.0 (1.7)	818.7 (232.6)	904.5 (267.8)	38.2 (6.1)	4.5 (0.3)	302.7 (78.6)	5.5 (1.0)	35.0 (4.8)
Adult females with calves n=4	29.3 (1.3)	736.1 (267.1)	528.6 (142.9)	43.6 (14.6)	3.8 (0.6)	223.8 (77.2)	7.1 (2.5)	39.9 (3.2)
Adult females without calves n=2	26.5 (2.5)	929.2 (362.9)	1042.1 (442.4)	109.1 (76.2)	3.0 (2.0)	310.0 (183.5)	8.2 (5.6)	27.2 (6.1)
Immature males n=2	33.5 (7.5)	549.1 (271.7)	697.6 (288.6)	55.3 (38.6)	3.5 (0.5)	215.4 (84.9)	8.7 (2.7)	31.2 (0.7)

There are no significant differences between the home ranges of males and females, or between adults and immatures, for both the minimum convex polygon and 95% isopleth areas (Mann-Whitney, U-test, $P > 0.05$ in all cases).

Table II.

Area of each habitat type found in the reserve, in hectares and as a percentage of the whole area. The average percentage of each habitat type with the home ranges and core areas of all rhino are also given (Standard Error in brackets).

	Area		Home ranges		Core areas	
Habitat	ha	%	Minimum convex polygon	Harmonic mean 95% isopleth	70% Clusters	Harmonic mean 60% isopleth
Grassland	2006	21	12.8 (2.6)	9.8 (1.4)	2.5 (1.3)	7.4 (3.5)
Acacia bushland	1646	17	13.3 (1.6)	14.1 (2.4)	8.6 (3.7)	9.0 (2.6)
Mixed bushland	3619	37	42.3 (2.5)	39.8 (3.9)	52.6 (7.0)	48.1 (5.1)
Euclea bushland	1020	11	22.7 (3.0)	22.3 (2.9)	21.3 (7.0)	25.8 (6.5)
Dense *Euclea* bushland	1090	11	6.5 (2.8)	7.4 (3.2)	5.3 (3.1)	5.1 (2.8)
Riverine Woodland	264	3	3.4 (0.8)	8.0 (2.5)	7.2 (2.4)	4.3 (1.6)
Marsh	24	0.2				
Total	8969					

Table III.

The density of different types of rhinoceros sign found in different habitats, calculated as the total number found divided by search time.

	Search Time in minutes	Habitat usage for different categories of rhino sign				
		Middens	Spoor	Bedding sites	Other *	Total
Open grass	666	0.015	0.012	0.000	0.003	0.030
***Acacia* bush**	1085	0.026	0.016	0.013	0.005	0.062
Mixed bush	3887	0.041	0.015	0.028	0.006	0.090
***Euclea* bush**	2351	0.066	0.034	0.009	0.004	0.113
Dense *Euclea* bush	853	0.052	0.020	0.020	0.002	0.094
Riverine Woodland	1104	0.114	0.035	0.002	0.003	0.154
All habitats	9946	0.053	0.022	0.016	0.004	0.096

*Other includes Wallows and Sightings. None of the different sign types were evenly distributed between habitat types (Middens $\chi^2 = 128.3$, 5 df, $P < 0.001$; Spoor $\chi^2 = 36.7$, 5 df, $P < 0.001$; Bedding sites $\chi^2 = 66.8$, 5 df, $P < 0.001$)

Table IV.

Mean overlap of home range and core area, each estimated by two methods, between animals in the same group, and between animal in different groups

Group	Minimum convex polygon home range				Harmonic mean 95% home range				70% Clusters core area		70% Harmonic mean core area	
	Within own group		Outside own group		Within own group		Outside own group		Within own group		Within own group	
	Number of ranges overlapped	Mean % overlap	Number of ranges overlapped	Mean % overlap	Number of ranges overlapped	Mean % overlap	Number of ranges overlapped	Mean % overlap	Number of core areas overlapped	Mean % overlap	Number of core areas overlapped	Mean % overlap
South East group	2	58.0	1.0	0.6	2	60.2	1.3	0.2	2	12.9	2	32.5
North East group	2	66.1	0	0.0	2	73.8	3	6.1	2	12.6	2	34.3
North West group	2	76.7	0	0.0	2	74.8	3	15.5	2	18.7	2	67.7
South West group	2	73.9	0.33	0.3	2	70.0	1.3	0.1	2	25.1	2	46.4
Overal mean	2	68.7				69.7				17.3		41.0

Table V.

Average distance of location fixes from Arithmetic mean centre of each home range in meters, with the number of fixes in brackets. ANOVA was used to determine if there was any difference between types of rhino sign. This distance will be greatest for middens if they are located at territorial boundaries - the data does not support this.

Rhino-id	Sex	Location fix type						Result of ANOVA between groups
		Middens		Bedding sites		Spoor & Sightings		
No 11	F	1124	(9)	1040	(9)	1421	(10)	ns
Kilo	F	1714	(14)	2370	(6)	2172	(7)	ns
Shemsha	F	1317	(13)	1231	(11)	1126	(9)	ns
No 7	F	1385	(12)	621	(8)	2102	(9)	$P < 0.005$
No 6	F	833	(12)	671	(5)	616	(12)	ns
No 8	F	934	(4)	786	(10)	1011	(9)	ns
Otoro	M	1605	(8)	1615	(6)	2039	(15)	ns
Kurkura	M	1746	(10)	896	(9)	1815	(13)	$P < 0.001$
Rodney	M	1286	(11)	1235	(4)	998	(22)	ns
Smith	M	898	(6)	665	(6)	918	(14)	ns
Jupiter	M	871	(9)	539	(20)	1368	(5)	$P < 0.001$
Job	M	1164	(14)	970	(13)	1248	(14)	ns

Figure Legends

Figure 1.
Home ranges of all adult male rhinoceros in the reserve, estimated as minimum convex polygons, shown within the boundary of Sweetwaters Rhinoceros Sanctuary; there is no overlap between individual males.

Figure 2.
Home ranges of all adult female rhinoceros estimated as minimum convex polygons, showing overlap between some individuals. Comparison with Figure 1 indicates overlap between each adult male and one or more adult female.

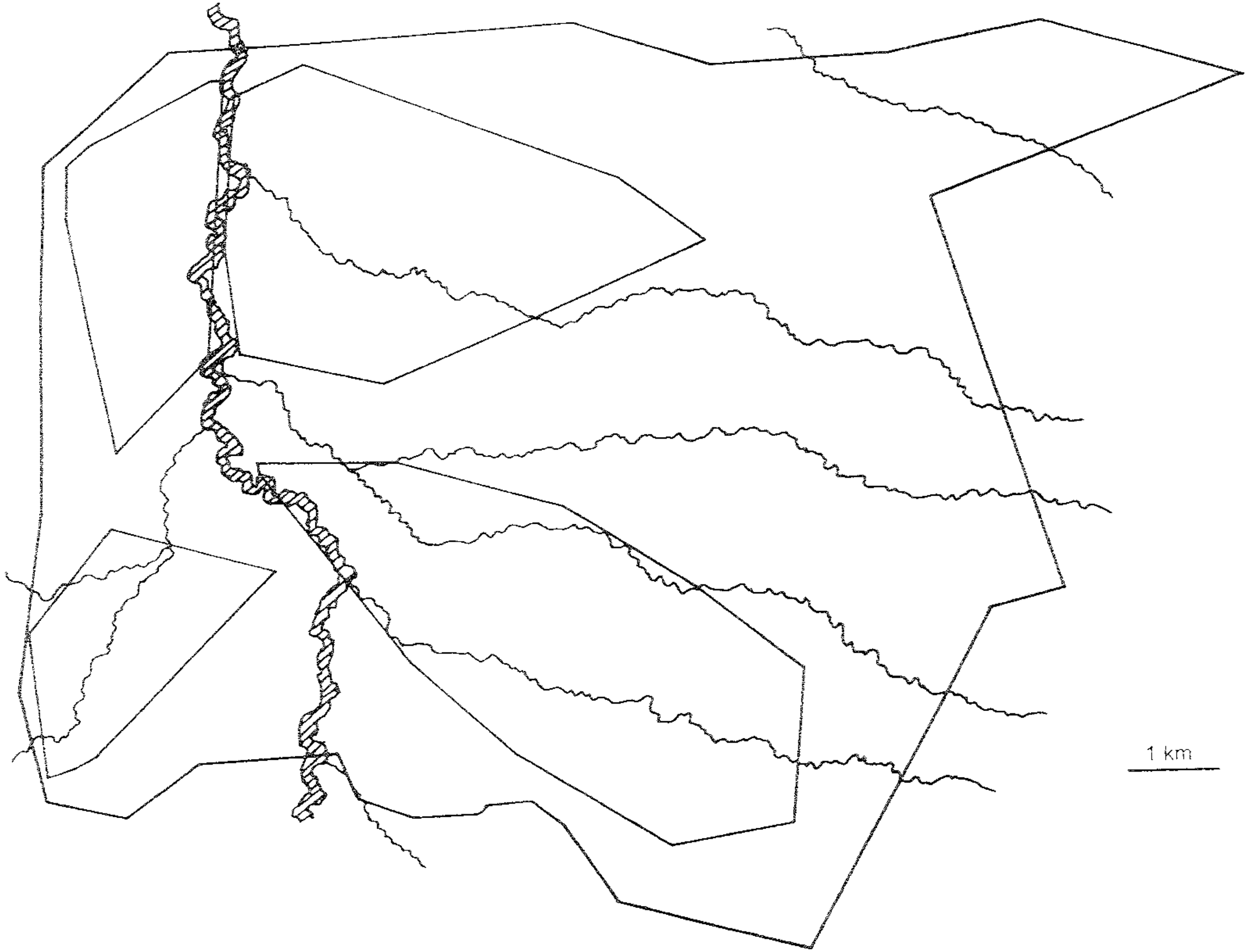

Figure 1 male

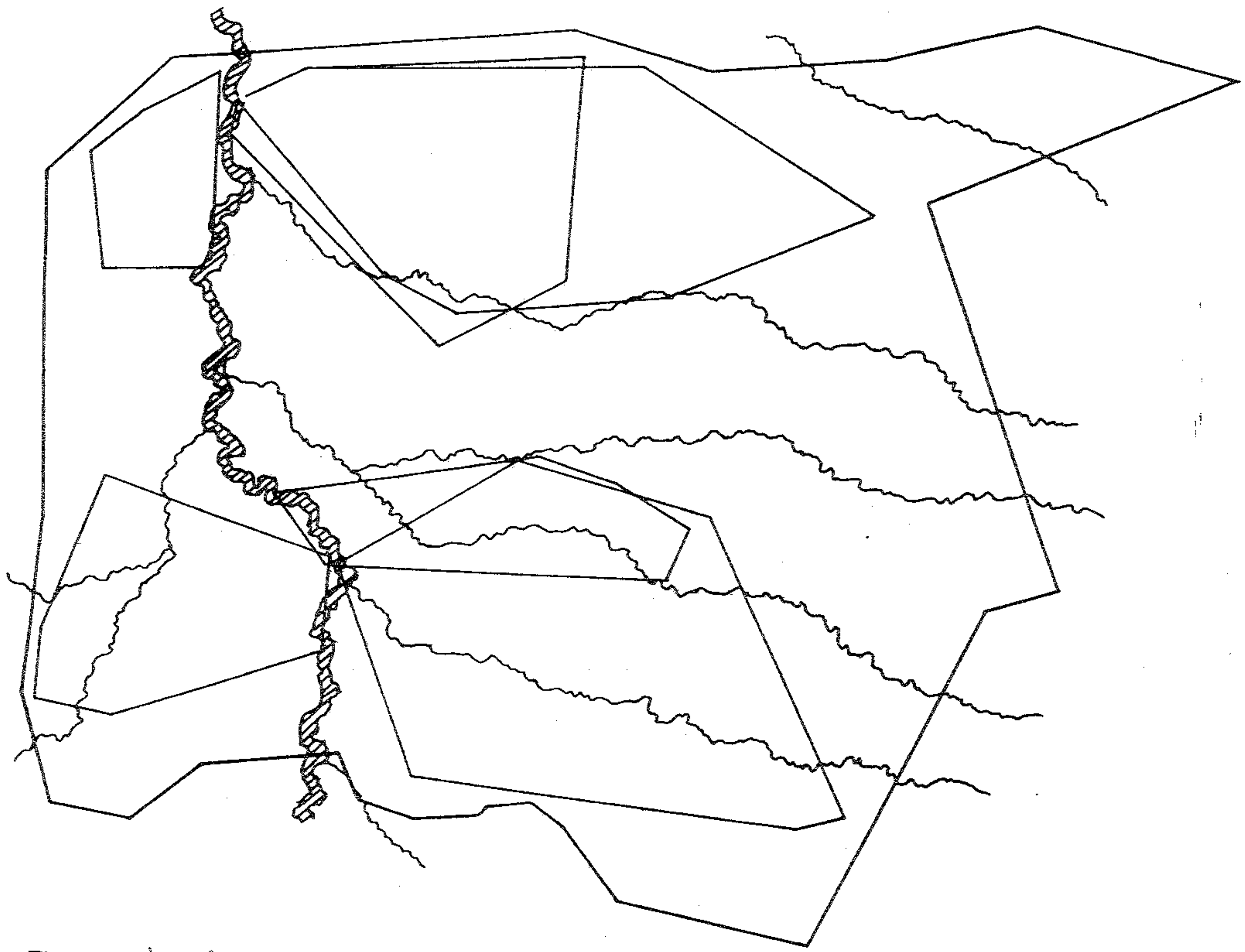

Figure 2 female

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