Habitat changes reduce the carrying capacity of Hluhluwe-Umfolozi Park, South Africa, for Critically Endangered black rhinoceros *Diceros bicornis*

Caroline Reid, Rob Slotow, Owen Howison and Dave Balfour

Abstract The Critically Endangered black rhinoceros *Diceros bicornis* occurs mainly in protected areas. Hluhluwe-Umfolozi Park, South Africa, contains a key source population for black rhino conservation, and declining population productivity has been attributed to negative habitat changes and a reduction in carrying capacity. As home range increase may be an index of declining habitat quality we determined the home ranges of the black rhino in the Park and compared these ranges with previous estimates. The average size of the home ranges during 1991–2001 was 23.07 ± SE 0.81 km², which is 54% greater than in the 1980s. Sex and the availability of water did not influence home ranges. Home ranges decreased in winter. Female:male ratios varied across the Park, indicating that one or both sexes may prefer specific areas. Changes in vegetation structure and composition may have caused rhino to maintain larger ranges in order to meet their nutritional requirements. Ongoing review of stocking rates, population performance (including indicators such as range size), and intervention strategies are necessary to manage black rhino in dynamic savannah ecosystems.

Keywords *Diceros bicornis*, habitat quality, Hluhluwe-Umfolozi Park, home range, South Africa, territoriality.

Introduction

Black rhinoceros *Diceros bicornis* are categorized as Critically Endangered on the IUCN Red List (IUCN, 2006). The estimated wild population in 2001 was *c.* 3,100 (IUCN, 2006), with about a third in South Africa (Brooks, 2001) in protected areas or private reserves. The population in Hluhluwe-Umfolozi Park, KwaZulu-Natal, South Africa, is one of the largest populations and therefore of international importance (Emslie, 1999). This population increased steadily from 1930 until 1960, with a decrease in numbers in 1961 when 46 rhino died in northern Hluhluwe (Fig. 1A). The population reached a peak again in 1993 (429 individuals) but thereafter there was a steady decline to 325 individuals in 2000. This can be partially explained by translocations and mortalities, with 84 mortalities and 131 translocations since 1993 (O. Howison, unpubl. data). However, there has been a negative growth rate of −1.29 since 1990 (Fig. 1b; O. Howison, unpubl. data). The decline in the 1980s was attributed to negative habitat changes and the resulting reduction in carrying capacity (Emslie, 1999). These habitat changes resulted in an increase in the average size of the home ranges of individual rhino from 3 to *c.* 15 km² (Emslie, 1999).

The managers of Hluhluwe-Umfolozi Park require information on both the spatial and temporal use of habitat by rhino to determine the influence of habitat and examine why the numbers of rhino are continuing to decrease. In this study we examined the spatial and temporal use of home ranges by selected individual rhino in the Park based on sightings over a 10-year period from January 1991 to February 2002. This was done by: (1) quantifying home ranges; (2) comparing the size of home ranges with that reported by Emslie (1999); (3) identifying the core areas of home ranges; (4) classifying the effect of sex on home range size; (5) quantifying the proportion of home range within 500 m of a water source; (6) quantifying the amount of preferred and rejected vegetation types within the home range; (7) quantifying changes in the above factors with season; (8) comparing seasonal home ranges and relating this to habitat characteristics.

Study area

The 900 km² of Hluhluwe-Umfolozi Park varies in altitude from 60 m in the south to *c.* 600 m in the north. There is a strong total annual rainfall gradient across the Park from 635 mm in the south-west to 990 mm in the

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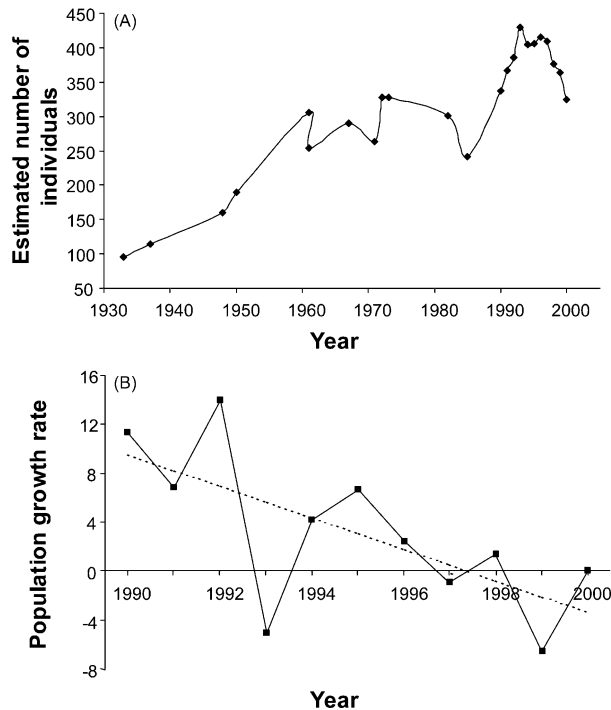
Fig. 1 Black rhino population estimates for 1933–2000 (A) and growth rates for 1990–2000 (B; solid line) in Hluhluwe-Umfolozi Park. The population had a negative growth rate (B; dashed line) of -1.29 from 1990 (linear regression $y = -1.29x + 10.82$; $R^2 = 0.450$; O. Howison, unpubl. data). Estimates for 1933–1990 from Emslie (1999) and 1990–2000 from Ezemvelo KZN Wildlife unpublished records.

north-east, and mean minimum and maximum temperatures are 13 and 35℃, respectively (Whateley & Porter, 1983). Whateley & Porter (1983) give a detailed description of the vegetation communities of the Park, which is completely fenced and divided into five sections for management purposes (Fig. 2).

Methods

We obtained data on black rhino sightings from records at Hluhluwe-Umfolozi Park. About 60% of the population is individually marked but this percentage varies between the five sections. Since 1989, staff patrolling the Park have collected sighting data whenever they encounter rhino. Sightings of 347 known individuals (identified by ear notches or natural characteristics) were available for January 1991 to February 2002. However, for many of these there were few sightings and therefore to map home ranges we used data for the 134 adult animals for which there were ⩾10 sightings. Of these we discarded data for nine individuals that shifted home ranges during the study period, giving a final data set of 125 individuals. Once duplicate entries had been deleted and misidentified individuals
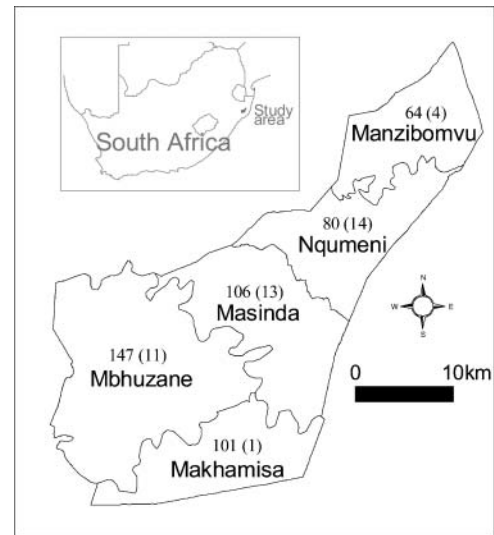

Fig. 2 The five management sections of Hluhluwe-Umfolozi Park. Numbers are the identified individual black rhino in each section, and in parentheses the number of adults for which there were >30 sightings, used in the seasonal home range analysis (see text for further details).

removed the data set totalled 5,271 sightings, with a maximum of 870 in 1993 and minimum of 76 in 2001 (for which data was only available until the end of February; Fig. 3A). The number of individuals sighted also varied between years, although the number of females was always greater than that of males (Fig. 3B).

Kernel home ranges were estimated using the *Animal Movement Analysis* extension (Hooge & Eichenlaub,
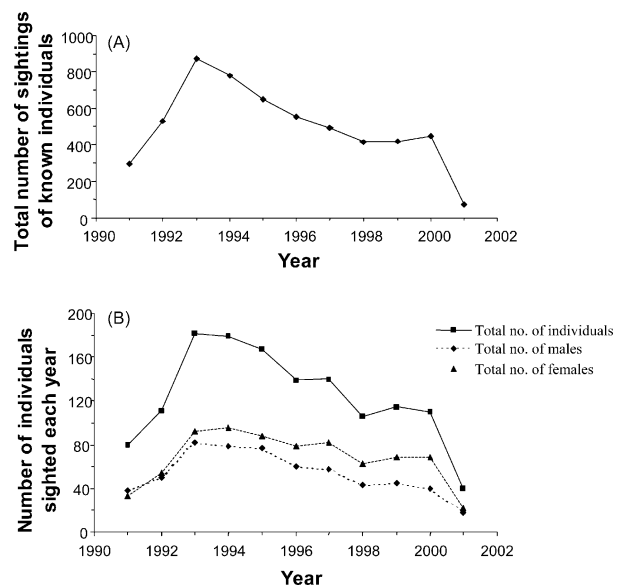

Fig. 3 Changes in the annual sightings of black rhino in Hluhluwe-Umfolozi Park during 1991–2001. (A) The total number of sightings of identified individuals. (B) The total number of individuals sighted. Data for 2001 is only to the end of February.

1997) to the geographical information system *ArcView 3.3* (ESRI, Redlands, USA). We used the 95% kernel for the estimate of maximum home range (referred to as the home range) and the 50% kernel for the estimate of the core area of use within the home range (referred to as the core range). We used an LSCV smoothing factor of 500 m for all individuals and the extent of the Park as the output grid extent, with a cell size of 100 m. When the home ranges overlapped the border of the Park we clipped them with the border of the Park and recalculated the area of the kernel contours. We did not include any boundary effects. We compared the home and core ranges of males and females using an ANOVA. To determine variation in home range within the Park we created contour maps of male and female home range sizes by creating a point estimated to be the centre of each home range. We assigned this point the value of the home range area, and interpolated a surface using *ArcView Spatial Analyst*. The output grid cell size was 100 m and the extent of the Park was used as the output grid extent. We used the inverse distance weighted method to interpolate the surface; the number of nearest neighbours used was 12, with a power of 2 and no barriers.

To determine seasonal shifts in home ranges we selected the 43 individuals (15 males and 28 females) for which there were >30 sightings. We plotted these sightings for October-March and April-September to represent home ranges in summer and winter, respectively. Analyses of seasonal changes were performed in *ArcView* by assessing the overlap of subsequent season polygons with previous season polygons. We used a Wilcoxon signed rank test to examine differences in the size of the home and core ranges in summer and winter, and compared the size of the seasonal home and core ranges of males and females using the Kruskal-Wallis one-way ANOVA as the data were not normally distributed.

We created a map of a 500 m wide buffer along the perennial rivers in the Park, over which we then overlayed the home and core ranges and determined the proportion of the ranges within 500 m of rivers. We compared these proportions for males and females using the Mann-Whitney U test as the data were not normally distributed. To assess the effect of water on the seasonal use of rhino home ranges we overlayed the river buffer map on the seasonal home ranges of individual animals and then determined the area within the buffer for winter and summer separately. We then calculated the proportion of the seasonal home range within the buffer and compared this for the summer and winter home and core ranges of males and females separately using the Kolmogorov-Smirnov two-sample test.

Vegetation types dominated by *Spirostachys africana* are the most important for rhino, followed by those dominated by *Acacia nilotica*, *Acacia karoo* and *Dichrostachys cinerea* (Emslie, 1999). To assess the influence of vegetation on rhino home range we created a map of four vegetation types based on the dominance of preferred rhino food plant species. The vegetation types were: (1) dominated by *S. africana*; (2) dominated by *Acacia* spp.; (3) dominated by both *S. africana* and *Acacia* spp.; (4) vegetation types not dominated by either *S. africana* or *Acacia* spp.. Vegetation dominated by *S. africana* covers the smallest area of the Park (5.8%; Fig. 4) and vegetation dominated by *Acacia* spp. the largest (43.4%). We overlayed on this vegetation map the home ranges of the selected individuals and determined the area of the four vegetation types within home ranges by intersecting the vegetation map and the home ranges. We compared the area of different vegetation types within the home ranges of males and females using the Mann-Whitney test (data not normally distributed: Kolmogorov-Smirnov test, $P < 0.05$).

To examine the distribution of rhino throughout the Park we used only adult males and females as they had well established home ranges. We converted the range maps of the selected rhino to grid cells, and then reclassified the home and core range values to give a new value of one for both. This made it possible for us to add all the home ranges to produce a cumulative map showing the total number of individuals using a particular area of the Park, i.e. the local density. We did this separately for males and females, and subtracted the number of males from that of females so that in any given area negative values indicated that there were more males than females and positive values the opposite.

Results

The home ranges of both males and females showed similarities that we broadly categorized into four characteristics according to the number of separate areas included in the home range as well as the number of core ranges within the home range (Fig. 5, Table 1). There were four home range patterns, independent of sex: either one single area (Fig. 5A,B) or split into spatially separate ranges (Fig. 5C,D), and either unimodal (one core range; Fig. 5A,C) or multimodal (more than one core range; Fig 5B,D). There was no significant difference (G-test $\chi^2_{0.05,3} = 7.815$, $P < 0.05$) between males and females in terms of these home range patterns. In addition, there were no significant differences in the sizes of either the home (ANOVA $F_{1,125} = 1.455$, $P = 0.230$) or core ranges (ANOVA $F_{1,125} = 0.320$, $P = 0.573$) of males and females, and the size of the
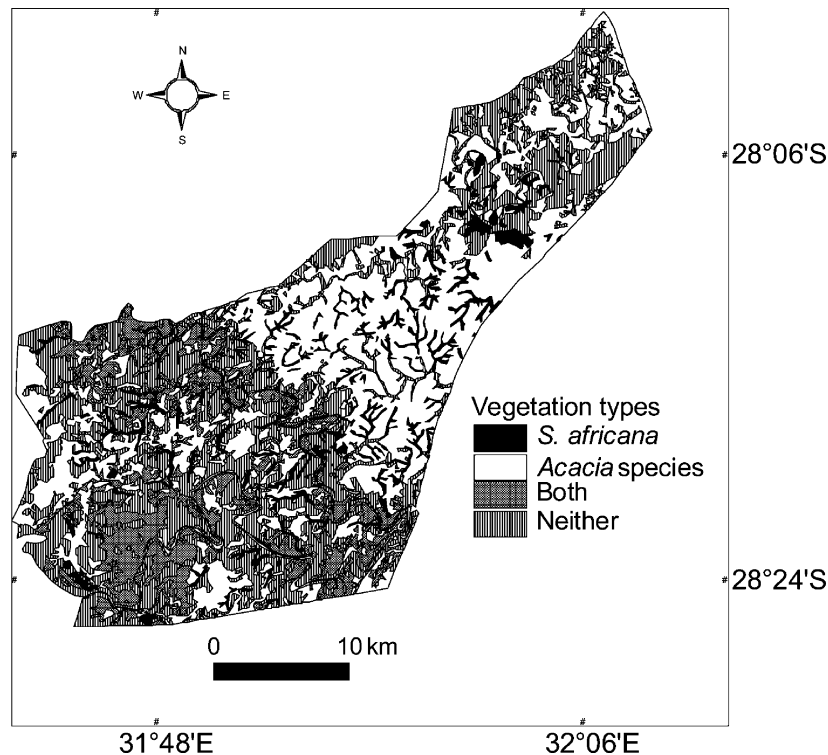
Fig. 4 The four vegetation types in Hluhluwe-Umfolozi Park that are important to black rhino (see text for details).

home range of both males and females was approximately 10 times larger than that of the core range. The average sizes of the home and core ranges were 23.02 ± SE 0.86 and 2.95 ± SE 0.15 km², respectively.

There was substantial variation in home range size across the Park (Fig. 6). The smallest ranges were in the Masinda (5–25 km²) and Makhamisa (10–35 km²) sections (see Fig. 1A for section locations). The range sizes in the Nqumeni, Mbhuzane and Manzibomvu sections were 40–55 km². Data in areas with few measured ranges (reflected by the lack of overlaying dots in Fig. 6) should be interpreted with caution. In particular, the lack of data in the centre of the Park may have led to underestimation of the home ranges (estimated to be 15–20 km²) in that area.

The majority of males and females exhibited differences in both home and core ranges between seasons (Table 2), with only *c.* 10% of the rhino having a similar core range in both seasons. There was no significant difference (G-test $\chi^2_{0.05,3} = 7.815$, P >0.05) in the way in which males and females utilized their home ranges during summer and winter. The winter home ranges were significantly smaller (21.13 ± SE 1.43 km²) than the summer home ranges (25.11 ± SE 1.26 km²; Wilcoxon signed rank test $Z_{2,43} = -3.236$, P = 0.001). There was no significant difference (Wilcoxon signed rank test $Z_{2,43} = -0.284$, P = 0.777) in the size of the winter and summer core ranges, which were 2.79 ± SE 0.27 and

2.86 ± SE 0.27 km², respectively. There was no significant difference in the size of either male or female home ranges in summer versus winter for either the home range (Kruskal-Wallis one-way ANOVA, $H_{1,86} = 2.249$, P = 0.134), or the core range (Kruskal-Wallis one-way ANOVA, $H_{1,86} = 0.030$, P = 0.863).

There were no significant differences in the proportions of the home (Mann-Whitney $Z_{0.05,125} = -1.606$, P = 0.108) or core (Mann-Whitney $Z_{0.05,125} = -1.073$, P = 0.283) ranges of males and females within 500 m of water, and there were no significant differences in the proportions of either the home or core range within 500 m of water in summer and winter (Kolmogorov-Smirnov test P >0.05 in all cases). Although not significantly different, the overall proportion of the core home range within 500 m of water was greater than that of the rest of the home range. Only vegetation dominated by *Acacia* spp. was present significantly more in the home range of females than of males (Mann-Whitney $Z_{0.05,125} = -2.144$, P = 0.032).

The majority of the male home ranges were in the Manzibomvu and Mbhuzane sections of the Park (Fig. 7A) whereas most of the female home ranges (Fig. 7B) were in the Nqumeni, Mbhuzane, and Masinda sections. The Makhamisa section had lower numbers of both male and female home ranges (Fig. 7C). The Mbhuzane section had more male home ranges than female home ranges (Fig. 7C). However, the greater numbers of both
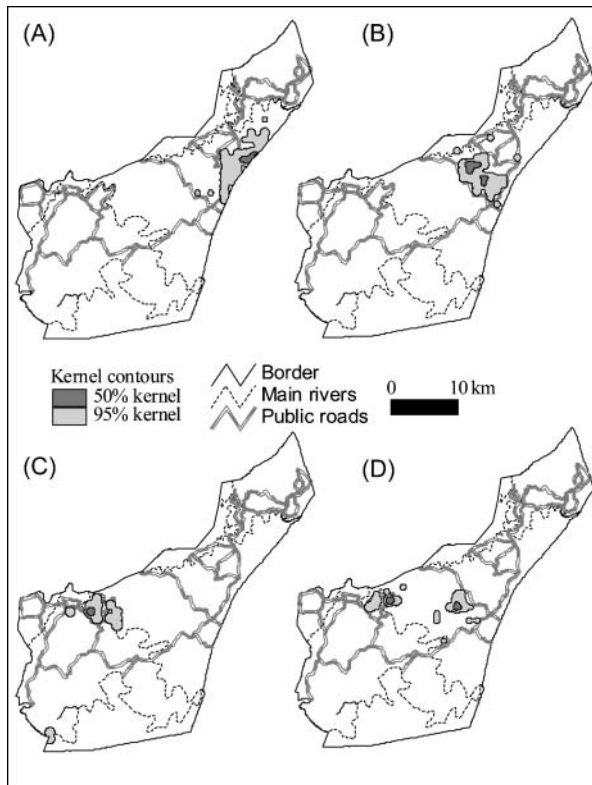
an artefact of sampling both male and female numbers would be expected to increase similarly.

Discussion

Our main findings from this study of the black rhinoceros of Hluhluwe-Umfolozi Park were: (1) Average size of home ranges from 1991 to 2001 was $23.07 \pm$ SE 0.81 km^2. (2) Home ranges are now 54% larger than the 15 km^2 reported by Emslie (1999). (3) There were no differences in either the home range size or in the patterns of home range use of males and females. (4) Proportion of the core range within 500 m of water was greater than that of the home range. (5) There was significantly more vegetation dominated by *Acacia* spp. in the home range of females than that of males. (7) Winter home ranges were significantly smaller than summer ranges. (8) There were no significant differences in the proportions of either home or core ranges within 500 m of water in summer and winter. We also found that the size of home ranges varied across the Park, with some areas having ranges substantially smaller than others and some with a female biased ratio and others a male biased ratio.

Sex and age of an individual black rhino influence home range size (Adcock *et al.*, 1998), with ranges of females larger than those of males, especially when accompanied by a calf (Goddard, 1967; Mukinya, 1973). However, home ranges of rhino in a Kenyan sanctuary were independent of either age or sex (Tatman *et al.*, 2000). The degradation of the habitat in Hluhluwe-Umfolozi Park (Emslie, 1999) and the subsequent increase in the size of individual home ranges could have resulted in the lack of difference in the home range sizes of male and female black rhino.

Black rhino are selective in their use of habitat (Tatman *et al.*, 2000), and the most important habitat features that influence the location of home ranges are the availability of water, food and cover, and the absence of human disturbance (Goddard, 1967; Mukinya, 1973; Berger & Cunningham, 1995). Sources of surface water in savannah systems are generally

Fig. 5 Black rhino home ranges could be broadly categorized (Table 1) into: (A) a single home range with a unimodal core area (rhino Corr171); (B) a single home range with a multimodal core area (Corr172); (C) more than one home range with a unimodal core area (W716); (D) more than one home range with a multimodal core area (C391).

males and females in this area may have been an artefact of sampling rather than habitat preference, as the area contains more open vegetation communities and is less mountainous, facilitating the sighting of rhino. Female home ranges appeared to aggregate in the Masinda section. Although there was a narrowing of the Park in this area, which may have lead to more sightings as game guards penetrated further into rhino territories, the greater number of females sightings may indicate an actual preference for this area because if it were merely

Table 1 Spatial characteristics of adult black rhino home ranges (see text for details) in Hluhluwe-Umfolozi Park , with number of males and females exhibiting each of four types (Fig. 5).

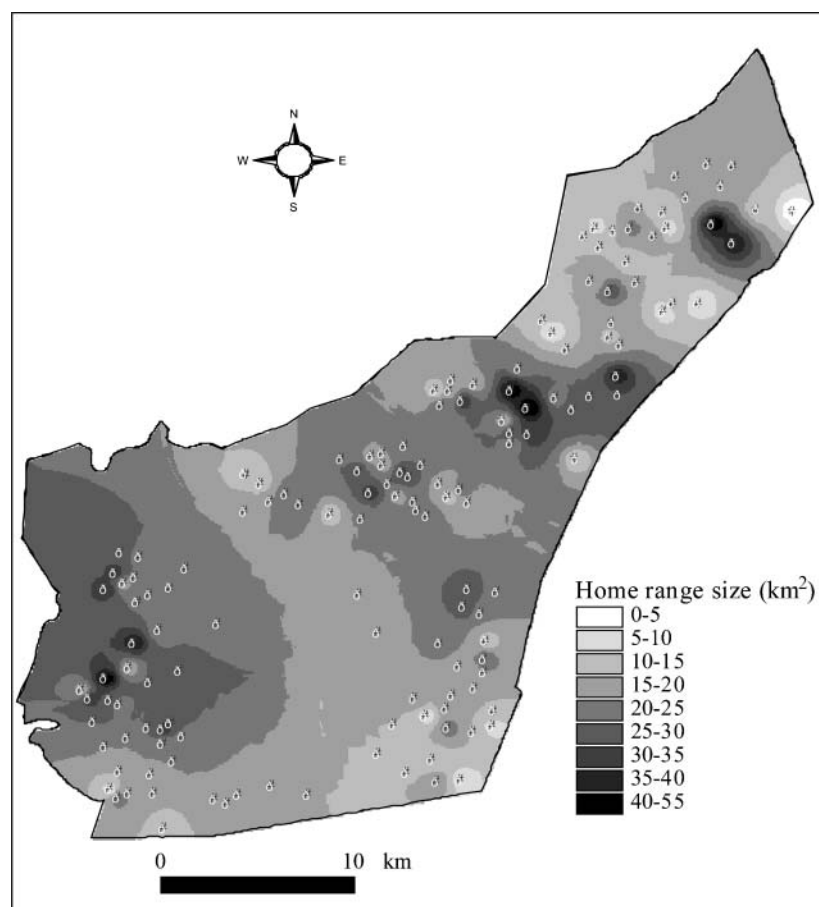| Characteristics of home range (95% kernel)	Characteristics of core range (50% kernel)	No. of males	No. of females	Total	Example
Unimodal	Unimodal	12	16	28	Fig. 5A
Unimodal	Multimodal	13	24	37	Fig. 5B
Multimodal	Unimodal	11	10	21	Fig. 5C
Multimodal	Multimodal	23	16	39	Fig. 5D
Total		59	66	125	

Fig. 6 Spatial variation in home range size of black rhino in Hluhluwe-Umfolozi Park. Values were estimated using an interpolated surface with the centre of the home range (black and white dots) of the selected individuals (see text for details). Light and dark shading indicate relatively small and large home ranges, respectively.

Table 2 Seasonal (summer and winter, see text for details) shifts in range use by male and female adult black rhino according to the characteristics of the home (95% kernel) and core (50% kernel) home ranges.

Characteristics of home range	Characteristics of core range	No. of males	No. of females	Total
Similar[1] for both seasons	Similar[1] for both seasons	0	0	0
Similar[1] for both seasons	Different[2] for both seasons	3	4	7
Different[2] for both seasons	Similar[1] for both seasons	2	2	4
Different[2] for both seasons	Different[2] for both seasons	10	22	32
Total		15	28	43

[1]Considered similar if >50% of their area overlapped
[2]Considered different if <50% of their area overlapped

restricted in the dry season (Ritter & Bednekoff, 1995) and in Hluhluwe-Umfolozi Park the proportion of the core range within 500 m of water was greater overall than that of the home range, suggesting that the presence of water is important for this population. The lack of differences in the proportion of either home or core ranges within 500 m of water in summer and winter may be because there is sufficient water throughout Hluhluwe-Umfolozi Park to meet individual requirements. The larger home ranges of both males and

females in Hluhluwe-Umfolozi Park in summer compared to winter may be because rhino are able to gain more nutrients from summer forage and are therefore able to expend more energy foraging further. In summer water is also more widely available in seasonal rivers and pans, which may reduce dependence on permanent rivers.

Emslie (1999) speculated that ranges had already increased in the 1980s because of declining habitat quality, and our results indicate further increases,
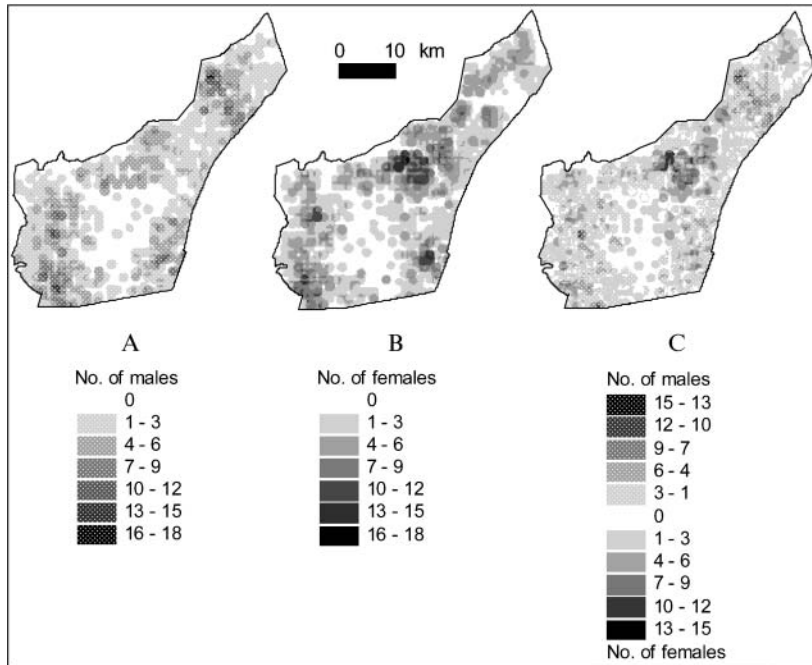
Fig. 7 Numbers of adult male (A) and female (B) black rhino in Hluhluwe-Umfolozi Park, calculated by adding the home ranges (see text for details) of the selected individuals, and (C) the difference between the number of adult males and females, calculated by subtracting the number of males (A) from the number of females (B). The density was greatest in the Mbhuzane section of the Park where both male and female home ranges were more numerous.

implying a further decline in habitat quality for rhino. An additional complication is that the changes and instability in range sizes could be related to the disruption of social networks through the continual removal of individuals for establishment of populations elsewhere. Our results indicate different male:female ratios across the Park. It is likely that this is a consequence of removals and dispersal following social disruption rather than a consequence of differential habitat selection by one of the sexes. This should be investigated further as it may have important implications for future management interventions.

The social behaviour of black rhino should be considered when removing individuals (Adcock *et al.*, 2001). An imbalanced social structure in an area of the Park could result in shifts in home ranges, and also in reduced productivity because more energy is expended in creating new home ranges rather than in reproduction. There is currently no strategy to relate removals in the Park to the relative abundances of the sexes. The poor dispersal of rhino may result in some areas containing high densities and little recruitment into vacated areas. In this way removals may not improve the nutrition of remaining individuals to the extent expected, and the population effectively remains close to ecological carrying capacity (Balfour, 2001). Any removal strategy needs to be planned spatially and temporally with regards to specific individuals to minimize disruption of the rhino social network. Reduced social disruption will lead to decreased

conflict, and potentially increase the productivity of the population.

The quality and quantity of information collected on individuals was not ideal, and this reduced the quality of our analysis. Great management effort was expended in marking *c.* 300 rhino but we obtained sufficient detail for seasonal range analysis for only 14% of the population. Marking of individuals needs to include commensurate monitoring and analysis but there was no systematic procedure for collecting information in the Park and patrolling and monitoring effort was markedly uneven between sections.

One of the key results of this study is that declining habitat quality across a major black rhino conservation area may have resulted in larger home ranges. The implication of this is that the Park has a lower carrying capacity for rhino, and productivity of individuals within the population may be reduced because of the need to range wider to meet resource needs. Habitat change has also occurred in other areas with rhino such as Kruger National Park. We have now instituted studies of the drivers of changes in habitat quality for black rhino, for example, the modification of woody vegetation by increasing elephant *Loxodonta africana* densities and the invasion of key black rhino habitat by alien plants such as *Chromalena odorata*. In addition, we are working with managers in a number of black rhino reserves to modify monitoring activities to facilitate improved investigation of the factors affecting rhino ranging and population productivity. Such

monitoring will be incorporated into new reserve management plans (as required by the recently passed Government Biodiversity Act).

Acknowledgements

References

Adcock, K., Balfour, D., Buk, K., Linklater, W. & Owen-Smith, N. (2001) Results and recommendations from working groups. Working group 2: Monitoring resources. In *Proceedings of a SADC Rhino Management Group (RMG) Workshop on Biological Management to Meet Continental and National Black Rhino Conservation Goals* (ed. R. Emslie), pp. 102–107. SADC Rhino Management Group, Harare, Zimbabwe.

Adcock, K., Hansen, H.B. & Lindemann, H. (1998) Lessons from the introduced black rhino population in Pilanesberg National Park. *Pachyderm*, **26**, 40–51.

Balfour, D. (2001) Paper 6: Managing black rhino for productivity. Some questions about current RMG assumptions and guidelines, and some ideas about data use. In *Proceedings of a SADC Rhino Management Group (RMG) Workshop on Biological Management to Meet Continental and National Black Rhino Conservation Goals* (ed. R. Emslie), pp. 35–37. SADC Rhino Management Group, Harare, Zimbabwe.

Berger, J. & Cunningham, C. (1994) Phenotypic alterations, evolutionary significant structures, and rhino conservation. *Conservation Biology*, **8**, 833–840.

Boyce, M.S. & McDonald, L.L. (1999) Relating populations to habitats using resource selection functions. *Trends in Ecology and Evolution*, **14**, 268–272.

Brooks, P.M. (2001) Paper 1: Setting the scene: current coordination and management arrangements and aims of the workshop. In *Proceedings of a SADC Rhino Management Group (RMG) Workshop on Biological Management to Meet Continental and National Black Rhino Conservation Goals* (ed. R. Emslie), pp. 1–8. SADC Rhino Management Group, Harare, Zimbabwe.

Eltringham, S.K. (1979) *The Ecology and Conservation of Large African Mammals*. Macmillan, London, UK.

Emslie, R.H. (1999) *The feeding ecology of the black rhinoceros (Diceros bicornis minor) in Hluhluwe-Umfolozi Park, with special reference to the probable causes of the Hluhluwe population crash*. PhD thesis, University of Stellenbosch, Stellenbosch, South Africa.

Fretwell, S.D. & Lucas, J.H.J. (1970) On territorial behaviour and other factors influencing habitat distribution in birds. *Acta Biotheoretica*, **19**, 16–36.

Goddard, J. (1967) Home range, behaviour, and recruitment rates of two black rhinoceros populations. *East African Wildlife Journal*, **5**, 133–150.

Hooge, P.N. & Eichenlaub, B. (1997) *Animal Movement Extension to ArcView v. 1.1*. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, USA.

IUCN (2006) *2006 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland [http://www.redlist.org, accessed 29 September 2006].

Mukinya, J.G. (1973) Density, distribution, population structure and social organization of the black rhinoceros in Masai Mara Game Reserve. *East African Wildlife Journal*, **11**, 385–400.

Owen-Smith, N. (1977) On territoriality in ungulates and an evolutionary model. *The Quarterly Review of Biology*, **52**, 1–38.

Ritter, R.D. & Bednekoff, P.A. (1995) Dry season water, female movements and male territoriality in springbok: preliminary evidence of waterhole-directed sexual selection. *African Journal of Ecology*, **33**, 395–404.

Tatman, S.C., Stevens-Wood, B. & Smith, V.B.T. (2000) Ranging behaviour and habitat usage in black rhinoceros, *Diceros bicornis*, in a Kenyan sanctuary. *East African Wildlife Journal*, **38**, 163–172.

Whateley, A. & Porter, R. (1983) The woody vegetation communities of the Hluhluwe-Umfolozi Game Reserve Complex. *Bothalia*, **4**, 745–758.

Biographical sketches

Caroline Reid's primary research interest is in the behaviour of animals in relation to their environment. She has also explored habitat influences on the behaviour of springbok in Augrabies Falls National Park.

Rob Slotow's research interests are in conservation ecology, and in particular the conservation of large mammals in small reserves. He is Director of the Amarula Elephant Research Programme.

Owen Howison is currently studying the spread of *Chromalena odorata* in Hluhluwe-Umfolozi Park, and the use and management of rangelands and other natural resources in KwaZulu-Natal.

Dave Balfour is interested in promoting research in the context of conservation and environmental management. This ranges from woody plant dynamics to the role of fire and elephants in determining vegetation structure.