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ORIGINAL ARTICLE

Evaluation of habitat use and ecological carrying capacity for the reintroduced Eastern black rhinoceros (*Diceros bicornis michaeli*) in Ruma National Park, Kenya

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Abstract

We carried out a postrelease evaluation to determine predictors of habitat use and carrying capacity for the black rhinoceros (*Diceros bicornis michaeli*), which are critical for monitoring how the Ruma National Park sub-population may contribute to Kenya's meta-population strategy. We determined whether level of elevation, rockiness, shade, distance to fence, roads, and human settlements predict habitat use, differences in habitat and diet preference between female and male black rhinoceros, and the ecological carrying capacity (CC) of black rhinoceros in the park. We used standard ecological methods to collect data on predictors of habitat use, habitat preference and to estimate CC. Results show, first, that none of the environmental and anthropogenic factors evaluated predicted habitat use by black rhinoceros in the park. Second, although there was no significant difference in habitat preference between the sexes (U = 16.50, p = 0.306), there was a 60% difference in Jaccard's dissimilarity in diet selection between the sexes. Third, the park can support 65 black rhinoceros. Altogether, the findings suggest that the park has potential to support other sub-populations in Kenya. We recommend that future similar studies should incorporate population viability analysis and a community-based approach to forecast the species health and extinction risk.

Résumé

Nous avons effectué une évaluation après la libération afin de déterminer les prédicteurs de l'utilisation de l'habitat et de la capacité de charge du rhinocéros noir (Diceros bicornis michaeli), qui sont essentiels pour surveiller la contribution potentielle de la sous-population du parc national de Ruma à la stratégie de métapopulationdu Kenya. Nous avons déterminé si le niveau d'élévation, les rochers, l'ombre, la distance par rapport aux clôtures, les routes et les établissements humains prédisent l'utilisation de l'habitat, les différences d'habitat et les préférences alimentaires entre les rhinocéros noirs femelles et mâles, et la capacité de charge écologique (CC) du rhinocéros noir dans le nord. parc. Nous avons utilisé des méthodes écologiques standard pour collecter des données sur les prédicteurs de l'utilisation de l'habitat, des préférences d'habitat et pour estimer le CC. Les résultats montrent, d'abord, qu'aucun des facteurs environnementaux et anthropiques n'a évalué l'utilisation prévue de l'habitat par le rhinocéros noir dans le parc. Deuxièmement, bien qu'il n'y ait pas de différence

significative entre les sexes en matière de préférence d'habitat (U = 16,50, p = 0,306), il existait une différence de 60% dans la différence de Jaccard dans la sélection du régime alimentaire entre les sexes. Troisièmement, le parc peut accueillir 65 rhinocéros noirs. Globalement, les résultats suggèrent que le parc pourrait potentiellement accueillir d'autres sous-populations au Kenya. Nous recommandons que les futures études similaires intègrent une analyse de la viabilité des populations et une approche basée sur la communauté pour prévoir le risqué d'extinction et de santé des espèces.

KEYWORDS
Diceros bicornis michaeli, ecological carrying capacity, habitat use, Kenya, Ruma National Park

1 | INTRODUCTION

The Eastern black rhinoceros (*Diceros bicornis michaeli)* is considered critically endangered by the International Union for Conservation of Nature (IUCN, 2017). The species' population size and distribution have declined throughout its African range since 1960s (Coeverden et al., 2011; Otiende et al., 2015) in part due to intensive poaching and habitat destruction (Buk & Knight, 2012). Conservation plans for the species by several African countries specify the need to establish new breeding populations (Morgan, Mackey, & Slotow, 2009).

Increased security and translocation enabled Kenya to recover a total of 623 black rhinoceros by the end of 2011 from less than 500 individuals in 1990s (KWS, 2012). Translocation in particular has received considerable attention and still remains a powerful conservation tool (Ebrahimi, Ebrahimie, & Bull, 2015). To control poaching and support recovery of the species, surviving black rhinoceros are translocated into high-security sanctuaries (Muya et al., 2011). In Kenya, new sanctuaries have been established to support the national strategy to conserve the species as a meta-population. It is in this backdrop that the Kenya Wildlife Service (KWS) initiated a translocation effort to reintroduce twenty-one black rhinoceros to Ruma National Park between December 2011 and January 2012 (KWS, 2012).

Apart from reintroduction of species into their historical ranges, translocation is an important conservation tool that has been used to rescue species from threats such as habitat destruction and poaching, to improve genetic diversity and to solve human–wildlife conflict (Linklater et al., 2011; Pinter-wollman, Isbell, & Hart, 2009). Despite advantages of translocation, it is associated with several challenges including homing, tendency of translocated animals to return back to the site of capture (Villasenor, Escobar, & Estades, 2013), infection by novel parasites and diseases, unavailability of suitable habitats (IUCN/SSC, 2013) and increased mortality especially for females during translocation (Landman, Schoeman, & Kerley, 2013). As a result, translocation yields mixed results for species recovery when management fails to account for the interaction between translocated individuals and their new environments (Holsman, Scheuerell, Buhle, & Emmett, 2012). Availability of suitable habitat types at the release site is thus a key factor for successful translocation. For black rhinoceros, several factors including proximity to roads, rockiness, elevation and human presence or activities determine habitat use (Buk & Knight, 2012; Graham, Adams, Douglas-Hamilton, & Lee, 2009; Morgan et al., 2009). For instance, black rhinoceroses visit water points at night and move faster and spend less time in highly fragmented landscape to minimise contact with humans (Buk & Knight, 2012; Graham et al., 2009; Ochieng, 2015).

The factors that promote or "pull" animals into certain areas may result in aggregations of animals in relatively small spaces, ultimately leading to con-specific competition for ecological resources, increased opportunities for disease transmission, and habitat degradation (Mccallum & Dobson, 2002). On the other hand, factors that constrain or "push" animals from certain areas may constrain habitat availability. Push factors for the most part derive from edge effects arising from anthropogenic activities such as roads and park boundaries. Although a number of studies have shown that slope, rockiness, distance to water, roads, boundary fences and human presence influence distribution and movement of black rhinoceros (Buk & Knight, 2012; Graham et al., 2009; Lush, Mulama, & Jones, 2015; Morgan et al., 2009; Ochieng, 2015), whether these factors promote or constrain habitat use by black rhinoceros in Ruma National Park remains unknown.

At the individual level, the forage-selection hypothesis and socio-ecological model have been postulated to explain differences in habitat use between the sexes. According to forage-selection hypothesis, diet preferences can differ between male and female due to different nutritional and energy requirements (Ruckstuhl & Neuhaus, 2000). In ungulates, for example, males select fibre-rich forage due to larger body size therefore efficient fibre digestion (Yearsley & Perez-Barberia, 2005), whereas reproducing females select plants rich in nitrogen, sodium or calcium due to higher energy demands during gestation and lactation (Ruckstuhl & Neuhaus, 2000). Therefore, although the ranges of male and female rhinoceros can overlap, the sexes may exploit habitat resources differently as a function of sex-specific differences in energetic and nutritional requirements. This may create niche partitioning between the sexes. Socio-ecological model links ecological factors with social characteristics and allows for predictions about the relationships between resource distribution, type of competition and social organisation (Dammhahn & Kappeler,

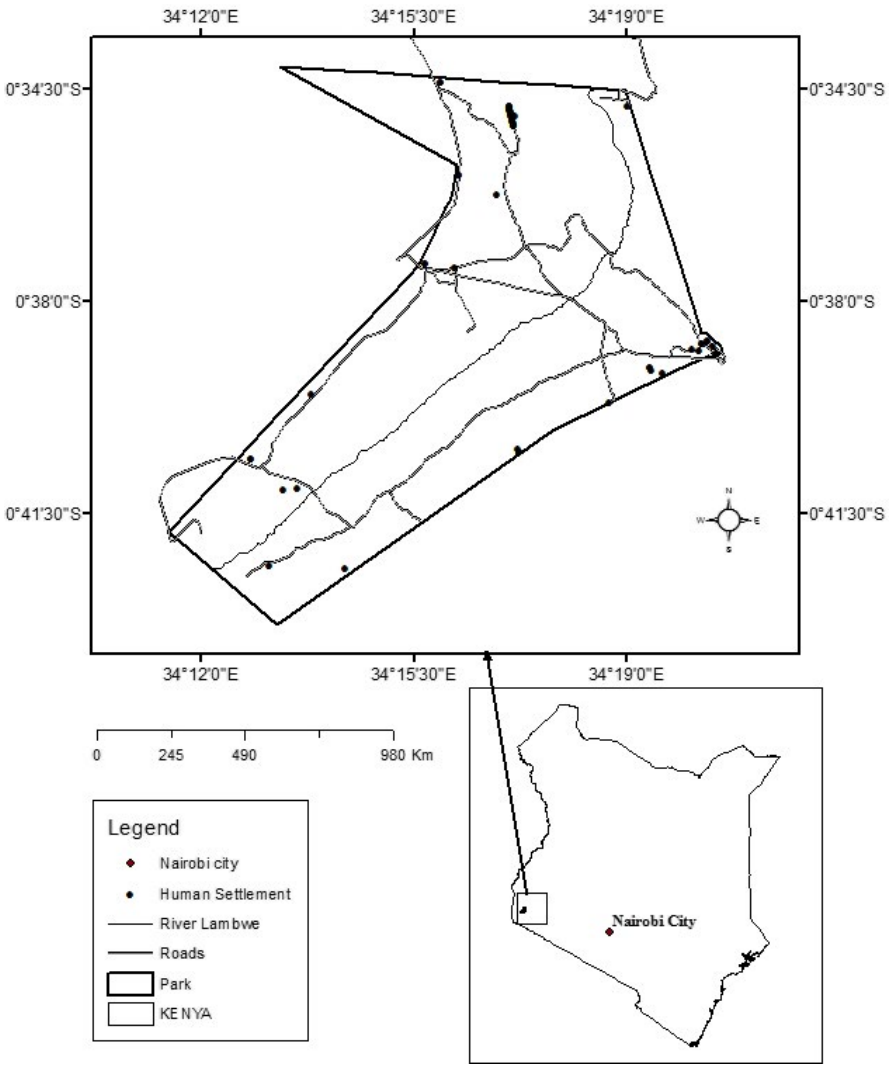

FIGURE 1 Map of Kenya showing the location of Ruma National Park [Colour figure can be viewed at wileyonlinelibrary.com]

2009). From the perspective of the socio-ecological model, females track the distribution of ecological resources while males track the distribution of female (Dammhahn & Kappeler, 2009). In terms of social organisation, adult males are generally solitary (Hutchins & Kreger, 2006) but associate closely with reproductively receptive females (Garnier, 2001). Thus, the only stable social group is between female black rhinoceros and her most recent offspring (Hutchins & Kreger, 2006), which persists until the mother gives birth again.

Factors that affect habitat use ultimately influence the carrying capacity of a given conservation area (Tregenza, 1995). Knowledge of carrying capacity is essential for sustainable conservation of black rhinoceros (KWS, 2012). However, since the translocation of black rhinoceros to Ruma National Park, the maximum number of species that the park can support has not been determined. A common mechanism that governs carrying capacity is ecological resource availability (Chapman & Byron, 2018). Previous estimates of carrying capacity have been based on species habitat use (Steenweg, Hebblewhite, Gummer, Low, & Hunt, 2016), productivity and quality of browse (Amin et al., 2006), how the species uses available space (Braithwaite, Meeuwig, & Jenner, 2012), and the absolute density of animals per unit area (Okita-Ouma, Amin, van Langevelde, & Leader-Williams, 2009). All these approaches do not take into consideration habitat selection by the species.

The goal of the present study was to evaluate habitat use and ecological carrying capacity for the reintroduced black rhinoceros' population in Ruma National Park. Specifically, the study aimed to determine whether habitat use by black rhinoceros was predicted by rockiness, shade, elevation, human settlement, distance to barriers and borders (roads and park boundary), and distance to water points; differences in habitat and diet preferences between male and female black rhinoceros; and the ecological carrying capacity for black rhinoceros in Ruma National Park.

1.1 | Study area

The present study was conducted in Ruma National Park beginning June 2016 to December 2017, approximately six years since the reintroduction of black rhinoceros in the park. The park is located to the southern shores of Lake Victoria in Homa Bay County between 0^0 33′-0^0 44′ S, and 34^0 10′-34^0 22′ E, about 23 km south-west of Homa Bay Town and 425 km west of Nairobi (Figure 1). The park lies at the bottom of Lambwe Valley between

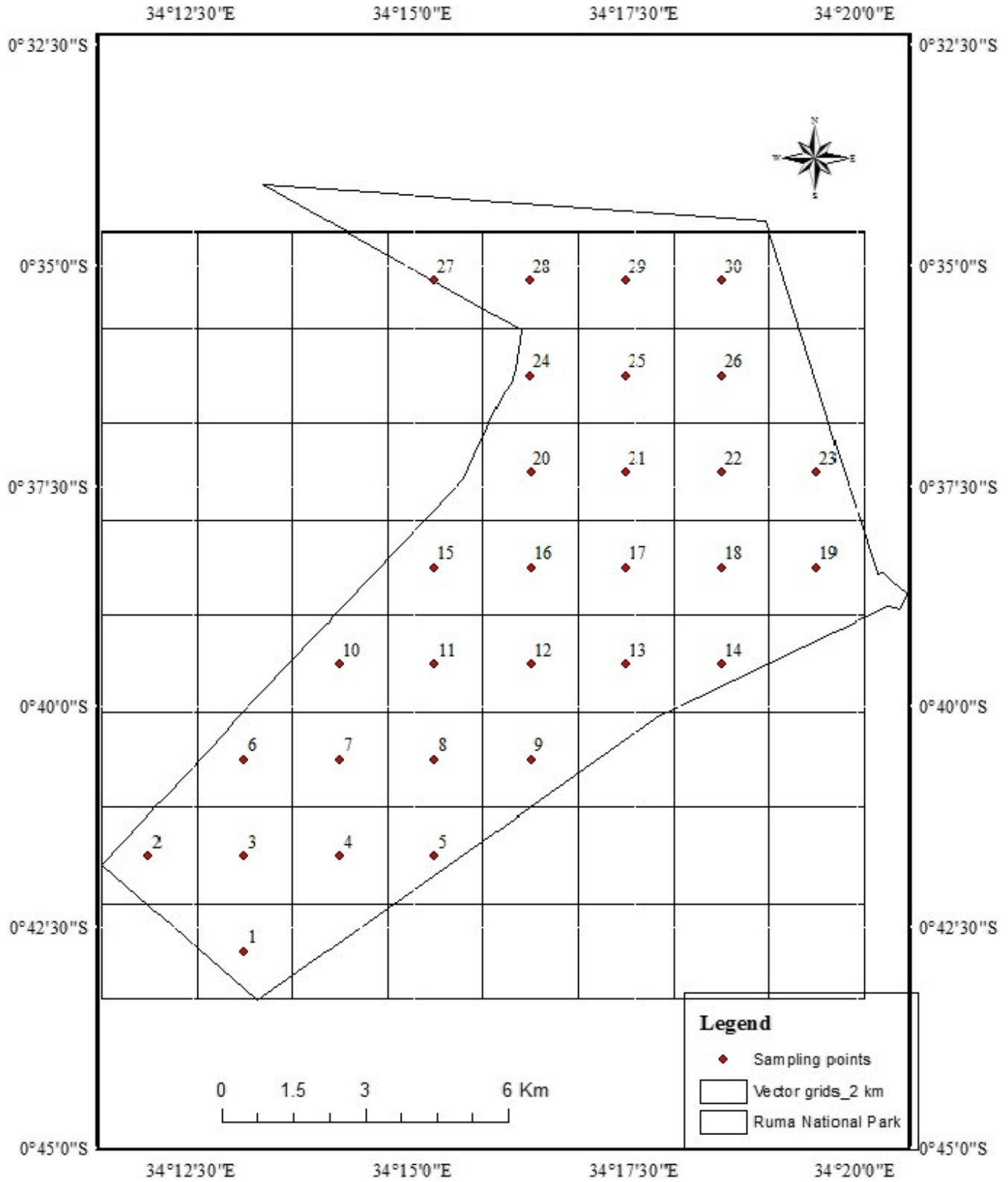

FIGURE 2 Map showing all sampling locations in the study area. Numbers indicate sampling identity for each sampling plot [Colour figure can be viewed at wileyonlinelibrary.com]

the Kanyamwa Escarpment and Gwassi Hill. The park experiences bimodal rainfall annually with peaks between March and May and between October and December with annual rainfall of between 1,200 and 1,600 mm. The climate is sub-humid to semi-arid (Kimanzi, 2011). The park covers an area of 126 km^2, and it is dominated by seven vegetation types: *Combretum* grassland association, *Balanites* grassland association, *Acacia* grassland associations, *Acacia* woodland, dense continuous thicket, isolated

thicket clumps and grassland. Ruma National Park has low tourist visitation and human activities due to poor infrastructure. The park is rich in wildlife species such as the Roan antelope (*Hippotragus equinus*) which is endemic to park, Rothschild giraffe (*Giraffa camelopardalis rothschildi*), impala (*Aepyceros melampus*), bush buck (*Tragelaphus scriptus*), white rhinoceros (*Ceratotherium simum simum*) and black rhinoceros (KWS, 2012; Njoka, Muriuki, Reid, & Nyariki, 2003).

2 | METHODS

2.1 | Predictors of habitat use

Thirty sampling blocks were established across the park using the vector grid method in QGIS 2.10 (Q GIS Development Team, 2009). Sampling points were 1 km apart from each other both vertically and horizontally to minimise spatial autocorrelation (Figure 2). A hand-held Global Positioning System device (Garmin etrex 30) was used to navigate to each sampling block; a 20 × 20 m square sampling plot was marked out from the centre point using a tape measure, and the boundary was marked using polyethylene string.

Distance from each plot to the nearest road, settlement, boundary fence and water sources were calculated using near feature table analysis tool in Arc GIS 9.2 (Environmental Systems Research Institute, 2006) with maximum near feature set at 1 to determine how proximity to these factors affects habitat use by black rhinoceros (Buk & Knight, 2012). Elevation of each sampling point was determined from the hand-held GPS device. Habitat rockiness was visually assessed as zero per cent, fifty per cent or greater than fifty per cent loose rock or bed rock at 25 pinpoints in each of the 30 sampling plots (Buk & Knight, 2012). At the sampling plot level, shade was measured by measuring the diameter of the canopy (≥4 m indicates presence of shade and <4 m indicates no shade). Plant canopy cover ≥4 m would provide shade for black rhinoceros because adult measures between 3.0 and 3.8 m in length. Habitat use at each sampling plot was measured by searching for evidence of the characteristic clean cut to vegetation made by black rhinoceros as they browse per shrub or tree (Muya & Oguge, 2000).

2.2 | Differences in habitat preference between the sexes

Vegetation was classified using cloud-free Sentinel-2A satellite images from Copernicus Science Data hub (https://sentinel.esa.int/web/sentinel/sentinel-data-access) and processed using QGIS 2.10 and the Semi-Automatic Classification Plugin (January 2017). Atmospheric correction was undertaken using the DOS 1 method to compensate for interference of electromagnetic waves by atmospheric constituents (Nguyen et al., 2015). Bands 8, 4 and 3 were combined using the bandset tool to give standard colour composite, which is appropriate for vegetation studies (Nguyen et al., 2015). Vegetation types were classified based on Allsopp and Baldry's (1972) classification scheme.

Data were ground-truthed by marking at least thirty locations of the seven classes of vegetation types using a Global Positioning System (GPS), and the output of the unsupervised classification was used to perform a supervised classification on the images, using the maximum likelihood classification algorithm (Trisakti, 2017). The algorithm was used because it incorporates the statistics of the training samples before assigning the vegetation types to each pixel which increases map accuracy (Trisakti, 2017). Vegetation type maps generated were filtered with the majority filter, a postclassification tool in Semi-Automatic Plugin (Lillesand, Kiefer, & Chipman, 2008), to remove any "salt-and-pepper appearance" and to enhance the cartographic presentation after the image classification. Lastly, map accuracy assessment was done using kappa statistics (Kimanzi, 2011).

Habitat preference was determined from locations of black rhinoceros foraging activities. A two-hour focal follow was carried out for each focal animal randomly drawn from the list of black rhinoceros in the park. Each focal animal was followed at a distance of 100 m from 06:30–08:30 hr on each field day. In cases where the focal animal went out of view, observation was stopped. Individual rhinoceros were identified by the unique ear-notch patterns to ensure that we did not mistakenly follow different animals during the same focal animal sampling session. We tracked a total of fifteen black rhinoceroses (nine males and six females) and recorded the location of each feeding bout on the GPS device. The total number of feeding incidents per individual ranged from 33 to 180 locations. In order to compute habitat preference, the formula by Morgan et al. (2009) was used;

$$\mathrm{HPI} = \frac{\mathrm{ri}}{\mathrm{ni}/(a \div A)}$$

ri is the number feeding locations in a given habitat type.

ni is the total number of feeding locations in all habitat types.

a is area of a given habitat type.

A is total area of all habitat types in the park.

Mann–Whitney *U* test was used to determine whether there was a statistical difference in habitat preference between the sexes. Three categories of habitat preference were used as follows: 0–0.75 = selection against, 0.76–1.25 = no selection and >1.25 = positive selection (Morgan et al., 2009).

2.3 | Differences in diet preference between the sexes

Rhinoceros feeding trails were located in the early morning and were followed until the animal to be observed was spotted. Along the feeding trails, freshly browsed plants were identified. Signs of feeding by rhinoceros were identified by a 45˚ clean cut on the stem of browse species. Data on diet preference were collected from a total of 15 black rhinoceroses (nine males and six females). Freshly eaten plants were identified in the field if possible, and those that could not be identified in the field were collected, pressed and dried for

identification at Maseno University Herbarium, see Data S1. Plant species collected during the focal sampling were used to determine diet differences between the sexes. Differences in diet between the sexes were calculated using Jaccard's Coefficient; the closer the index is to 100% the more similar the diet between the two sexes (Waweru, 1991):

$$Isj = \left(\frac{c}{a+b+c}\right) 100$$

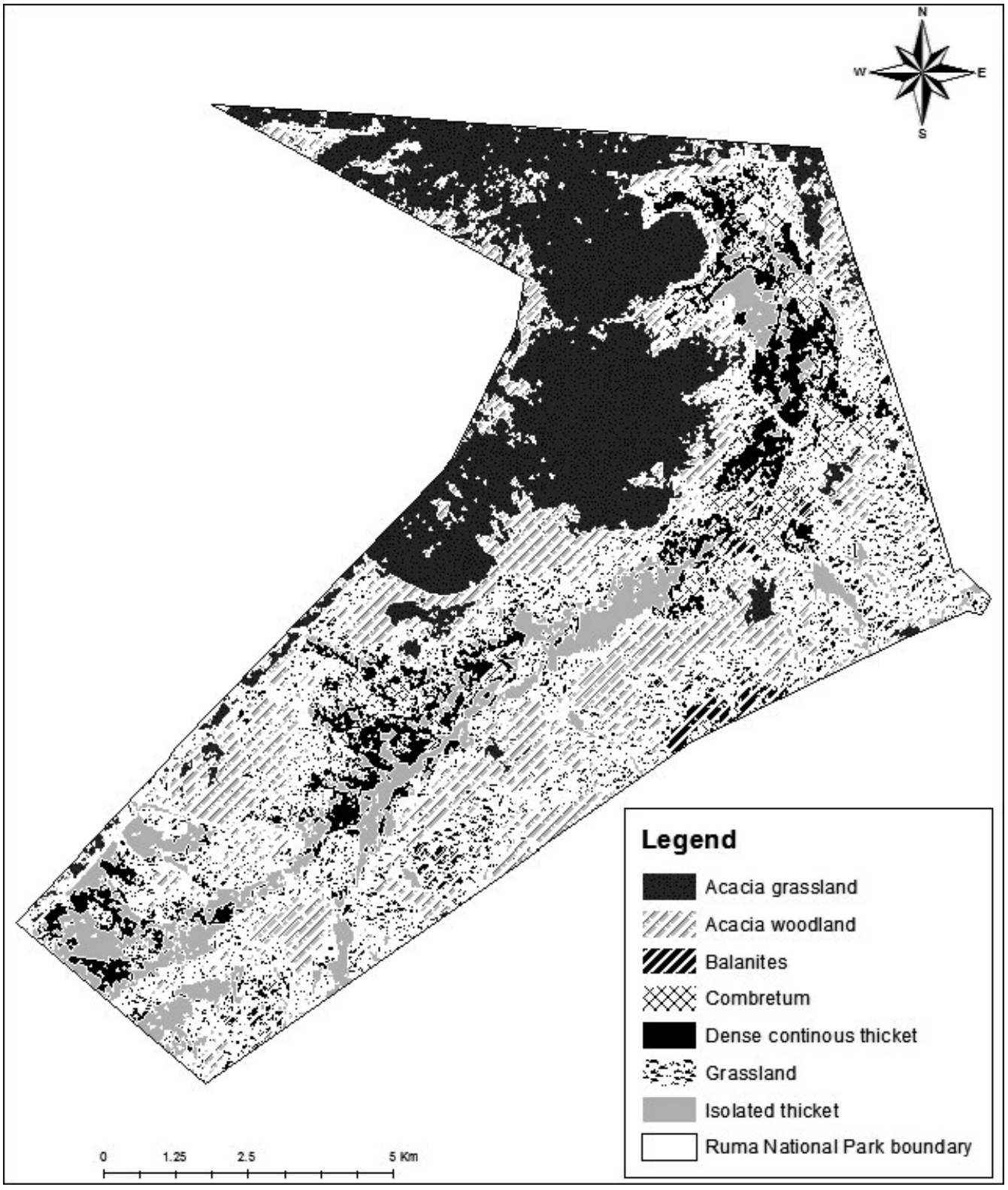

FIGURE 3 Vegetation types of Ruma National Park 2017

where Isj is Jaccard's index of similarity.

a is the number of plant species unique to male black rhinoceros.

b is number of plant species unique to female black rhinoceros.

c is number of plant species common to both male and female black rhinoceros.

In order to estimate Jaccard's index of dissimilarity, we used the formula.

$$d = 1 - \text{Isj}$$

where *d* is Jaccard's index of dissimilarity.

2.4 | Carrying capacity

To determine ecological carrying capacity, data on the total area of each habitat type were estimated in Arc GIS 9.2. A total of 1,086 feeding locations (data collected as described under habitat preference) of nine male and six female black rhinoceroses with at least 33 sightings per individual as recommended by Plotz, Grecian, Kerley, and Linklater (2016) were used to determine home ranges of black rhinoceros. Kernel home ranges were estimated using Hawth's analysis tool extension to Arc GIS 9.2. The 95% kernel was used to estimate maximum home range size and 50% for core areas of use within the home ranges (Reid, Slotow, Howison, & Balfour, 2007). The 50% kernel home range of black rhinoceros was used because it is significantly more accurate than 95% Kernel home range estimation (Plotz et al., 2016). We standardised home range estimates by using a single smoothing parameter (*h* = 1,000) to calculate the area of each habitat available within black rhinoceros' home range. This was important to reduce biasness as a result of variation in individual sample size (Horikoshi, Battley, Seaton, & Minot, 2017). Habitat selection index of each habitat type was obtained by dividing the proportion of habitat use by availability of the respective habitat within the home range (1.00–1.04 indicates neutral selection, >1.04 positive habitat selection and 0–0.90 indicates negative habitat selection). Habitat types not present within the home range were excluded from the individual analysis. Data on habitat selection, area of each habitat type and home range overlap enabled us to calculate carrying capacity following a modified version of Nascimento and Schmidlin (2011); the two modifications were that we used a 50% KHR and we factored in a group size of 1 which is more appropriate for a solitary species such as black rhinoceros:

K^* index = $\sum \left[\left(D_{cv} \times I_{cv} \right) / \left(A - S \right) \right]$where

K^* index is the ecological carrying capacity when habitat selection index is used.

A is the area of 50% kernel home range in each habitat type (ha).

S is home range overlap (ha).

D_{cv} is the total area (ha) of each habitat type available.

I_{vc} is the habitat selection index for each habitat type.

TABLE 1 Vegetation types and their respective area in Ruma National Park in 2017

Habitat type	Area (km^2)	Percentage
Acacia grassland association	34	27
Acacia woodland	25	20
Dense continuous thicket	17.9	14
Grassland	14.9	12
Isolated thicket clumps	13	10
Balanites grassland association	12.4	10
Combretum grassland association	8.7	7
Total	125.9	100

3 | RESULTS

3.1 | Predictors of habitat use

Seven habitat types in the park were described as follows: *Acacia* grassland association, *Acacia* woodland, *Balanites* grassland associations, *Combretum* grassland associations, dense continuous thicket, grassland and isolated thicket clump, see Figure 3 for a map of the seven habitat types. The final product of vegetation mapping provided an estimated area of each habitat type in the park (Table 1). Overall map accuracy was 94.1% with a kappa coefficient of 0.90.

The level of loose rocks in the park across all habitats ranged from 0 to <50%; 61% of the park was shaded with only 27% of *Acacia* grassland associations and 12% of grassland having no shade. Binomial logistic regression was performed to ascertain whether environmental factors (level of rockiness, shade, elevation and distance from water points) and anthropogenic factors (distance from

TABLE 2 Total number of observation period per individual

SN	Rhinoceros ID	Focal time (hr)	Days
1	Paula	6	3
2	Kirui	4	2
3	Laban	10	5
4	Betty	2	1
5	Kobia	4	2
6	Parri	4	2
7	Ipp	4	2
8	Rua	4	2
9	Moraa	4	2
10	Okute	4	2
11	Major	4	2
12	Baraka	4	2
13	Omo	4	2
14	Onginjo	4	2
15	Rusellas	2	1
	Total	64	32

TABLE 3 Habitat preference by both male and female black rhinoceros

Habitat type	Sightings per habitat	Area of each habitat (km^2)	Proportion of sightings	Proportion of total area	Habitat preference index
Acacia grassland	422	34.0	0.39	0.27	1.44
Acacia woodland	282	25.0	0.26	0.20	1.30
Grassland	124	14.9	0.11	0.12	0.97
Isolated thicket	95	13.0	0.09	0.10	0.84
Balanites	76	12.4	0.07	0.10	0.71
Dense thicket	66	17.9	0.06	0.14	0.43
Combretum	21	8.7	0.02	0.07	0.28

Note: sightings ratio is the proportion of rhinoceros' locations in a habitat; area ratio is the proportion of the habitat available within Ruma National Park; scale for habitat preference index of 0–0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection.

TABLE 4 Habitat preference by male black rhinoceros

Habitat type	Sightings per habitat	Area of each habitat (km^2)	Proportion of sightings	Proportion of total area	Habitat preference index
Acacia woodland	197	25.0	0.31	0.20	1.57
Isolated thicket	78	13.0	0.12	0.10	1.20
Grassland	71	14.9	0.11	0.12	0.96
Acacia grassland	156	34.0	0.25	0.27	0.92
Balanites	51	12.4	0.08	0.10	0.83
Dense thicket	56	17.9	0.09	0.14	0.63
Combretum	17	8.7	0.03	0.07	0.40

Note: sightings ratio is the proportion of rhinoceros' locations in a habitat; area ratio is the proportion of the habitat available within the park; scale for habitat preference index of 0–0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection.

TABLE 5 Habitat preference by female black rhinoceros

Habitat type	Sightings per habitat	Area of each habitat (km^2)	Proportion of sightings	Proportion of total area	Habitat preference index
Acacia grassland	266	34.0	0.58	0.27	2.15
Grassland	53	14.9	0.12	0.12	0.98
Acacia woodland	85	25.0	0.18	0.20	0.92
Balanites	25	12.4	0.05	0.10	0.55
Isolated thicket	17	13.0	0.04	0.10	0.36
Dense thicket	10	17.9	0.02	0.14	0.15
Combretum	4	8.7	0.01	0.07	0.13

Note: sightings ratio is the proportion of rhinoceros locations in a habitat; area ratio is the proportion of the habitat available within the park; scale for habitat preference index of 0–0.75 selection against, 0.76–1.25 no selection and >1.25 positive selection.

the fence, distance from human settlement and distance from roads) predicted habitat use by black rhinoceros in the park. None of the environmental and anthropogenic factors influenced the habitat use by black rhinoceros.

3.2 | Differences in habitat use between the sexes

At the home range level, there was no significant difference between male and female black rhinoceros kernel home range sizes (Mann–Whitney $U = 23$, $p = 0.897$). However, on average male black rhinoceros home range size was larger (mean ± standard deviation: 401.33 ± 230.95, range 150.17–864.55 ha) than female black rhinoceros (445.63 ± 338.01, range 139.79–1248.53). Overall, the home ranges of females and males overlapped by 1215.80 ha.

The observation period per individual ranged from 2 to 10 hr (Table 2). Habitat preference indices showed that *Acacia* grassland was most preferred by black rhinoceros with a habitat preference index of 1.44 followed by *Acacia* woodland with habitat preference index of 1.30 and lastly *Combretum* with a preference of 0.28 (Table 3). Although there was no statistical difference in habitat preference between female and male black rhinoceros ($U = 16.50$, $p = 0.306$), Jaccard's coefficient showed that there was a 60%

TABLE 6 Habitat selection by black rhinoceros in Ruma National Park

Habitat type	Proportion of use	Availability in KHR	Habitat selection Index
Acacia grassland	0.39	0.34	1.14
Acacia woodland	0.26	0.24	1.09
Balanites	0.07	0.08	0.83
Combretum	0.02	0.04	0.47
Dense thicket	0.06	0.08	0.75
Isolated thicket	0.09	0.09	0.96
Grassland	0.11	0.12	0.93

Note: KHR = Kernel home range; habitat selection index scale, 1.00–1.04 indicates neutral selection, >1.04 indicates positive habitat selection and 0–0.90 indicates negative habitat selection.

dissimilarity in diet selection between the sexes. Furthermore, habitat preference indices showed that male black rhinoceros prefer *Acacia* woodland and isolated thicket clumps as opposed to female black rhinoceros that prefer *Acacia* grassland (Table 4 and Table 5). In both sexes, *Combretum* was the least preferred habitat type with a preference index of 0.40 and 0.13, respectively.

3.3 | Carrying capacity

Table 6 summarises data on habitat selection indices that were used to compute carrying capacity. Carrying capacity in Ruma National Park was calculated to be 80 black rhinoceros, when habitat selection was not taken into consideration. This number decreased by about 19% when habitat selection index was included in the calculation resulting in 65 black rhinoceroses.

4 | DISCUSSION

4.1 | Predictors of habitat use

The finding that none of the environmental and suspected edge effects potentially deriving from proximity to road, park boundary and human settlement predicted habitat use by black rhinoceros suggest that these factors neither promote nor constrain habitat use by black rhinoceros in the park. This is not surprising for a factor such as rockiness given that the park is less rocky (0 < 50%), compared to parks where rockiness has been shown to predict habitat use through restricted movement (Buk & Knight, 2012).

Similarly, abundant shade in the park (61% shade) coupled with the observation that the animals foraged in cooler times of the day (early morning and late evening) suggests that shade may have not had a pronounced bearing on habitat use by the species as it does in parks with less shade (Buk & Knight, 2012). Apart from abundant shade, the observed tendency of the animals to forage during cooler times of the day, mostly early in the morning, may also limit the extent to which access to watering points may constrain habitat use by black rhinoceros (Cain, Jansen, Wilson, & Krausman, 2008).

Low tourist visitation and low human activities in the park might explain why anthropogenic factors associated with edge effects did not predict habitat use by black rhinoceros. This finding is in contrast to reserves such as Mun-Ya-Wana Game Reserve and Zululand Rhino Reserve where human settlement, roads and distance to protected area boundary have been shown to negatively impact habitat use by black rhinoceros due to high human activities in the park and around the park (Morgan et al., 2009; Odendaal-Holmes, Marshal, & Parrini, 2014). It is however important to state that the role of anthropogenic factors on habitat use may change as humans continue to return to Lambwe Valley in part because of the successful control of tsetse fly population in the region (Muriuki, Njoka, Reid, & Nyariki, 2005).

4.2 | Habitat and diet preference between the sexes

In accordance with the socio-ecological model (Crook, 1960; Emlem & Oring, 1977; Jarman, 1974; Ostefeld, 1990), male black rhinoceros were found to occupy home ranges that were in proximity to those of females. However, core areas of all the males remained exclusive of both other male and female home ranges, which is consistent with the territorial nature of male black rhinoceros (Hutchins & Kreger, 2006).

The absence of a difference in habitat preference between male and female black rhinoceros indicates that the sexes use the same habitats. However, we also observed that female black rhinoceros preferred *Acacia* grassland associations while males preferred *Acacia* woodland and isolated thicket clumps. This observation suggests that the sexes select different components of the habitat. It has been argued that open habitats such as *Acacia* grassland associations allow for free movement besides the fact that most food items are within reach (Tatman, Stevens-wood, & Smith, 2000) and thus may favour females with calves. This observation is also consistent with the predator-risk hypothesis that postulates that female ungulates preferentially use predator-safe habitats compared to males (Ruckstuhl & Neuhaus, 2002). However, whether this was the case in the population of black rhinoceros in Ruma was beyond the scope of the current study.

Even though we did not measure content of food plants, the 60% difference in diet preference between female and male black rhinoceros is consistent with the forage-selection hypothesis (Ruckstuhl & Neuhaus, 2000). Consequently, even though the sexes shared or had home ranges in close proximity, sex differences in diet preferences may mollify intersexual competition for ecological resources. This

dissimilarity in diet selection between the sexes may be attributed to sex differences in energy and nutritional requirements (Ruckstuhl & Neuhaus, 2000). For instance, female black rhinoceros has a long gestation period of about 1.3 years and lactation period of about 3–3.4 years which are both energetically and nutritionally demanding (Garnier, 2001; Okita-Ouma, 2014) unlike males. The implication of the sex difference in diet selection is low competition for food between male and female black rhinoceros and thus potential for future population growth.

4.3 | Carrying capacity

The estimated carrying capacity in Ruma National Park was above the number of black rhinoceros that was reintroduced in 2012. This shows that Ruma National Park has the capacity to accommodate additional black rhinoceros. However, the male-biased sex ratio and its concomitant competition for reproductive females may impede growth in the population (Gedir, Law, Preez, & Linklater, 2018). Furthermore, competition from other mega-herbivore such as giraffes may reduce the estimated black rhinoceros carrying capacity.

5 | CONCLUSION

The relatively large ecological carrying capacity for a park the size of Ruma National Park is supported by the results showing that neither the environmental nor anthropogenic factors that we studied neither promote nor constrain habitat use by black rhinoceros. In addition, diet preference between female and male black rhinoceros implies low competition for food between the sexes. Habitat preference between the sexes gives a broader understanding of potential intersexual competition for ecological resources. In sum, Ruma National Park has potential to substantially contribute to the meta-population strategy adapted by the Kenya Wildlife Service for the conservation of black rhinoceros. We recommend that future similar studies should incorporate population viability analysis and a community-based approach to forecast the species health and extinction risk. Such approaches help to identify key demographic and environmental factors that influence species health, extinction risk and thus form the basis for formulating a holistic conservation action plan.

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CONFLICTS OF INTEREST

None.

AUTHOR CONTRIBUTIONS

POO designed the study; SAO involved in field work and data analysis; and SAO, POA and POO wrote the article.

DATA AVAILABILITY

This article does not contain data.

ETHICAL STANDARDS

Given that the research did not involve invasive approaches such as capture and handling of black rhinoceros, ethical approval was not necessary. However, in order to carry out the research, research authorisation was obtained from the Kenya Wildlife Service REF. No. KWS/BRM/5001.

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