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RESEARCH NOTE

Index-based large carnivore population density and abundance estimates for the Ruaha-Rungwa conservation complex in Tanzania

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1 | INTRODUCTION

The Ruaha-Rungwa conservation landscape is a ~45,000 km^2 Protected Area (PA) complex in south-central Tanzania. The area is believed to harbour globally important populations of lion (*Panthera leo*; Bauer et al., 2016), cheetah (*Acinonyx jubatus*; Durant et al., 2017), and African wild dog (*Lycaon pictus*; Woodroffe & Sillero-Zubiri, 2020), as well as important populations of leopard (*Panthera pardus*), spotted hyaena (*Crocuta crocuta*), and striped hyaena (*Hyaena hyaena*) (TAWIRI, 2009). However, no empirical estimates of landscape-wide population abundance exist for these populations, with the only available estimates being based on expert opinion or extrapolations from densities elsewhere (Mesochina et al., 2010; Riggio et al., 2013). Here, we present landscape-level population density and abundance estimates of five large carnivore species in Ruaha-Rungwa. We calculated population density as an index from spoor (track) data, while acknowledging the technique's low precision (as revealed by recent research) and providing recommendations for future monitoring.

2 | MATERIALS AND METHODS

2.1 | Study area

The complex includes Ruaha National Park (NP), one of the largest NPs in eastern Africa at 20,226 km^2, which is used for photographic tourism; three Game Reserves (GRs – Rungwa, 9175 km^2; Kizigo, 5140 km^2; Muhesi, 2720 km^2), where trophy hunting tourism is the primary revenue generation mechanism; and a number of multiple-use areas, including Lunda-Mkwambi Game Controlled Area (GCA), Rungwa South Open Area (OA), and MBOMIPA and Waga Wildlife Management Areas (WMAs) (Figure 1). Vegetation cover primarily comprises a mosaic of *Acacia-Commiphora* open savannah/bushland

and central Zambezian and Eastern *Brachystegia*-dominated miombo woodland, complemented by riverine forests and floodplain grasslands (Olson et al., 2001).

2.2 | Study design and data collection

We carried out vehicle-based spoor surveys over two dry seasons, between July and November 2017 and June and November 2018. The study area was divided into 225-km^2 grid cells, and a minimum of 6 km and a maximum of 20 km were surveyed within all cells with sufficient road access (Henschel et al., 2020). The maximum 20 km of transects were carried out in all sites where this was possible. For data collection, we employed the protocols presented in Henschel et al. (2020).

2.3 | Spoor and population density estimation

We counted the number of fresh track observations for each species for each transect and from this calculated standardised 'track densities' (Table 1), equivalent to the number of fresh tracks per 100 km of transect (Funston et al., 2010). Population densities were

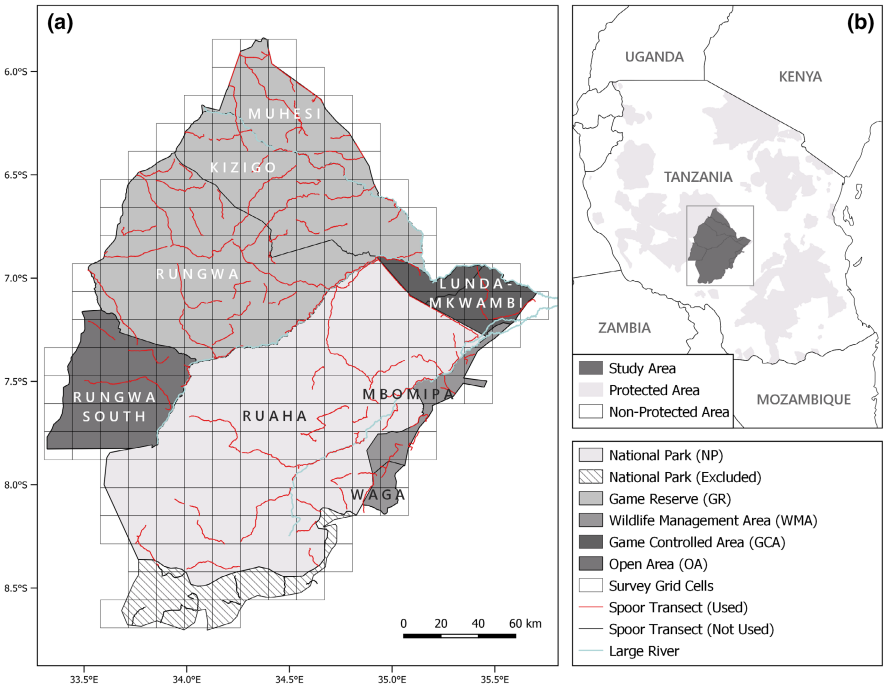

FIGURE 1 (a) Survey grid and spoor transects in the Ruaha-Rungwa conservation landscape and (b) the landscape within the wider context of Tanzania's protected areas. Both the gazetted and effective boundaries for Ruaha NP are depicted. Rungwa South OA comprises both Rungwa South OA and Rungwa Mzombe OA.

TABLE 1 Survey effort and large carnivore spoor densities in Ruaha-Rungwa

	Area (km^2)	Spoor surveys (km)[a]	Area coverage	Spoor density (fresh tracks/100 km)[b]				
				Lion	Leopard	Spotted hyaena	African wild dog	Cheetah
National Parks								
Ruaha NP[c]	17,827	901	72%	8.45 ± 2.62	2.01 ± 1.61	25.81 ± 6.46	3.14 ± 3.35	0.46 ± 0.44
Game Reserves								
Rungwa GR	9175	667	88%	7.60 ± 3.19	8.11 ± 2.15	27.53 ± 5.84	5.32 ± 3.98	0.39 ± 0.76
Kizigo GR	5140	349	85%	8.85 ± 5.74	8.59 ± 3.27	30.92 ± 9.99	0.65 ± 1.28	0.24 ± 0.47
Muhesi GR	2720	278	91%	2.79 ± 2.62	4.22 ± 2.60	19.85 ± 6.74	0.00 ± 0.00	0.00 ± 0.00
Landscape								
All GRs	17,035	1112	86%	6.80 ± 2.47	7.59 ± 1.62	26.81 ± 4.51	3.13 ± 2.28	0.28 ± 0.44
Ruaha NP + GRs	34,862	2013	76%	6.84 ± 1.75	6.76 ± 1.16	25.38 ± 3.83	3.25 ± 2.05	0.38 ± 0.33
Ruaha-Rungwa (inc. GCA & OA)	41,757	2393	85%	6.26 ± 1.58	6.45 ± 1.09	24.43 ± 3.46	2.99 ± 1.82	0.54 ± 0.49

[a]Surveys carried out along boundaries of two protected areas are used in calculations for both.

[b]Calculated as per Henschel et al. (2020).

[c]Excludes permanently settled areas in southwestern Ruaha NP.

TABLE 2 Large carnivore population density and abundance estimates for the different components of the Ruaha-Rungwa complex

		Lion		Leopard		Spotted hyaena		African wild dog		Cheetah	
	Area (km^2)	Density[a]	Population[b]	Density	Population	Density	Population	Density	Population	Density	Population
National Parks											
Ruaha NP[c]	17,827	2.65 (0.00-6.15)	473 (0–1097)	2.01 (0.02–3.99)	358 (3–712)	7.92 (0.00–16.24)	1412 (0–2895)	0.96 (0.00–4.15)	171 (0–741)	0.14 (0.00–0.66)	25 (0–118)
Game Reserves											
Rungwa GR	9175	2.33 (0.00–5.73)	214 (0–526)	2.49 (0.21–4.76)	228 (19–437)	8.45 (2.20–14.69)	775 (202–1348)	1.63 (0.00–6.02)	150 (0–552)	0.12 (0.00–0.89)	11 (0–82)
Kizigo GR	5140	2.71 (0.00–6.71)	139 (0–345)	2.64 (0.45–4.82)	135 (23–248)	9.48 (1.10–17.87)	488 (56–919)	0.20 (0.00–1.14)	10 (0–59)	0.07 (0–0.42)	4 (0–22)
Muhesi GR	2720	0.85 (0.00–2.45)	23 (0–67)	1.29 (0.00–2.88)	35 (0–78)	6.09 (0.71–11.46)	166 (19–312)	N.A.	N.A.	N.A.	N.A.
Rungwa-Kizigo-Muhesi	17,035	2.09 (0.00–5.54)	355 (0–943)	2.33 (0.13–4.52)	397 (23–770)	8.22 (1.47–14.98)	1401 (251–2551)	0.96 (0.00–4.29)	163 (0–730)	0.09 (0.00–0.63)	15 (0–107)
Landscape											
Ruaha-Rungwa (inc. GCA, OA, WMAs)	41,757	1.92 (0.00–5.01)	801 (0–2091)	1.98 (0.00–4.04)	826 (0–1686)	7.50 (0.36–14.63)	3130 (152–6107)	0.92 (0.00–4.21)	382 (0–1756)	0.17 (0.00–1.01)	69 (0–423)

Note: 95% confidence intervals are presented calculated as per Bauer et al. (2017) and Dröge et al. (2020).

[a]Population density (adult and sub-adult individuals per 100 km^2) and associated 95% confidence intervals.

[b]Estimated adult and sub-adult population size, using regression equations developed by Funston et al. (2010) and Winterbach et al. (2016) and associated 95% confidence intervals (calculated as per Bauer et al. (2017) and Dröge et al. (2020)).

[c]Excludes permanently settled and intensively farmed areas in southwestern Ruaha NP.

then estimated from track densities using the general equation for all large carnivore species developed by Winterbach et al. (2016), modified from Funston et al. (2010). We calculated confidence intervals (CIs) for the population density and abundance estimates using the method employed by Bauer et al. (2017) and Dröge et al. (2020); although this results in wider confidence intervals than the method from Funston et al. (2010), the latter has been shown to overestimate precision (Dröge et al., 2020).

As a result of ongoing land disputes, a portion of southwestern Ruaha NP (~2400 km^2) hosts permanent settlements and industrial agriculture activities and was found to be largely devoid of wildlife (Figure 1). Transects in this area were excluded from the analyses, and density and abundance estimates for Ruaha NP refer to the area of the NP without such activities (17,827 km^2).

3 | RESULTS AND DISCUSSION

We carried out a total of 2393 km of spoor transects. Overall, we surveyed ~85% of sampling sites in the landscape, ensuring similar sampling in both the primary vegetation types, as well as with regard to distance to rivers, PA boundaries and type, and other natural and anthropogenic features (Figure 1). We detected a total of 151 independent fresh tracks of lion, 149 of leopard, 9 of cheetah, 54 of wild dog, and 572 of spotted hyaena. Table 2 presents overall and PA-specific (where possible) population density and abundance estimates. See Appendix S1 for detection maps for all large carnivores, and Appendix S2 for the track and population density estimates calculations.

Our surveys indicate that Ruaha-Rungwa is home to important populations of lion, leopard, spotted hyaena, and African wild dog. Although cheetah population estimates exhibit very low precision, the low number of detections suggest a relatively sparse population (Table 2). Results confirm that Ruaha-Rungwa is home to an important population of lion, with detections suggesting that the Great Ruaha and Mzombe river valleys are particularly important for the population in the dry season (Appendix S1). Our findings also suggest that Ruaha-Rungwa hosts what is likely to be one of the continent's largest remaining populations of wild dogs, although standard errors for the estimate are especially high due to high variability in spoor densities between transects, which should be kept in mind when interpreting results. Rungwa GR appears particularly important for the species, possibly due to the area consisting primarily of miombo woodlands, which have been suggested to be particularly suitable for the species (Creel, 2001). Spotted hyaena were the species estimated to have the highest abundance in the complex, while leopard track densities were comparable with those from studies employing the same methodology elsewhere (Bauer et al., 2015; Henschel et al., 2020).

Finally, we appreciate that recent research (Dröge et al., 2020) showed that population density and abundance estimates from track densities exhibit lower precision than previously thought. Indeed, the CIs estimated through the amended formula presented by Dröge et al. (2020) (Table 2) are unlikely to be suitable to monitor population changes over time. Nevertheless, we believe that there is value in sharing our estimates, given the complete lack of empirical landscape-scale population estimates for Ruaha-Rungwa's large carnivores. Going forward, however, we recommend exploring instead the scalability of methods that can provide greater levels of precision, such as spatially explicit capture-recapture (SECR) models applied to data from camera traps (e.g., Strampelli, Henschel, Dickman et al., 2022) or direct sightings (e.g., Elliot & Gopalaswamy, 2016), which have typically been applied over smaller areas. Alternatively, where scalability proves challenging or too resource-intensive, we recommend considering the estimation of alternative robust status parameters (e.g., occupancy; Strampelli, Henschel, Searle et al., 2022) from track data to monitor population status over large scales.

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CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

DATA AVAILABILITY STATEMENT

Data employed in this study are freely available and can be accessed at: https://github.com/pstrampelli/RuahaRungwaLargeCarnivoreDensities.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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