Status of leopards (*Panthera pardus*) in L7 Concession, Niassa Special Reserve

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Abstract

Determining population estimates for large-bodied carnivores is necessary to inform adaptive management, particularly in species where offtake of adult animals may affect population density. In this study, we used 114 paired camera trap stations to record leopard presence across ~1,600km^2 in the L7 concession, in Niassa Special Reserve, Mozambique. Data was collected in two samples, taken across 5,843 camera trap nights in adjoining areas, and each was analysed using *secr,* a spatially explicit capture-recapture framework. We found that leopard (*Panthera pardus*) density was 3.6 individuals per 100 km^2 (2.5-4.7 95% CI) in the first sample, and 7.4 individuals 100 km^2 (5.9-9.2 CI) in the second sample, giving an overall average density of 5.5 individuals 100 km^2 (2.5-9.2 CI). Leopard density was notably was higher in the second site, which is consistent with predictions based on anthropogenic disturbance levels and geographical variation in habitat and conservation effort. Overall, density estimates suggest a substantial leopard population of approximately 247 individuals in the L7 concession; assuming generalisability of the sample and careful application of hunting quotas may be sustainable for this population.

Introduction

Large-bodied carnivore populations are declining across Africa, often in response to anthropogenic threats (Estes et al., 2011; Ripple et al., 2014). The most significant of these threats relate to habitat loss and declining availability of suitable prey, often a result of human encroachment. Even where natural habitats are preserved, humans can have a significant effect on populations, with predators such as lions and leopard notably impacted by unstainable trophy hunting and direct persecution (Woodroffe, 2000; Ceballos & Ehrlich, 2002). Leopards are the most widespread large felid, with populations across the Old World (Swanepoel et al., 2016). However, despite their wide habitat range and adaptable nature, populations have nevertheless declined by 63-75%, with formerly contiguous populations are becoming increasingly fragmented and isolated (Jacobson et al., 2016). As many leopard populations are utilised consumptively for trophy hunting, it is critically important to establish baseline population sizes and trends in those areas which are seeking to develop or maintain sustainable trophy hunting industries.

The Niassa Special Reserve (NSR) is one of the largest protected areas in Africa, and at 42,000 km^2 covers approximately 5% of Mozambique's land area. Consumptive tourism is a major component of the NSR's conservation management strategy, with the reserve area apportioned into a number of hunting concessions, which are managed privately. Leopard trophies are a significant source of income for both the overall reserve management and private concessionaires. To ensure that the impact of hunting on leopard populations is sustainable, an adaptive, negative-feedback quota system is used by the central reserve management to determine quotas for a given area in a given year. However, in an area of 42,000 km^2, establishing accurate, locally-specific leopard densities represents a challenge. At the behest of Luwire Limitada/Luwire Wildlife Conservancy, the organisation responsible for block L7, this study was carried out to establish the density of leopards in two key areas of the concession.

Methods

Study Site

The Niassa Special Reserve (12.1670S, 37.5450E) is the largest protected area in Mozambique, and abuts the southern border of Tanzania and the eastern shores of Lake Niassa (see Figure 1). The region is subject to highly seasonal water availability, with the dry season running from July to October, and seasonal rains between November and March. Soil quality is low, and the ecosystem is semi-arid, with less seasonal riparian areas along the major waterways. The NSR is composed of individual concessions, which have designated uses according to the reserve management plan; nine units are specifically allocated to hunting. Of these hunting units, the L7 block was used as the area for this study. The block covers approximately 4,500 km^2, with 300 km of its northern border following the course of the Lugenda river, and its southern border marking the edge of the NSR. The area is bisected by the main reserve access road, alongside which are a variable number of small, satellite villages and one main village.

Figure 1: Map of Niassa Special Reserve. Block L7 is on the Southern edge of the area. Triangles represent centres of population. Light grey lines show rivers; black lines demarcate the edges of individual concession blocks.

Data Collection

Two areas of the concession were identified as priorities for camera trapping (see Figure 2): the first, henceforth ‘Lugenda’, spanned the most high-use area of the concession, close to the primary tourism/hunting camp. This area was also adjacent to the main access road for the reserve, and was expected to show signs of anthropological disturbance from both the road and villages in the area. The second area – ‘Lusinge’ – is located to the eastern side of the concession, and is adjacent to a well-protected, designated conservation block. This area is typically used primarily for hunting, although had no hunting offtake between for the two years prior to this study (end-2019 to mid-2021) as a result of international COVID-19 travel closures.

All data were collected between March and September 2021. We deployed 114 paired camera trap stations, 50 in Lugenda and 64 in Lusinge. Cameras were deploying in Lugenda between March and June, and in Lusinge between July and September. Unbated cameras were placed at approximately 4km spacing, on game trails, roads, or other likely sites to maximise capture rates. Cameras were placed for a minimum of 48 days in each location, and were not moved during each survey.

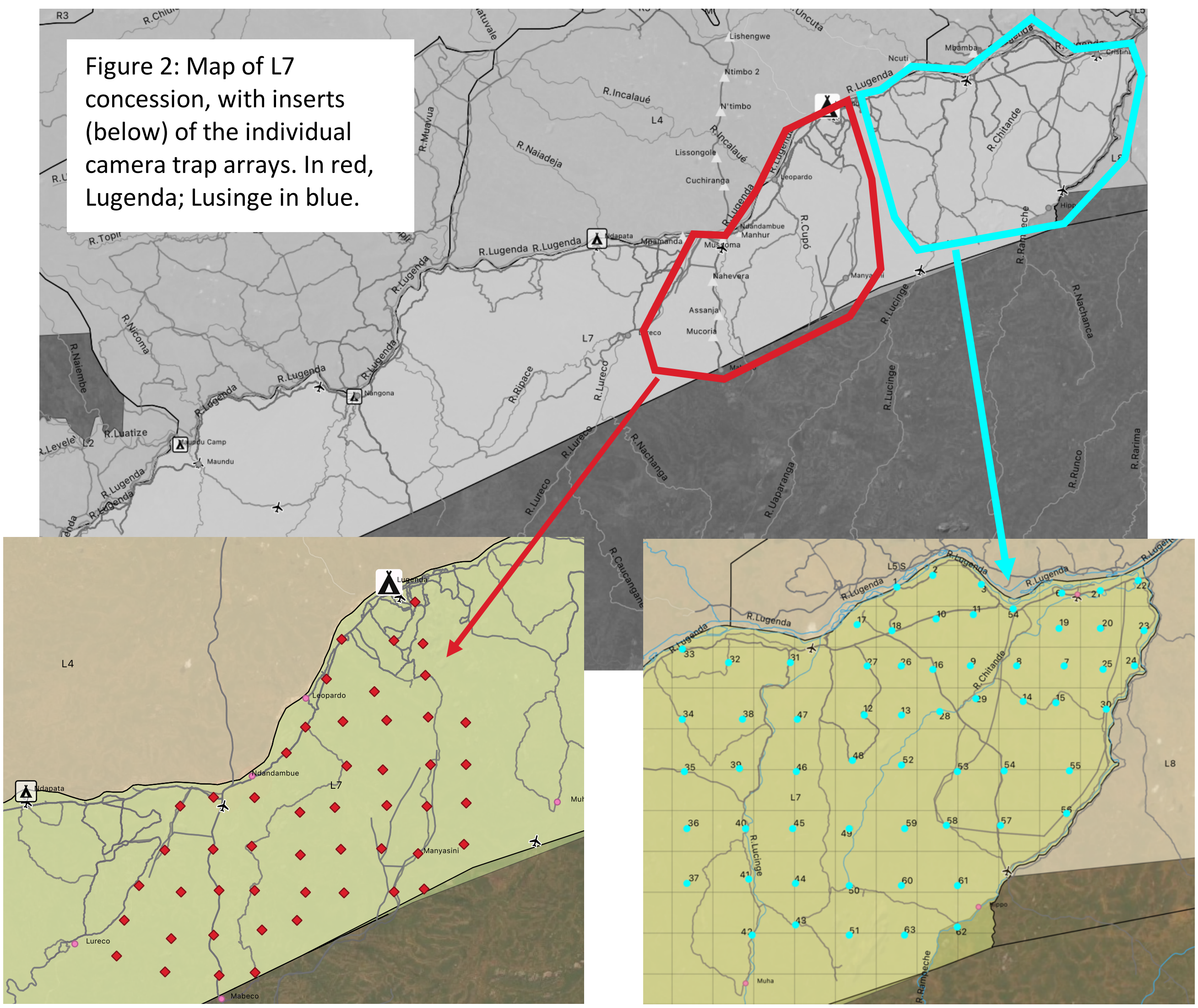


Figure 2: Map of L7 concession, with inserts (below) of the individual camera trap arrays. In red, Lugenda; Lusinge in blue.

Data Sorting

All data was processed using TrapTagger - an open-source web application that uses artificial intelligence to aid in the processing of camera trap images (see e.g., Vélez et al., 2022). For maximum accuracy, a manual annotation approach was used whereby all empty images were first removed using Microsoft's animal-detecting AI, MegaDetector, and the remaining images annotated though the TrapTagger interface. The species classifications generated by the TrapTagger AI were used as an aid in this process in order to optimise annotation efficiency, determining factors such as image ordering and prioritisation. Thereafter, all cases where the manually-annotated species differed from the AI classification, were manually checked in order to refine the species labels and improve accuracy; this process ensured that individual leopard captures were not inaccurately sorted, and therefore improved the reliability of the data-set. Lastly, individual identification of leopards could then be performed through a two-stage process that uses a combination of a heurstic algorithm and an open-source coat-pattern recognition algorithm, known as HotSpotter, to determine a similarity score between leopard images. All combinations of images above a pre-determined threshold were then manually examined through the interface to determine if they were indeed from the same individual, resulting in an incomplete, but extensive set of individuals. Finally, ID kits were compiled and verified to confirmed that all individuals were maximally populated, and to check for any matches not suggested by the prioritisation algorithm.

Analysis

Spatially explicit capture-recapture (SECR) models were run in R to determine leopard density in each of the two separate data collection regions. Filtered leopard images captured at each camera trap station were extracted and identification of individual animals was undertaken. We define here occasion as every 24-hour period from midday to midday to encompass the entire nocturnal time period when animals are most active. We assumed a normal detection function, and that home range centres followed a typical distribution. Two main data files are required by SECR: trap layout, and detection histories of known individuals.

A data matrix with ID, trapping period (date), and detector (camera station) was generated and analysed using Spatially Explicit–Mark Recapture statistical software. We used a spatially explicit population density model using maximum likelihood-based inference implemented in the R package ‘secr’ (Efford 2017; Efford and Fewster 2013). This method allows for robust population density estimates to be derived for the survey area (Efford and Fewster 2013). For the density estimation, we generate a state-space mask to account for animal movement on the edges of the survey and represent the available habitat for the species. The buffer distance is calculated with the ‘suggest buffer’ function and corresponds to 4 × sigma (Efford, 2017).

The habitat mask consists of 0.25km^2 grids covering the entire area encompassing the suggested buffer region around the trapping array since the whole area is potential habitat for wildlife. We then use *secr* to run the population density and report the results below.

Results

Table 1: Summary of number of occasions, stations, detections and identified individuals, together with the buffer (distance around each trap array) used to generate the state space mask, per survey.

	Occasions	stations	N detections	Animals	Buffer used (m)
survey 1	76	50	167	42	10000
survey2	70	62	504	81	8000

Survey1

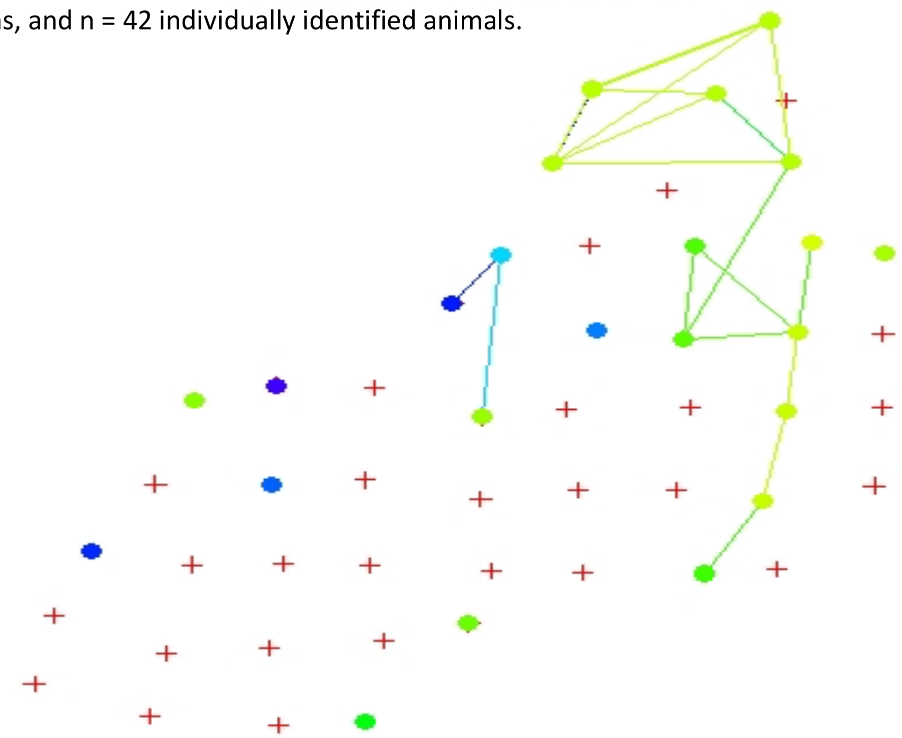
Null model (test effect of trap response in the detectability). Best model includes trap response.

Model	detectfn	npar	logLik	AIC	AICc	dAICc	AICcwt
Trap absent	halfnormal	3	-909.8621	1825.724	1826.356	1.447	0.3266
Trap present (g0~b)	halfnormal	4	-907.9138	1823.828	1824.909	0	0.6734

Model results from the most parsimonious (trap present) null model:

	estimate	SE.estimate	lcl	ucl	N observed	HRCIW
Density	0.036	0.006	0.025	0.047		**30%**
Derived abundance	69	8	58	88	42	**22%**

Figure 3: Map of camera trap survey 1 (Lugenda) grid. In total n = 76 capture events, n = 167 detections, and n = 42 individually identified animals.



Survey 2

Null model (test effect of trap response in the detectability). Best model excludes trap response

Model	detectfn	npar	logLik	AIC	AICc	dAICc	AICcwt
Trap absent	halfnormal	3	-2519.096	5044.193	5044.505	0	0.5863
Trap present (g0~b)	halfnormal	4	-2518.338	5044.676	5045.202	0.697	0.4137

Model results from the most parsimonious (trap absent) null model:

	estimate	SE.estimate	lcl	ucl	N observed	HRCIW
Density	0.074	0.0083	0.05949	0.09218		**22%**
Derived abundance	126	9	112	146	81	**14%**

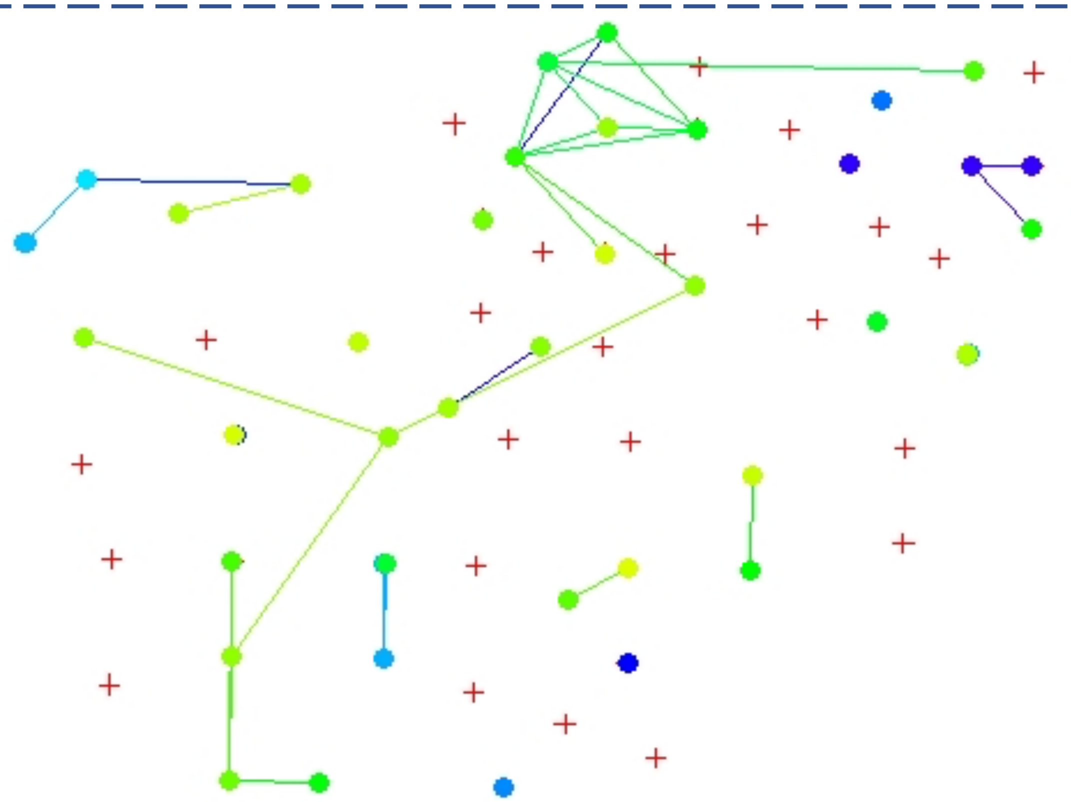
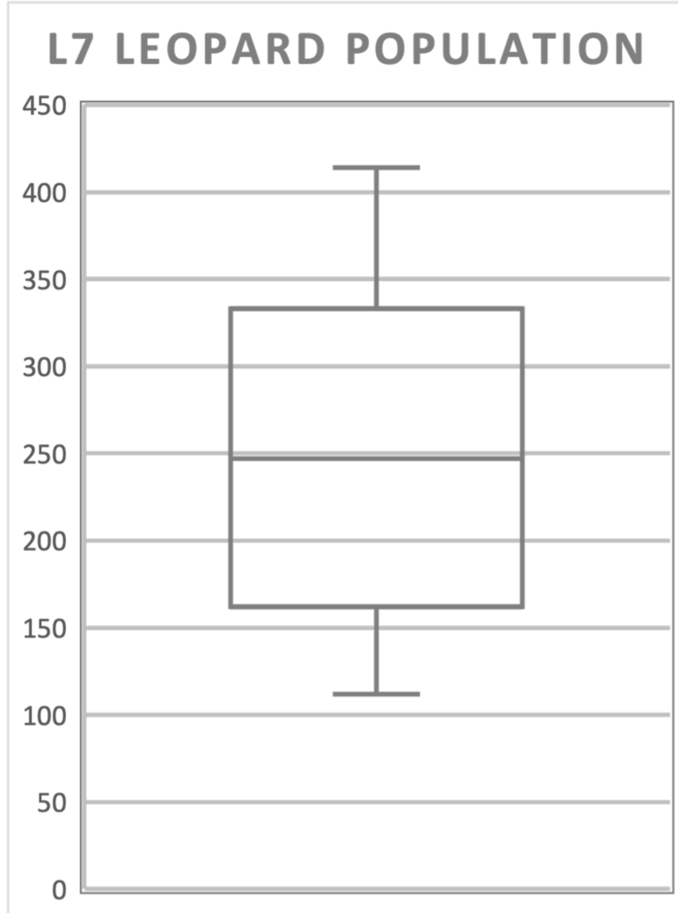


Figure 4: Map of camera trap survey 2 (Lusinge) grid. In total n = 70 capture events, n = 504 detections, and n = 81 individually identified animals.

Each survey was analysed separately, to account for non-contiguous time periods in the survey timetable. In summary, leopard density in survey 1 was estimated to be 3.6 individuals /100km^2 (2.5-4.7 95%CI) and this density translates to roughly 69 adults and subadult leopards (56-88 95%CI). In survey 2 the model estimates a density of 7.4 individuals/100km^2 (5.9-9.2 CI) and 126 adults and subadult leopards in the area (112-146 min max).



The L7 concession covers an area of 4,500 km^2, with differing levels of habitat suitability and human presence throughout. Although actual leopard densities are expected to vary throughout the area, between the two study sites, a basic average density of 5.5 individuals/100km^2 (2.5-9.2 CI) is calculated. This gives a total population estimate for the concession of 247 individuals. Using the lowest calculated density estimate found during this study period gives a lower expected boundary of 112 leopards, and using upper boundary values suggests a maximum of 414 individuals, although based on the average densities of the Lusinge and Lugenda camera trap grids, the true population size is likely to be between 162 and 333 individuals.

Discussion

In this study we calculated the densities of leopards in two areas of the L7 concession, which are managed as Luwire Wildlife Conservancy. In the first area, subjected to locally high levels of human disturbance, densities were found to be 3.6 individuals /100km^2 (2.5-4.7 95%CI); in the second, leopards were at higher density, with 7.4 individuals/100km^2 (5.9-9.2 CI). Extrapolating from these areas, which together cover 35.5% of the total land area of the conservancy, these figures suggest a total population for the concession of approximately 247 individual leopards.

Our results were consistent with previously published material on leopard densities from the Niassa area, with Jorge (2012) reporting densities of 2.18 – 4.31 leopard/100 km^2 in miombo woodland areas, and higher densities of 9.92 – 12.65 leopard/100 km^2 in more productive riparian areas. Overall, Jorge (*ibid*) concluded that leopards occur at similar densities in the Niassa area to other comparable sites in southern and central Africa, which concurs with our findings. Niassa Special Reserve abuts the Ruvuma river, which separates Mozambique from Tanzania. Across the border is a mixed-use landscape, with some areas used as strictly protect national park, and some used as hunting regions. Recent work from this region found the highest local densities of leopard (6.81 leopard/100 km^2) in the strictly protected Ruaha National Park, and the lowest densities in trophy hunted miombo woodland, at 3.36 and 3.23 leopard/100 km^2 respectively in Rungwa Game Reserve and the Ruaha National Park (Searle et al., 2021). Our results are consistent with these findings, with densities from Lugenda directly comparable to that of both the NSR overall and similar trophy hunted areas in Tanzania, and that in Lusinge similar to other NSR results from mixed habitat areas (although not within the confidence intervals of the higher densities reported for riparian habitat).

Hunting quotas across the NSR are adjusted on an annual basis, and informed by scientific monitoring of populations by the central reserve management and the Niassa Carnivore Project. In addition, post-hunt determinations of trophy suitability, using similar protocols in place to those used for African lions (*Panthera leo*) (Begg et al., 2018), are used to ensure that underage individuals are not hunted, and therefore minimise the effects of hunting on populations. Recommendations from Packer et al., (2010) suggest an annual offtake no higher than 1.0 leopard/1000 km^2, giving an absolute maximum recommended quota of 4.5 leopard per annum in the L7 concession. For 2021, the L7 leopard quota included 3 individuals. Based on the pre-existing literature and the leopard densities found in this study, we conclude this is likely to be a sustainable level of harvest, particularly where minimum age standards are adhered to.

Although hunting offtake is likely to be within sustainable bounds, the level of leopard poaching which occurs both within L7 and across the NSR is challenging to verify. Jorge reports mortality of 3 female leopards in one 800 km^2 area in 2010, giving an average mortality of 3.75 leopard/1000 km^2 , which is well above sustainable limits. Although this is a single report, it is critical that future calculations allow for illegal offtake and that measures of illegal leopard harvest are both collected and built into any calculations of sustainable trophy offtake.

As Searle et al. (2021) note, there is a general bias in the conduct of camera trap studies used for density estimates to preferentially select high quality habitat areas for study. In this research, one area (Lusinge) was specifically designated a priority region for carnivore conservation, and therefore may receive higher levels of protection than the concession at large. As density estimates can vary substantially across a landscape, it is important that management decisions are based on surveys conducted across large landscape areas, particularly where there is consumptive offtake of individuals. Indeed, the estimates in this report do not account for variations in habitat quality or human disturbance, and future studies should seek to establish variation in both habitat type, hunting pressure, and other anthropogenic presence across the area in order to define more precise estimates for leopard population across the concession.

Overall, we conclude that Luwire supports a relatively high density of leopards, particularly in the Lusinge area, and densities are all within the expected parameters based on previous leopard census work in the NSR. We suggest that, with continued monitoring and investment in anti-poaching, existing levels of hunting offtake may be sustainable in the long-term, and can be considered part of a viable management strategy for the concession.

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