ABSTRACT

In 2021, the TKPP team, in collaboration with CONNNECT, surveyed the Linyanti region of northern Botswana for large carnivores. 63 paired camera stations were placed across the region for more than 50 days. All six large carnivore species were recorded including lion, leopard, brown hyena, spotted hyena, cheetah and African wild dog. There is an estimated total of 105 ± 11 lions (95% CI 83 – 125), giving a density of 3.6 lions per 100 km2 (SE ± 0.38 min = 2.8 and max = 4.3) and estimated number of 54 ± 12 leopards (confidence interval range 35 – 82), with a density of 1.8 leopards per 100km 2 (SE ±0.4, min = 1.2, max = 2.8). Lion densities are comparable with the Okavango Delta, but leopard densities are lower, likely due to the larger proportion of woodland habitat to riparian habitat in this region. Two long distance dispersals were recorded as a result of data collected; one of a wild dog from Hwange of more than 250km, and another of a coalition of lions of more than 120km. These results confirm the importance of the Linyanti as a source and destination for large carnivores dispersing across the KAZA landscape.

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Introduction

The Linyanti region in northern Botswana is a large wetland area on the border between Botswana and Namibia (Figure 1). Much like the Okavango Delta, this system is fed by seasonal rain in the Angolan highlands, with rainwater flowing down the Kwando river, through the Caprivi Strip in Namibia into the Linyanti swamps. During high flood years, the Linyanti is connected through the Selinda Spillway to the Okavango Delta, and in exceptional years to the Mababe Depression through the Savuti channel. As such it forms an important stepping stone within the Kavango-Zambezi Transfrontier Conservation Area (KAZA) between the Okavango and Chobe to the Nkasa Rupara and Mudumu National Park in Namibia, and on the western side to Bwabwata National Park in Namibia, which in turn links the system to Sioma Ngwezi and Angola's Luenge Luiana National Park. The Linyanti is thus a vital connection for the Kwando Wildlife Dispersal Area.

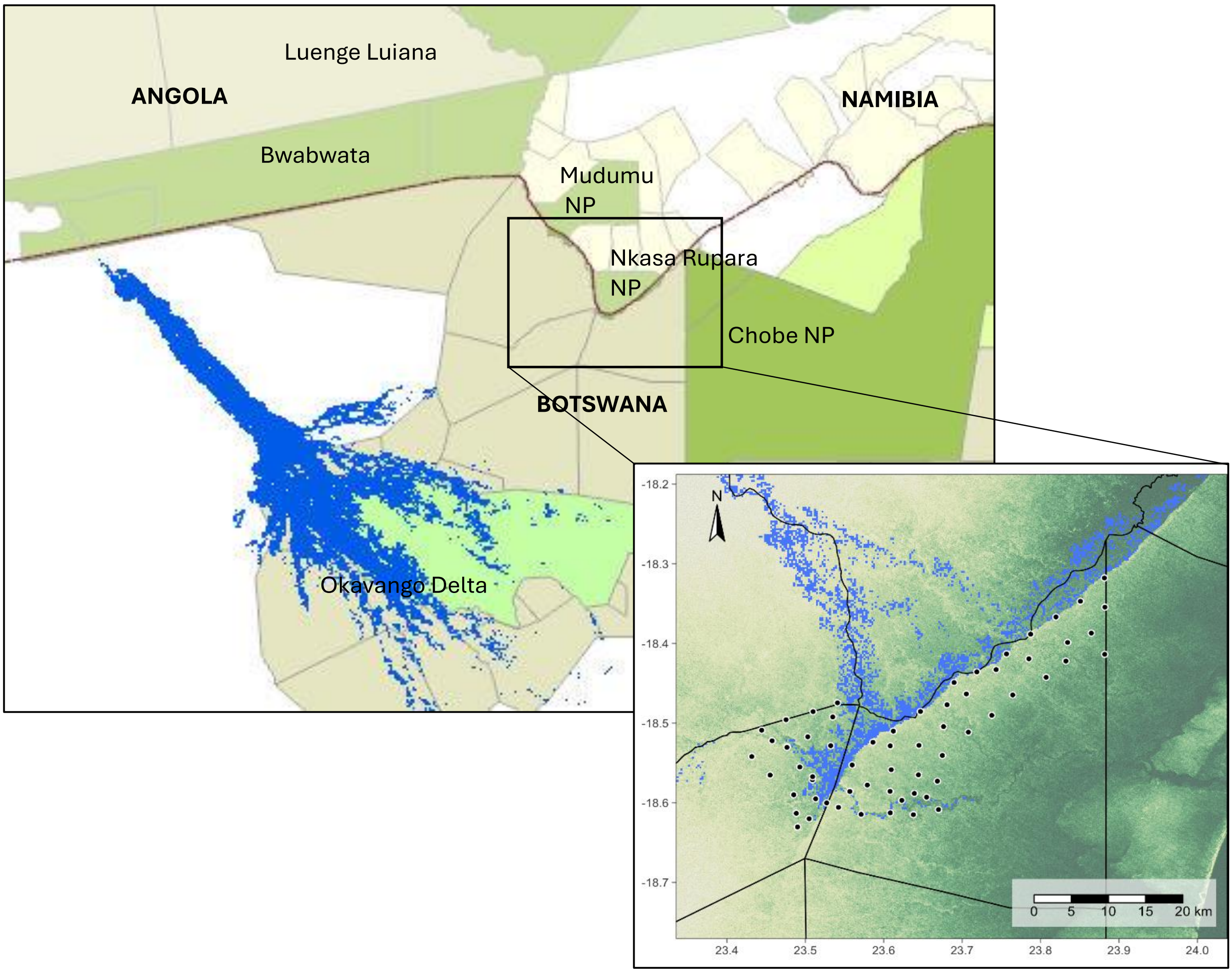

Figure 1. Location of Linyanti swamps within the broader region. The Linyanti is critical for connectivity between many protected areas. Surveys (inset) were conducted on the Botswana side of the swamps.

Due to the flooding in the late dry season, the Linyanti is a critical habitat for water dependent species like elephant and buffalo at this time of the year. Woodland species like roan and sable also use the Linyanti as a refuge during the dry season. The wetland is bordered by woodland areas to the west, south and east, and this combination of woodland and floodplain allows for a diversity of mammal species. The large prey base in this region thus also supports a diversity of carnivore species including lion, leopard, cheetah, wild dog and spotted hyena. Many of the large herbivores and large carnivores cross the Linyanti channel between Botswana and Namibia's Nkasa Rupara and Mudumu National Parks, and transboundary cooperation in maintaining the wildlife populations in this region is therefore critical.

Given the importance of this transboundary connection, the TKPP team with support from CONNECT, Wilderness Safaris and Great Plains Conservation, set out to survey the Linyanti area in 2021. The main aim of the surveys was to provide estimates for the carnivore populations in the region as part of larger efforts to provide baseline information on carnivore numbers in the landscape and to contribute to understanding connectivity across the KAZA region.

Methods

A total of 63 paired camera trap stations were set up across NG15 and NG16 concessions between 20/10/2021 and 16/12/2021 in the Linyanti region (Figure 1). Camera stations were placed between 3 and 4 km apart, which is the optimum distance for ensuring effective, unbiased detection of medium and large carnivores. In addition, this design makes the results comparable to other camera trap surveys conducted in many of the national parks and protected areas surveyed by TKPP in Botswana and Zimbabwe. Survey designs were planned on Google Earth prior to camera deployment, focusing on placement on roads where possible. During survey setup, teams navigated to pre-planned trap sites and placed cameras within a 500m radius of the original point to intersect with the closest road or prominent game trail to optimize detection probability, as well as ensure accessibility for checking traps.

Each camera trap station consisted of 2 Cuddeback X-change Colour cameras, mounted on metal poles, placed opposite each other on either side of a road or game trail. The cameras were slightly offset to reduce the number of false triggers which may result from the flash of the opposite camera at night. Cameras were placed 6 – 7 metres apart, and at a height of approximately 60cm, which is roughly shoulder height of a medium sized carnivore. The two cameras also ensured that both sides of each predator were recorded, to allow for accurate individual identification. All obstructions such as grass or vegetation between the cameras were removed to reduce the number of false triggers in the capture zone.

For each camera trap station, information such as date of setup, designated trap number, GPS location, camera number and SD card number were recorded to ensure accurate post-survey filing of data. In addition, photos were taken of each station to record placement on road or game trail and to note habitat type. To ensure statistical robustness and comparability with other surveys each survey was run for a minimum of 40 days, with the first day starting the day after the last trap of the grid was set up. Where possible, each trap was checked 1 to 2 times during the survey, with the exception of traps that were far off road and difficult to access. Checking traps regularly was beneficial in reducing data loss due to flat batteries or when traps were pushed over by elephants and other animals.

Analysis

The first stage of this analysis involved generating a list of all the mammal species detected during the survey. We calculated the total number of raw images captured (Number of Images) and the proportion of the dataset (Percentage of Dataset) represented by each species.

To visualise the spatial distribution of photographic detections for each species we used a relative abundance index (RAI) which is defined as the number of independent detection events of a particular species at a camera station per 100 trap days:

$$\text{RAI} = \text{Independent detections}/\text{Trap days} \times 100$$

All images of the same species at a camera station captured within 30 minutes of each other are considered to be part of the same detection event (independent detection). Put simply, RAI is a measure of how many capture events of a particular species would be expected if a trap was operational for 100 days in a particular area.

Some studies have shown that RAI can be used as a crude indicator of animal abundance when a species' density and photographic detection rate are directly proportional (Carbone et al. 2001; O'Brien et al. 2003; Rovero & Marshall 2009; Palmer et al. 2018). If the direct relationship between abundance and detection rate holds true, a higher RAI would point to a greater number of individuals occupying a particular area while a lower RAI would suggest that fewer individuals are present. However, it is important to note that detection probabilities (the likelihood of a species being detected by a camera trap) can vary across space and time because of changes in animal behaviour, environmental conditions and the study method (Sollmann et al. 2013; Mann et al. 2015). In such instances, RAI would be an unreliable indicator of absolute abundance but can nevertheless still provide a measure of how frequently a species was photographed. We advise readers to be cognisant of this caveat when interpreting RAI results.

In addition to visualising the spatial distribution of each species we also calculated the temporal (diel – 24 hour) distribution of detections which provides an indication of a species' activity pattern. We aggregated photo bursts/successive captures into independent detection events (all images of the same species at a camera station captured within 30 minutes of each other are part of the same detection event) and plotted the frequency of detections against hour of the day. All RAI maps can be seen in Appendix I.

For lion and leopard images, images were extracted for each trap, and individuals identified based on unique pelage patterns for leopard, and based on whisker spots, scars, ear notches and mane size/colour for lions (Miththapala et al. 1989, Pennycuick and Rudnai 1970, Strampelli et al. 2022). All individuals less than 1 year old have variable survival, and were therefore excluded from the analyses. Capture histories were then constructed for each individual, with each capture within a 24-hour period at a particular trap considered as independent captures. Both Bayesian approaches using SPACECAP (Gopalaswamy et al. 2012) and maximum-likelihood based approaches (secr; Efford 2017, Efford and Fewster 2013) were used to produce density estimates. At each survey site, a state-space mask, which depicts available habitat, was constructed to account for potential animal movement at the edges of the survey, and the masks excluded what is considered as permanent water in the region as potential habitat. To determine the effective area surveyed, including the buffer around the survey edge, we used the 'suggest buffer' function in secr, which corresponds to 4 x σ (Efford 2017), to define the buffer size. The total habitat mask thus consisted of 0.5km2 grids covering possible habitat across the survey area and the buffer zone.

Results

Camera stations were up for an average of 54.3 days and recorded data for a total of 3419 trap nights. General species distribution and relative abundance are available in Appendix 1.

Lions

A total of 858 lion images were recorded during the survey. From these, a total of 62 animals were identified. Cubs, however, were excluded from the density analyses. Results from the SPACECAP analysis show an estimated total of 105 ± 11 lions (95% CI 83 – 125), giving a density of 3.6 lions per 100 km2 (SE ± 0.38 min = 2.8 and max = 4.3). secr Analyses showed similar estimates of 104 ± 15 lions (79-138), also giving a density of 3.6 3.6 lions per 100 km2 (SE ± 0.51 min = 2.7 and max = 4.7).

The lion density surface shows peaks of activity on either side of the bottom piece of the channel, and further up towards King's Pool. The buffered area extends into Namibia into Nkasa Rupara National Park, as it is likely that some lions (particularly males) cross the river between the two areas. We suspect that some females identified on the Botswana side only once, and that were not associated with other females, were also possibly individuals that had crossed from Namibia.

Age and sex group	Number identified
Adult male (>4 years)	19
Adult female (>4 years)	23
Sub-adult male (1-4 years)	5
Sub-adult female (1 – 4 years)	7
Cubs (<1 year)	8

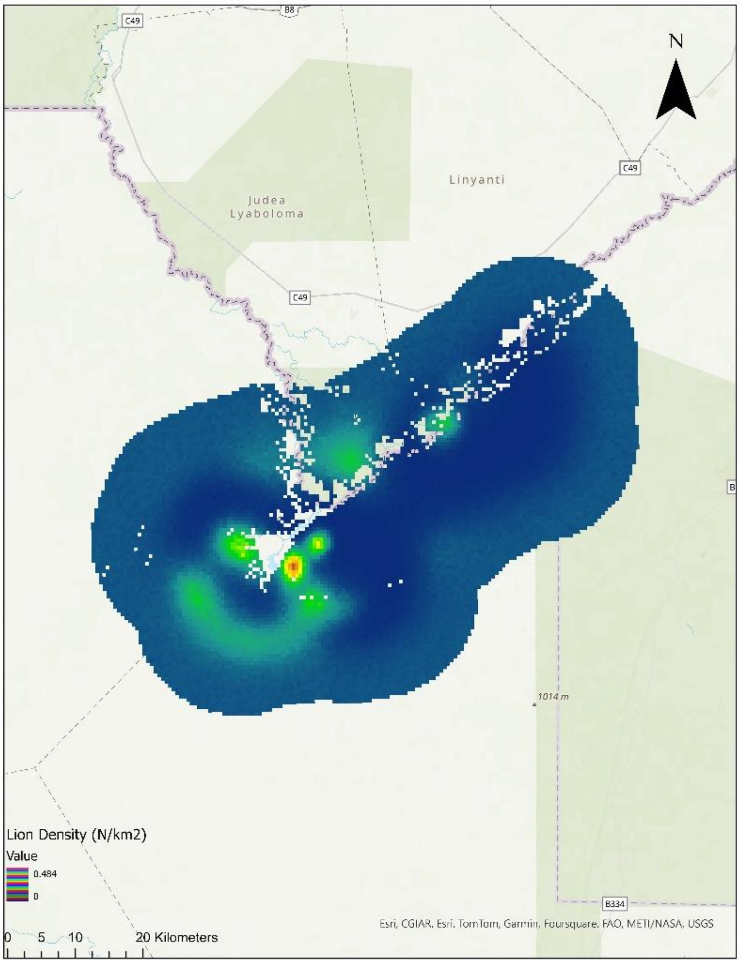

Figure 2. Distribution of lion density, which is better interpreted as intensity of use, across the Linyanti region. Lion hotspots appear to be concentrated along the southern tip of the swamp, and occur near bridges where the use of this features ‘funnel’ lions past the cameras.

Leopards

For leopards, a total of 251 leopard images were captured, from which 26 individuals were identified (see Table 2 for breakdown). Results from SPACECAP estimate a total population size of 55 ± 9 individuals (confidence interval range 37 – 72), with a population density of 1.9 leopards per 100km2 (SE ± 0.32, min = 1.3, max = 2. 5). Results from secr analyses show a similar estimated number of 54 ± 12 individuals (confidence interval range 35 – 82), with a density of 1.8 leopards per 100km 2 (SE ±0.4, min = 1.2, max = 2.8). The density distribution map shows activity hotspots around Selinda, Savuti and towards King's Pool, as well as out towards Selinda Explorer's camp (Figure x)

Age and sex group	Number identified
Male (> 1 year)	13
Female (>1 year)	10
Unknown (>1 year)	3

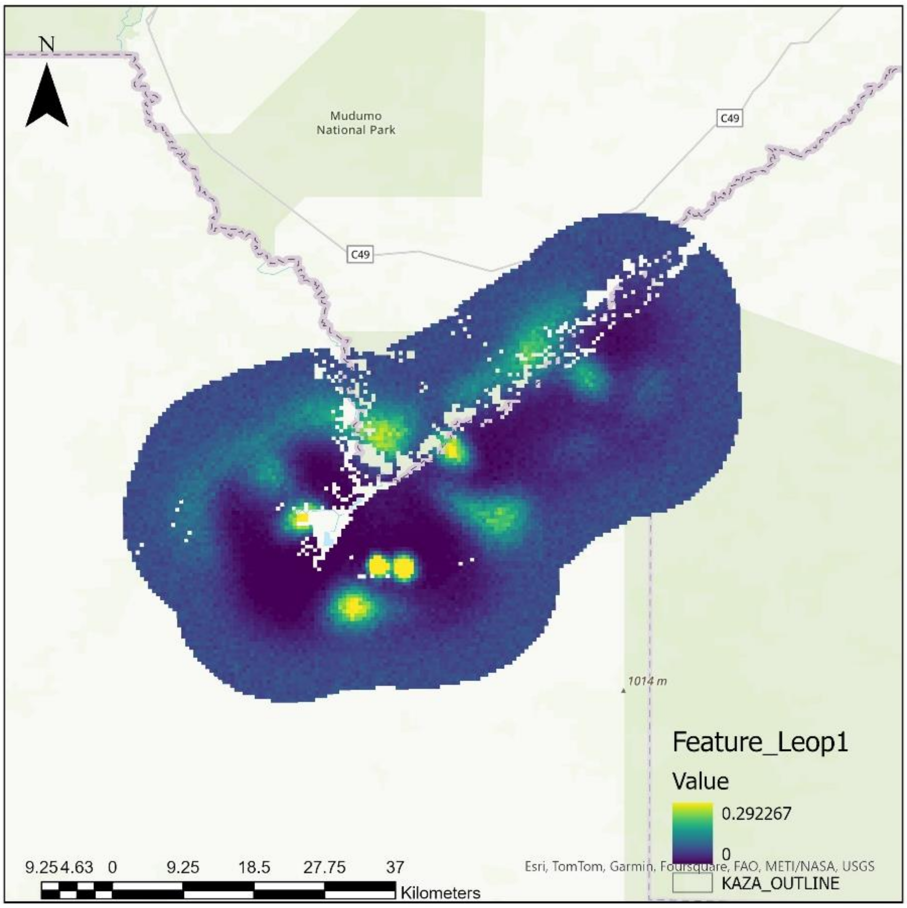

Figure 3. Leopard density, better interpreted as a representation of intensity of use, across the Linyanti region. Leopards are more evenly distributed across the region. As with lions, hotspots are located also at bridges where the use of bridges is likely to 'funnel' animals towards using that particular feature.

Discussion

Distribution and Relative Abundance of Species

As with many other surveys across northern Botswana, spotted hyena were by far the most captured predator species on the survey, and appear to dominate both floodplain and woodland habitats. In this survey, hyenas were photographed more frequently on the western side of the swamp. Lions were detected throughout the survey area, but appeared to favour the floodplain systems over surrounding woodland, likely due to prey concentrations along the water in the dry season. Leopards were fairly evenly distributed across the different habitat types across the concession. Bridges were highly utilized by both leopard and lion, and these clearly serve as pinch points for predators when moving across the concessions and over the channels. One brown hyena was captured on the survey, which is not surprising as their presence has previously been reported in the area. Only one cheetah was captured on the survey. However, cheetah do not tend to use roads as much as other large carnivores, and given the large areas they cover, can be difficult to capture in a systematic grid and require more targeted monitoring. Lastly, wild dog were captured across the survey site, but largely on cameras in woodland areas. Wild dog commonly avoid areas of high lion density, and so this trend is to be expected. Wild dogs also use woodland areas in this region for denning in the early dry season.

Water-dependent herbivores such as elephant, red lechwe and hippo were common along the waterways. Impala, giraffe, warthog and kudu were ubiquitous in both floodplain and woodland habitats, while waterbuck, tssesbe and wildebeest - which are more specialist grazers - were found more along the floodplains and along the Savuti channel. As expected, woodland specialists like sable and roan were mostly detected in the woodland regions away from the riverfront, and eland were detected in woodlands at the start of the Selinda spillway on the western side of the Linyanti. Rarer species like reedbuck, bushbuck and bushpig, which are often associated with wetland or riparian areas, were also detected in small numbers on the survey. Buffalo occurred throughout the survey, while zebra appeared to be concentrated in the grasslands on the western side of the Linyanti. Lastly, small herbivores like common duiker and steenbok were prevalent throughout. This high concentration of prey density is what facilitates the large predator guild.

For the smaller carnivore species, there were a mix of dryland and wetland associated species. Along the river and Savuti channels there was evidence of civet and side-striped jackal, which are fruit dependent, as well as serval which prefer wetter habitats. In the drier woodland areas, black-backed jackal, bat-eared fox and striped polecat were all detected.

Other small cat species detected included African wildcat and caracal, which were more prevalent in drier areas, while larger spotted genet and honey badgers appeared to occur across all habitat types. Burrow dependent species like aardvark, aardwolf, porcupine, scrub hare and spring hare were also all detected across the survey in reasonable numbers.

Lion and Leopard Densities

Camera trap surveys provide a repeatable and reliable means of conducting large predator surveys. This is particularly useful for detecting species like leopards which can be notoriously shy. Lion densities in the Linyanti are similar to what have been observed in the southern Okavango Delta, which is not surprising given the similarities in floodplain habitat. Leopard densities however, were considerably lower than in the Okavango Delta, which is also likely a function of habitat (see Loveridge and Kotze et al. 2024). In the Okavango, leopards prefer riparian woodland between islands, while lions make use of floodplain habitat. In the Linyanti, there are pockets of riparian woodland around the channels, but the majority of habitat located away from the riverfront areas are mopane and sandveld (particularly to the east of the Linyanti), which have naturally lower prey levels than floodplain areas. To the western side of the Linyanti, habitat also includes pockets of acacia scrubland, but these too are likely to have lower prey densities in the dry season, and also less trees which are important for leopards for caching food.

As the Linyanti is situated in prime wildlife area, and at a considerable distance from human settlement, it is likely that the densities of large carnivores are close to their natural carrying capacity, and driven largely by prey availability. This is also an important transboundary carnivore population, as there is frequent movement of lions in particular between Namibia and Botswana across the channel. Situated between the Chobe, Delta and Caprivi systems, the Linyanti is a key resource area for large herbivores particularly in the late dry season. There is almost continuous connectivity between this system all the way through to Hwange National Park for large herbivores and carnivores.

Additional Observations

One of the wild dogs captured during this survey had in fact dispersed all the way from Hwange National Park, where it was originally collared by WildCRU PhD candidate Elisa Sandoval a few months prior, travelling more than 250 km straight line (Sandoval-Seres et al. 2022).

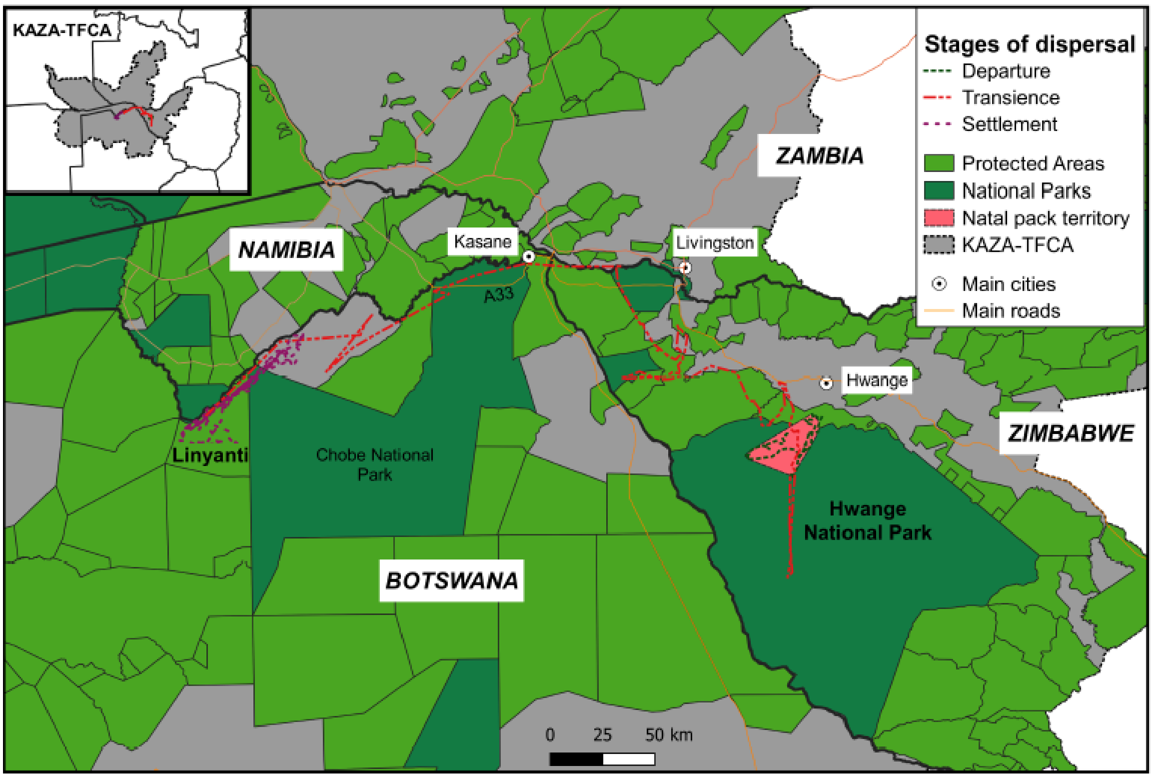

Figure 4. Map of dispersal route taken by the wild dog from Hwange National Park in Zimbabwe to Linyanti region. The dog was collared by WildCRU student Elisa Sandoval-Seres as part of her PhD. The map was copied from the manuscript Sandoval-Seres, E., Moyo, W., Madhlamoto, D., Madzikanda, H., Blinston, P., Kotze, R., van der Meer, E., & Loveridge, A. (2022). Long-distance African wild dog dispersal within the Kavango-Zambezi transfrontier conservation area. *African Journal of Ecology*, *60*, 1262–1266. https://doi.org/10.1111/aje.13065.

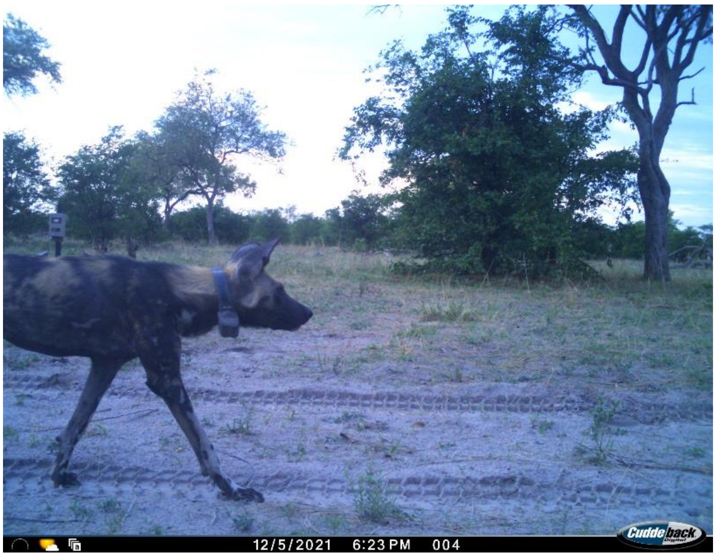

Figure 5. Collared dog, originating from Hwange National Park in Zimbabwe, detected in the Linyanti survey in northern Botswana in 2021.

In addition, a coalition of 6 male lions that were photographed during the Linyanti Survey matched IDs of lions recorded by Wild Entrust in Moremi Game Reserve, in Blackpools in

2020, showing a minimum dispersal of 120km. This, coupled with the evidence of stable resident carnivore populations, is indicative that Linyanti is an important core area for carnivores and a potential destination or stepping stone for carnivores dispersing from adjacent populations.

Figure 6. Map showing dispersal route for a coalition of 6 males from Blackpools region in Moremi recorded on a 2020 survey, to Linyanti in 2021.

Both of these recorded dispersals show the value of photographic monitoring and additional information that can be garnered from camera trap surveys.

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