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Zebra diel migrations reduce encounter risk with lions at night

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Appendix S1. Diel space use pattern of zebras.

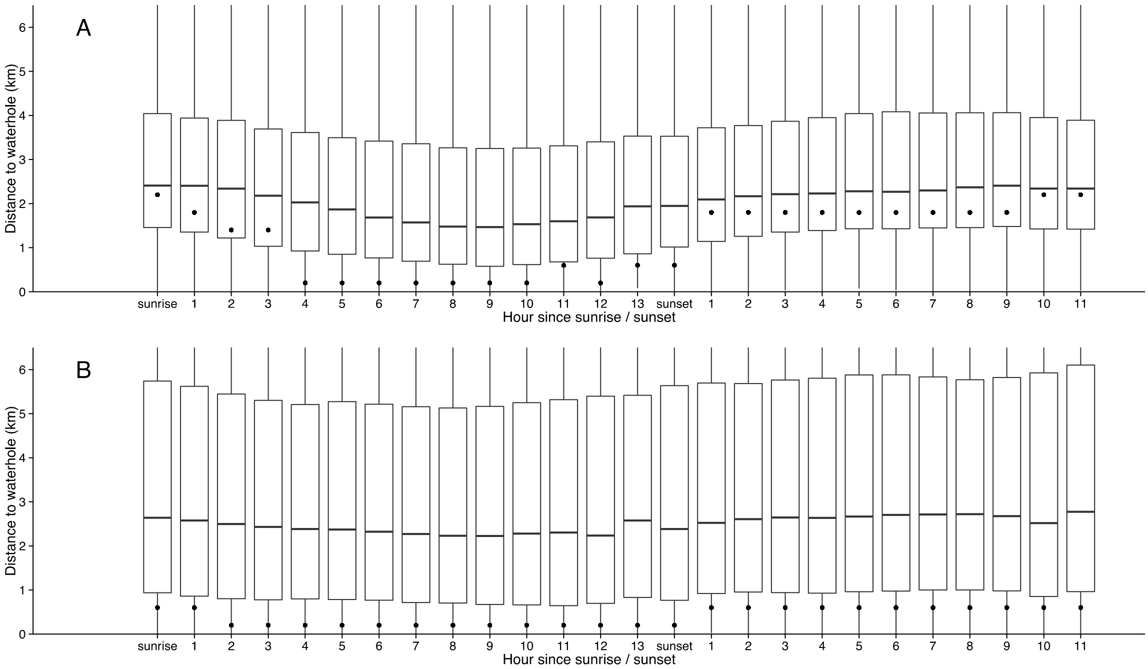

Figure S1.1. Distribution of GPS locations of zebras as a function of the distance to waterhole for each hour elapsed since the sunrise or sunset in dry (A) and wet (B) seasons. Each boxplot shows the 25th percentile (bottom), the 75th percentile (top) and the median (dark line). As the distributions were strongly right-skewed (many short distances to waterhole, a few large ones, the y-axis is truncated at 6km), the modal value of the distribution is also shown (solid circle). We defined daytime as the period ranging from 4h to 13h after the sunrise (thus excluding the displacement phase of the early morning). Nighttime was defined as the period ranging from 1h to 11h after the sunset (thus excluding the displacement phase at sunset).

Appendix S2. Spatial predictions of the risk of encountering lions during daytime and nighttime.

We estimated, for dry and wet seasons, the daytime and nighttime risk of encounter with lions for zebras based on spatial predictive maps of relative intensity of occurrence of lions. We built these maps by fitting resource selection functions (RSF, Manly et al., 2002; Johnson et al., 2013) using GPS-data collected from 46 lions, collared over the same area and the same period than zebras by qualified personnel using standard protocols (Fahlman et al., 2005). Collars acquired locations at 1h or 2h intervals during the night and every 2h or 2 or 3 times during the day. For each season and each daytime or nighttime period, we fitted a RSF model to those location data, including vegetation type, distance to waterhole and an interaction between them as predictors. Vegetation types were represented by six classes, obtained from the analysis and ground-truthing of Landsat-7 ETM+ satellite images (30-m resolution) (see Courbin et al., 2016 for details). Vegetation types were grassland, 3 types of bushlands (bushland-1, bushland-2, bushland-3) representing a decreasing gradient of openness, wooded bushland and woodland. Wooded bushland was the baseline vegetation type for all analyses.

RSFs were estimated with inhomogeneous Poisson point process (IPP) that gave the relative intensity (density of observations) of lions in the landscape (Aarts et al., 2013; Johnson et al., 2013; Warton & Aarts, 2013). More precisely, IPPs quantify variations in the spatial density of GPS locations as a function of predictors and can be modelled with a weighted Poisson log-linear model using an appropriate framework (see Warton & Shepherd, 2010; Johnson et al., 2013). We first created a set of available locations, where each location was put at the centre of each grid cell over a regular grid with a 30-m resolution localised within the individual seasonal home range. Individual home ranges were estimated for each season using the 95% utilization distribution obtained from a kernel density estimation with a reference bandwidth (Worton 1989). We then estimated RSF coefficients using a Poisson log-linear mixed model, where the response value is 0 for available locations and a count number *n* for GPS locations. For a given GPS location *i*, n_i is the total number of GPS locations occurring in the same cell as *i* plus one for the available location. All locations are given a prior weight equalled to $1/n_i$ (Aarts et al., 2013). We added a random intercept to account for the unbalanced number of locations collected across individuals (Gillies et al., 2006). Spatial predictions of lion intensity were not affected by any residual autocorrelation because serial correlation does not bias parameters estimates (Azzalini 1994).

Previous works have shown that lion occurrence decreases with the distance to waterhole (Valeix et al., 2010; Courbin et al., 2016). Here, we modelled this pattern by comparing the fit of RSF models with either a raw distance to waterhole values or their log-transformed values, as predictor. Each time, the RSF model with the log-transformed values provided a much better fit on the basis of the Akaike information criterion (AIC) and Akaike weights (Table S2.1). Variance inflation factor (VIF) was < 10 for all covariates of our top-ranked models, thereby allowing for valid statistical inference (Chatterjee, Hadi & Price, 2000). These top-ranked models were highly robust to cross validation in dry season ($\overline{r_s} \geq$ 0.91) and in a lesser extent in wet season ($\overline{r_s} \geq 0.72$) (Boyce et al. 2002). We therefore used these models to describe zebra-lion encounter risk. The models showed that lion occurrence differed more between daytime and nighttime than between seasons (Table S2.2, Fig. S2.1). Notably, the relative risk of encountering lions decreased more rapidly as the distance from waterhole increased during nighttime that during daytime. Generally, risk of encountering lions increased in grasslands and the two most open bushlands and this was more marked during nighttime (Table S2.2, Fig. S2.1).

References

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Table S2.1. Candidate lion RSF models. Maximum log-likelihood (LL), Akaike information criteria (AIC), relative AIC values (ΔAIC) and AIC weight (*w*) are shown. All models had the same number of parameters (*K*=12) and included the vegetation type, the distance to waterhole (either raw or log-transformed values) and their interactions as predictors. The column 'Tranformation' refers to the transformation applied to the 'distance to waterhole' predictor.

Season	Period	Transformation	LL	AIC	ΔAIC	*w*
Dry	Daytime	none (raw values)	-167937.5	335900.9	5058.1	<0.001
		log(1+ raw values)	-165408.4	330842.8	0	>0.999
Dry	Nighttime	none (raw values)	-261526.9	523079.7	8318.5	<0.001
		log(1+ raw values)	-257367.6	514761.2	0	>0.999
Wet	Daytime	none (raw values)	-347375.4	694776.8	5227.1	<0.001
		log(1+ raw values)	-344761.8	689549.7	0	>0.999
Wet	Nighttime	none (raw values)	-477051.7	954129.4	6911.2	<0.001
		log(1+ raw values)	-473596.1	947218.2	0	>0.999

Table S2.2. Mixed-effect models of resource selection function for lions during daytime and nighttime in the dry (*n*=40) and the wet (*n*=46) seasons. Selection coefficients (β) and their 95% confidence intervals (95% CI) are shown. Wooded bushland is the reference category for habitat type.

	Dry				Wet			
	Daytime		Nighttime		Daytime		Nighttime	
Variable	β	95% CI	β	95% CI	β	95% CI	β	95% CI
Grassland	1.16*	1.08;1.24	2.29*	2.23;2.35	1.29*	1.23;1.35	2.71*	2.67;2.75
Bushland-1	0.84*	0.76;0.92	1.57*	1.51;1.63	1.15*	1.09;1.21	1.66*	1.60;1.72
Bushland-2	0.59*	0.51;0.67	0.93*	0.87;0.99	0.69*	0.63;0.75	0.98*	0.94;1.02
Bushland-3	0.09	-0.01;0.19	0.29*	0.21;0.37	0.41*	0.35;0.47	0.35*	0.29;0.41
Woodland	-0.23	-0.47;0.01	-0.27*	-0.47;-0.07	-0.04	-0.18;0.10	-0.35*	-0.49;-0.21
Log(1+distance to waterhole (km))	-0.94*	-0.98;-0.90	-0.82*	-0.86;-0.78	-0.55*	-0.57;-0.53	-0.36*	-0.38;-0.34
Grassland x distance to waterhole	0.42*	0.36;0.48	-0.08*	-0.12;-0.04	0.03	-0.01;0.07	-0.52*	-0.56;-0.48
Bushland-1 x distance to waterhole	-0.05	-0.11;0.01	-0.34*	-0.38;-0.30	-0.35*	-0.39;-0.31	-0.52*	-0.56;-0.48
Bushland-2 x distance to waterhole	-0.17*	-0.23;-0.11	-0.24*	-0.28;-0.20	-0.29*	-0.33;-0.25	-0.35*	-0.37;-0.33
Bushland-3 x distance to waterhole	-0.04	-0.10;0.02	-0.11*	-0.17;-0.05	-0.25*	-0.29;-0.21	-0.17*	-0.21;-0.13
Woodland x distance to waterhole	0.12	-0.02;0.26	0.04	-0.08;0.16	-0.05	-0.13;0.03	0.02	-0.04;0.08

* 95% confidence intervals exclude zero.

Notes: Models were robust to cross-validation, with $\overline{r_s}$ of 0.91 ± 0.08 (mean ± SE) for daytime and 0.91 ± 0.06 for nighttime models in the dry season, and of 0.85 ± 0.11 for daytime and of 0.72 ± 0.10 for nighttime models in the wet season.

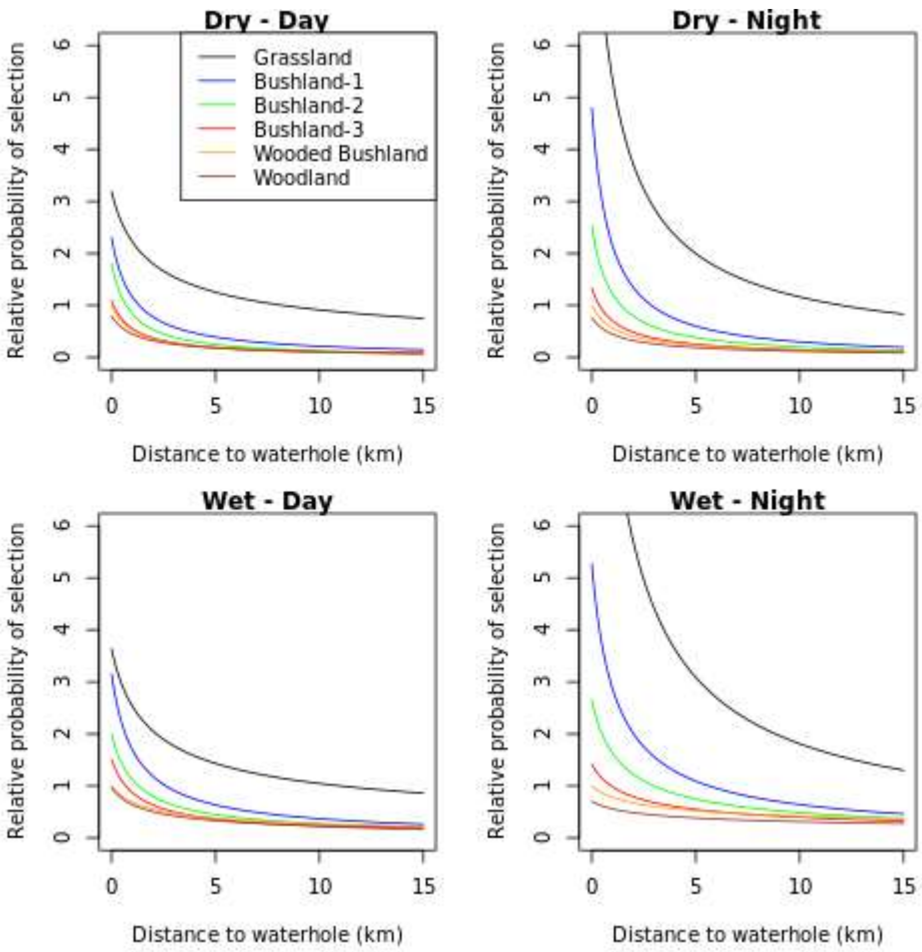

Figure S2.1. Relative risk of encountering lions in the different vegetation types as a function of distance to waterhole during daytime and nighttime, in the dry season and wet seasons.