Wildlife Biology

Appendix 1

Table A1. Covariates hypothesized to affect lion and hyena site occurrence in the W-Arly-Pendjari Complex, West Africa.

Covariate	Description	Data used	Development steps	Max	Mean	Min	SD
Distance to water (Dwa)	Distance of each cell from the closest water source in dry season (river or waterhole) 30 m resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models	PANTHERA Landscape Analysis Lab: WAP dry season rivers and waterholes extracted from land-use layer	We extracted rivers and waterholes from the land-use layer and then used the r.cost command in GRASS to generate a raster that contained the distance of each cell from the nearest boundary of a water source.	18580.6	6010.3	1664.9	3993.9
Distance to hunting concessions (Dhu)	Distance of each cell from the closest hunting concession boundary; Areas within concessions were assigned negative values.	PANTHERA Landscape Analysis Lab: vector of the hunting concession boundaries	We rasterized the hunting concession boundary and then used the r.cost command in GRASS to generate a raster that contained the distance of each cell from the nearest concession boundary. Finally, we multiplied all	49387.9	7200.6	-12291.5	14530.4

Covariate	Description	Data used	Development steps	Max	Mean	Min	SD
	30 m resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models		values within a concession by -1 to assign negative distance values to those areas.				
Distance to human settlements (Dset)	Distance of each cell from the closest human settlement 30 m resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models	PANTHERA Landscape Analysis Lab: point vector of villages in the broader WAP region	We rasterized the settlement layer and then used the r.cost command in GRASS to generate a raster that contained the distance of each cell from the nearest human settlement.	32292.4	17483.4	3246.6	8173.1
Habitat type (%): Grasslands (Grass); Riparian forests (Fores), Shrub savannahs (Sav), and Woodlands (Wood)	Proportion of a habitat type within a 1 arc (930 m) radius around each cell. Accuracy assessment: 84.2% across all classes.	PANTHERA Landscape Analysis Lab: Land-use layer of the WAP	We reclassified the original raster into six habitat types (Riparian forests, Shrub savannahs, Woodlands, Grasslands, Water, and Other) and generated binary maps of each habitat type.	Riparian 0.3 Savanna 0.6 Wood	Riparian 0.1 Savanna 0.4 Wood	Riparian 0.0 Savanna 0.0 Wood	Riparian 0.1 Savanna Wood

Covariate	Description	Data used	Development steps	Max	Mean	Min	SD
	30 m resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models		We then used the r.neighbors moving window command in GRASS to calculate the proportion of each habitat within a radius of 1 arc (930 m).	0.6 Grass 0.1	0.3 Grass 0.0	0.0 Grass 0.0	0.1 Grass 0.0
Prey (species-specific) habitat use	Relative intensity of habitat use of a cell by a prey species (large prey: buffalo, roan, antelope; medium prey: kob, warthog) Composite prey is the sum of all 4 primary prey species averaged. Carnivore survey grid resolution (200 km^2)	Prey resource selection function models developed during this study using data from the transect surveys Ratio of "used" to "available" locations: Buffalo: 78 / 312 Roan antelope: 116 / 464 Kob: 128 / 512 Warthog: 103 / 412	We developed resource selection function (RSF) models (binomial GLM logistic regression) in R for ungulate species which are known to be important lion and/or hyena prey species. We then produced predictive maps of each prey's relative likelihood of use of an area within WAP. The response variables were considered in a "use/available" manner (Manly et al. 2002).	Warthog 0.3 Roan 0.3 Kob 0.6 Buffalo 0.5 All prey 0.7	Warthog 0.2 Roan 0.2 Kob 0.2 Buffalo 0.2 All prey 0.2	Warthog 0.0 Roan 0.0 Kob 0.0 Buffalo 0.0 All prey 0.0	Warthog 0.1 Roan 0.1 Kob 0.2 Buffalo 0.1 All prey 0.1

Covariate	Description	Data used	Development steps	Max	Mean	Min	SD
Intensity of human disturbances: hunting or poaching pressure (Hunt) and illegal grazing by livestock (Pasto)	Relative intensity of hunting or livestock grazing activity in a cell Carnivore survey grid resolution (200 km^2)	Hunting or grazing resource selection function models developed during this study using data from the transect surveys Ratio of "used" to "available" locations: Poaching: 86 / 344 Grazing: 86 / 344	We developed resource selection function (RSF) models (binomial GLM logistic regression) in R for human disturbance (hunting and grazing) in the WAP. We then produced predictive maps of each disturbance's relative likelihood of occurring in an area within WAP. The response variables were considered in a "use/available" manner (Manly et al. 2002).	Hunting 0.3 Grazing 0.5	Hunting 0.2 Grazing 0.1	Hunting 0.0 Grazing 0.0	Hunting 0.1 Grazing 0.1
Percent tree cover (VCF)	Percent cover of an area by woody vegetation over 5 m height (i.e. trees) 250 m resolution; resampled at carnivore	MODIS Vegetation Continuous Field (2010 dataset) http://glcf.umd.edu/data/vcf/	Before using the VCF layer, we assigned NULL values to water (200) and missing values (253) so as not to skew the mean values calculated for the survey grids.	12.4	5.8	3.2	1.8

Covariate	Description	Data used	Development steps	Max	Mean	Min	SD
	survey grid scale (200 km^2) for inclusion in carnivore occupancy models						
Evapotranspiration (PET)	Climate data related to evapotranspiration 30 arc (930 m) resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models	Global aridity, evapotranspiration and rainfall deficit for potential vegetative growth database (http://www.cgiar-csi.org/data/global-aridity-and-pet-database)	We used the raster calculator command to generate a raster that contained only evapotranspiration data for the dry season.	194.7	189.3	179.3	2.4
Rainfall (Rain)	Climate data related to rainfall 30 arc (930 m) resolution; resampled at carnivore survey grid scale (200 km^2) for inclusion in carnivore occupancy models	WorldClim - Global Climate data, climate grids http://www.worldclim.org/	We used the raster calculator command to generate a raster that contained only rainfall data for the dry season.	30	12	1.3	5.9

* A cell in the table denotes the smallest unit found in each covariate land-use / raster layer and does not stand for a 200km^2 cell unit used for the occupancy modelling analysis.

Table A2. Spearman's correlation matrix of site-specific covariates giving the r-values. Bold type indicates strong correlation $|r| \geq 0.7$ resulting in one covariate being discarded from further analyses.

	Prey	Hunt	Pasto	Dset	Dwa	Dhu	Fores	Wood	Sav	Grass	Wart	Roan	Kob
Prey													
Hunt	0.43												
Pasto	-0.38	0.23											
Dset	0.25	0.08	-0.07										
Dwa	-0.64	-0.34	**0.70**	-0.01									
Dhu	0.02	-0.18	0.22	0.47	0.32								
Fores	0.11	0.58	**0.70**	0.23	0.24	0.12							
Wood	0.15	0.06	-0.07	0.11	-0.03	-0.37	-0.03						
Sav	0.25	0.60	0.18	0.34	-0.19	0.24	0.22	-0.2					
Grass	0.53	0.26	-0.21	0.13	-0.29	0.29	-0.06	-0.17	0.27				
Wart	**0.85**	0.46	-0.22	0.55	-0.52	0.38	0.19	-0.01	0.52	0.60			
Roan	**0.81**	0.59	-0.08	0.55	-0.37	0.12	0.36	0.37	0.51	0.42	**0.84**		
Kob	**0.89**	0.26	-0.27	-0.05	-0.53	-0.14	0.07	0.1	0.06	0.39	0.65	0.59	
Buff	**0.86**	0.37	-0.58	0.2	-0.69	-0.04	-0.06	0.16	0.12	0.48	0.65	0.63	0.63

Prey: composite preys (buffalo + roan + kob + warthog); *Hunt*: hunting pressure; *Pasto*: illegal pastoralism/grazing; *Dset*: distance to settlement (m); *Dwa*: distance to water (m); *Dhu*: distance to hunting concessions (m); *Fores*: proportion riparian forest habitat; *Wood*: proportion woodland habitat; *Sav*: proportion shrub savannah habitat; *Grass*: proportion grassland habitat; *Wart*: prey warthog; *Roan*: prey roan antelope; *Kob*: prey kob; *Buff*: prey buffalo.

Table A3. Ranking of survey-specific models developed to predict the probability of lion *Panthera leo* and spotted hyena *Crocuta crocuta* occurrence in the W-Arly-Pendjari Complex, West Africa, 2013-2014. Akaike information criterion (AICc) scores corrected for small sample sizes, AICc weights, and evidence ratios are presented.

Species	Models	AICc	ΔAICc	AICc wgt	ERatio	no.Par.
Lion	$\psi(.), p(Sub + Sec)$	174.11	0	0.8124	1	4
	$\psi(.), p(Sub)$	178.06	3.95	0.1127	7.2	3
	$\psi(.)\theta_0(.)\theta_1(.)p(Sub + Sec)\theta_0\pi(.)$	179.11	5.00	0.0667	12.2	6
	$\psi(.), p(Sec)$	184.05	9.94	0.0056	144.1	3
	$\psi(.)\theta_0(.)\theta_1(.)p(Sec)\theta_0\pi(.)$	185.78	11.67	0.0024	341.3	5
	$\psi(.), p(.)$	193.21	19.10	0.0001	14020.9	2
	$\psi(.)\theta_0(.)\theta_1(.)p(.)\theta_0\pi(.)$	194.09	19.98	0.0000	21807.3	4
	$\psi(.)\theta_0(.)\theta_1(.)p(Sub)\theta_0\pi(.)$	196.68	22.57	0.0000	79442.8	5
Hyena	$\psi(.), p(Sub)$	225.34	0	0.3634	1	3
	$\psi(.), p(.)$	226.32	0.98	0.2230	1.6	2
	$\psi(.), p(Sub + Sec)$	226.57	1.23	0.1965	1.8	4
	$\psi(.), p(Sec)$	227.81	2.47	0.1057	3.4	3
	$\psi(.)\theta_0(.)\theta_1(.)p(Sub)\theta_0\pi(.)$	229.95	4.61	0.0363	10.0	5
	$\psi(.)\theta_0(.)\theta_1(.)p(Sub + Sec)\theta_0\pi(.)$	230.00	4.66	0.0354	10.3	6
	$\psi(.)\theta_0(.)\theta_1(.)p(.)\theta_0\pi(.)$	230.34	5.00	0.0298	12.2	4
	$\psi(.)\theta_0(.)\theta_1(.)p(Sec)\theta_0\pi(.)$	232.56	7.22	0.0099	36.9	5

Covariates: *Sub*: roads substrate; *Sec*; management sector (western / eastern).

Table A4. Medium to large ungulate species recorded during the line-transects survey in Pendjari (317 transects) and the "W" National Park (192 transects), (CENAGREF-PAPE, 2013-2014)

Species	Scientific name	Pendjari NP		W NP	
		# Detection	Enc/km	# Detection	Enc/km
Bohor reedbuck	*Redunca redunca*	115	0.08	8	0.00
Buffalo	*Syncerus caffer*	65	0.04	13	0.01
Bushbuck	*Tragelaphus scriptus*	51	0.04	25	0.01
Bush duiker	*Sylvicapra grimmia*	104	0.07	70	0.04
Hartebeest	*Alcephalus buselaphus*	28	0.02	7	0.00
Kob	*Kobus kob*	116	0.08	13	0.01
Korrigum	*Damaliscus l. korrigum*	6	0.00	-	-
Oribi	*Ourebia ourebia*	91	0.06	29	0.02
Roan	*Hippotragus equinus*	64	0.04	53	0.03
Warthog	*Phacochoerus africanus*	48	0.03	55	0.03
Waterbuck	*Kobus e. defassa*	6	0.00	-	-

Detection: number of detections; Enc/km: encounter rate per kilometre. Notice here that while other species like bush duiker or oribi adopt a more solitary or small number individuals group, buffalo and roan antelopes are usually seen in groups of several individuals. Encounter rate per km does not reflect by any mean abundance of the observed species.

Table A5. Top models (ΔAICc<2) of the probability of ungulate prey resource use in the W-Arly-Pendjari Complex (2013-2014); df is the number of parameters, AICc the Akaike information criterion corrected, ΔAIC the difference between a given model and the lowest AIC model. Parameters in bold have a positive relation with species use, while in regular font those with negative relation. In asterisk are parameters that are significant in a given model.

Component models	df	AICc	ΔAIC	Weight
Buffalo				
Dhu* + Road* + Dset* + PET* + Rain* + Cover* + Dwa	8	337.22	0	0.26
Dhu + Road + Dset + PET + Rain + Cover	7	337.52	0.31	0.22
Dhu + Road + Dset + Grass + PET + Rain + Cover + Dwa	9	338.31	1.1	0.15
Dhu + Dset + PET + Rain + Cover + Dwa	7	338.39	1.17	0.14
Dhu + Road + Dset + PET + Rain + Cover	8	338.45	1.23	0.14
Roan				
Fores* + PET* + Sav	4	572.8	0	0.09
Dset + PET	3	573.39	0.59	0.07
Dset + Fores + PET + Sav	5	573.45	0.65	0.06
Fores + PET + Sav + Temp + Wood	5	573.6	0.8	0.06
Fores + PET + Sav + Temp	5	573.62	0.82	0.06
Kob				
Dhu* + Road* + Dset + Fores* + Grass + PET* + Rain* + Sav* + Cover*	10	404.47	0	0.37
Dhu + Road + Dset + Fores + PET + Rain + Sav + Cover	9	405.15	0.68	0.26
Dhu + Road + Fores + Grass + PET + Rain + Sav + Cover	9	405.45	0.98	0.22
Dhu + Road + Dset + Fores + Grass + PET + Rain + Sav + Cover + Dwa	11	406.31	1.84	0.15
Warthog				
Dset + Grass + PET* + Rain* + Dwa	6	489.22	0	0.22
Dset + Grass + PET + Rain	5	490.61	1.38	0.11
Dset + Fores + Grass + PET + Rain + Dwa	7	490.66	1.44	0.11
Dset + Grass + Rain + Dwa	5	490.85	1.62	0.1

Table A6. Top five Univariate models selection for carnivore occurrence in the W-Arly-Pendjari (WAP) complex, West Africa. AICc wgt: AICc weight; ER: Evidence Ratio (how less likely a model is compared to the top-ranked model); no.Par: number of parameters; β is the slope coefficient of the covariate, a negative sign indicates a negative relationship between carnivore occupancy and the covariate.

Species	Models	AICc	ΔAICc	AICc wgt	ER	no.Par.	β±SE
Lion	$\psi(Pasto)$	170.19	0	0.6967	1	4	1.82±0.81
	$\psi(Fores)$	172.72	2.53	0.1966	3.5	4	1.36±0.65
	$\psi(Dhu)$	176.07	5.88	0.0368	18.9	4	0.83±0.45
	$\psi(Sav)$	178.60	8.41	0.0104	67.0	4	0.57±0.42
	$\psi(Wart)$	178.74	8.55	0.0097	71.9	4	0.51±0.39
Hyena	$\psi(Hunt)$	218.97	0	0.6546	1	4	-2.50±1.21
	$\psi(Sav)$	223.01	4.04	0.0868	7.5	4	-1.47±0.74
	$\psi(Wood)$	223.19	4.22	0.0794	8.2	4	0.94±0.49
	$\psi(Pasto)$	224.39	5.42	0.0436	15.0	4	-0.79±0.44
	$\psi(Buff)$	225.60	6.63	0.0238	27.5	4	0.65±0.47

Prey: composite preys (buffalo + roan + kob + warthog); *Hunt*: hunting pressure; *Pasto*: illegal pastoralism/grazing; *Dset*: distance to settlement (m); *Dwa*: distance to water (m); *Dhu*: distance to hunting concessions (m); *Fores*: proportion riparian forest habitat; *Wood*: proportion woodland habitat; *Sav*: proportion shrub savannah habitat; *Grass*: proportion grassland habitat; *Wart*: prey warthog; *Roan*: prey roan antelope; *Kob*: prey kob; *Buff*: prey buffalo. All models have a fixed $p(Sub)$.
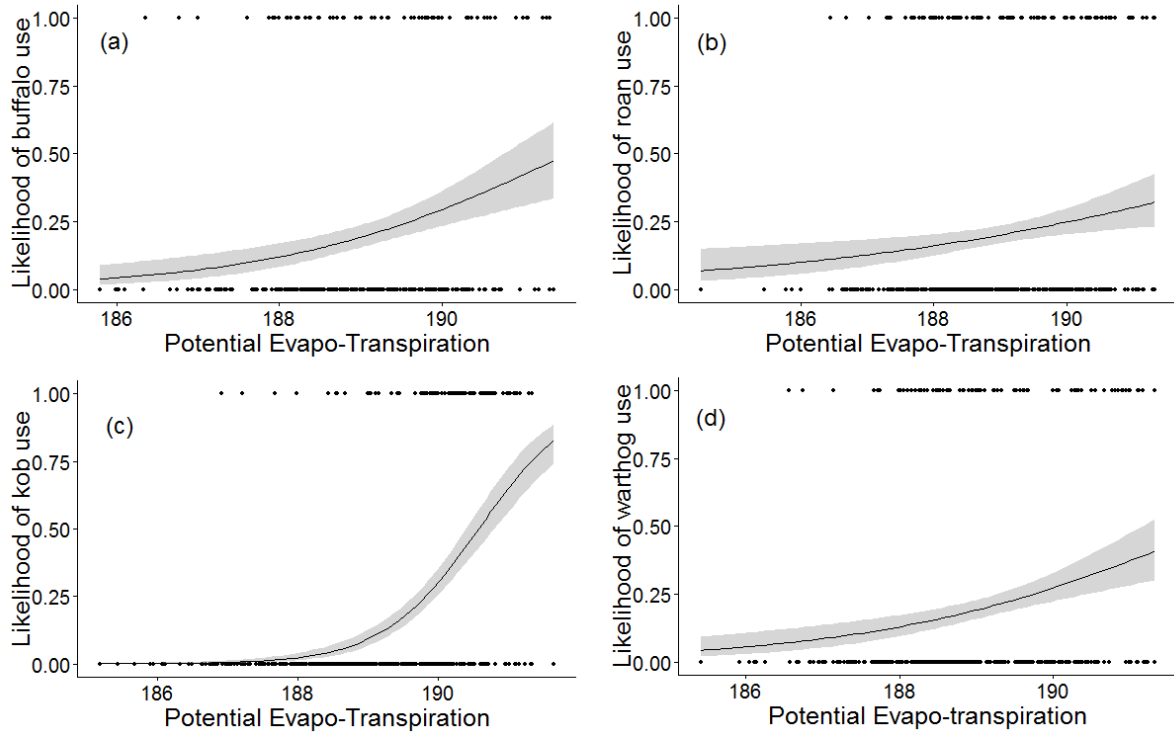
Fig. A1. Predicted relative intensity of habitat use within the W-Arly-Pendjari Complex, West Africa (2013-2014) in relation to: potential evapo-transpiration (a) for buffalo *Syncerus caffer*; (b) for roan antelope *Hyppotragus equinus*; (c) for kob *Kobus kob* and (d) for warthog *Phacochoerus africanus*. Fitted lines are represented by the black line with 95% confidence intervals of the estimate in gray shading
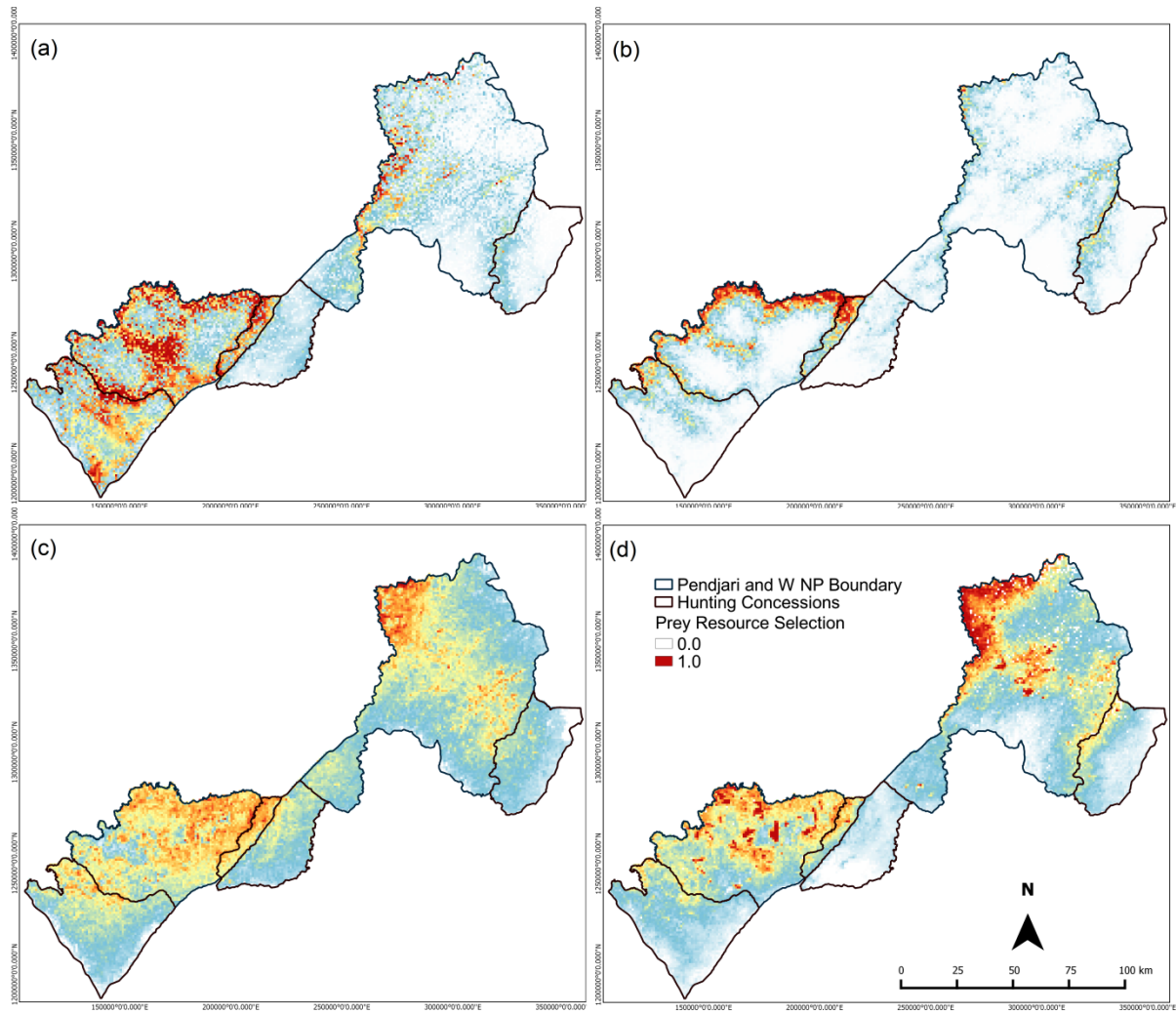
Fig.A2. Predicted relative intensity of habitat use at the landscape level for: buffalo *Syncerus caffer* (a); kob *Kobus kob* (b); roan *Hyppotragus equinus* (c) and warthog *Phacochoerus africanus* (d) in the W-Arly-Pendjari Complex, West Africa based on line transect surveys data, (2013-2014).
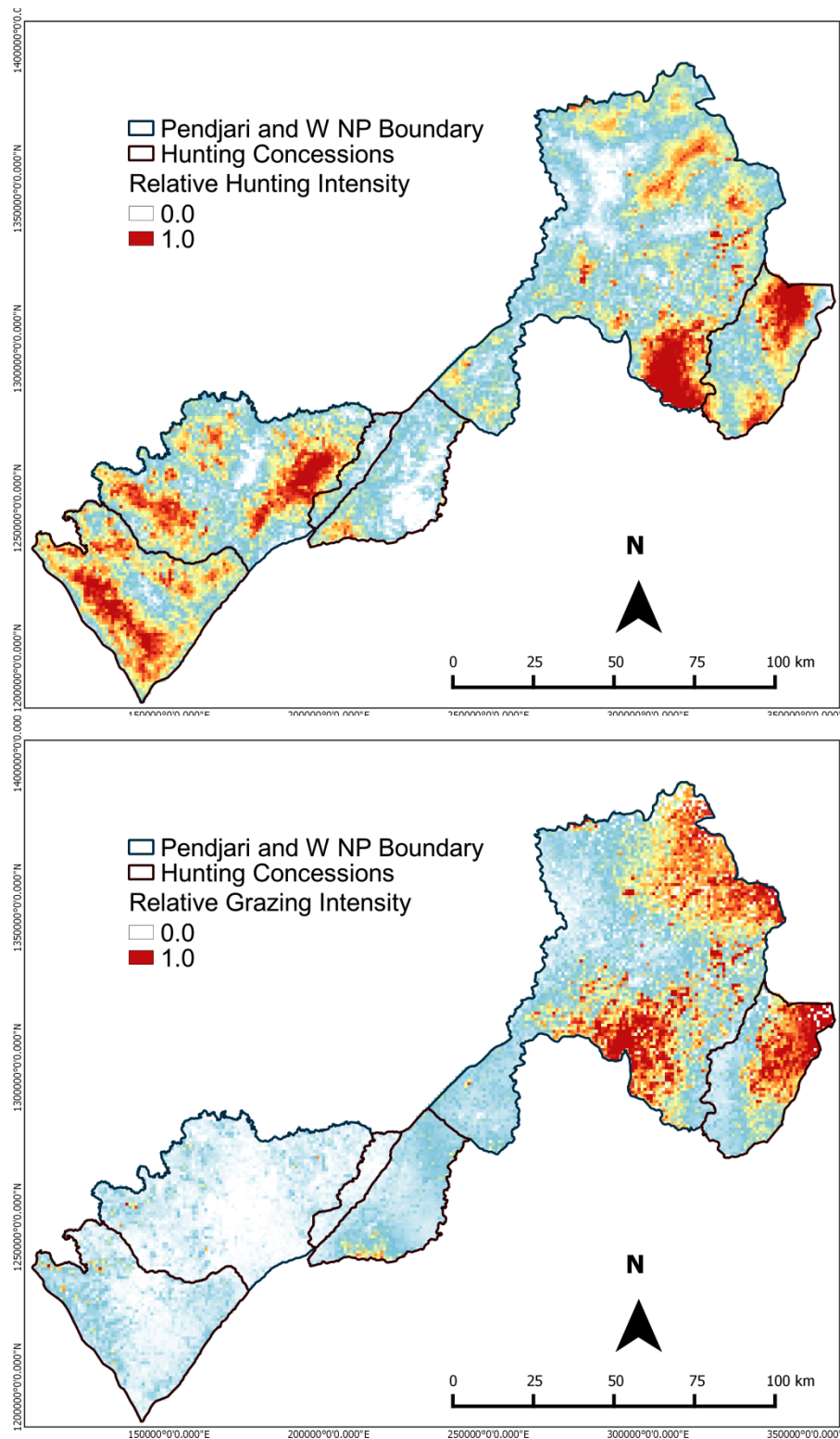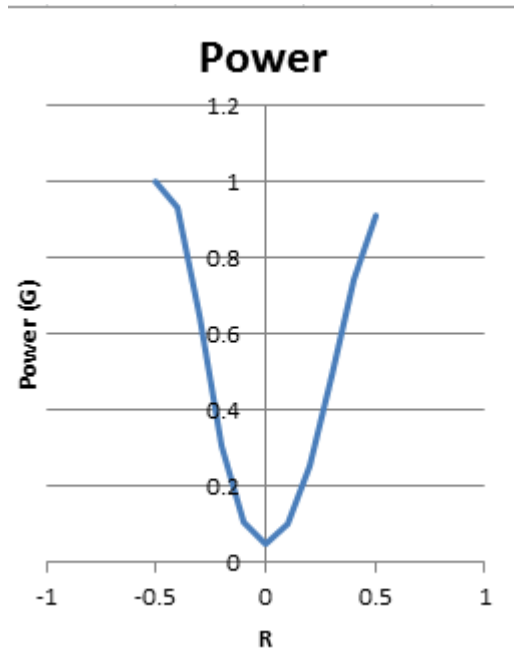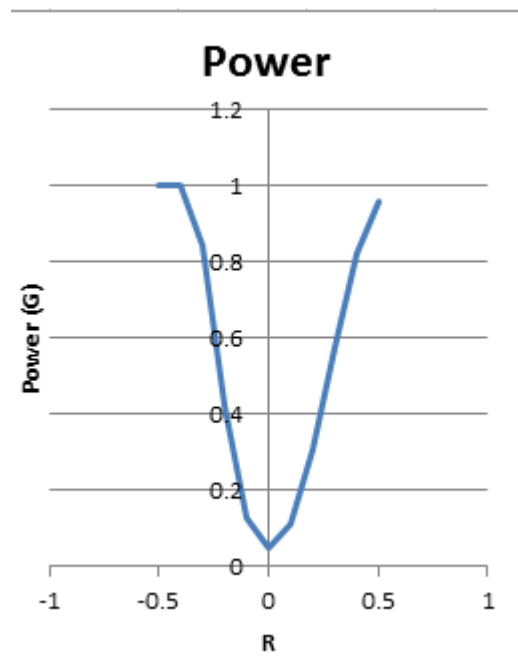
Fig. A3. Predicted relative hunting intensity and relative grazing intensity within the W-Arly-Pendjari Complex, West Africa (2013-2014).

Lion – current survey effort   Hyena – current survey effort

Fig. A4. The power of analysis of a) lion *Panthera leo* current survey effort and b) spotted hyena *Crocuta crocuta* current survey effort in the southern W-Arly-Pendjari Complex, West Africa, (2013-2014).