Ecography

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Supplementary material

Appendix 1

Table A1. Average (SD) temperature and snow depth during the winters (November-April) of the study period and long-term means as measured at a weather station 15 km north of Riding Mountain National Park, MB, Canada (http//:climate.weather.gc.ca).

Period	Temperature °C	Snow depth (cm)
2002-2003	-8.24 (8.53)	26.2 (9.16)
2003-2004	-7.10 (9.54)	29.28 (16.86)
2004-2005	-6.43 (9.93)	28.54 (22.6)
2010-2011	-7.96 (9.71)	32.80 (23.61)
1981-2010 (Long-term)	-6.91 (10.08)	31.28 (25.4)

Table A2. Overview of sample size (i.e., number of GPS collared elk) per winter. Note that the sample size is given for both males and females, but sex was not included as a covariate in the analyses.

		Winter				
Collar type	**Sex**	**2002-2003**	**2003-2004**	**2004-2005**	**2010-2011**	**TOTAL**
GPS	Female	5	8	7	5	**25**
	Male	4	0	0	4	**8**

Detailed description of the elk density data and density surface modeling

The population size of elk in RMNP is actively monitored (to evaluate the effectiveness of the population reduction management program described above) and is estimated from 25% coverage, standardized aerial surveys conducted annually (2000−2011) by Parks Canada Agency. During the annual population surveys permanent transects were flown using a fixed-wing aircraft flying at an altitude of 120 m at 120 km/hr. Transects were 200 m wide and ranged from 8.5–24.0 km^2 based on the shape of the park, with a total area surveyed of 745 km^2 each year (for more methodological details on the aerial surveys see: Vander Wal et al. 2013, van Beest et al. 2014). Flights were completed in late winter when sightability was at an optimum, with snow cover on the ground and canopy foliage on deciduous trees absent (Vander Wal et al. 2011). Animals did not react adversely (e.g., by long distance movements) to the presence or noise of the aircraft reducing the likelihood of double counts among transects. A GPS location was recorded for each observation site as well as the number of individuals present. Sightability bias in elk detection using independent aerial surveys in RMNP has previously been assessed (Vander Wal et al. 2011) and was largely attributed to temporal factors such as season (with more elk detected during winter than in other seasons) and time of day (with more elk detected during midday than morning and evenings). Because time of day was not recorded during the aerial surveys used in this study, we were unable to reliably account for sightability bias in our elk observations data. As a result, our estimates (as described in the next paragraph) are likely an underestimation and as such cannot be used to determine true abundance of elk in the study area. Instead, they provide a relative density measure, which we assume to be sufficiently accurate and precise for our purpose. This is because all surveys were flown under similar weather conditions, using the same pilot and observers so as to ensure that sightability bias and location error were as low as possible and, moreover, consistent and systematic both spatially (over the study area) and temporally (over time).

Elk observed during the aerial surveys were used to spatially predict and map local densities (km^2) across the study area for each winter separately. As such, we quantified variation in local elk density in both space and time. To do so we employed an established approach termed the 'count model' (Hedley and Buckland 2004) or 'density surface modelling' (Miller et al. 2013). In this approach, counts of individuals along transects are summarized into segments, which are then included as the response variable in a generalized additive model (GAM; Wood 2006). GAMs provide a suitable analytical framework to model changes in local animal density because explanatory variables, with potential nonlinear effects, can be fitted as parametric or nonparametric smoothing terms (Wood 2006). Here, we summed the abundance of elk along aerial survey lines into 200 m × 200 m cells for each winter separately.

For each cell we determined the dominant habitat type (6-level factor: mixed forest [both deciduous and coniferous species], coniferous forest, grassland, wetland and water [including lakes and streams], agricultural land, and built-up areas [sites with human influence such as buildings or houses]). Habitat types were derived from a 30 m spatial resolution vegetation map that was developed using Landsat-5 satellite imagery in 2003 (Geobase; http://www.geobase.ca). Ground-truthing of habitat types showed that the overall accuracy of the landscape-scale vegetation map was 84%, with 10% of the misclassification attributed to sites classified as deciduous forest on the land cover map but in reality being agricultural cropland (Dugal et al. 2013). We considered the accuracy of the vegetation map adequate for our density and RSF analyses (Johnson and Gillingham 2008). We also calculated the mean elevation (m), and the mean distance (m) to both paved and unpaved roads for each cell. These parameters are known to be important determinants of the spatiotemporal distribution of elk in our study area (van Beest et al. 2014) and were subsequently used as explanatory variables in the GAM models. Habitat type was included as a factor variable in the GAM model while elevation and distance to paved and unpaved roads were included as smoothing terms. We used thin plate regression splines with the optimal smooth curve estimated by the generalized cross-validation procedure (Wood 2006). Model selection was conducted using the χ^2 statistic and backward selection using alpha = 0.05 as the threshold for inclusion of explanatory variables. When a variable was removed, we verified that the simpler model provided a better fit than the more complicated model based on AIC. The outputs of the winter-specific GAM analyses are provided in Supplementary material Table A3. The models explained between 49% and 64% of the observed deviation in the elk count data.

The results of the GAM model were subsequently used to predict elk density over a larger area (6524 km^2) than was originally surveyed (743 km^2), and plotted as density surface maps (Miller et al. 2013) for each winter separately. In our case the density surface maps reflect relative elk densities and as such cannot be used to calculate an overall estimate of elk abundance in the area. We created a raster layer with prediction cells covering the complete RMNP study area in Quantum GIS, version 2.4.0-Chugiak (QGIS Development Team 2014). Each cell contained the values of the covariates included in the GAM model and we predicted a relative density surface map for each winter separately (Supplementary material Figure A1) with each cell on the raster map representing the relative density value of elk/km^2.

Once the density surface maps were created we quantified the level of autocorrelation in temporal density fluctuations across the study area using the autocorrelation function (acf) in R (R Development Core Team 2013). To do so we randomly sampled 5% of the data (>60000 pixels or density values) from each density surface map within and directly bordering RMNP, but excluding agricultural fields further than 5 km from RMNP as these area were rarely used by our study animals (see Supplementary material Figure A1). We then created a time-series object of these sampled data and plotted the autocorrelation function for each winter combination (6 combinations). The result (Supplementary material Figure A2) showed some autocorrelation in density estimates over space and time though the level of correlation was largely within the 20% confidence limits around 0 (i.e. no autocorrelation). As such, we considered the level of autocorrelation in temporal density fluctuations across the study area to be sufficiently low and suitable for our home range and Resource Selection Function analyses as described in the main article.

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Table A3. Parameter estimates of the GAM analyses predicting relative elk density for each winter in Riding Mountain National Park in southern Manitoba, Canada. The models form the analytical basis for Supporting material Figure A1.

Winter	Variable	β	SE	z-value	*P*-value
2002-2003	Intercept	0.844	0.045	1.865	<0.001
	Habitat type[a]				
	Agricultural land	-1.05	1.007	-1.044	0.297
	Coniferous forest	-0.844	0.714	-1.183	0.237
	Grassland	0.123	0.182	0.678	0.497
	Wetland & water	0.051	0.117	0.438	0.661
	Built-up	-1.91	0.37	-1.883	<0.001
	Smooth terms	***edf***	χ^2	***P-value***	
	s(elevation)	7.125	49.354	<0.001	
	s(dist. to unpaved roads)	6.484	42.488	<0.001	
	Deviance explained	63.8%			
Winter	**Variable**	**β**	**SE**	**z-value**	***P*-value**
2003-2004	Intercept	0.663	0.022	29.228	<0.001
	Habitat type[a]				
	Agricultural land	-0.039	0.229	-0.170	0.865
	Coniferous forest	-0.185	0.237	-0.782	0.434
	Grassland	0.307	0.139	2.212	0.027
	Wetland & water	0.615	0.255	2.408	0.016
	Built-up	-0.089	0.056	-1.589	0.112
	Smooth terms	***edf***	χ^2	***P-value***	
	s(elevation)	3.432	24.420	<0.001	
	s(dist.to unpaved roads)	2.691	21.330	<0.001	
	Deviance explained	58.9%			
Winter	**Variable**	**β**	**SE**	**z-value**	***P*-value**

2004-2005	Intercept	0.826	0.026	31.672	<0.001
	Habitat type[a]				
	Agricultural land	-0.124	0.390	-0.319	0.749
	Coniferous forest	-0.167	0.211	-0.792	0.428
	Grassland	0.011	0.129	0.092	0.926
	Wetland & water	0.165	0.060	2.727	0.006
	Built-up	-0.667	0.581	-1.149	0.25
	Smooth terms	***edf***	χ^2	***P-value***	
	s(elevation)	2.902	35.205	<0.001	
	s(dist.to unpaved roads)	4.358	59.340	<0.001	
	Deviance explained	49.6%			
Winter	**Variable**	**β**	**SE**	**z-value**	***P*-value**
2010-2011	Intercept	0.977	0.051	19.032	<0.001
	Habitat type[a]				
	Agricultural land	-0.763	0.614	-1.243	0.214
	Coniferous forest	-0.444	0.591	-0.752	0.452
	Grassland	0.857	0.157	5.438	<0.001
	Wetland & water	0.112	0.106	1.063	0.288
	Built-up	-0.105	0.404	-0.262	0.793
	Smooth terms	***edf***	χ^2	***P-value***	
	s(elevation)	7.011	20.97	0.007	
	s(dist.to paved roads)	8.075	28.32	<0.001	
	s(dist.to unpaved roads)	7.542	41.37	<0.001	
	Deviance explained	60.1%			

[a] = reference level is mixed forest

Figure A1. Density surface maps of elk in Riding Mountain National Park, Canada, for each winter considered in the home range and RSF analyses. Each cell on the raster map represents the relative density value of elk/km^2. The solid black lines are the 95% MCPs of the GPS-collared elk and the dotted black line is the boundary of the park.

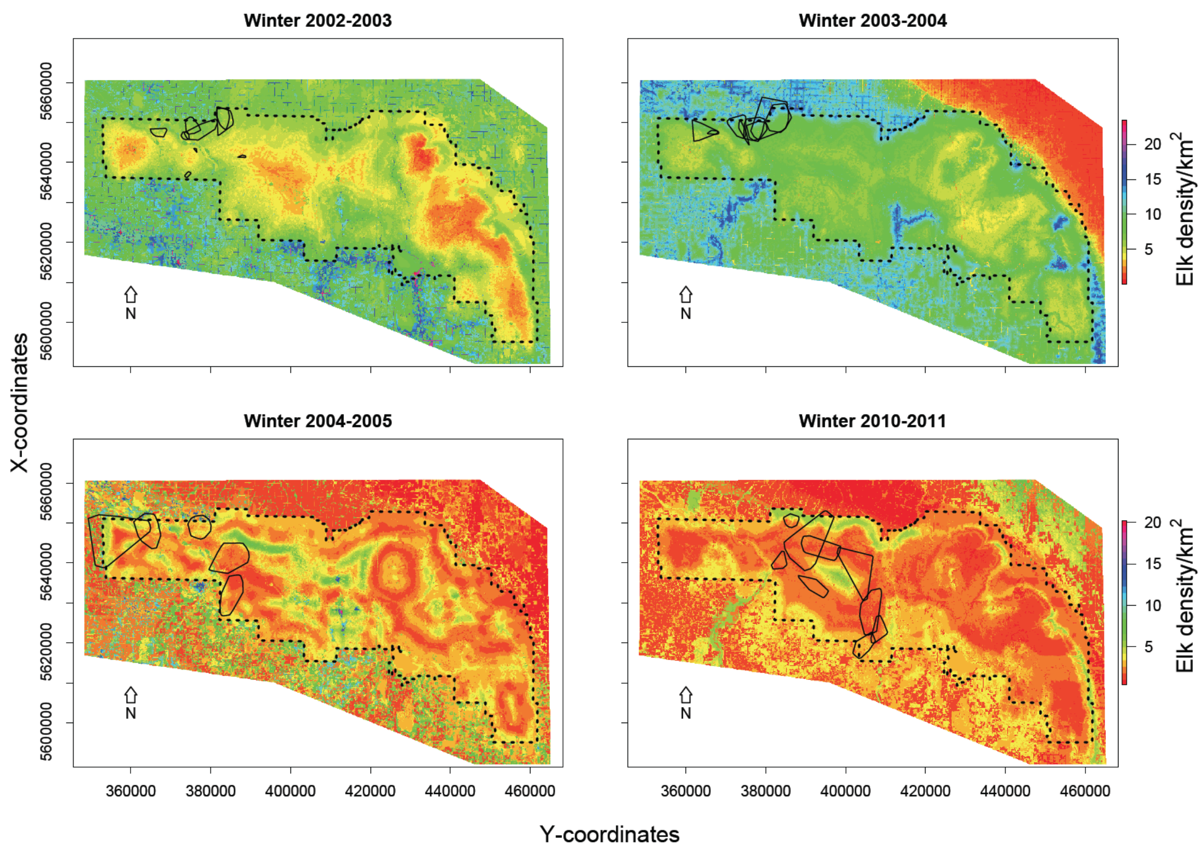

Figure A2. Plot of the autocorrelation function (ACF) estimating temporal correlation in local elk density estimates over the study area (Riding Mountain National Park, Canada) for each winter combination. The blue horizontal lines show the 20% confidence interval around 0 (i.e., no autocorrelation).