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Apparent Collapse of the Peary Caribou (*Rangifer tarandus pearyi*) Population on Axel Heiberg Island, Nunavut, Canada

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APPENDIX 1: ADDITIONAL DETAILS ON DISTANCE SAMPLING METHODS

Conventional and Multiple Covariate Distance Sampling

We considered right-truncated models that removed the top 5% of observations by distance to remove influential outliers and improve model fit (Thomas et al., 2010). We compared models with both half-normal and hazard-rate key functions, and with and without cosine adjustment terms. Observation-level covariates used for MCDS included those described under "Aerial Survey" in the main text, along with cluster size.

Other than cluster size, none of the observation-level covariates produced useful models (e.g., either did not converge or had other errors). We suspect this result is likely due to the low variation across these covariates. Detection functions with right truncation outperformed those without, and half-normal key functions typically performed better than hazard-rate key functions.

Density Surface Models

We tested DSMs using detection functions 2 and 5 from the first stage of the analysis. Although detection function 6 was also within 2 AIC of functions 2 and 5, it differed only from detection function 5 in its key function (Table A1). It seemed unnecessary to include both detection functions in our DSMs (Table A2), especially considering that in direct comparisons of detection functions that varied only in key function (i.e., 5 vs. 6, 2 vs. 4, 1 vs. 3), the half-normal function always produced lower AIC values.

The vegetation factor was included in models in one of two ways: as a parametric factor (i.e., with no corresponding smooth function in the generalized additive model [GAM]), and as an interaction with each smooth term in the model, with a different smooth generated for each factor level. We extracted environmental covariates to a 4 km^2 grid across the study area (Fig. A1).

We compared AIC scores from models fit via marginal likelihood to avoid issues in comparing models with different fixed effects, and fit final models using restricted marginal likelihoods. DSMs with quasi-Poisson response distributions are quasi-maximum likelihood models, and so we did not derive AIC scores. We compared these models to other candidates using explained deviance alone.

To estimate variance in DSMs, uncertainty from both the detection function and GAM must be combined (Miller et al., 2013). Because of the structure of our detection functions (i.e., most having no detection-level covariates) we estimated DSM variance using the delta method to combine the GAM uncertainty with detection function uncertainty (Miller et al., 2019). A drawback to this method is that it assumes independence between variance in the detection and spatial distribution processes, which is unlikely in our case, and so the final uncertainty estimates for our DSMs are probably underestimated.

TABLE A1. Candidate conventional and multiple covariate distance sampling models for distribution and abundance of muskoxen (*Ovibos moschatus*) on Axel Heiberg Island, 25 March to 6 April 2019.

Detection function					Model comparison			Abundance estimate			
No.	Key function	Truncation	Adjustment term	Covariates	AIC	ΔAIC	Log likelihood	N	LCL	UCL	CV
5	Half-normal	5% right	–	Cluster size	289.99	0	−142.99	4479	3218	6235	0.17
2	Half-normal	5% right	Cosine	–	290.00	0.01	−144.00	4143	3069	5592	0.15
6	Hazard-rate	5% right	–	Cluster size	291.53	1.54	−142.77	4338	2993	6287	0.19
4	Hazard-rate	5% right	Cosine	–	293.55	3.56	−143.78	3957	2593	6038	0.22
1	Half-normal	–	–	–	380.7	90.71	−189.35	4336	3220	5837	0.15
3	Hazard-rate	–	–	–	384.4	94.41	−190.2	3728	2763	5031	0.15

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TABLE A2. Candidate density surface models for distribution and abundance of muskoxen (*Ovibos moschatus*) on Axel Heiberg Island, 25 March to 6 April 2019. Detection function numbering corresponds to Table A1. The most-supported model is highlighted in bold font.

	Density surface model structure			Model comparison		Abundance estimate			
No.	Generalized additive model	Detection function	Response distribution	ΔAIC	Deviance explained	N	LCL	UCL	CV
1	Bivariate smooth of location	2	Quasi-Poisson	NA	24.95%	4115	3383	5005	0.10
2	Bivariate smooth of location, smooth of elevation	2	Quasi-Poisson	NA	28.31%	3858	3167	4700	0.10
3	Bivariate smooth of location, smooth of elevation	2	Tweedie	3.4	29.66%	3799	3020	4779	0.12
4	Bivariate smooth of location, binary factor smooth of elevation, both with vegetation	2	Tweedie	22.2	31.95%	3726	2958	4693	0.12
5	Bivariate smooth of location, binary factor smooth of elevation, both with vegetation	5	Tweedie	206.9	33.26%	4013	3163	5092	0.12
6	**Bivariate smooth of location, smooth of elevation, vegetation binary parametric factor**	**2**	**Tweedie**	**0.0**	**32.07%**	**3772**	**3001**	**4742**	**0.12**
7	Bivariate smooth of location, smooth of elevation, vegetation binary parametric factor	5	Tweedie	184.5	33.31%	4067	3213	5147	0.12

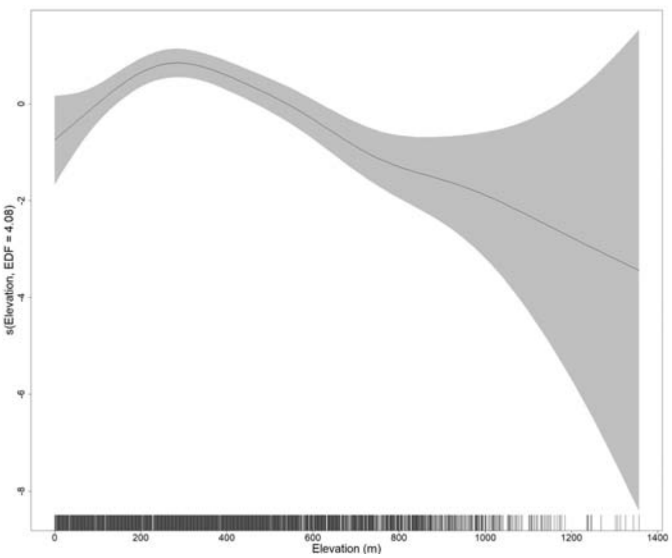

FIG. A1. Plot of the smooth of elevation from our most-supported density surface model. The small lines along the x-axis indicate the elevations of observed groups of muskoxen. The grey shaded area represents two times the standard error of the predicted values. EDF = estimated degrees of freedom.

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