Incorporating precision of empirical data on ungulate biomass to estimate wolves on winter ranges of Bathurst (BAH), Bluenose-East (BNE), and Beverly (BEV) caribou herds

Information Request

Initial estimates of wolf populations in Nishi et al. (2020) were based on deterministic values for ungulate biomass calculated from average population estimates for the Bluenose East (BNE), Bathurst (BAH), and Beverly (BEV) caribou herds. Following a Science Technical Session on October 5th, 2020 of the Wolf (Dìga) Management Proceeding, the Wek'èezhìı Renewable Resources Board (WRRB) requested an update on precision for the ungulate biomass index (UBI) estimates in the draft technical report.

Here we outline additional steps taken to incorporate precision of available empirical data and derive stochastic estimates of wolf populations based on a regression between ungulate biomass and wolf density. Key results are provided in tables and figures.

Methods

Analyses were based on Monte Carlo bootstrap resampling methods (1000 iterations) using the @RISK software add-in (Palisade Corp., NY) to Microsoft Excel (Microsoft Corp, WA).

1. The two most recent population estimates and associated SEs from the three caribou herds (BNE, BAH, and BEV) were used as input values to approximate normal distributions. We compared those empirical caribou herd estimates from 2018 and 2015 (2011 for BEV) to define distributions of population rate of change (*r*)[*] for each herd, where:

   r = (Ln Population_{2018} Estimate - Ln Population_{2015} Estimate) / (2018-2015)

2. We applied the herd-specific stochastic estimates of *r* to respective empirical population survey estimates from 2018 to generate simulated 2020 population estimates, where:

   Simulated Caribou Population_{2020} Estimate = Empirical Caribou Population_{2018} Estimate * e^{r2}

3. To estimate caribou density, we divided simulated 2020 caribou population estimates by respective winter range areas (km^2), which were defined as 95% utilization distribution polygons for collared caribou in March 2020. Caribou population density was multiplied by a factor of 2 to estimate a caribou-based ungulate biomass density (*sensu* Keith 1983).
4. We derived an uncertainty term in Kuzyk and Hatter's (2014) regression equation based on the distribution of residuals, i.e., differences between observed and predicted estimates of wolf density.

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[*] The exponent (*r*) is the power to which e (the base of natural "Naperian" logs, taking the value of 2.71828) is raised such that $e^r = \lambda$; *r* is the annual exponential rate of increase; λ (lambda) is the annual finite rate of increase and is the ratio of numbers in two successive years. When λ is greater than 1 the population has increased between successive years, when less than 1 the population has declined. The exponential rate of increase (*r*) is a useful expression of population increase for three reasons: 1) *r* is centered at zero, hence a rate of increase measured as r has the same value as an equivalent rate of decrease, apart from reversal of sign; 2) *r* converts easily from one unit of time to another, i.e., when *r* per year equals x, *r* per day equals x / 365; and 3) doubling or halving time of a population can be easily calculated from *r* by 0.6931 / *r*. For example, 0.6931 / -0.29 equals a halving time of 2.4 years.

We tested residuals for normality and then fit a distribution to approximate an uncertainty term in the regression.

5. We generated estimates of wolf density within respective caribou winter range areas based on caribou-based ungulate biomass density (mean UBI $\pm$ SD) in Step 3 and the UBI regression equation from Step 4. We applied regression coefficients to ungulate biomass density and added the uncertainty term to derive stochastic estimates of wolf density. The wolf density estimates were multiplied by the area of the caribou distribution in March 2020 to derive wolf abundance with associated estimates of precision.

6. To consider the potential influence of moose on a UBI estimate of wolves, we multiplied observed moose density (0.049/km^2; 0.035 – 0.069/km^2 95% CI) from a winter 2016 survey (Cluff 2018) by a factor of 6 to estimate UBI ($\pm$ SD) from moose (*sensu* Keith 1983). We derived associated estimates of wolf density using the moose-based UBI and the UBI regression equation (with uncertainty) from Step 4. Wolf density estimates were applied to the areas of overlap between the March 2020 caribou distribution and the stratum from the 2016 moose survey to generate estimates of wolves from moose-based UBI.

<u>Results</u>

1. Table 1. summarizes values for BNE, BAH, and BEV caribou population estimates in 2018 and 2015 (2011 for BEV), that were based on survey reports.

2. Figure 1 compares the probability distributions for the simulated estimates of *r* for the caribou herds based on bootstrap resampling of respective population survey estimates. Table 2 summarizes estimates of *r* and the corresponding simulated population sizes for the caribou herds in 2020, which were 12,154, 4,567, and 95,458 for the BNE, BAH, and BEV herds respectively.

3. Figure 2 illustrates the relative frequency distributions of the empirical population surveys for the three herds and their respective simulated population estimates in 2020.

4. Figure 3 shows the data points used in the polynomial regression by Kuzyk and Hatter (2014), along with the pattern of residuals and a corresponding normal distribution fitted to those residuals to estimate uncertainty in the relationship between ungulate biomass and wolf density.

5. Table 3 summarizes derived UBI wolf population estimates (and 95% confidence intervals) that may be associated with each of the three caribou populations; these estimates utilize Monte Carlo bootstrap resampling to more directly incorporate a) precision of empirical caribou population estimates from two recent surveys, b) uncertainty in rates of change in caribou populations, c) variance associated with simulated population sizes of caribou in 2020, and d) uncertainty in the relationship between ungulate biomass density and wolf density.

6. Moose density within areas of overlap between a 2016 moose survey and the BNE and BAH winter range areas (Figure 4) resulted in mean estimates of 9-10 wolves (Table 4).

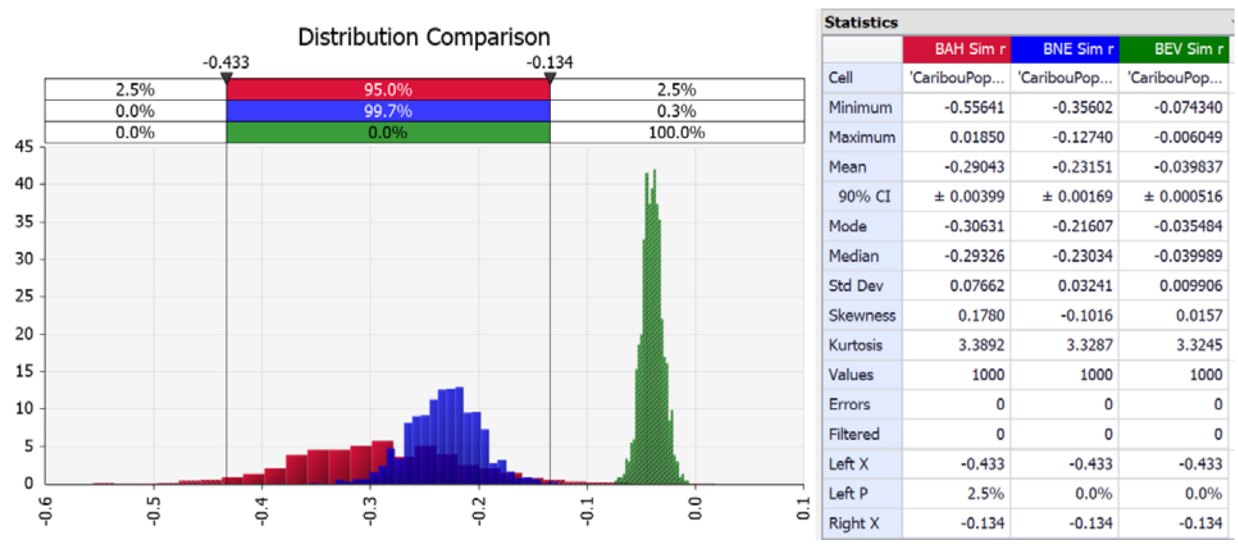
Table 1. Recent empirical estimates of caribou population that were used to estimate *r*

	2015 Population Estimate*				2018 Population Estimate*			
Herd	Herd Size	Standard Error	Lower 95% CI	Upper 95% CI	Herd Size	Standard Error	Lower 95% CI	Upper 95% CI
Bluenose East	38,592	2,233	33,859	43,325	19,294	1,475	16,527	22,524
Bathurst†	19,769	3,532	12,349	27,189	8,207	1,079	6,218	10,831
Beverly‡	136,608	6,603	124,102	150,373	103,372	5,109	93,684	114,061

*Adamczewski et al. 2019, Boulanger et al. 2016, 2017, and 2019, Campbell et al. 2012 and 2019

†Rate of change (*r*) between calving ground surveys also reflects movement of Bathurst cows (i.e., 3 of 11 collared females) to Beverly calving area in 2018 (Adamczewski et al. 2019)

‡First estimate shown for Beverly survey was from 2011 not 2015



	BAH Sim r	BNE Sim r	BEV Sim r
Cell	'CaribouPop...	'CaribouPop...	'CaribouPop...
Minimum	-0.55641	-0.35602	-0.074340
Maximum	0.01850	-0.12740	-0.006049
Mean	-0.29043	-0.23151	-0.039837
90% CI	± 0.00399	± 0.00169	± 0.000516
Mode	-0.30631	-0.21607	-0.035484
Median	-0.29326	-0.23034	-0.039989
Std Dev	0.07662	0.03241	0.009906
Skewness	0.1780	-0.1016	0.0157
Kurtosis	3.3892	3.3287	3.3245
Values	1000	1000	1000
Errors	0	0	0
Filtered	0	0	0
Left X	-0.433	-0.433	-0.433
Left P	2.5%	0.0%	0.0%
Right X	-0.134	-0.134	-0.134

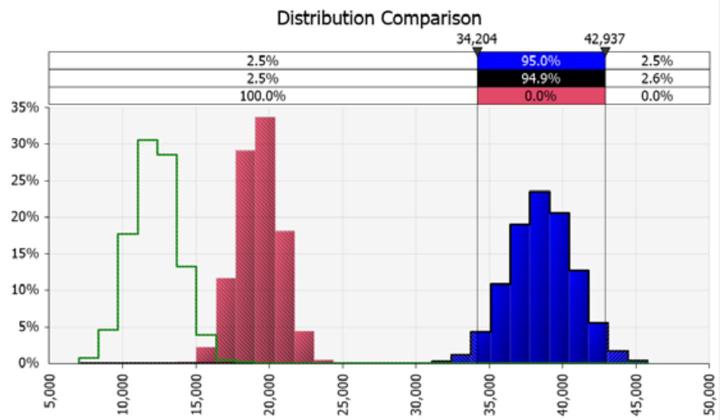
Figure 1. Probability density distributions of simulated estimates of r derived from comparing empirical estimates of caribou population sizes in 2018 and 2015 through bootstrap resampling (2011 for BEV); red is BAH (*r* = -0.290; SD = 0.077 SD), blue is BNE (*r* = -0.232; SD = 0.032 SD), green is BEV (*r* = -0.040; SD = 0.010 SD).

Table 2. Rates of change (*r*) derived from bootstrap resampling of recent surveys and used to simulate caribou population size in 2020.

	Rate of change *(r)* (2018 - 2015)			2020 Simulated Population Size			
Herd	*r*	Lower 95% CI	Upper 95% CI	2020	Lower 95% CI	Upper 95% CI	CV
Bluenose East	-0.231	-0.295	-0.165	12,154	9,244	15,723	0.14
Bathurst†	-0.293	-0.438	-0.133	4,567	2,681	7,362	0.25
Beverly‡	-0.040	-0.059	0.020	95,458	83,588	107,920	0.06

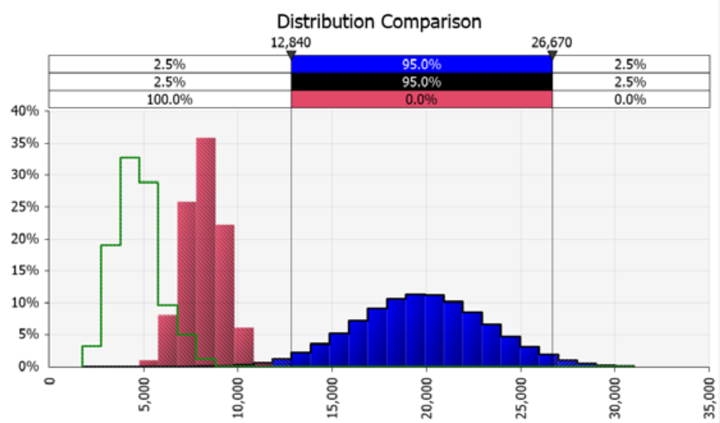
*Estimate for Beverly survey was from 2011 not 2015

a) BNE



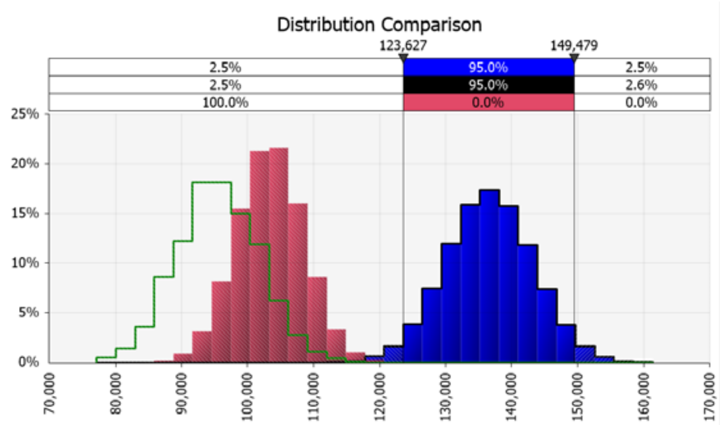
Statistics	BNE 2015	RiskNormal...	BNE 2018	BNE 2020
Cell	'CaribouPop...	'CaribouPop...	'CaribouPop...	'CaribouPop...
Minimum	31,497.78	−∞	14,523.30	6,999.62
Maximum	45,800.12	+∞	25,003.64	17,722.48
Mean	38,592.23	38,592.00	19,294.77	12,216.37
90% CI	± 116.16		± 76.92	± 84.15
Mode	38,563.59	38,592.00	19,311.79	11,294.80
Median	38,586.99	38,592.00	19,293.64	12,154.62
Std Dev	2,231.09	2,233.00	1,477.46	1,616.38
Skewness	0.0021	0.0000	0.0186	0.1181
Kurtosis	2.9602	3.0000	3.0526	3.0284
Values	1000		1000	1000
Errors	0		0	0
Filtered	0		0	0
Left X	34,204	34,204	34,204	34,204
Left P	2.5%	2.5%	100.0%	100.0%
Right X	42,937	42,937	42,937	42,937

b) BAH



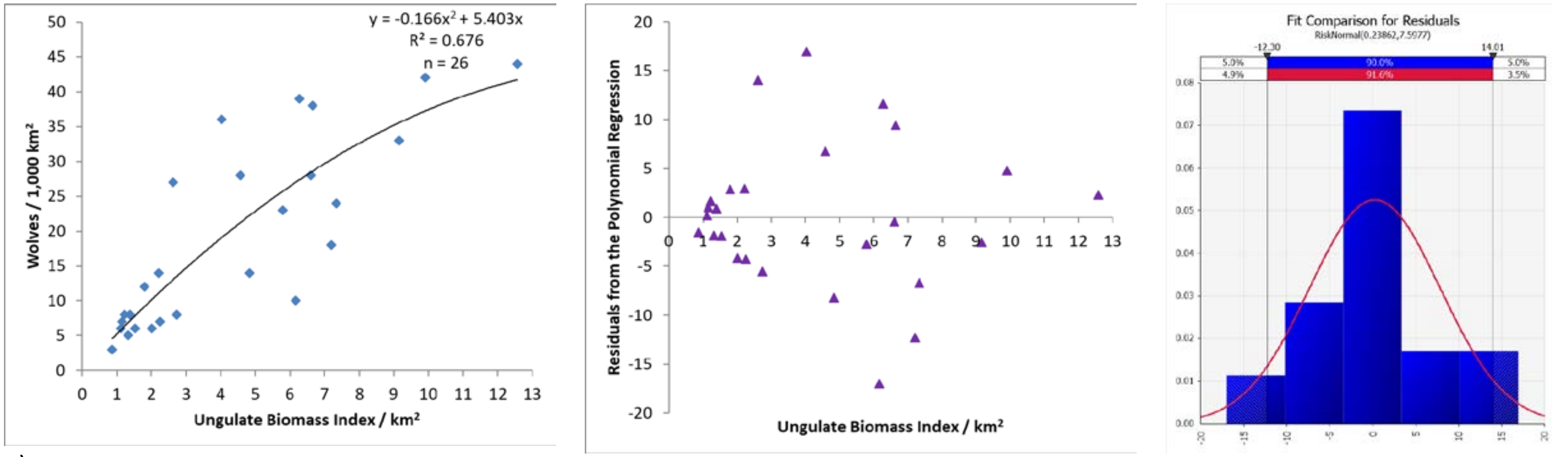
Statistics	BAH 2015	RiskNormal...	BAH 2018	BAH 2020
Cell	'CaribouPop...	'CaribouPop...	'CaribouPop...	'CaribouPop...
Minimum	8,687.98	−∞	4,665.43	1,730.46
Maximum	31,032.60	+∞	11,636.41	8,716.69
Mean	19,768.89	19,769.00	8,206.71	4,699.40
90% CI	± 183.81		± 56.18	± 61.86
Mode	19,901.87	19,769.00	8,274.82	4,796.25
Median	19,767.77	19,769.00	8,205.92	4,604.03
Std Dev	3,530.50	3,532.00	1,078.99	1,188.25
Skewness	-0.0015	0.0000	-0.0067	0.5307
Kurtosis	2.9641	3.0000	2.9806	3.3787
Values	1000		1000	1000
Errors	0		0	0
Filtered	0		0	0
Left X	12,840	12,840	12,840	12,840
Left P	2.5%	2.5%	100.0%	100.0%
Right X	26,670	26,670	26,670	26,670

c) BEV



Statistics	BEV 2011	RiskNormal...	BEV 2018	BEV 2020
Cell	'CaribouPop...	'CaribouPop...	'CaribouPop...	'CaribouPop...
Minimum	114,902.21	−∞	87,157.36	77,154.19
Maximum	161,320.12	+∞	119,816.21	114,942.00
Mean	136,611.04	136,608.00	103,373.25	95,543.47
90% CI	± 344.05		± 265.94	± 324.12
Mode	137,856.96	136,608.00	103,948.31	93,422.89
Median	136,603.24	136,608.00	103,369.98	95,420.21
Std Dev	6,608.38	6,603.00	5,108.00	6,225.49
Skewness	0.0154	0.0000	0.0060	0.0614
Kurtosis	3.0288	3.0000	2.9696	2.9490
Values	1000		1000	1000
Errors	0		0	0
Filtered	0		0	0
Left X	123,627	123,627	123,627	123,627
Left P	2.5%	2.5%	100.0%	100.0%
Right X	149,479	149,479	149,479	149,479

Figure 2. Relative frequency distributions from Monte Carlo bootstrap resampling (1000 iterations) of empirical caribou population estimates (blue is 2015 for BNE & BAH, 2011 for BEV; red is 2018) and simulated estimates in 2020 (green outline) that were derived from exponential rates (*r*) in Table 2.



a) b) c)

Figure 3. Relationships between wolf density and ungulate biomass density from Kuzyk and Hatter (2014) with a) empirical data and regression coefficients, b) residuals derived from differences between predicted and observed values of wolf density, and c) an uncertainty term for wolf density that was based on a normal distribution fitted to residuals (mean = 0.2386; SD = 7.598).

Table 3. Wolf population estimates (with lower and upper 95% confidence intervals) based on ungulate biomass index (UBI) from caribou derived from population survey estimates (2018) and projections (2020).

Population	**Bluenose East (BNE)**				**Bathurst (BAH)**				**Beverly (BEV)**			
Winter Range Area - March 2020 95% Utilization Distribution (km^2)	**37,244**				**24,754**				**153,944**			
Caribou Population Assumption	2018 Estimate		2020 Projection		2018 Estimate		2020 Projection		2018 Estimate		2020 Projection	
Species	Caribou	Wolves	Caribou	Wolves	Caribou	Wolves	Caribou	Wolves	Caribou	Wolves	Caribou	Wolves
Estimate	19,294	211	12,154	138	8,207	93	4,567	55	103,372	1,108	95,458	1,029
Lower 95% CI	16,527	193	12,053	120	6,218	81	4,493	43	93,684	1,035	95,070	956
Upper 95% CI	22,524	228	12,255	155	10,831	104	4,642	66	114,061	1,181	95,845	1,102
Density	0.5180	0.0057	0.3263	0.0037	0.3315	0.0037	0.1845	0.0022	0.6715	0.0072	0.6201	0.0067
UBI	1.0361		0.6526		0.6631		0.3690		1.3430		1.2402	
Removal (55%)		116		76		51		30				
Lower 95% CI		106		66		45		24				
Upper 95% CI		126		85		57		37				
Removal (60%)		126		83		56		33				
Lower 95% CI		116		72		49		26				
Upper 95% CI		137		93		63		40				
Removal (80%)		169		110		74		44				
Lower 95% CI		155		96		65		34				
Upper 95% CI		183		124		84		53				

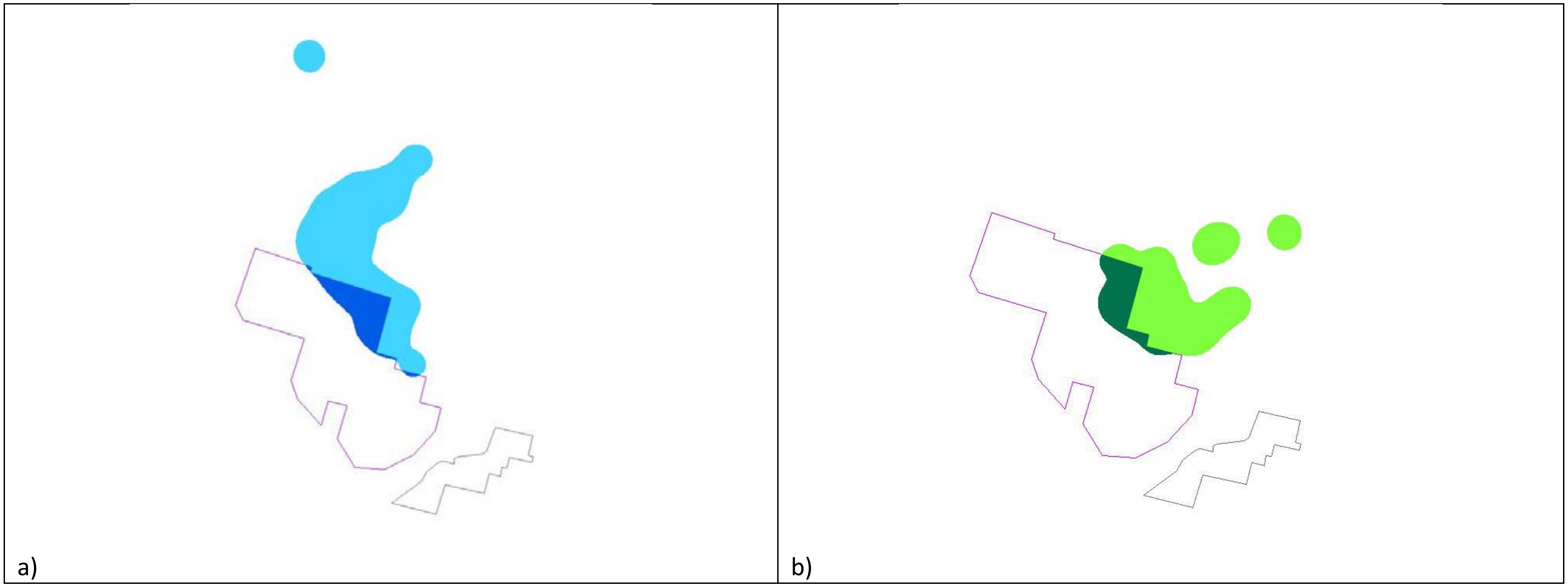


Figure 4. Area of overlap (dark shading) between 2016 moose survey stratum (outline with purple border), and March 2020 winter range areas (95% utilization distribution of collared caribou) of a) Bluenose-East (blue) and b) Bathurst (green) herds

Table 4. Estimate of wolves based on ungulate biomass index (UBI) of moose* in areas of caribou winter range.

	2016 Moose Survey (moose/km^2)	UBI moose	UBI Wolf density (wolf/km^2)	Caribou winter range overlap with 2016 moose survey area (km^2)	Caribou winter range overlap with 2016 moose survey area (%)	Moose estimate (within overlap area)	Lower 95% CI	Upper 95% CI	UBI Wolf estimate (within overlap area)	Lower 95% CI	Upper 95% CI
Bluenose-East				5,775	15.5%	283	208	358	10	8	13
	0.049	0.294	0.0018								
Bathurst				4,928	19.9%	241	165	318	9	7	11

* 2016 Moose Survey – North Slave Region, Environment and Natural Resources, GNWT (Cluff 2018).

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