Detecting Numerical Changes from Subsequent Aerial Surveys of Ungulates: Estimates of Breeding Females from Calving Ground Surveys

I designed this spreadsheet to understand the implications of survey precision on power to detect numerical changes in results from aerial surveys. The specific application of this spreadsheet was to compare data from subsequent estimates of breeding females from calving ground surveys of barren-ground caribou in the Bathurst herd.

Data Entry

The spreadsheet allows the user to derive an estimate of breeding females based on the estimate of 1+-yr-old caribou and the proportion of breeding females from composition surveys of strata on the calving ground. Data for the two subsequent calving ground surveys are entered in to separate tabs labelled "Survey 1" and "Survey 2" respectively. The green shading indicates cells that require data input for the respective surveys that the user is preparing to analyse. The pink shading indicates cells in which formulas have been entered to automate the calculations and do not require user entry. The spreadsheet has been preloaded with the most recent survey results of the Bathurst caribou herd in 2003 (Gunn et al. 2005) and 2006 (Nishi et al. 2007) respectively. The green shaded cells in the "Survey 1" and "Survey 2" tabs should be deleted prior to use of the spreadsheet.

The data required for a calving ground survey include the number of transects sampled within a stratum, as well as the respective population estimates (of 1+-yr-old caribou) and variances for each stratum (step 1). In order to estimate the number of breeding females (step 2), the user is required to enter the proportion of breeding females (and coefficient of variation - CV) from composition surveys of each of the strata. As these data are entered, the spreadsheet automatically calculates the estimate of breeding females for each statum and sums them to provide a total estimate. The variance, standard deviation, and CV for the estimate of breeding females is also calculated. The spreadsheet uses these data to calculate the degrees of freedom (step 3) that are associated with the survey.

For each of the survey tabs, the user can also convert the estimate of breeding females to a total population estimate (step 4). The dark green shading indicates the assumptions for adult sex ratio and pregnancy rates (with associated CV's) that have been used in this calculation.

Comparison and Power Analysis

The comparisons of the two surveys are based on t-test analyses and the formulas described by Gasaway et al. 1986 in Chapter 4 of their monograph on moose survey analyses; power analyses are also based upon Chapter 4.

The "Comparison" tab takes the user through 5 steps to compare the two surveys, and to evaluate the power of the test. Step 1, summarizes the degrees of freedom for each respective survey. Step 2 calculates the total degrees of freedom for the t-test. Step 3 requires that the user enter the estimate of breeding females and CV's for the respective calving ground surveys. By entering these data, the spreadsheet calculates the variance for the respective surveys. This step also requires the user to enter a percentage value (of the 1st survey) for the Consequential Difference of interest (CD) for subsequent power analyses (step 5).

Step 4 calculates the t-value and provides the critical values (at the appropriate degrees of freedom from the tab "t Distribution") at varying levels of alpha for two-tailed and one-tailed t-tests.

Step 5 allows the user to determine the power of the t-test if she rejected the null hypothesis in step 4 (above). The parameter that requires entry at this step is the t-value to the

Step 5 allows the user to determine the power of the t-test if she rejected the null hypothesis in step 4 (above). The parameter that requires entry at this step is the t-value to the corresponding value for alpha (Type I error rate). Since the parameters that are used to calculate the critical value for beta (Type II error rate) also include the CV's for the respective population surveys, and the Consequential Difference of interest (CD), the user can iteratively explore *post hoc* power analyses by changing those parameters singly or in combination. This exploratory analysis can also be used in an *a priori* fashion to consider the variance of a future survey may affect power to detect change in abundance of breeding females.

22 November 2007
J.S. Nishi

Updated on 17 February 2016: To compare estimates of Bluenose East breeding females in June 2013 and 2015, and to estimate minimum detectable change in breeding females in June 2018 - see Tabs labelled "Variance Next Survey" and "Variance Next Survey (2)"

References

Gasaway, W.C., S.D. DuBois, D.J. Reed, and S.J. Harbo. 1986. Estimating moose populations parameters from aerial surveys. Biological Papers of the University of Alaska Number 22, Institute of Arctic Biology.

Gunn, A., J. Nishi, J. Boulanger and J. Williams. 2005. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2003. Northwest Territories Department of Environment and Natural Resources Manuscript Report No. 164. 75 pp.

Nishi, J.S., B. Croft, J. Williams, J. Boulanger, and D. Johnson. 2007. An estimate of breeding females in the Bathurst herd of barren-ground caribou, June 2006. Northwest Territories Department of Environment and Natural Resources File Report No. 1XX. 85 pp.

TITLE FOR DATASET	Bluenose East Calving Ground Survey (June 2013)
Date: 16 Feb 2016	**Source:** Boulanger et al. 2014

1) Population Estimate

Stratum	# Transects	1+-Yr-Old Caribou Pop Est	Variance	SE	CV	Breeding Females Prop'n BF	CV Prop'n BF	Estimate	Variance	SE	CV
HD	38	40229	4693288.96	2166.4	0.05385	0.66072	0.027	26580	2563899.5	1601.2	0.06024
NW	11	4802	907256.25	952.5	0.19835	0.84824	0.032	4073	669770.5	818.4	0.20092
SW	18	5003	584613.16	764.6	0.15283	0.76336	0.056	3819	386404.9	621.6	0.16277
SE	15	4985	277202.25	526.5	0.10562			0	0.0	0.0	-
SR	12	5368	204304	452.0	0.08420			0	0.0	0.0	-
	.			0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-				0.0	0.0	-
SUM	94	60387	6666664.6	2581.99	0.043			34472	3620074.9	1902.65	0.055

2) Estimate of Breeding Females

Estimate	**34472**
Variance	3620074.9
SE	**1902.6**
CV	**0.0552**

Note: Any differences in data shown in this spreadsheet tab and summary tables in the Reference are due to rounding differences between co-efficients provided in the Reference tables and actual values tracked in data analyses

3) Degrees of Freedom (df) for the estimate of Breeding Females in a survey (Gasaway et al. 1986, Section 3.7.2.3; pg 39)

#VALUE!

4) Total Population Estimate*

Estimate	**68295**
Variance	61619825.4
SE	**7849.8**
CV	**0.1149**

*Assumptions (Boulanger et al. 2014, Table 12. 3004 females : 1281 males; 0.72 pregnant)

	Proportions	Females	Males	CV	Var	SD
Female to male ratio	0.701	3004	1281	0.013		
Pregnancy rate	0.720			0.1		

5) Reference and Data Tables

Boulanger, J., B. Croft, and J. Z. Adamczewski. 2014. An estimate of breeding females and analyses of demographics for the Bluenose-East herd of barren-ground caribou: 2013 calving ground photographic survey. File Report No. 143, Environment and Natural Resources, Government of Northwest Territories, Yellowknife.

Table 6: Final dimensions of strata for the Bluenose-East 2013 survey. The number of lines total for the HD stratum assumed the photo-plane was flying with a strip width of 1.11 km. Visual transects were flown for the other strata with a strip width of 0.8 km.

Stratum	Total transects possible	Sampled Transects	Area of stratum (km²)	Transect area (km²)	Coverage
HD	100	38	4,502.4	1,703.6	37.8%
NW	73	11	2,490.7	378.2	15.2%
SW	63	18	2,503.5	684.1	27.3%
SE	102	15	3,717.8	545.1	14.7%
SR	147	12	7,364.6	554.7	8.0%

Table 8: Estimates of caribou at least one year old on the calving ground based upon raw counts, double observer estimates, and caribou counted on the photos (in the HD stratum).

Stratum				Caribou Counted		Estimates			
Name	Transects	Transect Area	Coverage	Counted	Estimated (photo)	Density	$\widehat{N}$	SE($\widehat{N}$)	CV
HD	38	1,521.0	33.8%	2,873	2884.7 (10,705)[A]	8.93	40,229	2,166.4	5.4%
NW	11	378.2	15.2%	718	729.2	1.93	4,802	952.5	19.8%
SW	18	684.1	27.3%	1,340	1366.9	2.00	5,003	764.6	15.3%
SE	15	545.1	14.7%	543	787.1	1.44	4,985	526.5	9.8%
SR	12	554.7	7.6%	377	377.0	0.68	5,368	452.0	9.1%
						Total	60,387	2166.4	4.2%

[A]For the HD stratum, 10,705 caribou were counted on photos and 2,884.7 caribou were estimated from visual counts for a total count of 13,589.7 caribou on transect.

Table 12: Summary statistics for fall composition surveys conducted in 2009 and 2013.

Statistic	Year	
	2009	2013
Number of groups	79	117
Mean group size	43.38	36.73
Total caribou	4,531	5,381
Total adults (1.5+ year old)	3,427	4,297
Total cows	2,399	3,004
Total bulls	1,028	1,281
Total yearlings	0	12
Total calves	1,104	1,084

Table 13: Proportion of cows and bull-cow ratios from the 2009 and 2013 composition surveys. The proportion is based upon the total adults counted (excluding calves of the year) as listed in Table 11. Percentile-based confidence limits are shown (CI).

Year	Proportion of Cows	SE	CI		Bull-Cow Ratio	SE	CI	
2009	0.7000	0.008	0.684	0.716	0.429	0.017	0.396	0.463
2013	0.70105	0.009	0.685	0.720	0.426	0.019	0.389	0.461

Table 14: Extrapolated estimate of total herd size for 2012 using breeding female estimates (Table 10) and estimates of proportion of adult females in the entire herd from 2012 fall composition surveys (Table 12).

Survey data	Estimate	SE	CV	CI	
Number of caribou on the breeding ground	60,387	2,555.5	4.2%	54,512	66,262
Number of breeding females	34,472.4	1,898.1	5.5%	30,109	38,836
Proportion adult females in the entire herd	0.70105	0.0091	1.3%		
Proportion 1.5+ year females pregnant	0.72		10.0%		
Total population estimate (1.5+ year old caribou)	68,295	7,847.1	11.5%	50,254	86,336

Table 10: Estimates of proportion breeding females, SE, 95% confidence intervals (CI), and coefficient of variation (CV) in the Low and High strata.

Stratum	Proportion Breeding Females				
	Proportion	SE	Confidence Limits		CV
HD	0.66072	0.018	0.632	0.695	2.7%
NW	0.84824	0.027	0.781	0.891	3.2%
SR	0				
SE	0				
SW	0.76336	0.043	0.680	0.835	5.6%

Table 11: Estimates of breeding females based upon estimates of caribou in each stratum and composition surveys.

Stratum	Total 1^+ year caribou			Proportion of breeding females			Estimated breeding females		
	$\tilde{N}$	SE	CV	Proportion	SE	CV	$\tilde{N}_{breedf}$	SE	CV
HD	40,228.7	2,166.4	5.4%	0.66072	0.018	2.7%	26,579.9	1,595.3	6.0%
NW	4,802.3	952.5	19.8%	0.84824	0.027	3.2%	4,073.5	818.50	20.1%
SW	5,002.9	764.6	15.3%	0.76336	0.043	5.6%	3,819.0	622.05	16.3%
SR	5,368.5	526.5	9.8%	0.000			0.0		
SE	4,984.9	452.0	9.1%	0.000			0.0		
Total	60,387	2,555.5	4.2%				34,472.4	1,897.88	5.5%

TITLE FOR DATASET	Bluenose East Calving Ground Survey (June 2015)
Date: 16 Feb 2016	**Source:** Boulanger 2015

1) Population Estimate

		1+-Yr-Old Caribou				Breeding Females					
Stratum	**# Transects**	**Pop Est**	**Variance**	**SE**	**CV**	**Prop'n BF**	**CV Prop'n BF**	**Estimate**	**Variance**	**SE**	**CV**
Photo	25	18164.9	668796.8	817.8	0.045	0.657	0.041	11934	528107.7	726.7	0.061
North	10	2481.9	505378.8	710.9	0.286	0.833	0.047	2067	360118.6	600.1	0.290
Central	33	11098.6	1704330.3	1305.5	0.118	0.273	0.095	3030	209875.2	458.1	0.151
East	14	6295.4	1652253.2	1285.4	0.204	0.058	0.776	365	85841.6	293.0	0.802
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-			0	0.0	0.0	-
				0.0	-				0.0	0.0	-
SUM	82	38040.8	4530759.06	2128.6	0.056			17397	1183943.1	1088.1	0.063

2) Estimate of Breeding Females

Estimate	**17397**
Variance	1183943.1
SE	**1088.1**
CV	**0.0625**

Note: Any differences in data shown in this spreadsheet tab and summary tables in the Reference are due to rounding differences between co-efficients provided in the Reference tables and actual values tracked in data analyses

3) Degrees of Freedom (df) for the estimate of Breeding Females in a survey (Gasaway et al. 1986, Section 3.7.2.3; pg 39)

50.11

4) Total Population Estimate*

Estimate	**33804**
Variance	16228024.6
SE	**4028.4**
CV	**0.1192**

*Assumptions (Boulanger 2015, Table 3. 2,774 females : 1,107 males; 0.72 pregnant)

	Proportions	Females	Males	CV
Female to male ratio	0.715	2774	1107	0.017
Pregnancy rate	0.720			0.10

*Assumptions (100 females : 66 males; 0.72 pregnant)

	Proportions	Females	Males	CV
Female to male	0.603	100	65.9	0.10
Pregnancy rate	0.720			0.10

5) Reference and Data Tables

Boulanger, J. 2015. Estimates of breeding females from the 2015 Bluenose East calving ground survey - Draft Novembe 4, 2015. Integrated Ecological Research, Nelson, BC.

Table 2: Estimates of total caribou on the calving ground, proportions of breeding females (from composition surveys) and the resulting estimates of breeding females.

Strata	Caribou	Total caribou on calving ground				Proportion Breeding Females			Breeding Females		
	Counted	Density	N	SE(N)	CV	Proportion	SE	CV	N	SE(N)	CV
Photo	10,068	6.77	18,164.9	817.8	4.5%	0.657	0.027	4.1%	11,934	727.5	6.1%
North	496	1.31	2,481.9	710.9	28.6%	0.833	0.039	4.7%	2,067	599.9	29.0%
Central	2,120	2.42	11,098.6	1305.5	11.8%	0.273	0.026	9.5%	3,030	458.6	15.1%
East	699	1.83	6,295.4	1285.4	20.4%	0.058	0.045	77.6%	365	292.8	80.2%
Total			38,040.8	2128.6	5.6%				17,396	1088.6	6.3%

Table 3: Estimates of the proportion of cows and bull cow ratio for the Bluenose East caribou herd from fall composition surveys.

Year	Proportion of Cows	SE	Confidence Limit		Bull-Cow Ratio	SE	Confidence Limit	
2009	0.700	0.008	0.684	0.716	0.429	0.017	0.396	0.463
2013	0.701	0.009	0.685	0.720	0.426	0.019	0.389	0.461
2015	0.706	0.014	0.678	0.734	0.417	0.029	0.367	0.479

Detecting Numerical Changes and Estimating Rates of Change in Numbers of Breeding Females from Calving Ground Surveys of Barren-ground Caribou

1) Degrees of Freedom (df) for respective calving ground surveys of Breeding Females (Section 3.7.2.3; pg 39)

	Survey 1 (T1)		Transects		Survey 2 (T2)		Transects
Estimate	34472			**Estimate**	17397		
VAR Stratum 1	2563899.5		38	**VAR Stratum 1**	528107.7		25
VAR Stratum 2	669770.5		11	**VAR Stratum 2**	360118.6		10
VAR Stratum 3	386404.9		18	**VAR Stratum 3**	209875.2		33
VAR Stratum 4	0.0		15	**VAR Stratum 4**	85841.6		14
VAR Stratum 5	0.0		12	**VAR Stratum 5**			
VAR Stratum 6				**VAR Stratum 6**			
VAR Stratum 7				**VAR Stratum 7**			
VAR Stratum 8				**VAR Stratum 8**			
VAR Stratum 9				**VAR Stratum 9**			
VAR Stratum 10				**VAR Stratum 10**			
VAR Sum	3620074.9	Sum	94	**VAR sum**	1183943	Sum	82
SE	1903			**SE**	1088		
df (vo1)	57			df (vo2)	50		

2) Total Degrees of Freedom (df) for a t-test on estimates of Breeding Females from two calving ground surveys (Section 4.2.1.2.; pg 62)

df (vt)	89.0

3) Comparison of breeding females from calving ground surveys

Bluenose East 2013 Survey 1 (T1)				Bluenose East 2015 Survey 2 (T2)			
T1	Var(T1)	CV(T1)	CD (% of T1)	T2	Var(T2)	CV(T2)	
34472	3620075	***0.0552***	***30%***	**17397**	1183943	***0.0625***	
10.4			10342	9.8			-0.342

4) Critical Values Student t-test with 89 degrees of freedom

ALPHA α (2-tailed)

t_{Calc}	tcrit(0.20)	tcrit(0.10)	tcrit(0.05)	tcrit(0.02)	tcrit(0.01)
7.791	1.296	1.671	2.000	2.390	2.660

Reject Ho (there is no statistical difference between Survey 1 and Survey 2,
if |tcalc| > tcrit at the alpha level of probability.

ALPHA α (1-tailed)

tcrit(0.20)	tcrit(0.10)	tcrit(0.05)	tcrit(0.025)	tcrit(0.01)
0.848	1.296	1.671	2.000	2.390

α - the acceptable probability of error (from a practical point of view) if you were to conclude that a change in numbers had occurred when in fact it had not changed, i.e., a Type I error

β - The acceptable probability of error (from a practical point of view) if you were to conclude that no change in numbers larger than CD had occurred when in fact it had changed, i.e., a Type II error

CD - The consequential difference of interest, i.e., the minimum change in population size that would probably cause some change in management strategy.

5) Power of t-test

Set Alpha **_1.684_**
(use 1-tailed values from step 4 above)

Critical values of "to" to achieve Power at *89.0* degrees of freedom

Power	60%	70%	80%	85%	90%	95%
βo	0.40	0.30	0.20	0.15	0.10	0.05
t_{oCalc}						
3.034	0.254	0.527	0.848	1.046	1.296	1.671

If you do not reject Ho, the power analysis will help you determine if Ho can be accepted with a tolerable probability of error, β.

Compare "*toCalc"* with the row of t-values to find where it fits between the critical *"to"* values and visually interpolate to find the probability (βo) of *to*.

The value, 1-βo (power), is the probability that a difference of size CD could have been detected, if that difference existed. If βo is equal to or less than β, compared (Power (1-β) is the probability that a difference of size CD could have been detected, if that difference existed. If βo is equal to or less than β, conclude (with probability of error β) that no change as large as CD occurred. If βo is greater than β, then the results are inconclusive with respect to your established criteria of CD, α, and β.

Refer to formulas and methods described by Gasaway et al. 1986. Section 4.2.2.1 Estimating required precision of second estimate when first survey is completed

$$V(\hat{T}_2) = \frac{CD^2}{(t_{\alpha,\nu} + t_{\beta,\nu})^2} - V(\hat{T}_1).$$

1) Estimate of Breeding Females (BNE June 2015)

Estimate	**17,397**
Variance	1,183,943
SE	1,088
CV	0.0625
df	50
Alpha (t)	1.303
Beta (t)	0.851

Average Annual Rate of Increase	Expected Change in Population after 3 years (Consequential Difference as %)	Consequential Difference (CD) as reduction from initial population	**Variance of 2nd Survey**	2nd Survey Estimate	2nd Survey Standard Deviation (SD)	2nd Survey Coefficient of Variation (CV)
-0.010	3%	514	**(1,126,967)**	16,883	#NUM!	#NUM!
-0.020	6%	1,013	**(962,724)**	16,384	#NUM!	#NUM!
-0.030	9%	1,497	**(700,729)**	15,899	#NUM!	#NUM!
-0.040	11%	1,967	**(349,847)**	15,430	#NUM!	#NUM!
-0.050	14%	2,423	**81,669**	14,974	286	0.019
-0.060	16%	2,866	**586,134**	14,531	766	0.053
-0.070	19%	3,295	**1,156,404**	14,102	1,075	0.076
-0.080	21%	3,712	**1,785,831**	13,685	1,336	0.098
-0.090	24%	4,116	**2,468,242**	13,280	1,571	0.118
-0.100	26%	4,509	**3,197,901**	12,888	1,788	0.139
-0.110	28%	4,890	**3,969,486**	12,507	1,992	0.159
-0.120	30%	5,259	**4,778,061**	12,137	2,186	0.180
-0.130	32%	5,618	**5,619,051**	11,779	2,370	0.201
-0.140	34%	5,966	**6,488,217**	11,431	2,547	0.223
-0.150	36%	6,304	**7,381,639**	11,093	2,717	0.245
-0.160	38%	6,632	**8,295,692**	10,765	2,880	0.268
-0.170	40%	6,950	**9,227,026**	10,447	3,038	0.291
-0.180	42%	7,259	**10,172,552**	10,138	3,189	0.315
-0.190	43%	7,558	**11,129,420**	9,838	3,336	0.339
-0.200	45%	7,849	**12,095,008**	9,548	3,478	0.364
-0.210	47%	8,131	**13,066,903**	9,265	3,615	0.390
-0.220	48%	8,405	**14,042,889**	8,992	3,747	0.417
-0.230	50%	8,671	**15,020,935**	8,726	3,876	0.444
-0.240	51%	8,929	**15,999,180**	8,468	4,000	0.472
-0.250	53%	9,179	**16,975,922**	8,218	4,120	0.501

Question: Assuming Type I error rates of 0.10 and 0.05, and a Type II error rate of 0.20, what would be an expected rate of decline in abundance of breeding females that could be

A survey result of 14,974 ± 286 (CV=0.02) breeding females would be detected as a significant reduction (at p = 0.10) relative to the 2015 estimate. The result would represent a decline of 14% (*r* = -0.05; or 2,423 animals) relative to the 2015 estimate. (Power assumed to be 80%)

A survey result of 14,531 ± 3073 (CV = 0.02) breeding females would be detected as a significant reduction (at p = 0.05) relative to the 2015 estimate. The result would represent a decline of 20% (*r* = -0.06; or 3,505 animals) relative to the 2015 estimate. (Power assumed to be 80%)

2) Type I Error: Critical Values Student t-test with 50 degrees of freedom

	ALPHA α (2-tailed)				
t_{calc}	tcrit(0.20)	tcrit(0.10)	tcrit(0.05)	tcrit(0.02)	tcrit(0.01)
	1.303	1.684	2.021	2.423	2.704

ALPHA α (1-tailed)				
tcrit(0.20)	tcrit(0.10)	tcrit(0.05)	tcrit(0.025)	tcrit(0.01)
0.851	1.303	1.684	2.021	2.423

3) Type II Error: Critical Values

Critical values of "to" to achieve Power at 50 degrees of freedom

Power	60%	70%	75%	80%	85%	90%	95%
βo	0.40	0.30	0.25	0.20	0.15	0.10	0.05
t_{ocalc}	0.255	0.529	0.681	0.851	1.050	1.303	1.684

Refer to formulas and methods described by Gasaway et al. 1986. Section 4.2.1.4 One tailed t-test
- What is the detectable difference from a survey if a future survey has an assumed precision (that is used to estimate its variance)?

The test statistic is calculated as

$$t' = \frac{\hat{T}_2 - \hat{T}_1}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}.$$

1) Estimate of Breeding Females (June 2015)

Estimate	**17,397**
Variance	1,183,943
SE	1,088
CV	0.0625
df	50
df (Second Survey)	**50**

Question: If the next survey in 3 years (June 2018) had a CV of 0.10, what would be the decline (1-tailed test) in number of breeding females that the survey would be able to detect?

Average Annual Rate of Increase	Expected Change (decline) in Population after 3 years (%)	Reduction from initial Population	Variance of 2nd Survey	2nd Survey Estimate	2nd Survey Standard Deviation (SD)	2nd Survey Coefficient of Variation (CV=0.10)	t_{calc}	ALPHA α (1-tailed): tcrit(0.25)	tcrit(0.20)	tcrit(0.10)	tcrit(0.05)	tcrit(0.025)	tcrit(0.01)
-0.010	3%	514	2,850,242	16,883	1,688	0.100							
-0.020	6%	1,013	2,684,257	16,384	1,638	0.100							
-0.030	9%	1,497	2,527,938	15,899	1,590	0.100							
-0.040	11%	1,967	2,380,722	15,430	1,543	0.100	**1.042**	0.681	0.851	1.303	1.684	2.021	2.423
-0.050	14%	2,423	2,242,080	14,974	1,497	0.100	**1.309**	0.681	0.851	1.303	1.684	2.021	2.423
-0.060	16%	2,866	2,111,511	14,531	1,453	0.100	**1.579**	0.681	0.851	1.303	1.684	2.021	2.423
-0.070	19%	3,295	1,988,546	14,102	1,410	0.100	**1.850**	0.681	0.851	1.303	1.684	2.021	2.423
-0.080	21%	3,712	1,872,742	13,685	1,368	0.100							
-0.090	24%	4,116	1,763,682	13,280	1,328	0.100							
-0.100	26%	4,509	1,660,973	12,888	1,289	0.100							
-0.110	28%	4,890	1,564,246	12,507	1,251	0.100							
-0.120	30%	5,259	1,473,151	12,137	1,214	0.100	**3.227**	0.681	0.851	1.303	1.684	2.021	2.423
-0.130	32%	5,618	1,387,362	11,779	1,178	0.100	**3.504**	0.681	0.851	1.303	1.684	2.021	2.423
-0.140	34%	5,966	1,306,568	11,431	1,143	0.100	**3.781**	0.681	0.851	1.303	1.684	2.021	2.423
-0.150	36%	6,304	1,230,479	11,093	1,109	0.100	**4.057**	0.681	0.851	1.303	1.684	2.021	2.423
-0.160	38%	6,632	1,158,822	10,765	1,076	0.100	**4.333**	0.681	0.851	1.303	1.684	2.021	2.423
-0.170	40%	6,950	1,091,337	10,447	1,045	0.100	**4.608**	0.681	0.851	1.303	1.684	2.021	2.423
-0.180	42%	7,259	1,027,783	10,138	1,014	0.100	**4.881**	0.681	0.851	1.303	1.684	2.021	2.423
-0.190	43%	7,558	967,929	9,838	984	0.100	**5.153**	0.681	0.851	1.303	1.684	2.021	2.423
-0.200	45%	7,849	911,562	9,548	955	0.100	**5.422**	0.681	0.851	1.303	1.684	2.021	2.423
-0.210	47%	8,131	858,476	9,265	927	0.100	**5.690**	0.681	0.851	1.303	1.684	2.021	2.423
-0.220	48%	8,405	808,483	8,992	899	0.100	**5.955**	0.681	0.851	1.303	1.684	2.021	2.423
-0.230	50%	8,671	761,400	8,726	873	0.100	**6.217**	0.681	0.851	1.303	1.684	2.021	2.423
-0.240	51%	8,929	717,060	8,468	847	0.100	**6.476**	0.681	0.851	1.303	1.684	2.021	2.423
-0.250	53%	9,179	675,301	8,218	822	0.100	**6.732**	0.681	0.851	1.303	1.684	2.021	2.423

A survey result of 14,974 ± 1,497 breeding females would be detected as a significant reduction (at $p < 0.10$) relative to the 2015 estimate. The result would represent a

A survey result of 14,102 ± 1,410 breeding females would be detected as a significant reduction (at $p < 0.05$) relative to the 2015 estimate. The result would represent a

The number of independent pieces of information that go into the estimate of a parameter are called the **degrees of freedom**. In general, the degrees of freedom of an estimate of a parameter are equal to the number of independent scores that go into the estimate minus the number of parameters used as intermediate steps in the estimation of the parameter itself (i.e. the sample variance has N-1 degrees of freedom, since it is computed from N random scores minus the only 1 parameter estimated as intermediate step, which is the sample mean).

https://en.wikipedia.org/wiki/Degrees_of_freedom_(statistics)#cite_note-1

CRITICAL VALUES OF Student's t- Distribution For Type I (α) and Type II (β) error

α probability (2 tailed):		0.80	0.60	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01
α and β probability (1 tailed)	***v***	**0.40**	**0.30**	**0.25**	**0.20**	**0.15**	**0.10**	***0.05***	**0.025**	**0.01**	**0.005**
	1	0.325	0.727	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657
	2	0.289	0.617	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925
	3	0.277	0.584	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841
	4	0.271	0.569	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604
	5	0.267	0.559	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032
	6	0.265	0.553	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707
	7	0.263	0.549	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499
	8	0.262	0.546	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355
	9	0.261	0.543	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250
	10	0.260	0.542	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169
	11	0.260	0.540	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106
	12	0.259	0.539	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055
	13	0.259	0.538	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012
	14	0.258	0.537	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977
	15	0.258	0.536	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947
	16	0.258	0.535	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921
	17	0.257	0.534	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898
	18	0.257	0.534	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878
	19	0.257	0.533	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861
	20	0.257	0.533	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845
	21	0.257	0.532	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831
	22	0.256	0.532	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819
	23	0.256	0.532	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807
	24	0.256	0.531	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797
	25	0.256	0.531	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787
	26	0.256	0.531	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779
	27	0.256	0.531	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771
	28	0.256	0.530	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763
	29	0.256	0.530	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756
	30	0.256	0.530	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750
	40	0.255	0.529	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704
	60	0.254	0.527	0.679	0.848	1.046	1.296	1.671	2.000	2.390	2.660
	120	0.254	0.526	0.677	0.845	1.041	1.289	1.658	1.980	2.358	2.617
	∞	0.253	0.524	0.675	0.842	1.036	1.282	1.645	1.960	2.326	2.576

This table of critical values for Student's *t*-distribution was created from Table 14 in Gasaway et al. 1986. p. 62, and Table B.3 in Zar 1984, p. 484

Comment:
"Critical t-values for Type II error (β) and figuring the power of a test are always taken from [the 1-tailed values for α and β] Table 14, whether the test is one- or two-tailed."

#NAME?