Distribution and Abundance of Muskoxen on Southeastern Victoria Island, Nunavut

1988-1999

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ABSTRACT

To determine the trend in muskox (*Ovibos moschatus)* numbers on southeastern Victoria Island, Nunavut, we conducted systematic strip transect surveys in March 1988, 1993, and 1999. In 1988 we estimated 12,372 ± 1,064 (SE) muskoxen over an area of 44,390 kilometres^2 (km^2). In 1993 and 1999 we used the same methods as in 1988 and estimated 12,563 ± 1,254, and 18,290 ± 1,100 muskoxen, respectively, over a slightly smaller section (~39,100 km^2) of the same area. The 1988 estimate was a significant increase from the previous estimate of 3,300 ± 345 SE in 1983. Between 1988 and 1993 muskox density in our study area did not change significantly, but the increase between 1993 and 1999 (32%) was significant. All three surveys were precise, but a double-counting trial in 1993 suggested that the observers may have failed to detect 12-16% of the muskox herds at a survey altitude of 300 m above the ground and within a three km transect width. In this report we present information on calf production and harvest, but the information is insufficient to interpret the trend in muskox numbers. The survey areas are not population boundaries and muskox re-distribution is a plausible explanation for at least part of the trend in muskox numbers on southeast Victoria Island between 1988 and 1993. We believe that the increase between 1993 and 1999 resulted primarily from a demographic increase in numbers, rather than from shifts in distribution. Since November 1993, commercial harvesting of muskoxen near the center of our survey area may have reduced the abundance in a 5,500 km^2 area surrounding the harvest site. Although pregnancy rates may be low, muskox density in MX11 (South-Eastern Victoria Island) is high enough to easily sustain present levels of harvest.

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INTRODUCTION

Hunters reported increasing muskox (*Ovibos moschatus*) numbers on southeast Victoria Island (Figure 1) in the late 1970s and early 1980s. In March 1983, Jingfors carried out the first systematic aerial survey and estimated 3,300 ± 345 Standard Error (SE) muskoxen (Jingfors 1984). His survey report and the Kitikmeot Region muskox management strategy (unpublished) recommended that subsequent surveys be scheduled at approximately five-year intervals to track muskox numbers. Those recommendations, along with the establishment of a commercial harvest in 1993 and the resultant involvement of Cambridge Bay hunters in a local meat plant, lead to systematic aerial surveys in 1988, 1993, and 1999. Our objective for these surveys was to determine if the muskox numbers or distribution from the 1983 surveyed area had changed significantly over time.

The surveys were designed to track the trend in muskox numbers to help determine the appropriate levels of harvesting. Thus, the subsequent surveys were designed and timed to be comparable to the initial 1983 survey. The design of the 1983 survey provided an estimate with high precision, partly through increasing coverage of the survey area using wide transects. The observers each scanned a 1.5 km strip at an altitude of 300 m above ground level (agl). However, Caughley noted in his 1977 publication that a search area this large probably reduces accuracy. At that altitude, the muskoxen look small and detecting them can be compromised by fatigue and boredom. When herds of muskoxen are seen, counting them can be difficult as herds are at their seasonal largest in the winter (Heard 1992) and clumping may be additionally exaggerated as a response to the aircraft (Miller and Gunn 1980). During the 1993 survey, we undertook a small experimental survey whereby we used double counting to estimate inaccuracy in detecting and counting muskoxen.

The 1988, 1993, and 1999 surveys results have been reported to the local and regional hunters and trappers associations, which resulted in harvest quota changes. However, no written reports have been compiled until now. This report also includes previously unpublished information on muskox sex and age composition collected on Victoria Island between 1984 - 1988.

METHODS

MARCH 1988 SURVEY

In an effort to maximize the available flying time for the actual survey (i.e. to increase coverage), the systematic aerial survey was not preceded by an aerial reconnaissance flight. In anticipation of local muskox density differences, we divided the 1983 survey area into five strata to reduce the length of transects. As we did not know what those differences might be, we applied the same coverage to each stratum. We flew strip transects 9.6 km apart to achieve 30% coverage. Most transects were oriented north-south to be perpendicular to the long axis of the coastline and major rivers. We placed the first transect randomly along a line of latitude and evenly spaced the other lines.

We flew the survey in a Helio-Courier on skis. The survey crew consisted of a right and left observer, both seated in the rear, and the pilot who navigated and plotted observation numbers on 1:250,000 scale topographic maps. The left observer recorded the sightings for both observers by location number. Strata boundaries, transect lines and muskox observations were later digitized and imported into a Geographic Information System (GIS; *SPANS EXPLORER 7.1*) for analysis. A cord was stretched from an eye bolt on each wing to the fuselage (the Helio-Courier does not have wing struts) and red tape on the cords marked the boundaries for the inside and outside of the transect (Norton-Griffiths 1978). The transect width was 1.5 km on both sides of the aircraft. We checked the markers by flying at a survey altitude over the lights and runway end markers on the Cambridge Bay airstrip. The aircraft altitude was 300 m agl when flying along transects. The desired airspeed was 160 km/hr; however we could not always maintain that speed when traveling into the wind. We did not attempt to count calves (10-11 months-old) separately, as the herds were often large and huddled together, which obscured the smaller-bodied calves.

MARCH 1993 SURVEY

To increase the comparability of the surveys, we used the 1983 survey techniques (timing, altitude 300 m agl, 3 km strip width, speed 160 km/hr and same aircraft). We reduced coverage to approximately 20% and applied similar coverage to each stratum (Figure 1). We split Stratum VI near Cambridge Bay (Figure 1) to examine the effect of the no-hunting area around the community. We dropped stratum VIII as it was covered in the northeast Victoria Island survey (Gunn and Lee 2000). Dropping this stratum resulted in a 12% reduction in the total area surveyed relative to the 1988 survey.

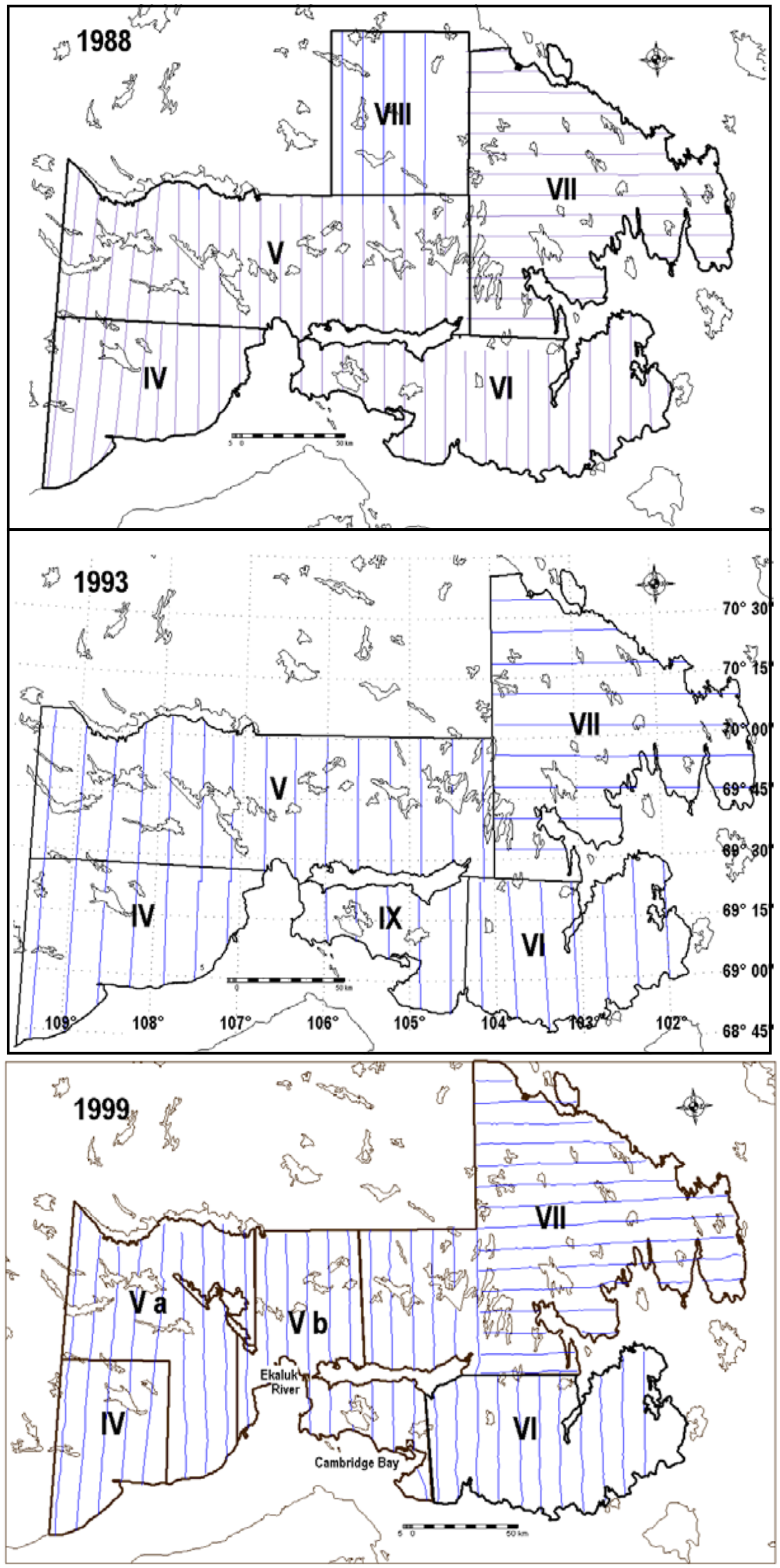

Figure 1: Study area and strata used to estimate muskoxen abundance on southeastern Victoria Island, March 1988, 1993 and 1999.

MARCH 1999 SURVEY

We repeated most of the techniques used during the previous surveys (timing, altitude 300 m agl, 3 km strip width, speed 160 km/hr and same aircraft). However, we used a third passenger in the front of the aircraft to serve as navigator and recorder. During this survey, our transect flight course and all muskox observations were marked and stored in a Garmin GPS 12XL, to facilitate GIS analysis.

A preliminary assessment of the previous two surveys suggested that we were unlikely to detect significant area-specific differences in muskox density using the stratification scheme employed in previous surveys (Figure 1). Nonetheless, real differences in muskox density likely exist among different areas of MX11. Between November 1993 and 1999, 1769 muskoxen were harvested at Ekaluk River (Figure 1) during the ten commercial harvests conducted in March and/or November of each year. These commercial hunts account for approximately 80% of the total muskox harvest in MX11. As this harvest is concentrated in a relatively small area, a local depletion of muskox abundance is a possible outcome. We flew the same overall 1993 survey area at an even coverage of 30%, with the intention to use post-stratification surveys to define more strata if regional differences in densities were apparent. We did, however, define one stratum in the area surrounding the commercial harvest (stratum Vb in Figure 1), to test the hypothesis that the abundance between 1993 and 1999 was lower in this area than in surrounding areas of MX11. We re-analyzed the 1988 and 1993 survey data according to a newly defined stratification scheme, to facilitate the comparison of changes in distribution or density between 1988 and 1999.

DOUBLE-COUNTING TEST FOR ACCURACY

In 1993, we flew the eight transects east of Cambridge Bay twice to quantify observer errors in detecting and counting muskoxen at the two different transect widths and flight altitudes. We flew four transects at 150 m agl and 0.75 km strip width and then repeated the flights along those lines at 300 m agl and 1.5 km strip width. In addition, we flew four lines twice at 300 m agl and 1.5 km strip width. For these tests, one observer sat next to the pilot with the other observer behind so they had similar fields of view. Each observer wrote down the time of his or her observation and muskox numbers without alerting the other observer. In compiling the counts, observations within one minute were considered to be the same herd. We used the observations of herds as the criterion for detectability and the counts of muskoxen within a herd as the criterion for counting accuracy.

DATA ANALYSES

We used Jolly's (1969) Method 2 estimate to calculate population estimates from the numbers of muskox (including calves) counted on transect. The probability that the muskox population size had not changed significantly between subsequent surveys (H_o: $T_1 = T_2 = T_3$) was tested using a one-way analysis of variance (ANOVA), or the Kruskal Wallis ANOVA on ranks if any of the assumptions required for the use of parametric statistics were violated (e.g., heterogeneity of variance, non-normal distribution of data). We assessed the probability that individual survey estimates differed significantly based on the overlap of the 95% confidence limits (CL) surrounding each estimate (analogous to paired *t*-tests). Two-tailed probability values were used, as we had no prior indication of whether any changes in numbers would be positive or negative. We tested for changes in the median group size observed during each survey using a Kruskal Wallis ANOVA on ranks. Furthermore, we tested for changes in the distribution of group sizes over time using two-sample Kolmogorov-Smirnov tests.

RESULTS

CHANGES IN DENSITY AND DISTRIBUTION

MARCH – APRIL 1988 SURVEY

We flew 4,295 km of strip transects for a total flying time of 61 hours (hr), which included 49 hr for the survey and 12 hr of ferry time between Norman Wells and Cambridge Bay. We completed the survey flights between March 21 and April 3, with an interruption on March 27-30 for caribou collaring. We did not fly on March 25, 26, 31 and April 1 because of poor weather. Coverage between the strata was even at approximately 30%. We counted 3,709 muskoxen and estimated that there were 13,031 ± 1,121 (SE) in the 44,389 km^2 survey area for an average density of 0.29 ± 0.03 muskox/km^2 (Table 1, Figure 2, Appendix A). The lowest muskox densities were observed in Stratum IV (southwest corner of the study area, 0.06 ± 0.02 muskox/km^2), with higher and relatively uniform densities being observed in Strata V, VI, and VII (0.30-0.42 muskox/km^2; Table 1, Figure 2). Densities may have been lower in stratum VIII than in V, VI and VII, but the variance of this estimate were too high to adequately test for this (0.18 ± 0.07 muskox/km^2, Table 1, Figure 2).

Table 1: Analysis of data from transect surveys, southeast Victoria Island, March 1988.

		IV	V	VI	VII	VIII	Total
Maximum no. of transects	N	32	65	65	52	17	231
No. transects surveyed	N	10	19	18	15	5	67
Stratum area, km^2	Z	5,731	12,829	8,550	12,071	5,208	44,389
Transect area, km^2	Z	1,199	3,431	2,610	3,582	1,346	12,168
Muskoxen counted	Y	114	1,447	826	1,086	236	3,709
Muskoxen/km^2	R	0.06	0.42	0.32	0.30	0.18	0.29
Population estimate	Y	341	5,407	2,707	3,661	915	13,031
Population variance	VarY	12,772	296,837	461,036	226,457	67,430	1,064,534
Standard error	SE Y	102	595	731	476	338	1121
Coefficient of variation	CV	0.30	0.11	0.27	0.13	0.37	0.09

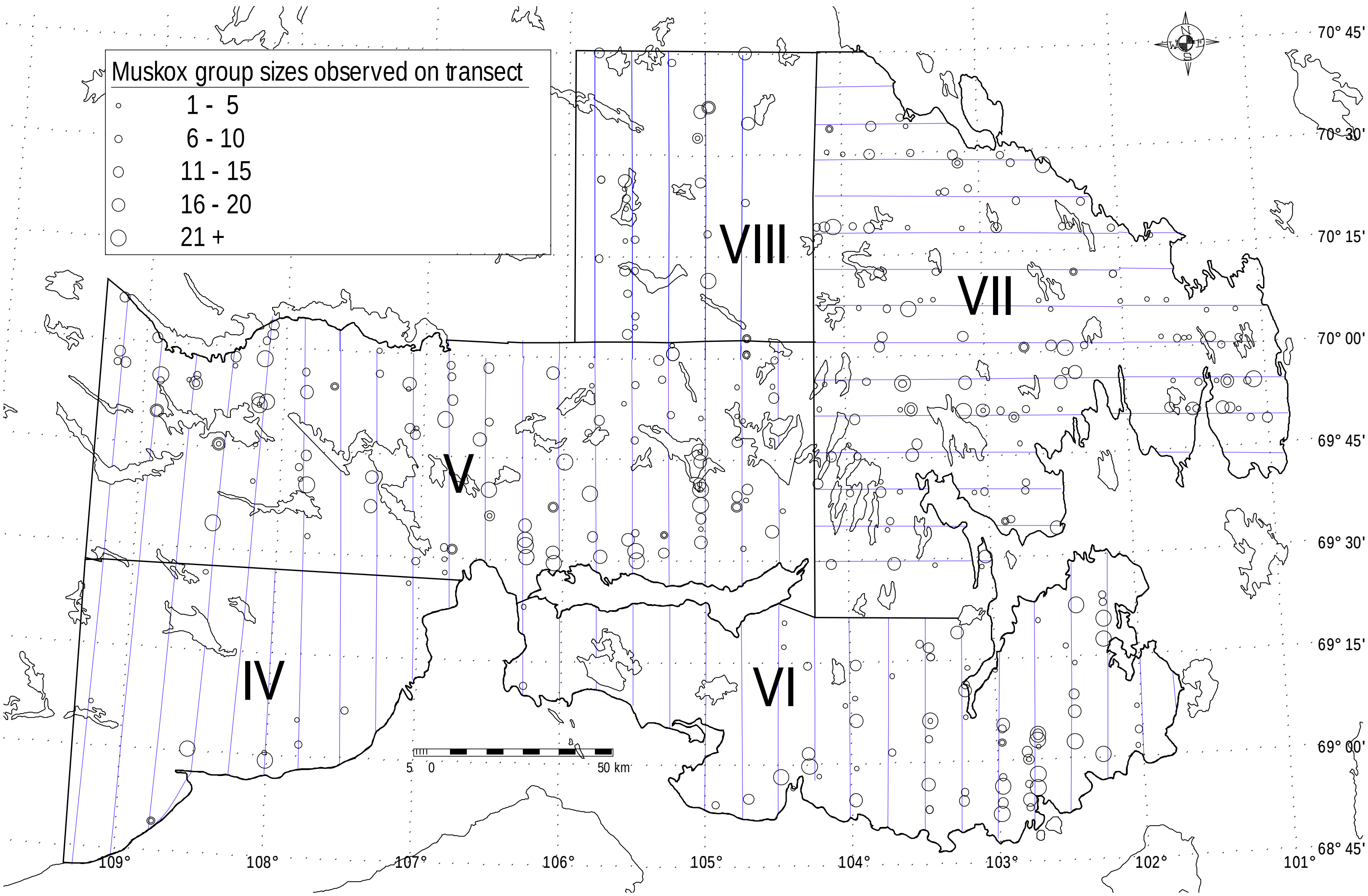

Figure 2: Muskox observations during an aerial survey of southeastern Victoria Island, Nunavut, March 1988.

MARCH 1993 SURVEY

We flew 2,746 km of strip transects between 6-10 March, 1993 for a total flying time of 51.5hr, which included 39.5hr for the survey and 12hr of ferry time between Norman Wells and Cambridge Bay. Coverage between the strata was even at approximately 20%. We counted 2,638 muskoxen and estimated 12,563 ± 1,254 muskoxen in our 39,104 km^2 survey area (Table 2, Figure 3, Appendix B), for an average density of 0.32 ± 0.03 muskox/km^2. Muskox densities were very similar among Strata IV-VII (0.30 – 0.33 muskox/km^2; Table 2, Figure 3). Density may have been higher in Stratum IX (exclusion zone around Cambridge Bay, 0.42 ± 0.19 muskox/km^2; Figure 3), but the variance of this density estimate was too high to allow meaningful statistical comparison (Table 2).

Table 2: Analysis of data from transect surveys, southeast Victoria Island, March 1993.

		IV	V	VI	VII	IX	Total
Maximum no. of transects	N	34	76	37	51	27	225
No. transects surveyed	N	7	15	7	9	5	43
Stratum area, km^2	Z	6,295	13,444	5,916	10,490	2,959	39,104
Transect area, km^2	Z	1,198	2,953	1,246	2,246	595	8,238
Muskoxen counted	Y	389	919	373	705	252	2,638
Muskoxen/km^2	R	0.33	0.31	0.30	0.31	0.42	0.32
Population estimate	Y	2,044	4,207	1,771	3,293	1,248	12,563
Population variance	VarY	181,237	504,203	325,712	519,158	389,971	1,920,281
Standard error	SE Y	450	673	514	593	574	1254
Coefficient of variation	CV	0.22	0.16	0.29	0.18	0.46	0.10

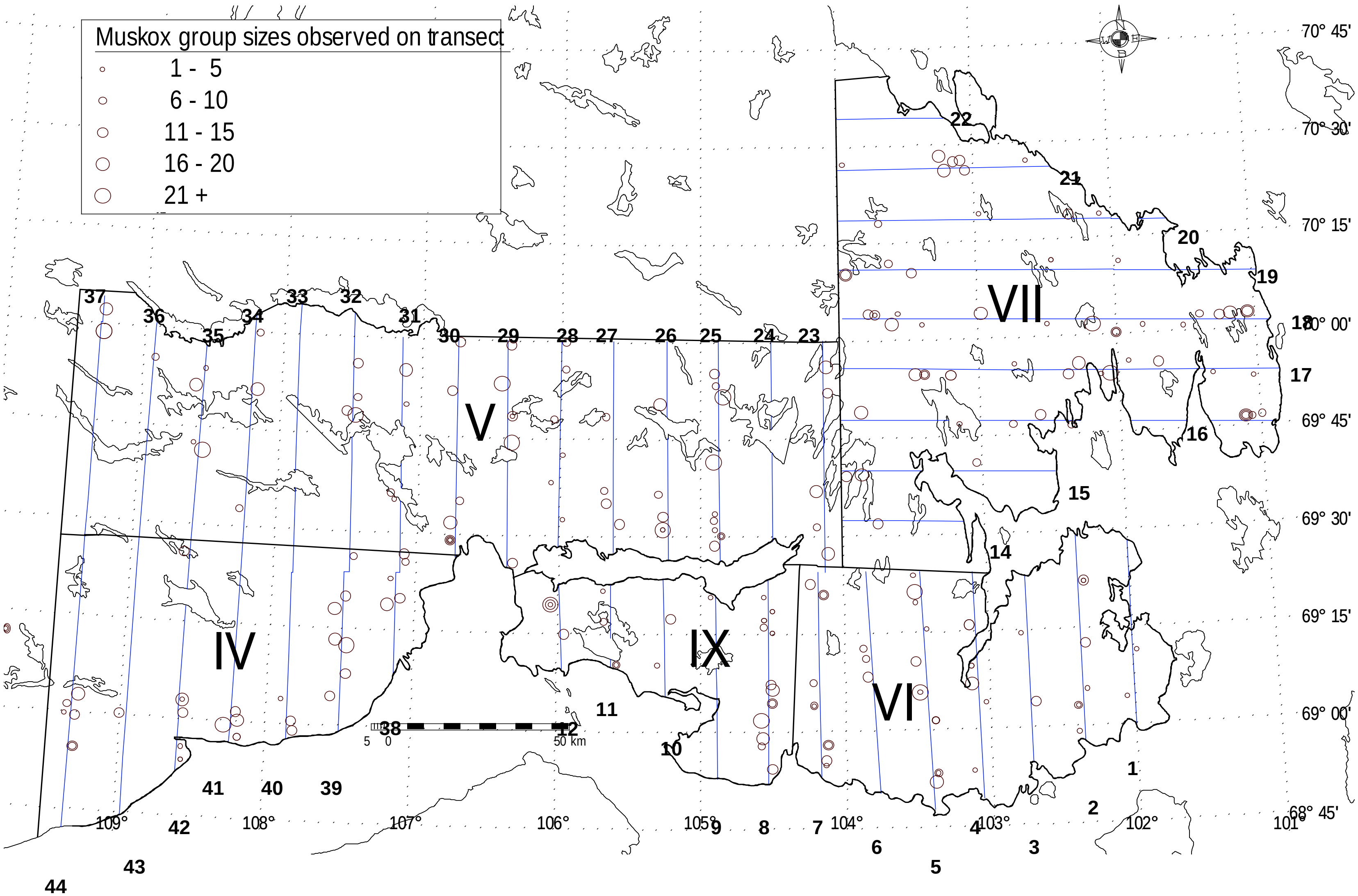

Figure 3: Muskox observations during an aerial survey, southeastern Victoria Island, Nunavut, March 1993.

March 1999 Survey

We flew 3,786 km of strip transects between 12-20 March 1999 for a total flying time of 61 hr, which included 49 hr for the survey and 12 hr of ferry time between Norman Wells and Cambridge Bay. No transects were flown on either the 15^{th} or 19^{th} because of bad weather. Coverage between the strata was even at approximately 30%. We counted 5,584 muskoxen on transect and estimated 18,290 ± 1,100 muskoxen (Table 3, Figure 4, Appendix C) in the survey area. We observed the lowest muskox densities in strata Vb that encompassed both the community of Cambridge Bay and the Ekaluk River commercial harvest site (0.27 ± 0.03 muskox/ km^2, Figure 4). Based on our impressions of regional differences in muskox densities, but prior to any formal analyses, we divided the survey area into five strata (including Vb, the previously defined area surrounding the commercial muskox harvest site, Figure 1).

The highest densities were observed in strata Va and VI (0.66 ± 0.11, and 0.72 ± 0.12 muskox/km^2, respectively, Table 3, Figure 4) with intermediate densities being observed in strata IV and VII (0.37 ± 0.11, and 0.45 ± 0.07 muskox/km^2, respectively, Figures 4 and 5). Our post-stratification scheme suggests that the densities increased between 1988 and 1999 in all strata except Vb (Figure 5).

Table 3: Analysis of data from strip-transect surveys, southeast Victoria Island, March 1999.

		IV	Va	Vb	VI	VII	Total
Maximum no. of transects	N	17	30	30	32	68	177
No. transects surveyed	N	5	9	9	10	21	54
Stratum area, km^2	Z	3,618	6,849	5,480	5,904	14,905	36,756
Transect area, km^2	Z	1,042	2,068	1,627	1,995	4,625	11,357
Muskoxen counted	Y	381	1,367	442	1,317	2,077	5,584
Muskoxen/km^2	R	0.37	0.66	0.27	0.72	0.45	0.50
Population estimate	Y	1,323	4,527	1,489	4,257	6,694	18 290
Population variance	VarY	20,169	26,888	21,327	262,062	220,778	1,210,571
Standard error	SE Y	142	519	146	512	470	1,100
Coefficient of variation	CV	0.11	0.12	0.10	0.12	0.07	0.06

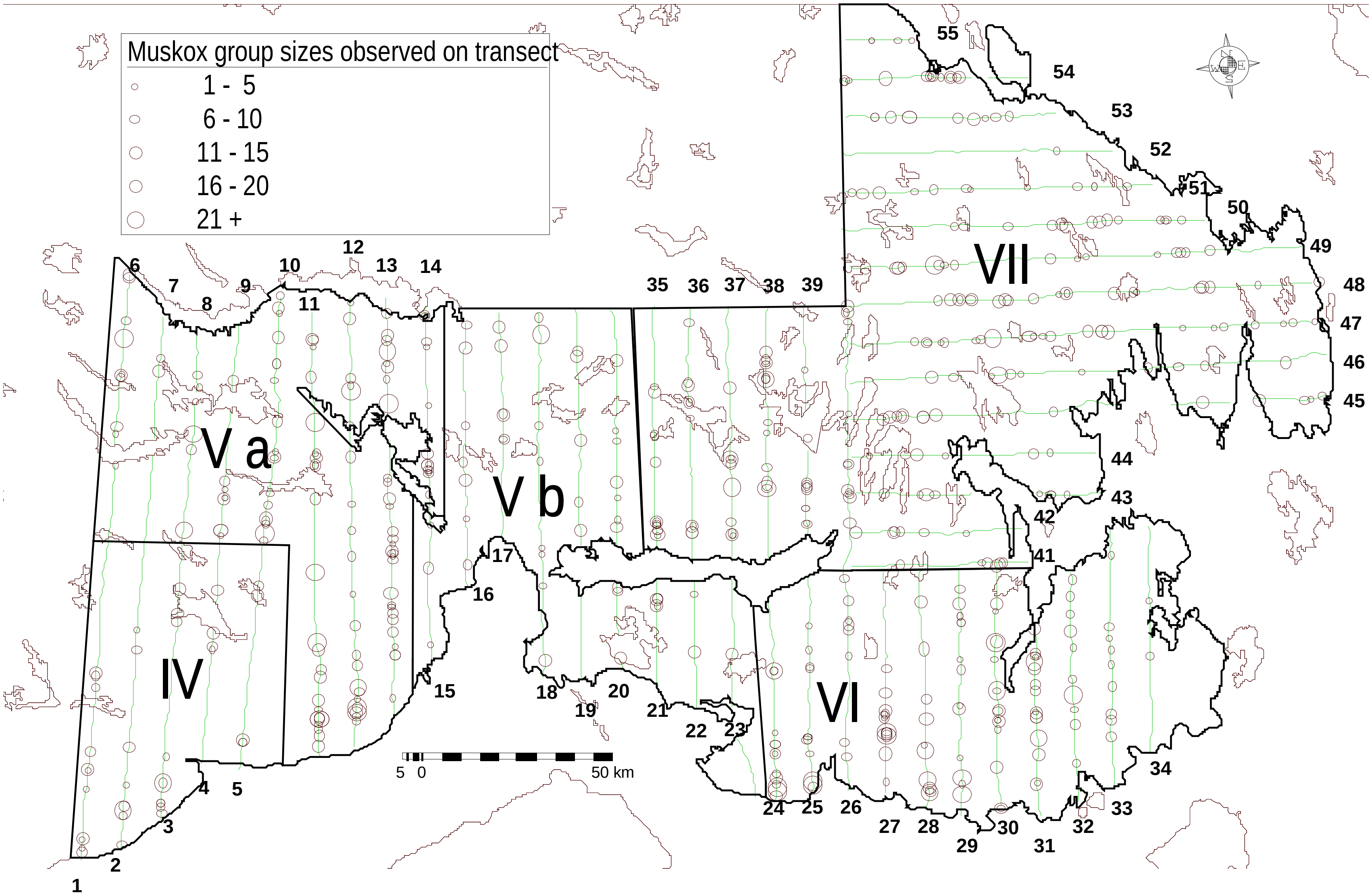

Figure 4: Muskox observations during an aerial survey, southeastern Victoria Island, Nunavut, March 1999.

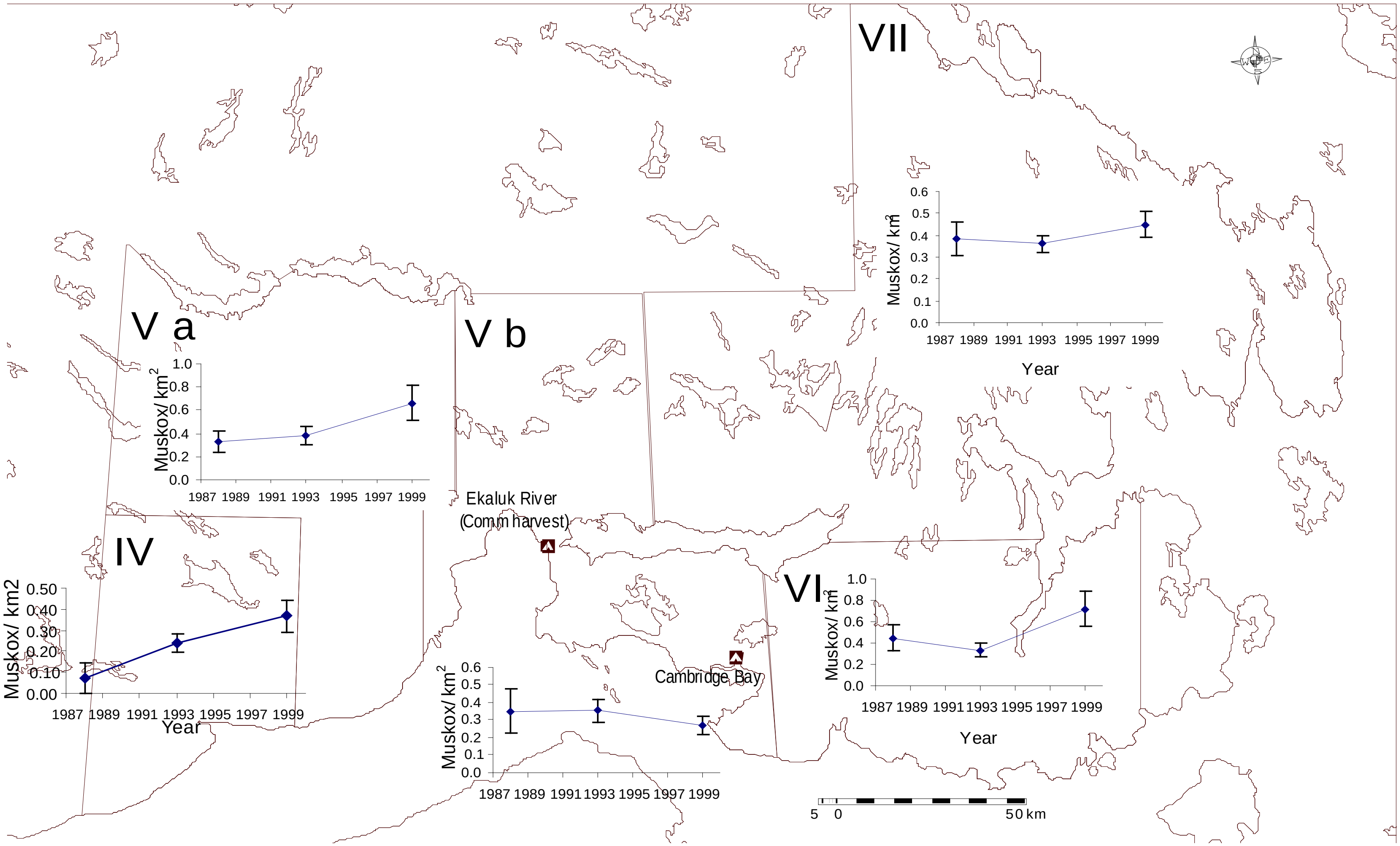

Figure 5: Trend in muskox numbers on southeast Victoria Island, Nunavut, 1983-99.

TEMPORAL CHANGES IN GROUP-SIZE DISTRIBUTIONS

Group size distributions recorded during all three surveys were clearly non-normal and generally followed a negative binomial distribution (Figure 6). Thus, we compared the median rather than mean group sizes. Median group size was ten during the 1988 survey and nine in 1993 (Mann Whitney U = 42,215, P = 0.85), also with similar overall distribution of group sizes between the two surveys (Kolmogorov-Smirnov z = 0.64, P = 0.80; Table 4, Figure 6). The median group size dropped to eight by 1999 (Mann-Whitney U = 67,226, P = 0.01) and the relative proportions of different group sizes also changed significantly (Kolmogorov-Smirnov z = 1.53, P = 0.02), with proportionately smaller groups during the later survey (Figure 6). Because our 1999 survey results suggested that harvest may have resulted in lower muskox densities in strata Vb (Figure 5), we also tested for differences in group size and the distribution of group sizes between this strata and the rest of the area surveyed during March 1999. Median group size (Mann Whitney U = 11,918, P = 0.87) and the distribution of group sizes (Kolmogorov-Smirnov z = 0.528, P = 0.94) were both similar between strata Vb and the remainder of the study area.

Table 4: Descriptive statistics for group size of muskox counted "on-transect" on southeast Victoria Island, March 1988, 1993, and 1999.

	1988	**1993**	**1999**
Median group size	9	10	8
Range	2 – 51	2 – 37	2 – 33
No. single bulls	14	13	22
No. herds	326	261	581

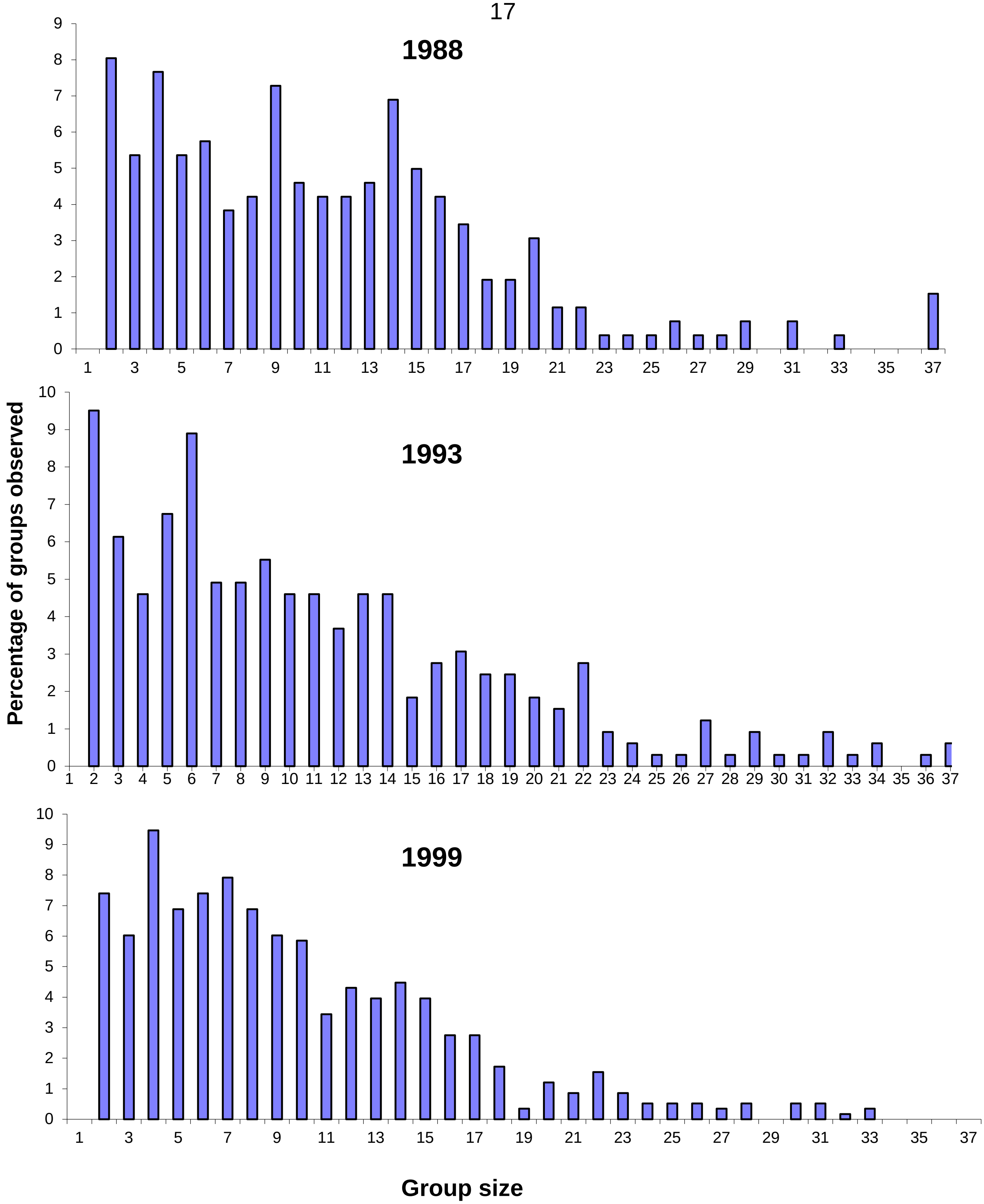

Figure 6: Muskoxen group size distributions observed during abundance surveys conducted on southeast Victoria Island, Nunavut, March 1988, 1993, and 1999.

DOUBLE-COUNTING TEST FOR ACCURACY

At the survey altitude of 150 m agl and 0.75 km strip width, the two observers each detected 88% and 100% respectively of the total herds observed (Table 5). One observer detected two herds that the other observer did not record and both observers detected the same eight herds on the four transects. For those eight herds, the counts of individual muskoxen in each herd agreed between the two observers for five herds, but differed by one muskoxen for the remaining three herds.

Twelve transects were flown at 300 m agl (1.5 km strip width): we re-flew four transects at 150 m agl and then flew four other transects twice, between one and eight hours apart. The two observers each detected 88% and 84% respectively of the total herds observed (Table 5). One observer detected 11 herds that the other observer did not record and that observer missed eight herds that the second observer detected. Both observers detected the same 48 herds on the 12 transects.

The two observers obtained the same counts for 48% of the 48 herds that they both counted. For herds where the counts differed, the observers' counts differed by an average of 2.2 ± 0.36 (SE), but the maximum difference was nine muskoxen. Observers tended to agree in their estimates of the size of smaller herds: median herd size was eight for herds in agreement and 15 for herds where the counts differed (Mann-Whitney Test P <0.01).

Table 5. Comparison of individual and combined counts of herds and muskoxen by survey altitude and strip width for repeated transects. Numbers in parentheses are muskox counts.

	150 m altitude			**300 m altitude**		
	Muskoxen observed by:			Muskoxen observed by:		
Transect	Observer 1 only	Both observers	Observer 2 only	Observer 1 only	Both observers	Observer 2 only
1	1(5)	3 (37/36)	0	4 (40)	3 (46/43)	5 (32)
3	0	2 (19/19)	0	1 (1)	5 (54 / 61)	1 (3)
5	0	2 (6/6)	0	0	1 (3/3)	0
8	1 (9)	1 (5/5)	0	0	3 (51/46)	0
Total	2 (14)	8(67/66)	0	5(41)	12 (154/153)	1 (3)

	300 m altitude			**300 m altitude**		
Transect	Observer 1 only	Both observers	Observer 2 only	Observer 1 only	Both observers	Observer 2 only
2	0	4 (25/29)	1 (11)	1 (11)	2 (8/10)	1 (8)
4	0	2 (13/13)	2 (9)	0	7 (108/107)	0
6	1 (15)	5 (82/80)	0	0	4 (59/61)	0
7	3 (39)	7 (93/99)	0	1(1)	5 (88/84)	3 (21)
Total	4 (54)	18 (213/221)	3 (20)	2(12)	18(263/262)	4 (29)

DISCUSSION

Muskox numbers in our southeastern Victoria Island study area increased from 3,300 ± 345 in 1983 to 13,031 ± 1,121 in 1988. The annual exponential rate of increase between 1983 and 1988 ($\lambda = 1.32$) can also be understood as the numbers doubling about every three years, which may be unrealistically high. Le Henaff and Crete (1989) reported an intrinsic (maximum) rate of increase for muskoxen of 1.30 and an observed rate of 1.25 between 1983-1986 in northern Quebec. However, such a high rate of increase is unlikely in an Arctic island system with relatively low productivity, particularly where muskoxen must contend with both harvest and predation. Between 1988 and 1993, muskox numbers did not significantly change whereas the population increased significantly (32%) between 1993 and 1999 (Tables 1-3).

The overall increase in numbers between 1988 and 1999 was not uniform among different areas within the study area. Between 1988 and 1993 muskoxen apparently immigrated from outside of the study area into Strata IV but by 1993 most areas in southern Victoria Island were occupied by muskoxen at moderate to high densities (relative to other areas occupied by muskoxen in the NWT and Nunavut – see Fournier and Gunn 1998) reducing the potential for substantial immigration/emigration within the study area between 1993 and 1999. Commercial harvesting at Ekaluk River has resulted in the virtual absence of muskoxen within a 50-70 km radius of the abattoir on ten occasions between November 1993 and March 2000. Either the harvest removes muskoxen at the rate they move into the area and/or there is a behavioural avoidance of the area. Between 1993 and 1999, 1,759 muskoxen have been commercially harvested near the Ekaluk River site. The continued success of this harvest demonstrates that muskoxen can quickly recolonize intensively harvested areas. Further, there were no changes in group sizes observed in Strata Vb relative to surrounding areas suggesting that entire groups moved into the newly unoccupied area following each harvest. Nonetheless, abundance in the area surrounding the Ekaluk River commercial harvest site was lower than in surrounding areas between 1993 and 1999 (Figures 4 and 5).

The area surveyed in 1993 and 1999 represents about 70% of MX 11 so a quota of 1,300 amounts to about five per cent of the 1999 population estimate for the entire management zone (~26,000). To date, no more than 329 muskoxen have been harvested during a single commercial harvest and less than 50% of the current annual quota is utilized each year. Although present levels of exploitation appear easily sustainable, increased monitoring will be required if present market and logistical difficulties are overcome and the full quota for MX 11 is realized.

DATA QUALITY AND THE ABILITY OF AERIAL SURVEYS TO MEASURE MUSKOX POPULATION CHANGE

One explanation for any results arising from a series of aerial surveys is the credibility of the surveys themselves. The four surveys between 1983 and 1993 met the Government of the Northwest Territories (NWT) criterion for acceptable muskox surveys (Coefficient of Variability (CV) equal to or less than 10% (Graf and Case 1989)). There were no problems encountered with the three surveys and we ensured that the methodology used was similar (aircraft type, speed and altitude, and strip width) and comparable to 1983 except for aircraft type, as Jingfors used a Cessna 185 in 1984. This standardization of methods improves the comparability of the surveys.

In 1999 we employed a different stratification scheme to that previously used. Basing a post-stratification scheme on the actual density data from the survey in question, rather than a separate correlate of density (e.g. habitat quality or density estimates from a previous survey) is generally thought to result in an underestimate of the variance associated with the density estimates for the resulting strata (Anganuzzi and Buckland 1993). However, empirically this should be little different than basing stratification on a reconnaissance flight conducted immediately prior to the "actual" survey. Further, because our post-stratification scheme was developed independent of the observations made during the 1988 and 1993 surveys, the variance associated with density estimates for the new strata employed with the 1988 and 1993 data should be unbiased. Similarly, although we may have underestimated the variance associated with the density estimates for specific strata, our post-stratification did not affect the population estimate or variance for the survey area as a whole.

We reduced the coverage from 30% in 1988 to 20% in 1993 but the effect on the CV was relatively minor – 8.6% in 1988 and 10% in 1993. However, lower coverage made it statistically impossible to make meaningful comparisons of density among strata. Caughley (1977) suggested as a general rule that each strata should have ≥ 10 transects. Each of the three surveys reported here had some strata with less than ten transects which reduced the potential for rigorous comparison of differences in densities among areas. We suggest that given the logistical constraints of surveying ungulate populations in what is now Nunavut, biologists should avoid the temptation to "over-stratify" their study areas and define individual strata only where marked differences in abundance are suspected or must be detected if present. For example, considering the

1999 survey, combining strata Va with VI, and IV with VII resulted in a three stratum classification with significantly different densities amongst all three (Kruskal Wallis X^2 = 15.8, d.f. = 2, *P* = <0.01, significance of differences in each of the paired density estimates was based on non-overlapping CLs). In March 1999 we once again increased coverage to 30%, which reduced but did not eliminate this problem.

In our test for accuracy of counts, we separated the observers' ability to detect herds from their estimates of the number of muskoxen in the individual herds. Our results suggest that at 300 m agl (transect 3 km wide) the two observers missed an average of 10% of the herds, which contributes directly to the inaccuracy of the estimates. At the lower altitude and narrower strip width, the sample size (number of transects) was too few to determine if detectability of herds improved significantly. The differences between the counts of muskoxen in herds by the different observers tended to balance each other out as neither observer consistently under or over-counted. Differences in counting muskoxen within the herds depend on herd size and the distance of the herds from the observers. Not surprisingly, the observers agreed more frequently when counting smaller herds.

Despite 3 km wide transects, we counted almost as many animals off-transect as we did on. This suggests a relatively inefficient use of available data. Distance sampling (Buckland *et al*. 1993) makes maximum use of available observations while minimizing bias resulting from inaccuracy in detecting and counting animals because the effective strip-width for each survey is calculated from the actual data itself. Errors in estimating group size in relation to animal distance from the observer can also be quantified and remedied by calculating the frequency of observed group sizes at various distances from the observer. Bias resulting from differences between observers can also be quantified and remedied by entering observer as a covariate in the estimate functions.

Distance sampling requires that the distance from the transect line to each observation be estimated. This can be estimated either with a laser range-finder (military models are now available with ranges of up to 10 km) or by partitioning the marks along the wing strut into 5-6 zones (i.e. different colour marks on the wing strut for 0-250 m, 250-500 m, 500-750 m etc.) and using a radar altimeter to maintain a constant altitude. However, we caution that assigning observations to several zones will require an experienced pilot to maintain level flying, and experienced trained observers. Although the overall precision of the three surveys reported here was good (CV <10%), the precision of strata-specific estimates was generally too poor for statistically meaningful comparison of densities. Employing distance sampling in future surveys should substantially increase survey precision and make the comparison of strata-specific density estimates a more realistic option.

A second and very real problem in interpreting the change in muskox numbers within our survey area is that the survey area boundaries, although similar among all three surveys, were not population boundaries. With the exception of the south coast of the island, the survey areas were not defined by natural geographic features that would influence muskox distribution. East of Wellington Bay, muskox distribution was similar between 1988 and 1993 (Figures 2 and 3). However, west of Wellington Bay, muskox density increased five-fold in Stratum IV between 1988 and 1993 (Tables 1 and 2, Figure 5) suggesting immigration from outside the survey area. Between 1983 and 1988 the rate of increase ($\lambda = 1.07$) for the entire surveyed population may have been due in part to muskoxen movement into the survey area. Le Henaff and Crete (1989) documented dispersal distances of up to 650 km indicating that geographic redistribution remains a real possibility. Excepting Strata Vb, muskoxen increased at a relatively uniform rate throughout the study area between 1993 and 1999 (λ = 1.06, Figure 5), and we suggest that this increase was probably demographic rather than a result of immigration.

CAUSES OF CHANGES IN MUSKOXEN DENSITY OF SOUTHEASTERN VICTORIA ISLAND

We lack detailed information on birth and survival rates of muskox in southeastern Victoria Island, which would assist in interpreting the trends in muskox numbers. Surveys in March do not provide accurate counts of short-yearlings as they are not readily distinguishable from the air. The ratio of calves to cows determined from ground-based segregations provides a more accurate measure of productivity because sex and year-class can be assigned from horn and pelage development and relative body size (Gray 1987, Olesen and Thing 1989).

Data on calf production and survival are available for only a few years between 1983 and 1993 (Table 6). In March 1984, during a survey using snow machines, Jingfors (1985) found that the population was composed of 20.3% short-yearlings, which suggests calf survival was high. In 1985 and 1986, we also classified the muskoxen sex and age composition during snow machine surveys while investigating calving chronology (unpublished data). In May 1985, we found 74 calves:100 three year and older cows (calving was not complete), which is relatively high compared to ground segregation data collected elsewhere. In May 1986, we did not segregate all herds to sex and age class but the proportion of calves was 17%, compared to 22% in 1985. The proportion of yearlings in May 1985 and 1986 was 14% and 19%, respectively.

Table 6: Sex and age composition of muskoxen on southeast Victoria Island, 1984-1988.

Date		Mixed herds/ muskoxen	Bull groups/ herds	3+-year olds		2-year-olds		Year-lings	Calves
				Male	**Female**	**Male**	**Female**		
1984	March	19/295	12/34	62	91	22	25	60	0
1984	Nov.	11/157	8/274	19	55	11	8	17	28
1985	22-24 May	8/274	12/27	33	81	16	18	39	60
1986	6-8 May	12/151	9/22	43	28	8		29	26
1988	August	138/1305	8/25	274	531	78	80	233	213

Elsewhere, Hubert (1974) on Devon Island in the High Arctic recorded calf: cow ratios of 52:100 and 60:100 between May 1971 and May 1973 (number of herds not reported). Tener (1965) found considerable annual variation in ratios on Ellesmere Island (16:100 to 79:100), but in two of the four years, samples were small (only four to five herds). Higher ratios have been reported from rapidly increasing populations in Alaska and on Banks Island. Jingfors and Klein (1982) reported exceptionally high calf:cow ratios for the introduced population of muskoxen on the Alaskan North Slope. The sample size was small and more recent data (Reynolds *et al*. 1985) based on a larger sample size from the increasing population was 75 calves:100 cows (15 herds).

Our data are too few to detect a trend in calf production and survival that would contribute to our explanation for the lack of change in muskox numbers between 1988 and 1993. The 1984-86 data suggest calf production and survival were relatively high. Pregnancy rates obtained during research on seasonal condition (Adamczewski 1995) averaged 58 ± 8.6 % for cows >3 years for the period of 1989 to 1992. We determined the reproductive status of 42 cows >3 years during the Ekaluk River commercial harvest in December 1998. Only 48% were pregnant and an additional 14% were lactating, supporting the suggestion of Adamczewski (1995) that pregnancy rates are low and some cows are only breeding in alternate years. However, Reynolds (1985) showed that individual cows varied greatly in their productivity over time in Alaska. Thus, we are not certain how much of the variation we observed in pregnancy rates is due to decreasing forage quantity or quality and how much is merely due to demographic stochasticity.

We suspect that mortality factors for adult muskoxen are relatively few. The quota was increased to 500 tags annually in 1988, 1,000 in 1994, and 1,300 in 1999 but not all tags have been used (less than 150 prior to 1993 and less than 500 per year since). Muskoxen collected between 1989-93 were healthy (Gunn *et al.* 1991) and wolves were initially rare. We suspect, however, by the 1990s the situation had changed and that both wolf and grizzly bear predation was increasing. In late winter 2001 we received many reports of muskoxen killed by wolf and bear in the Byron Bay area, west of Cambridge Bay.

We are left with two possible explanations for lack of increase in muskox numbers between 1988 and 1993. Adamczewski's (1995) data suggest that pregnancy rates may have decreased between 1989 and 1993. Alternatively, as muskox numbers continued to increase throughout Victoria Island in the early 1990s, annual movements may have confounded the interpretation of survey results. An efficient and effective approach to improving our ability to analyse data would be strategic placement of radio-collars with both the immobilization and subsequent monitoring being done by local hunters on snow machine. This would provide good data on the ability of muskoxen from surrounding areas to recolonize an area following intense commercial harvest as well as maximize involvement of local hunters. Given the potential for increased commercial harvesting of muskox to support the meat plant, there is a need to resolve the question of the possible muskox movements relative to the survey area boundaries.

We have documented a substantial increase in muskox numbers on Southeast Victoria Island between 1983 and 1999. Information required to interpret those trends is incomplete and introduces uncertainty into managing the muskox harvest for sustainability while minimizing the possibility of any density-dependent declines in muskox numbers in southeast Victoria Island. We suggested that documenting annual movements of muskox and adjusting survey design (e.g. employing distance sampling) to improve accuracy may be necessary to ensure sustainable harvesting if the demand for commercial use of this population continues to increase. We recommend continued monitoring of the fecundity and general condition of muskoxen taken during the commercial harvest each March to provide better information on the capacity of forage conditions on southeastern Victoria Island to support present densities of muskoxen, particularly given the possibility of continued muskox population growth.

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APPENDIX A: MUSKOXEN OBSERVED ON SOUTHEAST VICTORIA ISLAND, MARCH 1988.

Transect	Area	Muskoxen		Transect	Area	Muskoxen
Stratum V				**Stratum VI**		
1	202	32		1	77	13
2	165	36		2	67	0
3	161	35		3	81	0
4	163	85		4	106	0
5	192	175		5	173	7
6	192	96		6	163	13
7	182	21		7	173	25
8	172	47		8	134	58
9	168	54		9	169	15
10	211	64		10	173	9
11	169	107		11	173	117
12	196	90		12	173	72
13	177	129		13	154	145
14	177	81		14	184	192
15	177	93		15	204	52
16	188	46		16	184	97
17	188	165		17	184	11
18	186	43		18	38	0
19	165	48				
Totals	**3,431**	**1,447**		**Totals**	**2,610**	**826**
Stratum VII				**Stratum VIII**		
1	173	7		1	250	70
2	144	60		2	250	97
3	202	52		3	250	31
4	200	46		4	298	0
5	192	57		5	298	38
6	384	232		**Totals**	**1,346**	**236**
7	376	109		**Stratum IV**		
8	374	143		1	92	39
9	365	61		2	146	96
10	298	34		3	154	51
11	292	106		4	158	75
12	221	33		5	188	44
13	192	69		6	223	2
14	108	33		7	238	82
15	61	44		**Totals**	**1,199**	**389**
TOTALS	**3,582**	**1,086**				

APPENDIX B: MUSKOXEN OBSERVED ON SOUTHEAST VICTORIA ISLAND, MARCH 1993.

Stratum V				**Stratum IX**		
1	200	65		1	177	158
2	173	0		2	165	5
3	188	131		3	104	13
4	188	70		4	73	15
5	184	41		5	77	61
6	181	39		**Totals**	**596**	**252**
7	192	139		**Stratum VI**		
8	192	85		1	161	8
9	196	53		2	165	43
10	219	85		3	166	17
11	219	18		4	196	45
12	211	33		5	196	145
13	184	73		6	188	28
14	203	10		7	177	87
15	223	77		**Totals**	**1,249**	**373**
TOTALS	**2,953**	**919**				
Stratum IV				**Stratum VII**		
1	92	39		1	107	13
2	146	96		2	173	40
3	154	51		3	365	103
4	158	75		4	365	155
5	188	44		5	357	208
6	223	2		6	346	74
7	238	82		7	269	25
TOTALS	**1,199**	**389**		8	177	81
				9	88	6
				Totals	**2,247**	**705**

APPENDIX C: MUSKOXEN OBSERVED ON SOUTHEAST VICTORIA ISLAND, MARCH 1999.

Transect	Area	Muskoxen	Transect	Area	Muskoxen
			Stratum VI		
Stratum IV			24	164	165
1	220	118	25	174	111
2	176	62	26	182	64
3	244	69	27	177	185
4	147	42	28	190	163
5	255	90	29	196	110
Totals	**1,042**	**381**	30	194	175
			31	153	204
Stratum Va			32	182	81
6	199	101	33	204	52
7	167	23	34	179	7
8	157	63	**Totals**	**1,995**	**1,317**
9	162	73			
10	202	169	**Stratum VII**		
11	338	352	35	193	109
12	357	244	36	185	104
13	319	247	37	203	124
14	166	95	38	200	141
Totals	**2,067**	**1,367**	39	156	63
			40	204	82
Stratum Vb			41	140	53
15	113	27	42	136	57
16	212	62	43	143	53
17	177	64	44	195	38
18	293	63	45	319	162
19	258	64	46	350	104
20	239	88	47	368	212
21	84	44	48	371	235
22	101	16	49	360	146
23	151	14	50	289	120
Totals	**1,628**	**442**	51	243	76
			52	214	4
			53	167	88
			54	53	10
			Totals	**4,489**	**1,981**

APPENDIX D: WEATHER AND LIGHT CONDITIONS DURING AERIAL SURVEYS OF MUSKOXEN, SOUTHEASTERN VICTORIA ISLAND, NUNAVUT, MARCH 1988, 1993, AND 1999.

1988

Date	Cloud	Wind speed km/hr	Strata	Transects
21 March	Clear	< 5	III IV	28 - 32, 33 - 38
22 March	Clear	< 5	III V	39 - 42 43 - 54
23 March	Clear	< 5	V	55 - 61
24 March	Clear	< 5	VI	70 - 86
27 March	Clear	< 5	VII	87 – 92 102 – 105
2 April	Clear	10	VIII	93 - 105

1993

Date	Cloud	Wind speed km/hr	Strata	Transects
6 March	Broken	10	V	
7 March	Scattered-broken	< 5	V VII	23 – 25 15 - 22
8 March	Clear	10 - 40	VI IX	4 – 7 8 - 12
9 March	Broken - clear	5	IV VI VII	38 – 44 1 – 3 14 - 15
13 March	Scattered ground drift	20-30	Observer accuracy experiment	

1999

Date	Cloud	Wind speed km/hr	Strata	Transects
12 March	Clear	<5	VI	24-32
			VI	33 –34
			VII	36 – 46
13 March	Clear	< 5	Vb	22 - 23
14 March	Broken - clear	20-35 S	Va	14
			Vb	15-16,18–21
			VII	35
	Cloudy, hazy off transect		Vb	17
16 March	High ceiling some haze but vis > 3km	5	VII	47-48
			Va	12-13
17 March	1,300-1,400 ceiling	10-15 from S	VII	49-55
			IV	1,3,4
18 March		15-20 from S	Va	6,8,9,11
	Clear		IV	2, 5
20 March		Light	Va	7, 10