CALF SURVIVAL AND SEASONAL MIGRATIONS OF A MAINLAND MUSKOX POPULATION

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GOVERNMENT OF THE NORTHWEST TERRITORIES
YELLOWKNIFE, NWT

2000

The research documented in this report was carried out prior to the creation of Nunavut. Final report preparation was funded by the Government of Nunavut.

File Report No. 124

Northwest Territories Resources, Wildlife and Economic Development

ABSTRACT

Muskoxen (*Ovibos moschatus*) disperse away from a winter concentration along a broad valley drained by the Rae and Richardson rivers, west of Kugluktuk. Before calving in late March – early April, the muskoxen migrate up to 140 km north toward the coast. In August to October, the muskoxen slowly return to the Rae-Richardson river valley. We documented those seasonal migrations using radio-collars on 10-20 adult cows between 1988 and 1991. We also used the radio-collars to locate herds to record seasonal calf survival. The proportion of calves among all muskoxen counted in May (13 ± 0.9 SD) and November (11 ± 0.42 SD) for all years combined was similar. A decline in calf survival was only significant during summer 1989. We suggest that the low proportion of calves may be partially a consequence of low pregnancy rates as well as low survival. Five of the 8 radio-collared cows that died were either confirmed or probably grizzly bear kills. During the study we found that the muskoxen were infected with a lungworm, which may have contributed to deaths. This report includes a trial to treat the lungworm. Our documentation of seasonal movements contributes to effective survey design and our results on calf and adult survival suggest that the population is not likely to continue the increase described in the 1970s and early 1980s.

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INTRODUCTION

Muskoxen (*Ovibos moschatus*) were concentrated along the Rae-Richardson river valley (Figure 1) when the area was surveyed in March 1983 (Case and Poole 1985). As herd sizes were large in late winter, we elected to do the next survey in August when herds would be smaller and easier to count more accurately. However, in August 1987, we found that the muskoxen were scattered away from the Rae-Richardson river valleys, which precluded obtaining an estimate. We also observed few calves (11%) and a follow-up sex and age classification of the herds confirmed that a low ratio of calves to cows (Gunn 1995). The absence of calves was attributed to poor calf survival during the summer. Conventionally, the highest calf mortality is expected during their first winter.

The need for information on the seasonal distribution of the Rae-Richardson area muskoxen to determine optimum timing and design of aerial surveys and to investigate the low calf survival led to the research described in this report. The first step in investigating the low calf survival was to determine initial production and the seasonal loss of calves. To help locate herds to periodically describe the proportion of calves, we radio-collared cows. Seasonal relocation of the cows also allowed us to describe seasonal distribution of the muskoxen. We have also included the results of a treatment trial for lungworm. The lungworm was discovered during the radio-collaring study and the treatment trial used the radio-collared muskoxen as a control (untreated) during the trial.

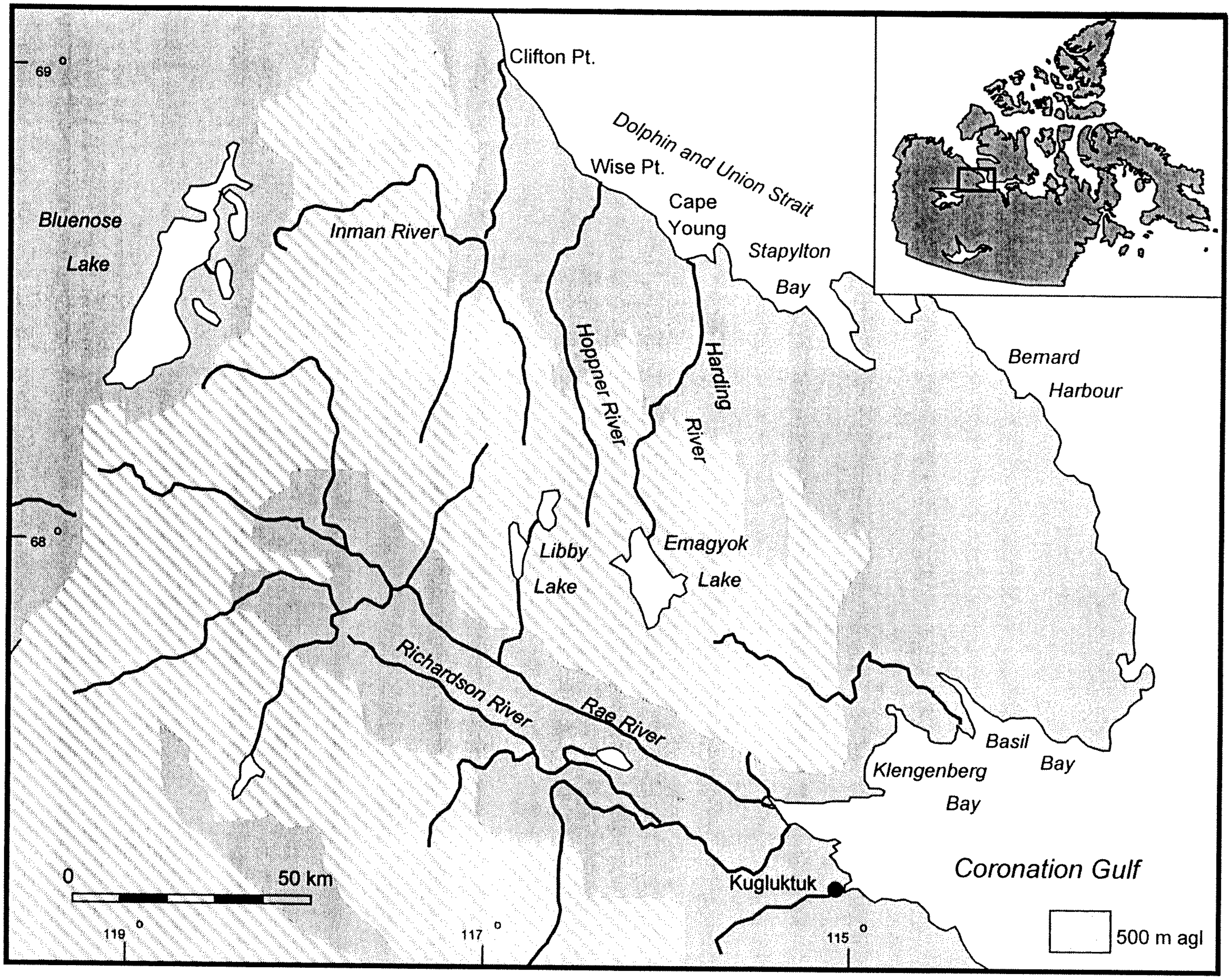

Figure 1. The Rae-Richardson rivers study area.

METHODS

Study Design

The hypotheses to be tested were:

1) The total proportion of calves significantly decreases between calving (May) and fall (early October).
2) Seasonal dispersion (distance between individual cows) significantly changes between summer (July) and early winter (November)
3) The proportion of radio-collared cows in the Rae-Richardson river valley (arbitrarily defining the valley as an area enclosed by a line 15 km on either side of the Rae-Richardson rivers, which approximates the 500 m above sea-level contour) significantly changes between summer (July) and early winter (November).

Initially, 10 adult cows were fitted with radio-collars in 1988, but the death of four cows in summer 1989 led to re-collaring in fall 1989. A further 10 collars were purchased to be fitted in March 1990 to increase the sample size in case the unexpectedly high mortality during the 1989 summer continued.

Radio-collaring

Four cows were radio-collared in June 1988 using Cap-Chur rifle and darts to deliver immobilizing drugs from a helicopter. Despite having a Helio-Courier fixed-wing as a spotter plane, not enough muskoxen could be found in the Rae-Richardson river valley and further radio-collaring was delayed until the fall. In November 1988, snowmachines were used to round up and hold herds until six cows were drug-immobilized and fitted with radio-collars. Lack of snow and rough travelling conditions meant that in November 1989, we used a helicopter to immobilize four cows to fit them with radio-collars retrieved from cows that had died during the summer. In March 1990, 10 additional cows were immobilized after round-up by snowmachines and fitted with radio-collars. One of these cows was shot within a month of collaring, and another cow shed its collar, so we collared an additional three cows in March of 1991, using snowmachines to round-up and hold the muskoxen while one of us walked up to the muskoxen to use a dart rifle.

We used a fixed-wing aircraft to radio-track and relocate the collared muskoxen three times in June and once in September 1988, twice in May 1989 and at monthly intervals from June to November 1989. The muskoxen were relocated monthly from March to November in 1990, and again from April to September in 1991 (with the exception of June both years and October in 1990). During each radio-tracking flight, we counted the number of muskoxen and the number of calves with each radio-collared cow located.

Data Analyses

We calculated the proportion of calves by dividing the total number of calves observed by the total number of animals observed each month. We converted these proportions to arcsine square-root values to compare summer with winter proportions using chi-square statistical analyses. Calf proportions were not analyzed in 1988 because we had too few observations. The herd locations were entered into a database (Dbase5), which was used to plot individual muskox movements and locations each month using Quikmap(30), Freelance(4) and Microsoft Powerpoint software. We used DBase5 to calculate distances between data points and SigmaStat (Jandel Scientific) to test for significant differences in muskox movements between years and between individuals. Daily rates of travel were calculated by measuring the minimum straight-line distance moved between radio-locations and dividing by the number of days between locations. Mean monthly distances traveled were calculated by measuring the minimum straight-line distances traveled monthly by each cow and finding the monthly means. We subsequently input the locations into Spans Explorer (7.1) to map and measure the overlap in the seasonal ranges and to analyze the seasonal distribution of collared cows in the river valley. If the ranges between successive months overlapped by an arbitrary 80% or greater, we grouped the months into seasons for analysis.

We examined the seasonal distribution from three aspects:

1) We tested the seasonal aggregation and dispersion patterns between collared cows by comparing the distance between one cow and the other collared cows in July (1989-91) and November (1988-90). We selected Cow #200 for this case study because we had location data for her over a 3 year period.
2) We examined seasonal distribution by determining what proportion of the collared cows were within a 15 km buffer zone along the Rae-Richardson rivers.
3) We used the monthly locations of the collared cows to determine the overlap in monthly distribution. We combined the monthly locations of collared cows for all years, except for Cows #342 and #120. These two cows were analyzed separately because their movements were east-west, unlike the majority of cows whose movements were oriented north-south.

RESULTS

We radio-tracked the muskox cows between 1988 and 1991 (Appendices A and B). Of 27 radio-collared muskox cows, 6 were collared for at least 35 months, 12 cows were collared for 19-23 months and nine cows were collared for less than 14 months (Figure 2).

Calf Survival

The null hypotheses that the total proportion of calves does not significantly decrease during the summer was rejected only for 1989 (Table 1 and Appendix A). We tested for significant differences in calf proportions between seasons for each of the 3 years separately (Table 2). The decrease in calf proportions from July to November was significant in 1989 ($X^2 = 6.6$, $P = 0.01$). Overall, there was no significant difference in the pattern of calf proportions between years (ANOVA, P=0.22).

Table 1. Total proportion of calves (number of herds) for the Rae-Richardson river valley muskoxen, 1989-91.

Month	% calves (no. herds)		
	1989	1990	1991
April	-	0.0 (18)	0.0 (20)
May	12.7 (20)	12.3 (32)	13.4 (20)
June	17.7 (10)	-	-
July	20.8 (6)	12.7 (18)	15.2 (19)
August	14.3 (7)	11.5 (17)	15.4 (18)
September	16.5 (5)	12.5 (17)	12.4 (7)
November	8.9 (10)	11.2 (18)	-

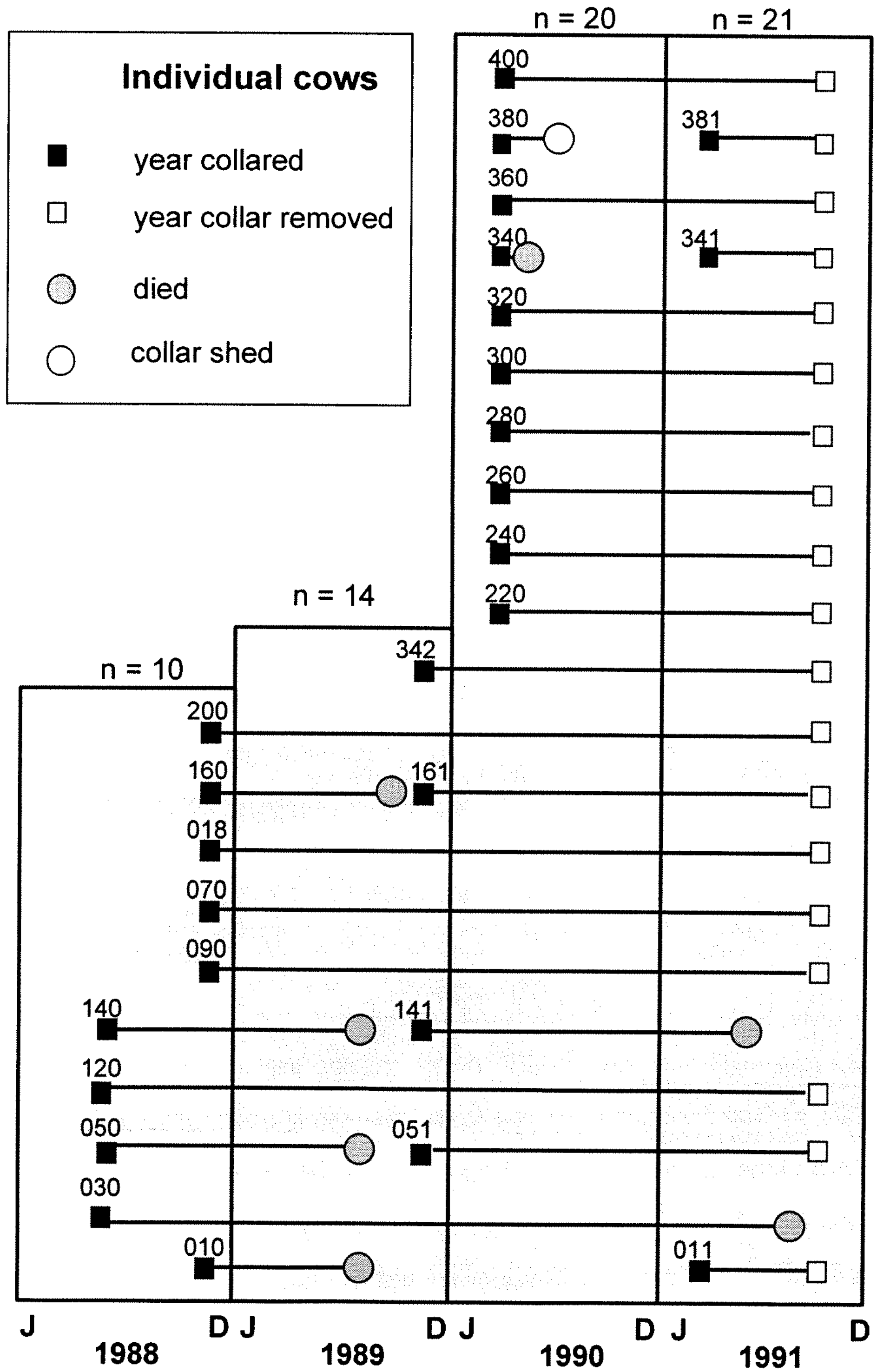

Figure 2. Chronology of radio-collar muskox cows studied in the Rae-Richardson river area.

Table 2. Chi-square test of calf proportions between summer (July) and early winter (Nov., Sept. (1991)).

Year	Month	Number of adults	Number of calves	% calves	X^2, df	P
1989	July	57	15	20.8	6.60, 1	0.01
	Nov.	225	22	8.9		
1990	July	131	19	12.7	0.13, 1	0.72
	Nov.	414	52	11.2		
1991	July	267	48	15.2	0.50, 1	0.48
	Sept.	148	21	12.4		

Seasonal Changes in Herd Size

We relocated the cows once a month (Table 3), with the exception of June 1988 (three times) and May 1989 and 1990 (twice). The monthly relocations allowed us to track seasonal changes in herd size. Herd sizes (excluding single bulls) decreased from April to a mean minimum (12.3 ± 2.4 SE) in July and then increased to an annual maximum (28 ± 1.6 SE) in October (1989) and November (Table 3). Herd sizes were significantly different between July and November for the 3 years (t=-4.5, P=0.01).

We observed radio-collared cows in 297 herds (mixed sex and age) between 1988 and 1991, but on 14 occasions we found the radio-collared cow to be solitary (no herd within at least 5 km). Half of the 14 single cow sightings were in June (Appendix B). Three of the cows (#30, #50 and #140) were seen alone twice in June 1988. All of these solitary cows were observed within a herd during the month before and after being seen alone, with the exception of Cow # 220, who was observed alone once during April 1990 and twice during May 1990. All other sightings of Cow #220 were within a herd.

Table 3. **Mean herd size ± Standard Error (number of herds) for the Rae-Richardson river valley muskoxen, 1988-91.**

Month	Mean monthly herd size			
	1988	1989	1990	1991
March	-	-	25.0 ±10.0 (4)	-
April	-	-	13.3 ± 1.9 (18)	16.5 ± 2.5 (20)
May	-	18.4 ± 2.3 (20)	16.0 ± 2.0 (32)	14.6 ± 2.1 (20)
June	8.0 ± 2.8 (12)	12.4 ± 2.3 (10)	-	-
July	-	12.0 ±2.0 (6)	8.3 ± 1.4 (18)	16.6 ± 3.1 (19)
August	-	12.0 ± 2.1 (7)	13.2 ± 2.4 (15)	16.2 ± 2.9 (18)
September	22.5 ± 5.8 (4)	15.8 ± 2.8 (5)	18.4 ± 2.3 (17)	24.1 ± 3.3 (7)
October	-	29.0 ± 15.6 (2)	-	-
November	31.9 ± 5.2 (7)	24.7 ± 7.2 (10)	25.9 ± 2.9 (18)	-

Seasonal Movements

We determined seasonal movements (late winter, summer to early winter) for 1990 and 1991 and seasonal movements for a shorter season (early summer to early winter) for 1988 and 1989. Sample size (number of collared cows) for seasonal movements within a year varied between 6 and 20 (Figure 2). We had 4 years of consecutive seasonal movements for two cows, 3 years of consecutive data for four cows and 2 years of consecutive data for ten cows (Figure 2).

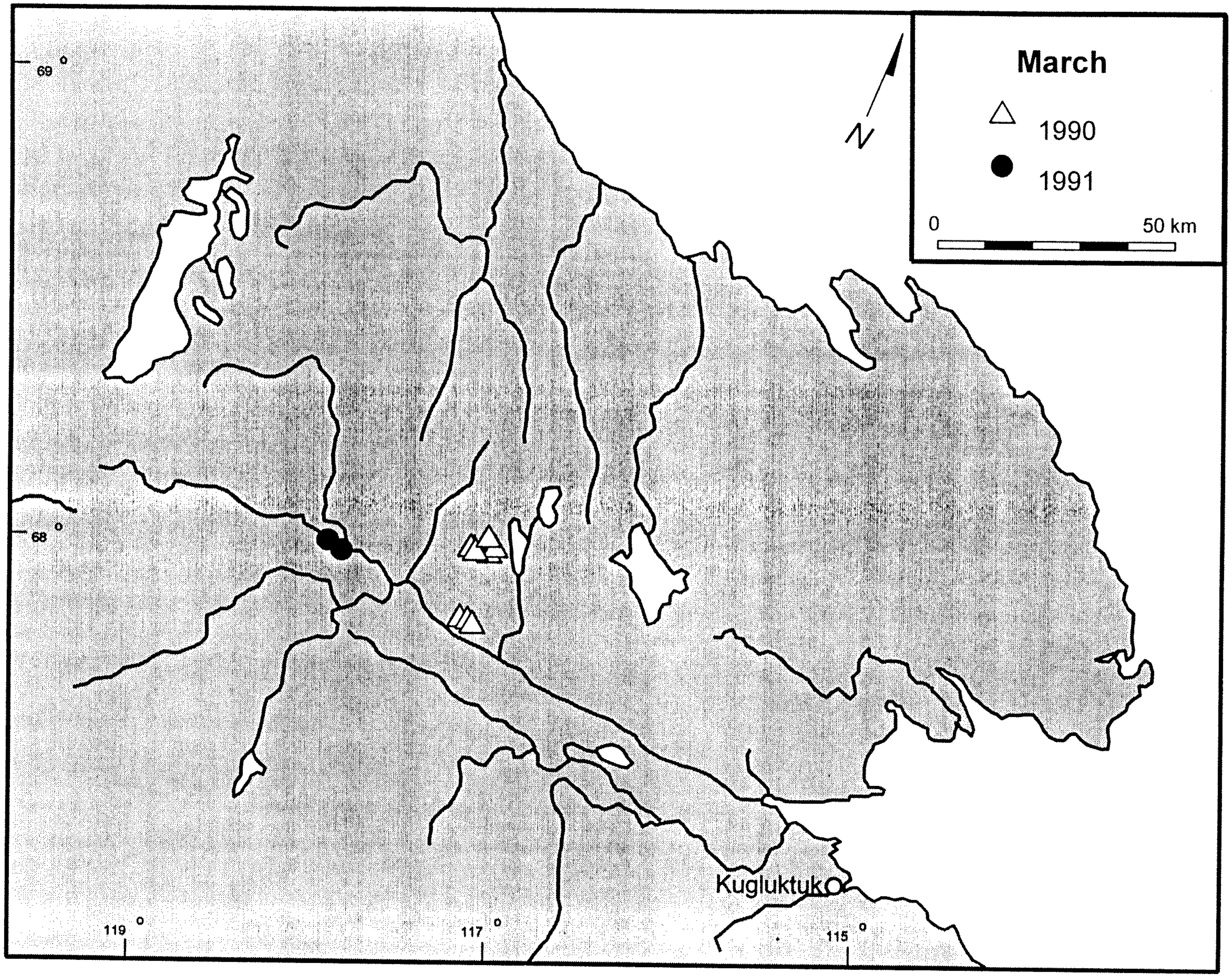

Figure 3. Locations of radio-collared muskoxen in March, 1990-91.

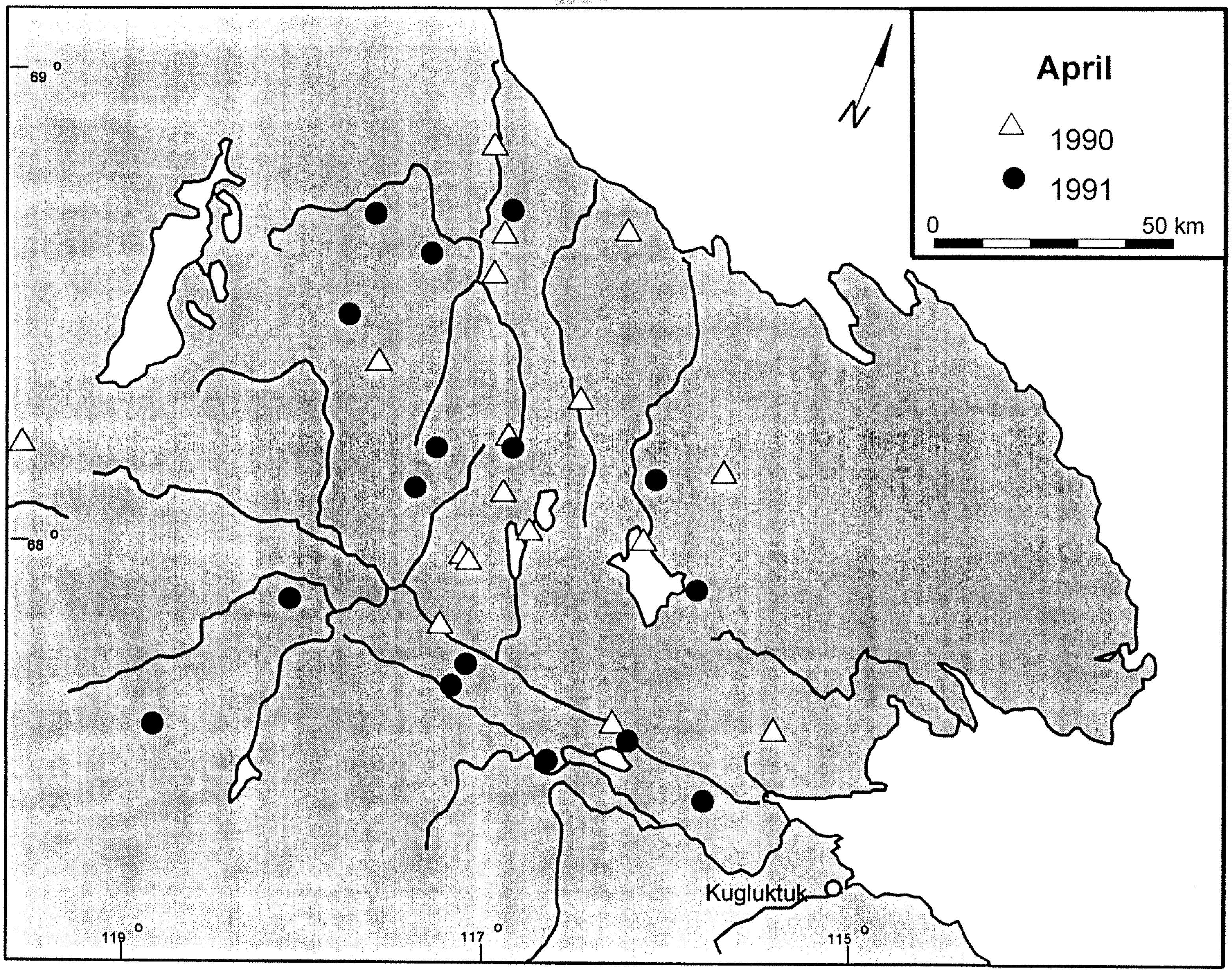

Figure 4. Locations of radio-collared muskoxen in April, 1990-91.

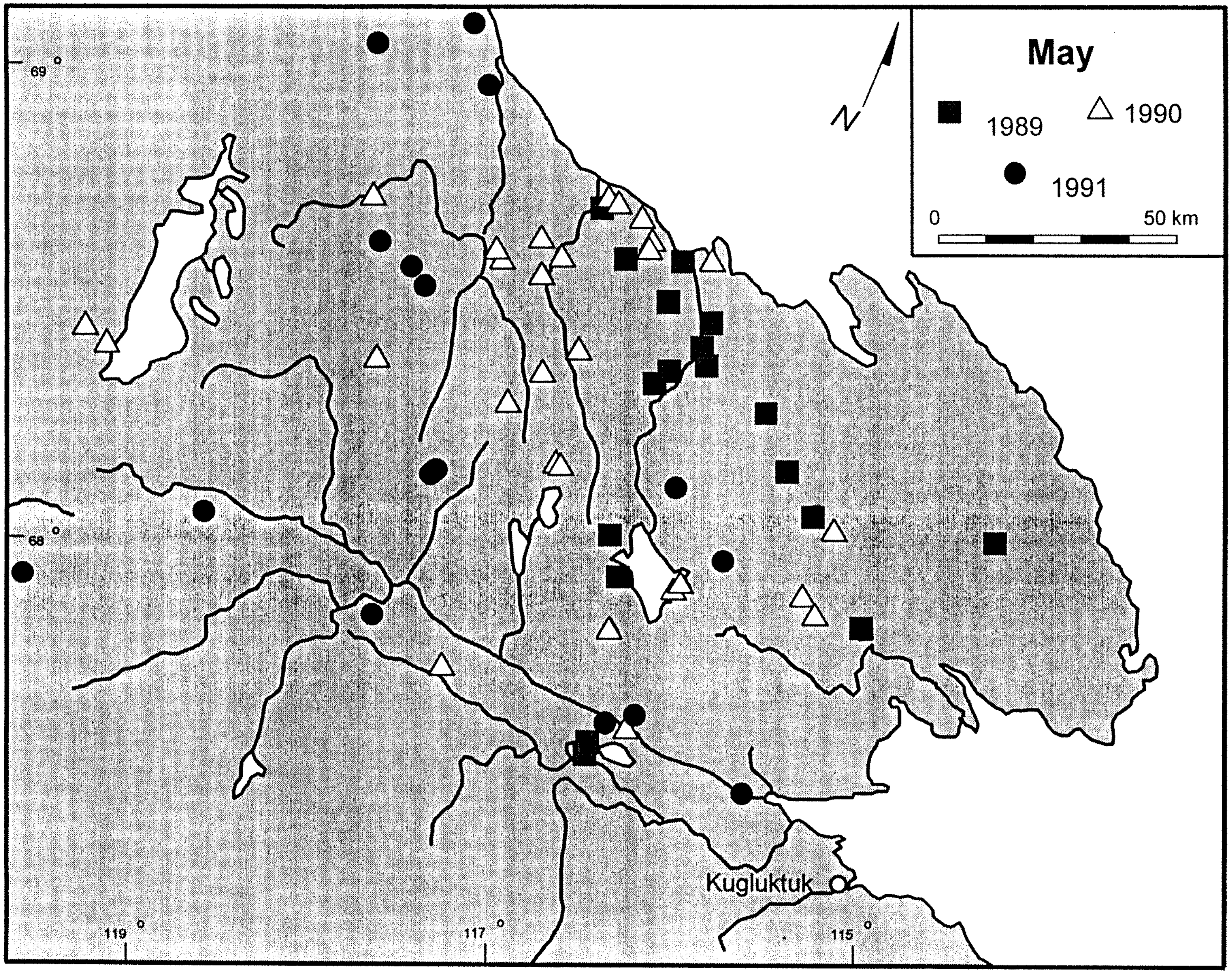

Figure 5. Locations of radio-collared muskoxen in May, 1989-91.

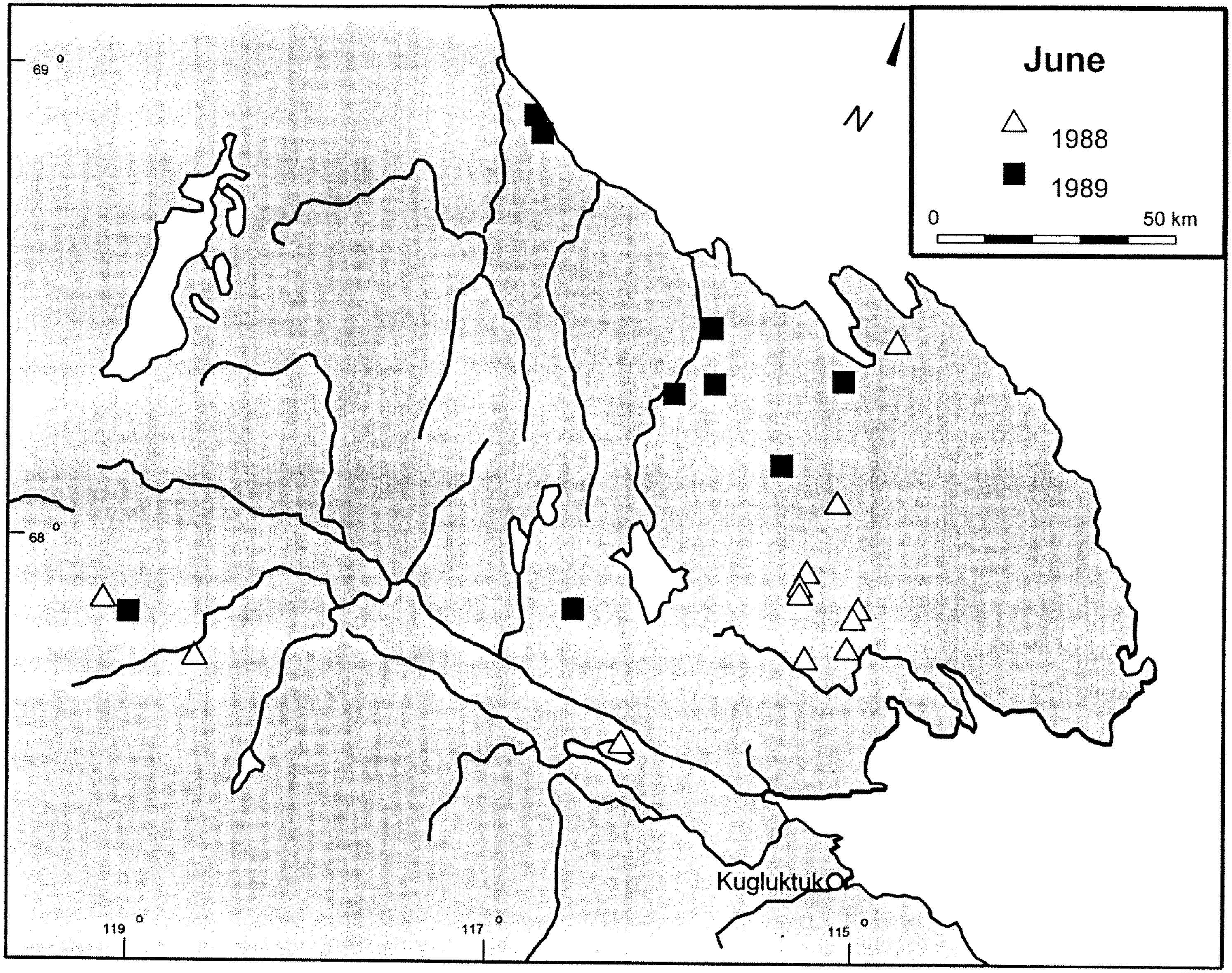

Figure 6. Locations of radio-collared muskoxen in June, 1988-89.

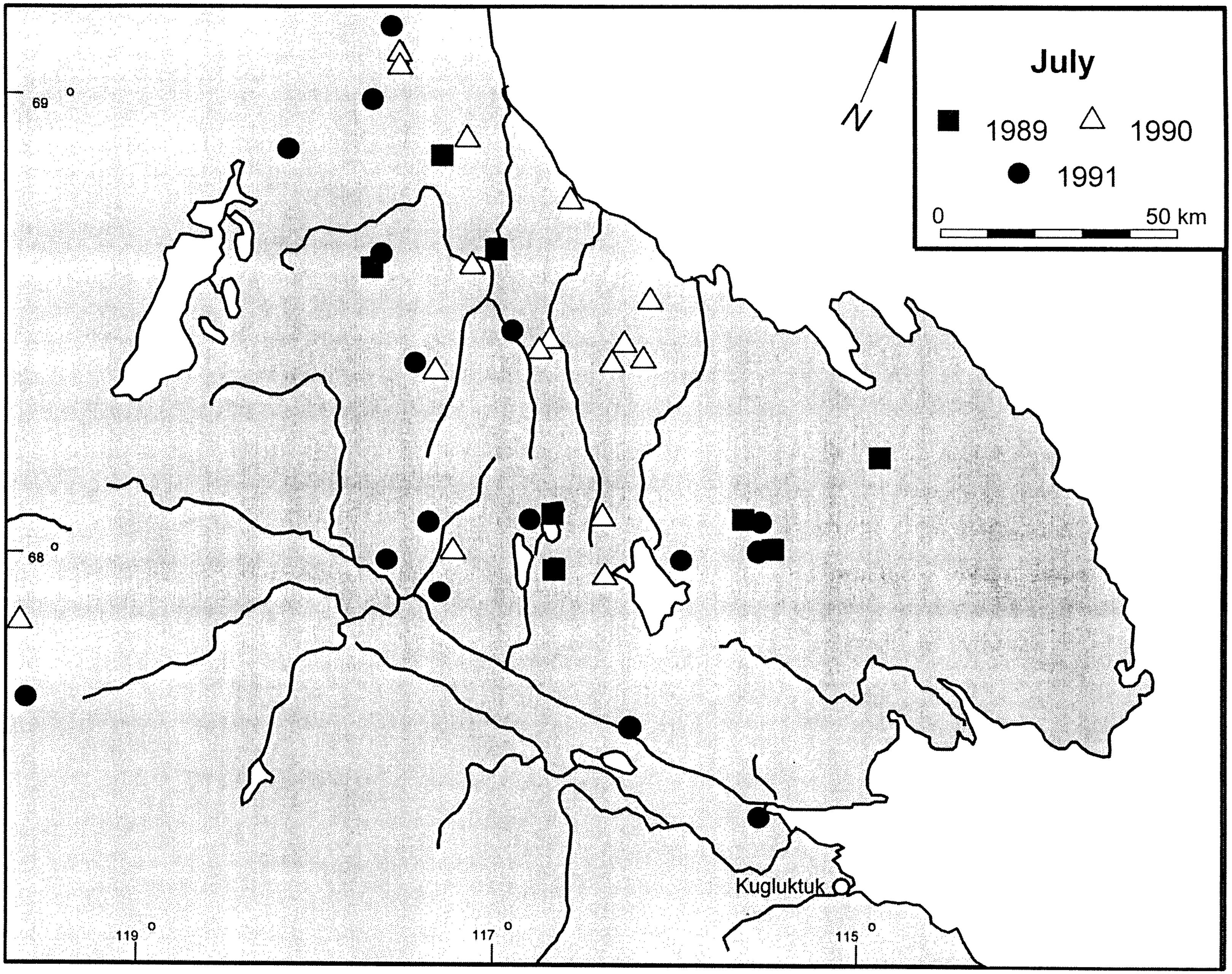

Figure 7. Locations of radio-collared muskoxen in July, 1989-91.

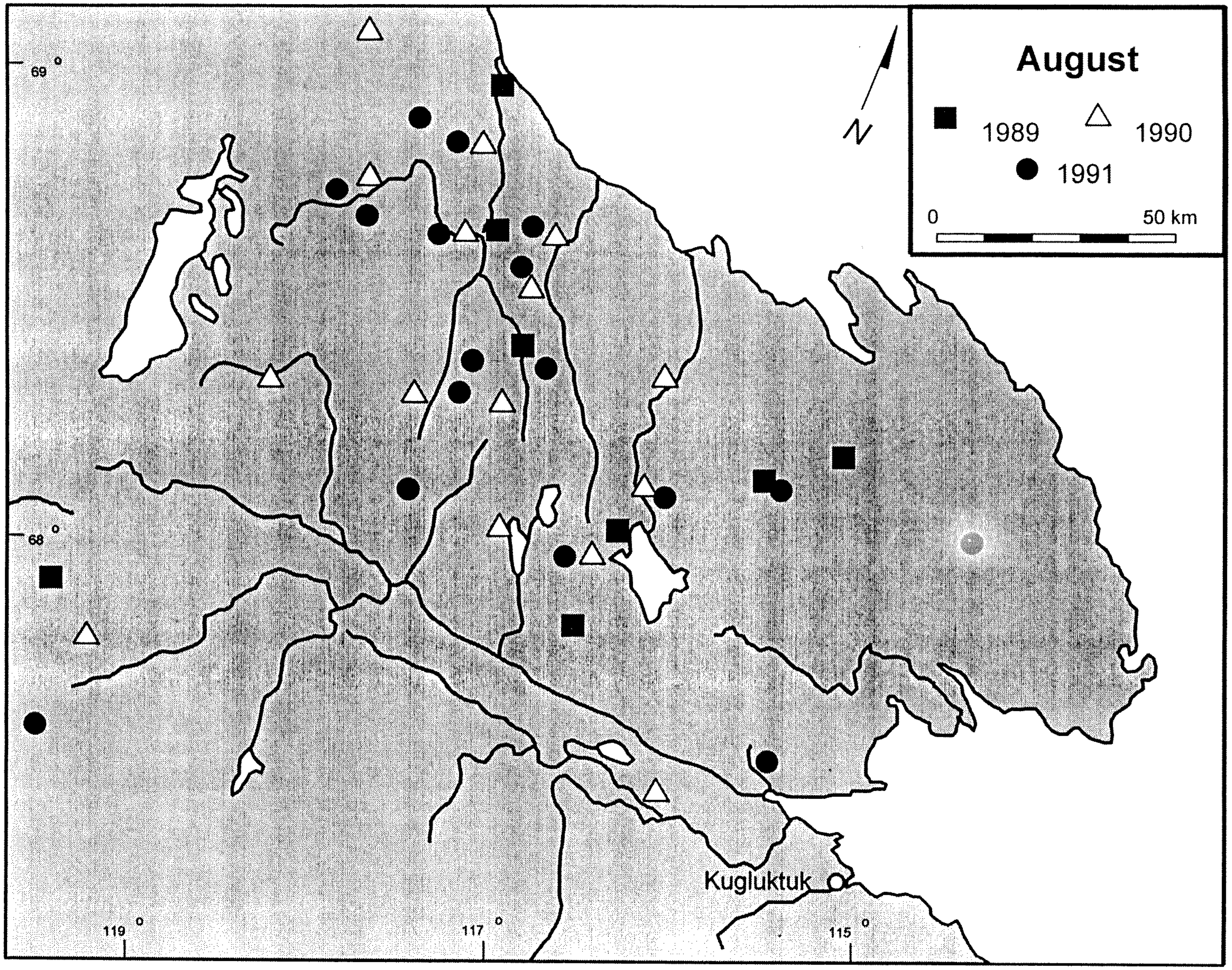

Figure 8. Locations of radio-collared muskoxen in August, 1989-91.

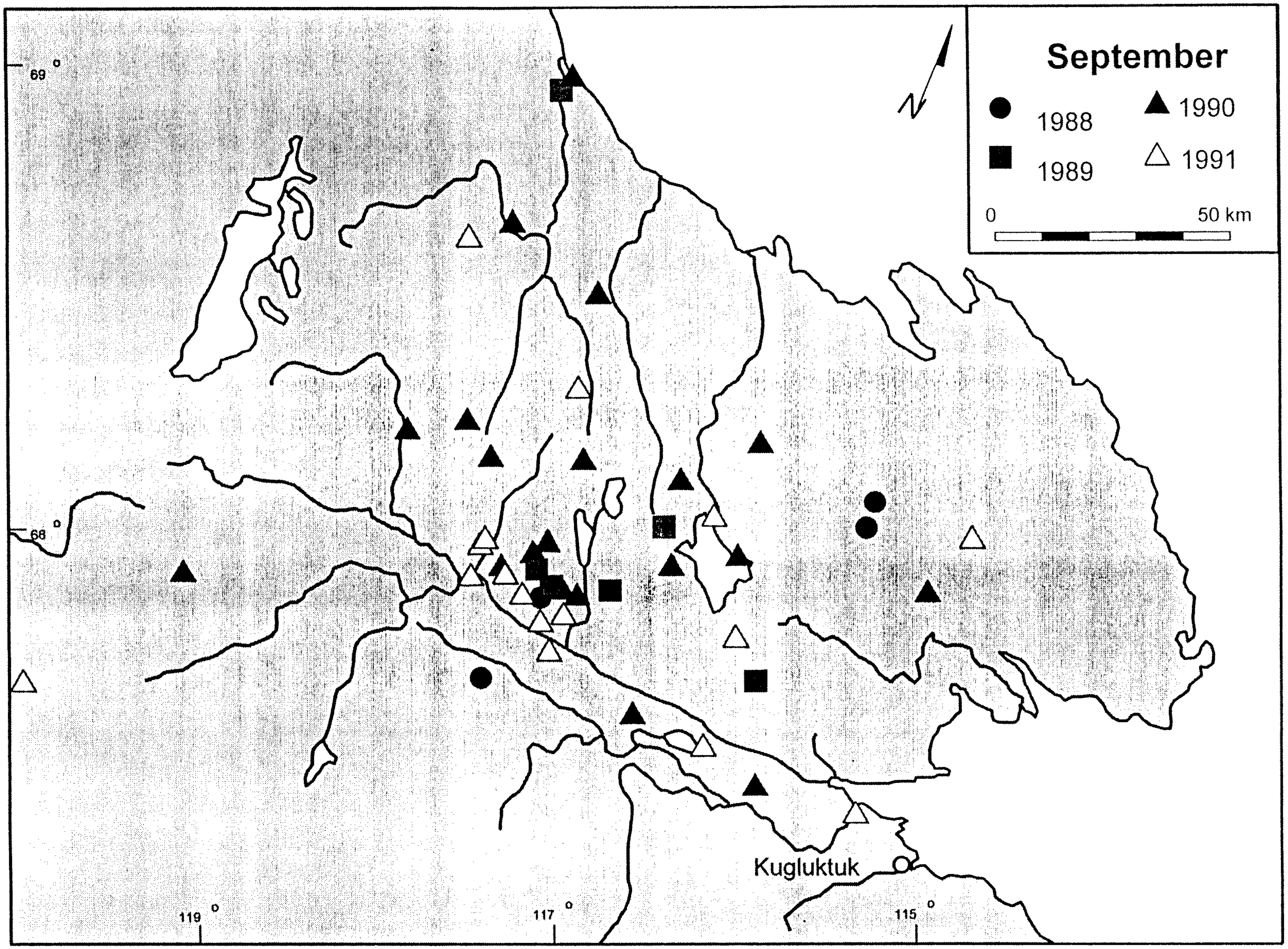

Figure 9. Locations of radio-collared muskoxen in September, 1988-91.

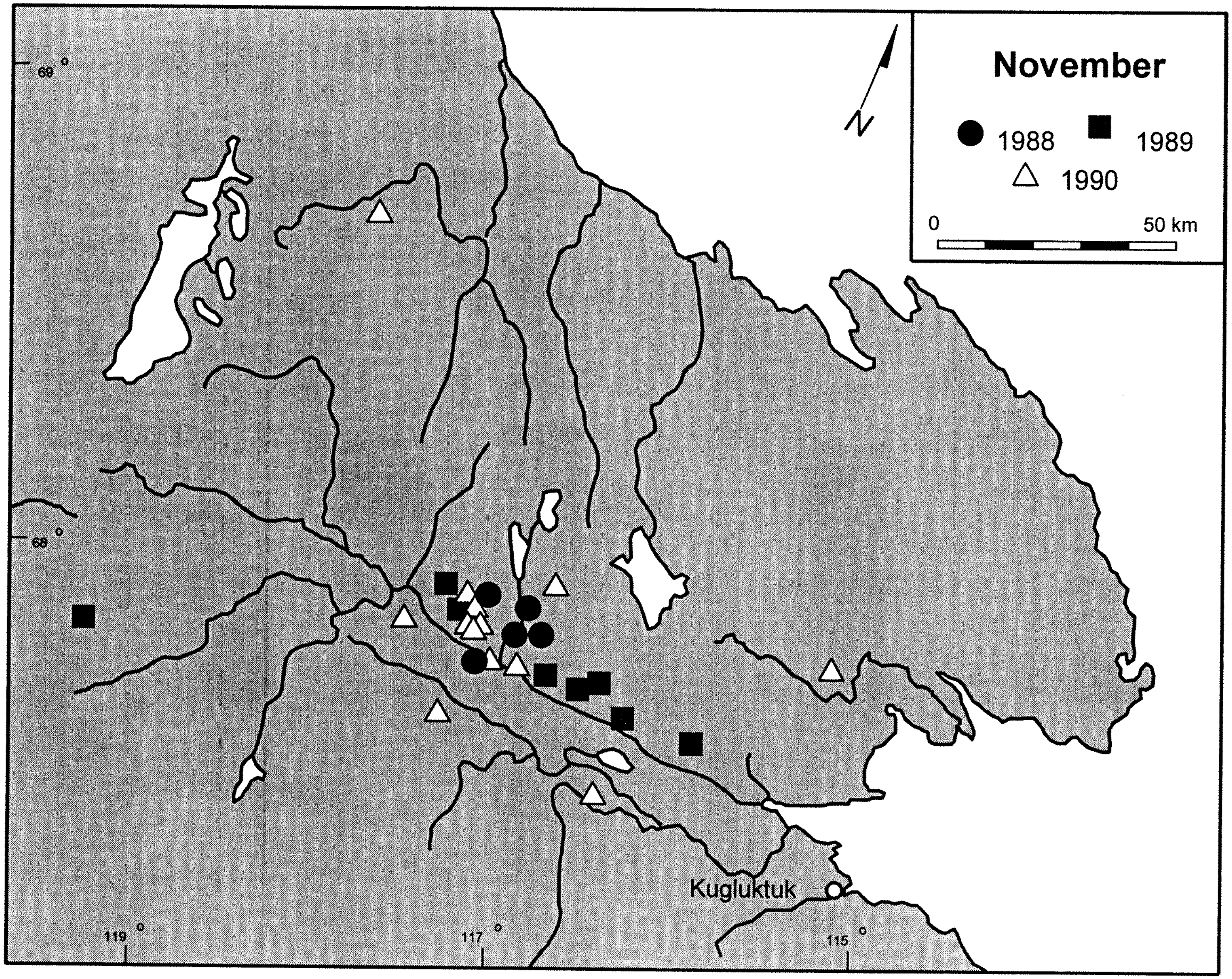

Figure 10. Locations of radio-collared muskoxen in November, 1988-90.

The monthly mapped locations (Figures 3-10) illustrate the seasonal patterns of movement for the collared muskox cows. The cows concentrated in the Rae-Richardson river valley in March and dispersed in April, with most cows moving north to the coast until September when they returned to the Rae-Richardson river valley. The percentages of collared muskox within 5, 10, and 15 km north and south of the Rae and Richardson rivers changed by month and year (Tables 4 and 5).

The proportion of radio-collared cows in the Rae-Richardson river valley changed between July and November in 1989 and 1990 (Tables 4 and 5). From June to August 1988-1990, 75-100% of the radio-collared cows were >15 km from the Rae-Richardson rivers. By contrast, 100% and 72% of the radio-collared muskoxen were < 5 km from the Rae-Richardson rivers in November 1989 and 1990, respectively.

Table 4. The monthly distribution of radio-collared muskox cows (%) by distance intervals from the Rae-Richardson rivers, 1988 and 1989.

Month	1988				1989			
	<5 km	5-10 km	10-15 km	>15 km	<5 km	5-10 km	10-15 km	>15 km
March	-	-	-	-	-	-	-	-
April	-	-	-	-	-	-	-	-
May	-	-	-	-	0	0	0	100
June	0	0	0	100	0	0	0	100
July	-	-	-	-	0	0	0	100
August	-	-	-	-	0	0	14.3	85.7
Sept.	0	0	0	100	0	0	66.7	33.3
Oct.	-	-	-	-	0	0	0	100
Nov.	-	-	-	-	100	0	0	0

Table 5. The monthly distribution of radio-collared muskox cows (%) by distance intervals from the Rae-Richardson rivers, 1990 and 1991.

Month	1990				1991			
	<5 km	5-10 km	10-15 km	>15 km	<5 km	5-10 km	10-15 km	>15 km
March	30	0	60	10	100	0	0	0
April	5.6	0	0	94.4	14.3	19.0	0	66.7
May	6.3	0	3.2	90.5	23.8	0	0	76.2
June	-	-	-	-	-	-	-	-
July	0	5.6	11.2	83.3	20	0	5	75
August	5.9	0	0	94.1	5.3	5.3	0	89.4
Sept.	24.9	0	18.8	56.3	52.6	5.3	0	42.1
Oct.	-	-	-	-	-	-	-	-
Nov.	72.0	5.6	0	22.4	-	-	-	-

Seasonal Dispersion of Collared Muskox Cows

The hypothesis that seasonal dispersion (distance between a focal cow and the other cows) would significantly change between summer (July) and early winter (November) was only partially supported. The mean distance between cow #200 and the other cows was 48 - 74 km in July and 24 - 30 km in November (Table 6, Appendices D, E). This measure of seasonal dispersion between the cows and cow #200 was significant in 1989 (t-test, df = 13, t = 2.29, P = 0.04) but not in 1990 (Mann Whitney Rank Sum Test, t = 298, P = 0.135). The decrease in distance in November reflects the clumping of muskox herds as well as the seasonal increase of herd size compared to the dispersed distribution and smaller herds in July (Table 2).

Table 6. Mean distance (km) between Cow #200 and other radio-collared cows in July and November, 1988-91.

Year	Distance between Cow #200 and other cows Mean ± Standard Error (number of cows)	
	July	November
1988	--	24 ± 13.4 (6)
1989	60 ± 12.6 (7)	30 ± 6.6 (8)
1990	48 ± 9.2 (16)	27 ± 6.4 (17)
1991	74 ± 7.9 (19)	--

Association Between Individual Cows

Cow #200 was associated with 5 other cows between 1989 and 1991 (Table 7). Distances to these other cows in November and July ranged from 1-72 km (Table 8).

Table 7. Radio-collared muskox cows observed in the same herd as Cow #200.

Cow #	Date of observation with Cow #200
010	May, June 1989
030	November 1990
051	August, September 1991
070	May 1990
320	April, May 1990; April, May 1991

Table 8. Distance (km) between Cow #200 in July and November 1988-91 and other cows she was observed with during other months of the year.

Year	Distance (km) from Cow #200 in July		Distance (km) from Cow #200 in November	
	Cow #	Distance (km)	Cow #	Distance (km)
1988	-	-	070	< 1
1989	030	71.6	030	31.3
	050	43.7	070	11.3
1990	030	34.7	030	0.3
	070	16.6	070	21.8
	-	-	320	13.2
1991	030	52.1	-	-
	070	29.1	-	-
	320	18.7	-	-

Seasonal Distances Traveled

Radio-collared cows varied in the furthest extent that they moved from the Rae-Richardson River valley in the summer (Table 9 and Appendix F). The straight-line summer-winter distances did not vary significantly between 1989, 1990 and 1991 (Kruskal Wallis ANOVA on ranks, H=0.79, P= 0.67). The mean maximum straight-line distance between summer (July) and winter (November) locations were most similar in 1989 and 1990 (Table 9). In 1991, the average maximum distance was less than the mean for the previous 2 years, but this calculation excludes the maximum distance of 4.76 km for Cow #400. In 1991, Cow #400 did not move away from Emagyok Lake, which is in contrast to her movements in 1990 (Appendix F) when the maximum straight-line distance between summer and winter locations was 138.5 km. The mean maximum straight-line distance for 1991, excluding Cow #400, was 75.6 ± 10.8 km (Table 9).

Table 9. Maximum straight-line distance (km) between winter (Nov. or Sept.) and summer (July) locations of radio-collared muskox cows in the Rae-Richardson river valley.

Cow #	Maximum distance winter to summer (km)		
	1989	1990	1991
18	70.1	84.7	60.4
30	83.0	83.0	69.5
51	-	96.6	44.1
70	82.6	94.6	69.2
90	74.2	70.5	92.7
120	116.5	126.1	28.8
141	-	61.3	-
161	-	56.1	41.6
200	85.2	82.0	99.0
220	-	137.8	20.3
240	-	114.8	89.0
260	-	60.9	126.5
280	-	109.3	135.1
300	-	69.6	123.6
320	-	69.7	47.0
341	-	-	109.8
342	-	23.7	27.2
360	-	74.6	41.6
381	-	-	76.0
400	-	138.5	4.8
Mean ± SE	85.3 ± 6.7	85.3 ± 9.2	75.6* ± 10.8

* excluding Cow #400

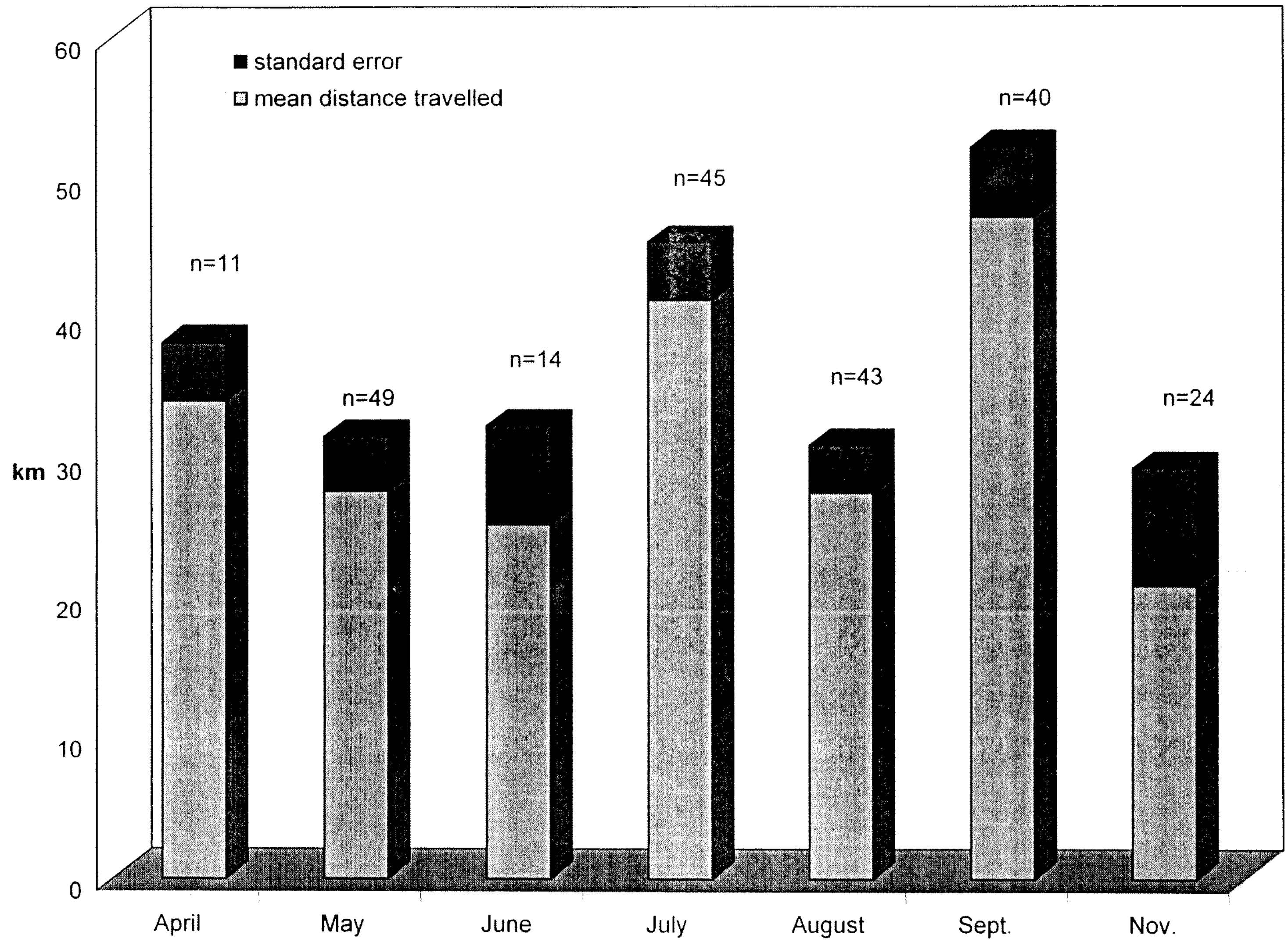

Figure 11. Histogram of mean monthly straight-line distances (km) traveled by radio-collared muskox cows, 1989-91

Differences in mean daily rates of travel between seasons within each year were significant (Table 10). The rate of travel was highest in summer (July - September) as compared to spring (April, May, June) and winter (November). Based on the mean monthly distance (Table 11 and Figure 11), the cows traveled the least during May, June, August and November and the most during July and September.

Table 10. Mean daily rate of travel (km/day ± standard error) between seasons.

	Mean ± standard error rate of travel, km/day (sample size)			Kruskal-Wallis ANOVA on ranks
	Seasons			
Year	April, May, June	July, Aug., Sept.	Nov.	
1989	0.7 ± 0.2 (21)	1.4 ± 0.2 (20)	0.6 ± 0.2 (6)	P=0.007
1990	1.1 ± 0.2 (27)	1.2 ± 0.1 (50)	0.8 ± 0.2 (18)	P=0.028
1991	0.9 ± 0.2 (23)	1.3 ± 0.1 (58)	-	P=0.047

Table 11. Mean monthly distance travelled, km ± standard error (sample size), for radio-collared muskox cows, 1989-91.

Month	1989	1990	1991
April	-	31.0 ± 4.4 (9)	47.8 ± 4.5 (2)
May	18.9 ± 8.5 (10)	34.7 ± 7.0 (9)	26.2 ± 5.2 (21)
June	26.8 ± 9.6 (11)	-	-
July	46.8 ± 9.2 (8)	46.1 ± 7.5 (17)	35.7 ± 5.7 (20)
August	36.1 ± 7.0 (8)	20.9 ± 4.0 (16)	29.6 ± 6.1 (19)
September	52.1 ± 11.8 (4)	39.2 ± 8.0 (17)	51.3 ± 7.9 (19)
November	18.7 ± 6.6 (6)	24.7 ± 5.2 (18)	-

The mean monthly distance traveled (Table 11) varied most among years in November between 1989 and 1990. Mean monthly distances traveled did not differ significantly between years (ANOVA, P= 0.48). Individual movements in 1989 and 1990 were not significantly different (ANOVA, p=0.89 and Kruskal-Wallis ANOVA on Ranks, P=0.52, H=17.0, 18 df). In 1991 there was a significant difference in individual movement (Kruskal-Wallis ANOVA on Ranks, P=0.03, H=31.5, 18 df), but when the movements of Cow #400 in 1991 were not included in the analysis, the differences were not significant (Kruskal-Wallis ANOVA on Ranks, P=0.054, H=27.3, 17df.). In 1991 the individual movements of Cow #400 (Appendix F) were close to Emagyok Lake and she did not move to the coast as she did in 1990.

Size and Overlap in Seasonal Ranges

The size of the seasonal ranges (all years combined) was smallest in winter (November and March) and largest in July (Table 12 and Figure 12). The decline in June was likely a consequence of the small sample size. This analysis excluded the movements of Cows #342 and #120 because their movements were west-east, rather than north-east.

Table 12. Size of areas within which radio-collared muskox cows from the Rae-Richardson river area, NWT, were located by month (years combined).

Month	Area (km^2)	Month	Area (km^2)
March	1165	July	13815
April	8965	August	9692
May	10348	September	5571
June	5549	November	2494

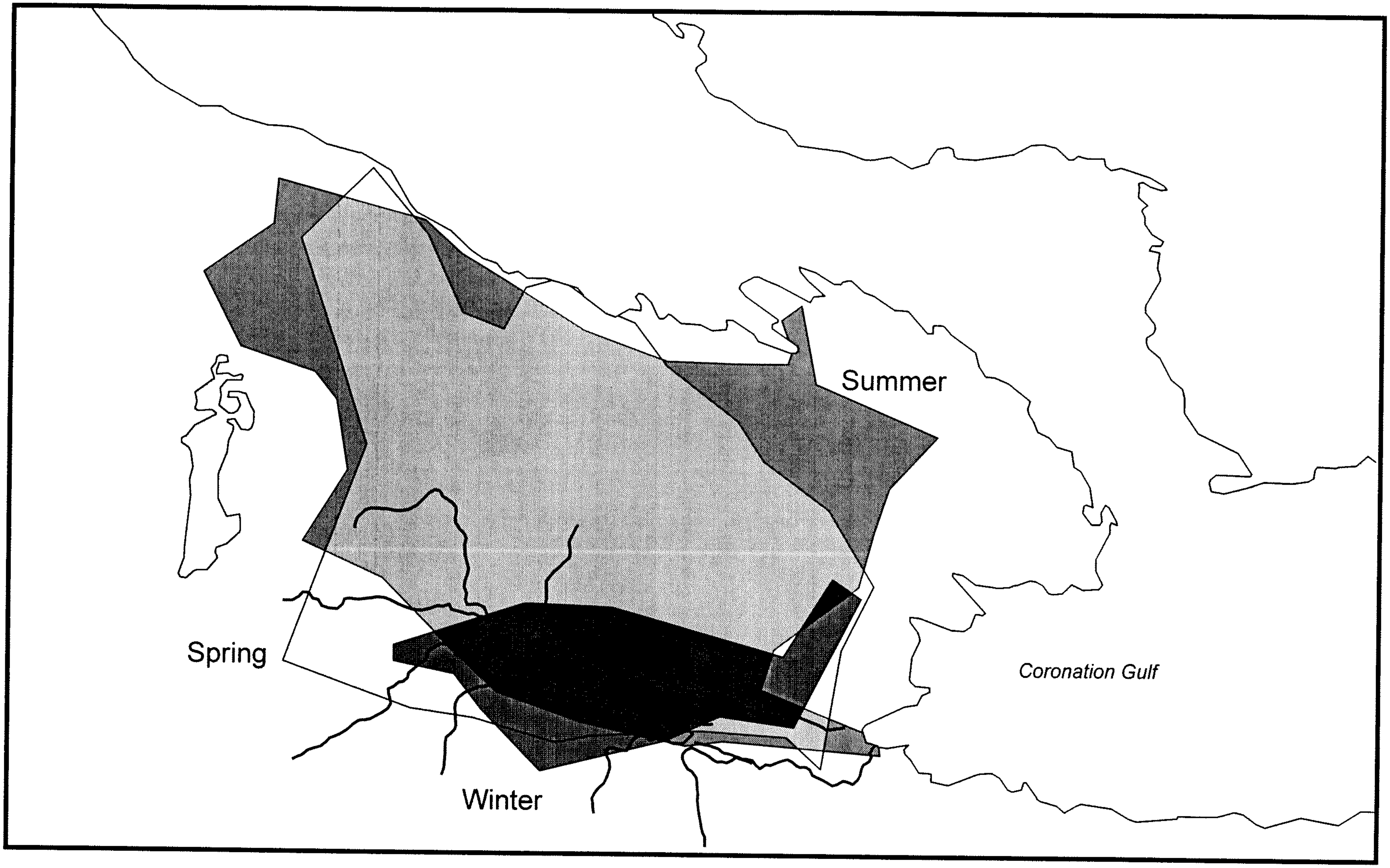

Figure 12. Seasonal overlap of ranges of the radio-collared muskox cows in the Rae-Richardson river valley, 1989-91.

Based on an arbitrary 80% overlap for the above months (Appendix H), we grouped April and May as spring (for a total spring range of 14 021 km^2); June, July, August, and September as summer (15 025 km^2) and November and March as winter (3 074 km^2).

The total area covered by spring and summer ranges had an overlap area of 68.3% (Table 13). Most (70-92.5%) of the winter range overlapped summer and spring ranges (Table 13) but the percentage of overlap of spring and summer ranges with the winter range was small because of the difference in the seasonal range sizes. This is consistent with our hypothesis that cows concentrate in the river valley in winter and are more dispersed in late winter and throughout the summer.

Table 13. Overlap between seasonal ranges used by radio-collared muskox cows (years combined), Rae-Richardson river area, NWT.

Seasonal ranges compared	% overlap within individual ranges	% overlap of combined ranges
spring	84.1	spring/summer (68.3)
summer	78.4	
spring	20.3	spring/winter (20.0)
winter	92.5	
summer	14.3	summer/winter (13.5)
winter	70.0	

The seasonal ranges of Cows #120 and #342, which moved east-west instead of north-south, did not overlap, except for a small part of the spring range (Figure 13). Based on an arbitrary 80% overlap, four seasonal ranges were studied: April, spring (May, early June), summer (late June, July, Aug., early Sept.) and winter (November, March). The winter range was largest for Cow #342, while the spring range was largest for Cow #120. The greatest range overlap for Cow #120 occurred between the summer and winter ranges (26.7%, Table 14). The greatest range overlap for Cow #342 occurred between the April and winter (20.6%, Table 15). This cow's spring range was entirely inside the larger winter range (Figure 13).

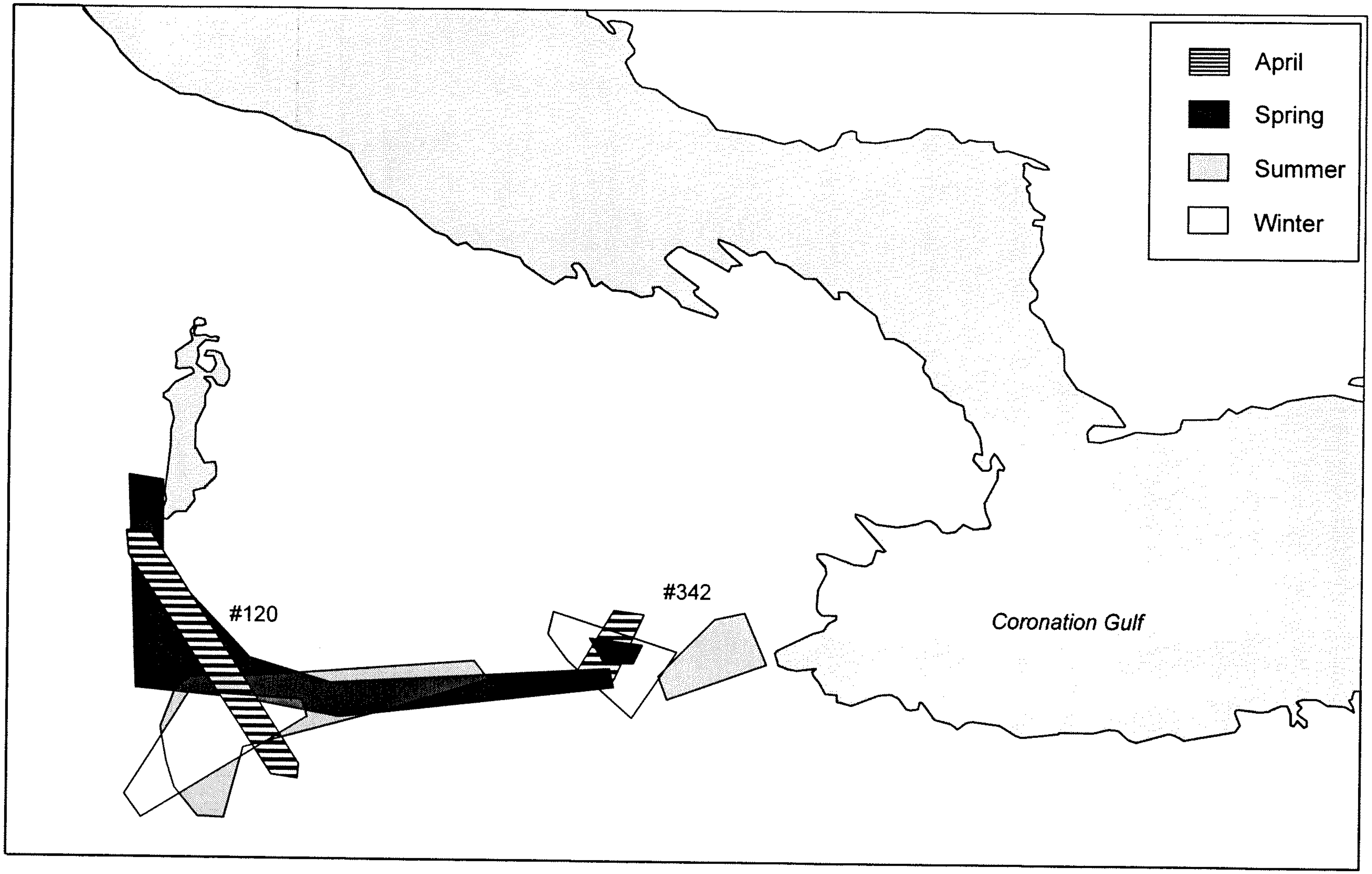

Figure 13. Seasonal range overlap for Cows #120 and #342 in the Rae-Richardson river valley, 1989-91.

Table 14. Overlap of seasonal ranges for Cow #120, 1989-90.

	Area (km^2)	% Total overlap		
		spring	summer	winter
April	731.5	17.2	7.9	8.5
spring	2060.5	-	16.4	1.6
summer	1734	-	-	26.7
winter	909.3	-	-	-

Table 15. Overlap of seasonal ranges for Cow #342, 1989-90.

	Area (km^2)	% Total overlap		
		spring	summer	winter
April	226.9	17.6	0	20.6
spring	72.2	-	0	11.7
summer	415.2	-	-	0
winter	544.8	-	-	-

Mortality of Radio-collared Cows

The first death documented was a radio-collared cow found dead on 6 June 1988, 2 days after drug immobilisation. The actual cause of death was likely rumen impaction. Four cows died in 1989 (Figure 2 and Appendix I): a grizzly bear was straddling the carcass of Cow #140 and her injuries were consistent with predation; two other cows (#050 and #010) were probable grizzly bear kills based on the state of the scattered remains (Appendix I); and Cow 160 probably died from complications with a lungworm infection.

In 1990, Cow #340 was probably shot approximately one month after collaring. In 1991, two cows died. Cow #030 died in July 1991 and was a suspected grizzly bear kill, based on the state of her scattered remains. Cow #141 died in May 1991 but we did not reach the carcass until July, at which time we found a few bone fragments of the cow and a new-born calf. We suspect grizzly bear predation, although we cannot rule out the possibility that a bear scavenged the remains.

The three cow carcasses that were intact enough to autopsy had lungworm cysts. The first cow that died in 1988 of probably rumen impacton had at least 30 lungworm nodules and probable pneumonia. Cow #140, found dead on 12 August 1989, was a grizzly-killed cow with numerous (50+) nodules in her lungs. Cow #160, which died in October 1989 (probably from pneumonia associated with a lungworm infection), had an estimated 50 protostrongylid nodules.

DISCUSSION

The seasonal movements of the radio-collared muskoxen revealed that the herds concentrate along the Rae-Richardson river valley in early winter and then scatter toward the north coast by early April, returning to the valley between September and November. Both dispersion and distance from the Rae-Richardson river valley changed significantly between seasons.

There is relatively little information on muskox seasonal migrations. Tener (1965) noted that muskoxen did seasonally move between winter and summer ranges but that the movements varied annually with environmental conditions and density. However, density may influence dispersal more than migration. Tener (1965) commented that his observations and those reported in the literature suggested that seasonal movements were usually short - up to 80 km and sometimes summer and winter ranges are adjacent or overlap. Tener (1965) did not have the advantage of marked individuals to determine migratory behaviour, but even with radio-telemetry there have been few studies of muskox migration.

Reynolds (1998) used both radio and satellite tracking to determine that muskoxen introduced to Alaska's North Slope used seasonal ranges that were separated by 20 – 30 km on average. The maximum distances (straight-line) moved were up to 114 km between calving and summer range on the North Slope compared to 140 km in our study. In Alaska, monthly rates of travel were highest in summer, which is comparable to the findings of study.

Tener's (1965) comment that muskoxen on the arctic islands had shorter seasonal migrations than muskoxen on the mainland is supported by data from Banks Island where radio-tracked muskox cows seasonally migrated over shorter distances. Radio-tracking was less frequent, as McLean and Fraser (unpubl. data) only radio-tracked in March, May, August and November or

December each year between October 1985 and August 1987. During that period, seasonal ranges were adjacent or overlapping, as 13 of the 20 collared cows remained within a 50 km radius circle of their capture location and all relocations were within an 80 km circle. The straight-line distances between successive relocations (Table 16), calculated from McLean and Fraser's unpublished data, suggested that the muskoxen moved further between May and August but that the distances moved by individual cows between December or November and March varied the most (Table 16).

Table 16. Straight-line distances between successive locations of radio-collared muskoxen, Banks Island, 1985-87.

Distance Travelled (km)	1985	1986				1987		
	Dec	Mar	May	Aug	Nov	Mar	May	Aug
Mean	24.7	12.7	11.5	35.11	27.4	23.4	22.09	38.49
Coefficient of Variation	15.5	26.7	16.2	13.4	16.1	26.3	14.0	11.9
Maximum	70	71	32	73	73	106	50	84

Inuit hunters report that muskoxen migrate to the coast of west Bathurst Inlet in June and return to more elevated rocky areas in late July (Gunn 1990). The muskoxen were probably following the pattern of willow (*Salix spp.*), whose leaves unfurl earlier on the coast. Robus (1981) described seasonal foraging patterns for muskoxen on the Alaskan North Slope and noted these seasonal shifts in distribution, which are described in more detail in Reynold's (1998) report on radio-collared muskoxen.

Relatively little information has been reported on seasonal movements of muskoxen in the Northwest Territories. We suggest that the seasonal migrations we described for west of Kugluktuk were a response to the terrain and its effect on snow conditions. Muskox choice of feeding sites is responsive to snow conditions (for example Schaeffer and Messier 1995) and we surmised that their winter movements could be explained, at least partly, in terms of changing snow conditions.

The Rae-Richardson river valley is about 30 km wide, lies below 500 m, agl and is composed of tundra with many willow thickets and dwarf birch. The only measure we have for snow conditions in the Rae-Richardson River valley is an index derived from average snow-water equivalent measurements for the area based on the period 1979-90 (Figure 14). Those measurements reveal a north-south gradient, with more shallow snow toward the coast. We speculate from those data and our personal observations of snow conditions in the valley that the snow is deeper in the valley but less wind packed and the muskoxen forage among the stands of willow (*Salix)* and birch (*Betula)*. However, at the end of March the snow in the valley becomes denser and crusted due to daytime warmth. In comparison, the area north of the valley rises to higher than 500 m above sea-level (Figure 1), is composed of wet sedge patches interspersed with limestone outcrops, and contains snow that tends to be more shallow and wind-packed.

We suggest that the late winter migration is a response to snow conditions, as the movements preceded spring plant growth. The muskoxen leave to calve on windblown areas free of snow and areas where the snow leaves the ground earlier than in the valley. Foraging in these areas would be less energetically costly, and cows and newborn calves would be less vulnerable to predators. Snow depth and hardness are important criteria for muskoxen selecting feeding sites.

Two cows and their herds, however, had seasonal movements that differed from this pattern. Cow #120 moved east-west along the valley in 1988 and 1989, and then in 1990-91 her seasonal movements were in a relatively small area in the

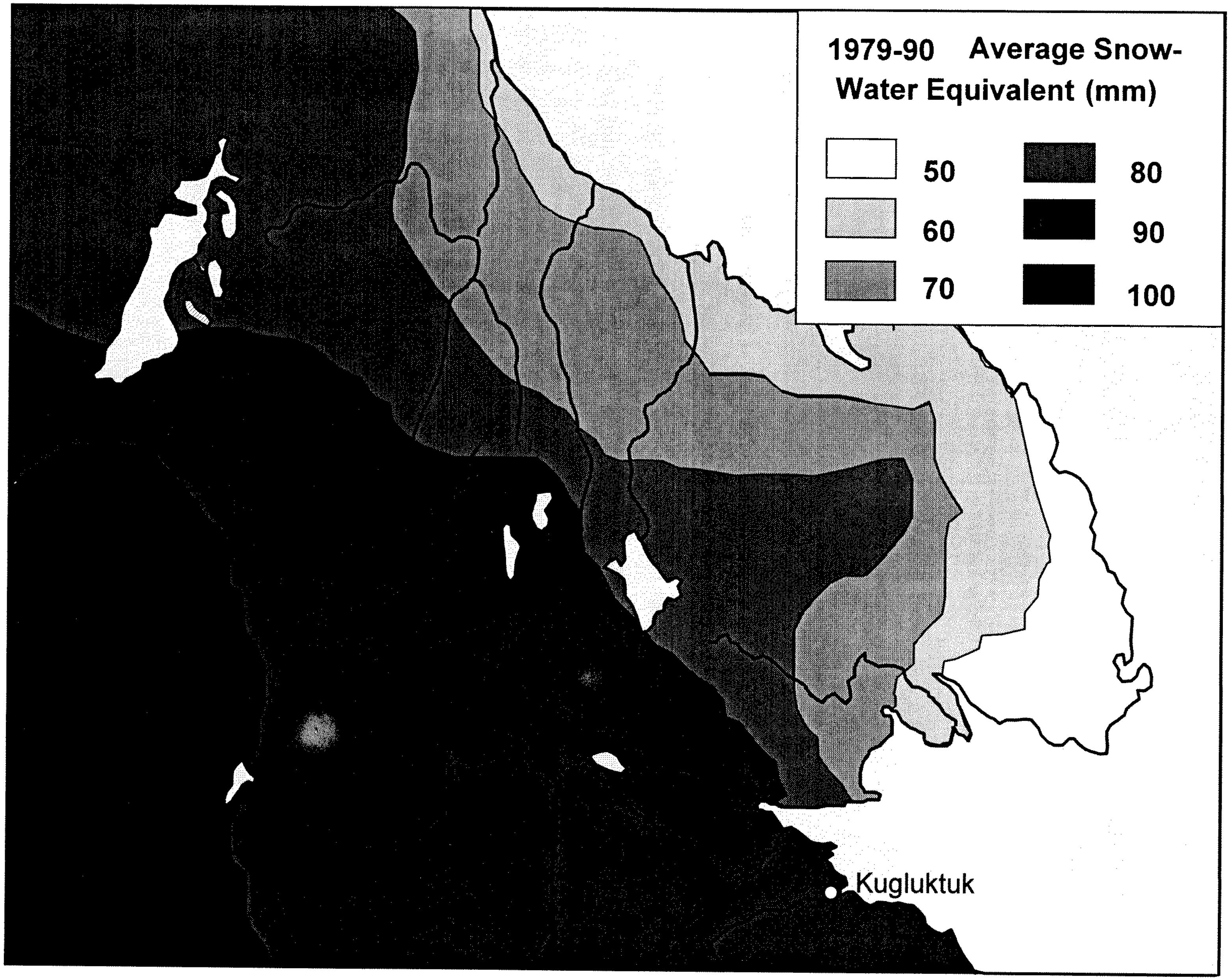

Figure 14. 1979-90 average snow-water equivalent in the Rae-Richardson river area.

headwaters of the Rae River. Cow #342 also moved east-west along the valley but further to the east, demonstrating this pattern for 2 years.

One objective of the radio-collaring project was to investigate whether calf survival declined during the summer, but we found that calf survival was only significantly reduced during the summer in 1989. However, the comparison is based on July with November, as the proportion of calves was highest in July. We cannot distinguish whether we missed seeing calves in May or whether calves were born later than May; elsewhere most muskox calves are born in late April and early May.

At the beginning of the study, we had believed that the proportion of calves seen during the aerial surveys was relatively low since, in August 1987, the proportion of calves was 11.0% during ground classifications of 235 muskoxen. Among the herds with radio-collared cows in July 1989 and 1990, the proportion of calves was 16.7 % and 14.0 %, respectively which, by November 1989 and 1990, declined to 8.4 % and 9.7 %, respectively. However, experience elsewhere during the study suggested that calf survival was also low elsewhere on the mainland, east of the Rae-Richardson river valley study area. For example, in the Queen Maud Gulf area east of Bathurst Inlet, the proportion of calves to total population was 10.3% and 14.7% in July-August 1988 and 1989, respectively (Gunn and Sutherland 1997), West of Bathurst Inlet, the proportion of calves seen during an aerial survey in August 1988 was 12.3% (Gunn 1990).

Predation on calves may have caused the relatively low proportion of calves on the mainland. Barren-ground grizzly bears and wolves frequent the Rae-Richardson river valley and some grizzly bears may have learnt to stampede muskox herds and take new-born calves, as has been observed further west (Clarkson and Liepins 1993). In the Rae-Richardson river valley, the remains of new-born muskox calves were visible in the stomachs of two male bears shot in

May 1991 (A. Atatahak pers. comm.). We also found the remains of a new-born calf with the bones of a radio-collared cow that was a suspected grizzly bear kill.

The discovery of a hitherto unknown lungworm in a radio-collared muskox cow found dead in June 1988 and in a radio-collared cow killed by a grizzly in 1989 added a new dimension to this study (Gunn and Wobeser 1992 and Appendix J). The lungworm was named and described as *Umingmakstrongylus pallikuukensis,* a new genus and species of protostrongylid nematode (Hoberg *et al.* 1995). The life-cycle, host range, geographic distribution in muskoxen and effect of this parasite on muskoxen were unknown at the time of this radio-collaring project, although subsequently Kutz (In Press) obtained much of this information.

We believed that the lungworm contributed to muskox deaths. The lungworm cysts reduce functional lung volume, and muskoxen with heavy infestation would lag behind a herd when galloping away from a predator. Only one of the four radio-collared cows suspected to have been killed by grizzly bears was sufficiently intact to examine her lungs, and she had many lungworm cysts. The 14 sightings of solitary radio-collared cows is unusually high, as most solitary muskoxen seen during surveys are adult bulls, and may suggest that if those cows had a high number of lungworm cysts, they might have had difficulty keeping up with a herd. Three of 7 cows seen at one time as solitary were found dead during the 4-year study.

Grizzly bear predation on muskoxen is not unusual (Gunn and Miller 1982, Case and Stevenson 1991, Clarkson and Liepins 1993), but two of the three published references are from the area where muskoxen are infected with *Umingmakstrongylus pallikuukensis.* However, in Alaska where the lungworm is unrecorded, grizzly bears also kill muskoxen (P. Reynolds pers. comm.).

At the time of the radio-collaring study, we undertook an experimental treatment of the muskoxen for this parasite. The radio-collaring and pilot treatment studies were complementary in logistics, as the radio-collared cows served as a control (untreated group) to compare with the treated muskoxen (Appendix J). The pilot treatment was partially successful in that the technology for administering the treatment worked under cold field conditions. However, we did not demonstrate that the drug Ivermectin was effective against the lungworm, partly because sample sizes were low and partly because the drug levels may have been low (G. Wobeser pers. comm.) as we did not realize at the time that the lungworm was unknown to science.

An alternative or additional explanation for the low proportion of calves is that pregnancy rates were low. Towards the end of the radio-collaring project, we obtained data to suggest that this was a possibility. In March 1991, we sampled progesterone serum levels during muskox capture in the pilot treatment project (Appendix J). The progesterone levels were measured for 36 cows; 0.5 ng/ml was used as the threshold for late pregnancy. Cows (3+ years) with lower levels (13 cows) were assumed not to be pregnant, which indicated a low pregnancy rate of 36% in late winter. Although seven of the ten cows collected in November 1991 (Appendix J) were pregnant, intra-uterine losses are known for muskoxen and early winter pregnancy rates can decrease by late winter (Adamczewski 1995). For comparison, the muskoxen on south-east Victoria Island were not increasing in number between 1988 and 1993 and pregnancy rates based on carcass examination in March 1989-92 averaged 58 $\pm$ 8.6 % for cows >3 years (Adamczewski 1995).

Explanations for the low pregnancy rates of the muskoxen are speculative. Conventionally, reduced pregnancy rates are typical of populations whose numbers have increased and whose forage becomes limiting. However, without diagnostic information, we can neither support nor refute density dependence in the population.

We cannot rule out disease as contributing directly or indirectly to the low pregnancy rate. Muskoxen from the Rae-Richardson River population sampled during the captures for collaring or the pilot treatment were serum-positive for toxoplasmosis (Kutz *et al.* In Press), which is recorded as reducing pregnancy in other mammals. However the effects of toxoplasmosis in muskoxen are unknown as this is the first time it has been recorded.

When we started the radio-collaring study in 1988, we considered the numbers of muskox to be increasing or stable based on the estimated trend. However, subsequent surveys revealed that muskox numbers were declining during the study. Since the 1960s, muskoxen in the Rae-Richardson river valley had increased and spread east along the valley (Case and Poole 1985). The 1983 estimate was 1295 ± 279 (S.E.) and in 1986 we estimated 1,800 ± 290 muskoxen, but by 1994 the numbers had declined to 974 ± 336 (Nishi and Gunn, In Prep.). The observed low pregnancy rate and low calf survival contribute to explaining why muskoxen were declining in the mid-1990s. Sample size is too small to allow us to extrapolate the death rate among the collared cows to the entire population.

Determining the seasonal distribution contributes to effective survey design. Surveying in winter means the muskoxen are concentrated in a relatively small survey area but herds are large, which hinders accurate counting. The radio-collared muskoxen moved in April, which suggests that surveys would be best timed in March. In summer, the radio-collared muskoxen are more dispersed but herds are smaller. Each season offers its own advantages, and the choice of study period will depend on the objectives of the study and the trade-off between precision and accuracy.

The seasonal migrations of muskoxen west of Kugluktuk were over longer distances but also demonstrated similarities with the movements of the muskoxen on the

The seasonal migrations of muskoxen west of Kugluktuk were over longer distances but also demonstrated similarities with the movements of the muskoxen on the Alaskan North Slope, such as the timing (before calving) of the late winter migration. The seasonal migrations reflect the local terrain, vegetation, snow characteristics and mechanisms by which muskoxen balance forage acquisition with energy conservation.

ACKNOWLEDGEMENTS

We thank Drs Eric Broughton, Brett Elkin, Susan Tedesco and Gord Glover for their assistance with the field immobilisation under sometimes difficult conditions. We also appreciated the field skills of the capture crew who worked patiently with us for the safe muskox handling: Colin Adjun, Bobby Algona, Gerry Atatahak, Jack Atatahak, Keith Hickling, Isaac Klengenberg, Allen Niptanatiak and Alec Taptuna. We thank Patricia Reynolds (US Fish and Wildlife) and Brent Patterson (Department of Sustainable Development) for their detailed and helpful comments.

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Appendix A. Number of muskoxen counted during radio-collar relocations, 1988-91.

Month	Year	No. of muskox	No. of calves	Percent calves
June	1988	21	3	14.29
		27	7	25.93
		8	1	12.50
		4	1	25.00
		1	0	0.00
		1	0	0.00
		8	1	12.50
		1	0	0.00
		22	1	4.50
		1	0	0.00
		1	0	0.00
		1	0	0.00
Totals		**96**	**14**	**14.58**

Month	Year	No. of muskox	No. of calves	Percent calves
September	1988	39	7	17.95
		18	4	22.22
		21	0	0.00
		12	1	8.33
Totals		**90**	**12**	**13.33**
November	1988	50	0	0.00
		50	0	0.00
		15	0	0.00
		30	0	0.00
		30	0	0.00
		30	0	0.00
		18	0	0.00
Totals		**223**	**0**	**0**

Appendix A (cont).

Month	Year	No. of muskox	No. of calves	Percent calves
May	1989	33	5	15.15
		39	8	20.51
		15	1	6.67
		34	2	5.88
		5	0	0.00
		13	2	15.38
		24	3	12.50
		19	1	5.26
		19	1	5.26
		15	1	6.67
		6	1	16.67
		17	2	11.76
		15	2	13.33
		9	1	11.11
		12	3	25.00
		21	3	14.29
		38	5	13.16
		10	3	30.00
		8	1	12.50
		17	2	11.76
Totals		**369**	**47**	**12.74**
June	1989	22	1	4.55
		11	2	18.18
		1	0	0.00
		6	2	33.33
		22	5	22.73
		17	3	17.65
		4	1	25.00
		15	3	20.00
		15	3	20.00
		11	2	18.18
Totals		**124**	**22**	**17.74**
July	1989	4	0	0.00
		12	3	25.00
		19	4	21.05
		11	2	18.18
		6	3	50.00
		20	3	15.00
Totals		**72**	**15**	**20.83**

Month	Year	No. of muskox	No. of calves	Percent calves
August	1989	10	2	20.00
		13	2	15.38
		24	1	4.22
		9	2	22.22
		7	1	14.29
		12	3	25.00
		9	2	22.22
Totals		**84**	**13**	**15.48**
September	1989	10	2	20.00
		8	2	25.00
		19	2	10.53
		22	4	18.18
		20	3	15.00
Totals		**79**	**13**	**16.46**
October		18	0	0.00
		40	2	5.00
Totals		**58**	**2**	**3.45**
November	1989	18	0	0.00
		8	2	25.00
		24	3	12.50
		7	0	0.00
		83	5	6.02
		33	3	9.09
		33	3	9.09
		7	1	14.29
		24	3	12.50
		10	2	20.00
Totals		**247**	**22**	**8.91**

Appendix A (cont).

Month	Year	No. of muskox	No. of calves	Percent calves
March	1990	10	0	0.00
		20	0	0.00
		30	0	0.00
		30	0	0.00
		90	0	0.00
Totals		**180**	**0**	**0.00**
April	1990	10	0	0.00
		7	0	0.00
		11	0	0.00
		5	0	0.00
		13	0	0.00
		25	0	0.00
		13	0	0.00
		4	0	0.00
		17	0	0.00
		2	0	0.00
		24	0	0.00
		17	0	0.00
		17	0	0.00
		16	0	0.00
		27	0	0.00
		24	0	0.00
		1	0	0.00
		7	0	0.00
Totals		**240**	**0**	**0**
May	1990	13	2	15.38
		36	4	11.11
		32	0	0.00
		34	7	20.59
		14	1	7.14
		18	2	11.11
		36	4	11.11
		1	0	0.00
		5	1	20.00
		14	1	7.14
		7	1	14.29
		2	0	0.00
		36	4	11.11
		7	1	14.29
		7	1	14.29
		13	3	23.08
		6	1	16.67
		14	3	21.43
		9	0	0.00
		29	3	10.34
		17	1	5.88
		12	1	8.33
		31	5	16.13
		14	2	14.29
		29	3	10.34
		1	0	0.00
		5	1	20.00
		10	2	20.00
		2	0	0.00
		29	3	10.34
		10	2	20.00
		20	4	20.00
Totals		**513**	**63**	**12.28**
July	1990	12	2	16.67
		2	0	0.00
		21	3	14.29
		10	2	20.00
		17	1	5.88
		7	1	14.29
		1	0	0.00
		3	0	0.00
		1	0	0.00
		3	0	0.00
		9	1	11.11
		6	0	0.00
		17	3	17.65
		3	0	0.00
		3	0	0.00
		12	0	0.00
		9	3	33.33
		14	3	21.43
Totals		**150**	**19**	**12.67**
August	1990	12	1	8.33
		23	2	8.70
		1	0	0.00
		14	1	7.14
		15	2	13.33
		15	2	13.33
		8	0	0.00
		19	2	10.53
		9	1	11.11
		5	1	20.00
		37	3	8.11
		8	1	12.50
		3	0	0.00
		3	0	0.00
		9	2	22.22
		10	3	30.00
		33	7	21.21
Totals		**244**	**28**	**11.48**

Appendix A (cont).

Month	Year	No. of muskox	No. of calves	Percent calves
September	1990	19	2	10.52
		21	3	14.29
		7	2	28.57
		2	0	0.00
		21	3	14.29
		19	2	10.53
		7	1	14.29
		38	4	10.53
		18	3	16.67
		18	3	16.67
		8	1	12.50
		42	4	9.52
		5	1	20.00
		24	3	12.50
		20	2	10.00
		20	2	10.00
		23	3	13.04
Totals		**312**	**39**	**12.50**

Month	Year	No. of muskox	No. of calves	Percent calves
November	1990	26	4	15.38
		23	1	4.35
		29	5	17.24
		43	4	9.30
		21	2	9.52
		5	0	0.00
		28	3	10.71
		26	4	15.38
		10	1	10.00
		43	5	11.63
		28	1	3.57
		8	1	12.50
		4	1	25.00
		43	5	11.63
		29	5	17.24
		29	5	17.24
		39	2	5.13
		32	3	9.38
Totals		**466**	**52**	**11.16**

Appendix A (cont).

Month	Year	No. of muskox	No. of calves	Percent calves
April	1991	16	0	0.00
		16	0	0.00
		10	0	0.00
		16	0	0.00
		20	0	0.00
		4	0	0.00
		16	0	0.00
		16	0	0.00
		9	0	0.00
		20	0	0.00
		16	0	0.00
		10	0	0.00
		6	0	0.00
		9	0	0.00
		42	0	0.00
		5	0	0.00
		5	0	0.00
		26	0	0.00
		46	0	0.00
		22	0	0.00
Totals		**330**	**0**	**0**
May	1991	15	0	0.00
		12	2	16.67
		15	0	0.00
		14	4	28.57
		13	1	7.69
		13	1	7.69
		11	2	18.18
		14	4	28.57
		12	2	16.67
		9	0	0.00
		44	9	20.45
		7	2	28.57
		17	1	5.88
		17	1	5.88
		7	2	28.57
		6	1	16.67
		6	1	16.67
		31	5	16.13
		5	0	0.00
		23	1	4.35
Totals		**291**	**39**	**13.40**
July	1991	53	10	18.87
		19	5	26.32
		53	10	18.87
		5	0	0.00

Month	Year	No. of muskox	No. of calves	Percent calves
		18	2	11.11
		17	1	5.88
		13	4	30.77
		3	0	0.00
		7	0	0.00
		13	2	15.38
		11	0	0.00
		14	4	28.57
		14	2	14.29
		14	2	14.29
		15	1	6.67
		13	2	15.38
		11	0	0.00
		5	0	0.00
		17	3	17.65
Totals		**315**	**48**	**15.24**
August	1991	47	9	19.15
		15	1	6.67
		14	2	14.29
		47	9	19.15
		20	5	25.00
		14	2	14.29
		5	0	0.00
		19	2	10.53
		6	0	0.00
		6	1	16.67
		13	4	30.77
		18	5	27.78
		14	3	21.43
		5	0	0.00
		6	0	0.00
		12	0	0.00
		16	1	6.25
		15	1	6.67
Totals		**292**	**45**	**15.41**
September	1991	38	4	10.53
		29	3	10.34
		20	2	10.00
		14	2	14.29
		14	2	14.29
		27	4	14.81
		27	4	14.81
Totals		**169**	**21**	**12.43**
Grand Total		**4926**	**514**	**10.43**

Appendix B. Single muskox cow sighting locations

Cow #	Date	Latitude	Longitude
030*	06/05/1988	68.867	115.933
030*	06/18/1988	68.533	115.917
030*	06/29/1989	68.767	116.133
050*	06/05/1988	68.333	115.933
050*	06/18/1988	68.217	115.783
050*	08/08/1990	68.633	117.033
140*	06/05/1988	68.350	115.617
140*	06/18/1988	68.267	115.617
161	07/06/1990	68.067	117.000
200	07/06/1990	68.717	117.400
220	04/21/1990	68.567	117.417
220	05/10/1990	68.617	117.500
220	05/29/1990	68.800	117.900
260	05/18/1991	68.650	118.467

*suspected grizzly bear kills later in study

Appendix C. Total distance travelled (km) each year (n=no. months) by individual muskox cows.

Cow #	Total distance travelled (km)			
	1988 n<=2	1989 n<=7	1990 n<=8	1991 n<=5
010	-	85.9	-	-
011	-	-	-	126.6
018	-	256.4	147.5	88.8
030	43.7	154.6	273.5	4.3
050	43.6	117.3	-	-
051	-	-	199.4	92.1
070	-	213.4	102.1	88.3
090	-	187.5	264.2	225.2
120	68.2	137.2	237.1	108.4
140	92.2	50.1	-	-
141	-	-	104.8	23.6
160	-	162.3	-	-
161	-	-	125.9	68.8
200	-	120.9	150.3	283.8
220	-	-	270.0	105.6
240	-		220.1	245.6
260	-	-	218.6	214.4
280	-	-	260.7	238.3
300	-	-	367.3	257.2
320	-	-	189.6	94.5
341	-	-	-	239.6
342	-	-	55.4	83.2
360	-	-	160.7	68.8
381	-	-	-	269.6
400	-	-	268.6	33.8

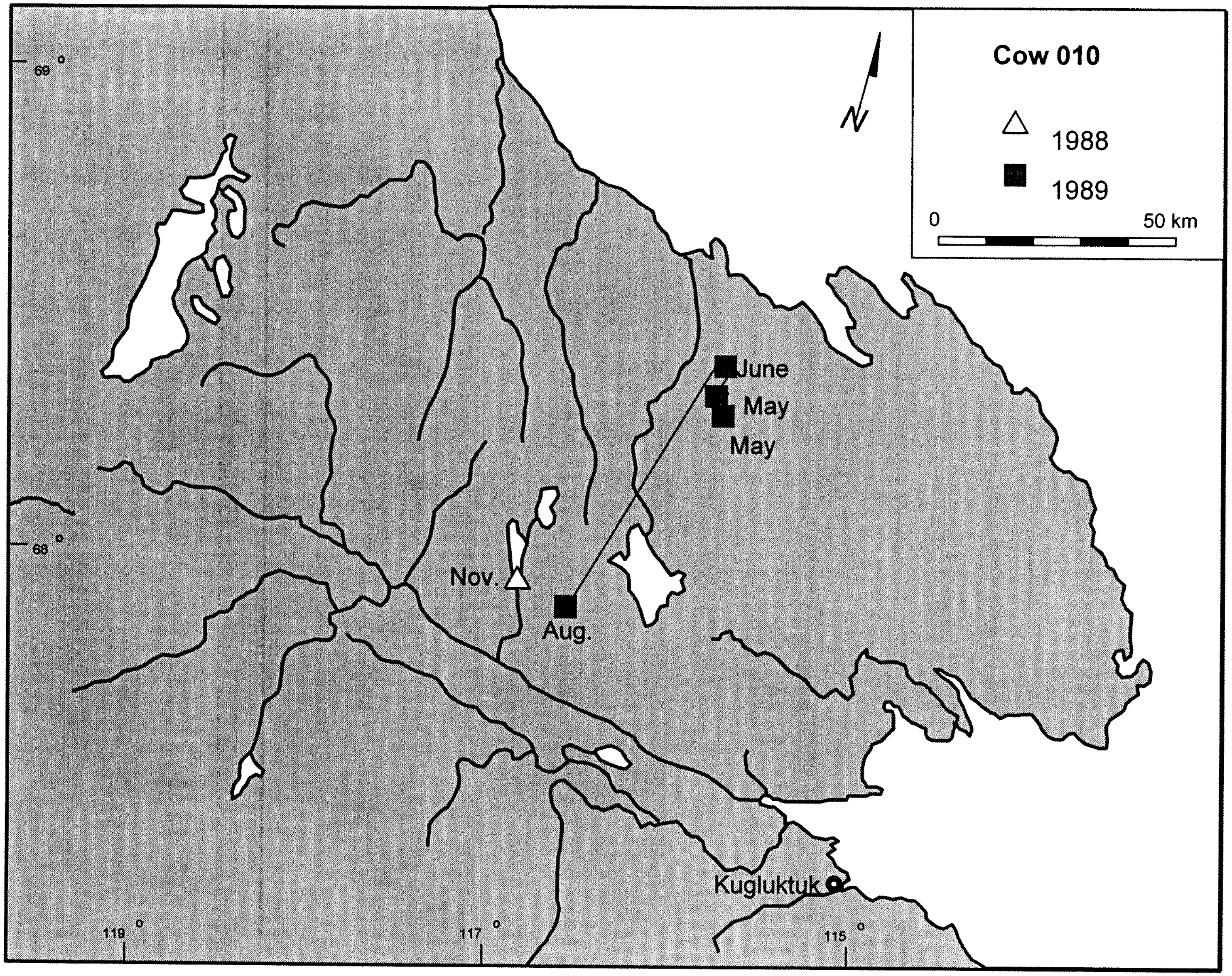
Appendix D. Distance (km) between Cow #200 and other cows in July 1989, 1990 and 1991.

Cow #	Distance (km) from Cow #200 in July
1989	
018	64.6
030	71.6
050	43.7
070	65.4
090	46.5
140	10.9
160	119.9
mean	60.4 ± 12.6
1990	
018	38.5
030	34.7
051	10.9
070	16.6
090	5.9
120	152.5
141	40.7
161	74.4
220	83.6
240	42.9
260	63.8
280	58.7
300	19.5
320	19.5
360	5.8
400	86.2
mean	48.0 ± 9.2

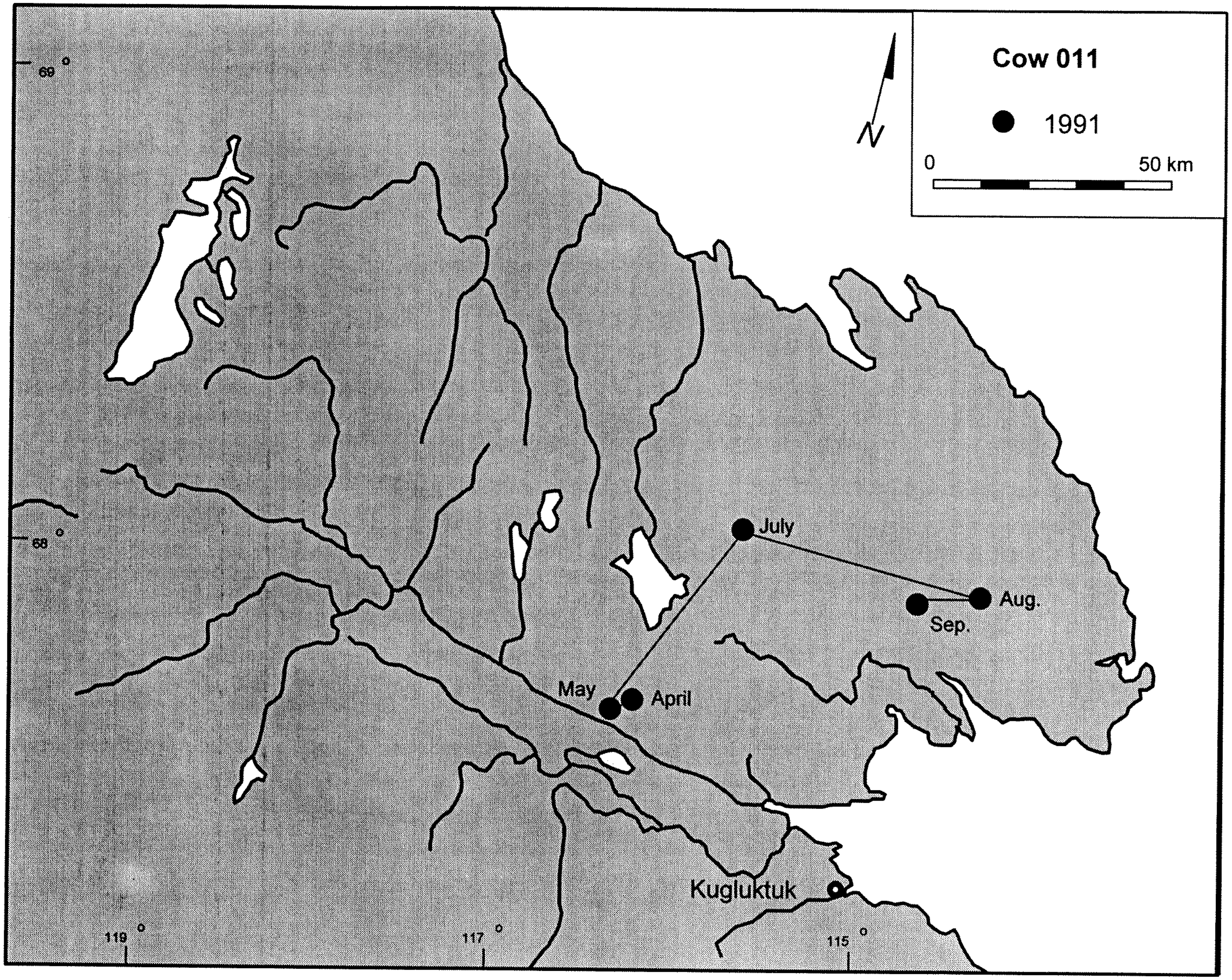
Cow #	Distance (km) from Cow #200 in July
1991	
011	73.5
018	54.9
030	52.1
051	88.4
070	29.1
090	15.2
120	96.6
161	72.8
220	64.2
240	82.1
260	134.0
280	134.0
300	109.3
320	18.7
341	116.2
342	88.4
360	72.8
381	54.9
400	54.9
mean	74.3 ± 7.9

Appendix E. Distance (km) between Cow #200 and other cows in November, 1988, 1989 and 1990.

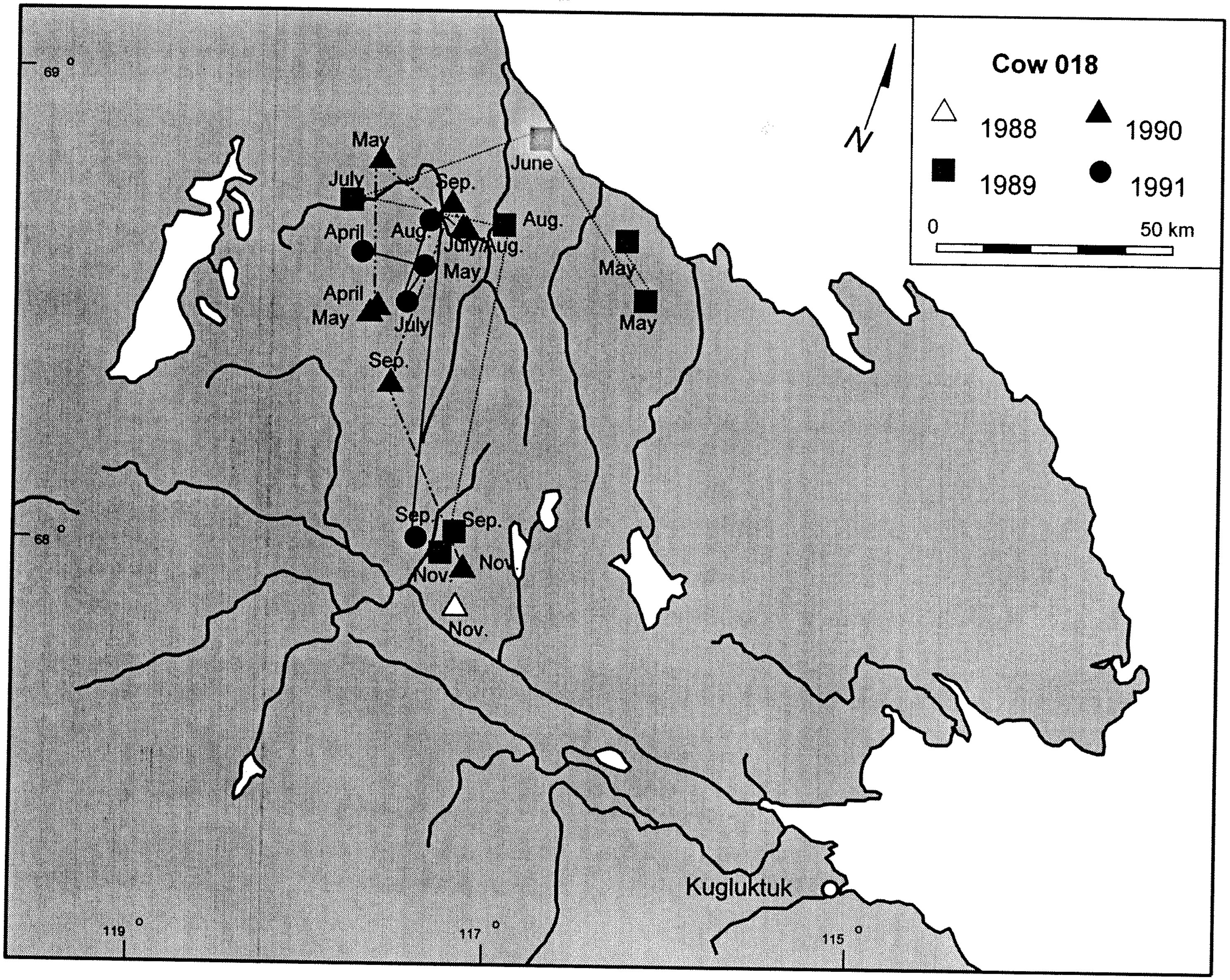
Cow #	Distance (km) from Cow #200 in Nov.	Cow #	Distance (km) from Cow #200 in Nov.
1988		**1990**	
010	< 1	030	0.3
070	< 1	051	69.6
090	16.9	070	21.7
120	88.4	090	12.6
160	20.4	120	109.0
018	18.1	141	20.6
		161	44.9
mean	24.0 ± 13.4	018	15.9
		220	15.2
1989		240	13.2
030	31.3	260	28.5
051	40.2	280	20.8
070	11.3	300	20.8
090	60.5	320	13.2
141	42.3	360	12.6
161	28.3	400	12.6
018	2.2	342	33.8
342	20.2		
		mean	27.4 ± 6.4
mean	29.5+ ± 6.6		



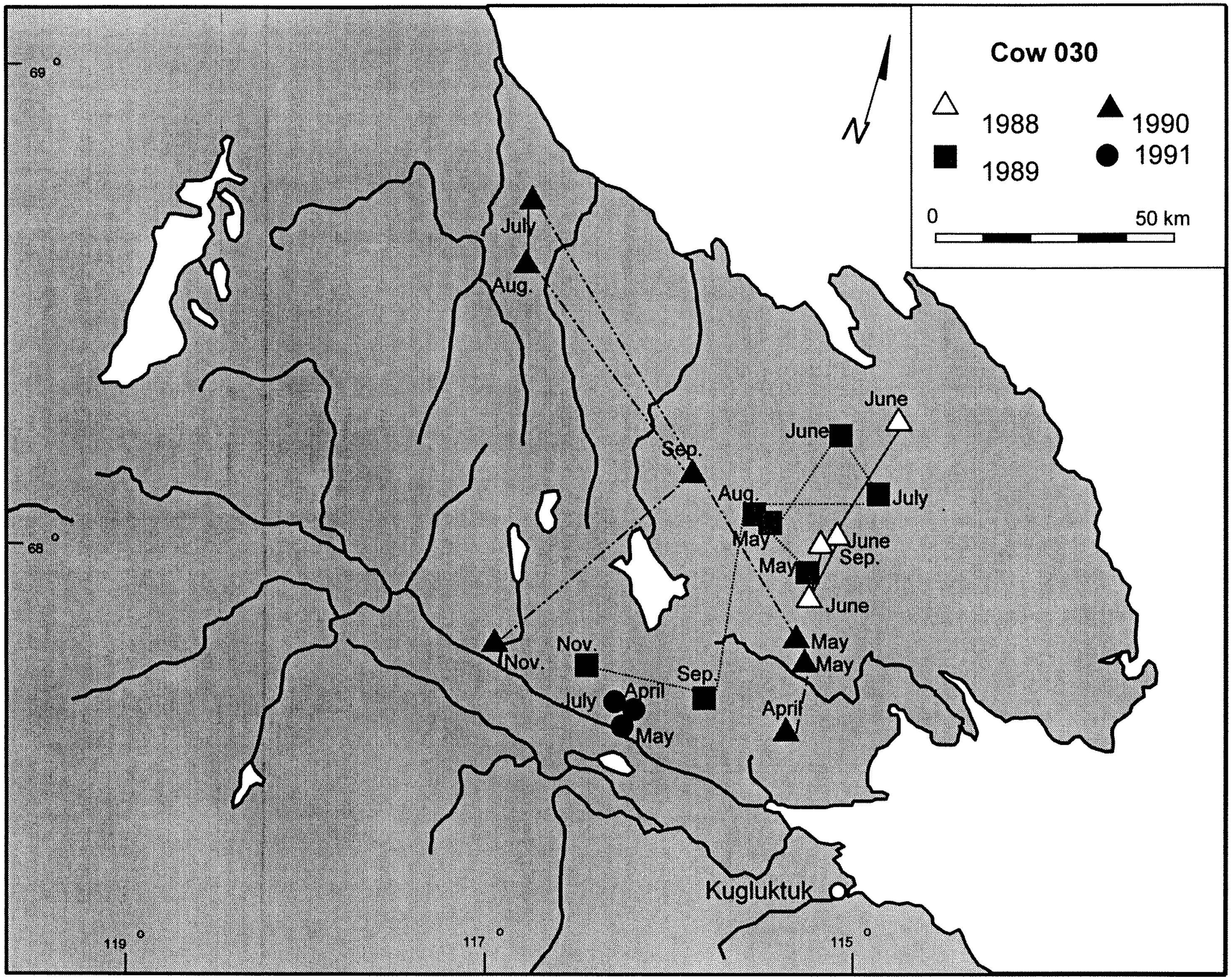
Appendix F. Maps of individual radio-collared muskox cow movements in the Rae-Richardson river valley, 1988-91.



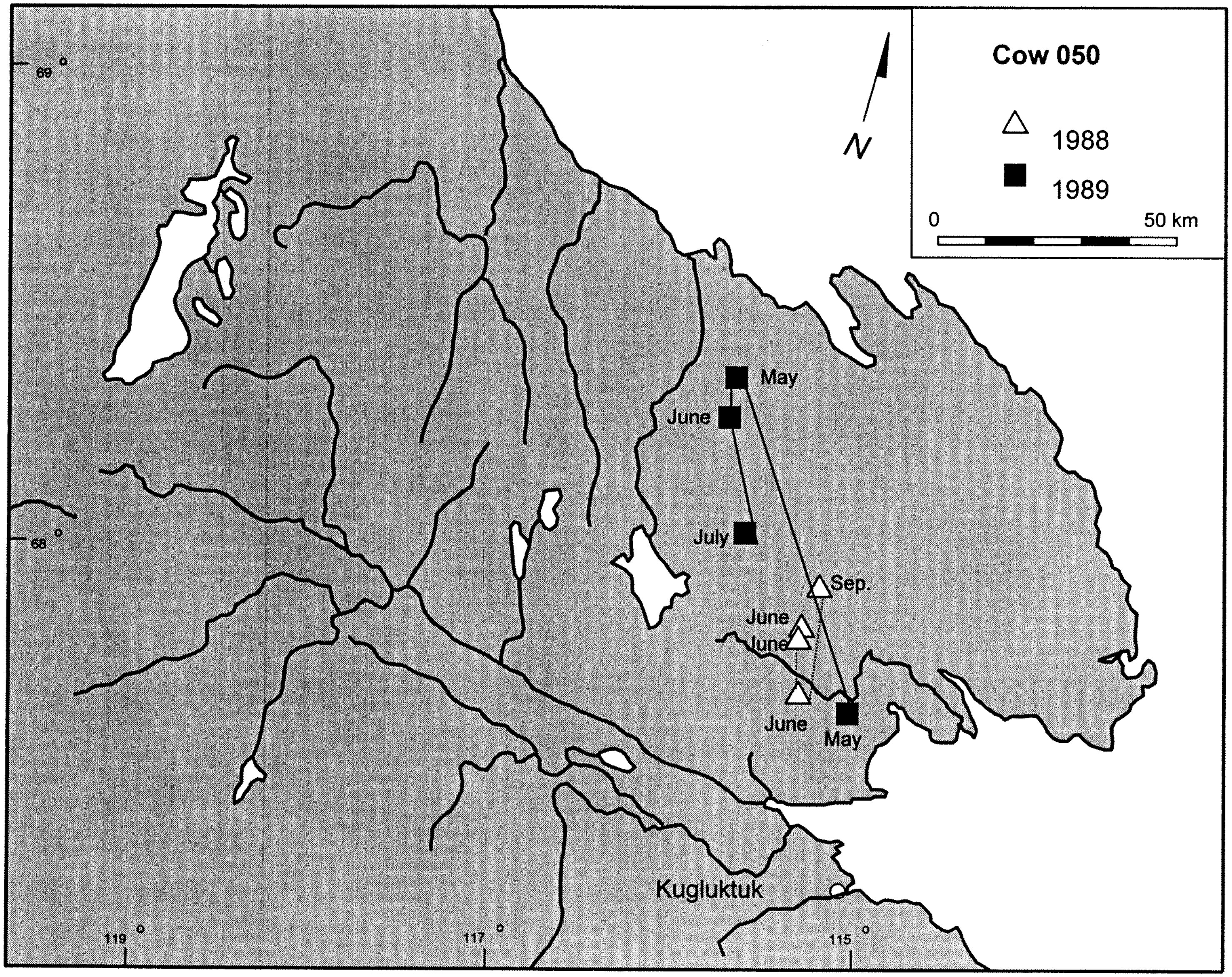
Appendix F (cont).



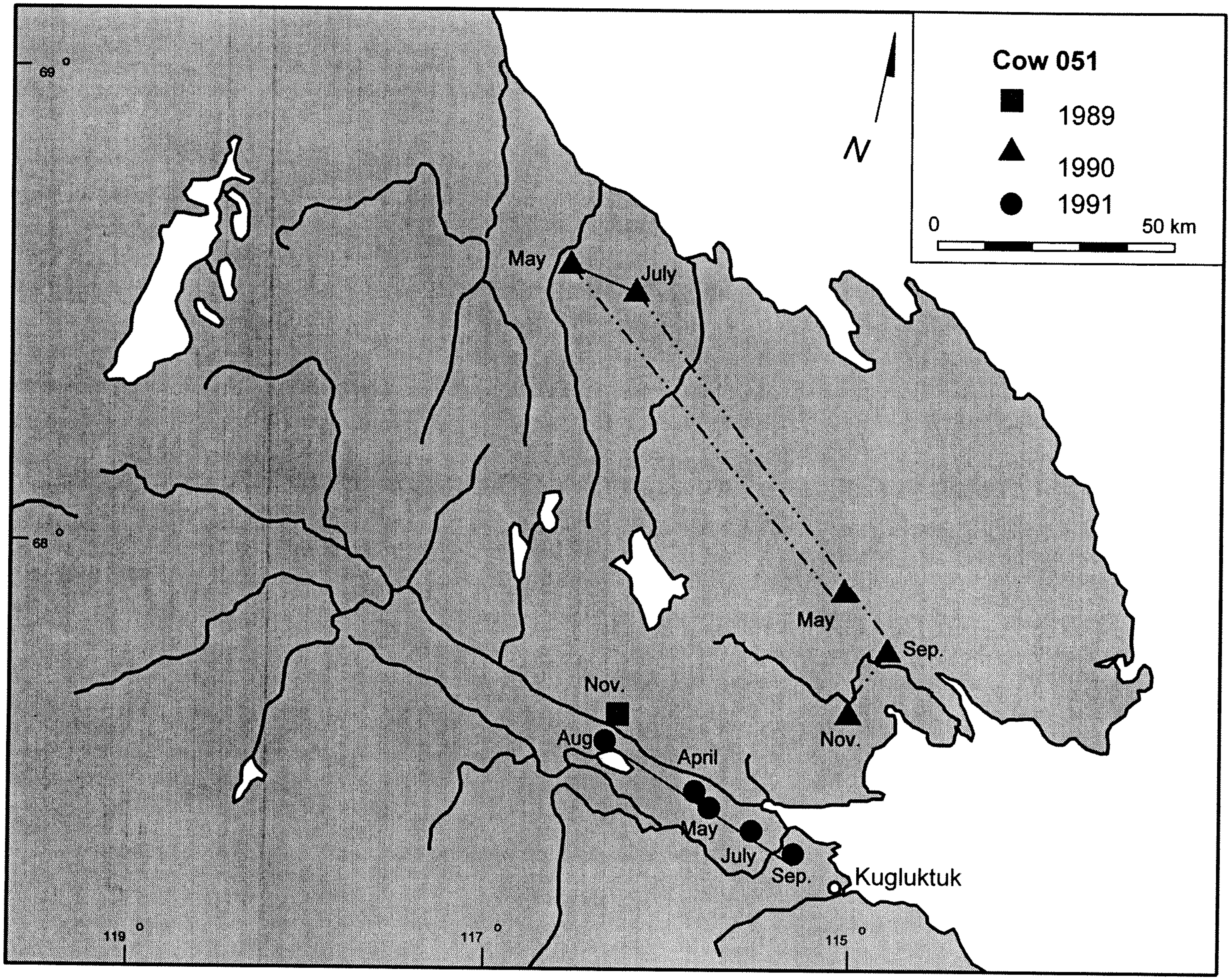
Appendix F (cont).



Appendix F (cont).



Appendix F (cont).



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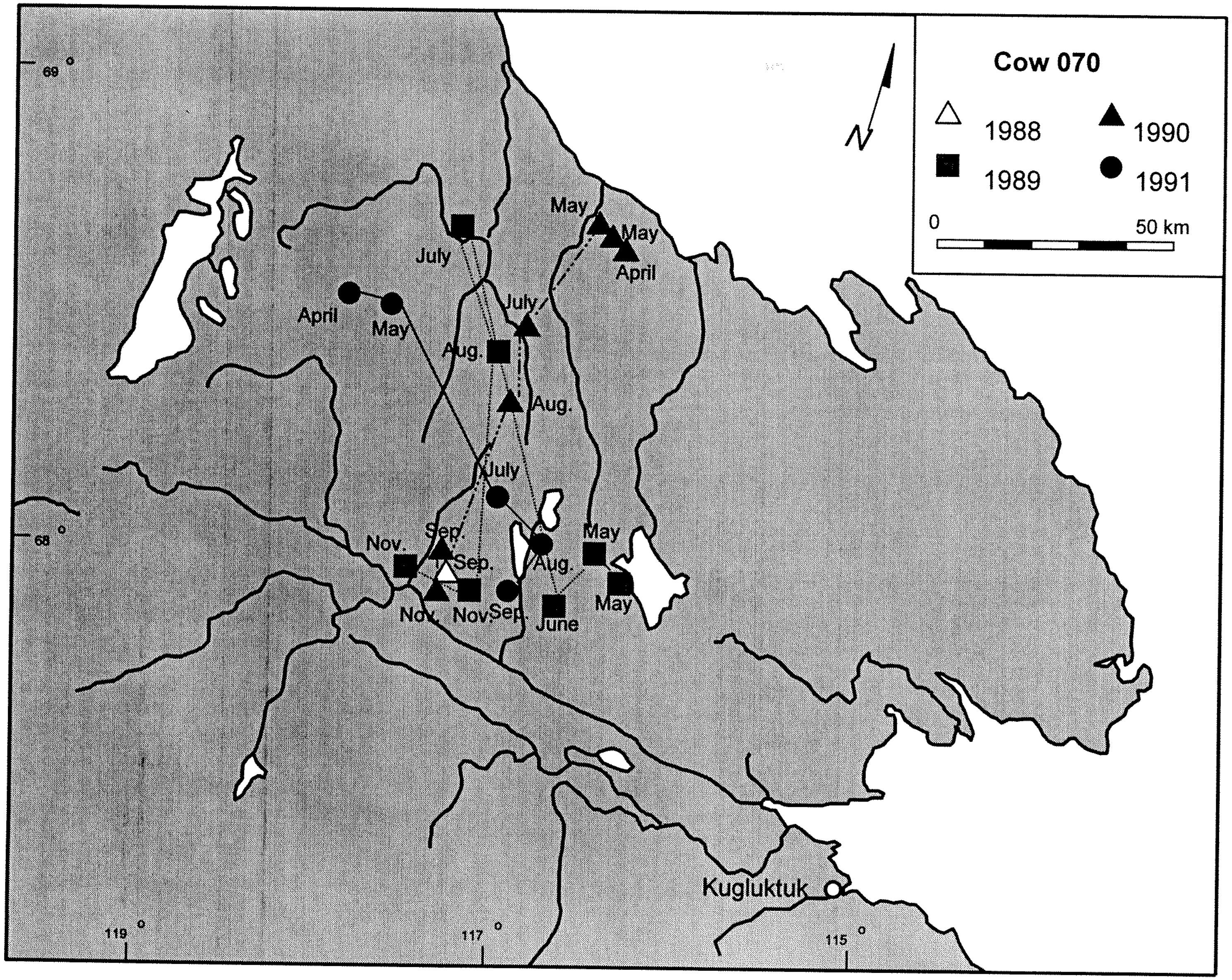

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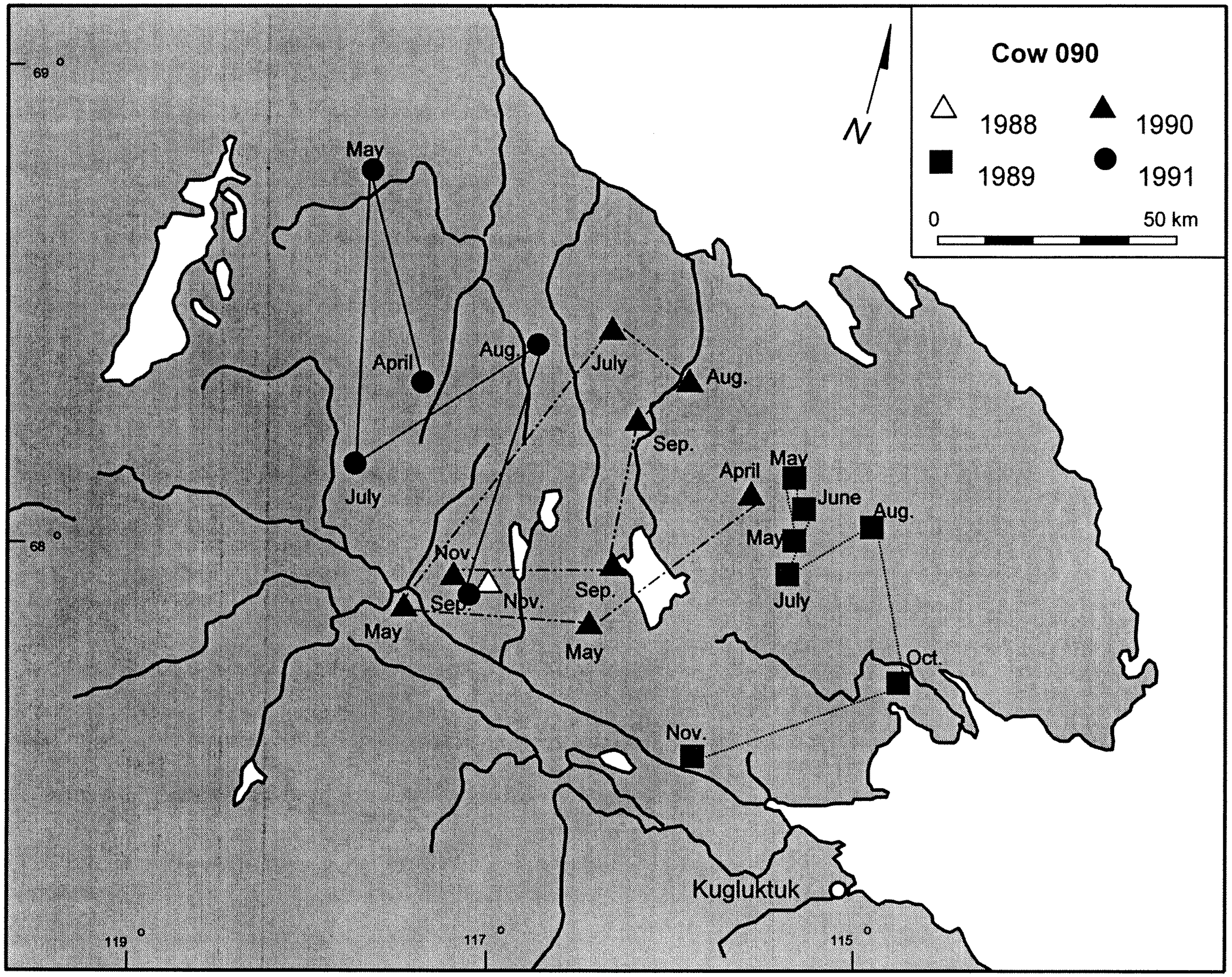
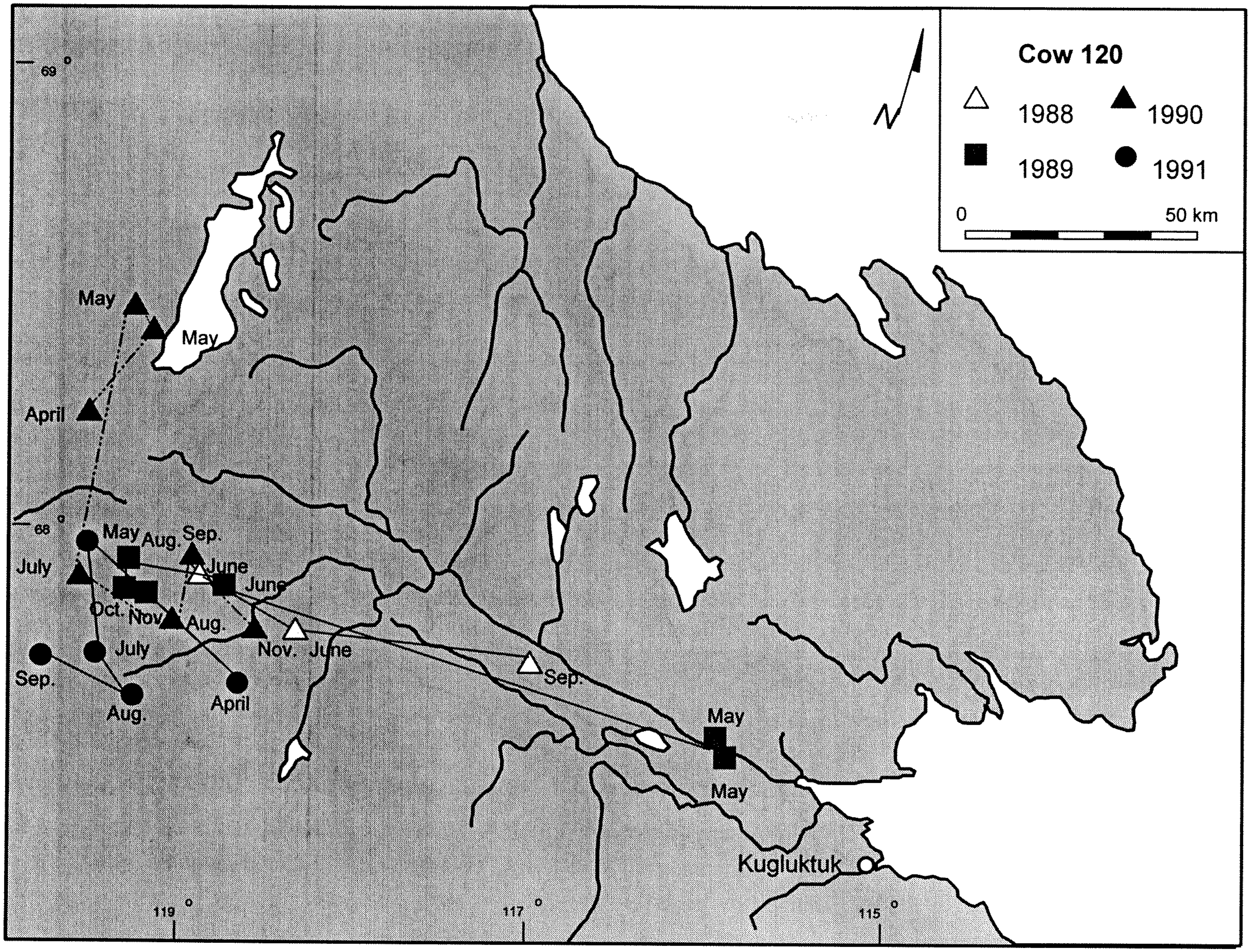
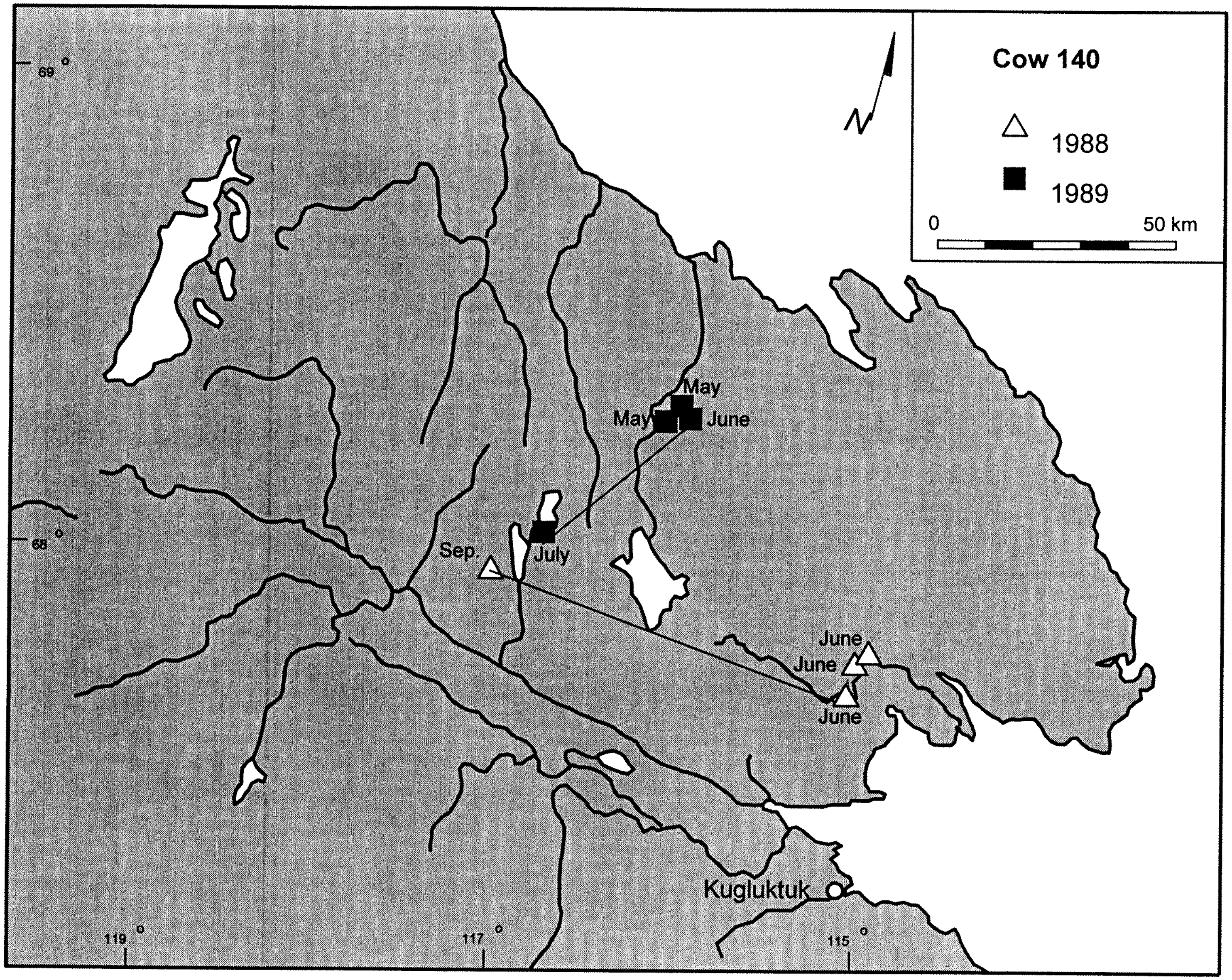


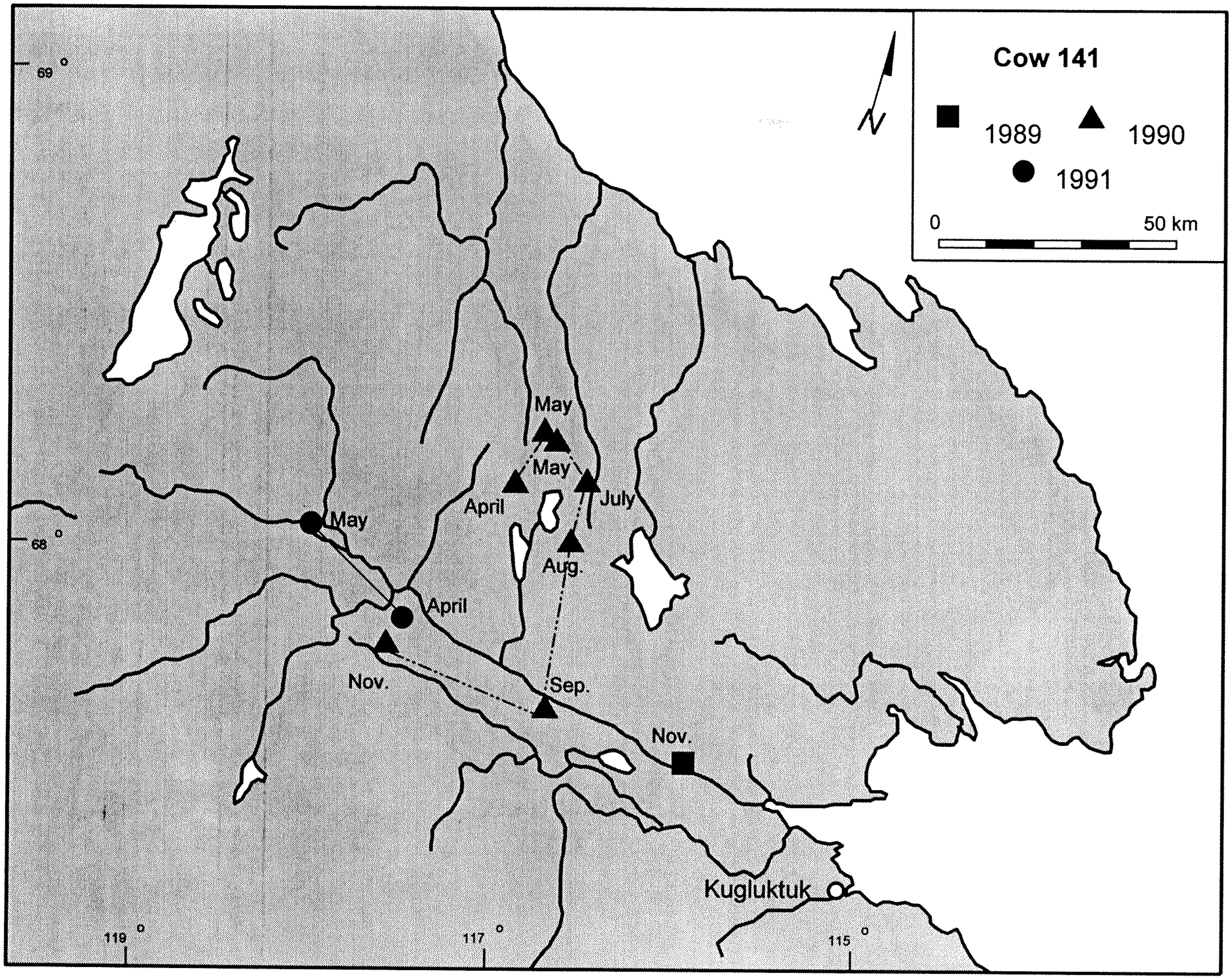
Appendix F (cont).



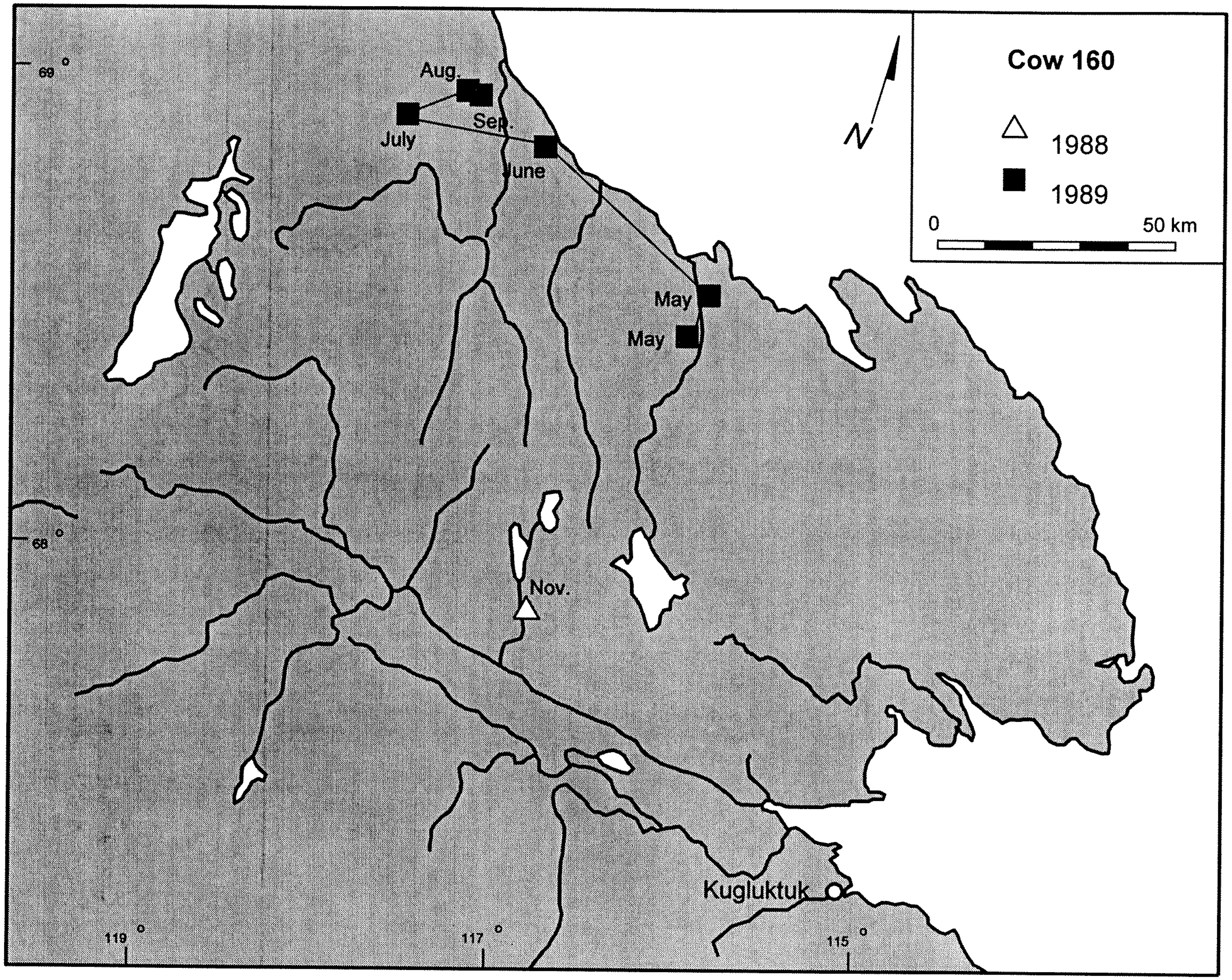
Appendix F (cont).



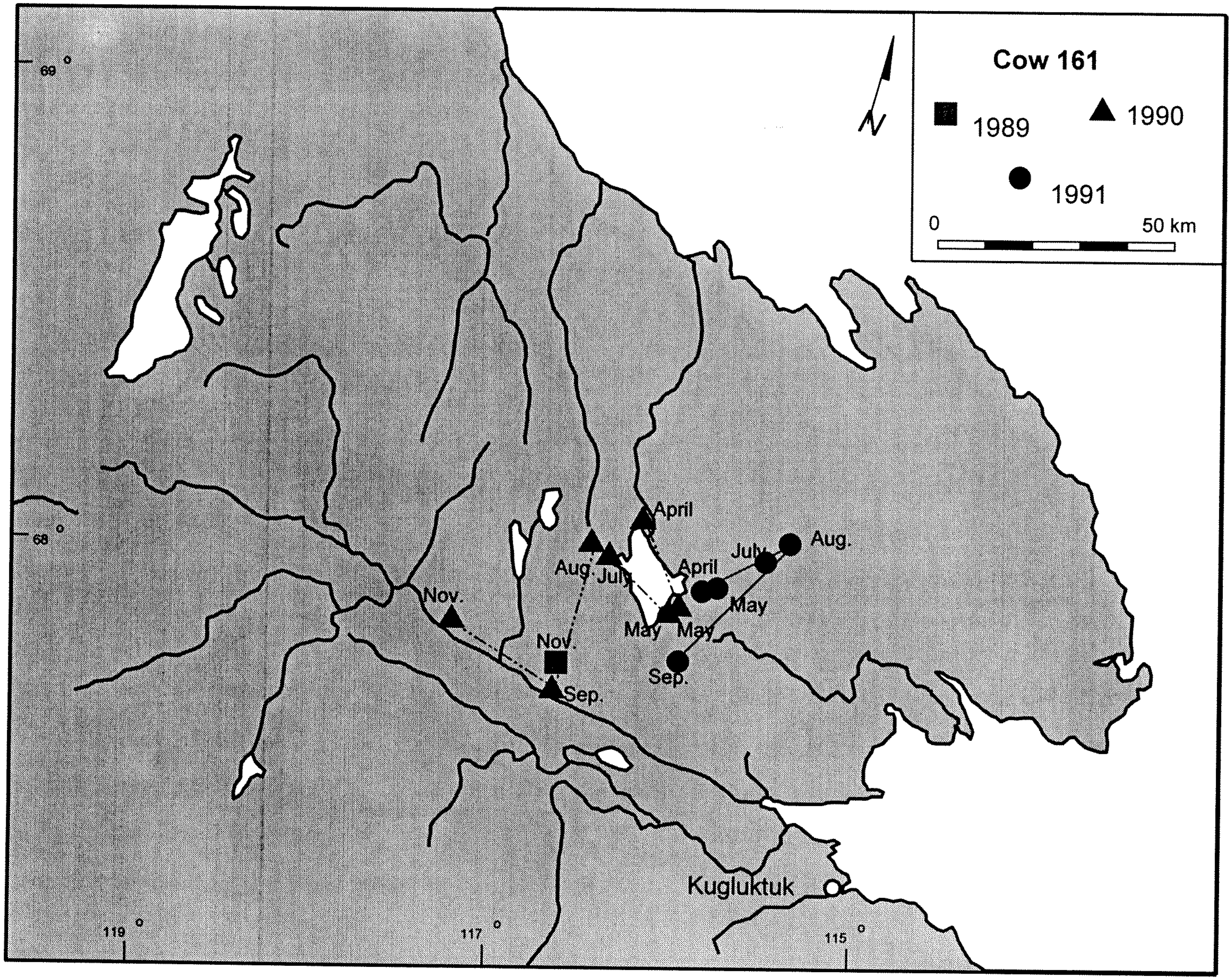
Appendix F (cont).



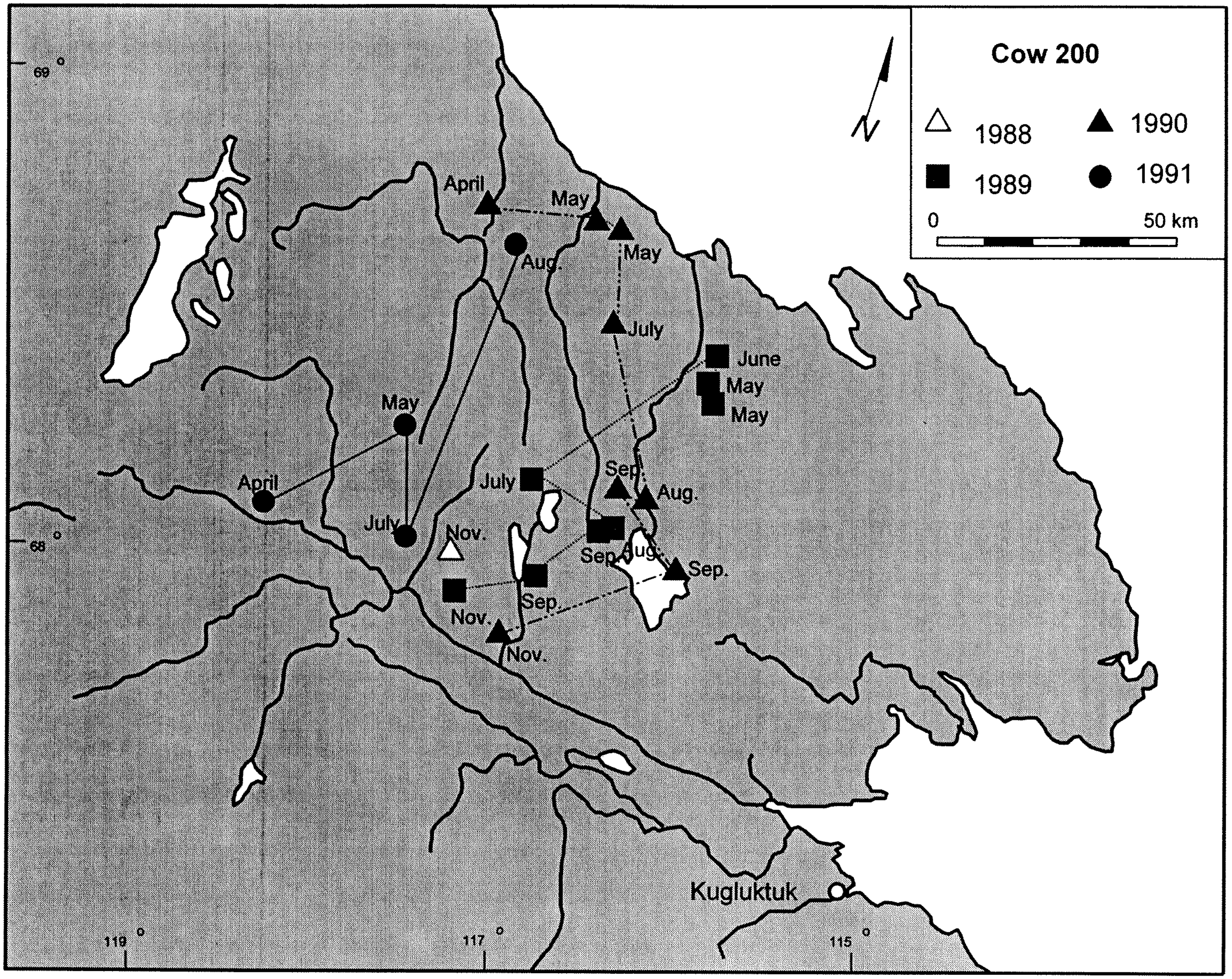
Appendix F (cont).



Appendix F (cont).



Appendix F (cont).



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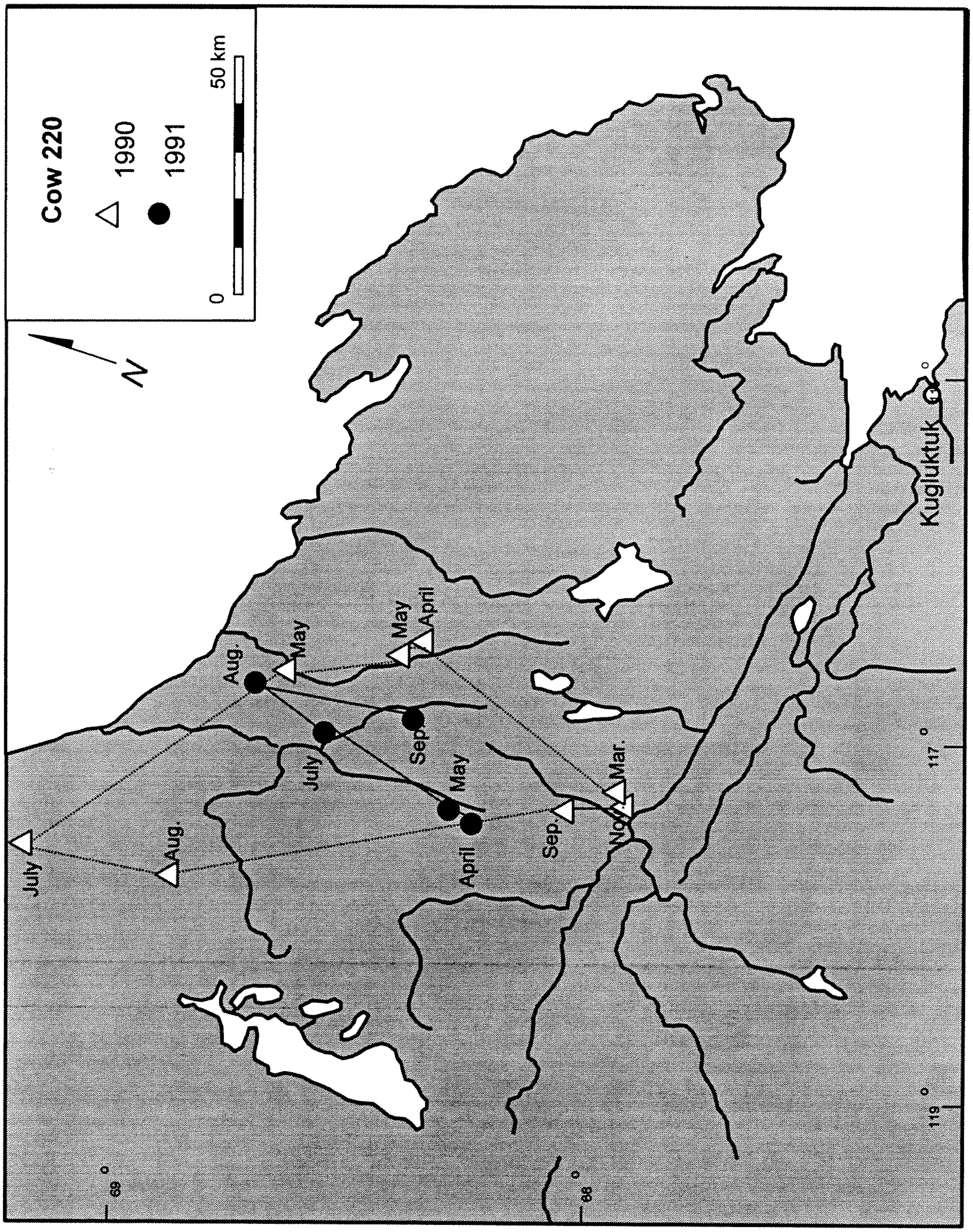
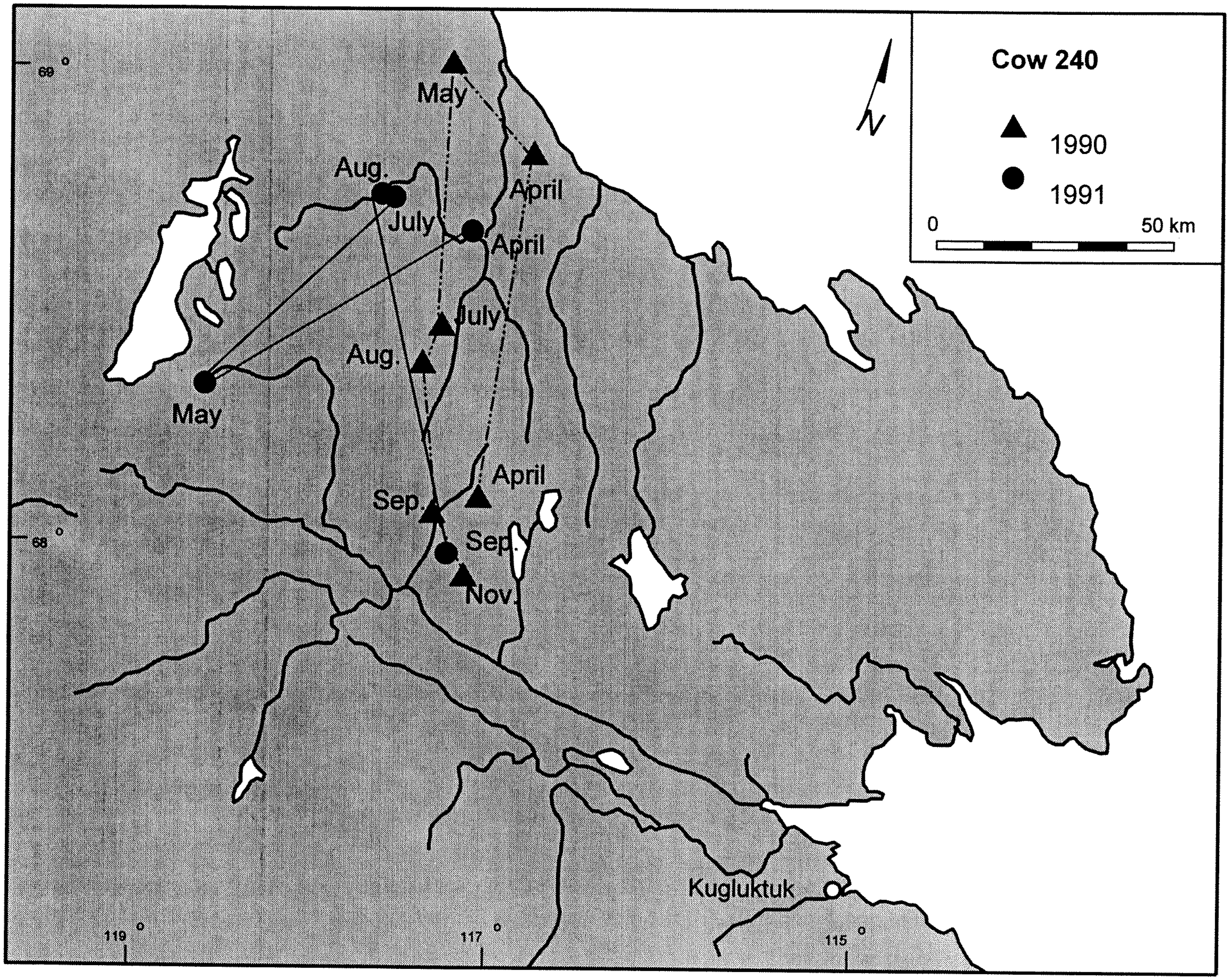


Appendix F (cont).



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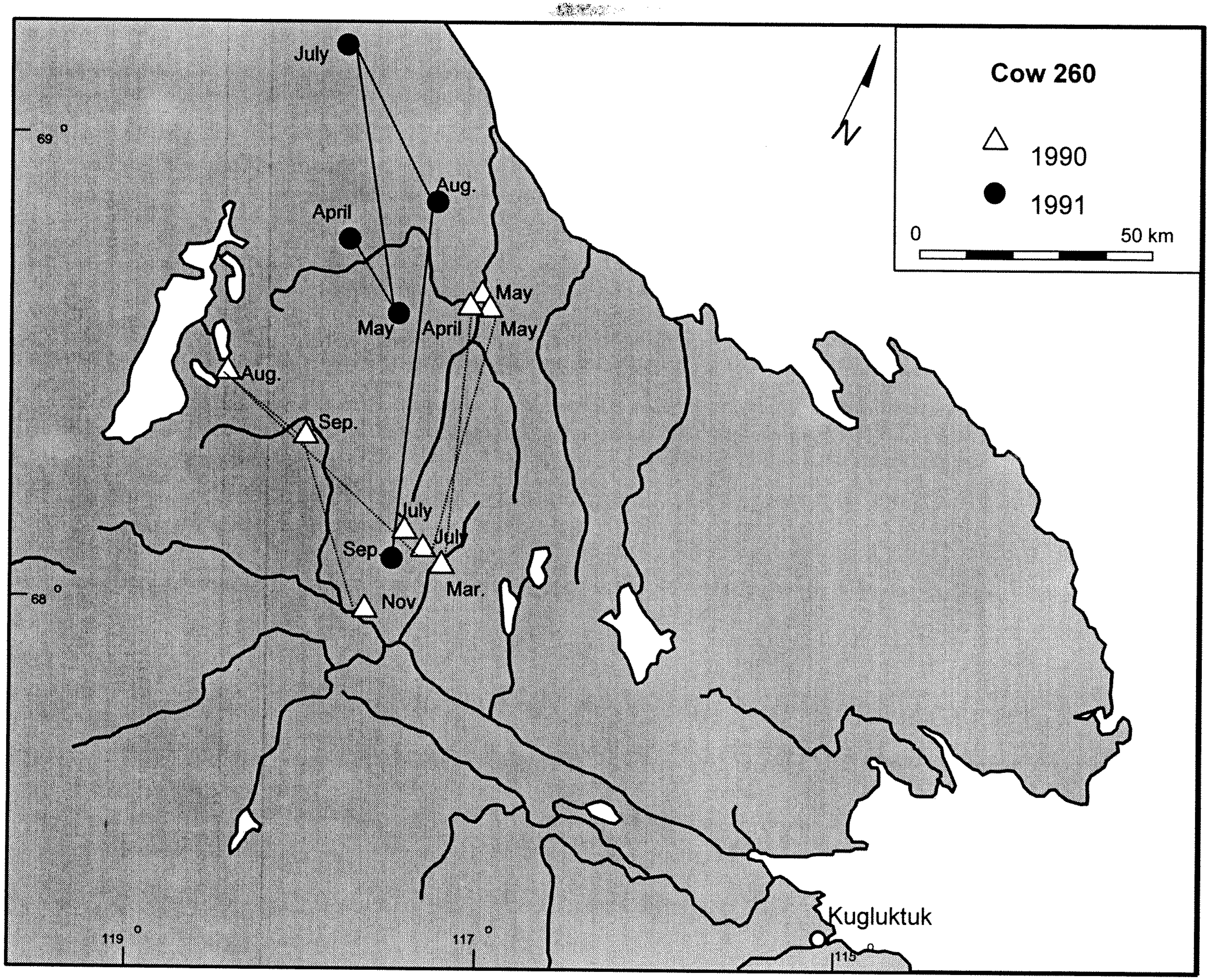

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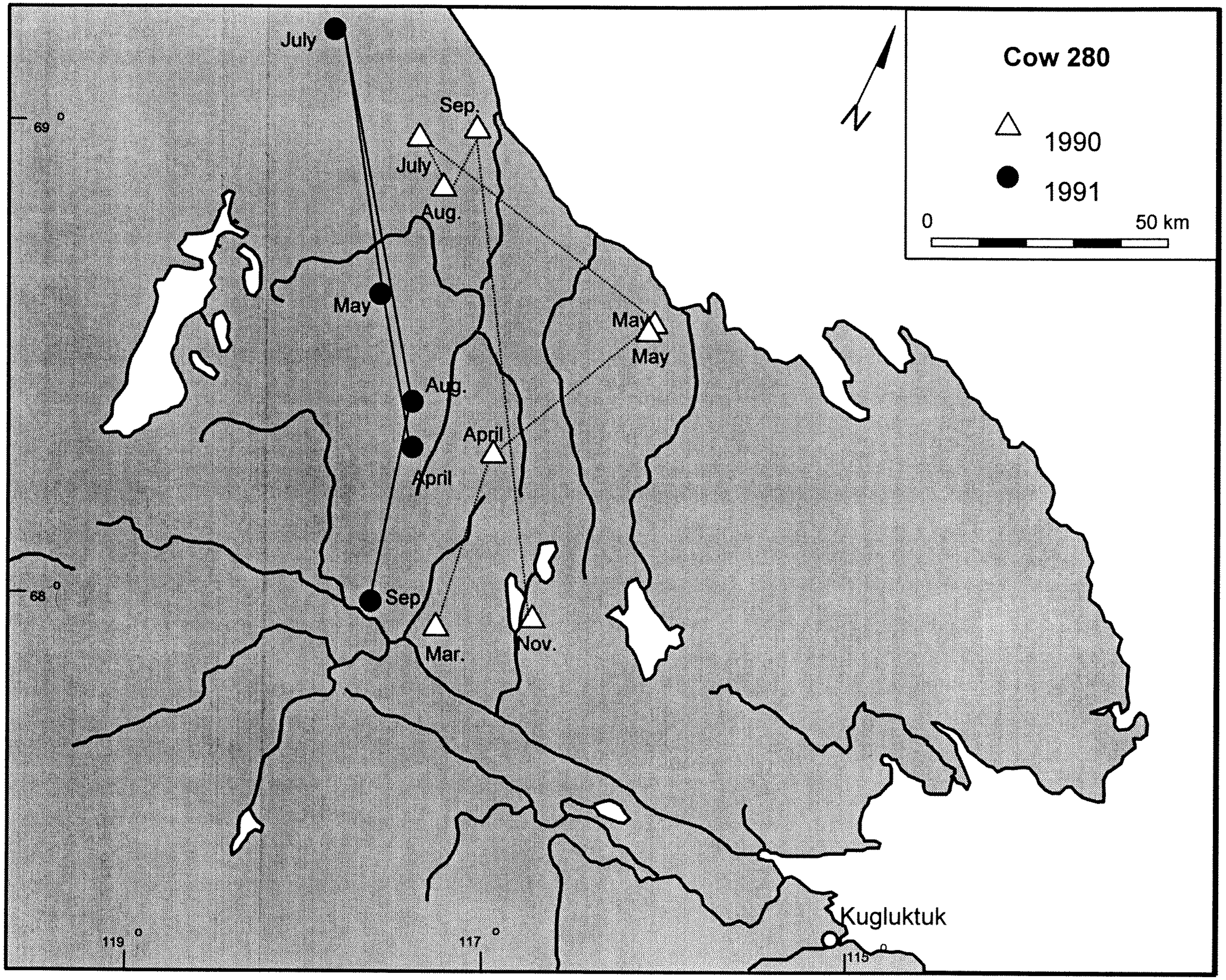

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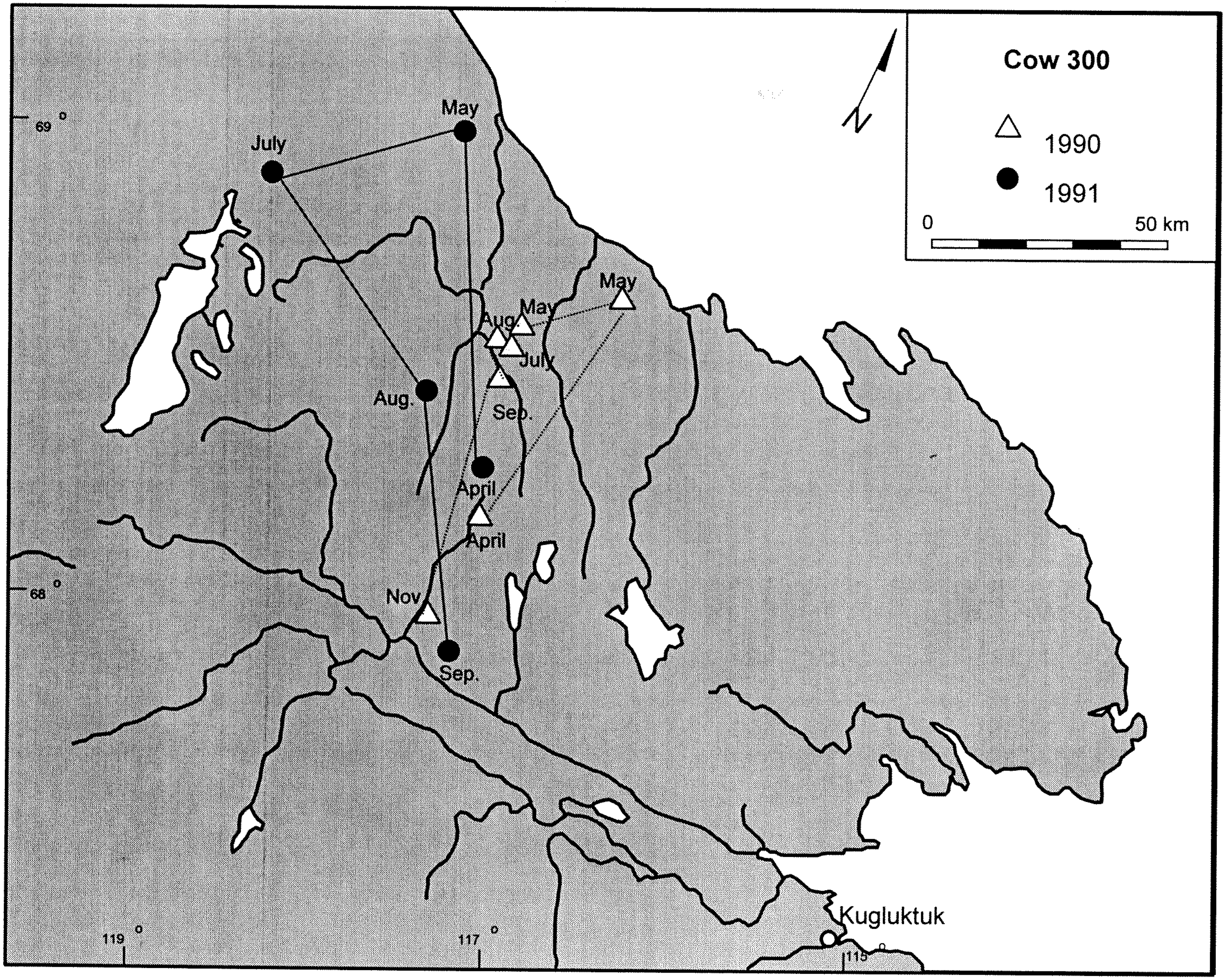
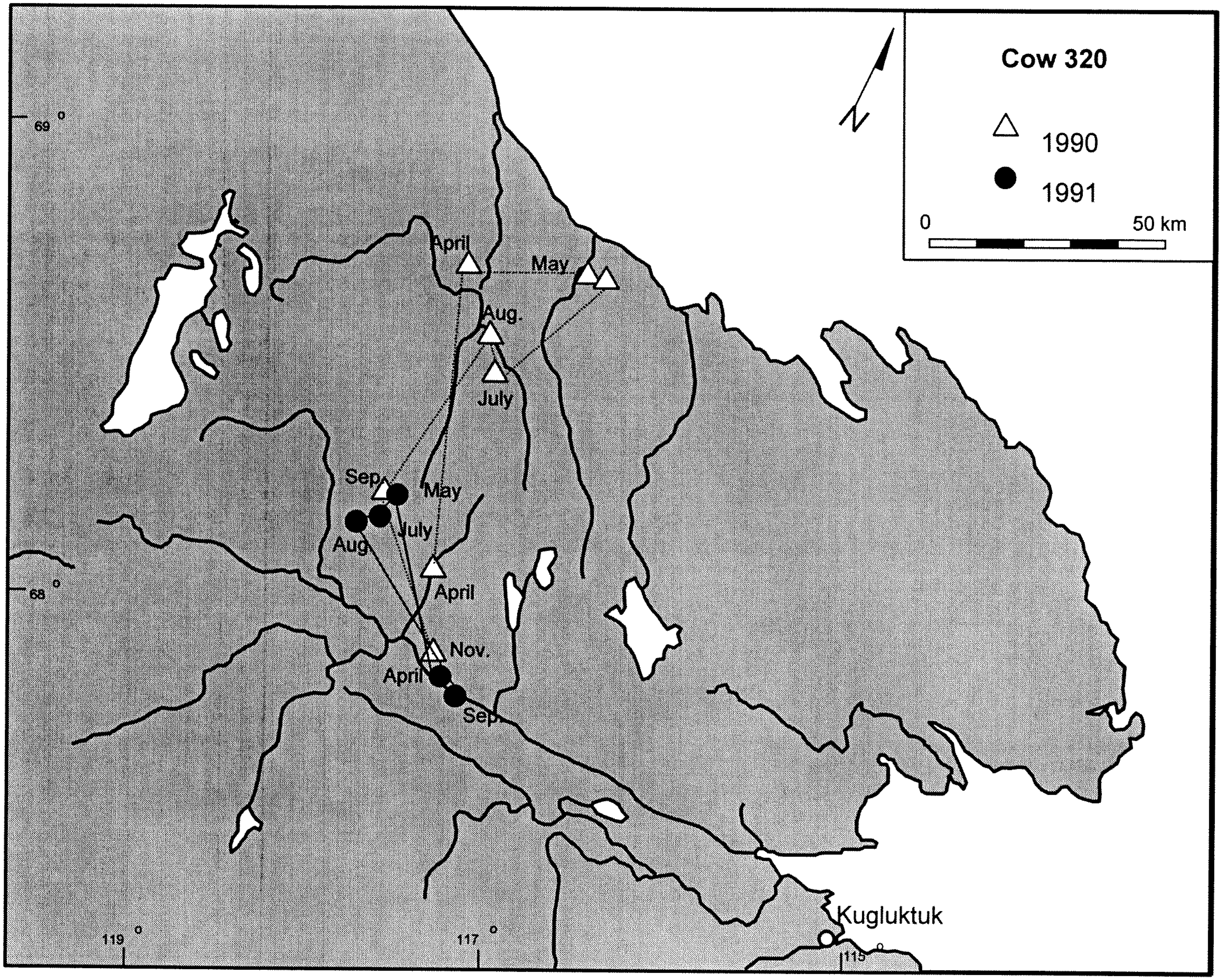
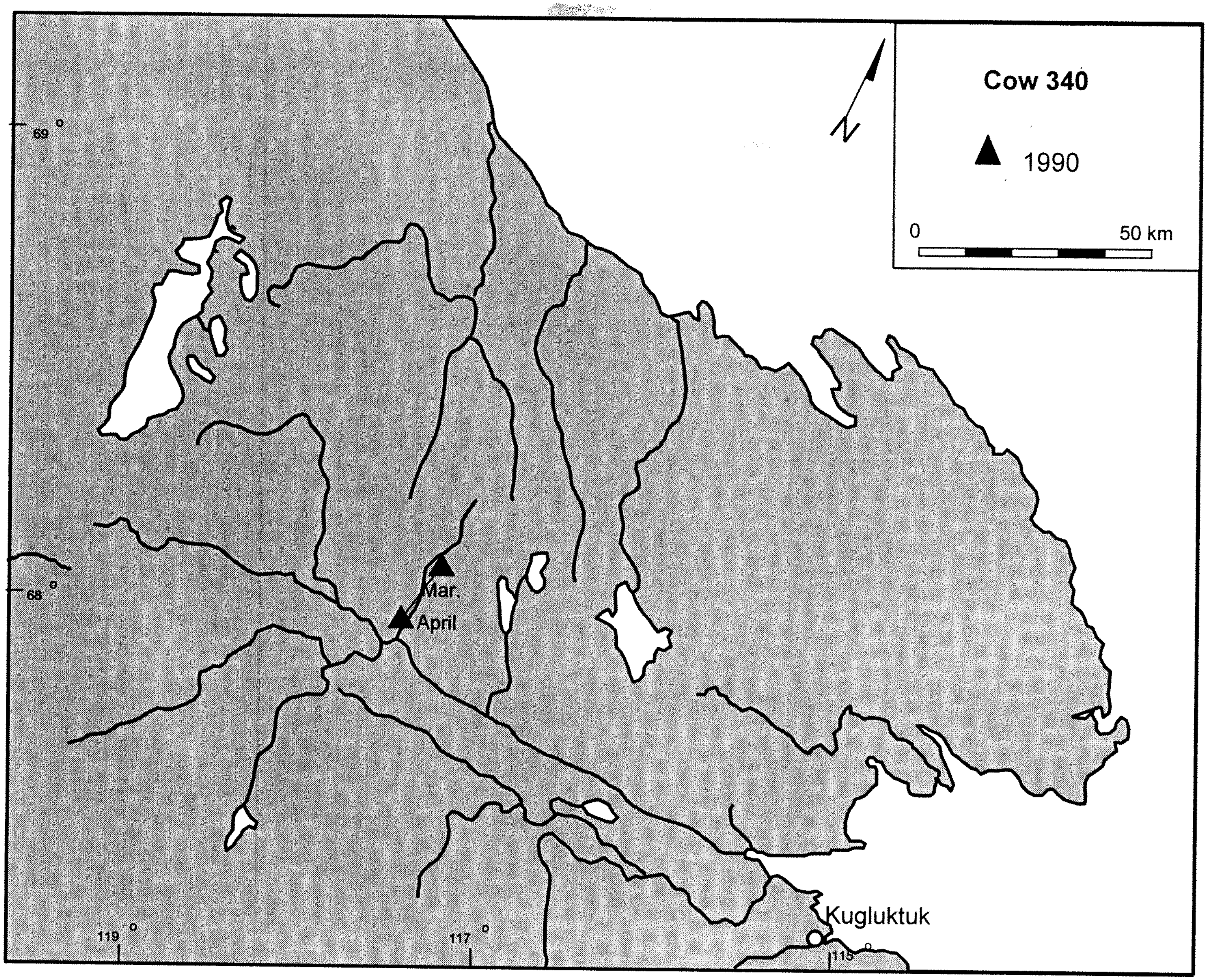


Appendix F (cont).



Appendix F (cont).



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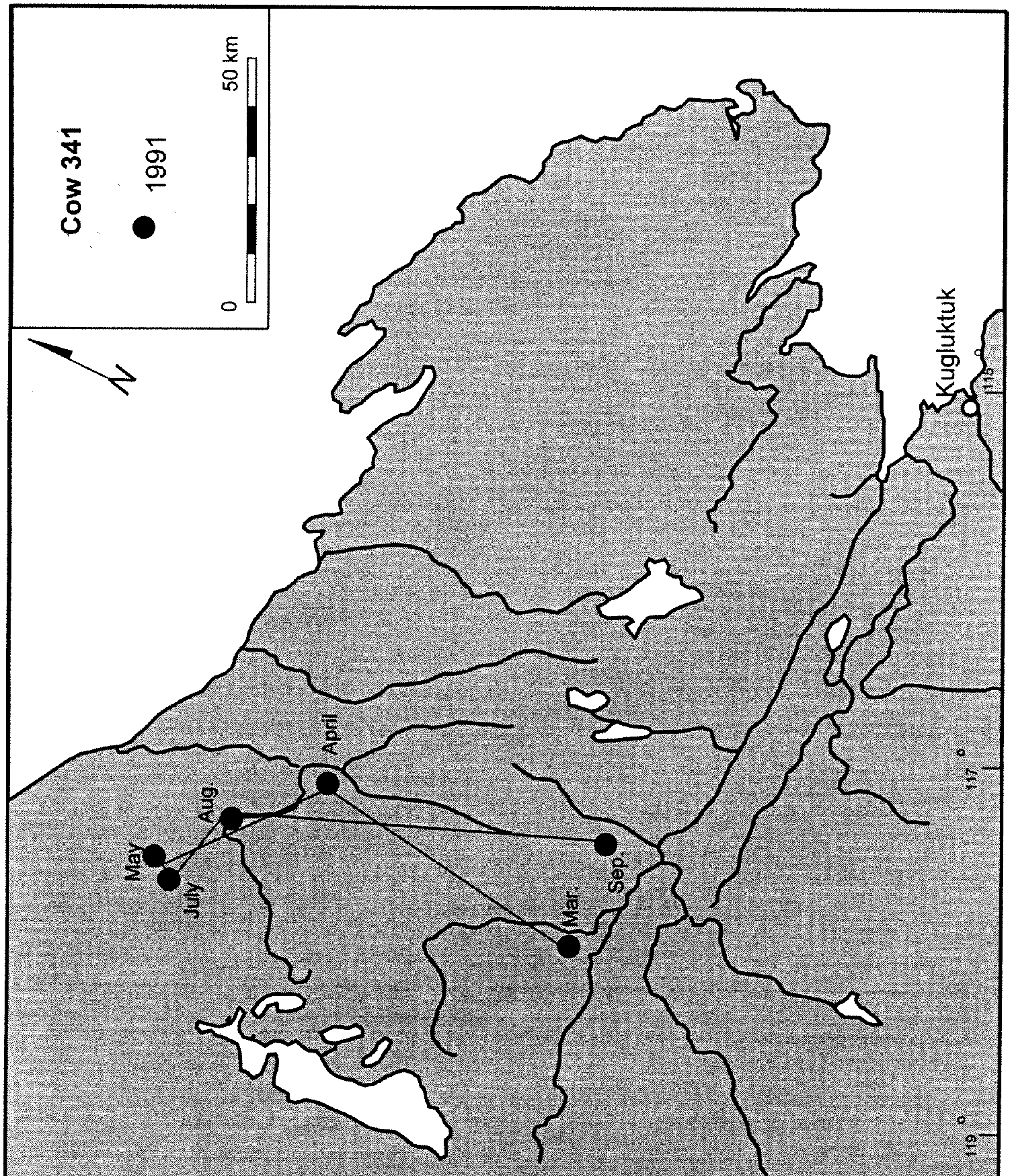
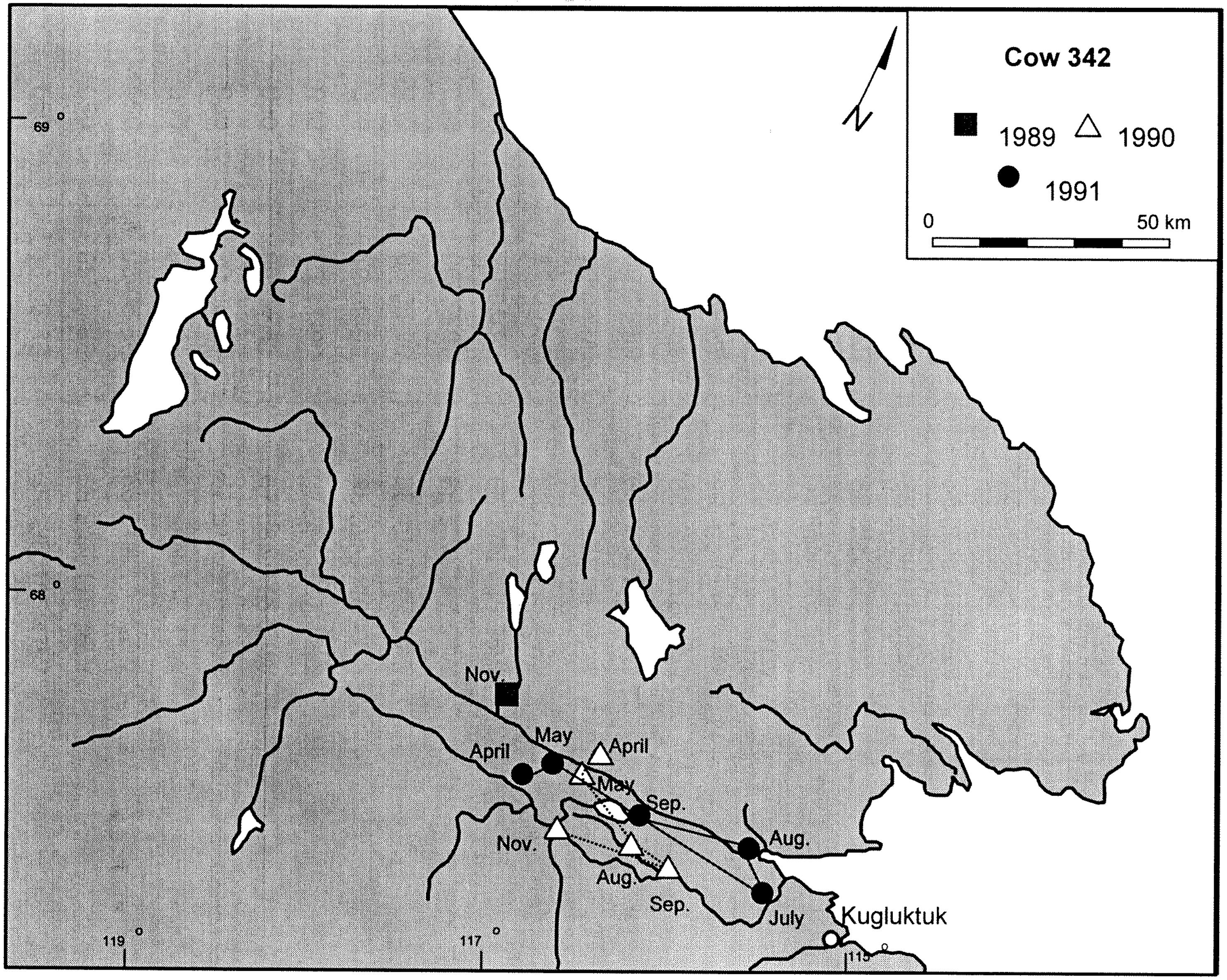
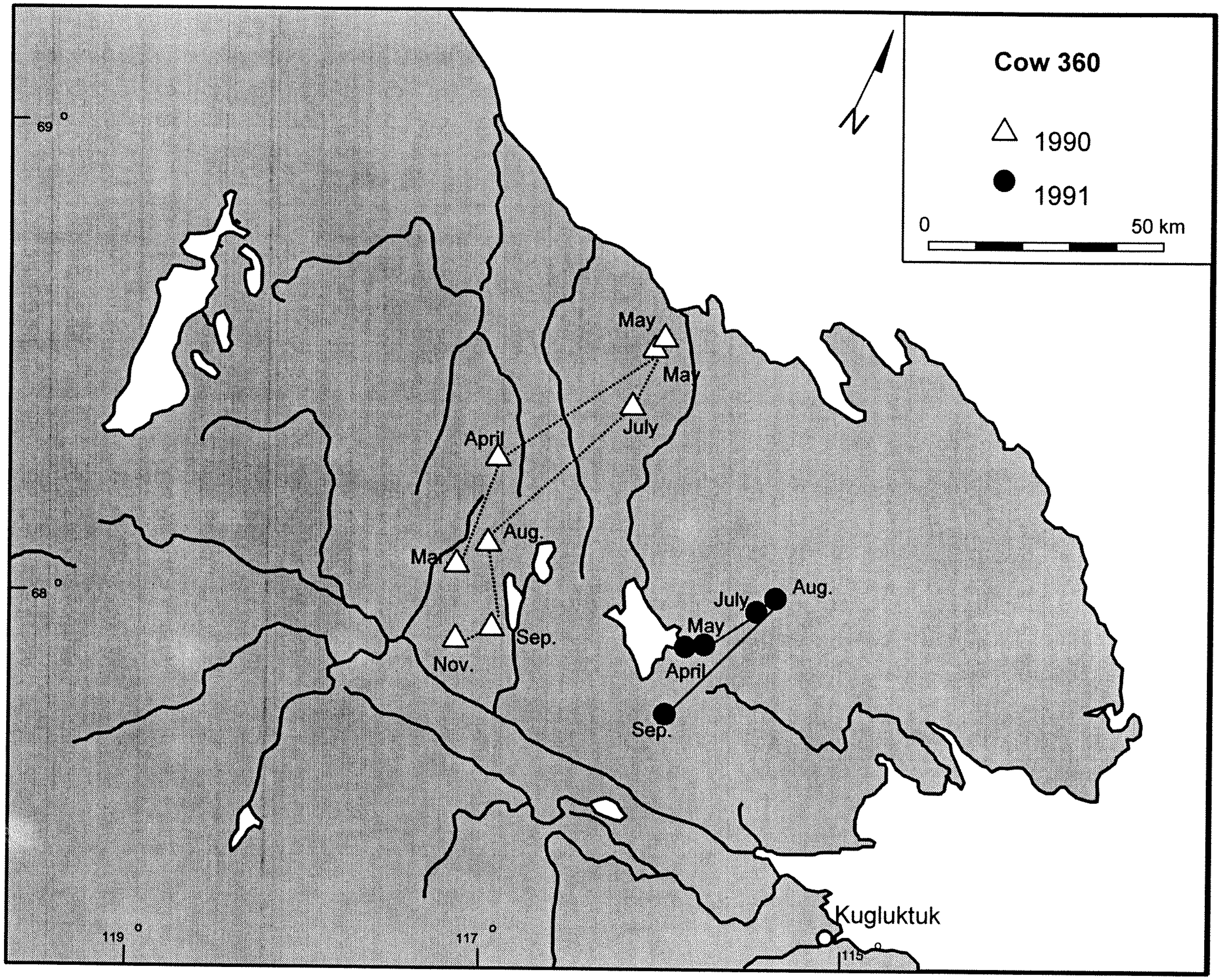


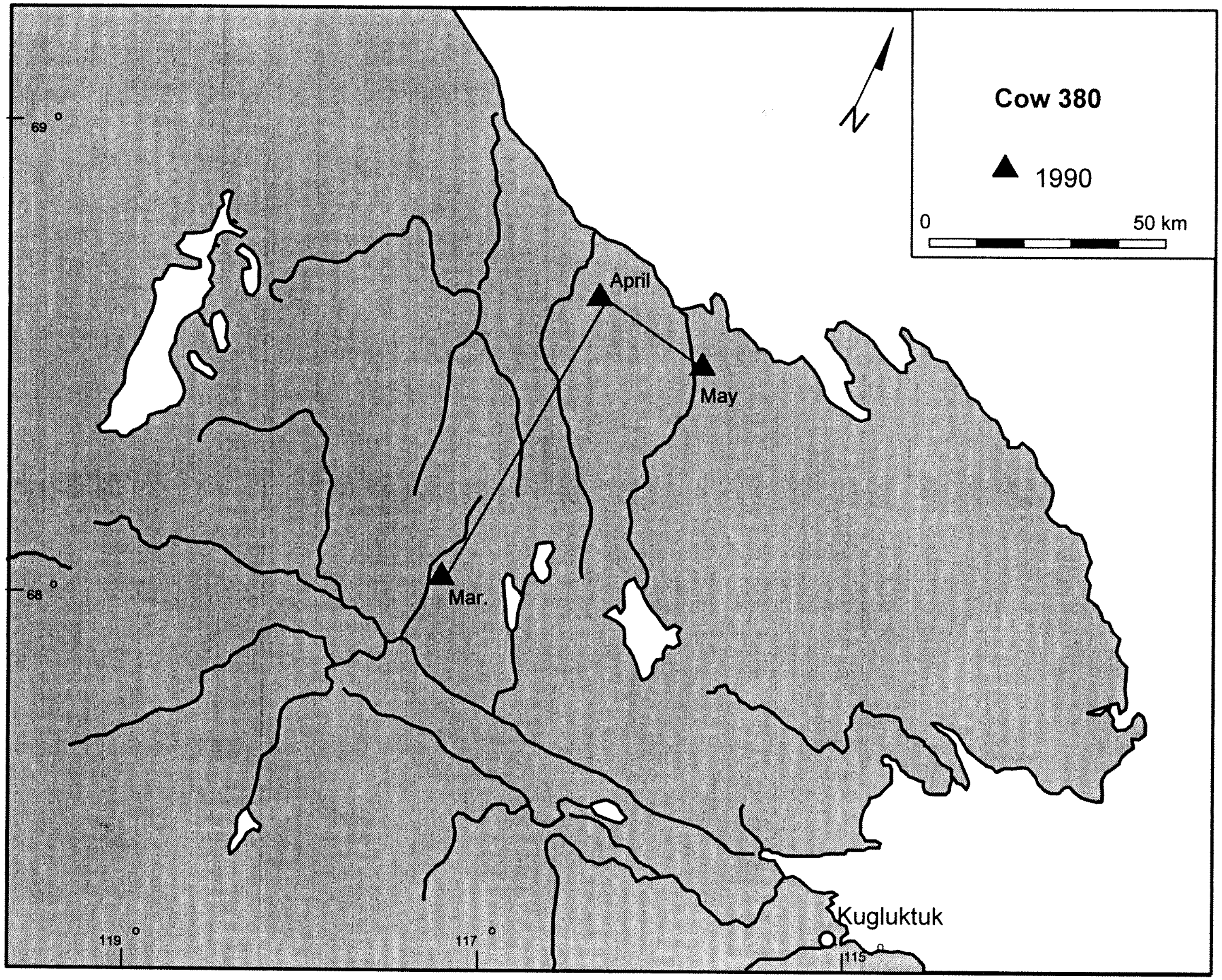
Appendix F (cont).



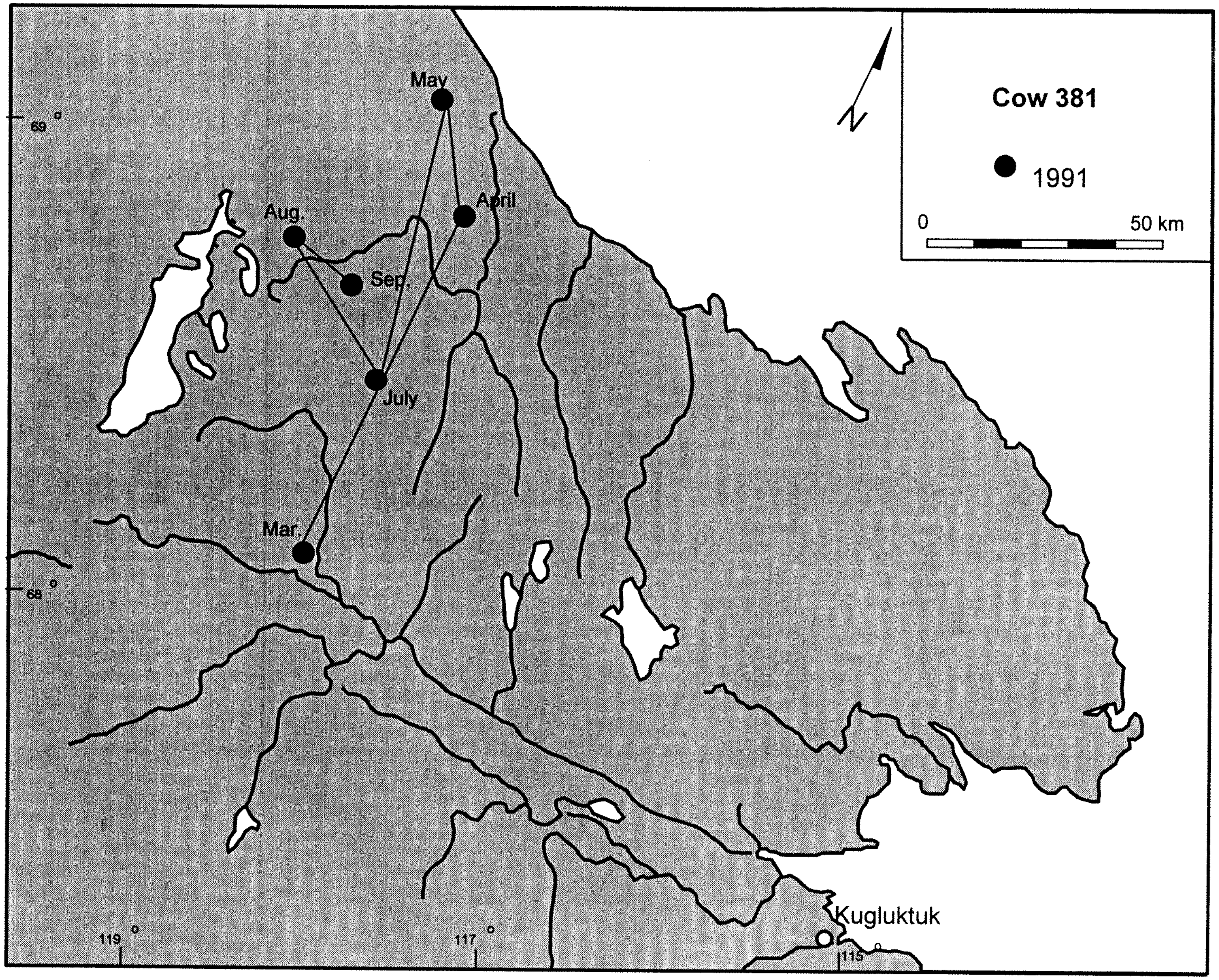
Appendix F (cont).



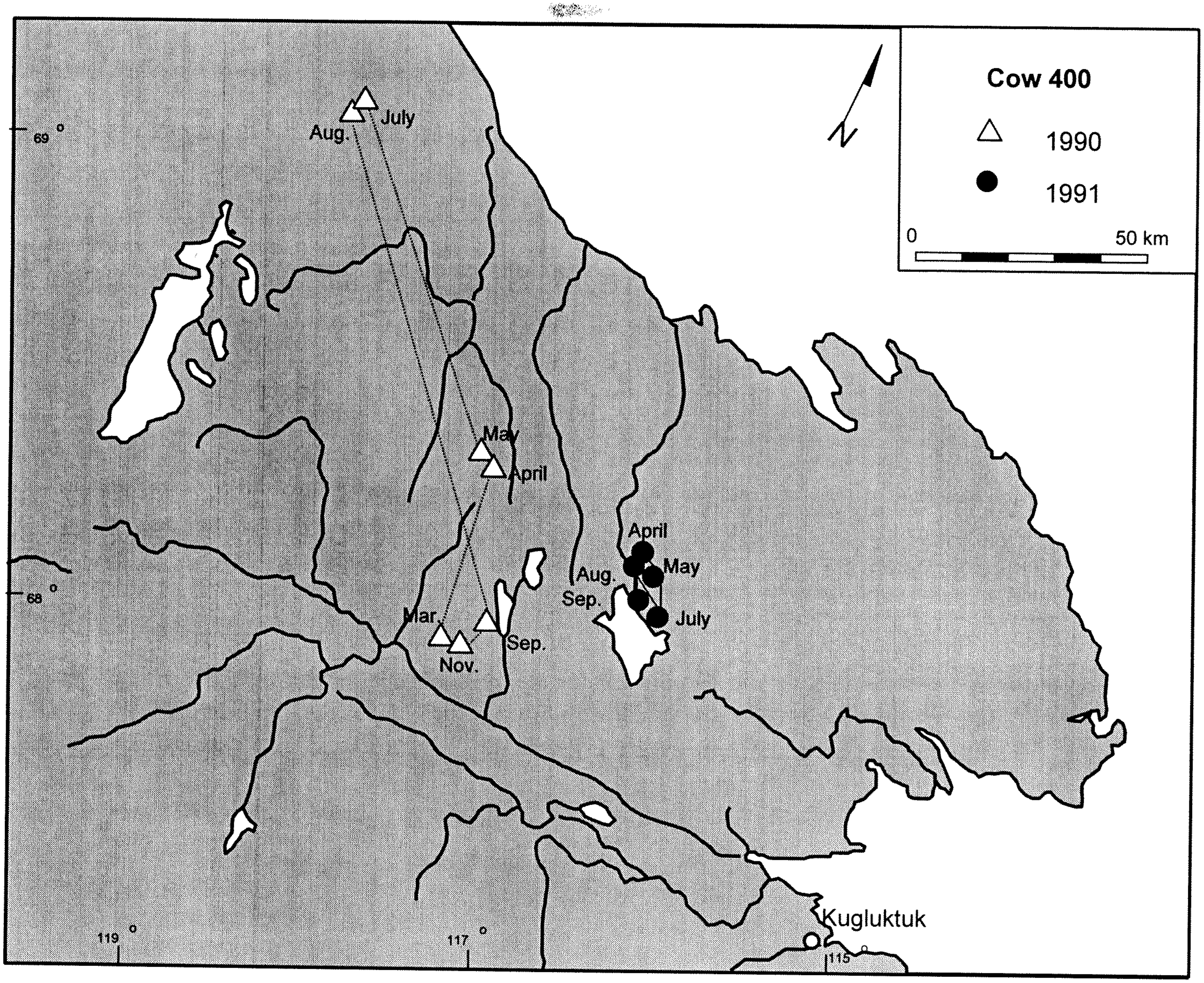
Appendix F (cont).



Appendix F (cont).



Appendix F (cont).



Appendix F (cont).

Appendix G. Radio-locations of collared muskox cows.

Cow#	Date	Location
010	11-11-88	68.06N/117.39W
010	07-05-89	68.40N/116.49W
010	31-05-89	68.42N/116.52W
010	29-06-89	68.46N/116.54W
010	14-07-89	-
010	17-08-89	68.06N/117.00W
011	09-04-91	67.58N/116.31W
011	20-05-91	67.57N/116.33W
011	07-07-91	68.29N/116.22W
011	13-08-91	68.35N/115.09W
011	18-09-91	68.30N/115.24W
018	10-11-88	67.58N/117.24W
018	08-05-89	68.54N/117.38W
018	31-05-89	68.49N/117.25W
018	29-06-89	69.01N/118.15W
018	14-07-89	68.26N/118.51W
018	18-08-89	68.47N/118.12W
018	30-09-89	68.07N/117.28W
018	09-11-89	68.03N/117.30W
018	20-04-90	68.29N/118.30W
018	10-05-90	68.28N/118.31W
018	29-05-90	68.46N/118.51W
018	06-07-90	68.45N/118.21W
018	08-08-90	68.45N/118.21W
018	12-09-90	68.21N/118.15W
018	10-11-90	68.03N/117.32W
018	08-04-91	68.34N/118.41W
018	18-05-91	68.37N/118.24W
018	07-07-91	68.31N/118.24W

Appendix G (cont).

Cow#	Date	Location
018	12-08-91	68.33N/118.28W
018	17-09-91	68.05N/117.43W
030	03-06-88	68.53N/115.57W
030	05-06-88	68.52N/115.56W
030	18-06-88	68.32N/115.55W
030	03-09-88	68.30N/115.59W
030	07-05-89	68.27N/116.00W
030	31-05-89	68.31N/116.13W
030	29-06-89	68.46N/116.08W
030	14-07-89	68.41N/115.50W
030	19-08-89	68.31N/116.20W
030	30-09-89	68.04N/116.14W
030	09-11-89	68.01N/116.45W
030	20-04-90	68.05N/115.47W
030	11-05-90	68.15N/115.49W
030	29-05-90	68.17N/115.55W
030	06-07-90	68.57N/117.59W
030	08-08-90	68.49N/117.54W
030	12-09-90	68.32N/116.42W
030	10-11-90	67.59N/117.12W
030	09-04-91	67.58N/116.31W
030	20-05-91	67.57N/116.33W
030	07-07-91	67.58N/116.34W
050	03-06-88	68.21N/115.57W
050	05-06-88	68.20N/115.56W
050	18-06-88	68.13N/115.47W
050	03-09-88	68.27N/115.59W
050	07-05-89	68.15N/115.32W

Appendix G (cont).

Cow#	Date	Location
050	31-05-89	68.45N/116.52W
050	29-06-89	68.40N/116.47W
050	14-07-89	68.28N/116.18W
051	13-11-89	67.58N/116.33W
051	10-05-89	68.26N/115.52W
051	29-05-89	68.47N/117.46W
051	06-07-89	68.49N/117.22W
051	20-11-89	68.13N/115.39W
051	09-04-91	67.55N/115.58W
051	20-05-91	67.52N/115.53W
051	04-07-91	67.54N/115.43W
051	10-08-91	67.55N/116.31W
051	19-09-91	67.53N/115.28W
070	11-11-88	68.06N/117.39W
070	07-05-89	68.15N/116.55W
070	31-05-89	68.17N/117.12W
070	29-06-89	68.09N/117.02W
070	14-07-89	68.48N/118.16W
070	18-08-89	68.35N/117.50W
070	30-09-89	68.06N/117.28W
070	09-11-89	68.05N/117.44W
070	20-04-90	68.55N/117.32W
070	10-05-90	68.55N/117.37W
070	29-05-90	68.55N/117.34W
070	06-07-90	68.40N/117.47W
070	08-08-90	68.28N/117.48W
070	11-09-90	68.09N/117.37W
070	10-11-90	68.04N/117.40W

Appendix G (cont).

Cow#	Date	Location
070	18-05-91	68.37N/118.24W
070	07-07-91	68.19N/117.29W
070	10-08-91	68.15N/117.12W
070	17-09-91	68.09N/117.17W
090	09-11-88	68.03N/117.16W
090	07-05-89	68.30N/117.15W
090	31-05-89	68.37N/116.25W
090	29-06-89	68.34N/116.17W
090	14-07-89	68.26N/116.12W
090	18-08-89	68.37N/115.59W
090	01-10-89	68.21N/115.34W
090	09-11-89	67.57N/116.04W
090	20-04-90	68.32N/116.32W
090	10-05-90	67.55N/117.18W
090	29-05-90	68.06N/116.50W
090	06-07-90	68.40N/117.25W
090	08-08-90	68.38N/117.02W
090	12-09-90	68.14N/116.54W
090	10-11-90	68.02N/117.28W
090	08-04-91	68.22N/118.03W
090	20-05-91	68.42N/118.45W
090	06-07-91	68.08N/118.07W
090	12-08-91	68.34N/117.43W
090	17-09-91	68.03N/117.20W
120	03-06-88	67.48N/119.13W
120	05-06-88	67.46N/118.45W
120	03-09-88	67.52N/117.38W
120	07-05-89	67.52N/116.45W
120	31-05-89	67.51N/116.45W

Appendix G (cont).

Cow#	Date	Location
120	30-06-89	67.48N/119.10W
120	18-08-89	67.47N/119.38W
120	01-10-89	67.42N/119.36W
120	09-11-89	67.43N/119.30W
120	21-04-90	68.10N/120.00W
120	10-05-90	68.18N/119.55W
120	29-05-90	68.19N/120.03W
120	06-07-90	67.38N/119.39W
120	08-08-90	67.37N/119.29W
120	12-09-90	67.43N/119.40W
120	10-11-90	67.44N/118.54W
120	09-04-91	67.36N/118.55W
120	20-05-91	67.48N/119.52W
120	06-07-91	67.33N/119.36W
120	11-08-91	67.29N/119.24W
120	18-09-91	67.29N/119.54W
140	03-06-88	68.20N/115.37W
140	05-06-88	68.21N/115.37W
140	18-06-88	68.16N/115.37W
140	03-09-88	68.04N/117.30W
140	07-05-89	68.36N/116.57W
140	31-05-89	68.38N/116.57W
140	29-06-89	68.37N/116.58W
140	14-07-89	68.14N/117.16W
141	13-11-89	67.58N/116.30W
141	20-04-90	68.17N/117.24W
141	11-05-90	68.23N/117.24W
141	06-07-90	68.22N/117.08W
141	08-08-90	68.15N/117.03W

Appendix G (cont).

Cow#	Date	Location
141	12-09-90	67.55N/116.48W
141	10-11-90	67.50N/117.30W
141	09-04-91	67.55N/117.30W
141	19-05-91	67.58N/118.03W
160	09-11-88	68.04N/117.10W
160	07-05-89	68.51N/117.08W
160	31-05-89	68.52N/117.08W
160	29-06-89	69.01N/118.15W
160	14-07-89	68.56N/119.45W
160	18-08-89	69.03N/118.30W
160	30-09-89	69.03N/118.29W
161	13-11-89	67.59N/116.50W
161	20-04-90	68.21N/116.49W
161	10-05-90	68.14N/116.33W
161	29-05-90	68.13N/116.35W
161	06-07-90	68.04N/117.00W
161	08/08/90	68.15N/117.03W
161	12-09-90	67.55N/116.48W
161	10-11-90	67.58N/117.21W
161	08-04-91	68.17N/116.28W
161	18-05-91	68.18N/116.23W
161	07-07-91	68.25N/116.16W
161	10-08-91	68.30N/116.13W
161	18-09-91	68.08N/116.25W
200	11-11-88	68.06N/117.39W
200	07-05-89	68.40N/116.49W
200	31-05-89	68.42N/116.52W
200	29-06-89	68.46N/116.54W
200	14-07-89	68.20N/117.23W

Appendix G (cont).

Cow#	Date	Location
200	18-08-89	68.19N/116.58W
200	01-09-89	68.18N/117.01W
200	30-09-89	68.08N/117.10W
200	09-11-89	68.02N/117.30W
200	21-04-90	68.49N/118.09W
200	10-05-90	68.55N/117.37W
200	29-05-90	68.55N/117.34W
200	06-07-90	68.43N/117.24W
200	08-08-90	68.25N/116.55W
200	12-09-90	68.18N/116.35W
200	10-11-90	67.59N/117.12W
200	08-04-91	67.59N/118.25W
200	18-05-91	68.18N/118.02W
200	04-07-91	68.05N/117.47W
200	10-08-91	68.46N/117.59W
200	19-09-91	67.53N/115.28W
220	11-03-90	68.02N/117.31W
220	21-04-90	68.34N/117.25W
220	10-05-90	68.37N/117.30W
220	29-05-90	68.48N/117.54W
220	06-07-90	69.06N/119.12W
220	08-08-90	68.47N/118.57W
220	12-09-90	68.06N/117.46W
220	10-11-90	68.01N/117.33W
220	08-04-91	68.16N/118.03W
220	19-05-91	68.19N/118.01W
220	07-07-91	68.39N/118.02W
220	10-08-91	68.51N/118.02W
220	20-09-91	68.30N/117.45W

Appendix G (cont).

Cow#	Date	Location
240	10-03-90	68.11N/117.38W
240	20-04-90	68.58N/118.23W
240	10-05-90	69.03N/118.31W
240	29-05-90	-
240	06-07-90	68.31N/118.18W
240	08-08-90	68.25N/118.16W
240	12-09-90	68.06N/117.46W
240	10-11-90	68.01N/117.30W
240	08-04-91	68.44N/118.27W
240	19-05-91	68.03N/119.06W
240	06-07-91	68.42N/118.52W
240	11-08-91	68.42N/118.55W
240	17-09-91	68.03N/117.36W
260	20-04-90	64.88N/118.07W
260	10-05-90	68.45N/118.06W
260	29-05-90	68.44N/118.04W
260	06-07-90	68.11N/117.49W
260	10-07-90	68.10N/117.49W
260	08-08-90	68.20N/119.01W
260	12-09-90	68.17N/118.32W
260	10-11-90	67.59N/117.53W
260	07-04-91	68.45N/118.50W
260	18-05-91	68.39N/118.28W
260	07-07-91	69.09N/119.18W
260	11-08-91	68.56N/118.33W
260	19-09-91	68.08N/117.54W
280	11-03-90	68.02N/117.32W
280	20-04-90	68.27N/117.42W
280	10-05-90	68.51N/117.19W

Appendix G (cont).

Cow#	Date	Location
280	29-05-90	68.52N/117.19W
280	06-07-90	68.59N/118.40W
280	08-08-90	69.03N/118.28W
280	12-09-90	69.05N/118.27W
280	10-11-90	68.10N/117.10W
280	08-04-91	68.22N/118.03W
280	18-05-91	68.39N/118.28W
280	07-07-91	69.09N/119.18W
280	12-08-91	68.29N/118.05W
280	17-09-91	68.03N/117.53W
300	10-03-90	68.11W/117.38W
300	20-04-90	68.20N/117.36W
300	10-05-90	68.51N/117.19W
300	29-05-90	68.44N/117.49W
300	06-07-90	68.38N/117.49W
300	08-08-90	68.42N/117.54W
300	12-09-90	68.32N/117.51W
300	10-11-90	68.05N/117.37W
300	08-04-91	68.26N/117.41W
300	18-05-91	69.03N/118.28W
300	06-07-91	68.49N/119.33W
300	11-08-91	68.32N/118.02W
300	17-09-91	68.01N/117.27W
320	10-03-90	68.11N/117.40W
320	20-04-90	68.49N/118.09W
320	10-05-90	68.55N/117.37W
320	29-05-90	68.55N/117.34W
320	06-07-90	68.38N/117.49W
320	08-08-90	68.42N/117.54W

Appendix G (cont).

Cow#	Date	Location
320	12-09-90	68.18N/118.03W
320	10-11-90	68.01N/117.30W
320	08-04-91	67.59N/118.25W
320	18-05-91	68.18N/118.02W
320	08-07-91	68.14N/117.58W
320	11-08-91	68.13N/118.06W
320	17-19-91	67.58N/117.20W
340	11-03-90	68.12N/117.33W
340	20-04-90	68.02N/117.38W
341	03-09-91	68.05N/118.25W
341	08-04-91	68.44N/118.27W
341	19-05-91	69.03N/119.06W
341	07-07-91	68.59N/119.13W
341	11-08-91	68.56N/118.49W
341	17-09-91	68.07N/117.55W
342	13-11-89	67.59N/117.02W
342	20-04-90	67.59N/116.35W
342	10-05-90	-
342	29-05-90	67.55N/116.35W
342	06-07-90	-
342	08-08-90	67.51N/116.15W
342	12-09-90	67.52N/116.02W
342	10-11-90	67.48N/116.33W
342	08-04-91	67.52N/116.49W
342	18-05-91	67.55N/116.42W
342	04-07-91	67.54N/115.43W
342	12-08-91	67.59N/115.50W
342	119-09-91	67.54N/116.22W
360	11-03-90	68.11N/117.35W

Appendix G (cont).

Cow#	Date	Location
360	20-04-90	68.27N/117.42W
360	10-05-90	68.51N/117.19W
360	29-05-90	68.52N/117.19W
360	06-07-90	68.42N/117.16W
360	08-08-90	68.14N/117.34W
360	12-09-90	68.06N/117.19W
360	10-11-90	68.02N/117.28W
360	08-04-91	68.17N/116.28W
360	18-05-91	68.18N/116.23W
360	07-07-91	68.25N/116.16W
360	10-08-91	68.30N/116.13W
360	18-09-91	68.08N/116.25W
380	10-03-90	68.11N/117.41W
380	21-04-90	68.55N/117.32W
381	05-03-91	68.05N/118.20W
381	08-04-91	68.52N/118.13W
381	19-05-91	69.11N/118.40W
381	07-07-91	68.31N/118.24W
381	12-08-91	68.45N/119.04W
381	20-09-91	68.30N/118.45W
400	11-03-90	68.02N/117.33W
400	20-04-90	68.27N/117.42W
400	10-05-90	68.28N/117.46W
400	29-05-90	-
400	06-07-90	69.05N/119.18W
400	08-08-90	69.03N/119.17W
400	12-09-90	68.06N/117.19W
400	10-11-90	68.02N/117.28W
400	08-04-91	68.28N/116.52W

Appendix G (cont).

Cow#	Date	Location
400	18-05-91	68.25N/116.47W
400	07-07-91	68.21N/116.40W
400	10-08-91	68.25N/116.51W
400	20-09-91	68.21N/116.47W

Appendix H. Seasonal range overlap for radio-collared muskox cows.

Overlap (km^2)	**% overlap**	**% overlap**
8397	April (**93.7**)	May (**81.1**)
4075	May (39.4)	June (73.4)
4417	June (**79.6**)	July (44.1)
7130	July (71.1)	Aug (**87.8**)
4610	Aug (56.8)	Sep (**82.7**)
1231	Sep (22.1)	Nov (49.4)
818	Nov (32.7)	Mar (70.2)

Appendix I. Summary of the dates for radio-collared muskox cows: their calving and necropsies.

Cow #010

Collared June 1988. Found dead August 1989; grizzly bear suspected cause of death. Collar, head and hide visible on a small patch of bare ground tussock area close to a drained lake bed.

Necropsy: skull intact except for one horn that was dislodged and lying beside skull with the hide, adhering to frontals and nasals. One half of the mandible was posterior to incisors, 2 m from skull. Both femurs articulated to lower limbs lying attached by hide but pelvis c. 5m away, chewed around all edges and dis-articulated from sacrum. Lumbar vertebrae articulated together but other vertebrae and front limbs were not visible. Sternum with stubs of ribs attached was present in same area. Bones covered an area of c. 6 m diameter from which the vegetation had been scraped and pulled around. Snow patches may have covered some bones and the ear tags were not found – radio-collar was undamaged.

Cow #011

Collared March 1991. Recaptured September 1991 and collar was removed.

Cow #018

Collared November 1988. Recaptured September 1991 and collar was removed.

Cow #030

Collared June 1988. Found dead July 1991 on level tussock area 200m from crest of escarpment; grizzly bear suspected cause of death.

Necropsy: The hide was found with the head and lower limb bones attached. The femur heads were gnawed and left femur was disarticulated. The hooves were gnawed and discarded. Turbinals were chewed and the mandibles were disarticulated and separated. Three bear scats in the area contained vegetation and three contained meat/blood. The left rib cage was attached to the sternum but dislocated from the vertebra. The pelvis and sacrum were intact but chewed. Most of the meat was cleaned off – bird scats and a brown feather present. The radio-collar was around the neck with skin and ear tags lying loose.

Cow #050

Collared June, 1988 and found dead July, 1989. The disassembled carcass was scattered on a small bench among limestone outcrops; suspected grizzly bear kill.

Necropsy: The head was attached to the hide with both femurs also attached. One femur was still articulated to the head of the tibia, which was fractured mid-shaft. One scapular was articulated to the radius head and attached to the hide.

Appendix I (cont).

The skull was exposed laterally to the orbits, with the muzzle pulled back from the nasals. The nasals were chewed. The skin was dried but looked intact with no perforations evident. The mandibles, except for the fractured incisor bar, were missing as were the lower limbs. The pelvis was fractured and there were scattered ribs of which three were still articulated to the vertebrae. The femur marrow was white and firm. The remains were lying on a bare area from which the sedge and *Dryas* cover had been scraped. There were three bear scats and two bed pits scrapped approximately 25 cm into the ground and approximately 1 m across.

Cow #051
Collared November 1989. Recaptured September 1991.

Cow #070
Collared November 1988. Recaptured September 1991.

Cow #090
Collared November 1988. Recaptured September 1991.

Cow #120
Collared June 1988. Recaptured September 1991.

Cow #140
Collared June 1988. Found dead 14 July 1989 with a grizzly bear on the carcass.
Necropsy: The carcass was lying on its right side and had been opened through the anus, exposing the heads of the femurs, the caecum and the rumen. Most of the femoral muscles had been removed and the pelvis was chewed posteriorly. The skin was peeled back from the ribs, exposing the scapular whose blade had been chewed and muscles removed. Most of the skin of the back had been peeled back and the thoracic spines were chewed. The head was disarticulated at the atlas but the ligaments were not severed. The trachea, esophagus and neck muscle had been removed; the fragments of the throat tissue were severely hemorrhaged. There was deep and extensive subcutaneous hemorrhaging over both scapulars but no skin perforations. The head was intact with no punctures or subcutaneous hemorrhages. The femoral marrow fat was white and firm. The lungs had many (not counted) conspicuous *Protostrongylus* cysts. Willows and sedges were scraped up around the carcass and about 5 m away was an area of flattened sedge and dirt with hoof prints 2-3 cm deep into the dry hard ground. Copious pools of blood had dried on the ground. Within 5 m of the carcass were two bed pits about one metre apart.

Appendix I (cont).

Cow #141
Collared November 1989. Found dead May 1991.
Necropsy: The carcass of cow and calf were located July 14, 1991, below an escarpment on a tussock area. The maxillary molar rows and femur shaft from the cow were found with the collar intact. The calf's nasal area and palate with premolars were present and the wool was attached.

Cow #160
Collared November 1988. Found dead 30 September 1989.
Necropsy: The carcass was found part way down a dry tussock slope, lying on on its flank with the legs stretched out and the upward-facing eye removed. It was otherwise unscavanged. The collar was loose and there was no matting or rubbing of the wool. No pellet groups were present, but 20 cm of snow had drifted around the carcass. No subcutaneous bruising or trauma was found when the left side was skinned. There was blood-stained fluid and leaves in the mouth and the perianal area was clean. There was no discernible back fat and only a small amount of mesenteric and kidney fat. The intestinal contents were watery and there were formed faecies in the colon. The rumen had dryish contents and was 2/3 full. The kidneys and liver looked normal but the heart was flabby. The chest cavity contained c. 1 litre of blood-tinged fluid. The lungs had a blotched and lumpy appearance with many (at least 50) *Protostrongylus* cysts.

Cow #161
Collared November 1989. Recaptured September 1991.

Cow #200
Collared November 1988. Recaptured September 1991.

Cow #220
Collared March 1990. Recaptured September 1991.

Cow #240
Collared March 1990. Recaptured September 1991.

Cow #260
Collared March 1990. Recaptured September 1991.

Cow #280
Collared March 1990. Recaptured September 1991.

Appendix I (cont).

Cow #300
Collared March 1990. Recaptured September 1991.

Cow #320
Collared March 1990. Recaptured September 1991.

Cow #340
Collared March 1990. Shot April 1990.

Cow #341
Collared March 1991. Recaptured September 1991.

Cow #342
Collared November 1989. Recaptured September 1991.

Cow #360
Collared March 1990. Recaptured September 1991.

Cow #380
Collared March 1990. Shed collar May 1990.

Cow #381
Collared March 1991. Recaptured September 1991.

Cow #400
Collared March 1990. Recaptured September 1991.

Appendix J. Attempted Treatment of a Protostrongylid Lungworm Infection in Muskoxen, Northwest Territories.

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INTRODUCTION

In wildlife management, treating wildlife disease has often been ignored. This is partly because the effects of disease were little known and partly because, other than administrating drugs in food supplements such as salt blocks, little could be done to practically treat or vaccinate wildlife without capturing them to administer individual doses. Technology is now being developed to administer drugs without the expense and difficulties of handling animals. At the same time, disease is now being recognised as a significant factor in the population ecology of wildlife (May 1983, Kistner 1982).

Muskoxen on the mainland Northwest Territories west of Kugluktuk are infected with a lungworm (Gunn and Wobeser 1992) recently named and described as *Umingmakstrongylus pallikuukensis,* a protostrongylid nematode (Hoberg *et al* . 1995). At the time of this research, the life-cycle, host range, geographic distribution in muskoxen, and effect of this parasite on muskoxen were uncertain. However, circumstantial evidence suggested that the lungworm was contributing to increased mortality in the population.

Preliminary investigations indicate that the infection is common and widespread, with 92% of 48 adult animals examined between November 1989 and 1990 having grossly visible lesions in the lungs (Gunn *et al* 1991). The infections can also be very severe in individual muskoxen, with one hunter-killed bull having 258 pea to grape-sized nodules in its lungs. In July 1990, we collected 79 individual muskox faecal samples dispersed between 17 herds. Prevalence was 96%, based on 68 of 71 muskox faecal samples (excluding calves) containing protostronglid larvae; five of eight calves (2-3 months old) were shedding protostronglid larvae in their faeces (unpubl. data).

The treatment of wildlife diseases will likely be most effective in small populations where a significant proportion can be economically treated to improve survival and reproduction. The Rae-Richardson muskox population is relatively small and isolated from other muskox populations, but it is not so logistically remote as to be prohibitively expensive to manage and monitor.

Practical treatment of wildlife diseases requires a procedure that avoids the stress and expense of handling individual animals but ensures that the individuals receive suitable doses. The Ballistivet Implant System uses Biobullets, which are bioabsorbable hydroxypropyl cellulose bullets packed with doses of vaccine or treatment drug in a freeze-dried state (Wildlife Specialities Inc., Whitebear Lake, Mn.). The bullet is fired by a pressurised air delivery system and has been shown to cause less tissue trauma than the more usual darting syringes. Inside the tissue, the Biobullet dissolves, releasing the drugs. We needed to test whether the pressurised air system would work under the rugged conditions of travel by snowmachine and extreme cold. If the equipment worked, we anticipated treating the muskoxen from the ground, using Inuit hunters to find and round up muskox herds.

The effectiveness of treatment in wildlife can only be established by trials on free-ranging animals. As we did not have information on required drug dosages, we selected the anthelmintic Ivermectin, which is effective against a wide variety of parasites. It has been used in captive muskoxen to treat other parasites without observed ill effects and was successfully used to treat protostrongylid lungworm in bighorn sheep (Schwantje 1988).

Our objective was a pilot study to test the feasibility of treating muskoxen in a small population in order to control the lungworm infection. In addition, we used a direct method of assessing the significance of the parasite by comparing the survival and productivity of animals that have been treated to reduce their lung worm infection to that of untreated control animals in the same general population.

The feasibility of treatment will depend on field testing the BallistiVet Gun delivery system for BioBullets on muskoxen under local conditions. Muskoxen will be rounded up by snowmachine and held in small groups for drugging and marking. Thirty five adult cows will be treated and ear-tagged; 15 cows will be ear-tagged but not treated. These 15 cows and the 20 previously radio-collared cows will be the control (untreated) group.

Research Design:
The design is the randomised selection and assignment of adult cow muskoxen to either control or treated group that will be exposed to comparable environmental conditions. The experiment is restricted to the cows and the survival of their calves in order to reduce the number of variables and therefore the required sample size. Seasonal changes in herd size and association of radio-collared cows suggests that the herds are not fixed social units and do coalesce and split during the year (This report.). The interchange of animals between herds allows the assignment of the cows to control or treatment group on a temporal (daily) basis to facilitate logistics. The assumption that the marking of half the control animals the previous year does not compromise the design is based on the

likelihood that they will be in the same area and probably in some of the herds that will be herded and handled. The justification for using the previously (1990) radio-collared cows as controls, even although they would not be tested at the time of the trial, is the high prevalence of the lungworm. The selection of the actual individual cows is based on the opportunity to place an immobilising dart while the herd is held in a defence formation. The herding is of brief duration so animals with compromised respiration do not usually have time to drop back and be excluded.

The outcome of the trial is on two levels. The first level is a comparison of the direct effect of the treatment (reduction or death of adult lungworms leading to a decline in the direct lung tissue response measured by (1) a decrease in the size of the encapsulated worms and (2) a decline in the shedding of lungworm larvae in the faeces). The second level of determining the outcome of the treatment is to compare changes in the assumed effects of the lungworm infection that have population level consequences (namely calf survival). It is not feasible to obtain a sample size for statistical comparison of the survival of the individually marked cows (assuming rates of survival comparable to the 80% survival of radio-collared cows in 1989 and 1990).

The results of monitoring the radio-collared cows is that calf survival is 30% at the end of the first 6 months, which suggests that a sample size of 30 is adequate at 95 % confidence levels. The pregnancy rate of the population is unknown but will be determined from serum progesterone levels for the trial. The determination of calf survival will, however, include possible last trimester intra-uterine mortality. The limitation to this aspect of evaluating the treatment is that it will not be possible to determine whether the expected improvement in calf survival is due to (1) absence of transplacental infection of the calf or (2) improvement in the maternal cow's condition such as increased lactation or lessened vulnerability to predators.

The muskoxen will be sampled during the immobilisation to determine pregnancy (assay of serum progesterone) and lungworm infection (faecal sample). The calf survival between the treated and control muskoxen will be compared by aerial survey in May and September. After 6 months, 5-10 cows from the treated and control muskoxen will be collected to determine if the lesions have resolved and if shedding of lungworm larvae is reduced or halted.

Research Hypotheses:

(1) The proportion of calves in the treatment and control group will significantly differ after 6 months.

(2) The mean diameters of the lung nodules will be significantly different between muskox cows in the treatment and control group.

(3) The mean numbers of larvae in faecal samples will be significantly different between muskox cows in the treatment and control group.

METHODS

Immobilisation

Muskoxen were immobilised so that they could be conspicuously marked to identify treated or control cows, and to determine if they were infected with lungworm and if they were pregnant. A team of five snowmachines split the large muskox herds into manageable units of 12 animals or less. When possible, the herders cut out the bulls, as bulls frequently hook at animals while the group is being held. The group was surrounded by the herders and snowmachines, and the shooter waited a few to 30 minutes until the group was no longer agitatedly milling and panting. The shooter slowly approached to within 20 m and knelt to dart an adult cow that presented either a neck, shoulder or rump shot. When possible, two cows were darted in each group so they would not be alone when revived. Once the animals were immobilised and in sternal recumbancy, the remaining animals were moved away by people approaching on foot. A snowmachine was only used if the animals were reluctant to leave. The group was held again if they were not agitated and if adult cows remained in the group. The immobilised cows were immediately checked by the veterinarian and blindfolded. The dart was removed and Hibitane applied to the wound.

The darts were 5 ml Cap-Chur darts with 35 mm needles whose barb had been shortened (to minimise trauma). Medium (yellow) or low (green) charges were used in the Palmer Cap-Chur rifle, depending on wind strength. The darts were prepared in advance for each day and held in an insulated container with an pre-heated ethylene glycol pack. The darts were filled with 5 mg Carfentanil, 25 mg Atrovet and injectable distilled water. The needle was filled with isopropyl alcohol (to reduce the possibility of freezing). As a contingency, we also had prepared darts with 3 mg Carfentanil without the Atrovet for supplemental doses.

Marking and Treatment

Muskoxen in the treatment group were marked with numbered yellow cattle ear-tags (All-Flex Extra Large) and those in the control group were marked with blue or green numbered tags. The hair was clipped from a small area on the back of the ear and the site dabbed with Hibitane, which was also smeared on the ear-tag.

Each cow received mg long-acting Penicillin as a subcutaneous injection in two sites. Blood samples were taken from the jugular into EDTA-and additive-free Vacutainers. The former samples of whole blood were kept unfrozen for subsequent mtDNA analysis at the University of Alaska (Groves 1995). Serum was drawn from the latter samples for subsequent assays for progesterone and cortisol (Western College of Veterinary Medicine), and brucellosis (Agriculture Canada). Fecal samples were collected from the rectum, frozen and examined (WCVM) for lungworm larvae. Cows with a full complement of permanent incisor teeth were classified as adult, and missing, broken or cracked incisor teeth were recorded.

Selection of individual cows was based on the opportunity to dart the cow in the group; cows that fell back during the brief chases or determinedly walked out of a group were not selected. The first 23 adult cows were assigned to the treatment group. Subsequently, cows were assigned to the treatment or control group as alternating sets of 5 consecutive immobilised cows. Cows in the treatment group received 50 mg Ivermectin by Biobullet fired into the rump of the immobilised muskoxen by a shooter standing 6-8 m away. The delivery of the Biobullet was verified by feeling for it under the skin. Five cows received a hand injection of 50 mg Ivermectin instead of the Biobullet administration.

Treatment Evaluation

Ten cows were shot by hunters in November 1991 and the accompanying biologist recorded the body measurements, removed the lungs, and collected faecal samples. The hunters found and shot 5 cows with yellow ear-tags (treated with Ivermectin) and 5 with blue, green or orange ear-tags (untreated). The lungs were macroscopically examined in the lab to count the lungworm nodules. WCVM used Baermann and Flotation to examine rectal faecal pellets and abomasal contents for protostronglyid larvae and nematode eggs.

RESULTS

The muskox cows were captured and treated with Ivermectin delivered by Biobullets with no injuries or drug-related problems. We were delayed by blizzards until 2 March 1991, but beween 3 and 14 March 1991, we immobilised, marked and treated 30 muskox cows (Appendices A-D). We caught and ear-tagged 12 cows as part of the control (untreated). All faecal samples from the immobilised cows were positive for protostrongyid larvae, but we were unable to sample 11 cows (the rectum was empty) and for 20 cows, there was sufficient faecal sample for quantitative examination. The faecal samples from the 9 treated and 11 untreated muskoxen differed in the number of larvae/g of faecal pellets (Mann-Whitney Rank Sum test, $T = 69$, $P = 0.0575$), with the treated muskoxen having fewer larvae (2.6 ± 0.94 Standard Error) than the untreated (8.2 ± 2.04 SE).:

The Biobullet gun worked well despite the cold. All Biobullets penetrated the skin and could be felt under the skin.

After 8 months, however, we found that the treatment was barely successful (Table 1). However, we only sampled five treated and five untreated cows as the hunters on snowmachines had difficulty finding enough ear-tagged cows in November 1991 because frequent storms hindered searches. Two of the four treated cows were positive on Baermann examination of the faeces, compared to the five untreated cows that were positive. There was no statistical difference between treated (59.3 ± 35.34 Standard Deviation) and untreated cows (58.8 ± 41.89) for the number of lungworm nodules in the lungs (F-Test, $F = 1.41$, $df = 3,3$, $P>0.2$).

Table 1. Results of examination for protostronglids from treated and untreated muskox cows killed in November 1991, Kugluktuk, N.W.T.

Lab. No.	Abomasal Baermann	Abomasal Flotation	Faecal Baermann	Faecal Flotation	Lung Nodules
Treated with Ivermectin					
1102	0	0	0	Nemat.eggs	92
1103	0	0	prot.lar.	Nemat.eggs	10
1106	0	0	missing		75
1108	0	0	prot.lar.	0	lost
1101	0	0	0	Nemat.eggs	60
Untreated					
1101	prot.lar.	0	prot.lar.	0	103
1104	0	0	prot.lar.	0	21
1105	0	0	prot.lar.	0	lost
1107	prot.lar.	0	prot.lar.	Nemat.eggs	86
1109	prot.lar.	0	prot.lar.	0	25

During the handling in March, we had taken serum and whole blood samples. Twenty-one samples were negative for brucellosis. The progesterone levels were obtained for 36 cows and we used 0.5 ng/ml as the threshold for late pregnancy. Cows with lower levels were assumed not to be pregnant (13 cows) which indicated a pregnancy rate of 36%.

DISCUSSION

The trial was a successful test of the equipment, as Biobullets fired with no difficulties under the testing conditions of –30 to –40°C, and penetrated cow's hide at close range, although we did not test penetration over greater distances or with the thicker hides of bulls.

The treatment was, however, not successful partly because of the small sample size resulting from logistical problems. The trial provided us with no clear information on the drug dose except the surmise that it was possibly too low as two treated muskoxen were shedding protostronglid larvae in faecal samples 8 months after treatment. However, in the absence of the parasite's life-history, early winter may also have been a season when larval-shedding is low.

The difference in the average larvae/g of faecal pellets between the treated and untreated muskoxen illustrates the difficulties of field trails where few variables can be influenced. The cows differed in whether they were lactating, had not calved or had calved but lost their calves. Considering the variability in larval output between cows, this finding probably indicates that the trial's sample size was too small

Acknowledgements

We thank Fred Paul and Terry McDermott (Ballistivet) for advice and equipment loans and Dr. D. Jessup (California Fish and Game) for technical advice. Renewable Resource Demonstration Project partially funded the project. We thank Dr.s Sue Tedesco and Brett Elkin for their assistance with the field immobilization under sometimes difficult conditions. We also appreciated the field skills of the capture crew who worked patiently with us for the safe handling of the muskoxen: Colin Adjun, Bobby Algona, Gerry Atatahak, Jack Atatahak, Keith Hickling, Isaac Klengenberg, Allen Niptanatiak and Alec Taptuna. Joachim Obst worked with Colin Adjun and Isaac Klengenberg to sample the muskox cows in November.

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Appendix A. Prevelence and density of protostronglid larvae and age for muskox cows immobilised March 1991 and lungworm nodules for muskoxen collected in November 1991, Kugluktuk, N.W.T.

	March 1991		November 1991 collection
Ear-tag no.	Protostronglid larvae/g	Est. Age	No. lungworm nodules
<u>Cows treated with Ivermectin</u>			
Y4/5	7.18	4+	
Y12/37	No sample	4+	
Y64/--	No sample	No information	
Y69/32	No sample	3	
Y13/75	No sample	3	
Y63/61	+	4+	
Y45/14	No sample	Worn	
Y16/--	No sample	3	75
Y66/--	+	Worn	
Y20/3	+	Worn	
Y19/71	+	Worn	--
Y34/25	+	4+	
Y38/44	+	4+	
Y17/33	No sample	4+	
Y22/73	No sample	4+	
Y65/21	0.91	No information	10
Y42/43	No sample	4+	
Y24/36	+	3+	Missing
Y125/124	0.25	4+	
Y67/72	No sample	4+	92

Appendix A (cont.)

Ear-tag no.	March 1991 Protostronglid larvae/g	Est. age	November 1991 No. lungworm nodules
Y121/122	6.0	4+	
Y70/40	0.42	Worn	
Y62/23	4.94	Worn	
Y55/123	+	4+	
Y35/6	+	Worn	
Y108/109	0.10	Worn	
Y1/8	0.54	Worn	60
Y33/11	3.09	Worn	
Y7/9	0.60	Worn	
Y102/103	No sample	Worn	
Control cows - not treated with Ivermectin			
B2/3	13.33	Worn	
B12/13	12.81	4+	
B21/22	13.07	Worn	103
B19/20	3.36	3	
B25/1	0.91	Old	
B5/8	13.28	3+	21
B6/24	2.44	Worn (emaciated)	
B7/9	20.90	Worn	
B11/10	5.61	3	
B14/15	+	Worn	
G24/25	3.76	Old	
G5/4	0.19	Worn	25

Appendix B. Induction, recovery, handling times and respiration rates for muskox cows immobilised with 5 mg Carfentanil, March 1991, Kugluktuk, N.W.T.

Ear-tag no.	Induct.[1] (min.)	Resp.[2] (bpm).	Recov.[3] (min.)	Handl.[4] (min.)
Cows treated with Ivermectin				
Y4/5	4	50	2	30
Y12/37	8	60	2.5	10
Y69/32	5	20	4	30
Y13/75	2	10	5	30
Y63/61	2	12	5.5	18
Y45/14	3	24	5	40
Y16/--	4	30	4	40
Y66/--	5	25	5.5	20
Y20/3	7	28	6	20
Y34/25	2	22	4	15
Y38/44	2	24	5	15
Y17/33	4	25	4	20
Y65/21	3	30	10	--
Y42/43	7	32	9	30
Y24/36	5	22	4	15
Y125/124	3	20	6	30
Y121/122	3	20	4	25
Y70/40	2	26	4	28
Y62/23	2	20	5	23
Y55/123	2	32	5	21
Y35/6	4	22	4	42
Y1/8	4	20	3	26
Y33/11	4	18	4	28
Y7/9	5	19	9	39

[1] Induction was the dart hit to the onset of sternal recumbancy.
[2] Respiration (breaths per minute).
[3] Recovery time was the reversal injection to muskoxen standing.
[4] Handling was sternal recumbancy to muskoxen standing.

Appendix B (cont.). Induction, recovery, handling times and respiration rates for muskox cows immobilised with 5 mg Carfentanil, March 1991, Kugluktuk, N.W.T.

Ear-tag no.	Induct.[1] (min.)	Resp.[2] (bpm).	Recov.[3] (min.)	Handl.[4] (min.)
Control cows (untreated)				
B2/3	2	28	5	30
B12/13	4	16	4	30
B21/22	4	16	4	28
B19/20	5	20	4	20
B25/1	4	28	3	20
B7/9	4	20	4	25
B11/10	4	26	5	25
B14/15	4	18	5	25
G24/25	3	20	4	33
G5/4	5	20	8	43

[1] Induction was the dart hit to the onset of sternal recumbancy.
[2] Respiration (breaths per minute).
[3] Recovery time was the reversal injection to muskoxen standing.
[4] Handling was sternal recumbancy to muskoxen standing.

Appendix C. Induction, recover, handling times and respiration rates for muskox cows immobilised with more than 5 mg Carfentanil, March 1991, Kugluktuk, N.W.T.

Ear-tag no.	Induct.[1] (min.)	Resp.[2] (bpm).	Recov.[3] (min.)	Handl.[4] (min.)	Comments
Cows treated with Ivermectin					
Y64/15	12	70	2.5	25	+ 3 mg dart[1]
Y19/71	7	32	5	20	+ 3 mg by hand[2]
Y22/73	14	25	5	20	+ 3 mg dart[1]
Y67/72	17	28	9	30	+ 3 mg dart[2]
Y108/109	8	20	4	40	+ 3 mg dart[2]
Y102/103	10	66	3	25	+ 3 mg by hand[3]
Control cows (untreated)					
B6/24	3	30	4	24	+ 5 mg dart[2]
B8/5	12	24	3	10	+ 5 mg dart[3]

[1] Incomplete induction as first dart poorly placed; cow high-stepping only in response to first dart.
[2] Incomplete injection of first dart; cow slightly high-stepping; possible problems with dart partially freezing.
[3] Dart bounced on impact; cow only high-stepping in response.

Appendix D. Dates, times, source groups and serum cortisol levels for muskox immobilization, Kugluktuk, N.W.T., March 1991.

Date Ear-tag no.	Time	Cortisol (nmol/l)	Single/ multiple darts
3/03 - Group 1 held 12:10 to 13:25 (3 cows taken as singles)			
Y4/5	12:20	21[1]	1
Y12/37	12:52	--	1
Y64/15	13:20	--	2
3/03 - Group 2 held 15:50 to 17:07 (3 cows taken as a pair and a single)			
Y69/32	16:11	--	1
Y13/75	16:15	128	1
Y63/61	17:04	137	1
5/03 - Group 3 held at 12:40 to 13:55 (4 cows taken as 2 pairs)			
Y45/14	12:45	184	1
Y16/--	12:52	227	1
Y20/3	13:47	209	1
5/03 - Group 4 held at 15:20 to 15:50 (1 cow taken[2])			
Y19/71	15:41	131	1
8/03 - Group 5 held at 09:45 to 11:03 (2 cows taken as a pair[3])			
Y34/25	10:59	96	1
Y38/44	11:00	--	1
6/03 - Group 6 held at 12:25 to 14:25 (5 cows as 2 pairs and a single)			
Y17/33	12:45	--	1
Y22/73	12:49	217	2
Y65/21	13:39	69	1
Y67/72	14:07	227	2
Y64/15	14:09	--	2
Y42/43	14:16	199	1

[1] Result unreliable as serum was hemolysed.
[2] Operation abandoned as darts jamming and freezing.
[3] Group abandoned as bull agitating the others.

Appendix D (cont). Dates, times, source groups and serum cortisol levels for muskox immobilization, Kugluktuk, N.W.T., March 1991.

Date Ear-tag no.	Time	Cortisol (nmol/l)	Single/ Multiple hits
6/03 - Group 7 held 17:00 to 17:18 (1 cow taken)			
Y24/36	17:11	233	1
7/03 - Group 8 held 11:10 to 12:18 (4 cows taken as 2 pairs)			
Y124/125	11:23	93	1
Y121/122	11:28	147	1
Y70/40	12:09	218	1
Y62/23	12:16	345	1
7/03 - Group 9 held 14:25 to 15:05 (1 cow hit but minimal response[1])			
9/03 - Group 10 held 10:26 to 12:22 (4 cows taken as 2 pairs)			
B2/3	11:30	90	1
B12/13	11:32	62	1
B21/22	12:15	89	1
B6/24	12:18	135	2
11/03 - Group 11 held 08:35 to 10:18 (6 cows taken as 3 pairs)			
B8/5	08:54	177	2
Y55/123	09:03	173	1
Y35/6	09:17	--	1
Y108/109	09:18	210	2
Y102:103	10:05	159	1 (+ 3 mg hand)
Y1/8	10:13	63[1]	1
11/03 - Group 12 held 13:05 to 13:25 (2 cows taken as a pair)			
B19/20	13:14	75	1
B25/1	13:19	158	1

[1] Group abandoned as bull agitating the others.

Appendix D (cont). Dates, times, source groups and serum cortisol levels for muskox immobilization, Kugluktuk, N.W.T., March 1991.

Date Ear-tag no.	Time	Cortisol (nmol/l)	Single/ Multiple darts
11/03 - Group 13 held 14:15 to 15:10 (4 cows taken as 2 pairs)			
B7/9	14:35	122	1
B11/10	14:36	84	1
Y33/11	15:01	24[1]	1
B14/15	15:05	178	1
12/03 - Group 14 held 10:05 to 10:30 (3 cows taken together[2])			
G24/25	10:14	126	1
G5/4	10:15	54	1
Y7/9	10:20	--	1

[1] Result unreliable as serum was hemolysed.
[2] Group abandoned as bull agitating the others.

Appendix E (cont). Estimated age, breeding status, and body measurements of muskox collected, Kugluktuk, N.W.T., November 1991.

Ear Tag	B21/22	B8/5	O22/21	B3R2	G4/5
Pregnant	Y	Y	Y	Y	N
Lactating	N	Y	N	N	Y
Est. Age	5.0	5.0	5.0	5.0	5+
Herd Sz +c	40+15	45+10	45+10	35+5	35+5
Brisket cm	68	59	55.5	51	64
Shoulder cm	122	117	119	129	120.5
Hindft len/cm	48	47	43	47.5	46
Femur mm	347.9	-	-	-	-
Femur g	834	-	-	-	-
Metacar mm	172.1	163.3	155.9	167.8	163.1
Metatar mm	185.4	178.1	170.1	177.7	172.3
Gastroc. g	550	540	535	580	545
Uterus kg	1.78	0.74	2.33	1.76	0.21
Kidney+fat g	608	502	623	645	382
Kid.1.Riney kg	417	401	484	478	354
Kid.1. wt/kg	165	170	139	175	202
Kid.2.+fatall g	641	504	549	607	378
Kid.2.Riney kg	531	400	372	459	322
Kid.2. kg	170	175	123	176	178
Liver kg	2.18	1.91	1.69	2.24	2.04
Liver cysts	0	0	0	5	0
Back fat cm	2.3	2.5	2.2	2.7	0.5

Appendix E. (cont.)

Ear Tag	Y67/72	Y651	Y181	Y24/36	Y8/1
Pregnant	Y	Y	N	N	Y
Lactating	Y	N	Y	Y	Y
Est. Age	5.0	4 ½	5+	5.0	5.0
Herd Sz +c	40+15	40+15	35+5	40+15	40+15
Brisket cm	64	62	62	62	61
Shoulder cm	124	127	128	118	120
Hindft len/cm	42	46.5	46	45	46
Femur mm	323.5	333.4	-	-	-
Femur g	786	745	-	-	-
Metacar mm	162.4	167.3	165.7	0	165.7
Metatar mm	177.1	181.8	175.3	168.9	179.1
Gastroc. g	505	551	530	425	670
Uterus kg	1.32	1.42	0.17	0.12	2.68
Kidney+fat g	428	627	269	284	529
Kid.1.Riney kg	337	491	242	266	411
Kid.1. wt/kg	160	165	171	143	169
Kid.2.+fatall g	463	591	243	367	434
Kid.2.Riney kg	289	451	213	311	385
Kid.2. kg	157	168	158	151	174
Liver kg	2.02	2.16	1.95	1.63	1.96
Liver cysts	1	1	0	0	0
Back fat cm	0.9	3.1	0.5	0.9	1.7