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MOOSE DENSITY AND COMPOSITION AROUND PRINCE GEORGE, BRITISH COLUMBIA, DECEMBER 1998

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ABSTRACT

We estimated the moose density within a 19,000 km^2 area within all or part of 11 Management Units around Prince George, British Columbia, in December 1998. We used a stratified random block survey design where stratification was based on forest cover type. Sightability bias was estimated from the vegetation cover density around each moose seen. Of the 1001 moose that we counted, there were 43 bulls and 38 calves per hundred females. We estimated the population size at 25,000 $\pm$ 3700 (1.3 moose/ km^2). The 1998 moose density estimate was similar to or higher than previous density estimates for all 4 management units that had been surveyed twice. There did not appear to be any trend in moose population composition. Moose numbers were high enough to sustain the annual kill by hunters. We suggest that the high moose density in our study area was possible because wolf density was reduced by the combined effects of human activities, such as legal hunting and killing wolves to protect livestock.

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INTRODUCTION

Moose (*Alces alces*) populations that are subject to hunting and predation from black bears, grizzly bears and wolves generally exist at low densities (Gasaway *et al.* 1992, Bergerud 1992, Messier 1994, 1996, Boertje *et al.*1996), sustain low hunter kill densities (Messier 1994) and usually have high twinning and yearling pregnancy rates (Franzmann and Schwartz 1985, Boer 1992, Boertje *et al.* 1996). Moose in the Sub-Boreal Spruce biogeoclimatic zone of central British Columbia do not appear to fit that pattern. In spite of the presence of hunting and all 3 predators, twinning and yearling pregnancy rates were low (Heard *et al.* 1996) and hunter kill density was high (Hatter 1997, in press). In order to better understand moose population dynamics and their implications to the management of moose hunting, we carried out a moose census in December 1998, around Prince George, British Columbia, and interpreted the results in relation to the history of moose hunting and moose population composition.

STUDY AREA

The study area comprised the rolling hills and low elevation (560 – 1200 m) forests around Prince George, British Columbia, including most of Management Units (MU) 707, 708, 709, 710, 711, 712, 713, 714 and 715, and parts of MU 716 and 724 (Fig. 1, 2). We based the study area boundaries on the following conditions; 1) the Ministry of Environment, Lands, and Parks Omineca administrative region for the south and west boundary, 2) the subjectively judged change from high to low moose densities for the north (S. Barry, personal communication), 3) elevations > 1200 m for the southeast, and 4) Tree Farm Licence #30 in the east, where forest cover information was not available to us. Within the study area, we excluded 2 areas with elevation > 1200m, the urban area around Prince George, the agricultural fields around Vanderhoof, the larger lakes, and some small patches of Tree Farm Licence #30 and Tree Farm Licence #10 within the study area, for a resulting census zone area of 18,962 km^2 (Fig. 3, 4).

The study area consisted mainly of the Sub-Boreal Spruce biogeoclimatic zone with a small amount of Engelmann Spruce - Subalpine Fir (MacKinnon *et al.* 1992, DeLong *et al.* 1993). Climax Sub-Boreal Spruce forests consist primarily of hybrid white-Engelmann

spruce (*Picea glauca* x *engelmannii*) and subalpine fir (*Abies lasiocarpa*), with extensive successional stands of lodgepole pine (*Pinus contorta*) and trembling aspen (*Populus tremuloides*) caused by recurrent disturbances. Engelmann Spruce - Subalpine Fir forests occur at higher elevations, with Engelmann spruce and subalpine fir as the dominant tree species in climax forests.

Based on the climatic characteristics for those biogeoclimatic units, the study area would be expected to have a mean annual temperature of 2.6 °C, and a mean annual precipitation increasing from 49 cm in the west to 73 cm in the east (DeLong *et al.* 1993). Snow usually covers the ground from late-November through mid-April. Mean annual snowfall increases from 200 cm in the west to 300 cm in the east.

Natural fires, once the dominant disturbance in those forests, have been largely eliminated. The primary disturbance is now logging. Selective large tree removal was typical until clearcut logging began in about 1965. Cutblocks ranged from 10-1000 ha, collectively covering about 20% of the study area (Fig. 1, 3).

In this area, moose were probably the predominant ungulate prey for wolves (*Canis lupus*), black bears (*Ursus americanus*), and grizzly bears (*U. arctos*) because other ungulates were rare, but included white-tail deer (*Odocoileus hemionus*), mule deer (*O. virginianus*), elk (*Cervus canadensis*) and caribou (*Rangifer tarandus*). Resident and non-resident hunting was regulated but hunting by Aboriginal people was not.

METHODS

Sampling Strategy

We divided the census zone into 2 strata based on forest cover classes (BC Ministry of Forests, Forest Inventory Program database) (Fig. 1). Stratum 1 (S1) included the 4 forest cover classes that were predominantly used by moose in early winter (Heard *et al.* 1999): 1) Age Class 1 (AC1) - forests 1-20 years old; 2) Age Class 2 (AC2) - forests 21-40 years old; 3) Non-Commercial Brush (NCB) - productive forest land that was $\geq$ 60% brush $\geq$ 1 m high; and 4) Not Sufficiently Restocked (NSR) - productive forest land covered with commercial deciduous or coniferous species, but the conifer density was below commercially acceptable

deciduous or coniferous species, but the conifer density was below commercially acceptable standards. Forest age refers to the age of the trees at the time of forest inventory map updates. The map updates varied across the census zone from 1993 to 1995, resulting in reported tree ages being up to 5 years less than their actual ages at the time of the census. Stratum 2 (S2) was composed of the remaining forest cover types, primarily forests > 40 years old and agricultural clearings, with small amounts of gravel bars, swamps, muskegs, roads, and recently logged areas that had not yet been entered into the database. Nineteen percent of the census zone was in S1, and 81% in S2.

We divided the census zone into 541 blocks of about 36 km^2 (5.5 x 6.6 km). We joined adjacent blocks to form sample units of at least 6 km^2 of S1 habitat, in an attempt to ensure that there would be some moose in every sample unit. S1 sample units were therefore made up of between 1 and 4 blocks for a total of 361 sample units. We randomly selected 44 S1 sample units (SU) for survey and from those 44, we randomly selected 8 SU's to comprise the S2 sample (Fig. 5). If an S2 sample unit contained more than one block, we randomly selected one to survey.

Between 10 and 18 Dec. 1998, each of 2 crews, consisting of 2 observers (one of whom recorded the data), a navigator, and the pilot (Appendix A), surveyed SU's from Bell 206B Jet Ranger Helicopters, flying 65-95 km/hr, 30-50m above the ground, at a mean survey rate of 5.2 min/km^2. SU boundaries were located using the helicopter's Global Positioning System (GPS). When moose were sighted near the SU or stratum boundaries, we recorded their location with a March II (Corvallis Microtechnology, Inc.) or Trimble Pathfinder (Trimble Navigation) GPS, and later determined their precise location from the differentially corrected position (Fig. 6, 7).

There was 100% snow cover for all SU's except for 1 that had only 80% cover. Temperatures ranged between -15 and +2 °C with clear to overcast conditions. We circled each moose (Fig. 6) and recorded its age and sex (based on the presence/absence of a white vulva patch, bell size and shape, face colouration and antler morphology) as a cow, calf ($\leq$ 8 months old), teen bull, sub-prime bull, prime bull, antlerless bull, or unknown. We estimated the vegetation cover to the nearest 5%, within 9m of where the moose was first seen,

according to standards developed by Unsworth *et al.* (1991). We also recorded the forest cover type for most (75%) of the moose observed in S1.

Data Analysis

Population Size and Density

To correct for sightability bias, vegetation cover estimates were grouped into 6 cover classes, each with a specific detection probability correction factor, as described by Anderson and Lindzey (1996) (Table 1) (see also Heard *et al.* 1999). Each moose observed was divided by the detection probability correction factor to obtain the corrected count, which was then summed by sample unit. The population estimate and sampling variance for unequal sized sample units was calculated using Jolly (1969). Sightability and model variance were calculated using the program Aerial Survey (Unsworth *et al.* 1998). We did not use this program to calculate the population estimate because: 1) the sightability correction factors used in the model differed from the sightability correction factors published by Anderson and Lindzey (1996); and 2) our survey was designed to use the area of the SU's surveyed divided by the area of the study area as the sampling fraction, but the model used the number of sample units surveyed divided by the number of sample units in the study area as the sampling fraction. The final variance estimate was the sum of the sampling, sightability, and model variances. Because the sightability model had not been thoroughly tested for our survey conditions, we did not feel that the calculation of confidence limits was justified.

We calculated MU specific population estimates for each of the 9 core MU's (i.e. excluding 716 and 724) to 1) compare with previous estimates, and 2) to relate to the number of moose shot by hunters. We estimated the uncorrected density of moose in each MU by multiplying the S1 area in the MU by the overall S1 density, and added that to the product of the remaining MU area, less high elevation and urban areas, multiplied by the census-wide S2 density. We compared uncorrected densities in 4 MU's with surveys conducted in 1991 and 1993. The January 1991, survey of MU's 710 and 712B (the east half of 712) was a stratified random sampling, adapted from Gasaway *et al.* (1986), from 105 quadrats (16km^2) in MU 710 and 130 in MU 712B. The survey effort of about 4 min/km^2 was similar to the 1998 effort of 5 min/km^2, suggesting that the sightability was similar among surveys. The January

1993, survey of MU's 7-07 and 7-09 was a stratified random sample from 203 quadrats ($25km^2$) and search intensity was similar.

Composition

Moose population composition was determined in December from 1972 –1998, except for 1981. Prior to 1998, sampling for composition was restricted to S1 forest type cover classes. Thus the 1998 composition ratios based on the number of moose observed in S1 (as opposed to population estimates for the age and sex classes) were the only values comparable to previous years. The calf:cow ratio and bull:cow ratio were calculated for both strata, and variance was calculated using Manly *et al.* (1993).

Hunter Kill

Hunting of calves and spike or 2-point bulls was open to anyone who purchased a moose hunting licence, but for most years permits to hunt larger antlered bulls and cows were limited and distributed at random among applicants (Appendix D). We estimated the mean annual number of bulls, cows, and calves shot by hunters in each MU, based on hunter surveys from 1975-1998. Resident hunters were surveyed via questionnaires that requested information about hunter effort and success. Questionnaires were mailed to all limited entry hunting (LEH) permit holders and 50% of those who purchased a license to hunt in the open seasons. Recipients that did not respond to the first questionnaire were mailed a second, and repeat non-respondents may have been further queried by telephone. Around 75% of hunters responded (J. Thornton, personal communication). All non-resident hunters were required to have a guide, and guides were required to submit information on the success and effort for all their non-resident clients. We made no attempt to estimate the number of moose shot by Aboriginal people.

RESULTS

Population Size and Density

We counted 1001 moose within 52 SU's, covering an area of 369km^2. The number of moose per SU ranged from 0 to 55 (Appendix B). The corrected study area population estimate was 25,000 $\pm$ 3700 moose, for an overall density of 1.33 moose/km^2 (2.75 moose/km^2 in stratum 1, and 0.99 moose/km^2 in stratum 2) (Table 2). Sightability correction resulted in an overall expansion factor of 1.41 (1.30 in stratum 1, and 3.05 in stratum 2).

The 1998 uncorrected density estimates for MU's 707, 709, 710, and 712B were the same as or higher than the 1991 and 1993 uncorrected estimates (Table 3).

Composition

For S1 and S2 combined, the uncorrected and corrected bull:cow:calf ratios were the same at 43:100:38 (Appendix C), but they differed substantially from estimated number of moose across the whole study area (i.e. after correcting for the stratum specific sampling fractions) because composition varied between strata (Table 4). S2 had greater vegetation cover than S1 (mean cover estimates were 19% and 35% for moose seen in strata S1 and S2 respectively), but the high calf:cow ratio in S2 was not a result of cows with calves selecting higher cover, because the composition estimates were the same for both the observed and the corrected number of moose.

The calf:cow ratio has remained between 30 and 55 calves per 100 cows since 1972, with a decreasing trend from 1991 to 1997 and a substantial increase in 1998 (Fig. 8). The sex ratio showed no trend over time (Fig. 9) except for a decline during 1986-1990 when there was an open season for mature bulls (Appendix D).

Distribution

Most moose observed in S1 were in vegetation cover class 1, and the number of moose observed decreased with increasing cover, but in S2 the number of moose observed was approximately equal among cover classes (Fig. 10). The same trend was apparent for the corrected counts in S1, but in S2 the corrected number of moose increased with increasing vegetation cover.

The observed moose density was highest in AC1 stands, and lowest in S2 cover types (Fig. 11). Corrected densities were similar among non-commercial brush, not-sufficiently restocked and S2 cover types, but less than AC1 and AC2. Corrected densities of bulls showed strong selection for AC1 stands, while cows with calves showed little selection for forest cover types (Fig. 12). In S2 cover types, cows with calves were the most abundant, while bulls were the least abundant.

Hunter Kill

On average, almost 7000 hunters spent 47,800 days (7 days / hunter) hunting moose each year from 1980 - 1998 in Management Units 707-715, ranging from 37,300 – 56,500 / year (Fig. 13). The annual kill by hunters ranged from 1260 to 2057 (mean = 1580 $\pm$ 43, Fig. 14). The number of bulls shot was highest during the open seasons from 1976-1979 and during an additional open bull season from 1986-1990. The bull kill was lowest in 1982. Except for the introduction of LEH in 1981 and the 1986-1990 open bull season, regulation changes have had minimal influence on the annual variation in the number of moose shot (Fig. 14, Appendix D). Because there was extremely deep snow during the winter of 1981/82 the number of LEH permits was reduced in 1982 in an attempt to compensate for the presumed higher mortality the previous winter. In all other years, 1210 LEH bull permits were given out. An average of 772 (range = 425-965) LEH cow permits have been distributed each year (Fig. 13).

Mean kill density since 1976 was 72 kills/1000km^2, varying from 58 – 94 kills/1000km^2 among years (Table 5) and from 44 to 109/km^2 among MU's (Table 6). Since the end of the open bull season in 1990, hunters have shot an average of 16% of bulls, 2% of cows, and 9% of calves, for an overall kill of 7% of the moose population (Table 6), for an average kill density of 69/1000km^2.

DISCUSSION

Survey Methods

A priori stratification of the census zone using GIS, forest cover data, and the moose habitat use pattern found in the Parsnip River (Heard *et al.* 1999), was effective at defining

high and low density strata, but S2 had higher and more variable densities than we expected. There were 2 potential explanations. First, we placed all agricultural clearings in S2 because most appeared to be in current use (e.g., as hay fields) and had very few moose. However, others had not been recently cultivated and were in early successional stages that were more like the NSR cover type and were attractive to moose. Second, moose around Prince George may use S2 forests more often than in the Parsnip River drainage. Nevertheless, stratification by forest cover type was effective and eliminated the need for costly pre-census stratification flights.

The precision of the survey might have been greatly increased with the same amount of flying time if we had reallocated effort from S1 to S2 as the survey progressed. Stratification is most efficient when the variances of all strata are equal, but they were grossly different in this survey (Table 2). In future, survey statistics should be monitored daily in order to be able to make timely decisions to reallocate effort to the most variable strata.

Periodic reference during the survey to the vegetation cover diagrams from Unsworth (1991), and pre-census training by experienced people, increased our confidence in our ability to estimate vegetative cover. We felt that the Anderson and Lindzey (1996) sightability model provided a reasonable population estimate because it provided an overall sightability correction factor (1.41) that was similar to the sightability correction factor we obtained from field trials using radio-collared moose in the Parsnip River drainage in central BC in January 1998 (1.54, Heard *et al.* 1999), where habitat and flying conditions were similar. Intensive resurvey trials (Gasaway *et al.* 1986) conducted in the Prophet River drainage of north central BC resulted in a similar correction factor of 1.44 (Poole, 1998), although MacHutchon (1998) obtained a sightability correction factor of 1.82 during sightability trials of radio-collared moose conducted in south central BC.

Population Dynamics

At 1.3 moose/km^2, moose density around Prince George was much higher than expected, given that the population was hunted and existed with bears and wolves (Gasaway *et al.* 1992, Messier 1994). Messier (1994:484 his Fig. 7) showed that, for a natural ecosystem, a density of 1.3 moose/km^2 would be expected if wolves were the only predator,

but where moose are also preyed on by bears, the population should stabilise at a low density equilibrium of 0.2-0.4 moose/km^2. However, the combined impacts of legal hunting and killing of wolves to protect livestock around Prince George have likely reduced wolf densities. Natural wolf:moose ratios suggest that there should have been about 700 wolves in the study area (Messier 1994). We observed 8 wolves in two groups in the 639 km^2 surveyed for an estimate of only 237 wolves. Wolf sightability was unknown. Application of Mladenoff's wolf habitat suitability model, based on road densities (Mladenoff *et al.* 1995), also suggested that wolf densities should be well below natural levels (Fig. 15). Messier's model indicates that if wolf densities were reduced by about 50% from natural levels, the stable equilibrium for a moose population that was also subject to bear predation and hunting would be about 1.3 moose/km^2 (Fig. 16).

Based on a habitat capability/suitability model (Fuhr and Demarchi 1990, Tony Hamilton pers comm.) we estimated the grizzly bear population at about 380.

Black bear density in our study area appeared to be relatively high, as judged by Ian Ross (pers comm.), based on 1) the number of incidental sightings he made during 2 springs searching for grizzly bears in and around the study area, and 2) his experience in a variety of locations elsewhere in North America. Assuming that the black bear density was equal to the mean of all North American black bear density estimates (Garshelis 1992), the black bear estimate for the study area would be 6300. Assuming our mean annual hunter kill of 242 black bears/year was less than or equal to the maximum sustained yield of at least 6%/yr (as estimated for grizzly bears, Harris unpublished), the population estimate would be at least 4000 bears.

Grizzly bears were lightly hunted and black bears appeared to be moderately exploited (Table 7). There was no trend in the number of predators shot by licensed hunters or Conservation Officers from 1988 to 1997 (Appendix E).

The absence of any decline among years in the number of moose shot by hunters or hunter success rates over 23 years demonstrated that a 7%/yr kill is sustainable, when the kill is primarily, but not exclusively, bulls. The strong bias toward bulls in the kill did not distort

the sex ratio enough to influence pregnancy rates or the timing of conceptions (Heard *et al.* 1996).

At 72 moose/1000km^2, the hunter kill density in this study was much higher than reported for other places where moose were living with both wolves and black bears. In Quebec, Crete and Jolicoeur (1985) and Crete *et al.* (1981) found yields of 42 and 47 moose/1000km^2 respectively. Low kill densities were the norm in adjacent areas of British Columbia (Hatter 1997).

Composition and Distribution

Because population composition did not change when corrected for sightability bias, there did not appear to be differential selection for vegetation cover among age and sex categories. We have not found segregation by cover in the past (Heard *et al.* 1999), as some others have (Stephens and Peterson 1984, Timmerman and McNicol 1988, Miquelle *et al.* 1992). This is worthy of further investigation, because segregation between the S1 and S2 cover types would mean that all past composition estimates are biased. We suspect, however, that the stratum differences were an artifact of sample size, as the S2 calf:cow ratio was based on only 17 calves and 33 cows, versus 191 calves and 514 cows in S1. We used the composition estimates based on the observed number of moose in all our calculations.

In 1998 the calf:cow ratio was higher than it had been in the previous 4 years, a trend that was also observed in the Parsnip River drainage (Heard *et al.* 1999). This could be attributable to the mild conditions of the 1997/98 winter, however based on communication with biologists in other regions, this trend did not occur elsewhere in the province.

The distribution of moose across forest cover types indicated that AC1 and AC2 stands were selected over NCB, NSR, and S2 stands. Because moose occurred at the same density in NCB stands as S2 stands in early winter, and because NCB stands tended to be small patches of brush that were not always easy to identify in the field, we recommend placing NCB stands in S2.

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Table 1. Vegetation cover classes and their associated detection probability correction factors (adapted from Anderson and Lindzey 1996).

Vegetation Class	Percent Vegetation Cover	Detection Probability Correction Factor
Class 1	0 - 17%	0.963
Class 2	18 - 35%	0.818
Class 3	36 - 53%	0.432
Class 4	54 - 71%	0.115
Class 5	72 - 89%	0.022
Class 6	90 - 100%	0.004

Table 2. Number of moose estimated around Prince George, British Columbia, December 1998.

	Stratum 1	Stratum 2	Total
Moose Observed	937	64	1,001
Corrected Number of Moose	1,215	195	1,410
Expansion Factor	1.30	3.05	1.41
Area of Surveyed Sample Units (km^2)	442	197	639
Total Stratum Area (km^2)	3,616	15,346	18,962
No. of Sample Units Surveyed	44	8	52
No. of Sample Units in Study Area	361	541	902
Corrected Density (moose/km^2)	2.75	0.99	1.33
Corrected Study Area Population Estimate	9,939	15,218	25,157
Sampling Variance	833,585	12,266,583	13,100,168
Sightability Variance	8,336	99,850	108,186
Model Variance	1,111	17,787	18,898
Total Variance	843,032	12,384,220	13,227,252
Standard Error	913	3,502	3,674
Coefficient of Variation	0.09	0.23	0.15
Degrees of Freedom	-	-	8

Table 3. Comparison of moose density estimates in 4 management units around Prince George, British Columbia.

Management Unit	Year	Count	Density (moose/km^2)	Area Surveyed (km^2)	n
710	1991	326	0.62	527	21
710	1998	131	0.63	38	3
712B	1991	118	0.18	671	29
712B	1998	95	0.63	43	5
707	1993	92	0.67	137	6
707	1998	114	0.92	48	5
709	1993	152	0.73	208	9
709	1998	31	0.85	24	2

Table 4. Number of bulls and calves per 100 cows by moose census stratum around Prince George, British Columbia, December 1998.

Stratum	Corrected (Y/N)	Bulls	Calves	Total
1	N	44	37	937
1	Y	45	35	1215
2	N	36	52	64
2	Y	27	57	195
1 and 2 combined	N	43	38	1001
1 and 2 combined	Y	43	38	1410
1 and 2 estimated[1]	Y	36 $\pm$ 8	47 $\pm$ 15	

1. estimate weighted by stratum specific sampling fractions

Table 5. Number of moose shot by hunters each year in 9 management units around Prince George, British Columbia, from 1975 to 1998*.

Year	Number of Moose Shot				Hunter Success (Kills/Hunter)	Kill Density (Kills/1000km^2)
	Bulls	Cows	Calves**	Total		
1976	1097	235	131	1463	0.22	67
1977	1481	75	34	1590	0.21	73
1978	1348	174	123	1645	0.20	75
1979	1376	173	134	1683	0.18	77
1980	806	285	298	1389	0.18	64
1981	480	297	663	1440	0.21	66
1982	413	264	583	1260	0.18	58
1983	551	269	840	1660	0.23	76
1984	555	295	704	1554	0.23	71
1985	594	266	704	1564	0.23	72
1986	753	377	927	2057	0.27	94
1987	1070	367	503	1940	0.25	89
1988	950	398	532	1880	0.22	86
1989	958	341	459	1758	0.25	81
1990	721	297	346	1364	0.18	62
1991	755	273	462	1490	0.23	68
1992	864	259	407	1530	0.22	70
1993	802	277	457	1536	0.23	70
1994	707	212	377	1296	0.21	59
1995	809	282	456	1547	0.24	71
1996	967	340	383	1690	0.26	77
1997	834	217	373	1424	0.27	65
1998	843	236	519	1598	0.25	72
Means	858	270	453	1581	0.22	72

* management units 707, 708, 709, 710, 711, 712, 713, 714, and 715

** between 1981 and 1986 'Calves' also included 2-point bulls

Table 6. Mean annual number of moose shot by hunters from 1991-1997 in the 9 surveyed management units around Prince George, British Columbia, December 1998.

MU	Area (km^2)	Population Estimate	Kills/ $1000km^2$	Kills/ Year	Percent of prehunt population shot				Percent of the kill by age and sex		
					Bulls	Cows	Calves	Total	bulls	cows	calves
707	3,021	3,100	77	234	18	3	8	6	55	22	23
708	1,934	2,200	60	117	14	2	5	5	62	20	18
709	1,774	1,700	63	112	17	2	7	5	61	17	22
710	1,534	1,600	109	167	19	4	17	10	44	21	35
711	1,914	2,300	83	158	17	2	8	7	60	14	26
712	5,298	5,200	62	331	14	1	11	6	53	12	35
713	2,770	2,400	44	121	11	1	8	4	52	16	32
714	1,665	2,000	66	110	13	3	5	5	56	26	18
715	2,294	2,200	66	152	16	2	9	6	55	16	28
Total or Mean	21,828	22,700	69	1,502	16	2	9	7	55	18	26

Table 7. Hunting intensity on potential moose predators around Prince George, British Columbia.

Predator Species	Mean Number of Animals Killed / yr	Estimated Density* (animals/km^2)	Estimated Population Size	Percentage of Population Shot
Black Bears	242	0.21 - 0.33	4000 - 6300	4 to 6
Wolves	33	0.037	237	14
Grizzly Bears	2	0.02	380	0.4

* see text for explanation

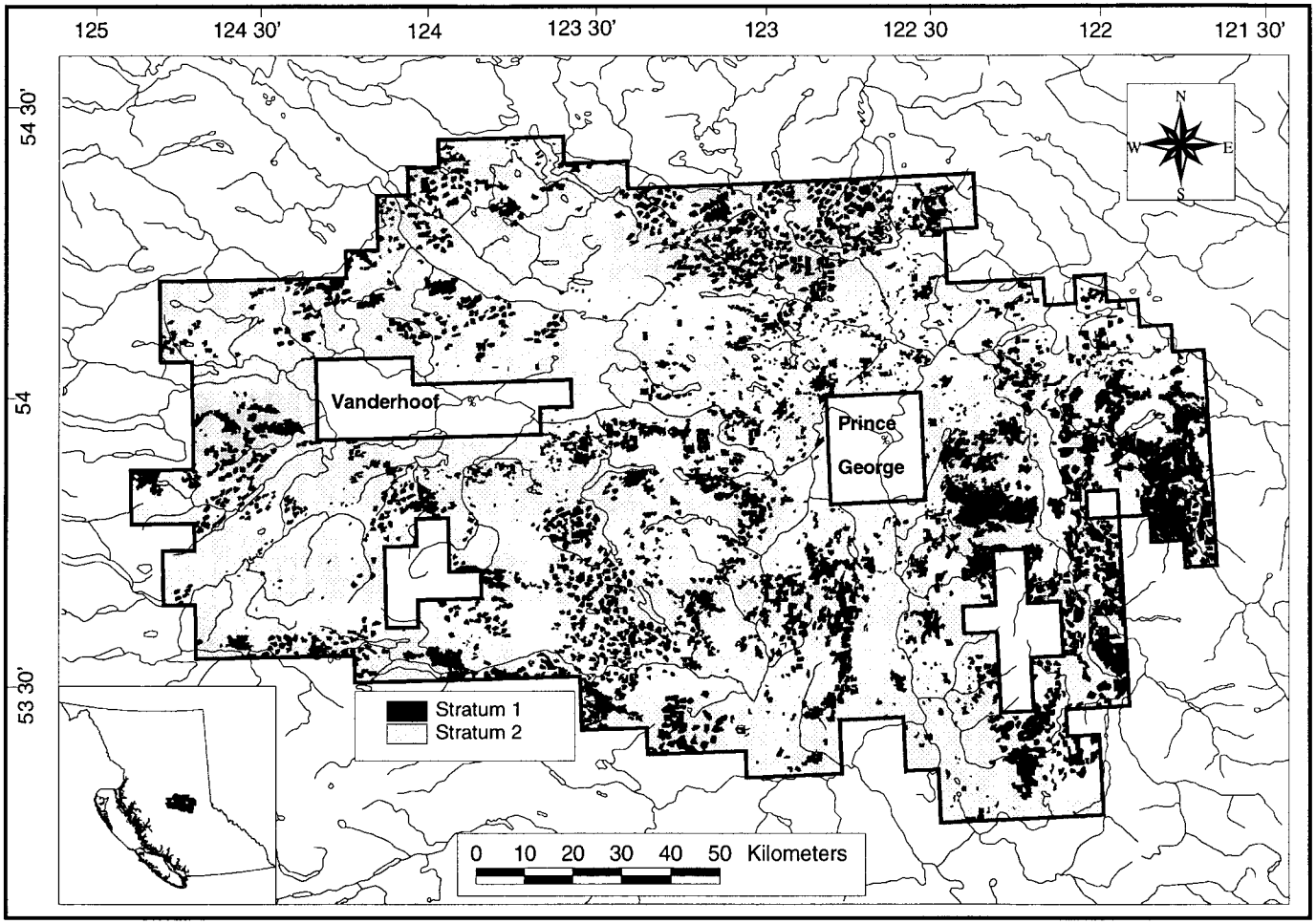


Figure 1. The moose census zone around Prince George, British Columbia, December 1998.

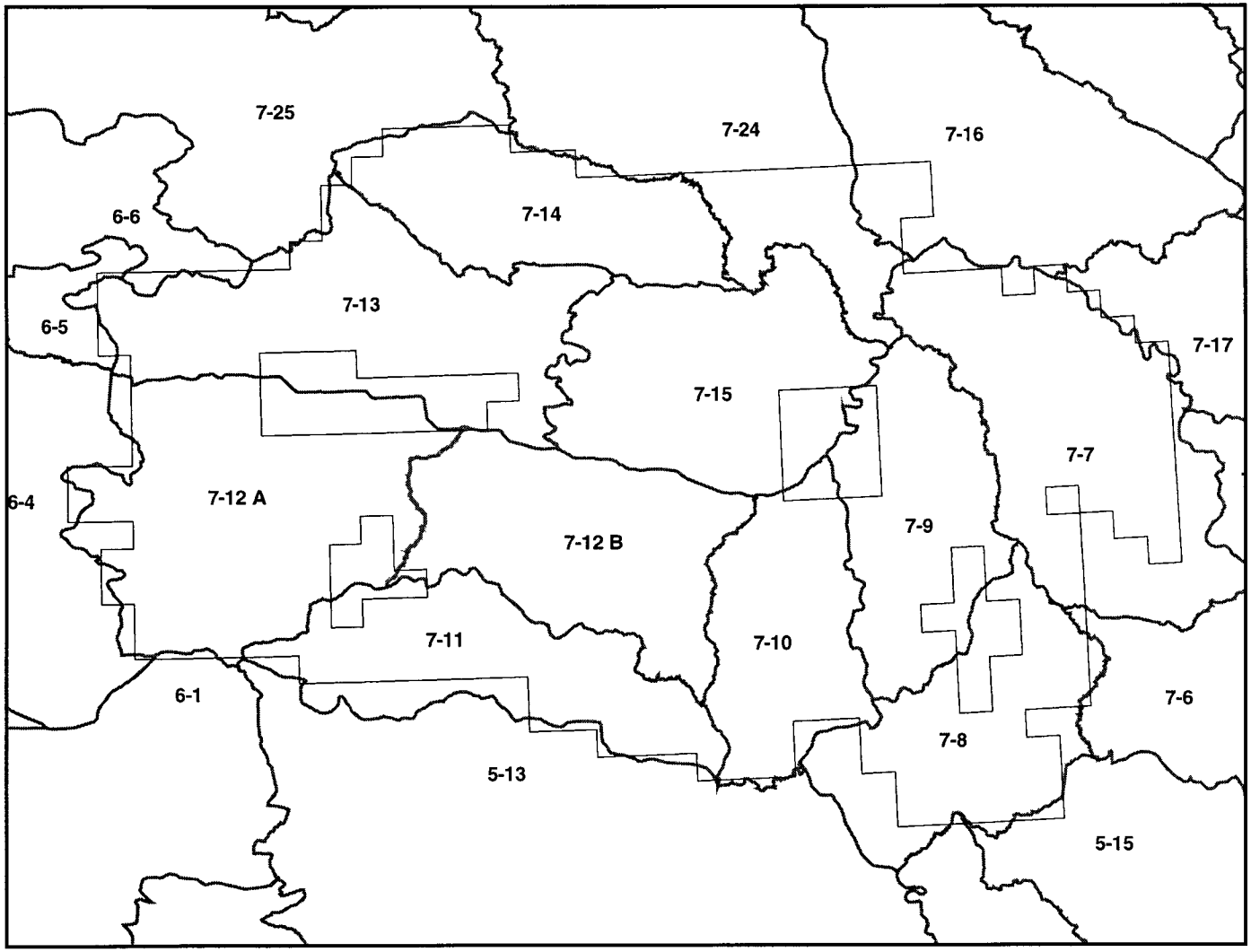


Figure 2. Management units within the moose census zone around Prince George, British Columbia, December 1998.

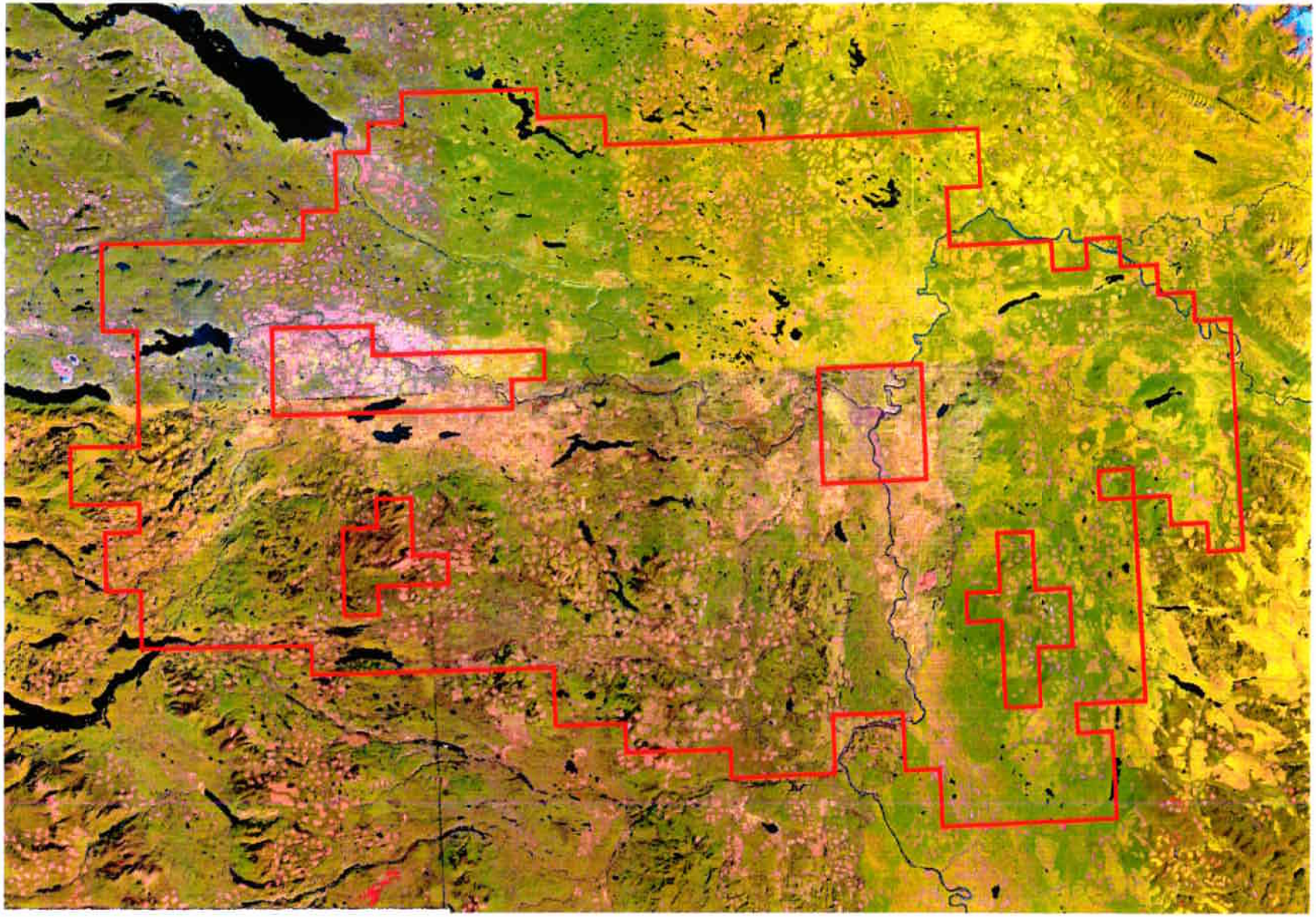


Figure 3. Landsat photograph of the moose census zone around Prince George British Columbia.

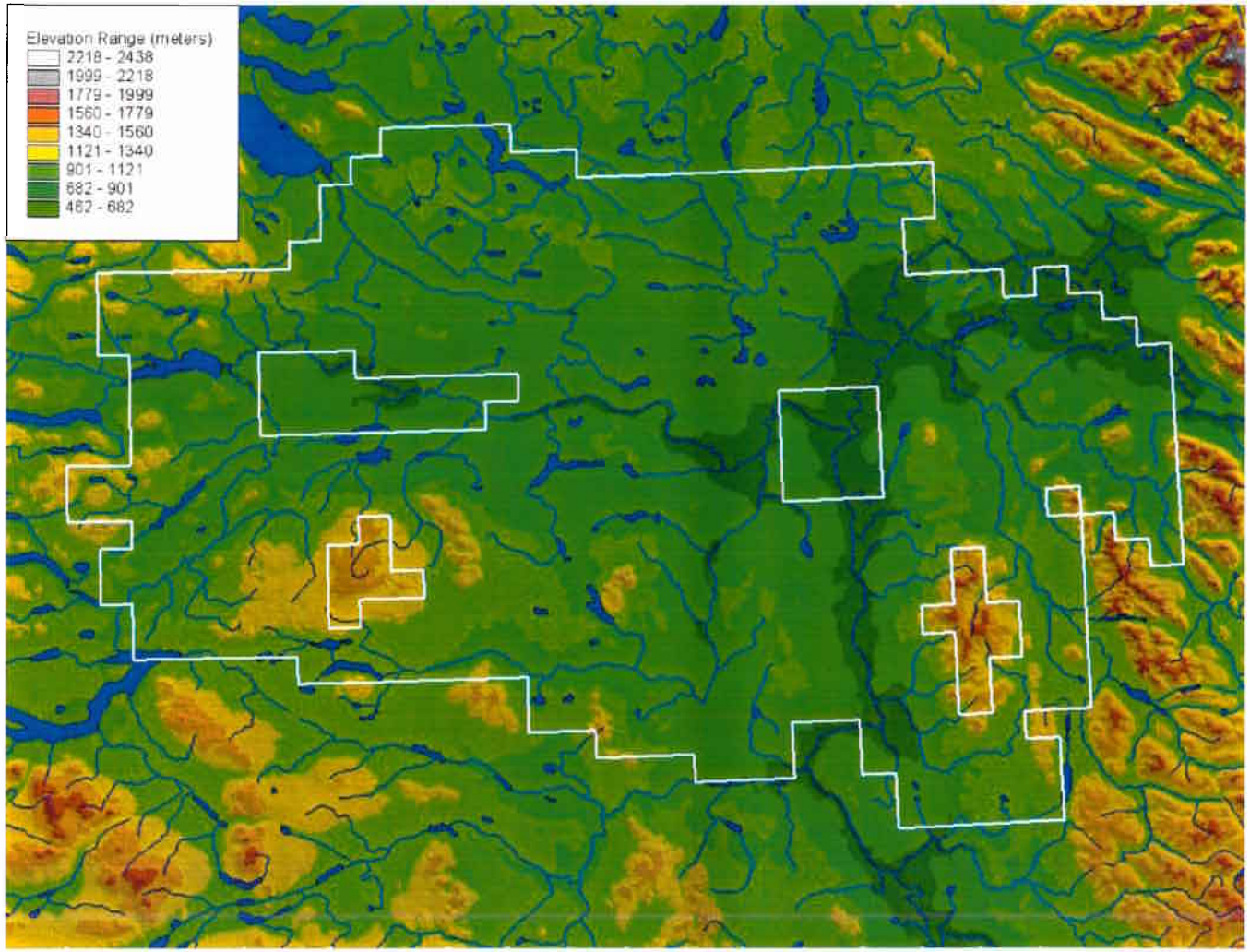


Figure 4. Terrain map of the moose census zone around Prince George British Columbia showing the relatively low elevation of the census zone compared to the surrounding area.

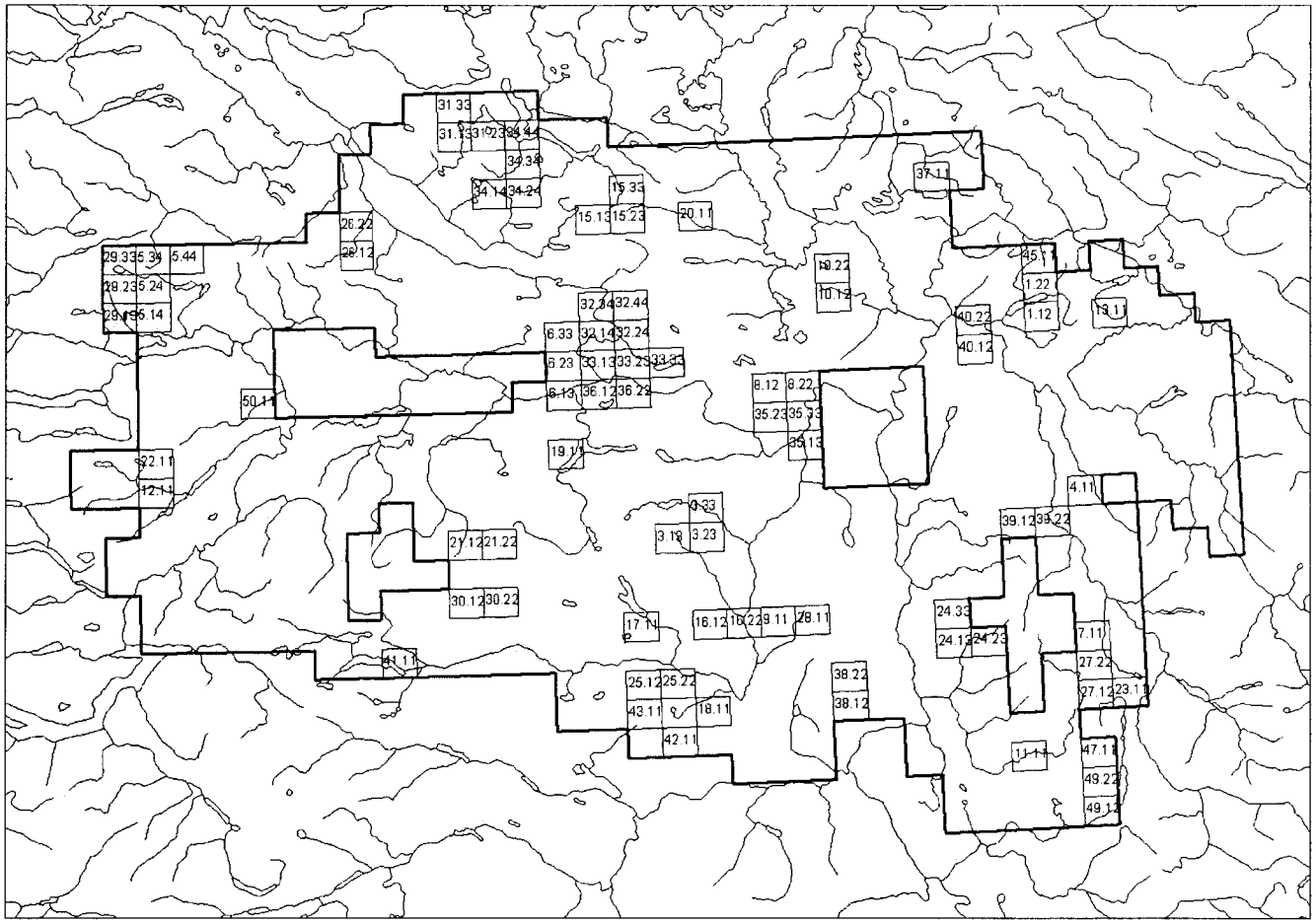


Figure 5. Location of the 44 sample units counted during the December 1998 moose census around Prince George, British Columbia.

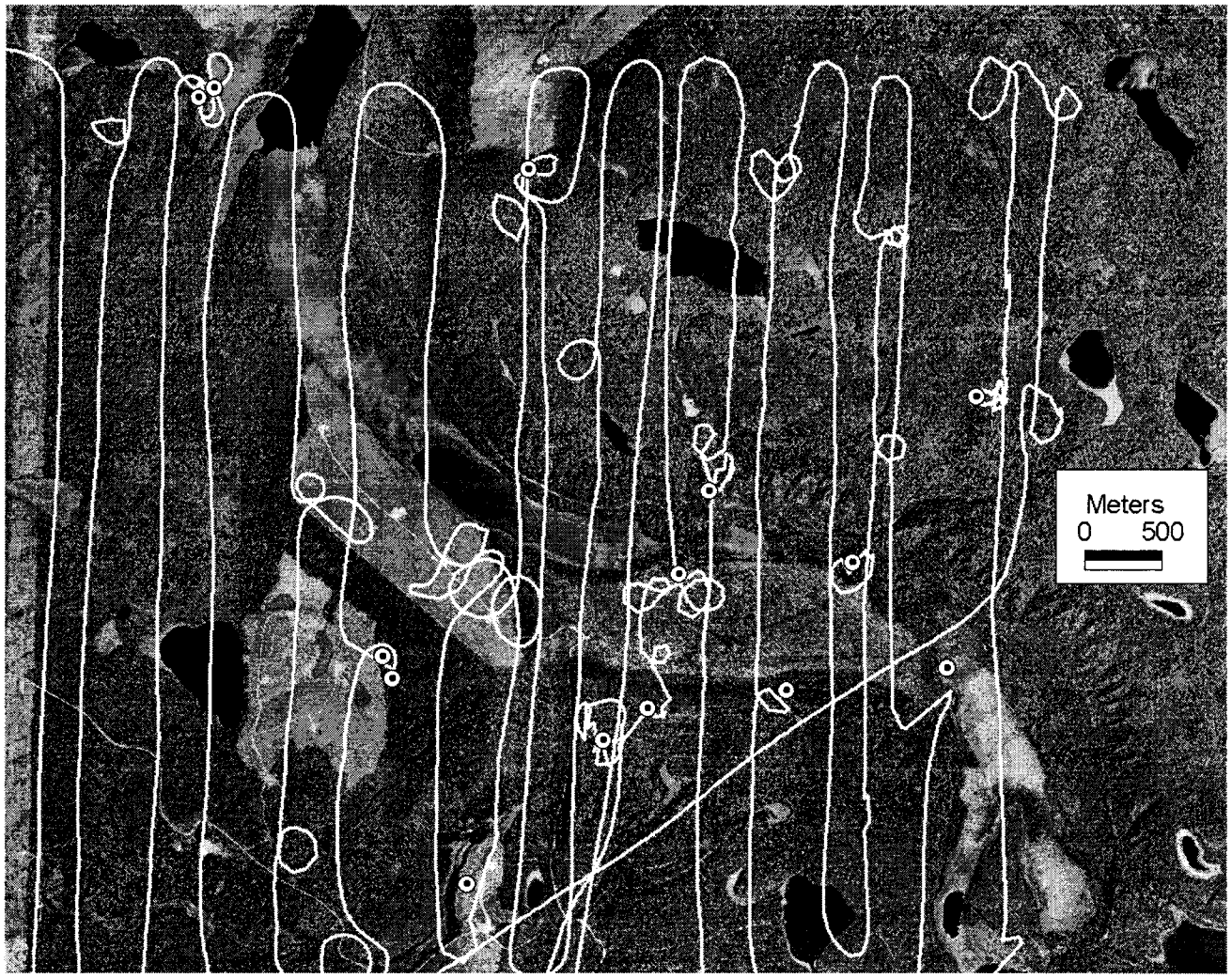


Figure 6. Aerial photograph taken in the summer of sample unit 37.11 surveyed during the moose census around Prince George, British Columbia, December 1998, showing the helicopter's flight path recorded by the onboard GPS programmed to store a position every second. Dots represent the position of some of the moose observed, and loops in the flight line usually represent the location of other moose. Every moose was circled, but the GPS occasionally failed to obtain a position fix every second when the helicopter was turning. All AC1 cut blocks are obvious in the photograph but most of the AC2 stands are not.

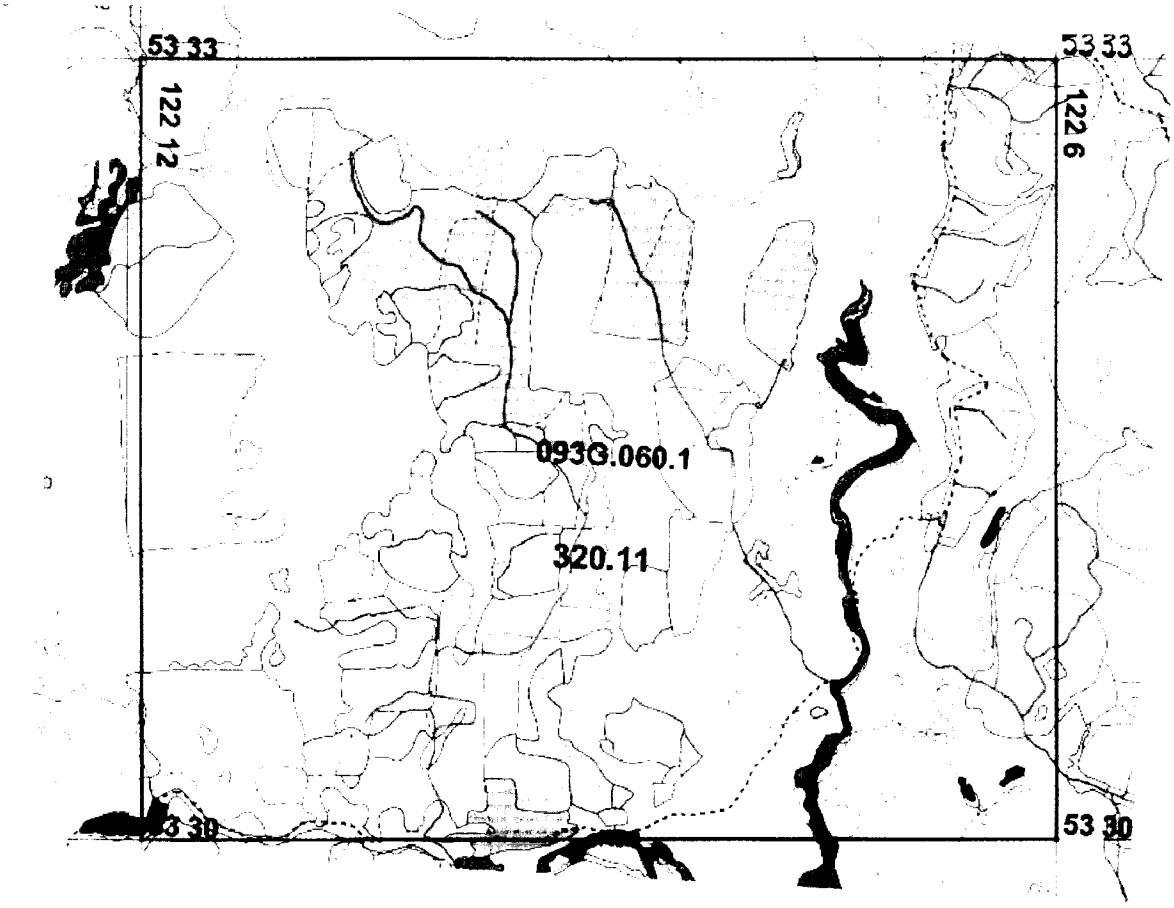


Figure 7. Typical sample unit map used in the field for the moose census around Prince George, British Columbia, December 1998. Sample unit 320.11 is the 36.91 km^2 rectangle outlined in dark blue between 53° 30' and 53° 33', and 122° 06' and 122° 12' showing the 4 forest cover classes in Stratum 1 (Age Class 1 – yellow, Age Class 2 – pink, Non-Commercial Brush – brown, and Not Sufficiently Restocked – gray), totalling 16.29 km^2. The remainder of the block is Stratum 2 (the white and green areas). Roads are in red, water in blue.

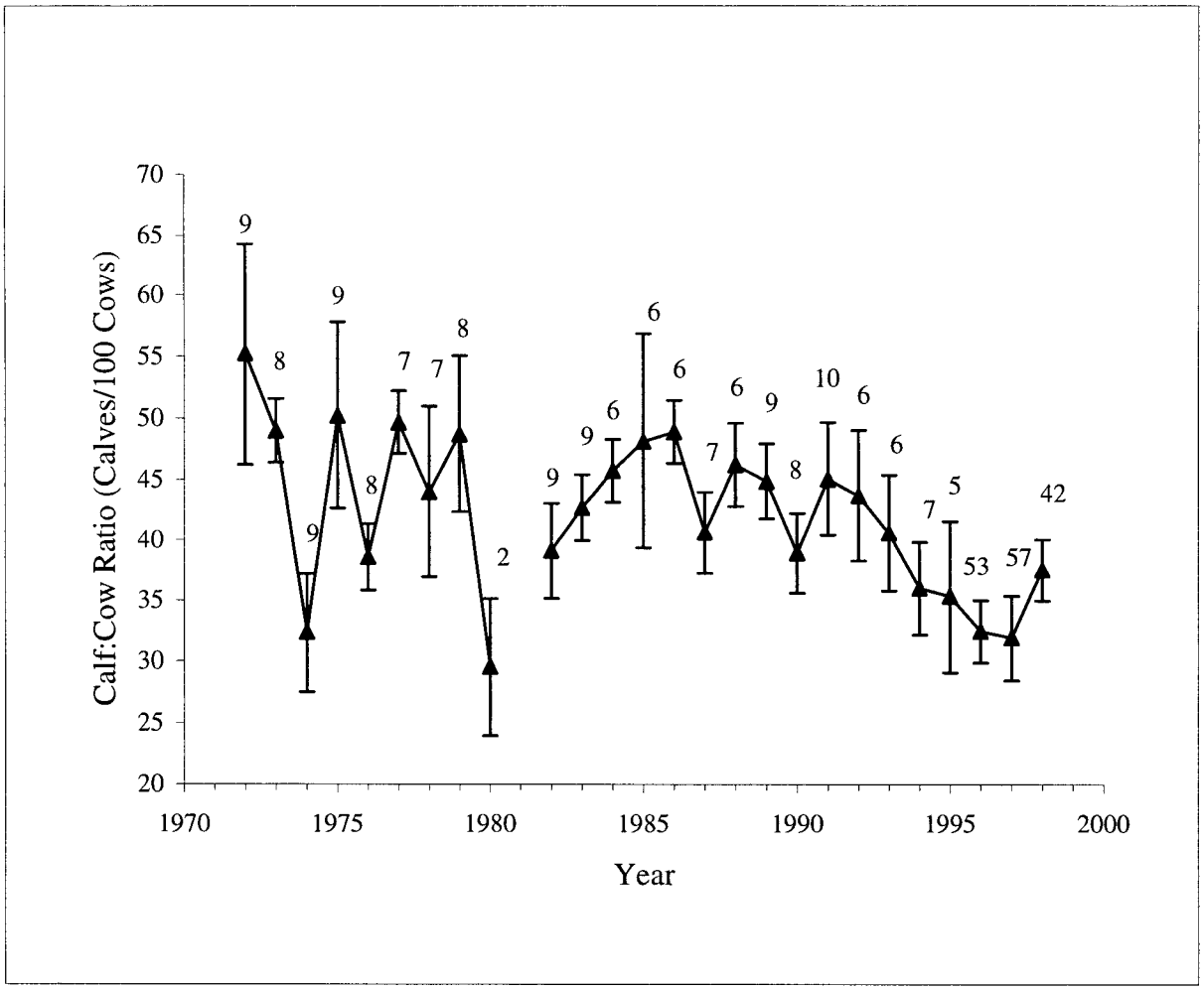


Figure 8. Moose calf:cow ratios around Prince George British Columbia between 1972 and 1998. Numbers above the standard error bars represent the number of sample units surveyed.

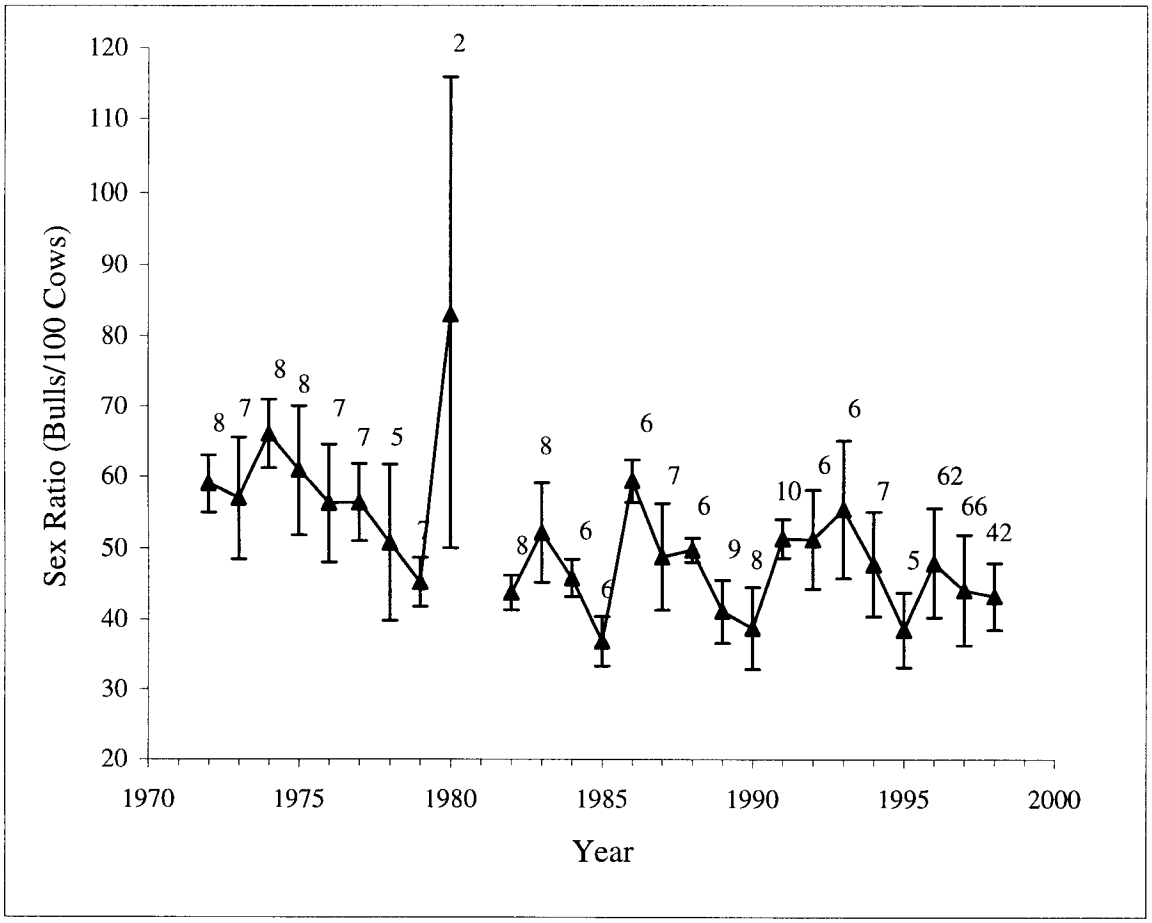


Figure 9. Moose bull:cow ratios around Prince George British Columbia between 1972 and 1998. Numbers above the standard error bars are the number of sample units surveyed.

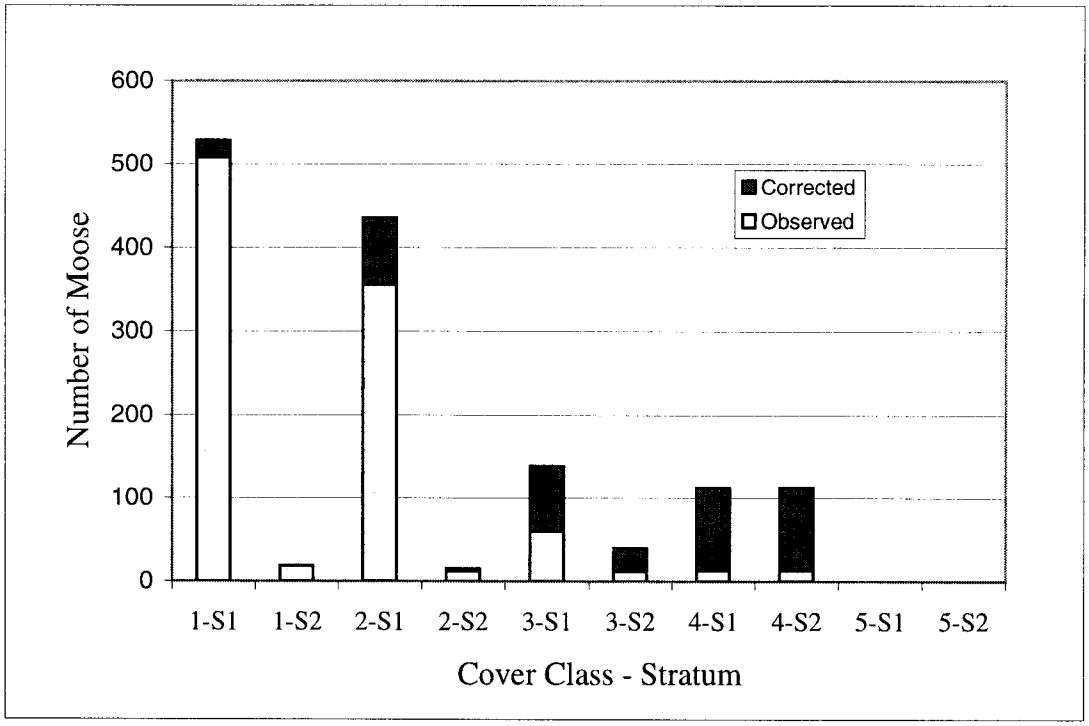
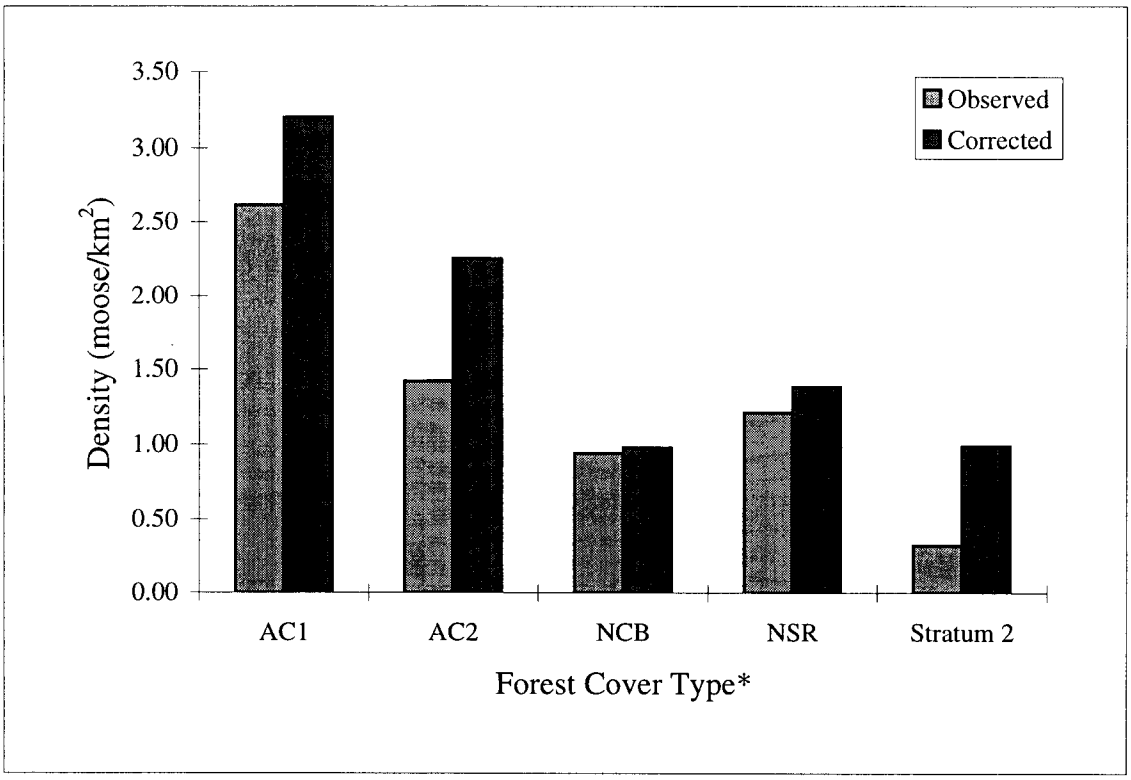
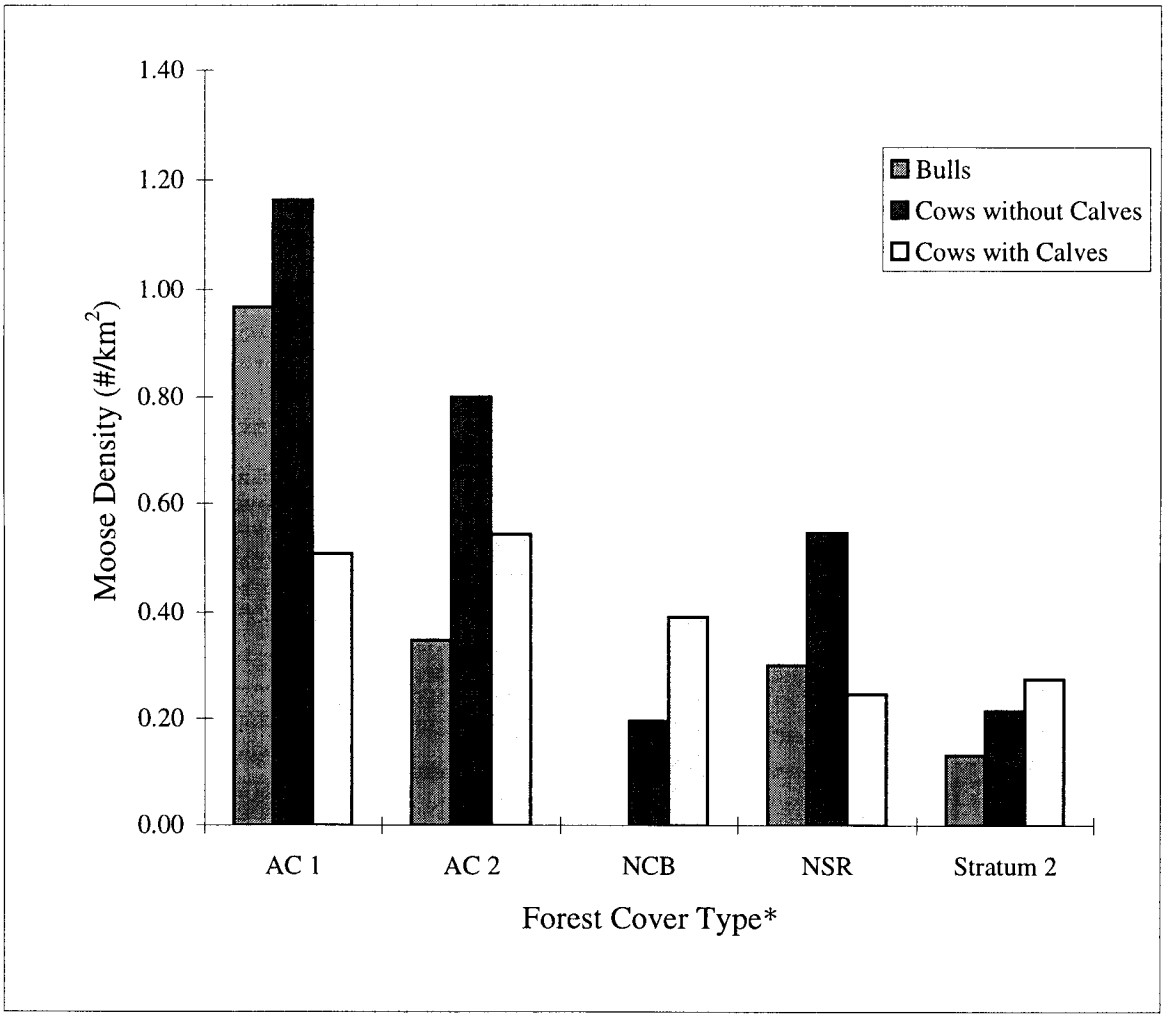


Figure 10. Number of moose observed and the corrected number of moose by vegetation cover class and stratum around Prince George, British Columbia in December 1998.



* AC1 = age class 1; AC2 = age class 2; NCB = Non-Commercial Brush; NSR = Not Sufficiently Restocked

Figure 11. Corrected and uncorrected moose densities across the 5 forest cover types sampled around Prince George British Columbia, December 1998.



* AC1= age class 1; AC2= age class 2; NCB= Non-Commercial Brush; NSR= Not Sufficiently Restocked

Figure 12. Corrected moose densities by age/sex category for the 5 identified forest cover types around Prince George British Columbia, December 1998.

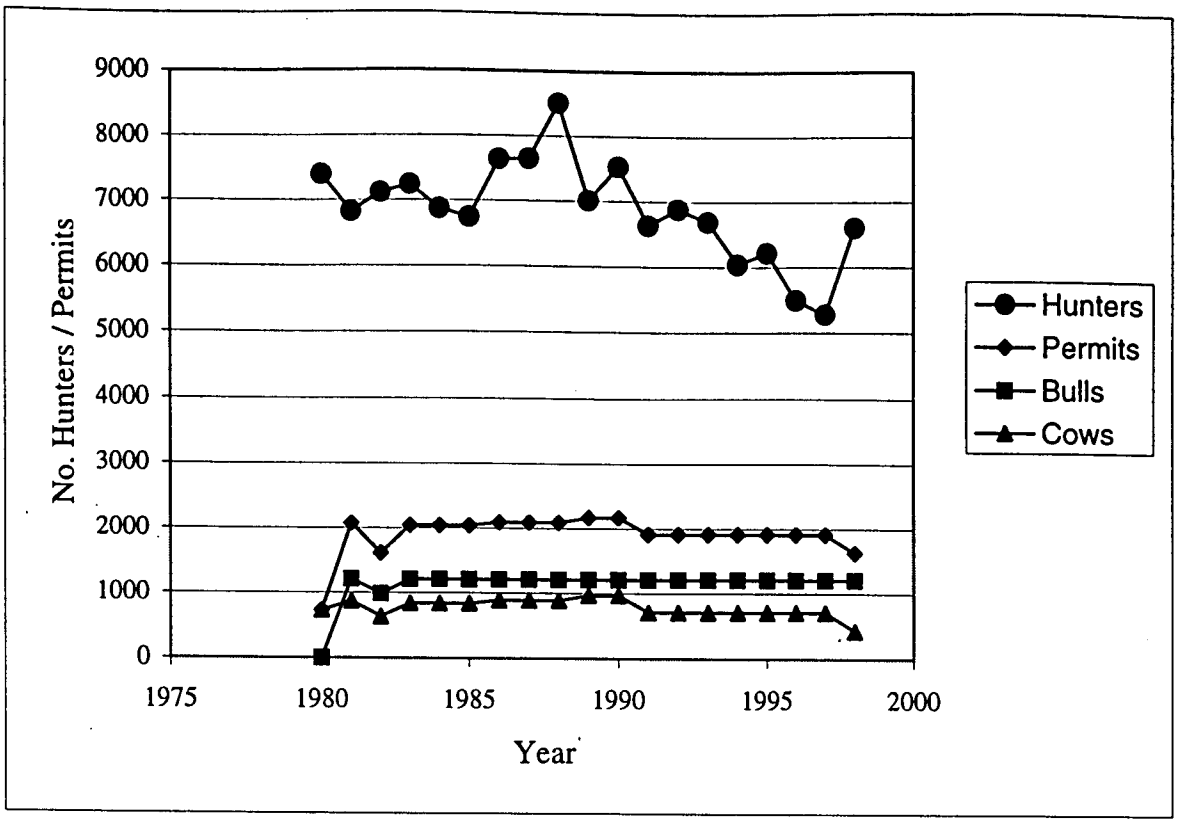
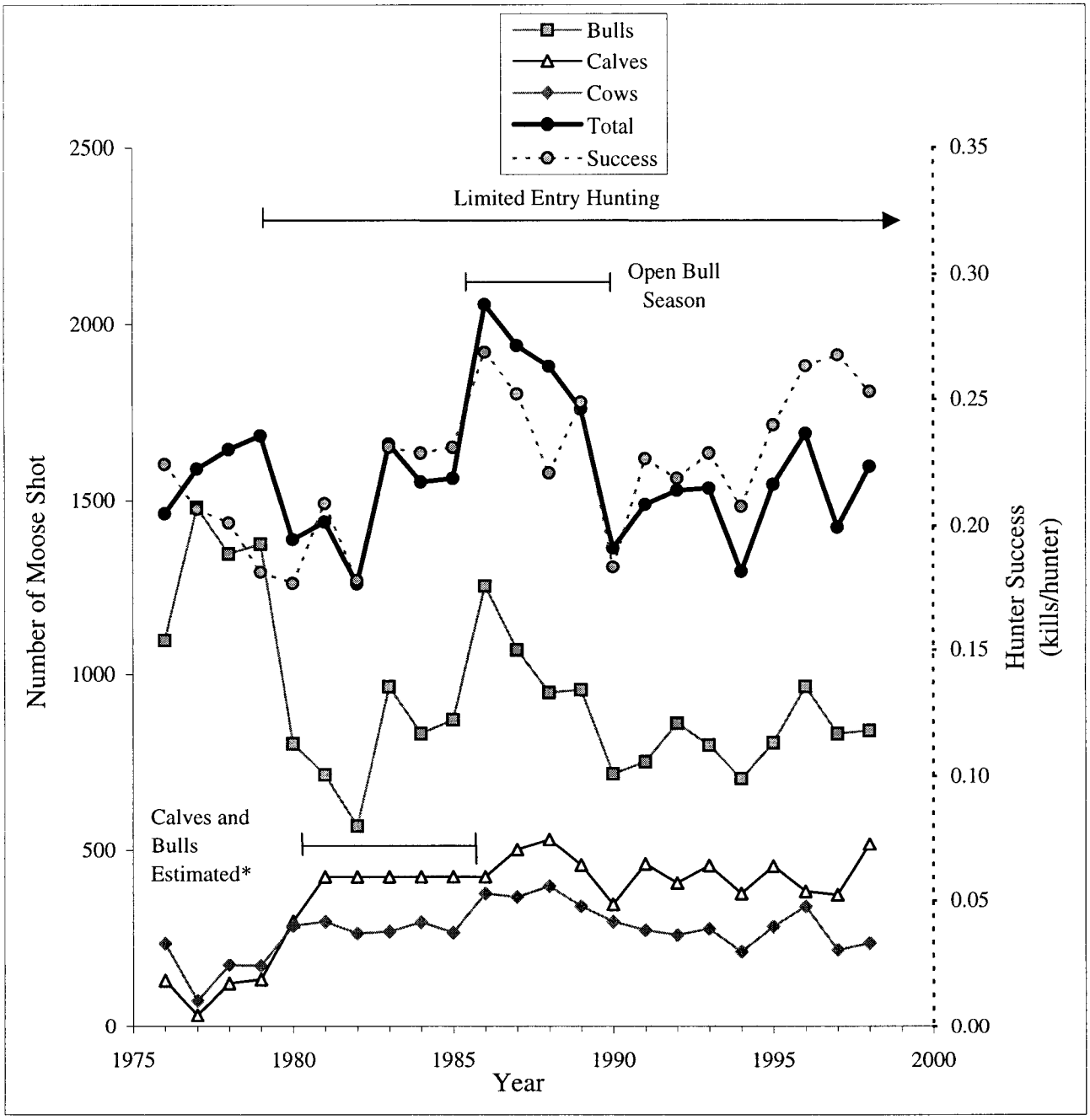


Figure 13. The number of hunters and the total number of hunting permits issued both for bulls and cows, for each year between 1980 and 1998 in the 9 management units around Prince George, British Columbia. Hunters without a permit were restricted to hunting bull moose with a spike or 2-point antler and calves (see text for details).



* between 1981 and 1986 kill estimates of calves and 2-point bulls were combined. We assumed that the calf kill during that period was equal to the mean calf kill from 1987-1997 (425) and the remainder were 2-point bulls

Figure 14. Number of moose shot and hunter success in 9 management units (Mu's 707 - 715) around Prince George British Columbia.

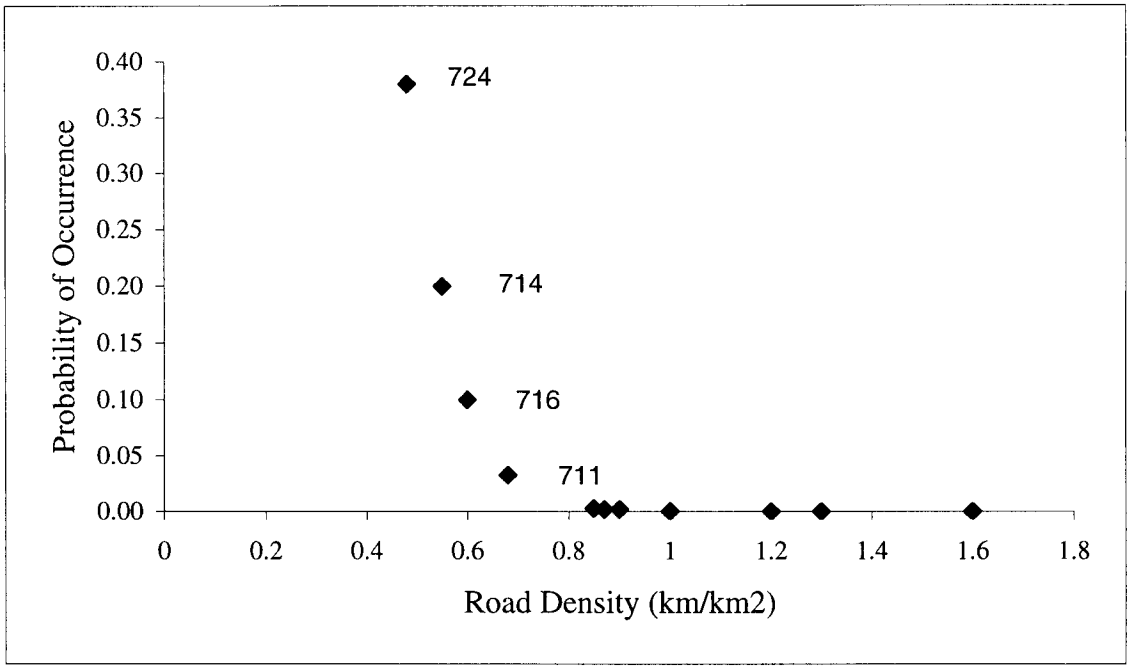


Figure 15. Probability of the occurrence of wolves in relation to road density for Management Units around Prince George, British Columbia

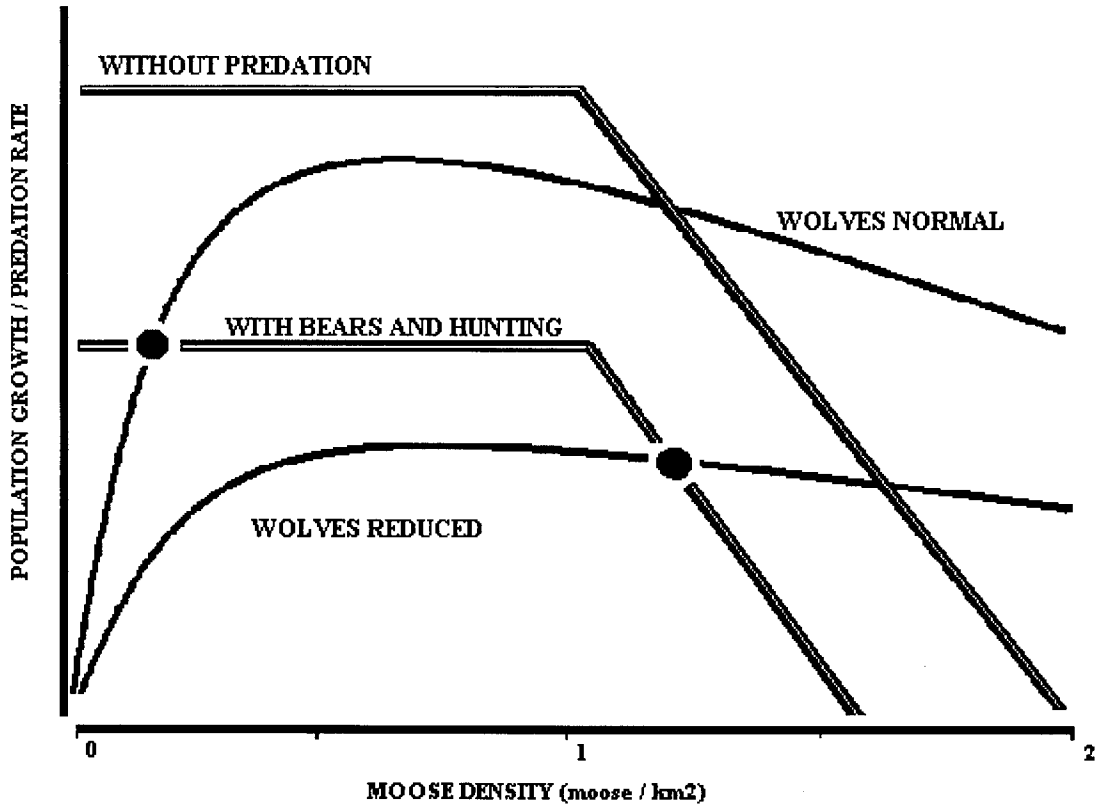
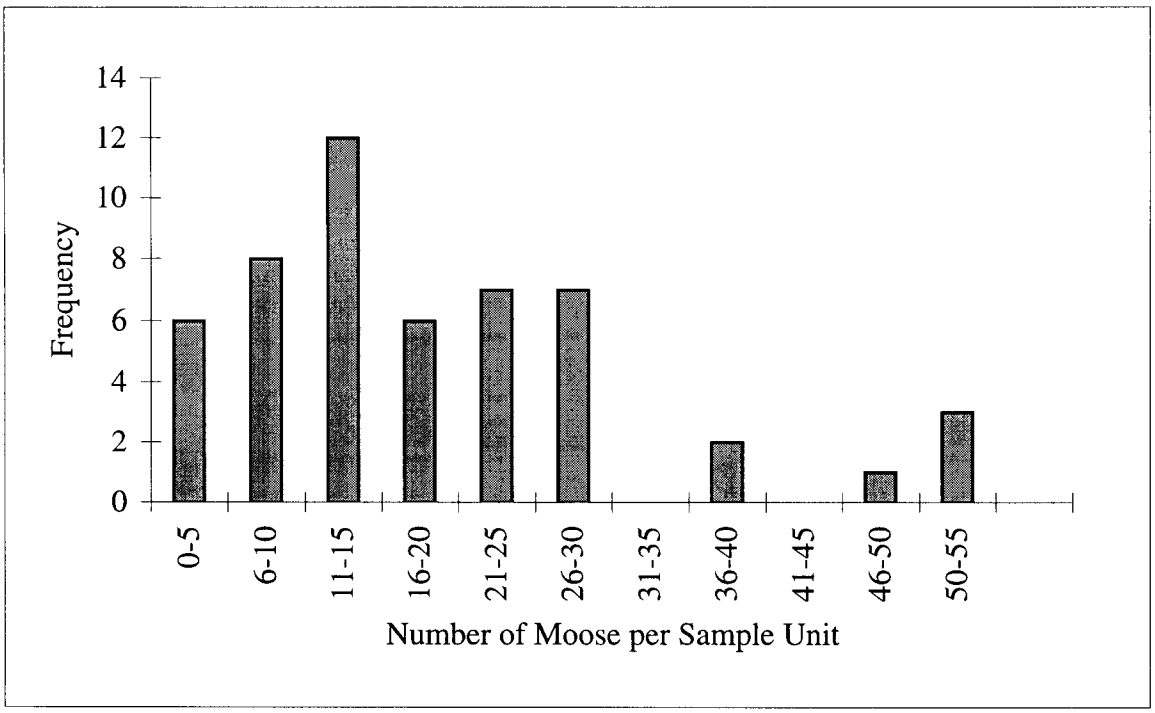


Figure 16. Conceptual model of moose-wolf dynamics. The double lines represent moose population growth rate without predation and with bear predation and hunting. The solid curves represent wolf predation rate on moose (the combination of wolf functional and numerical responses) where wolves exist at natural densities and where wolf densities have been reduced about 50%. Equilibrium conditions exist where the lines cross. A moose density of about 0.2 moose/km^2 would be expected around Prince George, but a moose density of 1.3 moose /km^2 can be maintained because wolf numbers are reduced below normal densities.

Appendix A. Aerial moose survey itinerary Prince George BC December 1998.

	HELICOPTER SURVEY			
Date	Navigator	Data Recorder	Observer	Pilot
10-Dec-98	Doug Heard	John Metcalfe	Robert Piccini	Bob
	Kathi Zimmerman	Sean Barry	Curt Vagt	Pierre
11-Dec-98	Doug Heard	Don Cadden	Andrew Wilson	Bob
	Kathi Zimmerman	Sean Barry	Barry Smith	Pierre
14-Dec-98	Doug Heard	Doug Wilson	Larry Gardner	Nick
	Kathi Zimmerman	Sean Barry	Mike Richardson	Pierre
15-Dec-98	Doug Heard	Curt Vagt	Barry Smith	Nick
	Kathi Zimmerman	Sean Barry	Lynn Rocchini	Pierre
16-Dec-98	Doug Heard	John Metcalfe	Gary van Spengen	Nick
	Kathi Zimmerman	Tom Muirhead	Doug Forsdick	Pierre
17-Dec-98	Doug Heard	Doug Wilson	Chris Ritchie	Nick
	Kathi Zimmerman	Sean Barry	Ted Zimmerman	Pierre
18-Dec-98	Doug Heard	Sean Barry	Cam Hill	Nick
	Kathi Zimmerman	Tom Muirhead	Dave McAllister	Pierre

Appendix B. Frequency distribution of the number of moose observed per sample unit during the December 1998 moose census around Prince George, British Columbia.

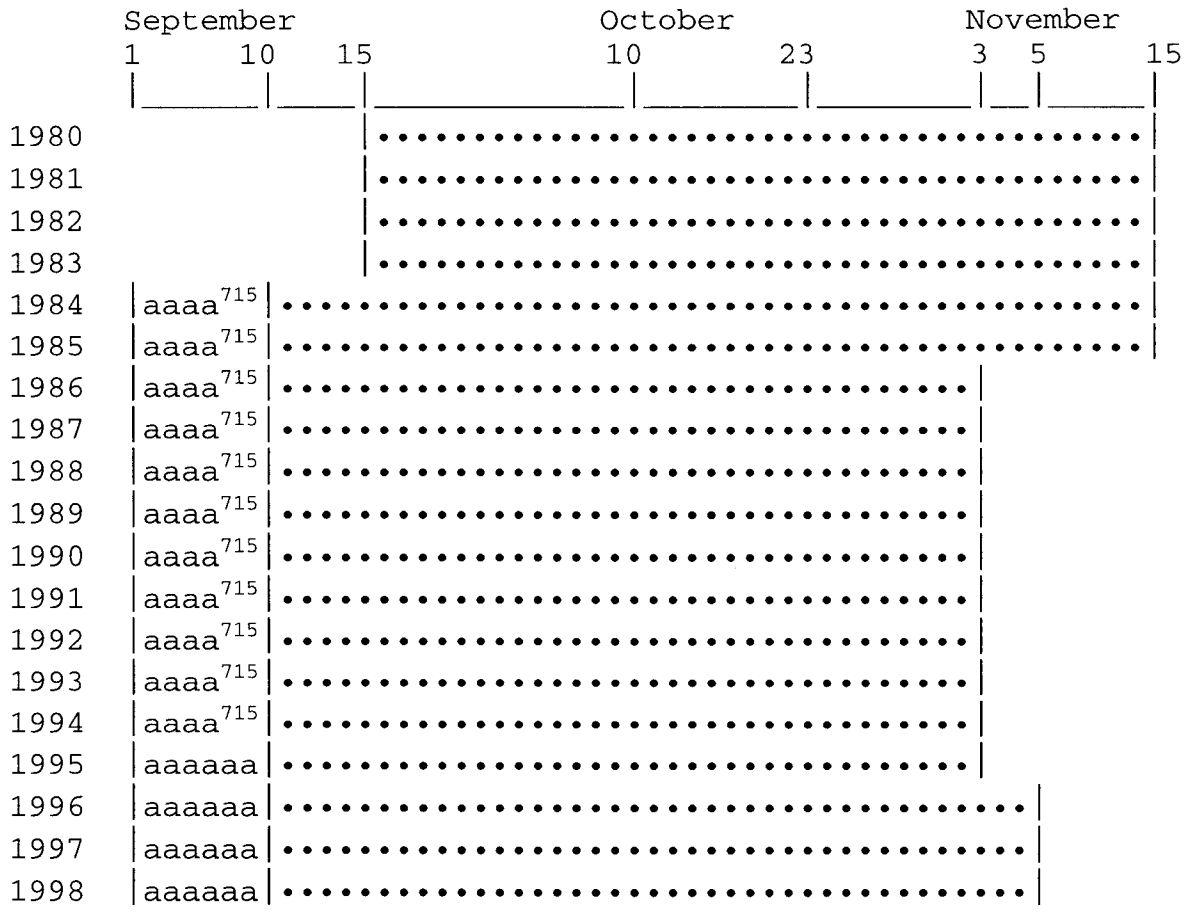


Appendix C. Moose observed in each sample unit during the December 1998 moose census around Prince George, British Columbia.

Sample		BULLS				Cows With:			Lone		
Unit	Stratum	Teen	Sub-prime	Prime	Antlerless	No Calf	1 Calf	2 Calves	Calf	Unknown	Total
1	1	1	4	1	-	15	12	-	-	-	55
3	1	2	-	5	2	1	2	-	-	-	13
4	1	4	3	3	2	3	-	-	-	-	3
5	1	-	1	-	2	13	10	1	-	1	45
6	1	-	-	-	1	5	6	1	-	-	25
7	1	2	1	1	1	3	-	-	-	-	16
8	1	1	-	1	1	5	3	-	-	-	18
9	1	4	9	3	-	12	3	-	-	-	21
10	1	-	2	-	-	2	4	-	-	-	16
11	1	4	1	5	6	6	6	-	-	-	22
12	1	1	-	-	-	5	4	-	-	1	14
13	1	2	4	-	1	-	-	-	-	-	0
15	1	3	-	-	1	21	6	1	-	-	44
16	1	2	2	-	-	1	3	-	-	-	9
17	1	5	2	1	-	4	1	-	-	-	9
18	1	1	-	3	-	4	3	-	-	-	12
19	1	-	-	-	-	7	6	1	-	-	26
20	1	-	1	2	-	1	3	-	-	-	15
21	1	-	1	-	-	13	2	1	-	-	22
22	1	-	1	-	1	7	2	-	-	1	14
24	1	-	-	2	-	16	4	-	-	-	30
25	1	-	-	-	-	8	1	-	-	-	12
26	1	-	-	-	-	21	11	-	-	1	51
27	1	-	-	6	2	3	-	-	-	-	4
28	1	1	2	1	-	16	3	-	-	-	30
29	1	-	4	1	2	4	3	1	-	1	15
30	1	-	-	-	-	1	3	1	-	-	13
31	1	1	-	1	1	2	2	1	-	-	9
32	1	-	-	-	2	1	1	-	-	-	3
33	1	1	2	-	3	1	1	-	-	-	3
34	1	3	1	1	3	3	5	1	-	-	25
35	1	3	1	1	3	6	3	-	-	-	18
36	1	1	6	-	2	3	1	-	-	-	7
37	1	2	3	3	-	8	4	-	-	-	23
38	1	1	4	2	-	3	4	-	-	-	13
39	1	1	1	1	3	13	5	-	-	-	26
40	1	2	3	1	-	-	4	-	-	-	12
41	1	-	-	-	-	-	2	-	-	2	10
42	1	1	1	-	1	3	2	-	-	-	8
43	1	2	1	-	2	9	1	-	-	-	12
45	1	1	1	-	1	9	8	-	1	-	29
47	1	2	3	1	3	12	-	-	-	-	18
49	1	1	-	7	5	-	-	-	-	-	0
50	1	1	-	-	-	13	8	-	-	1	42
11	2	-	-	-	2	18	6	-	-	-	33
18	2	-	2	-	2	4	3	-	-	-	11
30	2	-	-	-	1	10	3	1	-	-	28
35	2	2	-	-	-	7	3	-	-	-	17
37	2	-	1	-	-	8	4	-	-	-	25
42	2	-	-	-	-	4	2	-	-	-	9
43	2	-	-	1	1	1	2	-	-	-	10
50	2	-	-	-	-	16	11	-	1	1	56
TOTAL		**58**	**68**	**54**	**57**	**351**	**186**	**10**	**2**	**9**	**1001**

APPENDIX D. ARCHERY, LIMITED ENTRY AND OPEN HUNTING SEASON DATES FOR MANAGEMENT UNITS 707-715 FROM 1975 TO 1998[1].

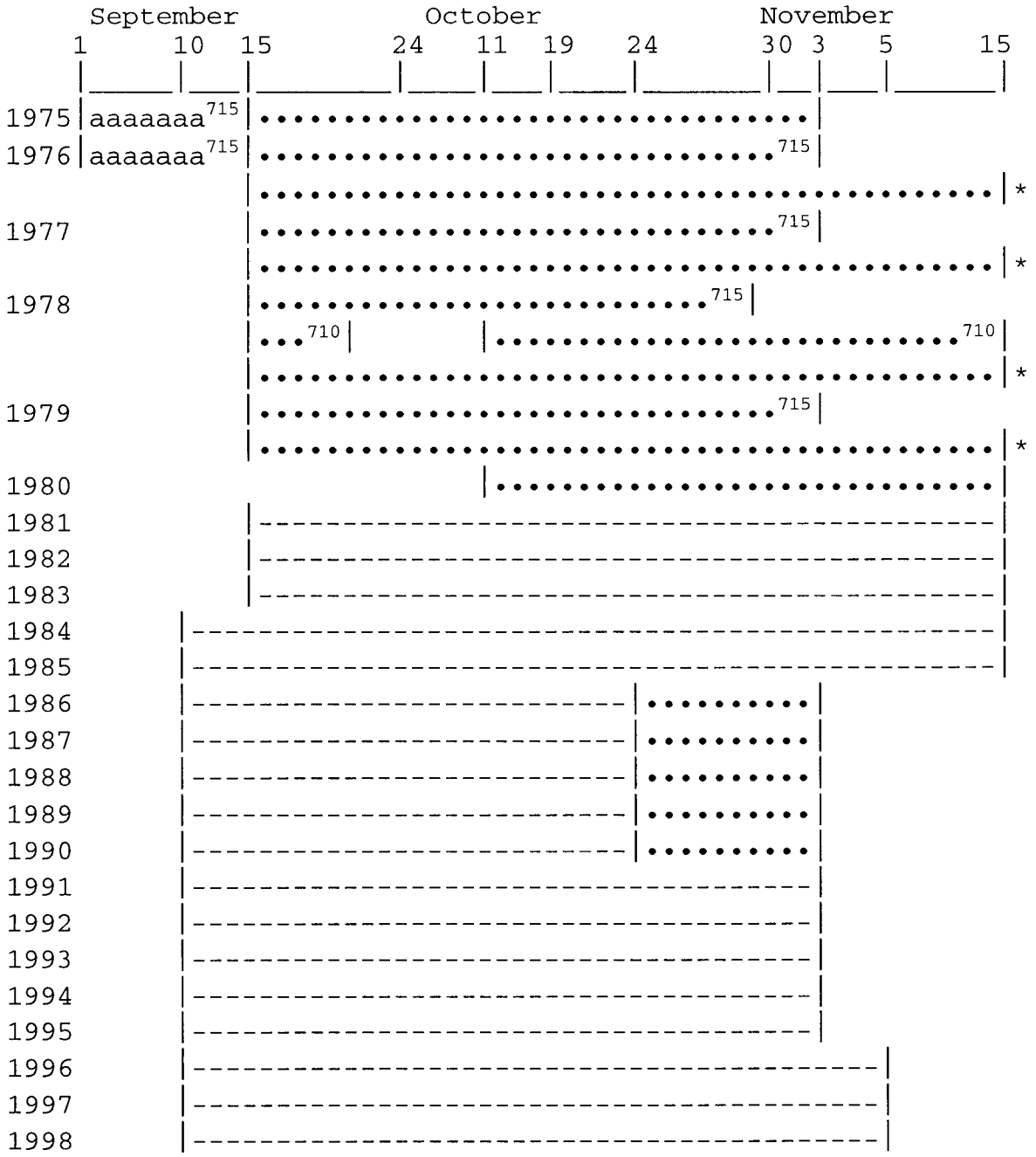
Spike or 2-Point Bulls



[1] ranges represented as |•••| are open seasons
ranges represented as |aaa| are archery-only seasons

[715] indicates dates specific to the MU referenced by superscript, otherwise refers to all MU's

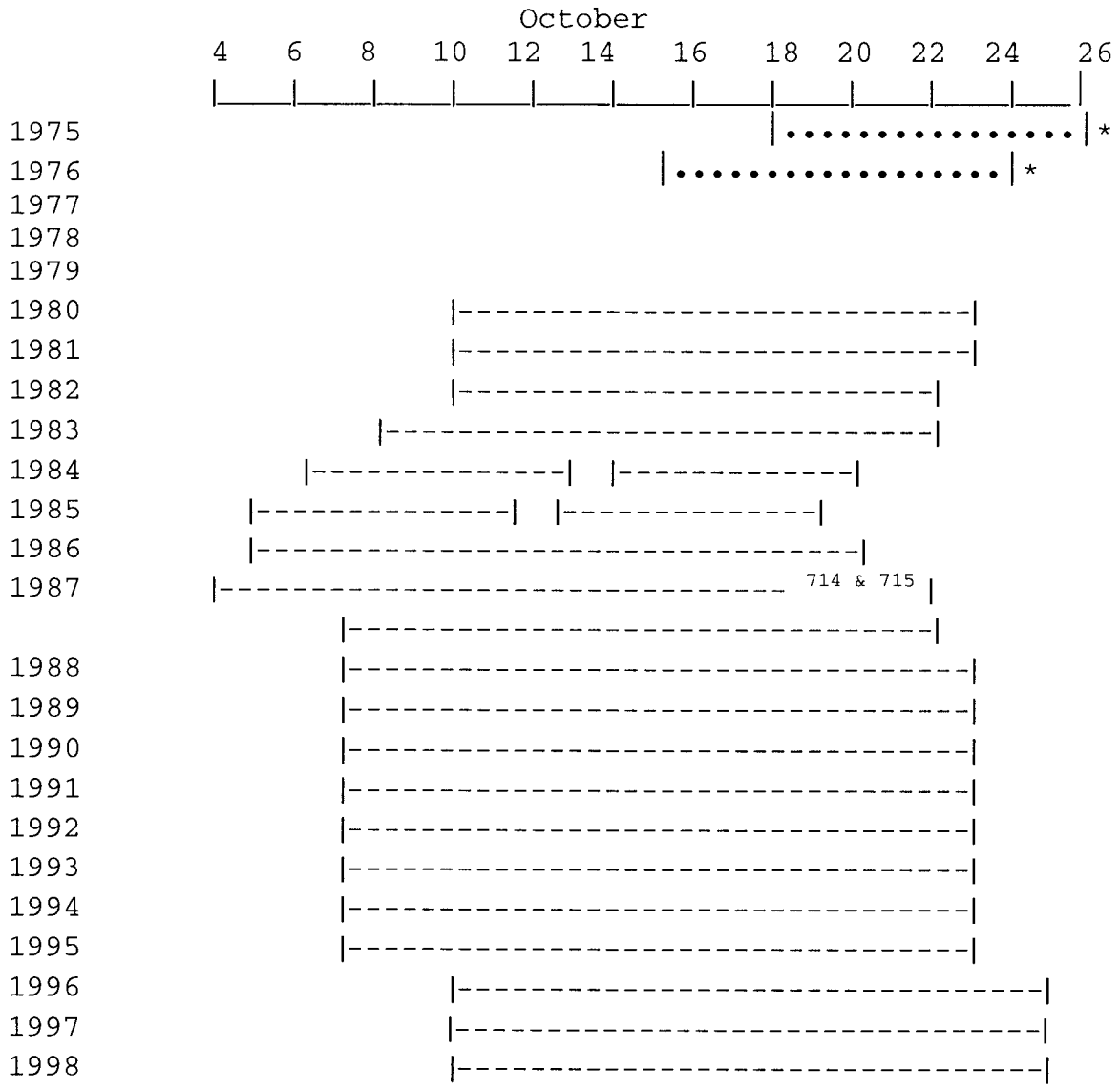
Any Bull



* = all remaining MU's

ranges represented as |aaa| are archery-only seasons
ranges represented as |•••| are open seasons
ranges represented as |---| are Limited Entry Hunt seasons for which 1210 permits were available every year except 985 in 1982

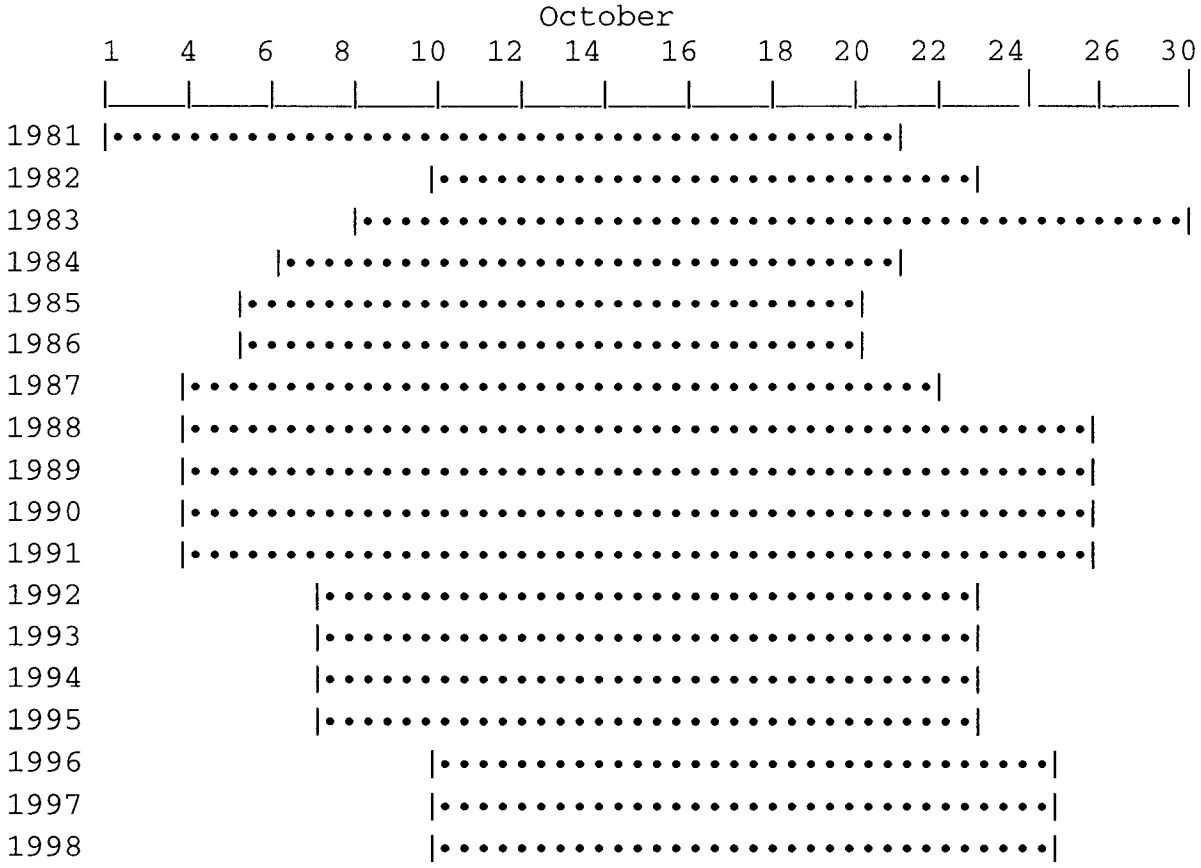
Antlerless Moose in October



* MU's 707, 708, 711 and 714

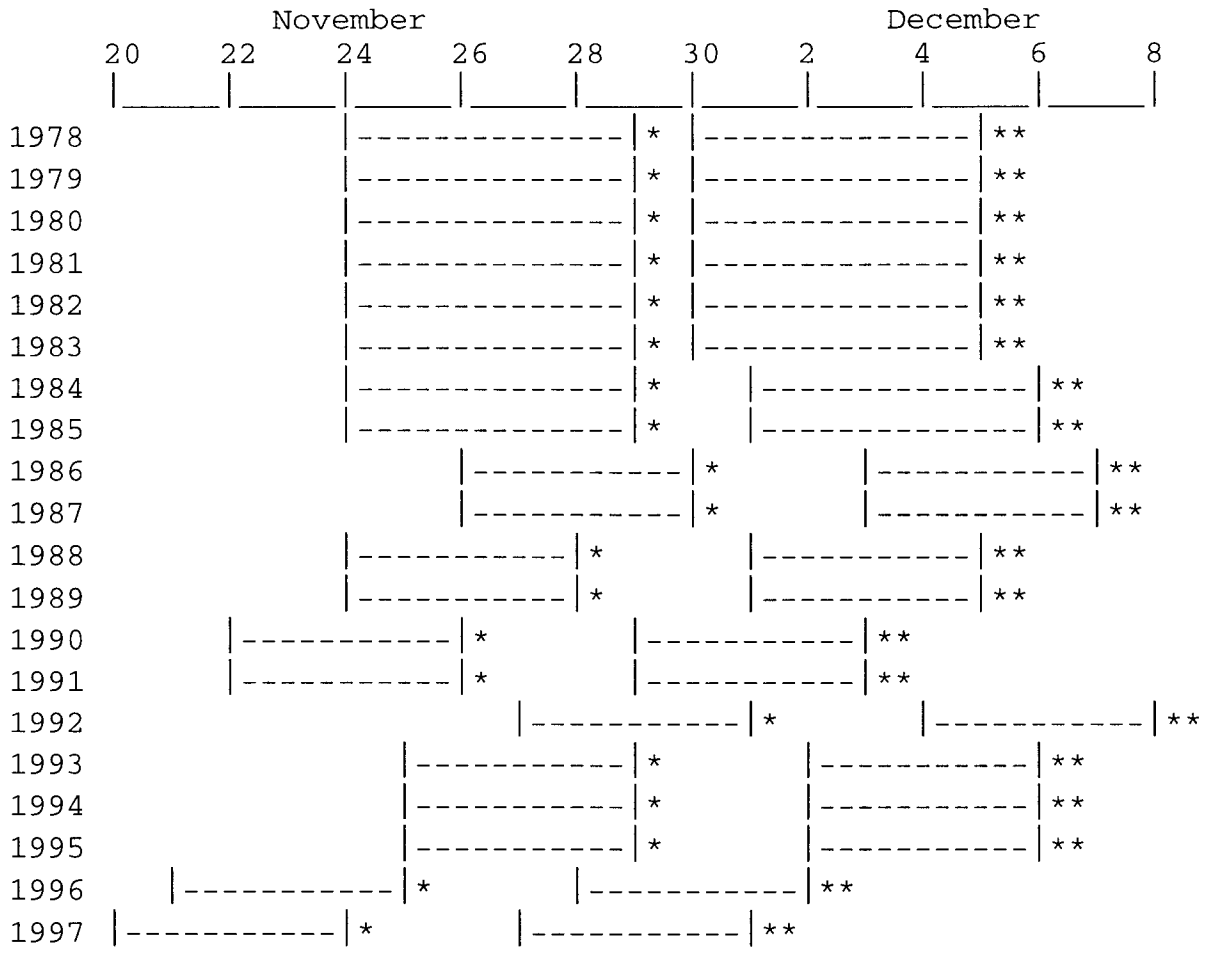
ranges represented as |•••| are open seasons
ranges represented as |---| are Limited Entry Hunt seasons for which an average of 611 permits were available (range 525-765)

Calves



ranges represented as |•••| are open seasons

Antlerless Moose in November and December[1]



[1]Kill was mostly cows but also included calves and males that had dropped their antlers.

* MU's 707, 710, and 712, (only 710 and 712 in 1984 and 1985)
** MU's 713 and 715

ranges represented as |---| are Limited Entry Hunt seasons for which an average of 185 permits / year were available (range 150-200) until the season was closed in 1998

Appendix E. Estimated number of black bears, wolves, and grizzly bears shot by hunters and Conservation Officers between 1988 and 1997 in 9 management units around Prince George, British Columbia*.

Year	Species	# of predators shot				Hunter Success (kills/hunter)
		Males	Females	Juveniles	Total	
1988	Black Bears	201	59	51	311	0.27
	Wolves	25	13	0	38	0.52
	Grizzly Bears	1	0	0	1	0.25
1989	Black Bears	128	35	14	177	0.18
	Wolves	0	12	12	24	0.15
	Grizzly Bears	0	0	0	0	0.00
1990	Black Bears	154	31	9	194	0.23
	Wolves	17	13	0	30	0.26
	Grizzly Bears	2	0	0	2	0.33
1991	Black Bears	176	46	8	230	0.25
	Wolves	24	0	0	24	0.17
	Grizzly Bears	1	0	0	1	0.33
1992	Black Bears	200	23	5	228	0.30
	Wolves	20	20	20	60	0.41
	Grizzly Bears	2	0	0	2	0.17
1993	Black Bears	187	44	9	240	0.26
	Wolves	27	0	0	27	0.26
	Grizzly Bears	1	0	0	1	0.25
1994	Black Bears	165	38	2	205	0.27
	Wolves	37	9	0	46	0.71
	Grizzly Bears	2	0	0	2	0.17
1995	Black Bears	208	50	4	262	0.33
	Wolves	16	25	0	41	0.72
	Grizzly Bears	0	1	0	1	0.13
1996	Black Bears	230	81	3	314	0.39
	Wolves	9	9	0	18	0.16
	Grizzly Bears	1	1	0	2	0.13
1997	Black Bears	198	57	8	263	0.31
	Wolves	13	7	0	20	0.20
	Grizzly Bears	2	2	0	4	0.21
Mean Annual Kill:	Black Bears	185	46	11	242	0.28
	Wolves	19	11	3	33	0.35
	Grizzly Bears	1	0	0	2	0.20

* management units 707, 708, 709, 710, 711, 712, 713, 714, and 715