THE 1977 FORT McMURRAY AOSERP MOOSE CENSUS: ANALYSIS AND INTERPRETATION OF RESULTS

by

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for

ALBERTA OIL SANDS ENVIRONMENTAL RESEARCH PROGRAM

Project TF 7.2.2

December 1978

The Hon. D.J. Russell
Minister of the Environment
Legislative Building
Edmonton, Alberta

and

The Hon. L. Marchand
Minister of State for the Environment
Fisheries and Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "The 1977 Fort McMurray AOSERP Moose Census: Analysis and Interpretation of Results".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Terrestrial Fauna Technical Research Committee (now part of the Land System), under the Alberta-Canada Agreement of 28 February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

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THE 1977 FORT McMURRAY AOSERP MOOSE CENSUS: ANALYSIS AND INTERPRETATION OF RESULTS

DESCRIPTIVE SUMMARY

ABSTRACT

A stratified random sampling procedure involving a helicopter census of square-mile (2.6 km^2) quadrats in a 648 mi^2 (1,678 km^2) pilot area in the AOSERP study area was continued in February 1977. The census produced a weighted mean estimate of 0.49 moose/mi^2 (0.19/km^2), or a study area estimate of 320 moose $\pm$ 29 percent. This was not significantly different from the population of 363 $\pm$ 30 percent estimated in 1976. The 1977 moose population of 320 moose was contained in an estimated 196 groups distributed on 23 percent of the square-mile study area quadrats at the time of census. Analysis of front and back observer data indicated a visibility bias in the 1977 census of approximately 50 percent. Adequate visibility bias models are required to provide biologically meaningful and statistically reliable estimates on any future moose censuses of the area.

BACKGROUND

This report gives the second-year interim results of an ongoing project which will be completed in 1978. The project is one of a series to establish the baseline states of the terrestrial fauna in the AOSERP study area.

The purpose of this project is to determine the population size of moose in the AOSERP study area with regard to sex and age ratios and distribution according to habitat and seasonal climatic features. The changes in these characteristics will be monitored yearly.

ASSESSMENT

The Alberta Oil Sands Environmental Research Program has reviewed and accepted the report on "The 1977 Fort McMurray AOSERP Moose Census: Analysis and Interpretation of Results", which was prepared by R.D. Cook and J.O. Jacobson of Interdisciplinary Systems, Ltd.

In view of the value of the data, the Alberta Oil Sands Environmental Research Program, through its Terrestrial Fauna Technical Research Committee (now the Land System), in agreement with the Oil Sands Environmental Study Group, recommend that the report be made public and available to AOSERP researchers as soon as possible.

Although the report does not meet the standards set by AOSERP for publication and wide distribution, it is fairly comprehensive and includes flight logs, summary of sample distribution and census results, and analysis of the data.

As an interim report, "The 1977 Fort McMurray AOSERP Moose Census: Analysis and Interpretation of Results" represents a working document which contains data that should be of some use as a basis for research on moose populations in the AOSERP study area. Readers should note the evident autocorrelation of means and variances and use the data with appropriate reservations.

The content of this report does not necessarily reflect the views of Alberta Environment, Fisheries and Environment Canada, or the Alberta Oil Sands Environmental Research Program. The mention of trade names for commercial products does not constitute an endorsement or recommendation for use.

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ABSTRACT

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ACKNOWLEDGEMENTS

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1. INTRODUCTION

A long-term study of moose population dynamics was initiated in 1975 by the Terrestrial Fauna Committee, Alberta Oil Sands Environmental Research Program (AOSERP) on their study area in the Fort McMurray, Alberta region (Figure 1). A pilot program was conducted in January 1976 to test the feasibility and statistical adequacy of an aerial quadrat census for moose on the AOSERP area (Jacobson 1978). This study concluded that, although relatively expensive, a helicopter census on square-mile quadrats was the only feasible aircraft technique alternative available for a statistically adequate moose census on the AOSERP area.

Snow and temperature conditions during the 1976 census caused a sub-optimum moose dispersion pattern relative to the original stratification, and resulted in a population estimate of 50 percent less reliable than anticipated. The study recommended that subsequent censuses concentrate on identifying and controlling as many visibility bias variables as possible, that the study area be restratified on the basis of 1976 census results and more detailed habitat analysis, and that an attempt be made to schedule the census coincident with the movement of moose into the high density stratum.

The 1977 census was designed to test the census procedure initiated in 1976 on the same study area restratified on the basis of a pre-census distribution survey, test a visibility bias adjustment model, and provide a statistically reliable 1977 moose population estimate for use in the long-term population studies. The authors determined census procedures and sampling design; T. Hauge stratified the study area and, together with L. Windberg, J. Jorgenson, and T. Fuller, conscientiously conducted the study and collected the data. This report includes the analysis and interpretation of their census data.

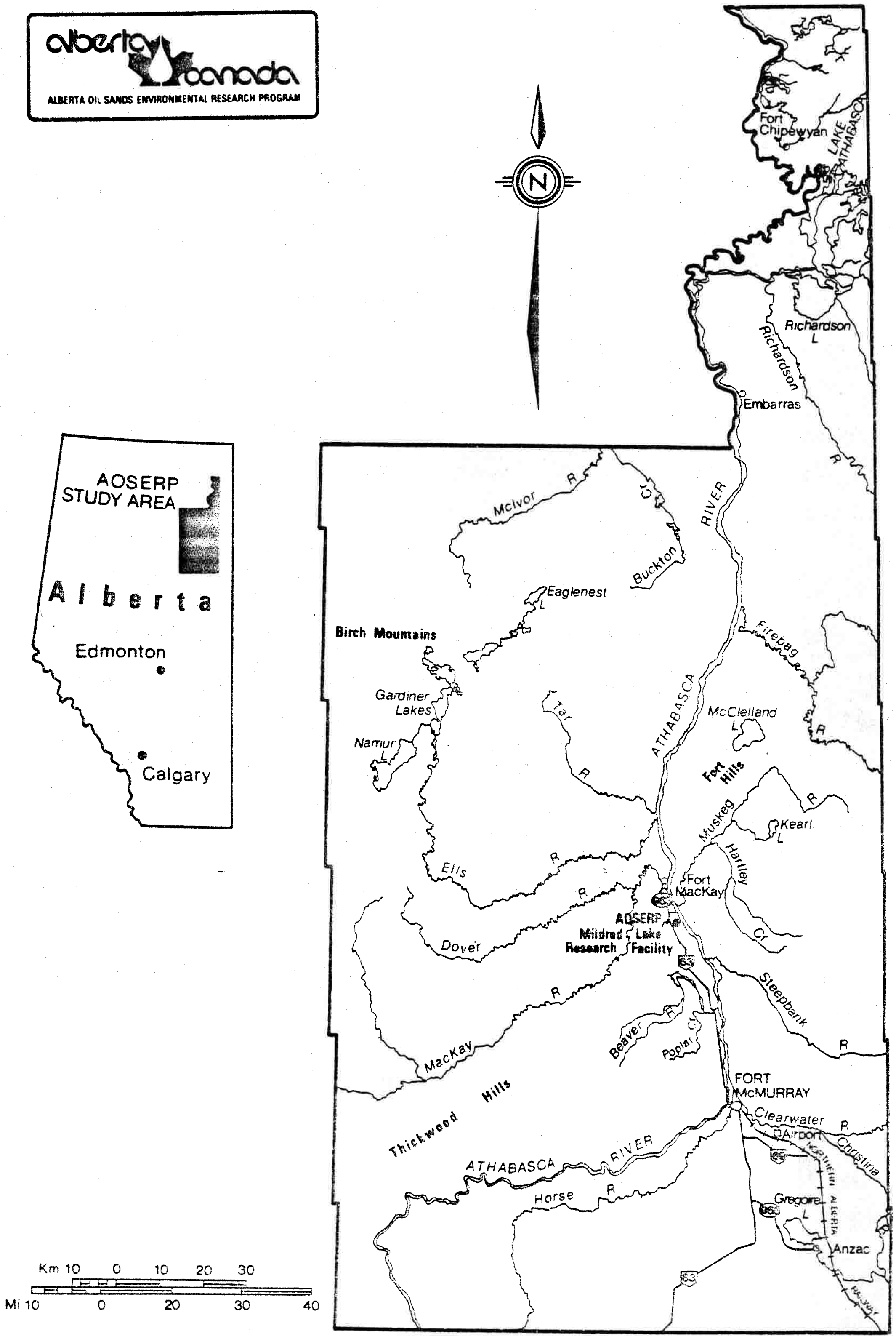

Figure 1. Location of the AOSERP study area.

2. METHODS

The 630 mi^2 (1,638 km^2) pilot area north of Fort McMurray was expanded to 648 mi^2 (1,678 km^2) for the 1977 census. Because the below-design reliability of the 1976 population estimate was attributed to weather conditions causing moose dispersion patterns inconsistent with pre-defined stratification, a stratification procedure more consistent with dispersion patterns at the time of census was used in the 1977 census (Figure 2). Existing studies of moose-habitat relationships on the study area required a fixed-wing transect survey. Regularly spaced transects a quarter of a mile apart (0.4 km) were flown across the entire study area in January 1977 and these d ta were used to stratify the study area for the 1977 census.

Stratification was based on existing habitat information in combination with the transect survey data (T. Hauge personal communication). It resulted in 78 high density, 433 medium density, and 137 low density quadrats (Figure 3). Preliminary analysis of the transect data indicated densities of 2.0, 0.25, and <0.02 moose per mi^2 in the high, medium, and low density stratum, respectively (personal communication, Tom Hauge, Research Project TF 1.1 "Moose, Caribou, Wolf Ecology). Preliminary analysis of expected variance in moose numbers by strata (Cochran 1963:95) indicated 197 samples (Table 1) would be required to estimate the study area population with a precision of ± 20 percent ($p<0.05$).

Sample quadrats were allocated to respective strata using Neyman's optimum allocation (Cochran 1963:97) and represent an overall sampling intensity of 30 percent of the study area. This allocation was modified slightly to increase sample size in the low density quadrats, and 66 high, 97 medium, and 25 low density quadrats were finally selected for sampling. Quadrats were numbered sequentially within each stratum and sample quadrats were randomly selected using the random number generating function of the Hewlett-Packard 9830 computer. Sample quadrats were outlined on 3 inch per mile aerial photos for navigation.

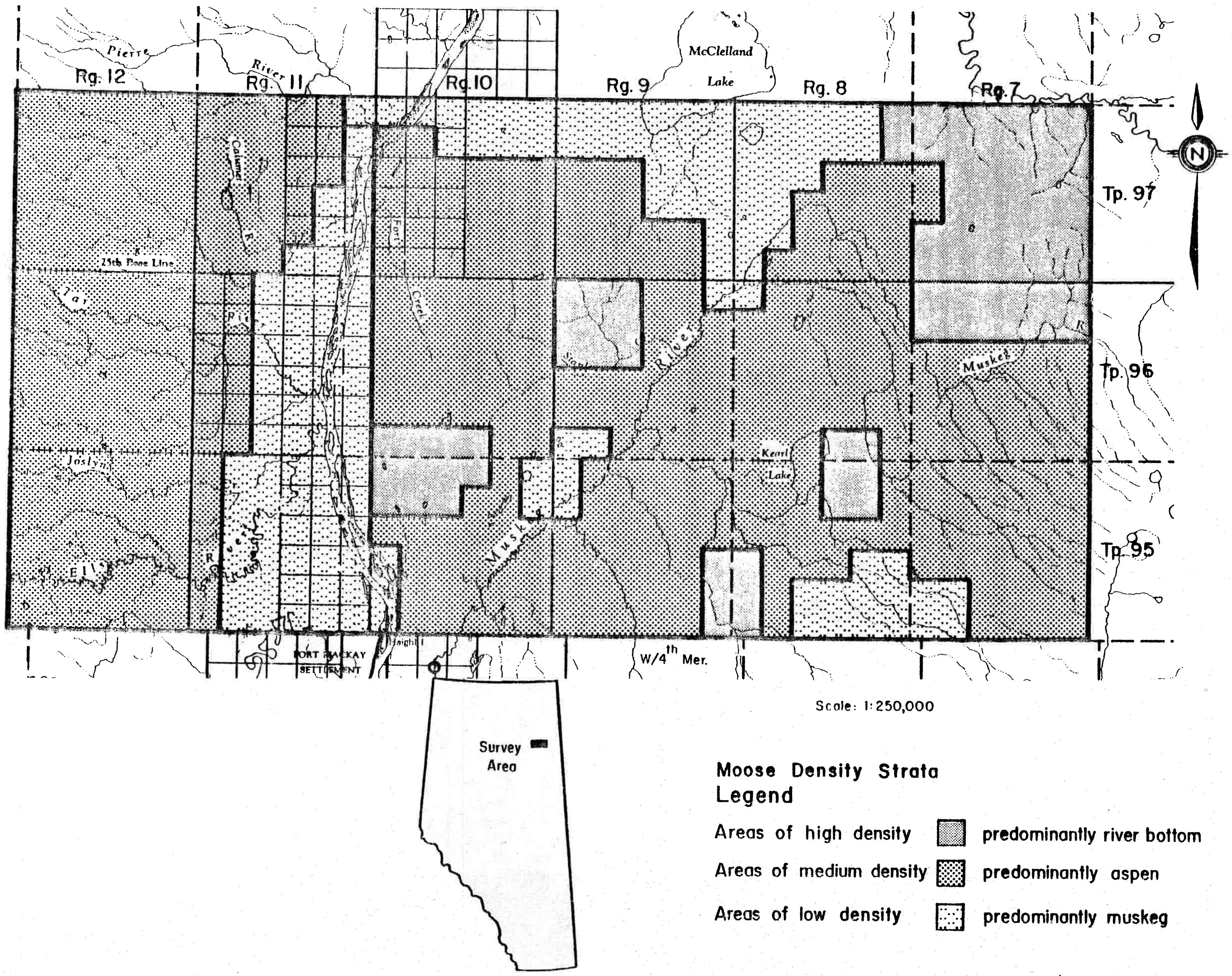

Figure 2. Distribution of the 1977 moose density strata in the AOSERP study area (reduced from original scale of 1:250,000).

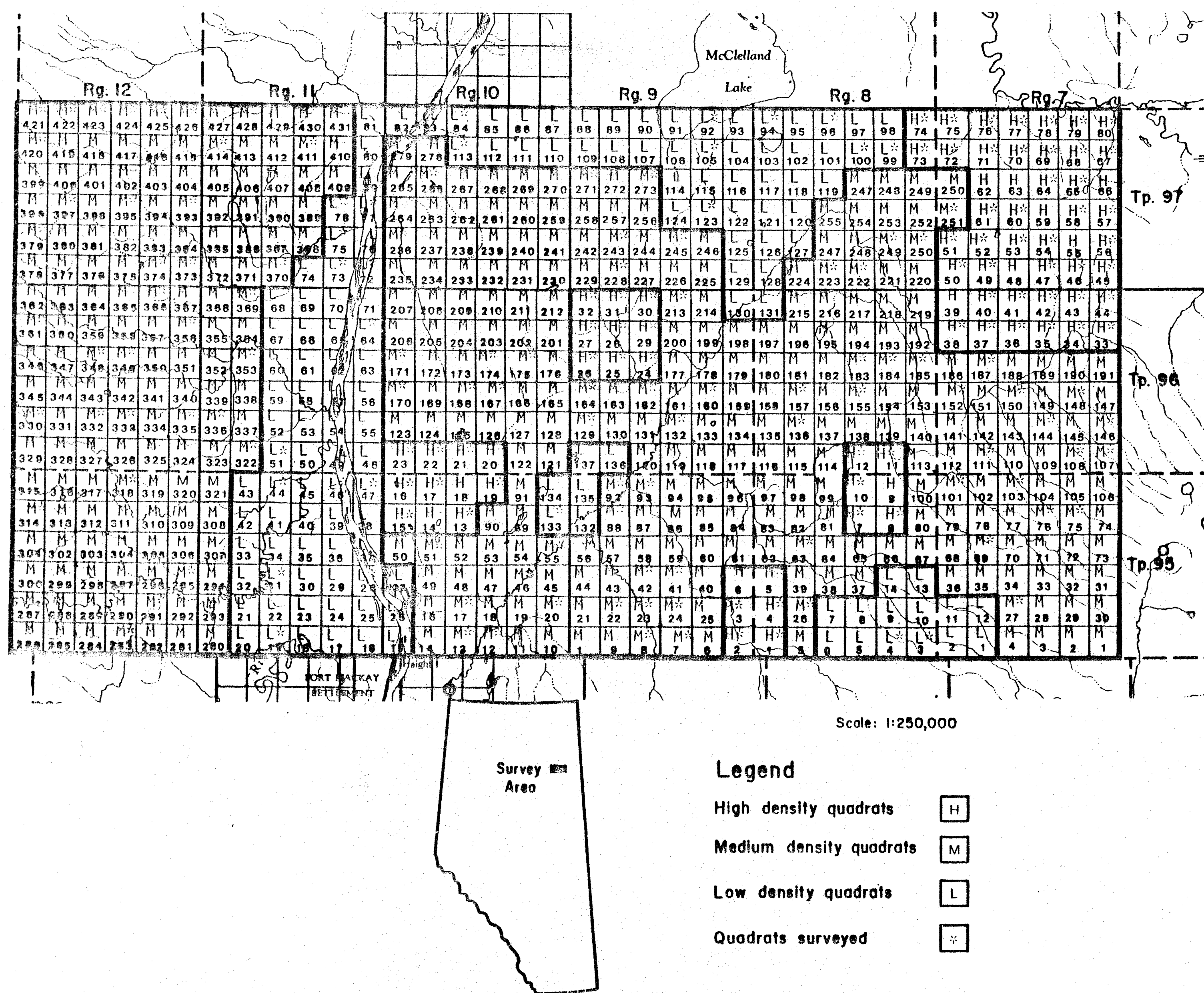

Figure 3. Distribution of the 1977 aerial survey quadrats in the AOSERP study area (reduced from original scale of 1:250,000).

Table 1. Optimum allocation of sampling effort based on an estimated 1977 moose population of 300 on the Fort McMurray AOSERP study area.

	Total quadrats	Estimated variance	Estimated sample size at given precision level 30%	25%	20%	15%	10%
High	78	8.00	45	57	73	78	78
Medium	433	0.60	68	87	111	162	253
Low	137	0.08	8	10	13	19	29
Totals	648		121	154	197	258	360
Total sampling intensity (%)			19	24	30	40	56

The census was flown in a Hughes 500C helicopter at an altitude of 150-300 ft (46-92 m) and an airspeed of 50-65 mph (80-105 km/h). Quadrats were flown in a clockwise pattern of ever decreasing "square circuits". Moose were recorded as groups (one or more moose observed in close proximity [Bergerud and Manuel 1969]). One additional restriction on this definition, necessary for visibility bias analysis (Cook and Martin 1974), is that group size is determined by the number of individuals mutually observed or observed as a result of other group individuals.

Both observers were seated on the right side of the helicopter and a recorder was seated in the left rear seat. The front observer acted as the primary observer; the back observer confirmed if he saw the front observer's sightings as well as picking up sightings missed by the front observer. Observers rotated between front and back positions. Moose observations were reported to the recorder over the intercom headsets, and were recorded on a special census data sheet (Appendix 7.1). The census was conducted 20-28 February 1977. An unusually warm winter with low snowfall contributed to general census conditions ranging from poor to good depending on lighting conditions. Snow cover ranged from 90-100 percent with a base of 10-15 cm of old snow. All censuses were flown between 0852 and 1647. The mean daily census period (excluding noon break) was 5.3 hours, with a range of 4.32-6.48 hours (Table 2).

Table 2. Flight log for helicopter moose census, Fort McMurray AOSERP study area, February 1977.

	20 February	21 February	22 February	24 February	25 February	26 February	27 February	28 February
Aircraft	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter	Hughes 500 Helicopter
Pilot	D. McCuaig	D. McCuaig	D. McCuaig	D. McCuaig	D. McCuaig	D. McCuaig	D. McCuaig	D. McCuaig
Navigator/ observer	T. Hauge	L. Windberg	L. Windberg	L. Windberg	L. Windberg	T. Hauge	T. Hauge	T. Hauge
Observer	L. Windberg	T. Hauge	J. Jorgenson	J. Jorgenson	T. Hauge	L. Windberg	L. Windberg	L. Windberg
Redorder	T.K. Fuller	J. Jorgenson	-	-	J. Jorgenson	J. Jorgenson	J. Jorgenson	J. Jorgenson
Total hours	5.37	5.55	4.32	4.68	6.48	5.43	5.37	5.45
Census hours	2.95	3.35	2.45	2.53	4.0	3.5	3.7	4.25
Quadrats Censured	18	22	17	18	30	25	30	28
Cloud Cover	High Scattered	High Overcast	Low Overcast	Clear	Clear	Clear	Clear	Clear
Wind (km/h)								
Temperature (°C)	+6	-2	-2	-5	-9	-12	-10	-6
Snow Cover	10-15 cm old snow	15 cm crusty	15 cm	15-18 cm	15 cm	15 cm	15 cm	15 cm
General Observation Conditions	Fair-Good	Fair-Good	Good	Fair-Good	Fair	Poor	Fair	Fair

3. RESULTS

The 188 sample quadrats were censused from 20-28 February 1977 (Table 2), and produced a total of 105 moose counted on 49 of the sample quadrats (Table 3). Moose per quadrat ranged from 0-6, 0-5, and 0-2 on the high, medium, and low density quadrats, respectively (Table 4). The weighted mean of the combined strata was 0.49 moose per quadrat (Table 5), resulting in a weighted study area population estimate of 320 moose ± 29 percent ($p<0.05$).

The weighted proportion of quadrats with moose of the combined strata was 0.228 ± 0.056 (Tables 6 and 7). Thus at the time of sampling the estimated total moose population of 320 was contained on about 23 percent of the study area quadrats.

Sixty-eight groups were observed on the 49 quadrats. Groups per quadrat ranged from 0-4, 0-3, and 0-1, on the high, medium, and low density quadrats, respectively (Table 8). The weighted estimate of the total number of groups in the study area was 196 ± 26 percent (Table 9). In summary, therefore, the estimated total population of 320 moose was contained in an estimated 196 groups contained on an estimated 23 percent of the square-mile study area quadrats at the time of sampling.

The census required a total of 46 hours of flying time, of which 26.7 were quadrat census hours (Table 2). This compared to 21.9 census hours for 225 quadrats in 1976 (Jacobson 1978). Mean census time per quadrat varied from 8.8 minutes on the high density quadrats to 8.9 minutes on the medium and 6.9 minutes on the low density quadrats; this difference between strata was highly significant ($p<0.005$, Table 10). The mean census time per quadrat of 8.5 was 46 percent higher than the mean quadrat search time of 5.84 in 1976 (Jacobson 1978). This increased search time may have been indicative of the relatively more difficult census conditions in 1977.

Table 3. Summary of quadrat sample distribution and aerial moose census results on the Fort McMurray AOSERP study area, 20-28 February 1977.

	High Stratum	Medium Stratum	Low Stratum	Total
Total square miles	78	433	137	648
Square-mile quadrats sampled	66	97	25	188
Sampling intensity (% of area)	85	22	18	29
Quadrats with moose	22	26	1	49
Total moose counted	46	57	2	105
Range (moose/quadrat)	0-6	0-5	0-2	
Stratum mean	0.70	0.59	0.08	
Stratum variance	1.753	1.307	0.160	

Table 4. Distribution by stratum of the number of moose per quadrat, 1977 Fort McMurray AOSERP moose census.

	Frequency			
Moose	High Stratum	Medium Stratum	Low Stratum	Total
0	44	71	24	131
1	10	7	0	17
2	8	13	1	22
3	0	2	0	2
4	2	2	0	4
5	0	2	0	2
6	2	0	0	2
Total quadrats	66	97	25	188
Total moose	46	57	2	105
Average moose per quadrat	0.697	0.588	0.080	0.559
Sample variance of moose per quadrat	1.753	1.308	0.1600	1.338

Table 5. Moose population estimate from square-mile (2.6 km^2) quadrat census, Fort McMurray AOSERP study area, February 1977. See Cochran (1963:140) for detailed explanation of symbols and calculations.

	N_h	n_h	$\bar{y}_h$	s_h^2	$\bar{Y}_{st}$	$s_{\bar{Y}_{st}}$	Population estimate[a]
High	78	66	0.70	1.753			
Medium	433	97	0.59	1.307			
Low	137	25	0.08	0.160			
Total	648	188			0.49	0.071	320 ± 91[b] or $320 \pm 29\%$

[a] $(N)(\bar{Y}_{st}) \pm (t)(N)(s_{\bar{Y}_{st}})$ where t = Students t, ($p<0.05$) with effective degrees of freedom calculated as in Cochran (1963:95).

[b] degrees of freedom = 107

DEFINITIONS

N_h = Square mile sample units per stratum (h)

n_h = Samples per stratum (h)

$\bar{Y}_h$ = Stratum mean

s_h^2 = stratum mean

$\bar{Y}_{st}$ = Weighted population mean per quadrat

$S_{\bar{Y}_{st}}$ = Standard error of weighted mean

Table 6. Proportion of quadrats with moose by stratum, 1977 Fort McMurray AOSERP moose census.

Stratum	Quadrats Sampled	Quadrats With Moose	Proportion
High	66	22	0.3333
Medium	97	26	0.2680
Low	25	1	0.04
Total	188	49	

Table 7. Estimate of proportion of quadrats with moose, 1977 Fort McMurray AOSERP moose census.

Stratum	N_h	n_h	$\bar{P}_h$	s_h^2	$\bar{P}_{st}$	$s_{\bar{P}_{st}}$	Population Estimate
High	78	66	0.333	0.003			
Medium	433	97	0.268	0.002			
Low	137	25	0.040	0.002			
Total	648	180			0.228	0.028	0.228±0.056

Table 8. Distribution, by stratum, of the number of groups per quadrat, 1977 Fort McMurray AOSERP moose census.

Number of Groups	Frequency			Total
	High Stratum	Medium Stratum	Low Stratum	
0	44	71	24	131
1	16	19	1	36
2	3	6	0	9
3	1	1	0	2
4	2	0	0	2
Total quadrats	66	97	25	188
Total groups	33	34	1	68
Average groups per quadrat	0.50	0.351	0.040	0.362
Sample variance of groups per quadrat	0.808	0.413	0.040	0.518

Table 9. Estimate of total number of groups, 1977 Fort McMurray AOSERP moose census.

Stratum	N_h	n_h	$\bar{G}_h$	s_h^2	$\bar{G}_{st}$	$s_{\bar{G}_{st}}$	Population Estimate
High	78	66	0.50	0.808			
Medium	433	97	0.35	0.413			
Low	137	25	0.040	0.040			
Total	648	188			0.303	0.0395	196 ± 50 or 196 ± 26%

Table 10. Analysis of individual quadrat search time, by stratum, on the 1977 Fort McMurray AOSERP moose census.

			Analysis of Variance				
Stratum	Mean	Variance	Source	df	SS	MS	F
High	8.8[a] (66)[b]	6.463	strata	2	80.708	40.354	5.686**
Medium	8.9 (97)	8.239	error	185	1312.930	7.097	
Low	6.9 (25)	4.243	total	187	1393.638		

[a]Mean search time in minutes.

[b]Sample size (n)

[c]Significant at p<0.005.

4. DISCUSSION

One objective of the 1977 census was to improve upon 1976 results by improving the stratification. The 1977 stratification was based on combining existing habitat information with the results of the transect survey conducted in January, and was expected to provide better results because of the up-to-date moose dispersion information.

Table 11 summarizes the effectiveness of the 1977 stratification based on the pre-census transect study and compares the effectiveness of this allocation with three other possible sampling designs. The allocation used in the 1977 census was the optimal Neyman allocation (Cochran 1963:97) based on variance estimates derived from the pilot transect study. The "optimum allocation" column refers to the optimal Neyman allocation based on 1977 census results, and is idealized in the sense that it would never be found unless, by rare chance, pilot study estimates happened to be exactly the same as the estimates from the final census. It is used here as a baseline to represent the best possible allocation. The "1976 allocation" column displays the optimal Neyman allocation based on the results of the 1976 survey; the "proportional allocation" column displays the allocation that distribution sampling effort in proportion to the size of the strata (Cochran 1963:89).

In retrospect, the allocation used is the least effective of the allocations in Table 11; it increased the variance by 23 percent over the optimal allocation. The proportional and 1976 allocations would have increased the variance by 9.3 percent and 1.4 percent, respectively, over the optimal allocation. Also, the 1977 allocation increased the variance that would have been obtained from simple random sampling by about 13 percent (Cochran 1963:137). The relatively poor performance of the 1977 allocation (20 percent of that expected) was due mainly to an overestimate of the high stratum variance.

Table 11. Summary of the effectiveness of stratification, 1977 Fort McMurray AOSERP moose census.[a]

		Pilot Study Estimates		Survey Estimates		Allocation used	Optimal Allocation	Proportional Allocation	1976 Allocation
Stratum	N_h	$\bar{Y}_h$	s_h^2	$\bar{Y}_h$	s_h^2	n_h	n_h	n_h	n_h
High	78	2	8.0	0.70	1.753	66	30	23	31
Medium	433	0.25	0.6	0.59	1.307	97	142	126	134
Low	137	0.02	0.08	0.08	0.16	25	16	39	23

[a]The proportional increase in variance due to deviation of an allocation, n_h^1, from the optimal allocation, n_h, is given by (Cochran 1963:115).

$$\frac{1}{n} \sum_{h=1}^{3} \frac{(n_h - n_h^1)^2}{n_h^1}$$

where $n = \Sigma n_h = \Sigma n_h^1$. For example, the allocation used increased the variance by

$$\frac{1}{188} \left(\frac{(66-30)^2}{66} + \frac{(142-97)^2}{97} + \frac{(25-16)^2}{25}\right) = 0.233, \text{ or } 23 \text{ percent.}$$

These remarks should not be taken to mean the design was not effective. In fact, it appears the 1977 allocation was quite good. In surveys of this type where it is difficult to anticipate stratum variances, some increase in variance relative to the optimum is inevitable. For example, the allocation used in the 1976 survey resulted in a 46 percent increase in variance over optimum allocation. The 23 percent increase obtained in this survey, thus, seems quite tolerable. The 13 percent increase in 1977 variance over simple random sampling is due mainly to the fact that in this survey the optimal allocation is quite close to proportional allocation; and simple random sampling is, in expectation, the same as proportional allocation (Cochran 1963:135).

The similarity between the optimal and 1976 allocations warrants special emphasis. Recall that if the 1976 allocation had been used and all other estimates remained constant only a 1.4 percent increase in variance would have resulted. Other similarities between the 1976 and 1977 results were noted previously. This suggests that the results of past surveys can be used effectively to design future surveys. The data in this report should produce an effective allocation for future studies of this type in which the stratification scheme remains fairly constant.

It is apparent from 1977 results that pre-census transect surveys are not a particularly effective method of stratification. A standard stratification procedure based on sound habitat information (Hildebrand and Jacobson 1974) and sample allocation based on the prior census data appears to be the soundest approach to long-term census design. If substantial restratification is attempted and good estimates of stratum variances are not available then it is recommended that proportional allocation be used until an adequate data base is developed for optimal allocation.

Based on the results of the 1976 and 1977 surveys, however, restratification does not seem reasonable unless good additional information is obtained on moose density. Some additional increase in precision could be obtained if it were possible to sample, for example, one-half of the allocation in each stratum and then reallocate the remaining half based on the data from the first half.

Table 12 presents a comparison of the estimates of stratum means and population estimates for the 1976 and 1977 censuses. The results of the two censuses are surprisingly consistent, and it is noteworthy that the means for the medium stratum are almost exactly the same for 1976 and 1977. All other results are well within the range of expected sampling variation. The hypothesis that the population total has not changed from 1976 to 1977 may be tested using the usual two-sample t-test (Cochran 1963:37). The standard error of the difference between the estimates of population totals was estimated to be 70.77. Thus, the value of the test statistic is t = 363-320 /70.77 = 0.61, which corresponds to a p-value of about 0.54. Consequently, there is no evidence from the census data to suggest that there has been much change of the total population size from 1976 to 1977.

This conclusion also holds true when visibility bias is present provided that the degree of bias is the same in 1976 and 1977. However, if the bias is more severe in one year, the conclusion that the population total has not changed substantially may not be sound.

Inability to adjust census estimates for visibility bias can severely limit the usefulness of aerial census data, since without adjustment, estimates are subject to continuing underestimation of an unknown amount. In addition, subsequent estimates of the same population are subject to fluctuations of a number of visibility bias variables that, unless controlled or adjusted for, could invalidate year to year comparisons.

One example of these fluctuations is in the analysis of census results in the morning and in the afternoon. The mean number of moose per quadrat for 77 aspen (medium density) quadrats flown in the morning of the 1976 census was 0.45, compared to a mean of 0.69 for the 86 quadrats flown in the afternoon (Jacobson 1978). It was pointed out that a population based solely on afternoon

Table 12. Comparison of 1976 and 1977 census results and population estimates, Fort McMurray AOSERP moose census.

Stratum	1976 $\bar{Y}_h$	1976 s_h^2	1977 $\bar{Y}_h$	1977 s_h^2
High	0.64	2.386	0.70	1.753
Medium	0.60	1.403	0.59	1.307
Low	0.21	0.411	0.080	0.160
Population Estimate	363 ± 110 or 363 ± 30%		320 ± 91 or 320 ± 29%	

counts would be approximately 53 percent higher than one based solely on morning counts. In comparison, the mean number of moose per quadrat for the 31 medium density quadrats flown in the morning of the 1977 census was 0.65, compared to a mean of 0.56 for the 66 medium density quadrats flown in the afternoon. The regression of the time of day (expressed as the mid-point of the census time on quadrat) on the number of moose per quadrat produced a linear regression model of $y = 0.855 - 0.02\,x$ ($F = 0.16$; df = 1.95). In 1977 a population estimate based solely on afternoon counts would be approximately 14 percent less than one based solely on morning counts.

The reasons for this anomaly between 1976 and 1977 are not known. If the sampling is relatively equal between morning and afternoon within each stratum this factor would be relatively constant and would not invalidate year-to-year comparisons. The example, however, clearly illustrates the potential implications of uncontrolled and unadjusted visibility bias for the interpretation of aerial census results.

There are several ways the problem of visibility bias can be addressed in census data. Cook and Martin (1974) developed a visibility bias model for quadrat sampling utilizing the information contained in the distributions of the numbers of groups per quadrat and the group size. Their model was based on the assumption that larger groups will have, on the average, a higher probability of being observed than will smaller groups. The model utilizes the observed groups per quadrat and the observed group size distributions to generate maximum likelihood estimates of the adjusted groups per quadrat and adjusted group size, based on the assumption that both parameters follow an underlying Poisson distribution.

The moose group size distribution on the 1977 census (Table 13) showed a good fit to a Poisson distribution (Table 14), and was remarkably similar to 1976 results, with a variance/mean ratio of 0.847 in 1977 and a variance/mean ratio of 0.819 in 1976

Table 13. Moose group size distribution by stratum, 1977 Fort McMurray AOSERP moose census.

Group Size	Frequency: High Stratum	Frequency: Medium Stratum	Frequency: Low Stratum	Total
1	20	17	0	37
2	13	12	1	26
3	0	4	0	4
4	0	1	0	1
Total groups	33	34	1	68
Average group size	1.394	1.676	2	1.544
Sample variance of group size	0.246	0.651	0	0.454

Table 14. Goodness of fit analysis of the 1977 AOSERP moose group excess distribution (group size minus 1) to the Poisson distribution.

Group Excess	Observed Frequency	Expected Poisson Frequency
0	37	39.46
1	26	21.47
2	4	5.84
3	1	1.22

SUMMARY STATISTICS

Total cells	= 4
Total groups	= 68
Mean group excess	= 0.544
Variance	= 0.461
Index of dispersion (S^2/mean)	= 0.847
Chi-square	= 1.729
Degrees of freedom	= 2
Tail-classes combined	= 0
Probability of exceeding Chi-square	= 0.418

(Jacobson 1978). These variance/mean ratios less than 1.0 prevent visibility bias analysis by the existing Cook-Martin model since the theoretical assumptions upon which the model is based requires adjustment to a Poisson distribution from a variance/mean ratio of greater than 1.0. The reasons for this were discussed by Jacobson (1978). However, it appears to be a function of small group size (hence a small number of cells in the distribution) which in turn appears to be a function of relatively low densities. These low densities appear to be characteristic of moose populations in other boreal forest areas of Alberta and Manitoba and may require the modification of the Cook-Martin Poisson model to a binomial distribution for it to be useful on northern boreal moose censuses.

The records of the number of moose seen by each observer, if properly kept, can also be used to estimate the probability that a group of size S will be observed. These estimated probabilities can then be used to produce a population estimate adjusted for visibility bias. This adjusted estimate can then be compared to the usual stratified estimate based on the number of observed moose per quadrat and the magnitude of visibility bias determined.

The technique requires that the front person act as a primary observer and the back person act as a secondary observer. The secondary observer confirms whether or not he also sighted groups reported by the primary observer and also reports groups missed by the primary observer. The recorder keeps track of the groups sighted only by the front observer, groups sighted by both observers and groups sighted only by the back observer. The secondary observer may assist in counting moose in a group originally seen by the primary observer, but must not aid the primary observer in the detection of groups. The assumption required for the model is that the two observers are of approximately equal ability. If this is not a reasonable assumption (probably the majority of cases) the technique can still work provided that in each stratum the primary and secondary observers change positions halfway through the stratum.

To see how the technique works, first let:

$\bar{X}_{h,s}$ = average number of groups of size S in stratum h.

α_s = probability that a single observer sees a group of size S.

N_h = total number of quadrats in stratum h.

The usual weighted estimate of the total number of animals can be written as:

$$Y_{st} = \sum_h N_h \sum_s S\bar{X}_{h,s}$$

Once the probabilities, α_s, have been estimated the adjusted estimate of the total number of animals is determined by:

$$Y_{st,adj} = \sum_h N_h \sum_s \frac{S\bar{X}_{h,s}}{\alpha_s(2-\alpha_s)}$$

where:

$\alpha_s(2-\alpha_s)$ = probability that a group of size S is seen by either observer.

Also, α_s is estimated using:

$$\alpha_s = 1 - \frac{X_{s,\ secondary}}{X_{s,\ primary}}$$

where $X_{s,secondary}$ denotes the total number of groups of size S observed by the secondary observer, $X_{s,primary}$ is defined in the same way.

Table 15 summarizes the observation records for this census. Note that the recorder and pilot observed several groups of moose which the front and back observers missed. In addition, these results indicate a considerable inequality between the number of moose observed by the front and back observers. For this reason, all moose sighted by the front observer, recorder, or pilot were considered observations by the primary "observer", and the observer in the back seat was considered the secondary observer.

Table 15. Front and back observer records, 1977 Fort McMurray AOSERP moose census.

Group Size	Front[a]	Back[a]	Both[b]	Recorder[a]	Pilot[a]
1	2	15	10	5	4
2	3	11	8	1	3
3	2	1	1	0	0
4	1	0	0	0	0

[a]Observations by indicated observer which were missed by all other observers.

[b]Observations by both front and back observers.

Table 16 summarizes the estimates of α_s and $\alpha_s(2-\alpha_s)$ for the 1977 census. Using these probability estimates the adjusted estimate of the total number of animals is:

$$Y_{st,adj} = 623 \pm 157 \text{ (see Table 13 for the } \bar{X}_{h,s} \text{ values necessary for these calculations)}$$

which is approximately twice the standard stratified estimate based on the number of moose observed. The standard error used in the calculation of the half-width of the confidence interval is based on the assumption that estimated probabilities in Table 16 are the true probabilities. The correct standard error will be somewhat larger owing to the uncertainty of the estimates of α_s. This analysis suggests that visibility bias could have had a substantial effect on 1977 census results: almost 50 percent of the moose present in the sampled quadrats were not observed. This conclusion is not inconsistent with that expected from a census with poor-to-good observability conditions and snow cover ranging from 90-100 percent on a base of 10-15 cm of old snow.

LeResche and Rausch (1974) conducted a controlled study to determine effects of observer experience and snow conditions on visibility bias of moose surveys in Alaska. They found that experienced observers detected about 70, 61, and 40 percent of the total moose under excellent, good, and poor snow conditions, respectively. Since the 1977 Fort McMurray census was conducted under poor-to-good conditions, the visibility bias estimate of almost 50 percent is clearly within the range identified in Alaska.

Table 16. Analysis of observer records, 1977 Fort McMurray AOSERP moose census.

Group Size, S	Primary[a]	Secondary	Total	α_s[c]	$\alpha_s(2-\alpha_s)$[d]
1	21	15	36[b]	0.286	0.490
2	15	11	26	0.267	0.462
3	3	1	4	0.667	0.889
4	1	0	1	1.00	1.00

[a]Primary = Front + Both + Recorder + Pilot.

[b]This total is one less than the number of groups in Table 2. The observer of one group was not recorded.

[c]Estimated probability that a single observer sees a group of size S.

[d]Estimated probability that a group of size S is seen by either observer.

5. RECOMMENDATIONS

It is apparent that visibility bias is a major component of any helicopter census of moose on the Fort McMurray study area, and if future censuses are to provide meaningful long-term population data, visibility bias must be accounted for. There are two basic approaches to solving this problem. First, researchers can attempt to control all variables related to visibility bias. These include variables associated with the animals being counted, observers, physiography, weather, equipment, and methodology.

The difficulty in controlling these variables is illustrated by the variability, discussed earlier, between the 1976 and 1977 morning and afternoon results. Even if all these variables could be controlled, the estimates would still be only an index of population change since they would be a constant, but unknown, percent of the actual population total. Other methods would still be required to relate these estimates to the population total.

Two visibility bias models appear technically feasible after reviewing the 1976 and 1977 results. The first, a model based on moose group size and groups/quadrat distributions adjusted to a binomial distribution, may be feasible and merits further investigation. A second adjustment model could be based on data collection from front and back observations as outlined in this report. This model is theoretically simple, but requires careful sample design and data recording. Neither of these models relieves the researcher from making maximum efforts to control visibility variables during the census, since the more that are controlled or eliminated the easier it is to interpret results from the visibility bias adjustment models. Ideally, both models should be developed for future census work since the information required for each model is easily collected during a standard quadrat census.

This problem of visibility bias must be given careful consideration before additional moose censuses are conducted on the AOSERP study area. Without adjustment for a complex of census variables that are nearly impossible to control and a combined visibility bias that may underestimate the true population by as much as 50 percent, the final results may be meaningless or even misleading. With the application of visibility bias models, censuses can be designed and conducted to provide statistically valid population estimates for research and management requirements.

6. LITERATURE CITED

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7. APPENDICES

7.1 FIELD DATA SHEET, AERIAL QUADRAT CENSUS

A field data sheet, reduced from the original, is shown on page 35.

Field Data Sheet

Aerial quadrat census

Note: always fly quadrats clockwise. Indicate starting corner and flight direction with a large arrow.

NW N NE

W E

SW S SE

Study area ....

Quadrat no. ....

Date ....

Time in ....

Time out ....

Total census time ....

Total MOOSE ....

Scale
1 mi. = 6 in.
1 km. = 3.75 in.

7.2 RESULTS OF THE AERIAL QUADRAT MOOSE CENSUS ON THE FORT McMURRAY AOSERP STUDY AREA, 20-28 FEBRUARY 1977.

Table 17. Results of the aerial quadrat moose census on the Fort McMurray AOSERP study area, 20-28 February 1977.

Quadrat Number	Census Time	Group Size Distribution	Total Groups	Total Moose
H 13	913-920	-	0	0
H 15	925-935	1	1	1
H 16	940-951	2	1	2
H 23	954-1002	-	0	0
H 22	1004-1015	-	0	0
H 17	1016-1026	1	1	1
H 21	1027-1035	-	0	0
H 20	1036-1044	-	0	0
H 19	1045-1050	-	0	0
H 32	1210-1218	-	0	0
H 31	1221-1229	-	0	0
H 30	1233-1240	-	0	0
H 27	1300-1307	-	0	0
H 24	1453-1458	-	0	0
H 29	1459-1506	-	0	0
H 28	1510-1517	-	0	0
H 25	1519-1527	-	0	0
H 3	917-926	2	1	2
H 2	932-945	2	1	2
H 1	951-1000	1	1	1
H 4	1008-1020	1	1	1
H 5	1039-1043	-	0	0
H 8	1147-1154	-	0	0
H 7	1155-1204	-	0	0
H 9	1205-1212	-	0	0
H 12	1214-1222	1	1	1
H 11	1224-1231	-	0	0
H 33	1000-1004	-	0	0
H 34	1005-1017	1, 1, 2	3	4
H 35	1019-1027	1, 1	2	2
H 36	1029-1037	1	1	1
H 37	1038-1046	-	0	0
H 38	1047-1054	-	0	0
H 50	1131-1142	2	1	2
H 49	1143-1152	-	0	0
H 40	1153-1202	2	1	2
H 41	1203-1210	2, 2, 1, 1	4	6
H 42	1212-1223	-	0	0
H 47	1224-1232	-	0	0
H 46	1233-1239	-	0	0
H 43	1240-1249	2, 2, 1, 1	4	6
H 44	1252-1301	1	1	1
H 45	1300-1310	1	1	1
H 73	1011-1020	-	0	0
H 74	1021-1029	-	0	0
H 72	1032-1043	1	1	1

continued ...

Table 17. Continued.

Quadrat Number	Census Time	Group Size Distribution	Total Groups	Total Moose
H 75	1044-1055	-	0	0
H 71	1056-1106	1, 1	2	2
H 60	1107-1120	-	0	0
H 54	1136-1144	-	0	0
H 70	1145-1156	2, 2	2	4
H 77	1157-1206	-	0	0
H 69	1217-1239	-	0	0
H 68	1231-1243	2	1	2
H 79	1244-1254	-	0	0
H 80	1255-1303	-	0	0
H 67	1359-1406	-	0	0
H 76	1408-1416	1	1	1
H 65	1417-1425	-	0	0
H 58	1427-1436	-	0	0
H 53	1437-1446	-	0	0
H 56	1449-1456	-	0	0
H 64	1458-1505	-	0	0
H 52	1507-1516	-	0	0
H 57	1604-1613	-	0	0
H 61	1614-1621	-	0	0
M 83	926-936	-	0	0
M 291	943-953	2	1	2
M 295	1000-1012	-	0	0
M 314	1023-1031	-	0	0
M 318	1039-1044	-	0	0
M 322	1146-1154	-	0	0
M 336	1158-1205	-	0	0
M 335	1209-1218	-	0	0
M 333	1224-1233	-	0	0
M 332	1237-1245	-	0	0
M 330	1250-1259	4	1	4
M 248	1306-1316	-	0	0
M 349	1437-1446	-	0	0
M 361	1453-1506	3, 1, 1	3	5
M 353	1517-1526	-	0	0
M 356	1521-1548	-	0	0
M 366	1552-1559	-	0	0
M 365	1602-1609	-	0	0
M 373	848-856	-	0	0
M 374	900-910	1	1	1
M 379	917-925	-	0	0
M 397	930-941	3, 2	2	5
M 395	947-959	2	1	2
M 393	1005-1013	2	1	2
M 369	1019-1027	-	0	0

continued ...

Table 17. Continued.

Quadrat Number	Census Time	Group Size Distribution	Total Groups	Total Moose
M 411	1100-1111	-	0	0
M 414	1118-1129	2	1	2
M 420	1137-1148	1, 1	2	2
M 421	1151-1207	1	1	1
M 423	1211-1223	2, 2	2	4
M 425	1228-1238	-	0	0
M 370	1434-1444	1	1	1
M 13	1316-1324	-	0	0
M 14	1325-1336	-	0	0
M 17	1344-1353	3	1	3
M 41	1446-1455	-	0	0
M 7	1508-1515	-	0	0
M 55	1626-1637	-	0	0
M 22	1552-1559	-	0	0
M 20	1601-1611	-	0	0
M 42	1540-1549	-	0	0
M 23	1529-1538	-	0	0
M 46	1612-1624	2	1	2
M 8	1519-1528	-	0	0
M 24	1456-1504	-	0	0
M 266	1044-1053	-	0	0
M 236	1100-1109	-	0	0
M 171	1116-1124	-	0	0
M 88	1309-1318	-	0	0
M 93	1424-1433	2	1	2
M 92	1434-1442	-	0	0
M 170	1446-1454	-	0	0
M 101	1524-1531	-	0	0
M 111	1534-1543	1, 1	2	2
M 103	1545-1555	-	0	0
M 76	1557-1607	1	1	1
M 75	1608-1616	-	0	0
M 69	1624-1632	-	0	0
M 51	903-911	-	0	0
M 271	1130-1133	-	0	0
M 224	1142-1151	1, 1	2	2
M 228	1155-1203	-	0	0
M 213	1245-1254	-	0	0
M 132	1427-1435	-	0	0
M 160	1436-1444	-	0	0
M 162	1445-1452	-	0	0
M 129	1532-1542	3	1	3
M 175	1611-1620	-	0	0
M 174	1622-1630	-	0	0
M 167	1632-1640	1	1	1
M 168	1642-1652	1	1	1

continued ...

Table 17. Continued

Quadrat Number	Census Time	Group Size Distribution	Total Groups	Total Moose
M 129	901-908	-	0	0
M 26	1025-1032	-	0	0
M 63	1123-1130	-	0	0
M 69	1134-1144	1	1	1
M 136	1225-1245	-	0	0
M 157	1246-1254	-	0	0
M 155	1445-1455	2	1	2
M 183	1456-1504	-	0	0
M 184	1507-1515	-	0	0
M 185	1518-1525	-	0	0
M 152	1526-1534	-	0	0
M 187	1535-1544	-	0	0
M 150	1545-1552	-	0	0
M 144	1554-1602	-	0	0
M 108	1607-1618	1, 1	2	2
M 107	934-938	-	0	0
M 146	940-947	-	0	0
M 148	950-956	-	0	0
M 246	1405-1411	-	0	0
M 273	1431-1439	-	0	0
M 223	1531-1537	2	1	2
M 222	1538-1544	2	1	2
M 250	1552-1559	-	0	0
M 249	1545-1551	-	0	0
M 78	1207-1216	-	0	0
M 251	1555-1603	-	0	0
L 46	1412-1417	-	0	0
L 47	1421-1429	-	0	0
L 78	1449-1457	-	0	0
L 75	1501-1508	-	0	0
L 73	1515-1522	-	0	0
L 72	1524-1531	-	0	0
L 64	1536-1544	-	0	0
L 28	1550-1555	-	0	0
L 51	1225-1232	-	0	0
L 44	1235-1244	-	0	0
L 31	1249-1257	-	0	0
L 19	1302-1310	-	0	0
L 84	1014-1023	-	0	0
L 113	1024-1035	-	0	0
L 133	1301-1307	-	0	0
L 4	1403-1410	-	0	0

continued ...

Table 17. Concluded.

Quadrat Number	Census Time	Group Size Distribution	Total Groups	Total Moose
L 3	1411-1418	-	0	0
L 123	1413-1420	2	1	2
L 114	1423-1429	-	0	0
L 105	1441-1449	-	0	0
L 92	1450-1452	-	0	0
L 94	1454-1501	-	0	0
L 96	948-956	-	0	0
L 100	958-959	-	0	0
L 99	1000-1007	-	0	0

8. AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
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21.		AOSERP Second Annual Report, 1976-77
22.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
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28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
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