MOOSE DENSITY ESTIMATION WITH LINE TRANSECT SURVEY

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ABSTRACT: Developments in the theory and analysis of line transect survey make it a candidate for replacement of moose (*Alces alces*) aerial plot survey. By incorporating perpendicular distance data in estimates, visibility bias correction is built into the method. A 1988 helicopter line transect survey, which included track group observations and searches to determine group size, was used to examine if assumptions were met. The non–parametric Fourier series model was the best candidate estimator, but the parametric half normal curve did almost as well. Two radio–collared moose were in clusters recorded on the basis of fresh tracks, lending support to inclusion of track determined clusters. Although some line transect assumptions were violated (movement prior to detection, non–independence of observations) these can probably be fixed with adjustments to methods. Line transect survey holds promise for increases in precision, accuracy, and cost effectiveness over plot survey methods.

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Line transect survey (Eberhardt 1968, Burnham *et al.* 1980) incorporates a visibility bias (Cook and Martin 1974) correction factor into each individual density estimate. Visibility bias correction factors have been an achilles heel for widely used plot surveys for moose (*Alces alces*) (Gasaway *et al.* 1978, Gasaway and Dubois 1987). Thompson (1979) presented a line transect method for correction of moose population, sex and age survey estimates. However, no further development work for moose density estimate with line transect has been done, and the method is not applied for operational surveys. I applied line transect methods to this research survey where an independent sightability correction factor (SCF) (Gasaway and DuBois 1987) was not available for moose. The method may have utility for moose management survey although validation and refinement of field techniques is required. This paper examines aspects of line transect theory pertinent to understanding its relevance to moose density estimation, and presents results of the survey as a step towards method refinement.

The rationale, theory, and appropriate estimators for line transect survey have greatly matured recently (Robinette *et al.* 1974, Burnham and Anderson 1976, Eberhardt 1978, Eberhardt *et al.* 1979, Anderson *et al.* 1979, Burnham *et al.* 1980, Seber 1982, Burnham and Anderson 1984, Burnham *et al.* 1985). Gasaway and DuBois (1987) presented a concise synopsis of the technique in a review of moose population estimation. Anderson and Pospahala (1970) present the basics of line transect survey in easily understood terms. Weaknesses both in application to moose, and in the theory of variance estimates have been noted (Gasaway andDuBois 1987). Work continues in the areas of confidence intervals (Quang 1990), and estimators (Drummer and McDonald 1987).

Application of line transect to particular species rests on meeting four basic assumptions (Burnham *et al.* 1980). However, the method is not adequately understood in this regard (Guthery 1988, Whitesides *et al.* 1988, Thompson 1979, Gasaway and Dubois 1987) and no validation has been attempted. On the practical side, one remains mindful that line transect assumptions are best met in ground searches for immobile objects (Anderson and Pospahala 1970).

Line transect sampling does not assume a strip width. Perpendicular distance measurements are used to generate a frequency distribution. A parametric or non–parametric curve is then fitted. The rectangular area surrounding the curve, divided by the area under the curve, represents the SCF (Fig. 3c in Gasaway and DuBois 1987, see also Anderson and Pospahala 1970).

Line transect survey does not assume any particular distribution of animals if sampling is random, so it is suitable for non–parametric estimators (Eberhardt 1978, Burnham *et al.* 1980). Observations must be independent events (Burnham *et al.* 1980). Clustered (clumped or grouped) distributions are accommodated by calculating density for groups (cluster density) (Eberhardt 1978, Burnham *et al.* 1980). Observational bias due to group size (Cook and Martin 1974, Samuel and Pollock 1981, Thompson 1979) does not affect cluster density calculations (Burnham *et al.* 1980). Group size observation bias is one variable in a set which cause variation in the shape of distance–visibility curves. This set of variables includes: between habitat bias (overstory cover), between survey days bias (snow conditions), within survey day bias (shadows), between observers bias (skill, sunlight glare, fatigue), and between age–sex population components bias. All bias variables are treated cumulatively, and are collapsed into an average function (Burnham *et al.* 1980). There may be limits to this robustness (Holt and Cologne 1987).

A secondary level of assumptions must be imposed when extrapolating from cluster density to population density (Eberhardt 1978, Burnham *et al.* 1980). Bias and variability in group size estimates introduce error to the population density estimate. Population density variance is a product of cluster density variance and group size variance. Group size observation bias and visibility bias remain though to confound accuracy. The assumptions are well understood but should be field tested. In addition, I am not aware of any algorithms which are available for generating estimates where group size data is collected. This tool will have to be developed before line transect methods can be considered operational.

Confidence intervals can be generated by assuming objects are distributed randomly (Poisson), assuming aggregation, or by empirical calculation based on replicate lines. The distribution of moose is contagious but less so if counts of moose groups are analyzed rather than counts of individuals (Fraser and Barbowski 1978). One should favor the empirical calculation (Eberhardt 1978) but an assumption of random distribution of groups, although somewhat optimistic, is not unreasonable (Fraser and Barbowski 1978). Quang (1990) developed a bootstrap method for confidence interval estimation which might prove useful.

Pollock and Kendall (1987) gave a mixed review to line transect density estimation. They suggested the method was not used in terrestrial aerial surveys because distance data was hard to collect, and observing all animals on the transect center line was deemed unrealistic. For moose, pessimism based on distance measurement difficulties may not be warranted. Thompson (1979) demonstrated this to be practical even under difficult mapping conditions. Analysis procedures are available for data grouped by distance classes (Burnham *et al.* 1980), but it is highly recommended to collect exact distance measurements for curve fitting. Continuous data can be analyzed using a wide range of distance class settings to determine if it was robust for data recording (rounding) errors.

One should not expect aerial survey line transect methods to eliminate visibility bias which depends on the percentage of animals missed on the center line (Anderson and Pospahala 1970). There will be animals on the center line which must simply be considered unavailable for sighting due to cover conditions (Marsh and Sinclair 1989), and others which will be missed because aircraft characteristics limit observer efficiency (Thompson 1979). However, a basic truth should remain intact; observers will miss more animals far from the center line than close to it. Line transect takes advantage of the distance information inherent in a set of observations to yield a more accurate estimate than possible without distance data.

If visibility bias is not going to be eliminated, the management question becomes one of cost–benefit. For example, if line transect estimates are as accurate as other estimators, are they less costly? In theory, line transect surveys should be less expensive to conduct than plot surveys (Gasaway and DuBois 1987). Alternately, is line transect survey significantly more accurate than other estimators, with equal or justifiably greater costs?

STUDY AREA

The 722 km^2 study area was 250 km west of Thunder Bay, Ontario (Fig. 1). Rowe (1972) described it as the Quetico (L.11) region of the Great Lakes St. Lawrence Forest Region. More recently an ecoclimatic description (Ecoregions Working Group 1989) placed the area at the boundary of the Moist Low Boreal (LBx) and the Subhumid Transitional Low Boreal (LBst) regions. The area was primarily well drained boreal forest dominated by upland jack pine (*Pinus banksiana*) associations with trembling aspen (*Populus tremuloides*). Lowlands, of restricted extent, were characterized by stands of stagnant black spruce (*Picea mariana*). The area had moderate slopes rising to hilltops of 75 meters elevation from lake levels. The study area is on Precambrian Shield bedrock. Soils were shallow on hilltops with frequent bedrock outcrop. There were numerous lakes and ponds.

A third of the area surveyed had been clear cut logged to remove 50% of the production forest (Fig. 1). Clear cut size averaged 100 hectares, and leave blocks of timber were approximately equal in size.

METHODS

The characteristics of this data set differs from Thompson's (1979) in two main respects. Observations were not truncated at 250 meters from the transect center line; this was done to remove assumptions about the tails of fitted distributions, and to provide a comparison of survey efficiency. Secondly, the survey attempted to reduce center line visibility bias by surveying with a helicopter instead of fixed–wing aircraft; the goal being to meet an assumption that all animals on the transect center line are seen.

The line transect survey was designed to obtain 70 – 120 cluster observations within the 722 km^2 study area. Based on past density and group size estimates (files), transect lines were spaced at 1 km intervals. Transects were flown north–south so that both observers would be shaded from the sun.

The survey was conducted January 25 – 27 and February 1, 1988 after fresh snowfalls on January 24th, and 31st. The sky was generally clear during the survey, with less than 20% of transect distance conducted in medium overcast conditions. The survey was flown at 90–95 km/h (50 knots) at 62 – 91 m AGL (200 – 300 feet AGL) from a Bell 206 Jet Long Ranger with wedged (approx. 10 cm) rear windows. The pilot, with > 50 hours in the 1987–88 survey season, participated in detecting moose and their tracks. The navigator/observer (left front seat) and one observer (right rear seat) had current experience also. One observer (left rear seat) was inexperienced. On day 4 of the survey the right rear seat observer was not available. The left rear observer switched to right and was replaced by an experienced, but not current, observer.

Observations were recorded on Forest Resource Inventory (FRI) maps (1:15,840 – 1982 photography) prepared in continuous strips folded accordion style. Lakes, rocks, swamps, clear cuts, and flight lines were highlighted. The 1985 FRI was updated to pre–survey conditions. Federal 1:50,000 topo-

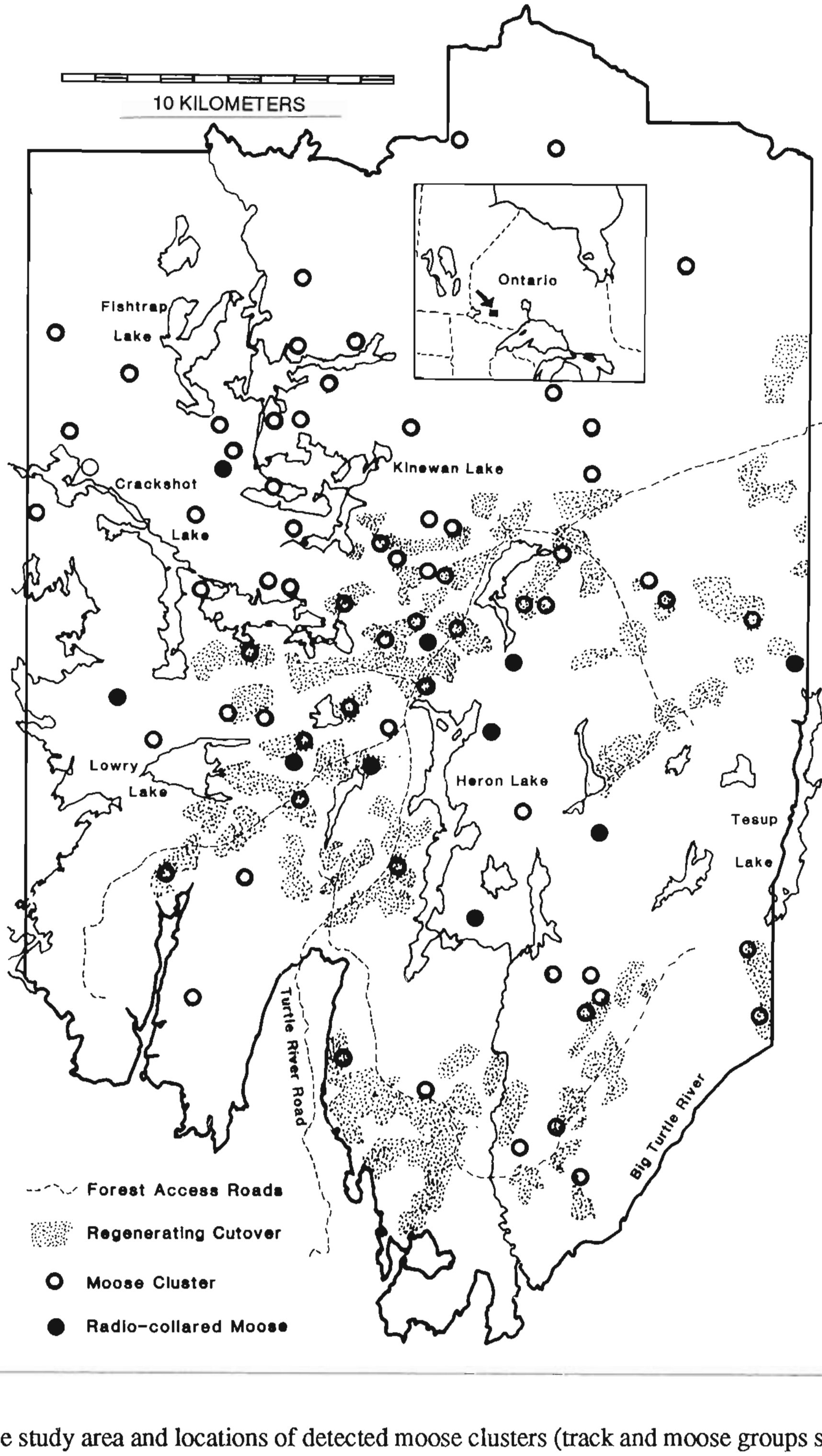

Fig. 1. The study area and locations of detected moose clusters (track and moose groups seen), radio-collared moose, and clear cuts. Line transects were flown north-south at 1 km intervals.

graphic series maps with highlighted flight lines were used by the pilot and navigator.

When moose were detected while 'on line' the location was recorded on the FRI map. The transect was then disengaged ('off line')(Cook and Martin 1974) and the moose seen were aged and sexed (Mitchell 1970, Oswald 1982). The track group was searched for other moose to include in the cluster. When fresh tracks were seen but no moose were detected immediately, the helicopter remained 'on line' until the track group was passed. The helicopter then went 'off line' to search for the moose. If undisturbed moose were found, the location was mapped. Otherwise, a location for the cluster was determined by back–tracking to the most probable undisturbed location. If moose could not be seen, and the tracks were fresh and without outward trekking tracks, then all the fresh tracks seen were mapped. The cluster location was defined as the geometric center of the mapped tracks polygon (i.e. location was weighted by area).

Perpendicular distances were measured from the mapped moose 'locations' (moose seen, backtracked, or geometric center) to the nearest 16 meters, based on a 1 mm FRI map resolution(1:15,840). The attempt to map positions exactly avoided setting arbitrary distance classes pre–survey with consequent boundary decisions. As such, all analysis was based on ungrouped data. This allowed goodness of fit testing of various distance class histogram plots against the calculated Fourier series, a strong point of the analysis. It does not imply a level of accuracy in mapping, something which was not tested. The 1mm FRI resolution allows only 6.25 possible discrete distances per 100 meters to do goodness of fit analysis with. It is probably close to the minimum number of divisions acceptable in a raw data set with the majority of animals within 500 meters of the transect. A map measurement of 1 versus 3 mm from a distance class boundary has value in that it expresses the relative confidence that a cluster lies within or beyond that point.

The ungrouped line transect data were analyzed with Program TRANSECT (Version 2.1, 7/15/87, G. C. White, Dept. of Fishery and Wildlife Biology, Colorado State University, Fort Collins, CO 80523).

Ten radio–collared moose were used to check the assumption that track groups contained animals. At the end of each day, the collared moose in the days survey area were located. The composition of the radio–collared moose was 5 adult males, and 5 adult females (two with twins, two with singles, and one without a calf).

RESULTS

Moose were seen in 48 of the 67 clusters recorded (Fig. 1) on 704 km of transect. Composition of the 86 moose observed was 6 unknown adults:74 bulls:100 cows:66 calves.

There were no significant differences in the mean distances which clusters of cow and calf (217 m), single cow (336 m), single males or groups of moose (347 m), and tracks only (223 m) were observed from the center line. This is largely due to small samples and wide variances. Wide variance is expected since, in the unbiased case, all classes of moose should show up at all distances from the transect center line. A Kolmogorov–Smirnov test would have been a better test for differences in sub–population distributions, since the detection functions are the major interest (reviewer comm. D.J. Reed).

In a comparison of distance from center line by group size, the classes were collapsed into single moose (including cow–calf groups), tracks only, and groups of moose. Grouped moose were recorded at significantly longer distances ($\bar{x}$= 328 m, n = 15) than track group clusters ($F < .05$, $\bar{x}$= 223 m, n = 19), or single moose ($F < .05$, $\bar{x}$= 248 m, n = 33). No clusters (except cow–calf groups) with group size greater than 1 were detected in the distance class adjacent the center line, and the distribution peaked in distance class 4.

Four observations were determined to be radio–collared moose. Two males were seen and sexed correctly. The other two moose were detected from track presence only: a male was alone and did not flush when relocated by telemetry; the other was a cow with twin calves in mature timber. Among the other 6 radio-collared moose, 5 were available in surveyed area while 1 male moved from unsurveyed to surveyed area between survey days.

Within the 5 radio–collared moose available but not detected by the survey, 4 had track groups which did not intercept the transect center line. The fifth moose track group could not be determined due to two other clusters in the immediate area. Among the 4 radio–collared moose detected from transects, 2 had tracks intercepting the center line, while 2 did not.

Four parametric models and the Fourier series non-parametric model were computed. Data failed a test for uniform distribution so the negative exponential function was excluded (Table 1). The exponential power series and exponential polynomial had high coefficients of variation and broad confidence intervals. The half–normal estimator performed almost as well as the Fourier series estimator.

The calculated Fourier series utilized one term (F(X) = 1/W + A(1)* COS(3.14159*X/W), where A(1) = 0.00109, X = perpendicular distance, W = transect width per Burnham *et al.* 1980). Moose cluster density was estimated to be 0.11 clusters/km^2±27.8% (95% confidence interval based on Poisson distribution assumption, coefficient of variation = 14.2%). Moose density was extrapolated from the mean group size of 1.79 moose/cluster to be 0.20 moose/km^2.

Default TRANSECT histograms were fitted to the Fourier series. However, none of these histograms fit the calculated series very well (154 m interval, P = 0.08; 97 m, P = 0.16; 78 m, P = 0.14). Heaped distance measurements (i.e. measurements whichtend to clump at certain values due to recording bias, Burnham *et al.* 1980:48) resulted in some problems at the selected boundaries. A set of user selected distance classes (7 classes, 107 m interval) generated the best fit to the Fourier series (P = 0.36) (Fig. 2).

There was no correlation (n = 28, r = 0.07, P > 0.75) between the perpendicular distances to track group center and animal location where both were known. In addition, a fixed effects one–way ANOVA revealed no effects (P > 0.50) between track group cluster distance from center line where no moose were

Table 1. Performance comparison of the Fourier series estimator with three Parametric estimators. Density is the density of clusters. P is the achieved significance level.

Estimator	Density	S.E.	% Coef. variation	95% C.I. (±%)	Total Chi^2_{df}	P	% Variation due to sample variance of N
Fourier series	0.1133	0.0161	14.2	27.8	6.567_6	0.3627	74.4
Esponential power series	0.1126	0.0225	20.0	39.3	7.197_5	0.2064	37.2
Exponential polynomial	0.1965	0.0505	25.7	50.3	15.92_5	0.0071	22.6
Half normal	0.14212	0.0181	15.0	29.4	6.007_6	0.4224	66.7

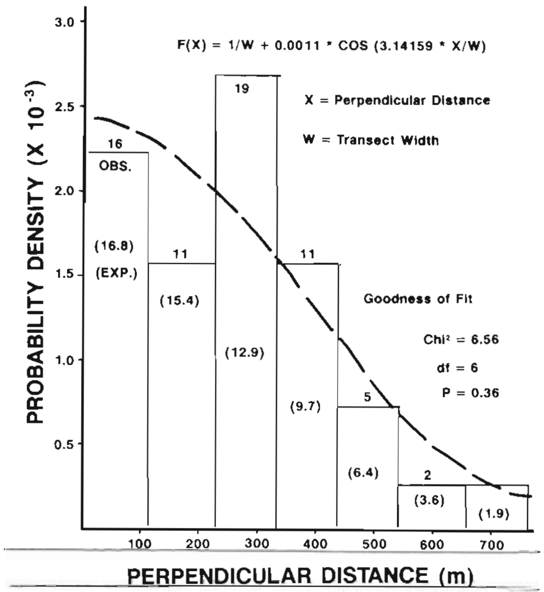

Fig. 2. The calculated Fourier Series estimator and the best-fit histogram of the observed perpendicular distances (N = 67).

seen (n = 18), and clusters where only the animals were noted (n = 19).

There were no detectable trends towards longer sighting distances where observations were in open canopy forests ($P > 0.50$), or when clusters were less than 0.5 km from cutovers ($P > 0.10$), or where forest openings aided detection ($P > 0.25$). With sufficient sample sizes and refined methods these factors should induce detectable increases in average sighting distance. Proportions of clusters which were tracks only, single moose (including cows with calves), and groups of moose were roughly equal in each of the breakdowns above ($P > 0.10$, $P > 0.50$, $P > 0.10$). The breakdowns were highly interdependent.

Clusters which were less than 0.5 km from the cutovers had a peak frequency in the 4th distance class from the center line. When these clusters were separated by group size (Fig. 3), single moose (including cows with calves) were observed closer to the center line, and no groups were observed in the two distance classes adjacent the center line; however, mean distances were not significantly

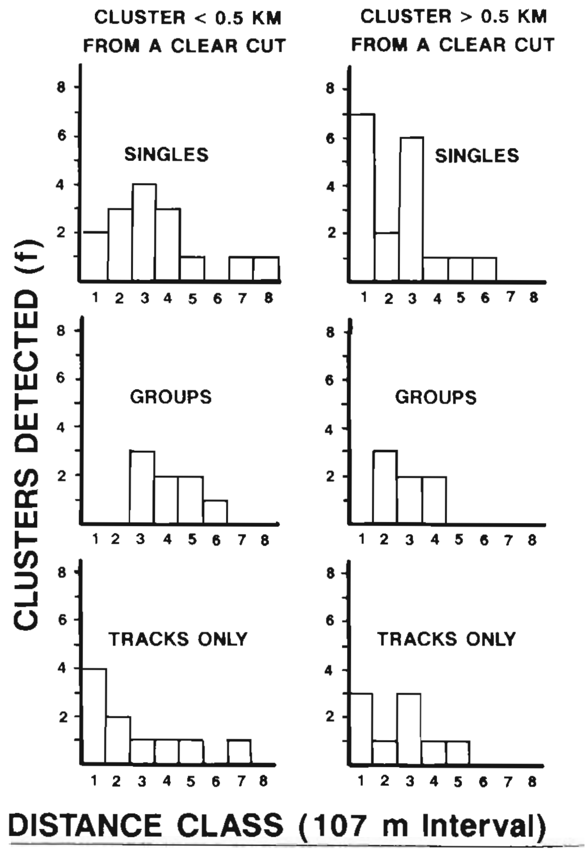

Fig. 3. Histograms of perpendicular distance to clusters, by distance from clear cuts and moose group size ('singles' includes cows with calves).

different ($P > 0.25$), this was probably due skewed frequency distributions and low sample sizes.

DISCUSSION

Four basic assumptions should hold when using line transects. The results will be discussed with respect to the assumptions, each in turn after Burnham *et al.* (1980:14).

1) Moose Clusters On The Center Line Are Not Missed.

The assumption that all clusters on the survey center line are detected may have been satisfied. Neither radio–collared moose or habitat variables examined provided any useful information to the contrary. The histogram plot of detection distances may be depressed close to the center line, but sampling variability or movement (see 2) could account for the frequency distribution.

Inspection of histograms showed some irregularities in the distribution of observations about the center line. A bimodal frequency distribution of distance observations, with peaks adjacent the center line and at 250 m, might be characteristic of the helicopter as a viewing platform. Physical configuration of the craft and duties of the crew could play a role. Pilot and navigator both have duties which keep their attention off the ground and on the forward horizon for a considerable proportion of the flight. Their contribution to observations probably meets the strict sense of line transect theory fairly well and likely accounted for many of the center line observations. Rear seat observer side scanning positions make it uncomfortable and largely impractical to look down. In open habitats there is probably a tendency to raise ones eyes to a more comfortable viewing angle, hence the peak at 250 m. Flying at very low altitude above ground would minimize the bimodal effect but be unsafe and make navigation next to impossible. Bubble windows would allow rear seat observers to see forward and downward more freely, allowing them to detect and 'follow' eye catching features under the flight path. A slow motion video camera looking downward could capture center line data for subsequent lab analysis. The video tape audio track(s) could monitor onboard communications to flag survey progress and observations (Marsh and Sinclair 1989). Forward looking infra-red scanners are available which are capable of downward scanning and linking to video equipment (FLIR Systems Inc. 16505 SW 72nd "Ave., Portland Oregon. 97224).

One reviewer (D.J. Reed) suggests censoring the strip underneath the aircraft such that the 'center line' is outboard the aircraft. This would cause some problems with boundary decisions and would not work where tracks are used to detect moose.

2) Clusters Are Fixed At The Initial Sighting Position.

Group size detection bias should be least near the center line and increase with distance (i.e. bivariate functions, Drummer and McDonald 1987). The significantly longer sighting distances for groups does not suggest group size bias in this case though. The data indicate a paucity of groups near the center line, which is not a consequence of group size bias. Pre–detection movement of groups, or recording bias, is suggested. On average, did singles or cows with calves not respond to the approaching helicopter as quickly as groups of moose? This seems to be the most reasonable explanation for groups to be absent from the near center line area. This bias depresses the cluster density estimate. Burnham *et al.* (1980) provide procedures for analysis of data where animals initiate movement before detection. My purpose was not to obtain a 'best estimate' so this avenue was not pursued. The best way to deal with movement bias is adoption of procedures which reduce its impact. Burnham *et al.* (1980) recommend higher speed on transect, and more forward area concentration by observers. Higher altitude would assist also. However, the trade–off generated is more center line visibility bias.

3) Distances Are Measured Exactly.

Heterogenous terrain was variable enough for navigation from topographic maps, and the up–to–date FRI maps seemed to be adequate for plotting animal locations.

The use of FRI maps rather than aerial photographs (Thompson 1979, Thompson *et al.* 1981) to plot animals has some advantages. Although the utility of air photos for accurate relative locations cannot be denied, most aerial photo mosaics are not controlled so absolute location of transect lines and distance measurements cannot be exact. FRI maps are controlled. Landmarks (lakes, classes of lowlands, cutovers) can be highlighted on

FRI. FRI maps have detailed stand descriptions which cannot always be extracted from the photos without stereoscopic interpretation. Forest managers update the FRI database constantly to include recent cutover boundaries.

Distance measurements were not exact. Plotting on FRI maps involves interpolation of location from identifiable features. However, this was not felt to have had a great impact on the analysis. If this technique were to be adopted, a program of validation in the context of local circumstances would be advisable. FRI maps have low capital cost compared to aerial photographs, but I have not done a comparison of total preparation cost. The arguments over preparation difficulties may soon be redundant. High resolution digital scanning techniques could make aerial photo map production cost effective. The use of multi–spectral digital scanners when flying aerial 'photography' presents even more exciting possibilities for remote sensing maps.

Two techniques have been introduced which could find utility in line transect survey. The first is a hand held range finder, and calculations which provide a distance estimate (Heinemann 1981). The device is used in line transects at sea, and may not be useful in an aircraft; however, some analog to judge the angle in conjunction with a radar altimeter, may serve the same purpose for quantification. Second, is the use of Loran–C (Boer *et al.* 1989), and/or the new global positioning system as navigation and location aids.

4) Observations are Independent Events

The detection function extended to 750 m. That is, past the half way point between the 1 km spaced transects. To avoid creative rationalizing of moose detected from adjacent flight lines (n=2 in this study), transects should be a minimum of 2 km apart.

When the helicopter leaves the line to search a track group there is an implicit assumption that the moose found comprise a single cluster (group). However, if two clusters are located during a search they are not independent.

For example, within the same track network a cow and her calves were found. Separated by 100 m, more or less, a bull was found. Cow–calf and bull were not normally associated in the study area (unpubl. telemetry studies). There is no way to determine which cluster should be included in the observation. Tracks which attracted our attention could have belonged to either, or both. Also, there is no way to determine if one, the other, or both would have been detected had the track networks been entirely separate, but with the same respective orientations to the center line.

The conservative strategy would be to reject the second 'cluster' encounterred. In management units with high moose density, or local areas of high density, the rejection of a series of observations which potentially should have been included will bias the estimator. My intuition suggests, that the 'extra' moose should be considered part of the cluster and their number be included in group size calculations. The magnitude of bias could be evaluated by simulation modelling of the importance of overlapping and indirect cluster detections. There was one recognizable observation with non–independent clusters. The distance used was the mean for the two 'clusters'.

Non-independence was encountered in two circumstances: between transect lines, and between groups of moose. The independence of observations assumption was not met in this survey. However, for practical purposes few individual observations were actually affected. Line spacing can be managed but overlapping clusters requires further evaluation.

Track Detected Clusters

The lack of correlation between perpendicular distances in observations with and without moose seen, suggests no bias was induced by including clusters where moose were not seen. If there were correlation it would indicate a data transformation is required before analysis. Without correlation, I view the tracks–only clusters as another population component. This component does have a detection function different from groups detected directly from the transect. Since visibility functions are additive this is not a hinderance to density estimation, except in the sense that Fourier series curves may not be suited when sightability is 100% for some distance from the center line (reviewer comm. D.J. Reed).

It may turn out that perpendicular distances to moose located in searches of track groups may not be real data. Once the transect line is left to search out moose, it may only be appropriate to use track group geometric center as the observation. My data were not handled this way since distance to moose was used if available. When I roughly re–analyzed the data using the track group data preferentially, the density estimate was higher and the function was a better fit.

Survey Efficiency

On the third survey day, three days post–snowfall, track groups were spread out and search time was becoming excessive. This was compounded because the snow depth on the ground was shallow in 1988, about 20 cm at the time of the survey.

Survey efficiency was increased by including all observations rather than truncating observations further than 250 m from the center line (Thompson 1979). In this survey 42 of 70 clusters were within 250 m of the transect center line; that is for each observation within 250 m there was 0.66 observations greater than 250 m. As such, 66% more line would have to be flown to obtain the same total observations.

Cost Effectiveness

Line transect survey cost effectiveness is expected to be better than plot surveys (Caughley 1977, Gasaway and DuBois 1987). Much depends on the cruising speed of the aircraft flown.

Plots in Ontario (2.5 km X 10 km) are generally searched with a minimum of 40–50 km flown per plot. When helicopter cruising speed is 90 km/hr (50 knots), time on plot is usually 45–60 minutes, total time including ferry often exceeds 70–80 minutes per plot. In small units the surveys usually call for 30–40 plots, on large units 50–60 plots. Total survey flying time ranges from 35–53 hours to 58–80 hours respectively.

Line transect survey is essentially area independent; large or small management units can be surveyed with the same cost, given they have the same moose density. That is, the number of observations required is the basis for survey planning. The total length of line flown is a function of moose density. Independence of observations and minimum numbers of observations does impose a minimum survey area consideration. Forty observations constitutes a minimum sample line transect survey. However, a more satisfactory sample is in the order of 70–130 observations. Given a desired n=100 observations, 2 km between transects, and the Fourier function from this study (0.11 clusters/km^2), this survey would require 1,050 km of transect (minimum survey area = 2100 km^2), and 30-35 hours helicopter flying time.

Search time for moose in track groups and for age–sex classification was included in both the transect and plot survey examples above. However, line transect has a fairly fixed input for search and classification regardless of population density since the number of observations required is stable. The variable input is the total distance needed to be flown to obtain the required observations. As moose density increases survey costs can decline in theory. In practice this effect would probably be used to increase sample sizes to some extent.

Survey Accuracy

Line transect density estimates should approach true density closer than plot methods, because more information is used. A year previously, plots surveyed by helicopter in the study area yielded an observed 0.15 moose/km^2 (files). A rough extrapolation, from 1.79 moose/cluster in the line transect survey, yields a density estimate of 0.20 moose/km^2. Of course, this comparison between surveys cannot demonstrate greater accuracy for line transect survey. However, the higher line transect estimate is encouraging.

A major effort is required to evaluate the accuracy of line transect survey and plot survey. A known population on an area functionally equivalent to a wildlife management unit is required. The potential benefit of accuracy validation is a payback in survey cost effectiveness.

Population Density Extrapolation

Use of mean group size to extrapolate the cluster density to population density is an invalid procedure, if clusters with different group size have different detection functions (Eberhardt 1978, Cook and Martin 1974, Samuel and Pollock 1981).

If, after experimentation, this turns out to be so, (Thompson 1979), either of two approaches could resolve this problem.

i) Sufficient transects could be flown such that >40 observations each of 'small' and 'large' groups are obtained (or >40 each of singles, cow–calf groups, other groups). The stratified data would be analyzed separately and the group size data from each applied separately. Total numbers would be the sum the two, or three, expansions.

ii) Less satisfactorily, a correction equation could be developed from independent radio–telemetry field trials: of detections by group size, and of moose versus group size response to approaching aircraft.

Group–size stratified data is intuitively satisfying because the correction would be self–contained within the survey, similar to visibility bias in line transects themselves. However, it might impose excess demands on sampling intensity. Telemetry based corrections are subject to criticisms about variable conditions between surveys which plague plot sampling. In the case of group size, differences between surveys may not be important. Telemetry validation of transect survey will be required in any case to validate the major assumptions.

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In my first season as a field assistant in 1977, Dr. A. Tom Bergerud set me the task of walking a 'King' census of the Slate Islands caribou. The spring survey ritual on the Slates is an abject lesson in the utility and rightness of the logic that line transects employ.

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