MOOSE MARK-RECAPTURE SURVEY IN NEWFOUNDLAND

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ABSTRACT: The mark-recapture survey (Lincoln-Petersen method) using a dye marking technique reduced many biases in aerial surveying and therefore increased accuracy in estimating moose density. The mark-recapture method eliminated visibility bias associated with aerial surveying, since the method depends only on the ratio of marked moose to the total numbers observed. The spray painting dye marking technique provided an easier method of marking large numbers of moose and created less disturbance to the animal as compared to capturing and immobilization for radio-collaring or tagging. Population estimate for the Northwest Gander-Gambo Management Unit in winter 1985 was 4421 ± 30%. The four major assumptions of mark-recapture survey were evaluated by testing (1) for differences in distance moved, mortality and sightability between marked and unmarked radio-collared moose and (2) differences in habitat used and proportions of age-sex classes between mark and recapture surveys. Time and costs of mark-recapture surveys are justified in areas with high moose density (>2 moose/km^2) or in areas where the majority of moose are found in open habitat.

Using data from five combined mark-recapture and block surveys, we calculated an adjusted sightability for block surveys which varied from 1.7 in open cover areas (4% forest) to 2.7 in closed cover areas (64% forest). A mean correction factor of 2.4 suggests that less than half of the moose are seen on block surveys.

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Management of large game cervids requires estimation of population size (McCullough and Hirth 1988) but generally inaccurate and imprecise survey information has resulted in unreliable estimates (Caughley 1974, Caughley and Goddart 1972, Otis *et al.* 1978, Gasaway *et al.* 1986). Aerial total count surveys have a visibility bias (Samuel and Pollock 1981) and often over 1/3 of the animals are missed (Caughley 1977). Random block or quadrat methods (Bartmann *et al.* 1986, Bergerud 1963), strip transect (Bergerud 1963, Heard 1985), and stratified random survey methods (Kufeld *et al.* 1980) tend to underestimate fairly consistently.

Aerial survey biases may occur as a result of observers (LeResche and Rausch 1974, Samuel *et al.* 1987, Fong *et al.* 1985), technical problems (Heard 1985, Caughley 1974, 1976, Shupe and Beasom 1987, Siniff and Skoog 1964), or more commonly sightability factors (Samuel *et al* 1987). McCullough and Hirth (1980) considered visibility the most important factor affecting population estimates. Visibility is affected by weather and lighting conditions (Gasaway *et al.* 1985, Kufeld *et al.* 1980, LeResche and Rausch 1974, Bergerud 1963), season (winter versus summer; McCullough and Hirth 1988), vegetation cover (Gasaway *et al.* 1985), heterogeneity of terrain (Siniff and Skoog 1964, Beasom 1979, Caughley *et al.* 1976, Beasom *et al.* 1986) and distribution patterns of cervids (Samuel *et al* 1987, Siniff and Skoog 1964, Bergerud 1963).

Mark-recapture survey techniques minimize visibility bias provided researchers meet the assumptions. This survey method has been used for mule deer (Odocoileus hemionus) (Bartmann *et al.* 1987, Kufeld *et al.* 1986), white-tailed deer (*Odocoileus virginianus*) (Rice and Harder 1977, McCullough and Hirth 1988) and caribou (*Rangifer tarandus*) (Gauthier and Theberge 1984, Fong *et al* 1990). However, small sample sizes and violation of the assumptions of equal catchability and observability of marked and unmarked animals have led to mixed results.

The major limitation of the Lincoln-Petersen method occurs because of problems in meeting the underlying assumptions. The criteria for application of the method requires that the population remain closed or constant, with no recruitment (births or immigration) or losses (mortality or emigration), that no animals lose marks during the course of the study, that field researchers have an equal probability of sighting and counting each individual animal (Caughley 1976), and that aerial samples are independent (Rice and Harder 1977). In this report, we address the assumptions of the Lincoln-Petersen method and discuss accuracy of the population estimates.

In this study, an operational management survey using mark-recapture techniques (Lincoln 1930) was assessed for moose (Alces alces) in Northwest Gander-Gambo, Newfoundland (Management Unit 24; Fig. 1) during January-March 1985. The survey was designed to test mark-recapture assumptions in an operational setting, and to assess the efficacy of this method relative to other aerial survey methods. Also, we used information collected on mark-recapture moose surveys to estimate a sightability correction factor for the quadrat or block sampling method.

METHODS

We wanted the estimated moose population of Management Unit 24 to have an associated error of ± 25%. We assumed a population of 3000 moose based on a 1983 population size of 3172 ± 23% estimated using quadrat sampling methodology (data on file). Therefore, we selected an option to mark 200 and recapture (resight) 750 moose according to tables provided by Rice and Harder (1977). We calculated effort and cost to mark this number of animals based on previous block surveys and we assumed that we could mark half of the total moose spotted.

The marking team conducted a preliminary aerial search, flying systematic 1000 m wide N-S transects of Management Unit 24. Moose encountered along the flight paths were marked with pink alkaline paint ejected from a pressurized nozzle held to the side and below a Bell 206L helicopter (procedure detailed by Mercer *et al.* 1990). A moose was considered marked only if paint was successfully applied to the midline of the back since observers had problems identifying marks on the side of moose during resighting. Personnel tried to mark every moose they could within the transect while maintaining an average of 60 kph thereby spreading marks over the length of the transect and throughout the study area. We estimated 475 km transect distance (475 km^2 area) to mark 200 moose. Also, 64 radio-collared moose in the study area were monitored during the study to increase sample size of marked animals and determine mortality and possible emigration.

Initial plans were to repeat the transect procedure for the recapture phase. However, as marking proceeded, we observed that most marking occurred in open canopy habitat and in a highly clumped pattern. For some portions of the study area, although field crews readily spotted moose, the dense canopy made it impossible to apply marks to animals.

For the recapture phase, we used a stratified random sampling design (Gasaway *et al.* 1986) because of the non-random distribution of marked moose (Fig. 1). We decided on the number of blocks (approximately 25 km^2) sampled within subareas according to perceived moose density, sighting efficiency from the marking phase, and required number of animals sighted derived for appropriate confidence intervals of the Lincoln-Petersen estimate. To obtain a useful estimate for the population, we needed to apply a disproportionate searching effort in closed canopy habitat. Areas of closed and open canopy habitat were identified through LANDSAT imagery for each block and we assigned a total flying time based on respective search intensity for each canopy type.

Aerial survey crews consisted of 2 observers and a navigator who also recorded

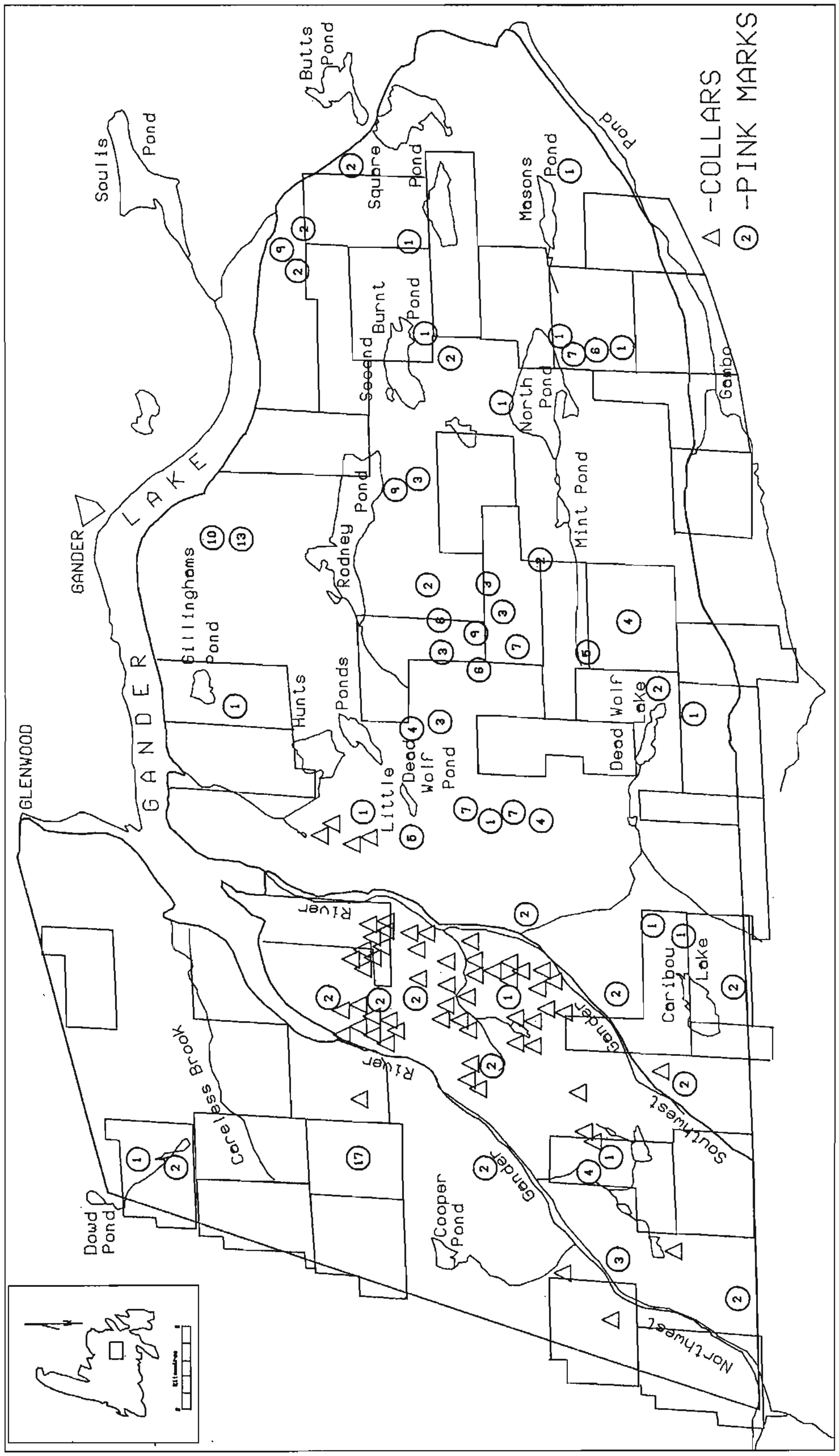

Fig. 1. Moose mark-recapture survey study area for Northwest Gander-Gambo Moose Management Unit in Newfoundland and location of radio-collared moose, paint marked moose and blocks for recapture survey.

information. Only those moose which presented a clear view of their backs were counted. We instructed all crews to ensure that the same moose was not counted twice.

The Lincoln-Petersen estimate of the population was calculated as:

N=[(M+1)(C+1)/(R+1)]-1, where N = Population size; M = Number of marked moose, R = Number of recaptured marked moose; and C = Number of moose seen during recapture survey (contains R) from Seber (1982:60).

Upper and lower limits of the population estimate were calculated from a Poisson distribution using R as the entering variable and 95% as the confidence coefficient (Ricker 1975).

RESULTS

During 11-24 January 1985, 241 moose (214 pink, 24 white and 3 radio-collared moose painted pink) of 353 moose seen were marked. Also, within the study area were 64 radio-collared moose (24 painted white, 3 pink and 8 yellow) with coloured neck and ear tags. A total of 33.2 hours of helicopter time was used to mark 241 moose providing a marking rate of 7.3 animals per hour. During the recapture phase, 26 February - 6 March, 616 moose were sighted, 46 of which were marked (29 pink and 17 radio-collared). Forty blocks (mean size = 25.6 km^2) were surveyed during recapture with a mean searching time of 45 minutes/block. A mean population estimate of 4421$\pm$30% was obtained by using only the pink marked moose (n=214).

TEST OF ASSUMPTIONS

The first major assumption of the simple Lincoln-Petersen mark-recapture technique (one marking, and one recapture period) is that the population studied is closed to additions (births or immigrants) and deletions (deaths or emigrants). If additions occurr, then they are always unmarked, and therefore population size estimated during recapture is still valid. If deletions occur randomly with respect to marked and unmarked animals, then the Lincoln-Petersen estimator is again valid.

The second major assumption is that marks are not lost or overlooked by the observers. If animals lose their tags then the estimated population size will be too large.

Sixty-four radio-collared marked moose were present for testing these two assumptions by checking movement and mortality of marked versus unmarked moose, as well as problems related to visibility of marks. All marked radio-collared moose stayed within the study area and no deterioration of marks or mortality was observed during the 7 weeks of study. Twenty-four radio-collared moose were marked white, 8 yellow, 3 pink and the remaining 29 were not marked. White marks were not considered adequate for reliable identification due to snow which occasionally brushed onto the backs of the animals. Observers identified the yellow and pink marks on radio-collared moose on all occasions and yellow and pink marks remained visible over the duration of the study. Therefore, we used only pink marked moose (n=214) to estimate population size.

The third major assumption is of "equal catchability" of animals, and this assumption is unlikely to be true in many wild populations (Pollock *et al.* 1990). Variation in capture probability is a property of the animals and may vary due to many factors such as age, sex, social status or location in relation to capture habitat. If animals are more likely captured in the first sample than recaptured in the second, then the population estimate will be too small. But if capture probabilities are heterogeneous in each sample but independent from sample to sample, then no bias results (Pollock *et al.* 1990).

The greatest potential problem concerning mark-recapture assumptions occurred with the randomness of marking and recapture. Comparing age-sex proportions of moose classified between mark and recapture surveys allowed us to test the assumption of randomness. During the marking survey 49% of the adult moose classified (n=446) were males compared to 42% males (n=293) in the recapture survey. Also, 47 calves/100 females (n=109 calves) and 41 calves/100 females (n=71 calves) were classified during marking and relocation surveys respectively. These differences in age-sex proportions do not indicate a substantially different surveyed moose population.

Although moose in closed canopy forest were less available for marking or recapture, we reasoned that the distribution of animals in respect to open, or closed canopy habitats was basically a random process among individuals. We assumed that marked animals represented a random sample of moose located in more open habitat and that no distinguishing habitat preferences among age and sex groups occurred. All moose in open habitat had an equal chance of being marked since we chose a random sampling design, and mixing of moose between open and closed habitat occurred before the resurvey. The heterogeneous vegetation cover of Management Unit 24 allowed for an interspersion of open and closed habitat types (conifer, cutover, deciduous and mixed). Sampling problems would not occur during the recapture phase, as long as random mixing of moose among habitats occurred between the time of capture and recapture surveys.

To test these assumptions, we compared habitat selected by radio-collared moose. No significant change in the proportion of radio-collared moose seen by field crews in open and closed habitat occurred, with 45% (n=80) and 50% (n=28) of moose observed choosing open habitat during the marking and recapture surveys respectively. Of moose telemetry locations where field crews described the habitat during both marking and recapture surveys, we found no significant pattern of habitat preference (G-test: G=0.59, p=0.44, df=3). Nine moose originally found in closed habitat during the marking period (11-14 January) were later found in open habitat during the recapture period (7 February); seven moose had moved from open to closed habitat; seven were again found in closed habitat and another five were again found in open habitat.

Marks and/or radio-collars did not predispose moose to be seen relative to unmarked or uncollared moose. There were no measurable differences between distances travelled by marked (2.7 km) and unmarked (2.8 km) moose (Mann-Whitney U test: U=423, df=17,30, p=0.76).

Another problem with randomness concerns areas of low moose density in either open or closed habitats. Flying costs place impractical demands on marking and recapturing in these low moose density areas. Researchers often use stratification, based solely on moose density, to distribute effort in block surveys but this procedure does not address the bias in ability to mark or spot moose relative to habitat type. Therefore mark-recapture surveys in low moose density areas can potentially result in problems with meeting the assumption of randomness if a mixture of open and closed habitat occurs.

Visibility biases occur when sightability or catchability of marked moose differs relative to the total population. Visibility factors affecting the total numbers (marked and unmarked) counted include weather conditions, vegetation cover, and technical aspects. The mark-recapture method reduces inaccuracies due to visibility biases as the technique is not dependent on the total number counted, but rather, on equal sightability of the ratio of marked and unmarked moose. Approximately 7.6% of the moose were marked and marks were equally distributed throughout the study area. Survey personnel sighted moose before discerning whether they were marked or not, thereby ensuring no bias from increased visibility due to marks. Also, we assumed similar habitat preferences of marked and unmarked moose.

Observations of radio-collared moose in the study area confirmed that moose moved often during the winter period and particularly between open and closed habitat types.

DISCUSSION

The mark-recapture survey of Moose Management 24 (Northwest Gander-Gambo) estimated 4421 ± 30% moose. The higher than expected confidence limits resulted from our initial expectation of a total population of only 3000 moose. To obtain our desired ±25% error limit we should have marked close to 300 moose and examined 1000 moose for marks according to Robson and Regier (1964).

We tested the three major assumptions of the mark-recapture survey method by comparing characteristics of marked and unmarked radio-collared moose and by comparing characteristics of the moose observed on mark and recapture surveys. Marked and unmarked radio-collared moose moved similar distances, showed no deterioration of marks, no mortality, and similar sightability. Classification results from marking and recapture surveys showed similar proportions of calves:females and males:females. Although moose in open habitat types were more likely to be captured, we found no major differences in the habitat moose were located on the marking and recapture surveys. Also, radio-collared moose showed a pattern of mixing relative to their use of open and closed habitat types between surveys.

Mark-recapture surveys of cervids have provided a wide range of error estimation but most studies of forest dwelling species reported errors in the range of the 30% estimated in this study. McCullough and Hirth (1988) reported errors using the Lincoln-Petersen method for deer ranging from -30 to +138% with more overestimation of the population than underestimation. Gauthier and Theberge (1985) studying caribou reported an error of 49%. Ferguson *et al.* (1988) reported errors of 24-35% for three consecutive annual estimations for caribou living in forested habitat during summer. Rice and Harder (1977) reported an error of 4% for caribou which was the same as the error reported for a caribou survey in Newfoundland (Fong *et al.* 1990). The higher caribou densities during winter surveys and the more open habitat make caribou a suitable species for mark-recapture survey.

Mark-recapture studies, beside estimating moose density, can also test the block survey method for sightability bias. Using data from four other moose mark-recapture surveys calculated an overall correction factor of 2.4 (Table 1). The Newfoundland and Labrador Wildlife Division generally uses a correction factor of 2 to adjust total moose estimated from block surveys to account for moose not seen. The relationship between the correction factor and the amount of forest cover (log(forest)=-1.56+1.91.(factor); Prob.=0.01; df=4; $r2$=0.92) suggests a correction for sightability bias of 1.7 for open cover (5% forest) and 3.2 for greater than 90% forest cover.

The Newfoundland and Labrador Wildlife Division commonly uses the mark-recapture survey technique for caribou (Fong *et al.* 1990) but few mark (paint)-recapture surveys have been used to estimate moose numbers (Table 1). This technique was used for moose surveys primarily to determine sightability bias for block surveys. Mark-recapture surveys are generally more expensive than block surveys and costs are substantially more in areas with mostly closed habitat or areas with low moose density. We therefore suggest using moose mark-recapture surveys only in areas with higher than average moose densities, perhaps greater than 2 moose/km^2 or in areas with more open than closed habitat.

The painting technique provided an easy method of marking large numbers of moose while causing minimal disturbance to the animals relative to radio-collaring. The disad-

Table 1. Summary of mark-recapture (M-R) and block surveys for five Moose Management Units (MMU) in Newfoundland, 1983-1989.

MMU	Dates flown dd/mm/yy	% Forest cover	M-R survey Area (km^2)	M-R survey Moose Den.	Block survey[a] Area (km^2)	Block survey[a] Coverage	Block survey[a] Moose den.	Block survey[a] Effort (min./km^2)	Sightability correction factor
37[b]	1-10/03/83	4	656	0.5	656	100%	0.3	3.0	1.67
24	15/01-6/03/85	64	2357	1.9	1024	43%	0.6	1.7	3.12
36	11-14/02/86	13	900	2.6	132	15%	1.2	1.9	2.17
33	20-21/01/87	41	232	2.8	116	50%	1.1[c]	3.7	2.49
40	23-25/01/89	29	192	4.1	192	10%	1.6	-	2.60
Mean				2.4			1.0	2.6	2.41

[a] Methods after Bergerud and Manuel (1969).

[b] Survey conducted by helicopter and fixed-wing.

c Moose density of 1.6 moose.km^{-2} normalized to mean search effort of 2.6 min..km^{-2} (1.6/3.7.2.6=1.1; Mercer *et al.* 1988).

vantages of this technique included negative public perception of the cosmetic markings which are left on the animal until moulting, and harassment of animals during the marking procedure.

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