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DETECTION OF MOOSE IN MIDWINTER FROM FIXED-WING AIRCRAFT OVER DENSE FOREST COVER

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Despite some well-documented shortcomings, aerial census in winter has persisted as the only common technique used to estimate moose (*Alces alces*) density and other population parameters (Gasaway and DuBois 1987). During the past 25 years wildlife managers and researchers have gradually abandoned attempts at total area census in favor of a sampling approach, employing aerial coverage of transects or intensive search over plots of varying size, or some combination thereof (Timmermann 1974, Rivest et al. 1990). There also has been considerable progress in developing techniques to assess visibility bias, or detection rate, in aerial censuses of moose and other large ungulates in winter (Crête et al. 1986, Gasaway et al. 1986:31–34, Samuel et al. 1987).

In practice, moose detection rate (proportion of moose seen) is most commonly estimated through a recount, in which census plots or transects are covered a second time more intensively, either by incorporating a more efficient aircraft (helicopter rather than fixed-wing), or by increasing search intensity. These approaches have been evaluated using radio-collared moose in trial counts (Crête et al. 1986, Gasaway et al. 1986:31–34).

The most thorough tests of moose detection in aerial surveys have been conducted in interior Alaska, where intensive searches using overlapping circles by fixed-wing aircraft achieved a detection rate of 94–100%, except in spruce- (*Picea* spp.) dominated habitats,

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where 86% of the moose were observed (Gasaway et al. 1981). Tree cover in moose habitat in the boreal forest of eastern North America is dense compared to much of Alaska (Tuhkanen 1984), which may further reduce detection in moose censuses.

Considerable variation exists in estimates of moose detection rates from eastern North America, arising in part from use of different aircraft and flight patterns. Previous studies have demonstrated that counts from helicopters usually are superior to those from fixed-wing aircraft, and that intensive searches with a circling flight pattern provide a higher detection rate than transect flights. For example, during level transect flights in a Piper PA-18 Supercub, Thompson (1979) estimated (using a right-angled frequency distribution of sightings) that 57% of the moose were detected in northern Ontario. In the same region, Novak and Gardner (1975) found that transect counts using larger fixed-wing aircraft (Cessna 180 or De Havilland Turbo-Beaver) were 94% of helicopter counts over the same areas. Employing a similar approach in southern Quebec over plots containing radiocollared moose, Crête et al. (1986) found that 88% of the moose occupied track networks visible in level transect flights by fixed-wing aircraft (De Havilland Beaver), whereas 83% of moose within track networks were observed during helicopter searches. Thus, helicopter counts of track networks located by fixed-wing aircraft would yield a maximum detection rate of 73%.

Moose habitat selection also influences detection during aerial surveys. Moose characteristically exhibit a shift from deciduous to mixed and coniferous habitats in winter, coinciding with an increase in snow depth and hardness (Coady 1974, Peek et al. 1976). Lynch (1975) suggested that high detection during moose surveys in mixed boreal forests is likely achievable only in early winter, before moose move into coniferous cover. Crête et al. (1986) found that counts in March were only about half those in January, and in both periods there was great daily variability in moose detection rate.

We evaluated moose detection during intensive searches from small, highly maneuverable fixed-wing aircraft (Piper PA-18) in an eastern boreal forest in Isle Royale National Park, Michigan. Also, we evaluated the effects of moose habitat selection and time of survey on the efficiency of transect and intensive search counts of moose.

STUDY AREA

Moose density in Isle Royale National Park approaches the highest level attained by this species in the wild, often >500% higher than comparable habitats on the mainland (Peterson 1977:122, Crête 1987). The largest island (544 km^2) in Lake Superior, Isle Royale is dominated by common elements of the boreal forest, especially white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), quaking aspen (*Populus tremuloides*), and paper birch (*Betula papyrifera*). Large areas burned in 1936 and 1948 provided little suitable winter habitat for moose after the 1960's (Peterson 1977:136). During our study, moose used mixed stands of old forests in midwinter, especially those containing balsam fir and northern white cedar (*Thuja occidentalis*).

Techniques used to census moose from aircraft on Isle Royale have steadily evolved, beginning with the pioneering transect counts of Krefting (1951), flown in a Waco biplane in 1947. Moose censuses in winter are limited to a period in midwinter (approx mid-Jan to early Mar) when there is reliable ice for landing ski-equipped aircraft.

Snow depths average near 50 cm in open areas in midwinter (range = 30–100 cm, Peterson and Allen 1974). During the winter study period, both snow depth and snow hardness typically increase and usually there are periods of thaw that produce surface crusting conditions by late February (Peterson 1977:189–191).

METHODS

Three sources of data derived from aerial observations were used to determine moose detection rate and its dependence on moose habitat selection: (1) trial counts employing intensive aerial searches for radiocollared moose, flown under typical census conditions, 1985–1987; (2) moose observations using intensive aerial searches for radiocollared moose conducted for other studies, 1985–1987; and (3) moose observations recorded from aircraft during noncensus transect flights, primarily used to locate wolf tracks, 1972–1990. Data were gathered annually from mid-January to 1 March and were subdivided for data analysis into 3 periods of 2 weeks to evaluate aspects of survey timing. Snow depth was measured daily in an open area throughout each study period.

We used a Piper PA-18 150 aircraft that accommodated the pilot and 1 observer, seated behind the pilot. All detection trials for radiocollared moose were flown using an experienced pilot and observer working together to spot moose. The radiocollars were visually unobtrusive, yet could be readily detected once a moose was spotted. We observed 15–20 radiocollared moose during the study, including both males and females, with and without calves. Eight females and 6 males provided data during all 3 years of the study.

If only 1 person was observing, 1-km^2 plots were established on a 1:62,500 topographical map around radiocollared moose the day before the trial, allowing time for the moose to change location or even leave the plot. If an alternate observer was available, this person delineated a plot around the moose on the day of the trial after determining its approximate location from an aircraft while the pilot refrained from observations. In the latter case dummy plots also were established that did not include a radiocollared moose, so that the pilot and observer did not know if a radiocollared moose (the target moose) was actually present on the plot during the trial. Only 1 trial count/day was flown over an individual moose.

Moose density during our study averaged 2.0–2.6 moose/km^2 on the entire island and 4.1 moose/km^2 on trial plots (R. O. Peterson, unpubl. data). Trial plot size (1 km^2) and mean search intensity (14 min/km^2) were similar to those used annually at Isle Royale during aerial counts. Flight pattern was a series of overlapping circles at an altitude of 100–150 m, with added circling over each observed moose to look for additional animals. Plots were counted only when winds were <10 knots, snowcover complete, and when there was low contrast on the snow surface. We censused moose within 3 hours of sunrise (long, uniform shadows) or under an overcast sky (few or no shadows). When the plot count was completed, the location of both detected and undetected radiocollared moose in relation to plot boundaries was determined. Overstory forest canopy at the moose location was visually classified as coniferous, mixed, deciduous, or other type. In "mixed" forests the overstory canopy was approximately 10–50% coniferous, whereas in "coniferous" forests canopy coverage by conifers was usually $>50\%$.

Radiocollared moose also were located regularly during aerial searches in other studies. Usually, ≤ 4 minutes were expended circling over the moose radiolocation in an effort to see the animal, in a flight pattern very similar to that used in aerial censuses. Overstory habitat for each moose's location was classified the same as in trial counts. The relative success in observing radiocollared moose was used only to indicate potential visibility bias during a census.

For both trial counts and regular searches for radiocollared moose, chi-square tests and tests for differences between proportions after arcsine transformation (Sokal and Rohlf 1969:607–608) were used to compare detection rates among years, habitats, and sampling periods. For some comparisons we determined confidence intervals for proportions derived for the binomial distribution (Daniel 1990:61–62). Analysis of variance (ANOVA) and Student's t-tests were used to evaluate seasonal change in moose habitat selection.

During noncensus transect flights all moose observed were recorded. The daily number of moose observed/hour of flight was calculated, and used to evaluate seasonal changes in moose detection rates for level transect flights. These data were normalized by log-transformation, and analyzed by ANOVA and Student-Newman-Keuls test (Sokal and Rohlf 1969:239–246) for within- and between-year differences ($P < 0.05$). Regression equations were estimated for the trend in moose observation frequencies associated with the midwinter shift toward mixed and coniferous cover.

Finally, moose observed both on and off census plots were used to evaluate moose activity (bedded vs. standing) throughout the day, as standing and moving animals are more likely to be detected than bedded animals (Samuel et al. 1987).

RESULTS

The target radiocollared moose was actually on the test plot in 80 of 120 trial counts. An alternate observer established the plot boundaries in 14% of the trials. Combining all results, collared moose were detected in 64 trials (80%) (Table 1). Significant variability was not evident when results were compared across sample periods ($\chi^2 = 1.45$, 2 df, $P = 0.49$) or between years ($\chi^2 = 3.09$, 2 df, $P = 0.22$).

Observations of radiocollared moose, used as a surrogate for formal detection trials, provided larger samples with which to compare moose detection rates between seasons and years. Again, very little variation was evident (Table 1). Overall moose detection in this pooled data set (78%) was virtually the same as in the trial counts (80%).

Moose observation frequency in noncensus transect flights exhibited variation both annually ($F = 7.2$, 2 df, $P = 0.001$) and seasonally ($F = 28.2$, 2 df, $P = 0.001$), caused by high initial counts during late January in 2 of 3 years (Table 1). In 2 of 3 years, aerial observations of moose declined in late January, and then moose observation frequency consistently stabilized at a relatively low level throughout the remainder of the study period.

During plot trials, habitat selection by radio-

Table 1. Proportion of moose seen during intensive searches (aerial counts and radiolocation attempts) and moose observation frequency during level transect flights, Isle Royale National Park, Michigan, 1985–1987.

Year	Proportion seen,[a] trial counts (n)	Proportion seen,[a] other radiolocations (n) 15–30 Jan	31 Jan–14 Feb	15 Feb–1 Mar	Total	Moose/hour, level flight (SE) 15–30 Jan	31 Jan–14 Feb	15 Feb–1 Mar	Total
1985	0.94 (18)	0.71 (83)	0.83 (89)	0.87 (93)	0.81 (265)	23.1 (3.2)[b]	9.0 (2.0)	4.8 (0.9)	13.4 (2.0)
1986	0.75 (44)	0.78 (78)	0.81 (108)	0.74 (74)	0.78 (260)	9.3 (1.1)	6.1 (0.7)	3.4 (0.4)	6.2 (0.6)
1987	0.77 (18)	0.88 (24)	0.63 (51)	0.89 (19)	0.74 (94)	17.0 (5.3)[b]	5.1 (1.5)	6.1 (1.1)	7.5 (1.7)
Total	0.80 (80)	0.76 (185)	0.78 (248)	0.82 (186)	0.78 (619)	17.1 (2.1)	6.5 (0.8)	4.9 (0.6)	9.0 (0.9)

[a] Proportion of trials or locations in which the target radiocollared moose was observed.
[b] Mean values for periods compared both within and between years were different ($P < 0.05$) from each other and from other values (Student-Newman-Keuls test).

collared moose did not clearly influence effectiveness of intensive aerial searches in deciduous, mixed, and coniferous habitats ($\chi^2 = 2.98$, 2 df, $P = 0.30$), although a difference between the proportion seen in deciduous habitats (100%) and those seen in either mixed or coniferous cover (77%) was likely ($t_s = 2.97$, $P = 0.005$) (Table 2). For the larger sample of intensive searches for radiocollared moose, the extent of coniferous cover clearly influenced the proportion seen, ranging from 70 ± 5% (95% CI) in coniferous habitats to 100% in deciduous habitats ($\chi^2 = 27.5$, 2 df, $P = 0.0001$). In mixed stands, collared moose were observed 89 ± 4% (95% CI) of the time (Table 2).

In late January, most radiocollared moose (78%) inhabited coniferous or mixed habitats, where visibility was impeded, and relatively few moose (14%) were found in deciduous cover (Table 2). In February, the proportion of moose in deciduous habitats declined further ($F = 3.03$; 2,13 df; $P = 0.09$), while those in mixed forests increased ($F = 3.27$; 2,13 df; $P = 0.08$).

Deep snow seemed to increase movement of moose to mixed and coniferous cover, where detection was lowest. In January, moose observations during level flights were less frequent in 1986, when snow depth was 67–84 cm, than in 1985 or 1987, when snow depth was only 38–51 and 36–43 cm, respectively (Fig. 1).

In midwinter, most moose on Isle Royale were solitary and group size did not influence detection rate during intensive searches. During observations of radiocollared moose, 61% ($n = 639$) were solitary, and almost all groups were females with offspring. Detection rate was 81% and 80% for females with ($n = 185$) and without ($n = 132$) offspring, respectively.

Moose were most likely to be standing shortly after sunrise at approximately 0800 hours (Fig. 2). Beyond 2 hours after sunrise, moose increasingly were bedded, and activity reached

Table 2. Moose detection rate during aerial surveys and habitat selection in midwinter in Isle Royale National Park, 1985–1987.

Habitat	Proportion seen, intensive search (n) Plot trials[b]	Other observations[c]	Mean proportion in major habitat types (SE)[a] 15–30 Jan	31 Jan–14 Feb	15 Feb–1 Mar
Coniferous	0.75 (32)	0.70 (277)	0.44 (0.06)	0.48 (0.04)	0.46 (0.05)
Mixed	0.78 (37)	0.89 (278)	0.34 (0.05)	0.41 (0.02)	0.46 (0.04)
Deciduous	1.00 (10)	1.00 (62)	0.14 (0.03)	0.09 (0.02)	0.07 (0.02)

[a] Based on regular observations of 14 radiocollared moose.
[b] Proportion of trial counts in which radiocollared moose were observed.
[c] Proportion of midwinter observations in which radiocollared moose were observed.

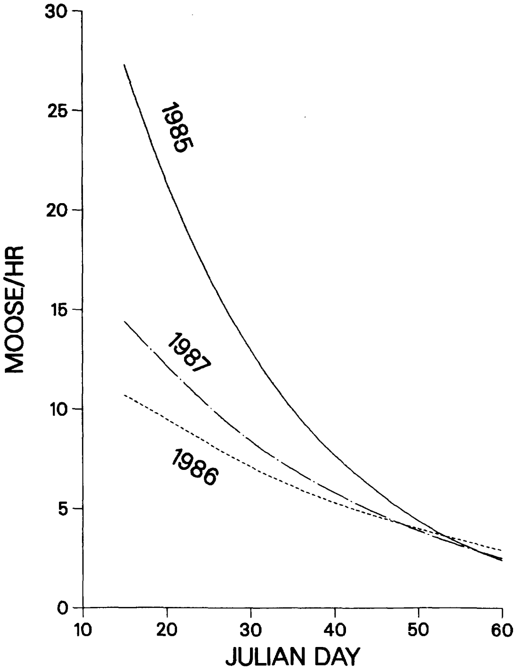

Fig. 1. Midwinter moose observation frequency during level-flight transects from mid-January (Julian day 15) to early March (Julian day 60) in 1985–1987, Isle Royale National Park, Michigan. Fitted regression lines are of the form $Y = a - bX$, where X = Julian day and $Y = \log_{10}$ (moose observed/hour + 1). Annual constants and statistical summaries are: 1985, a = 1.76, b = 0.02, $R^2 = 0.69$, $F = 68.3$, $P = 0.001$; 1986, a = 1.23, b = 0.01, $R^2 = 0.50$, $F = 34.9$, $P = 0.001$; 1987, a = 1.40, b = 0.01, $R^2 = 0.21$, $F = 10.0$, $P = 0.003$.

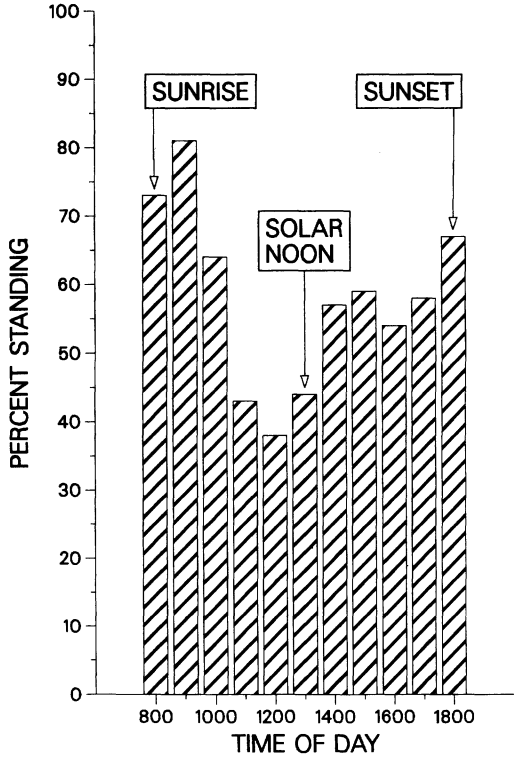

Fig. 2. Proportion of moose standing during daylight hours in midwinter during 1972–1990, Isle Royale National Park, Michigan. Included are 9,022 moose observed during transect flights and 2,341 moose observed using intensive searches over census plots, as both sets of observations were similar ($P = 0.99$). Hourly sample size ranged from 183–1,446.

a low point during midday before increasing in the afternoon.

DISCUSSION

Our study indicated that a correction for visibility bias should be incorporated into aerial surveys for moose in eastern North America. Observations of radiocollared moose from intensive aerial searches indicated that detection rate for moose was directly proportional to their use of coniferous and mixed habitats, and somewhat lower than in Alaska (Gasaway et al. 1981:App. I:29). Results of plot trials, using a similar search pattern, were less clear, perhaps because of relatively small sample sizes.

In midwinter on Isle Royale, moose exhibited a shift in habitat selection that influenced moose observation frequency during level transect flights. This probably was the final stage of a gradual transition from deciduous to coniferous habitats. Peek et al. (1976) found that moose in Minnesota usually initiated this shift in December, and that its timing was dependent on increasing snow depth. A midwinter shift in moose habitat selection toward coniferous cover is a pervasive aspect of their winter ecology in the boreal forests of North America (Lynch 1975, Peek et al. 1976, Crête et al. 1986). It is surprising how little attention has been paid to the effect of this behavior on moose census effectiveness.

We attribute the decline between January and February in moose observations during transect flights to a habitat shift by the few moose still remaining in deciduous habitats. Most moose at Isle Royale inhabited areas with a substantial coniferous canopy by mid-January, when only 14% of observations of radiocollared moose were in deciduous forests. This proportion was only 7–9% during February, when moose distribution was evidently stable and the move to coniferous cover complete.

From late January to early February the frequency of moose observations declined 200–500% (Table 1). Similarly, on a 60-km^2 plot counted repeatedly through the winter, Crête et al. (1986) found that transect counts of moose from fixed-wing aircraft declined 4-fold from January to February. We found it possible to maintain a relatively stable detection rate throughout the midwinter period, provided intensive search techniques were used.

In addition to moose habitat selection, Crête et al. (1986) believed that moose activity also contributed to variability in transect moose counts from fixed-wing aircraft. We found that moose were twice as likely to be standing just after sunrise as during midday. Samuel et al. (1987) found that standing elk (*Cervus elaphus*) were more likely to be observed during aerial censuses than bedded elk. Furthermore, habitats selected by bedded moose may reduce the proportion observed from aircraft. Minzey and Robinson (1991) showed that in late winter (after mid-Jan) moose selected coniferous habitats when bedding down. Des Meules (1964: 77) also found that the depressions in snow beneath coniferous trees were attractive to moose as bedding sites. Thus the pronounced temporal regularity in moose activity patterns is likely to influence the results of a transect survey for moose in winter.

A comparison between transect-type flights in Quebec and Isle Royale illustrates that such flights may not provide a useful proportional index to moose density. Our data on moose/hour were comparable to moose/100 km recorded in Quebec (Crête et al. 1986), because our average flight speed was about 100 km/hour. Moose density on Isle Royale was 17 times greater than in Quebec (2.0 vs. 0.12 moose/km^2), but January and post-January counts were only about 7 and 4 times greater, respectively.

MANAGEMENT RECOMMENDATIONS

It may not be possible to determine moose detection rates during annual surveys for logistic and financial reasons. At Isle Royale, we now assume that midwinter moose censuses achieve a detection rate of 75%, when done according to guidelines developed to maximize moose detection and minimize its variance. Annual moose density estimates incorporate this correction factor. Samuel et al. (1987) pointed out that routine application of such a constant ratio correction factor is justifiable if visibility bias is uniform. Although moose observation frequency declined in midwinter for transect flights, our trial counts and observations of radiocollared moose indicate relatively constant visibility bias during intensive searches between mid-January and early March, provided that standardized guidelines are followed.

Many of our standardized procedures were tailored for sampling a high-density moose population. Thus plot size was kept small (1 km^2), compared to 60-km^2 plots in Quebec (Crête et al. 1986), where moose density was lower. Fixed-wing aircraft were used in Quebec to locate track aggregations for intensive counts by helicopter (14 min/km^2), whereas at Isle Royale all plot counts were intensive efforts (13 min/km^2).

SUMMARY

Moose observations from fixed-wing aircraft and trial counts using radiocollared moose in Isle Royale National Park were used to estimate the proportion of moose observed during aerial censuses in midwinter in dense forest habitats. Using an intensive search flight pattern (small overlapping circles) with low-contrast daylight, moose detection from fixed-wing

aircraft (78–80%) was comparable to that reported for helicopter counts. Using intensive searches, detection was lowest (70–75%) in coniferous forests, whereas virtually no moose were missed in counts in deciduous habitats. In the absence of trial counts for detection rate during an aerial survey, an assumed rate of 75% is consistent with our results. Ideally, moose counts in winter should be timed to coincide with the period of greatest moose activity, just after sunrise.

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