EVALUATION OF INFRARED TECHNOLOGY FOR AERIAL MOOSE SURVEYS IN NEW HAMPSHIRE

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ABSTRACT: We evaluated the potential of infrared aerial surveys to monitor moose populations in northern New Hampshire during January 1995. Surveys were conducted at 2 sites: near Pittsburg, an area with high moose density (>0.8 moose/km²) and Milan, a region with moderate moose density (<0.8 moose/km²). Both sites contained extensive deciduous and mixed-wood forests and were known moose wintering areas. The surveys were conducted by Airscan Inc. using a Cessna 337G that employed a Westinghouse WesCam DS 10X infrared sensor.

Three surveys were conducted at each study site. Surveys I and II were designed to determine the sightability of moose in different cover-types and terrains by surveying 500 hectare subsites under different search intensities in a deciduous and a mixed-wood cover-type, respectively. Analysis of variance was used to determine the influence of terrain, elevation, cover type, and population density on sightability. A sightability correction factor was derived to produce a corrected moose density from the initial search data. Survey III, an intense search of the entire site, was used to compare with the corrected results of Surveys I and II.

Moose were observed in a variety of cover-types, terrains, elevations, and at moderate to high population densities. Search effort averaged 1.0 min/km² during initial searches. The overall sightability was 88% for both sites combined and was influenced by terrain and elevation. The moose densities corrected for sightability at Pittsburg (1.6 moose/km²) and Milan (0.7 moose/km²) were similar (±6%) to those from Survey III. Infrared surveys were cost effective relative to traditional aerial surveys, had greater survey area, and were applicable at least in moderate to high population density areas. This study indicated that this technique can monitor population fluctuations and provide reasonable population estimates of moose in northern New Hampshire.

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Accurate estimates of wildlife populations are a major objective of most management programs (McCullough and Hirth 1988). Resource managers need reasonably accurate and precise estimates of cervid abundance to evaluate interactions among animals, vegetation, human activities, societal concerns of local herd size, and to assess long-term outcomes of population and habitat management strategies (Storm *et al.* 1992). Estimating population size is rarely an easy or straightforward task because population monitoring techniques used in the past have limitations imposed by underlying assumptions and/or the amount and kind of data required (Burnham *et al.* 1980, Seber 1982). Large ungulates living in structurally complex habitats are virtually impossible to census directly (Novak *et al.* 1991) and a number of theoretically sound estimation methods (e.g., Seber 1973, Davis and Winstead 1980) fail in practice because underlying assumptions cannot be met, or the criteria for application are too restricted to achieve in field conditions (McCullough and Hirth 1988).

Because ground based observation of moose often is limited by forest cover, aerial surveys are the only practical methods to estimate moose populations in most of North

America (Bergerud and Manuel 1969). However, these techniques have limitations because of observer bias (Fong *et al.* 1985), technical problems (Shupe and Beasom 1987), or more commonly, sightability (Samuel *et al.* 1987). Visibility, the most important factor affecting population estimates (McCullough and Hirth 1988), is influenced by weather, lighting conditions, and vegetative cover (Gasaway *et al.* 1985), season (McCullough and Hirth 1988), heterogeneity ofterrain (Beasom *et al.* 1986), observer fatigue, search speed, altitude (Shupe and Beasom 1987), and the distribution pattern of cervids (Bergerud 1963, Samuel and Pollock 1981).

Technological advances with infrared (IR) sensors mounted on aircraft have provided new avenues for aerial surveys. Infrared sensors have been used to detect small mammals (Boonstra *et al.* 1994), turkeys (*Meleagris gallopavo*; Garner *et al.* 1995), mule deer (*Odocoileus hemionus*; Parker and Driscoll 1972), and white-tailed deer (*Odocoileus virginianus*; Wiggers and Beckerman 1993). Infrared sensors detect the heat emissivity of an animal if it contrasts sufficiently with that of the environmental background. Presumed benefits of IR over traditional aerial surveys include: 1) IR sensors can detect moose at greater distances than human observers, 2) aircraft can fly at much higher altitudes allowing for faster ground coverage, increased safety, and reduced flight cost, and 3) reduced negative influence by habitat structure.

Early IR surveys relied on computer analysis of survey tapes to identify target species and involved measuring the emitted temperature of an animal and the environmental background prior to surveys. The difference between the temperatures (ΔT) was calculated and a computer was programmed to search the survey tape for objects with a defined ΔT. Problems with this procedure (Garner *et al.* 1995) included: 1) ΔT is not a constant but a relative value, therefore several species may have overlapping ΔT's, making species distinction impossible; 2) ΔT may change as an animal moves from one location to another (e.g., stands from a bed, walks onto or out of snow cover), thus the animal may not be detected; and 3) ΔT may be represented by an inanimate object (e.g., a sun-heated rock against a snow background), thus incorrect targets may be recorded.

An alternative method to computer analysis is real-time identification, whereby sensor operators detect and identify animals immediately by recognition of specific body features during surveys. Infrared surveys are similar to traditional aerial surveys in that trained observers are imperative to reliability. For example, some companies require that their sensor operators have a minimum of 5 years or 1000 hours of experience with IR sensors. The goal of this study was to evaluate the effectiveness of IR surveys to locate and identify moose, and provide reasonably accurate estimates of moose density in New Hampshire where terrain and weather conditions make low level visual survey flights impractical.

STUDY AREA

Two 5000 ha survey sites were established; one near Pittsburg, and the other on the Kilkenny Wildlife Management Area of the White Mountain National Forest, Milan, NH. These sites were known moose wintering areas and were chosen to assess the IR survey techniques at different moose densities; the Pittsburg area was defined as high population density (>0.8 moose/km^2) and the Milan area as moderate population density (<0.8 moose/km^2).

The Pittsburg site ranged in elevation from 400-1000 m and was characterized by moderate mountains and flat lowlands with a hardwood dominated forest type. Hardwoods included sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and paper birch (*Betula papyrifera*). Intermingled softwood stands consisted of red spruce (*Picea rubens*) and balsam fir (*Abies balsamea*).

The Milan site ranged in elevation from 250-1200 m and was characterized by steep mountains and lowland valleys. Mountain tops were dominated by red spruce, white pine (*Pinus strobus*), and Eastern Hemlock (*Tsuga canadensis*). Mountain slopes and valleys were comprised of sugar maple, red maple (*Acer rubrum*), and American beech (*Fagus grandifolia*).

Subsites

Two 500 ha subsites (1 deciduous, 1 mixed forest) were established at both Pittsburg and Milan sites, and were intensively surveyed to develop a sightability correction factor (SCF) and investigate the effects of cover type and other environmental factors on sightability. Subsites were circular with a radius of approximately 1.3 km and were chosen to represent each site with respect to topography, canopy coverage, and cover-type. The four subsites chosen during pre-survey flights with the IR contractor all contained observable moose.

The deciduous subsite (70% deciduous:30% coniferous) in Pittsburg had an average elevation of 692±70 m (mean±standard deviation); the mixed subsite (60% deciduous:40% coniferous) had an average elevation of 641±35 m. The deciduous subsite (75% deciduous:25% coniferous) in Milan had an average elevation of 902±127 m; the mixed subsite (50% deciduous:50% coniferous) had an average elevation of 610±75 m . The standard deviation of elevation indicates the degree of terrain heterogeneity within each subsite.

METHODS

Each site was surveyed three times during 26-29 January 1995 by Airscan Incorporated (Titusville, FL) using a Cessna 337G aircraft and a Westinghouse WesCam DS infrared sensor. The sensor had a combination 10X forward looking infrared (FLIR) sensor and a >10X Sony zoom lens color television camera. This sensor had 5 times the magnification power and increased resolution over traditional IR sensors.

The design of Surveys I and II consisted of 100% initial coverage of a site followed immediately by intense coverage of each subsite. Initial coverage of the entire site was accomplished by attempting to fly consecutive 3.2 km diameter orbits (Fig. 1). However, high winds (>20 knots) caused most orbits to be elliptical with diameters in excess of 3.2 km. Intense coverage of a subsite was accomplished by starting at a subsite's midpoint and spiraling outward in tight circles until the sensor operator was confident that all moose had been detected and identified (Fig. 1). The design of Survey III consisted of intensively surveying each orbit within the site by flying the orbit's perimeter and then spiraling inward in tight circles until the sensor operator was confident that all moose had been detected and identified. Thus, the intensity of coverage of Survey III for the entire site was equivalent to that at the subsites during Surveys I and II.

We flew at approximately 1500 m above mean sea level (MSL) at Pittsburg and 1750 m above MSL at Milan. This elevation resulted in flying approximately 1000 m above ground level at both sites. The aircraft's bank angle averaged 15° during initial searches and 30° during intense searches. Flight speed was 100 knots. Snow cover ranged from minimal (patches of bare ground) to moderate (0.5 m) at both sites. Surveys I and II each required 1.5 h and Survey III required 2.0 h to complete and all surveys occurred between 0800 and 1500 h. These hours corresponded to acceptable flying conditions rather than the desired periods of peak moose activity at dawn and dusk.

Global positioning system (GPS) points

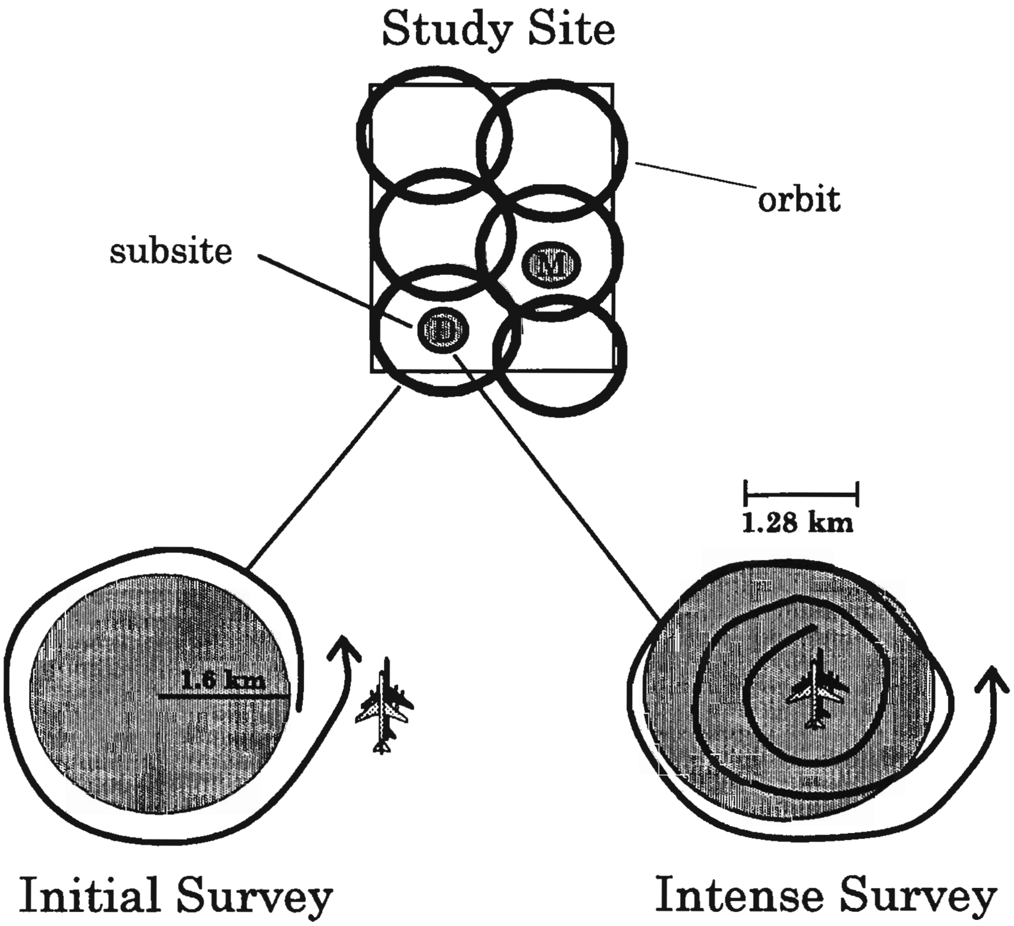

Fig. 1. Aircraft flight pattern during initial (light intensity) and intense infrared aerial moose surveys at Pittsburg and Milan, New Hampshire, January 1995 (D=deciduous subsite, M=mixed subsite).

were programmed on the perimeter of each map-drawn orbit prior to the surveys. During surveys, the aircraft was positioned at each GPS point and then the orbit was flown using geographic features as boundaries. The sensor operator scanned from the left side of the aircraft using various scanning patterns to ensure complete coverage. Moose were located by their level of emitted heat versus background temperature, then positively identified by identification of specific body features. All moose identified were recorded by time of sighting and heading of the aircraft. Upon completion of the surveys, the sensor operator reviewed each sighting on IR tape and recorded the number of moose present.

Airscan Inc. plotted all identified moose based on the programmed orbits, however, it was known that the orbits flown did not always conform to the programmed orbits. Therefore, the plane's exact flight patterns for each survey were manually plotted by viewing the IR tapes and recording latitude and longitude at 30 second intervals. All moose locations were subsequently plotted manually with the aid of a computer program written by K. Gustafson. The program estimated moose locations from the latitude, longitude, heading of aircraft, and pitch and yaw angles of the sensor at each moose sighting; the aircraft's average altitude above MSL, airspeed, and bank angle; and the range of ground elevations within each orbit. The program ensured that all identified moose were plotted at their correct locations within 200 m. These locations were used to get elevation, terrain, and distance from the plane for each moose sighting. This procedure was used to plot only observed moose, and not to adjust the number of moose observed.

Data Analysis

Moose sightings were categorized by group size (single or multiple), elevation, terrain, and distance from plane. Elevation was defined as low (<600 m), medium (600-900 m), or high (>900 m). Terrain was categorized as flat (<10% slope), moderate (10-20% slope), or steep (>20% slope). Distance from plane was defined as close (<0.5 km), medium (0.5-1 km), or far (>1 km). The uncorrected moose density for each survey was calculated by dividing the number of identified moose by the survey area; survey area was calculated by measuring a manually plotted flight pattern with a dot grid (25 dots/cm²).

Because the subsites were relatively small (500 ha), and 1 hour elapsed between the initial and intense searches, groups of identifiable moose were known to move into and out of the subsites during Surveys I and II. This movement violated the assumption of closure (Gasaway *et al.* 1986). Assuming that moose moved in and out at an equal rate during the two surveys, we combined the number of moose identified during Surveys I and II in both the initial and intense searches of subsites to increase the sample size.

Sightability (%) was calculated by comparing the number of moose located on the initial and intense searches at each subsite by the equation:

$$\text{Sightability} = \frac{\text{number of moose identified on initial search}}{\text{number of moose identified on intense search}} * {}_{100} \quad (1)$$

We assumed that 100% of the moose in each subsite were identified on the intensive searches based on sensor operator experience. Sightability from Survey III also was assumed as 100% based on sensor operator experience and because the entire site was surveyed intensively.

Factors that potentially affected sightability were tested for Surveys I and II by analysis of variance (ANOVA) and multivariate analysis of variance (MANOVA). Sightabilities were arcsine transformed (Zar 1984). Difference in sightability between sites was tested by chi-square analysis of observed frequencies. We analyzed the effects of group size, elevation, terrain, and distance from plane between the initial and intense searches on sightability for each subsite.

An SCF was calculated as follows:

$$SCF = SCF_o * SCF_c \qquad (2)$$

where: SCF_o= observed sightability correction factor

SCF_c= correction factor for moose missed while measuring SCF_o.

The SCF_c is usually derived experimentally by analyzing the success of observation of known radio-collared moose (Gasaway *et al.* 1986). If the SCF_c cannot be determined in this manner, the SCF can be estimated with a search effort of 30 min/mi² (12 min/km²) for helicopter surveys and assumed equal to the SCF_o (Gasaway *et al.* 1986). Since radio-collared moose were not available for this study, we assumed that $SCF=SCF_0$ and derived the SCF by the following equation (from Gasaway etal. 1986):

$$SCF = \frac{\text{number of moose identified on intense search}}{\text{number of moose identified on initial search}} + \text{correction for small sample bias} \quad (3)$$

The correction for small sample bias = $[(n_o s^2_{uv})/(\Sigma_k v_k)^2] - [(n_o(\Sigma_k u_k)s^2_v)/(\Sigma_k v_k)^3]$

where: $s^2_{uv} = [(\Sigma_k u_k v_k)/(n_o-1)] - [(\Sigma_k u_k(\ _k v_k))/(n_o(n_o-1))]$

and $s^2_v = [(\Sigma_k v_k^2)/(n_o-1)] - [((\Sigma_k v_k)^2)]/[(n_o(n_o-1))]$

n_0=number of 2 square mile plots surveyed with an intensive search

u_k=number of moose seen during the intensive search in the kth sightability plot; $k=1...n_o$

v_k=number of moose seen during the standard search in the kth sightability plot; $k=1...n_o$

The number of moose, corrected for sightability, for Surveys I and II was calculated by multiplying the number of moose identified on the entire site by the SCF. The population densities for Surveys I and II were calculated by dividing the number of moose (corrected for sightability) by the survey area. Since Survey III was an intense survey of the entire site, we assumed that the population density calculated from the number of observed moose divided by the survey area was equivalent and comparable to the population density calculated for Surveys I and II.

RESULTS

Moose were identified in open, deciduous, mixed, and coniferous forest stands; on low, medium, and high elevations; on flat, moderate, and steep terrain; in areas where presumed moose density was <0.8 moose/km²; and at distances 3.7 km from the aircraft. Search effort averaged 1.0±0.04 (mean±standard deviation) min/km² during initial searches, and 1.7±0.2 min/km² during intense searches. Search time was influenced primarily by topography and cover type with steep, heavily vegetated areas requiring increased search effort.

The total number of observed moose during the 3 surveys ranged from 78-102 and 44-55 at Pittsburg and Milan, respectively (Table 1). Moose density estimates uncorrected for sightability, ranged from 1.3-1.6 moose/km² at Pittsburg and 0.4-0.7 moose/km² at Milan (Table 1). The calculated sightability was 89% at the deciduous subsite and 88% at the mixed subsite in Pittsburg, and 30% at the deciduous subsite and 84% at the mixed subsite in Milan (Table 2).

Environmental factors that affected sightability included terrain and elevation based on results of ANOVA. Sightability was significantly higher on flat (87±3.3%) than steep (69±4.8%) terrain (P<0.001), and significantly lower in high (40±11.2%) than medium (77±2.8%) or low (89±1.4%) elevations (P<0.001). When terrain and elevation were analyzed using MANOVA against sightability, both were significant factors (P<0.001). Sightability was not different for single or grouped moose (P=0.7852), by distance from the aircraft (P=0.3663), or by subsite type (P=0.1950).

Sightability was presumably low at the Milan deciduous subsite because of the very steep slopes (40%). Very few areas on either site exhibited this terrain and less than 5% of the identified moose were found on 40% slopes. Therefore, we omitted these data from this subsite and reanalyzed the environmental factors that affected sightability. No change was realized with regard to the influence of the environmental factors on sightability.

Since no significant difference in sightability existed (P=0.876), we combined the Pittsburg and Milan sites (deciduous subsite omitted), and given that subsite type did not influence sightability, we combined the deciduous and mixed subsite data at both sites (with the exception of the Milan deciduous subsite) yielding an overall sightability of 88% (98/112) (Table 2). The SCF calculated from the overall sightability was 1.18 (112/98 + 0.037). Based on the corrected number of moose for Surveys I and II, moose densities averaged 1.6±0.1 moose/km² at Pittsburg and 0.7±0.2 moose/km² atMilan. These moose densities were similar to those calculated during Survey III (intense search) in both areas (Table 3).

DISCUSSION

This study showed that IR surveys could detect moose in a variety of cover types and terrains within New Hampshire forests. How-

Table 1. Search effort, number of identified moose, survey area, and uncorrected moose density for infrared aerial surveys in northern New Hampshire, January 1995.

Site	Survey	Search Effort (min/km²)	Number of Moose Observed	Survey Area (km²)	Uncorrected Density (moose/km²)
Pittsburg	I	1.1	100	10.5	1.4
	II	1.0	78	9.2	1.3
	III	1.9	102	9.5	1.6
					1.4±0.2[a]
Milan	I	1.0	44	15.0	0.4
	II	1.0	55	11.0	0.7
	III	1.5	48	10.9	0.7
					0.6±0.2[a]

[a] Mean±standard deviation.

Table 2. Number of moose seen on initial and intense searches for deciduous and mixed subsites, and percent sightability for infrared aerial surveys in northern New Hampshire, January 1995.

		Deciduous Subsites				Mixed Subsites			
Site	Survey	Survey Area (km²)	Initial Search	Intense Search	Sightability[a] (%)	Survey Area (km²)	Initial Search	Intense Search	Sightability[a] (%)
Pittsburg	I	2.5	21	26		1.6	28	19	
	II	1.5	21	21		1.2	7	21	
			Σ =42	Σ=47	89		Σ=35	Σ=40	88
Milan	I	0.8	0	8		1.2	10	12	
	II	0.8	6	12		1.7	11	13	
			Σ =6	Σ =20	30		Σ =21	Σ=25	84

[a] Sightability calculated assuming 100% sightability during intense searches.
Sightability = (sum of moose identified on initial searches/sum of moose identified on intense searches) * 100.

ever, sightability of moose was influenced by the factors terrain and elevation that are often interrelated in mountainous regions. Anderson (1994) found that terrain in Wyoming affected moose sightability when analyzed univariately, but not when analyzed multivariately. He also found that distance from transect and group size did not influence sightability. Conversely, group size influenced sightability of moose in forest habitat in Alaska (Gasaway *et al.* 1985). The distribution pattern of cervids affects sightability in traditional surveys because larger groups have a higher probability of

Table 3. Number of moose corrected for sightability, survey area, and density corrected for sightability for surveys I and II, density from survey III, and percent difference between densities for infrared aerial surveys in northern New Hampshire, January 1995.

Site	Survey	Number[a] of Moose	Survey Area (km^2)	Density[a] (moose/km^2)	Density Survey III (moose/km^2)
Pittsburg	I	118	10.5	1.7	
	II	92	9.2	1.5	
				1.6±0.1[b]	1.62(1%)[c]
Milan	I	52	15.0	.5	
	II	65	11.0	0.9	
				0.7±0.3[b]	0.66(-6%)[c]

[a] Number of moose and density corrected based on 88% sightability (SCF=1.18).

[b] Mean±standard deviation.

[c] Percent difference between average density, corrected for sightability, and density from survey III by the equation:

$$\text{Percent difference} = (1-AD/TD) * 100,$$

where: AD=average density from surveys I and II,
TD= density from survey III.

being observed than smaller groups (Samuel and Pollock 1981). Where cover types in northern New Hampshire are more similar to those in Alaska than Wyoming, there is no evidence from this study of an increased probability of detection of grouped versus single moose.

The Pittsburg mixed subsite and the Milan deciduous subsite were of particular interest because substantial differences existed between the counts of initial and intense surveys (Table 2). These differences were not explained by a single environmental factor. The low sightability during Survey I at the Milan deciduous subsite (Table 2) was probably due to the combination of high elevation and steep terrain. The majority of moose in this subsite were located in steep terrain on 40% slopes, versus typical 20-25% slopes at the other sites. Relatedly, the moose identified during the initial search of Survey II at this subsite were on 20-25% slopes, whereas, the additional moose identified during the intensive search were on 40% slopes. Very few areas on either site exhibited this terrain,and less than 5% of the identified moose were observed on 40% slopes in the entire study.

The number of moose observed in the initial search exceeded that in the intense search at the mixed subsite during Survey I at Pittsburg (Table 2). This subsite was at low-medium elevation, contained abundant hardwood vegetation, had minimal snow cover (≤0.5 m) and contained a network of logging roads that provided access to the subsite. Moose were observed walking on roads within and outside the perimeter during both searches. During the initial search, the sensor operator noted that approximately half of the observed moose were walking. It is speculated that movement out of the study area occurred in the approximate 1 hour that elapsed between the initial and intense searches that could account for this result.

Specifically, a group of 5 moose located near a road on the initial search was not found on the intense search in Survey I. Conversely, groups of 4 and 5 moose were located near the subsite during the initial search of Survey II. Groups of 4 and 5 moose were subsequently located within the subsite's perimeter during the intense search an 1 hour later. Further, this subsite averaged low-medium elevation and flat-moderate terrain, factors that promoted high sightability, indirectly suggesting that another factor(s) influenced the observations. If entrance or exit from a study area can be confirmed by tracks in the snow, then data can be adjusted appropriately (Gasaway *et al.* 1986). Unfortunately, poor snow conditions and the plane's altitude made such adjustments impossible in this study.

Movement into or out of the sites was not considered a problem during initial searches because of the flight pattern (consecutive orbits) and survey speed (100 knots). Movement was presumably a problem during intense searches because of the delay between the initial and intense searches, and because the subsites were relatively small. Movement should be of minimal concern in larger study sites, but intensive searches would still be conducted in future surveys to refine the SCF.

The overall SCF (1.18) was calculated using data from Pittsburg and Milan because the actual differences in sightability were negligible between the sites (5%, 1.13 versus 1.19; deciduous site in Milan omitted). In a hypothetical survey where 50 moose were observed, the range of corrected observations based on the 3 SCF values is 57-60 moose. This minimal difference suggests the application of one SCF value across areas of moderate and high population densities in the study area.

Since moose were identified with the airborne IR sensor in a variety of cover types and terrains, this technology appears capable of detecting moose in New Hampshire forests, and has certain advantages over traditional aerial surveys. Infrared surveys have less stringent survey conditions because (i) IR sensors detect heat from great distances (5.5 km), and (ii) do not require daylight, direct visual observation, or snow cover (Gasaway *et al.* 1986). Sightability can be maximized by timing surveys to correspond with peak activity periods of moose. Inclement weather has minimal effect on IR surveys because the survey plane can fly 1000 m above ground versus 100 m for typical aerial surveys. However, weather was a factor in this study (11 of 14 days), and surveys can be affected by winter weather in northern regions such as New Hampshire. Additionally, because of the rugged topography in much of New Hampshire, low level visual flights are not safe. The increased altitude also provides increased crew safety, less wind influence, and increased ground coverage per unit time.

About a two fold increase in efficiency (Table 1) was realized relative to ground coverage by traditional aerial surveys which require 4-8 min/mi^2 (1.5-3.1 min/km^2) for standard surveying, and 12 min/mi^2 (4.6 min/km^2) for intensive searches (Gasaway *et al.* 1986). Flight costs for these surveys were \$410 per hour versus \$415 per hour for helicopter surveys (Joe Brigham Inc., Concord, NH). Because search effort for these surveys averaged 1.0 min/km^2, the cost was \$6.83/km^2 versus \$10/km^2 for traditional helicopter surveys. An additional cost however, is the analysis of survey tapes and plotting of identified animals on topographic maps. Airscan Inc. charged \$610/day for this service and required 5 days to complete our tapes and maps.

Traditional surveys incorporate biases due to visibility problems associated with weather and lighting conditions (LeResche and Rausch 1974), terrain heterogeneity (Siniff and Skoog 1964), search speed and altitude (Shupe and Beasom 1987), and the distribution pattern of cervids (Samuel *et al.* 1987). Infrared surveys are not affected by lighting conditions and weather effects are reduced. Increased aircraft altitude allows for constant flying height, thus the effects of terrain heterogeneity are also reduced. Occasionally, terrain and associated weather patterns may make surveying an area impossible due to unsafe flying conditions.

Visibility problems of traditional aerial surveys often translate to low sightability levels which may produce an inaccurate population estimate or a prohibitively expensive, accurate estimate; up to one third of a population may go undetected (Caughley 1977). In Alaska, only 68, 61, and 40% of moose were seen by experienced observers flying in excellent, good, and poor snow conditions, respectively, while spending 15 min/mi^2 (5.8 min/km^2) over enclosures ranging in density from 7-43 moose/mi^2 (3-17 moose/km^2) (LeResche and Rausch 1974). Sightability during Surveys I and II in Pittsburg averaged 89% with ground coverage of 1.0 min/km^2 over areas with a minimum density of 1.4 moose/km^2, assuming 100% sightability during intensive searches. Many moose positively identified with the IR sensor could not be viewed with the video camera because they were obscured by trees or dense canopy. These individuals would probably have been missed by an observer during a traditional aerial survey.

Infrared surveys are not without biases including observer experience and vegetative cover. Observer (sensor operator) experience can account for statistically significant differences insightability (LeResche and Rausch 1974). Vegetative cover causes less of a problem for IR surveys because an animal's cryptic coloration does not conceal them from an IR sensor. Problems associated with vegetative cover can be minimized by flying after leaf fall and when moose typically use open habitat. However, moose located under near complete coniferous canopy probably would not be detected by IR. This study was designed to utilize the predominant use of open, deciduous stands by moose during winter (Miller 1989). Current IR technology offers a practical and efficient technique for surveying moose densities during winter when densities are 0.7-1.6 moose/km^2. When applied over a large area in a Gasaway style survey (Gasaway *et al.* 1986), with an IR sensor replacing visual observations, this method should provide an acceptably accurate and precise moose population density estimate.

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