WINTER DISTRIBUTION OF MOOSE AT LANDSCAPE SCALE IN NORTHEASTERN VERMONT: A GIS ANALYSIS

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ABSTRACT: A GIS analysis of landscape scale distribution of moose (*Alces alces*) in northern Vermont during winter 2010 showed that most moose were located at elevations of 300–600 m, with little discernible elevational gradient. Slope and aspect were not correlated with locations as moose were distributed in the study area with the relative amount in each descriptive class. The distribution of >85% moose based on NOAA cover types was in deciduous, mixedwood, and coniferous stands relative to their availability; locations in scrub/shrub and wetlands were higher and lower than expected, respectively. Higher resolution AIMS imagery indicated that moose used mixedwoods more and coniferous stands less than available. The most significant landscape characteristic influencing the location of moose was proximity to forest openings/timber cuts that presumably provide important seasonal browse.

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Key words: *Alces alces*, distribution, GIS, moose, Vermont, winter.

INTRODUCTION

Most landscape analyses of moose (*Alces alces*) have been focused upon coarse-scale location and description of home ranges, or fine-scale seasonal habitat selection and utilization through use of radio-telemetered animals, aerial mark-recapture surveys, and/or fieldwork (Courtois and Beaumont 2002, Courtois et al. 2002, Potvin and Courtois 2004, Poole and Stuart-Smith 2005, Scarpitti et al. 2005, Dussault et al. 2006, Gillingham and Parker 2008, Van Beest et al. 2010). Although increased use of GPS collars has provided more accurate and plentiful locations of individuals, most studies are limited by animal sample size due to the difficulty and cost associated with monitoring the broader population itself. A recently developed airborne thermal vertical-imaging system integrated with GIS has presented the opportunity to identify and map locations of hundreds of moose during mid-winter (Millette et al. 2011), with subsequent exploration of landscape attributes associated with their locations. Because locations are accurately geocoded with GPS by the thermal imaging system, it is possible to use a wide variety of off-the-shelf GIS databases to model habitat characteristics. The landscape distribution and winter habitat use examined here is thought to be unique in that no such winter "snapshot" of a regional moose population has had such high sample size of animals.

METHODS

Study Area

The study area was 682 km^2 within Wildlife Management Unit (WMU) E1located in the northeastern corner of Vermont and bordered by New Hampshire and Quebec (Fig. 1). The area is topographically expressive, and heavily forested with expansive maple (*Acer saccharum, A. pensylvanicum*) and American beech (*Fagus grandifolia*), stands of balsam fir (*Abies balsamea*), spruce (*Picea rubens, P, glauca,*

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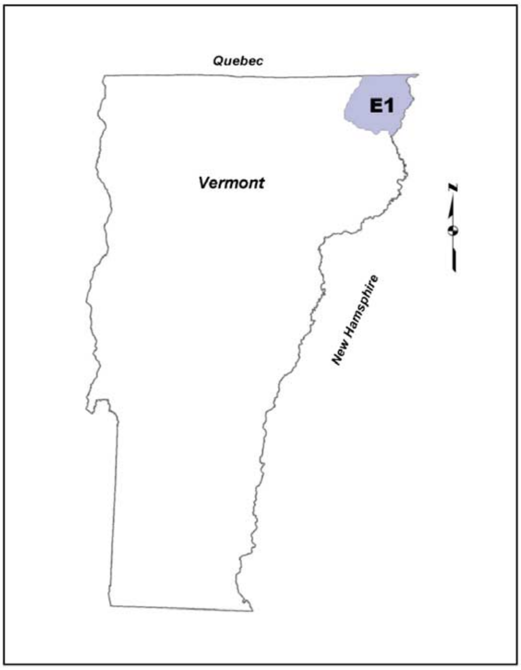

Fig. 1. Location of the study area in WMU E1 in northeastern Vermont, USA.

P. mariana), hemlock (*Tsuga canadensis*), and eastern white pine (*Pinus strobus*); conspicuous evidence of timber harvesting existed throughout. The estimated moose density based on a rolling 3-year average of moose sightings by November deer hunters was 0.89 moose/km^2 (C. Alexander, Vermont Fish and Wildlife Department). Similarly, the estimated density was 0.84 moose/km^2 during the aerial thermal census (Millette et al. 2011) that produced the data for this study.

Data

The study area was sampled with 35 survey units (SU) distributed (relatively) evenly throughout. Each was laid out non-randomly in a GIS to account for the variety of topographic settings and land cover types, while avoiding major changes in elevation along flight lines to maintain constant height above ground level (agl); thus, the image swath-width was as constant as possible during flights. The total area surveyed was 131.6 km^2 or 20% of WMU E1. To insure that land cover types along flight line transects were representative of WMU E1, a GIS overlay analysis was used to compare the proportions along transects with those from the NOAA Coastal Service Center Land Cover Data (NOAA 2006) (Fig. 2). This analysis indicated that the relative proportions of cover types were almost identical between transects and the entire WMU such that no cover type was under- or over-sampled. Details of the sampling design can be found in Millette et al. (2011).

The data were developed using the AIMS-Thermal airborne imaging system. The sensor array pairs a 16-bit radiometric thermal camera to detect warm targets on a cold background, and simultaneously acquires 8-bit high resolution color photos to identify specific heat sources. Unlike most aerial thermal systems used in previous research, the AIMS-Thermal acquires its imagery vertically like a mapping system rather than using a low-oblique viewing angle while panning across the landscape. The vertical orientation of the cameras causes minimal screening effect in coniferous stands that is more typical of systems with oblique look-angles, and preserves uniform scale and spatial resolution throughout each image allowing detailed measurements within an image. A complete description of the AIMS-Thermal system can be found in Millette et al. (2011).

The AIMS-Thermal system was deployed in January and February 2010 over a 4-week period when 6 flights were flown between 0700 and 1100 hr. In total, these flights produced 94,605 thermal images and 12,530 high-resolution color images under continuous snow cover and sky conditions ranging from heavy overcast to bright sunshine. Snow cover never exceeded 45 cm and no restrictive crust layers existed.

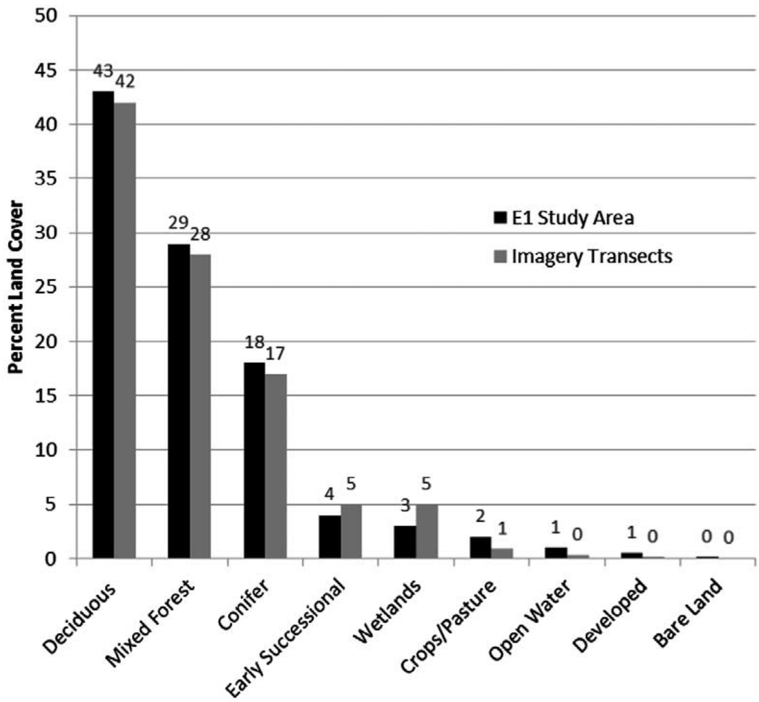

Fig. 2. Comparison of NOAA land cover types with imagery transects that indicates the similarity between availability of cover types in the study area and the actual survey area in winter 2010, northeastern Vermont, USA.

All imagery exposure times and associated flight data were processed into GIS attribute tables that support creation of shapefiles containing photo centers for each exposure from the thermal and natural color cameras, as well as the flight path of the aircraft. This table also provides the framework for the integration of related spatial data such as sampling transects, flightlines, topography, and vegetation and facilitates the landscape-scale analysis described here. All GIS database development operations were done using software developed by the researchers; all GIS analyses used ArcGIS software tools.

GIS Analyses

An assessment of moose locations relative to landscape attributes was conducted to explore whether relationships or patterns existed that would describe habitat selection during the winter study period. The locations of 112 observed moose were used in a series of GIS overlay procedures with the USGS National Elevation Data (Gesch et al. 2002), the NOAA Coastal Service Center Land Cover Data (NOAA 2006), and the National Agriculture Imagery Program (NAIP) Vermont Digital Color Orthophotography (2009) to examine the distribution of locations relative to elevation, slope, aspect, land cover type, and land management practices. All GIS data were generalized to 90 m spatial resolution to limit landscape data heterogeneity.

Elevation was divided into 7–100 m classes with the majority (90%) of the landscape ranging from 300–700 m. Slope was divided into 4 classes of <2.5°, 2.5°–5°, 5°– 10°, and >10°. Aspect was divided into the 8 cardinal and inter-cardinal points of the compass. The analysis of locations relative to land cover was done using classifications from the NOAA CSC Land Cover Data with 30 m spatial resolution, which was generalized to 90 m to reduce artificial heterogeneity in the land cover data derived from Landsat TM data, and to allow the spatial resolution of the land cover data to better match the 1.3 ha footprint of each thermal image. A second classification created from the AIMS-Thermal natural color data with 3.2 cm spatial resolution was visually interpreted for each 2.2 ha image containing a moose. The AIMS-Thermal classification differs from the NOAA data since it had to be generalized into deciduous, mixedwood, and coniferous cover types due to snow cover which prevented accurate delineation of wetlands, scrub/shrub, and grassland.

We performed a series of Chi Square Goodness of Fit tests (Snedecor and Cochran 1989) to determine if the distribution of moose was random among the different classes of elevation, slope, aspect, and land cover:

$$X^2 = \sum \frac{(O - E)^2}{E} \qquad (1)$$

where O = the number of observed moose in each category and E = the expected number of moose if the distribution were random and determined only by the proportion of the area sampled. For this test we counted the number of pixels in each GIS layer (e.g., DEM, land cover) that had a moose and those that did not, as well as the total number of pixels in each category. We then estimated the number of pixels that should be expected if the distribution were random. This estimation was adjusted to sum to 112, the number of moose observed. A similar analysis was done to test the randomness of moose distribution relative to the parameter distance to forest openings/cut areas. In this analysis, there is no underlying image to count pixels, so we generated approximately 10 random ground points within each survey unit (totaling 341) using the GIS. The distance from these points and the locations of moose to cut areas were then compared in a similar way.

RESULTS

Elevation

The elevational distribution of moose was not random ($P = 0.012$); however, locations were not clustered at one elevational range. The majority of moose (78%) were at low to mid elevation (300–599 m), as was most of the study area (71%). At higher elevations (>599 m) use (21%) was less than available (28%), and use declined sharply above 699 m (Fig. 3).

Slope

There was no relationship between any slope category and locations ($P = 0.444$); the proportion of locations was correlated with (similar to) the proportion available in each category. The majority of locations (~88%) were on slopes of <10° and were evenly distributed (27–32%) among the 3 classes of lower slope. Moose were found at the highest slope category (>10°) at a rate of 13%, similar to what was available (11%) (Fig. 4).

Aspect

There was no relationship between aspect and location ($P = 0.932$) with moose located in all aspect categories (Fig. 5). Proportional use was highest in the east (20%) and lowest in the north (7%). The proportion of locations in north-northeast-east directions (38%) was slightly higher than in southeast-south-southwest directions (35%) with more solar exposure (Fig. 5).

Land Cover

The land cover analysis indicated that the proportional use of cover types was

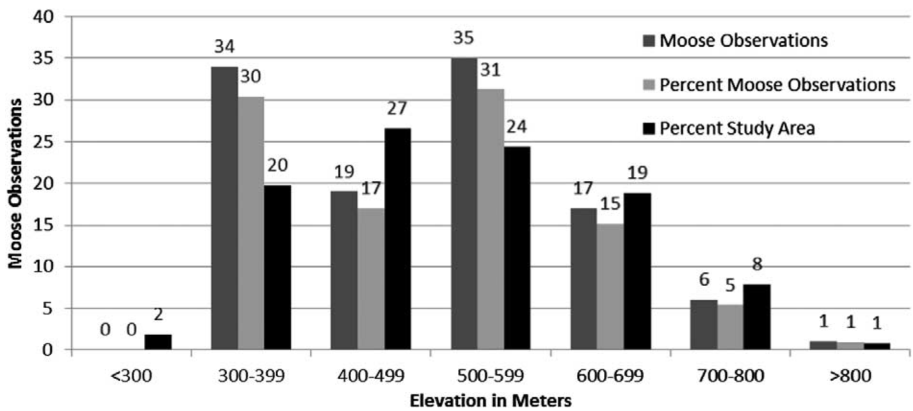

Fig. 3. The distribution of moose observations by elevation class (USGS National Elevation Data) indicating that most moose (78%) were located at 300–600 m, yet moose were observed at higher elevations similar to availability (χ^2 =16.34, P = 0.0121) in winter 2010, northeastern Vermont, USA.

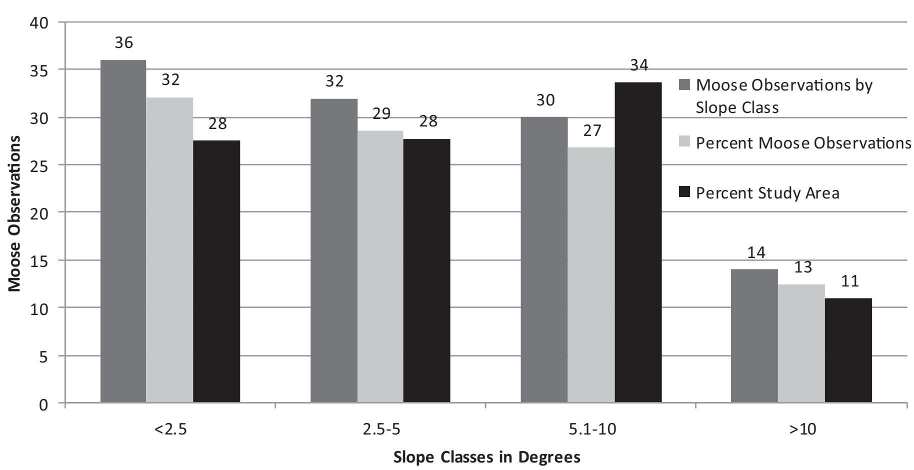

Fig. 4. The even distribution of moose observations by slope class (USGS National Elevation Data) indicating no relationship (χ^2 =2.68, P = 0.444) between slope and location, including steep slopes in winter 2010, northeastern Vermont, USA.

not entirely proportional with availability (P = 0.001), although the proportional use (locations) and availability in the 3 most common cover types (deciduous, mixed-wood, coniferous) were similar (88 and 87%, Fig. 6), indicating no preference for any forest type. Use of scrub/shrub was ~3 x higher than available (4%), and conversely, use of wetlands was negligible with 4% availability (Fig. 6); the scrub/shrub cover type represented young forest openings.

There were certain differences between the analyses with the NOAA and AIMS land cover data. Availability of the 3 major forest cover types and use of the deciduous cover type was similar in both analyses; however, use was measurably lower (30 vs. 48%) in mixedwood and higher in coniferous (17 vs. 6%) in the NOAA analysis than the AIMS analysis (Fig. 7). In part, the difference was due to the reallocation of 13 moose (12% of total moose identified)

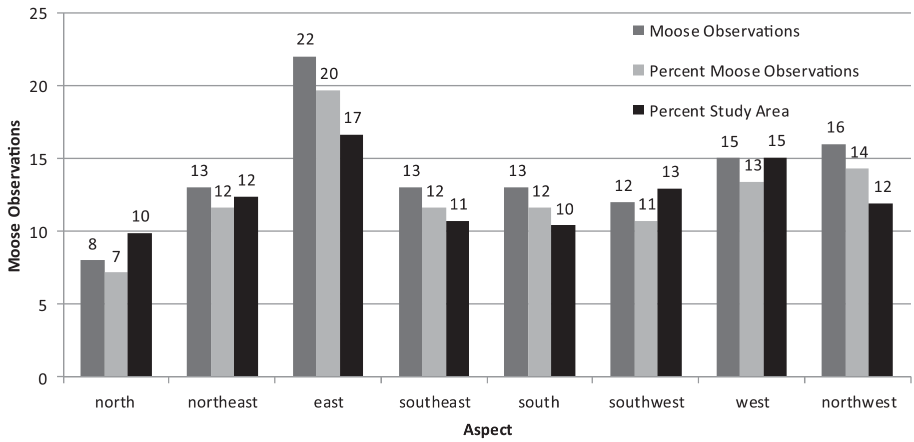

Fig. 5. The even distribution of moose observations by aspect class (USGS National Elevation Data) indicating no relationship (χ^2 = 3.04, P = 0.9319) between aspect and location in winter 2010, northeastern Vermont, USA.

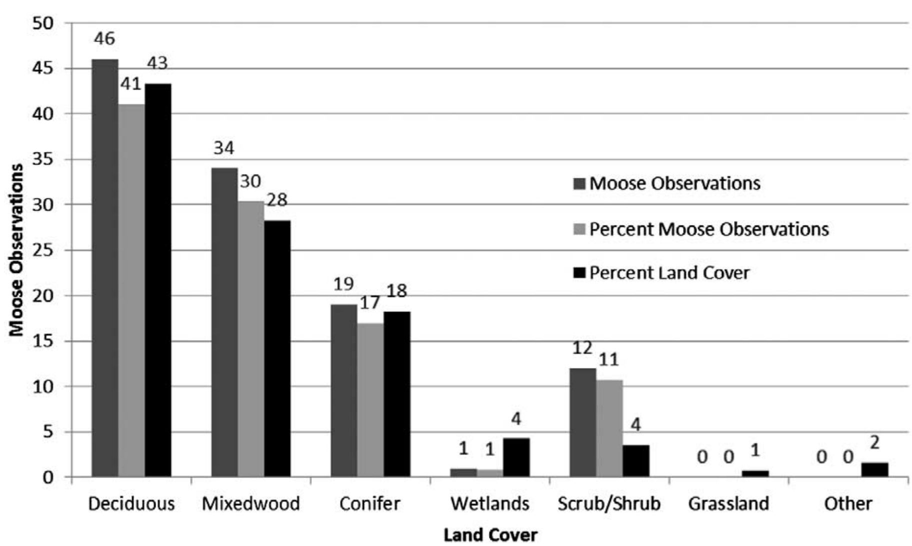

Fig. 6. The distribution of moose observations by NOAA land cover type indicating the uneven use (χ^2 =22.39, P = 0.001) of shrub/scrub (higher) and wetlands (lower); major forest cover types were used relative to availability and accounted for the majority of observations (88%) in winter 2010, northeastern Vermont, USA.

located in the wetland and scrub/shrub categories in the NOAA classification into either deciduous, mixedwood, or coniferous classes in the AIMS classification. Further, the more accurate mapping of mixedwood and coniferous stands supported by the 3.2 cm AIMS imagery reclassified certain moose from coniferous to the mixedwood cover type.

Distance to Timber Cuts

Based upon visual analysis of >100,000 thermal and natural color images associated with the 2010 census, we had strong

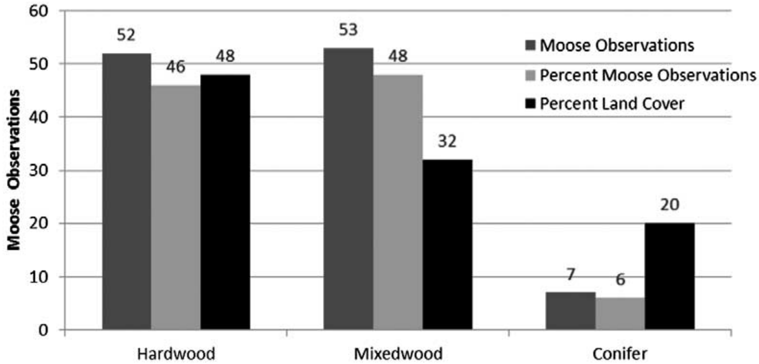

Fig. 7. The distribution of moose observations with AIMS land cover types in winter 2010, northeastern Vermont, USA. Locations increased in mixedwood and declined in conifer relative to the proportional distributions based on NOAA cover types.

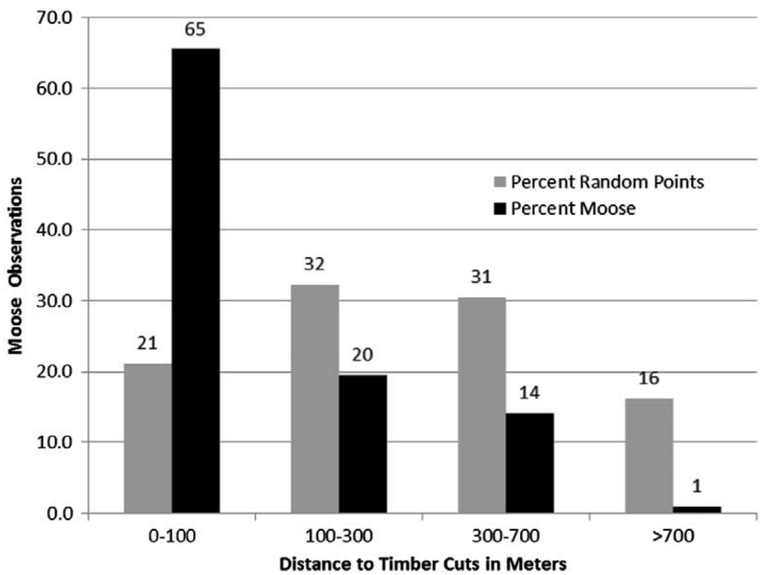

Fig. 8. The distribution of moose observations relative to distance to forest opening/timber cut (Vermont 2009 Orthophoto Data) in winter 2010, northeastern Vermont, USA. A strong correlation (χ^2 =133.09, P <0.0001) existed between distance and the proportion of locations with the majority of locations at <100 m.

anecdotal evidence that moose locations were influenced by the relative distance to forest openings associated with timber harvest. An analysis using Vermont Orthophotography at 1.0 m spatial resolution was done to measure the radial distance from each location to the nearest forest opening. The distribution of locations relative to the proximity of forest openings was non-random (P < 0.0001). The strong, direct relationship was evident as 65% of all locations were within 100 m, 85% within 300 m, and 99% within 700 m of a forest opening (Fig. 8).

DISCUSSION

This GIS analysis of the winter distribution of moose at the landscape level indicated that, for the most part, moose were located throughout the study area in proportion with available cover types, and were little influenced by elevation to 600 m, slope, or aspect. We further investigated whether moose distribution between 300–500 m was influenced by availability of cover type and forest openings but found no pattern. The only obvious deviation in use and availability of cover types was in wetlands (lower) and scrub/shrub (higher); forage use is presumably minimal in wetlands during winter whereas scrub/shrub areas were likely regenerating forest providing preferred winter browse in the region (Thompson et al. 1995, Scarpitti et al. 2005, Bergeron et al. 2011, Andreozzi et al. 2014).

Both analyses with the NOAA and AIMS land cover data were reasonably consistent with most locations either in deciduous or mixedwood forest areas (as expected) and fewer in coniferous forest. However, a lower observation rate in the coniferous cover type could possibly reflect reduced sightability due to higher canopy cover. Due to the inaccessibility of the survey transects and resource limitations, no independent attempt was made to estimate the sightability or error rate of moose not captured in imagery. Therefore, the 93 thermal images containing moose were analyzed to test if the camera lens parallax produced different probabilities of detection inside and outside the image nadir due to screening effects of trees. Images with moose were divided into 5 zones, each representing 20% of the image area from the west-edge to the east-edge, and the numbers of observations were totaled for each zone. The distribution of moose across these zones indicated that there was no apparent screening effect due to lens parallax since more observations were at the edges of images where parallax distortions are highest (Fig. 9; Millette et al. 2011). With regard to the NOAA land cover assignments (Fig. 6), the number of observations in coniferous stands was similar to the available coniferous forest, as it was in the deciduous and mixedwood stands, suggesting that the AIMS-Thermal sensor with its vertical view angle did not suffer from the screening effects of coniferous canopy; overall, coniferous stands (with

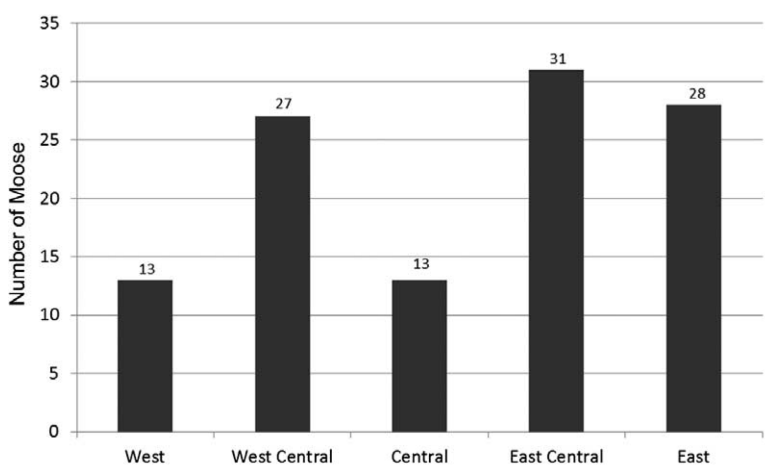

Fig. 9. The distribution of AIMS imagery parallax observations (93 images with 112 moose) indicating that minimal screening effects probably occurred in the coniferous cover type (see Millette et al. 2011).

and without moose) as seen in the AIMS color imagery were not considered densely stocked with tight canopy closure. Interestingly, in adjacent northern New Hampshire, moose were also observed in all cover types with less powerful infrared technology (Adams et al. 1997).

A substantial number of observations moved from coniferous to mixedwood stands when using the AIMS versus NOAA classification. Because the AIMS land cover classification is the product of fine (3.2 cm) spatial resolution color imagery processed by an experienced photo-interpreter, it is considered to be more accurate than the NOAA land cover classification derived from machine-processed Landsat TM data that is less sensitive to distinctions between coniferous and mixedwood forest. Analysis of most observations that were reassigned from the NOAA coniferous cover type to the AIMS mixedwood cover type indicated that, although conifers were present, they represented <20% of the total forest cover in each image. Therefore, we believe that the AIMS analysis provided more accurate use of cover types. High use of mixedwood forest during winter was also measured in northwestern Quebec (Courtois et al. 2002) and northern New Hampshire (Scarpitti et al. 2005). Mixedwood forest can be ideal winter habitat if it contains openings that provide preferred winter forage and coniferous canopy that provides thermoregulatory cover if needed. About 20% of moose were observed bedded in the study and sheltered by a conifer in either coniferous or mixedwood stands.

The most striking landscape metric identified in this study was the strong relationship between moose locations and proximity to forest openings/timber cuts (Fig. 8). Although this relationship is widely recognized (see Peek 1997), this study is based on a very large sample size of moose that can be analyzed at both the landscape and local scale. Because locations were in proportion to the availability of cover types, it is apparent that timber harvesting activity both influenced winter habitat use and was extensive throughout the study area. Given that use of regenerating forest is generally temporal (about 10–15 years), regular use of these surveys could identify shifting habitat use and/or sites with high winter fidelity that are often of concern relative to adequate forest regeneration. For example, Andreozzi et al. (2014) identified certain 10–20 year old clear-cuts in the study area that had poor regeneration.

Although this study was conducted principally to provide a population estimate, it also provided GIS imagery databases that can be explored for current and temporal analyses of habitat use. Specifically, high resolution aerial imagery can be used to produce detailed forest metrics of tree species, stocking density, DBH measurements, and shrub condition in areas of dense winter moose populations. Further, given the concentration of wintering moose, it is possible to cost-effectively task additional survey flights at lower altitudes to produce color imagery with sufficient spatial resolution (1.0 cm) for detailed assessments of size, age, and sex of individuals, twinning rates, and potentially health status based on weight and coat condition. Future studies that simultaneously measure habitat use and population characteristics with this technology will have the distinct advantages of large sample size and accurate temporal information regarding changes in cover type, land use, and moose population size and distribution.

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