USING COVER TYPE COMPOSITION OF HOME RANGES AND VHF TELEMETRY LOCATIONS OF MOOSE TO INTERPRET AERIAL SURVEY RESULTS IN MINNESOTA

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ABSTRACT: Although home ranges of radio-collared moose are typically used to establish habitat requirements and range size of moose, they can be useful in the implementation of aerial surveys. A survey area is usually stratified into low, medium, and high moose density blocks, and radio-collared moose can provide data to improve the stratification procedure because cover type composition in home ranges could help stratify survey blocks. VHF telemetry locations and home range data can also be used to evaluate survey results. In Minnesota high moose density survey blocks contained more of the Conifer Forest cover type and less of the Wet Bog cover type than was present in moose home ranges or VHF telemetry locations. Proportionately more moose were observed in the Mixed Forest and Regenerating Forest cover types during the aerial survey, even though VHF telemetry locations indicated moose were using the Wet Bog cover type. The survey will be biased and underestimate the moose population if undetected moose are not corrected for by a Sightability Correction Factor. Further evaluation of survey data and increased resolution of moose locations is required to resolve this issue.

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Key words: *Alces*, home range, cover type, survey, stratification.

Home range size of moose reported in the literature from VHF radio-collars varies from 4-> 250 km^2 (Hundertmark 1997); seasonal home ranges are usually 10-20 km^2. The cover type composition of home ranges can be calculated based on a GIS layer derived from classified satellite imagery or aerial photograph interpretation. Home range size and cover type composition could be used when designing or evaluating aerial surveys. For example, stratification could be based in part on how much of a preferred cover type is in a survey block.

Annual and seasonal home ranges have historically been calculated using the Minimum Convex Polygon (MCP) method (Mohr 1947). More recently, kernel estimators (Worton 1989, Laver and Kelly 2008) are the preferred method to calculate home range, especially when GPS locations are available. Most radio-telemetry research with moose was done before the advent of GPS collars, and telemetry studies focusing on survival still commonly use VHF collars. Therefore, the MCP remains a common denominator for comparison of home ranges across space and time because of its long history of use.

Most moose aerial surveys are done using a Stratified Random Block (SRB) technique (Gasaway et al. 1986). Pre-survey stratification flights are part of the protocol, but not always done because of the cost and timing of such flights. Most agencies have background knowledge of moose distribution from prior aerial surveys that can be used to stratify blocks into low, medium, or high density. The initial stratification is typically based upon knowledge of moose distribution and previous surveys. In Minnesota, survey blocks are re-stratified annually if an unexpected number of moose are observed in specific blocks during the previous year's survey (Lenarz 1998).

Variance in population estimates of moose generated from aerial surveys is usually so high that a >20% change in the population estimate is required to produce a statistically significant change between years (Gasaway et al. 1986). It follows that attempts to reduce sources of variance would be beneficial for moose management. Low precision in survey results is often caused by incorrect stratification (Lenarz 1998); for example, variance increases if many moose are observed in a low density survey block during the survey.

Sightability is an additional factor affecting moose population estimates. Moose are less visible in thicker cover types such as conifers. Logistic regression sightability models originally developed in western states correct for the reduction in sightability (e.g., Anderson and Lindzey 1996, Unsworth et al. 1998, Quayle et al. 2001). If the difference in cover type composition among strata is assessed, it could theoretically correct for sightability.

One *a priori* approach when habitat use by moose is known is to use cover type in the stratification procedure. For example, in British Columbia existing satellite imagery and past research on moose behavior was used to stratify blocks as high or low density (Heard et al. 2008). Block shape and size was variable and blocks could be stored in GPS units in the helicopter. This was possible because the survey area included cover types identifiable by satellite imagery that were rarely used by moose in winter.

An alternative *a posteriori* approach to evaluate stratification is to use VHF telemetry locations and home range to interpret survey results. Logical predictions are that home ranges would contain proportionately more preferred cover types, moose would be more frequently located in preferred cover types, and survey blocks stratified as high density would contain more area of preferred cover types. This should be especially true in low density moose populations because moose should not have to use marginal habitats.

We used home range and satellite imagery to interpret aerial survey results in Minnesota. We first calculated home range size and cover type composition for moose wearing VHF radio-collars in Minnesota. Next, we compared habitat use by males and females, and contrasted cover type for the different home range calculation methods. Finally, we tested whether cover types of home ranges corresponded to the cover type composition in low, medium, and high-density survey blocks, and whether cover types of moose seen during the survey were consistent with VHF telemetry locations.

STUDY AREA

Our study area was in northeastern Minnesota where moose are currently surveyed (Fig. 1). Forests in northern Minnesota are transitional between Canadian boreal forests and northern hardwood forests to the south (Pastor and Mladenoff 1992). Historic and

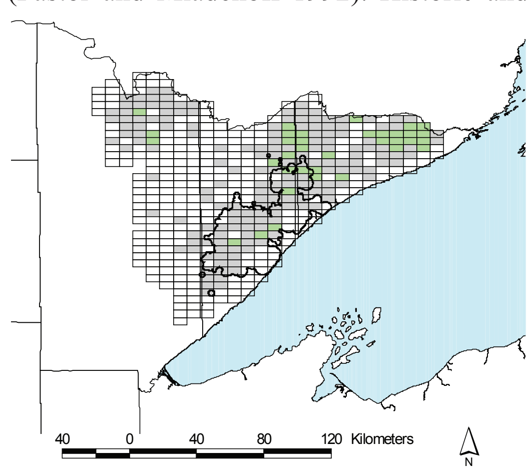

Fig. 1. Study area in northeastern Minnesota in which moose are currently surveyed (Lenarz 2010). Each block is ~35 km² and about 10% of blocks are flown in each annual survey. Shading represents low (white), medium (gray), and high (green) stratification levels. The outline of the composite 95% kernel home ranges of radio-collared moose is shown with a heavy black line.

recent land use has reduced the proportion of upland conifers (white spruce [*Picea glauca*] and white pine [*Pinus strobus*]) in northern Minnesota forests (Frelich 2002, Wolter and White 2002).

Northern Minnesota has a continental climate with moderate precipitation, short warm summers, and severe winters. Snow cover is usually present from December-March. Land ownership in the study area is mostly public within the Superior National Forest and the Boundary Waters Canoe Area and Wilderness; state, county, and tribal lands are also part of the landscape, and blocks of industrial forest land exist outside of the Superior National Forest.

METHODS

Aerial Survey

Moose in northeastern Minnesota are surveyed annually by the Minnesota Department of Natural Resources (MDNR) and tribal biologists (Edwards et al. 2004); here we evaluate survey results from 2004-2011. An aerial survey is used following the Gasaway technique with survey blocks stratified as low, medium, or high density (Lenarz 2011); pre-survey flights to stratify survey blocks were not done. Stratification into low, medium, and high density blocks is based on knowledge of past moose density in the area and collective knowledge of local managers about current moose numbers and recent habitat changes; classification is based on the expected number of moose to be observed in each block if surveyed within a 5 year period. Search effort in low, medium, and high density blocks is 1.4 ± 0.3, 1.6 ± 0.3, and 1.7 ± 0.3 min/km^2 (mean ± SD), respectively (M. Lenarz, MDNR, pers. comm.).

The helicopter survey is flown annually in early January and includes 40 plots with at least 6 high density; the remaining plots are allocated based on variances from the previous year's survey (M. Lenarz, pers. comm.). Moose observed within a survey block are identified to sex and age class, and a GPS waypoint is taken directly over each observation point.

In addition, a Visual Obstruction Covariate (VOC) estimate is made relative to how much vegetation would prevent observation of an adjacent moose (Lenarz 2006, 2011). The VOC is similar to the Vegetation Cover Class described in a moose sightability model developed in Wyoming (Anderson and Lindzey 1996). One exception was that rather than use the criteria of a 3-m perimeter, observers were instructed to estimate percent visual obstruction within 2 moose body lengths of where a moose is first observed; both approaches evaluate the relatively same size area.

Animal Capture and Radio-collars

In 2002-2005 moose were captured and fitted with VHF radio-collars (Advanced Telemetry Systems, Inc., Isanti, Minnesota) in February or March. Moose were netgunned or darted from a helicopter (Lenarz et al. 2009, 2010); animal capture and handling procedures met guidelines recommended by the American Society of Mammalogists (Gannon and Sikes 2009). We divided the VHF telemetry locations into periods relevant to the survey: all year, winter (1 December-30 April), and near the aerial survey dates (1 December-31 January).

Radio-collared moose were monitored weekly from a Cessna 185 aircraft by a single observer with the same pilot on each flight. Location was recorded on a GPS unit carried by the observer or by the pilot in the aircraft. Mean location error was 300 m in a blind test (M. Lenarz, unpubl. data). We tested the effect of location error with simulated data sets. We assumed no directional bias in location error and estimated parameters of the error distance distribution using maximum likelihood with built in non-linear optimizers in Program R (R Development Core Team 2006). We used 30 replicates of location error for each VHF location (J. Fieberg, MDNR, unpubl. data) to test for the effect of location error on cover type composition.

Home range was calculated for all moose with ≥15 locations per year with at least 285 days between the first and last locations. When locations were available for >1 year from the same animal, we calculated a second or third home range for the same individual. We did not use 14 home ranges that had disjunct areas because we wanted to maintain a 1:1 relationship between Minimum Convex Polygon (MCP) home ranges and fixed kernel-based home ranges. We calculated home range in ArcView 3.3 with the Animal Movement Analyst extension (Hooge and Eichenlaub 2000). We compared the size of male and female MCP, 50% kernel, and 95% kernel home ranges with an unpaired *t*-test. We first tested for homogeneity of variance using a folded F-test; we used a t-test if variances were not different between groups and a Satterthwaite *t*-test if variances were different between groups.

Cover Type Analysis

We used the Land Use Land Cover (LULC) raster data set that was based on source imagery from June 1994 with an overall classification accuracy of >95% (MDNR 2007). Only 6 terrestrial cover types comprise >90% of the area where moose occur in northeastern Minnesota. The Mixed Forest type (~50% of the area) has a mature canopy that includes aspen (*Populus tremuloides*), paper birch (*Betula papyrifera*), white spruce, and balsam fir (*Abies balsamea*). The Conifer Forest type has at least 67% conifer species in the canopy and is primarily upland conifers. The Deciduous Forest type has at least 67% deciduous species including red maple (*Acer rubrum*) and oaks (*Quercus spp.*) in the canopy and is primarily in upland areas above the Lake Superior shoreline. The Wet Bog type has black spruce (*P. mariana*) or tamarack (*Larix laracina*), although trees may be at low density in this cover type. The Regenerating Forest type identifies disturbances occurring in 1973-1994. Managed forests often have regenerating aspen and red (*P. resinosa*) or jack pine (*P. banksiana*) plantations. The Marsh and Fen type has small marshes and fens and comprises a relatively small portion of the area. Water covers about 10% of the area. Other cover types included Shrubby Grassland, Human Developments, and Gravel Pits that cumulatively represented <5% of land area and were not analyzed.

We used ArcView to determine the LULC type for VHF telemetry locations, simulated location error of VHF telemetry locations, home range estimators (MCP, 50% kernel and 95% kernel), and the 35 km^2 survey blocks used in the aerial survey. Cover types of actual locations and simulated error locations were compared using each moose as the experimental unit. We calculated cover type composition of the 50% kernel, the 95% kernel, and the MCP home ranges for each moose. We also calculated cover type composition of the composite of the 95% kernel home ranges buffered by 10 km, and the cover type composition of the area surveyed annually for moose (Lenarz 2011).

We compared cover type use by cow and bull moose in winter using home ranges, VHF telemetry locations, and moose locations from the aerial survey. For the home ranges (MCP, 95% kernel, and 50% kernel) we used a *t*-test for cover type composition differences between cow and bull home ranges. To test for differential habitat use in winter, we used a proportion test with H_0 being that cow and bull moose did not use habitat differently for the VHF telemetry locations. We also used ANOVA to test for a difference in cover type composition between home range estimators and point locations.

We tested for the effect of error in position locations on cover type composition by comparing the mean percent composition of all simulated error locations to the cover type compositions of the VHF telemetry location. We also compared the cover type composi-

Table 1. Annual home range size (km^2, mean ± SE) of adult male and female moose in northeastern Minnesota. Kernel home ranges and MCP calculated with Animal Movement Analyst (Hooge & Eichenlaub 2000). Number of locations was 25 ± 1 for females and 24 ± 1 for males. Duration of time period was 342 ± 2 days for females and 350 ± 3 days for males.

		Mean ± SEM	Median	Min - Max
MCP	Females	28 ± 3	19	2 - 141
	Males	45 ± 6	30	10 - 243
95%	Females	40 ± 3	31	4 - 163
Kernel	Males	61 ± 5	46	19 - 158
50%	Females	7 ± 1	4	1 - 38
Kernel	Males	10 ± 1	7	2 - 35

tion of the VHF telemetry locations against the cover type composition of 5 replicates of the position error data set, using the percent of area in each cover type as the test variable, and locations from a single moose as the experimental unit.

We used several comparisons to determine the relationship between moose seen during the aerial survey and moose located via VHF telemetry. First, we compared cover type composition of the low, medium, and high density survey blocks to the cover type composition of VHF telemetry locations from December and January. Next, we compared the cover type composition of locations of moose taken during the survey to the cover type composition of the VHF telemetry locations from December and January using a χ^2 test. Finally, we tested whether the VOC (Lenarz 2011) and group size of moose were affected by cover type in the survey using ANOVA.

We used Statistix (v. 4.1, Boca Raton, Florida) for all statistical tests. Significance level for all tests was set at P = 0.05. GIS analysis was done with either Arcview 3.3 or ArcMap 9.1 (ESRI, Redlands, California).

RESULTS

We calculated annual home ranges of 84 cows and 47 bulls (Table 1). Bull home ranges were larger than cow home ranges (Satterthwaite t-test, MCP: $t_{54.8}$ = 2.22, P = 0.03; 95% kernel: $t_{64.4}$ = 2.87, P = 0.01; 50% kernel: $t_{67.0}$ = 2.50, P = 0.01); an unpaired t-test was also significant for each home range type (t_{115} > 2.57, P <0.001). The Satterthwaite t-test was preferred because the Folded F test for homogeneity of variance indicated there were differences in variance between bulls and cows ($F_{39,76}$ = 2.64, 1.50, and 1.48 for MCP, 95% kernel, and 50% kernel, with P-values of 0.001, 0.07, and 0.07, respectively).

Because bull home ranges were larger than cow home ranges, we compared the percent of each cover type within their home ranges. Cover type composition was not different between bulls and cows in 23 of 24 possible comparisons of MCP, 50% kernel, 95% kernel, and point locations (t-test ($|t_{115}|$ < 1.03, P >0.31 for equal variance or $|t_{>52}|$ <1.14, P >0.36 for unequal variance). The exception was that cows had more Marsh and Fen type in their home range than bulls (t-test, $|t_{113.4}|$ = 2.50, P = 0.01 for unequal variance); this cover type comprised only 3% of the landscape and contained ≤3% of moose locations.

We grouped bull and cow data together since cover type composition of locations and home range estimates were not different between sexes. The percent area in each cover type was not different whether annual MCP, annual 95% kernel home range, annual 50% kernel home range, or all VHF telemetry locations were used to estimate cover type use (ANOVA, $F_{3,463}$ <1.86, P >0.14) (Table 2).

We tested sensitivity of cover type classification of each moose location to error in estimating true position. The mean percent of each cover type from simulated location errors was within a 95% confidence interval for VHF locations of both cows and bulls, except for the Marsh and Fen type (Table 3). When we compared cover type composition using individual animal as the experimental unit, there were no differences in cover type

Table 2. Results of binomial probability tests comparing cover type composition of VHF telemetry locations of cows and bulls in winter; cows n = 1,457 for cows and n = 606 for bulls.

Cover Type	Cow (%)	Bull (%)	Cow:Bull ratio	Z	P
Regeneration/Young Forests	15.9	16.7	0.95	-0.39	0.70
Mixedwood forest	42.8	43.6	0.98	-0.29	0.77
Deciduous forest	1.9	1.3	1.46	0.77	0.44
Coniferous forest	20.3	17.2	1.18	1.59	0.11
Wet Bog	15.7	19.5	0.81	-2.01	0.04
Marsh and fens	2.1	1.3	1.61	1.05	0.29

composition in 5 different replications of the error data set compared to the actual locations in any comparison (t-test ($|t_{162}|$ <1.52, P >0.17 for equal variance or $|t_{>141}|$ <1.52, P >0.17 for unequal variance).

Survey Stratification and Home Range

Moose did not use cover types in proportion to availability whether the comparison was based on MCP, 95% kernel home range, 50% kernel home range, or VHF telemetry locations. Moose used the Wet Bog, Conifer Forest, and Regenerating Forest types proportionally more than their respective availability. In Wet Bog, Conifer Forest, and Regenerating Forest types, the percent of VHF locations and all home range estimators was more than twice the SEM calculated for the respective aerial survey (Fig. 2).

For the survey blocks, stratification led to clear trends in some cover types. Proportions of Conifer Forest and Regenerating Forest increased as stratification increased from Low to High moose density survey blocks (Fig. 3). In contrast, the Deciduous Forest and Mixed Forest types declined as stratification increased from low to high moose density. The Wet Bog cover type increased from low to medium density survey blocks, and then decreased.

Cover type composition in high moose density survey blocks was somewhat similar to the cover types of moose VHF locations in December and January, but there were differences (Fig. 3). Of most biological importance were the differences between the Wet Bog and Conifer Forest types. Moose had more VHF telemetry locations in the Wet Bog type, while the high density survey blocks had more area in the Conifer Forest type (Fig. 3). The Regenerating Forest and the Mixed Forest types were also used by moose relatively more in the high density survey blocks compared to availability.

Cover types that moose were observed in during the survey were different from cover types of VHF telemetry locations in December and January (Fig. 4). Moose were less likely to be seen during the aerial survey in Conifer Forest and Wet Bogs than they should have been according to cover type use from VHF telemetry locations across the survey area (χ_5^2 = 34, P <0.0001) or the cover types of VHF telemetry locations within the 95% kernel home range area (χ_5^2 = 40, P <0.0001). Instead, both bulls (χ_5^2 = 45, P <0.0001) and cows (χ_5^2 = 88, P <0.0001) were observed more often in Mixed Forest during the aerial survey than indicated from VHF telemetry locations. Cover type composition of locations of cows without calves and cows with calves was not different (χ_5^2 = 3.2, P = 0.66).

The differences in cover types between survey locations and VHF telemetry locations were also present within the medium and high density survey blocks separately (Table 4). In the medium and high density survey blocks (χ_5^2 = 68, P < 0.001, and χ_5^2 = 40, P < 0.001, respectively) there were more moose observed in the Mixed Forest and Regenerating Forest types during the aerial survey. Fewer moose were seen in the Wet Bog and Conifer Forest

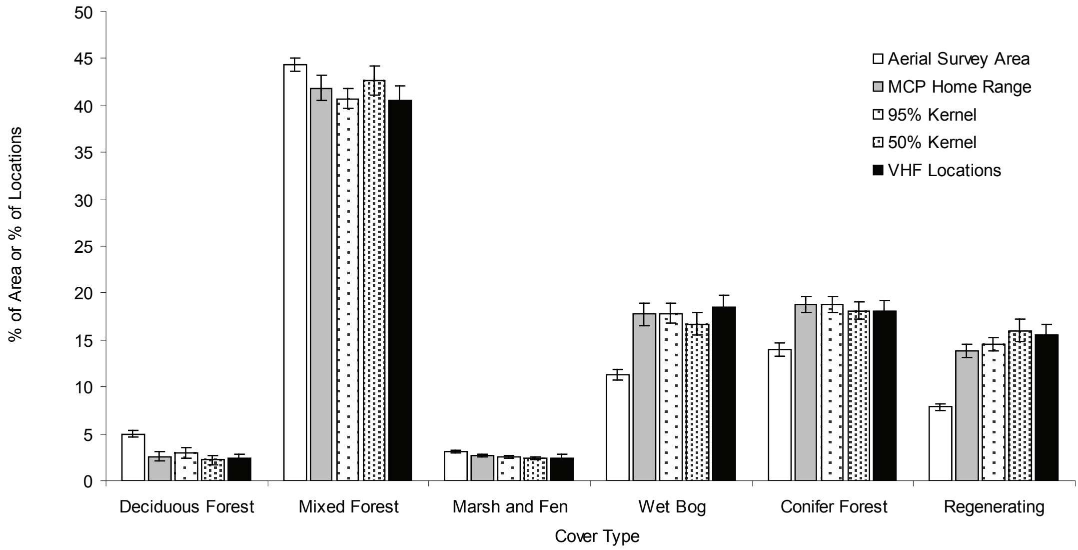

Fig. 2. Area in terrestrial cover types on northeast moose range in Minnesota that is covered in the aerial survey compared to area of Minimum Convex Polygon, 95% kernel, and 50% kernel home ranges of VHF radio-collared moose. The cover type of VHF telemetry locations from which home range was calculated is shown. The SE is for percent of area in each cover type or for the number of VHF locations by moose. The SE on the aerial survey area is across the 453 possible survey blocks.

cover types, yet more moose were present in those cover types based on VHF telemetry locations.

Using data from 2004-2011, the VOC varied among cover types (ANOVA, $F_{5,1343}$ = 2.87, P = 0.01) and among years (ANOVA, $F_{6,1343}$ = 6.54, P <0.001). However, the only difference in cover types was that VOC in Regenerating Forest was lower than VOC in Mixed Forest; all other pairwise comparisons were not different. Similarly, there was only one difference among years; 2011 had a lower VOC than all years except 2007. The overall mean VOC was 38%, with a range of 0-90% for most cover types.

Group size is another possible confounding factor in analysis of cover type use; however, group size did not vary among cover types (ANOVA, $F_{5,1594}$ = 1.27, P = 0.27), although it varied among years (ANOVA, $F_{7,1594}$ = 4.22, P <0.001). No increasing or decreasing trend was evident in group size across years. Overall mean group size during the aerial survey was 1.97 ± 1.09 (SD) moose.

DISCUSSION

Cover type composition of seasonal home ranges or VHF telemetry locations did not correspond with survey block stratification. One reason for this may be the different decision rules under which moose behave and manag-

Table 3. Cover type of simulated locations with position error (n = 30) compared to mean percent of VHF telemetry locations in each cover type for cows and bulls. The SE for VHF locations is based on individual animals (84 cows and 57 bulls); for the simulated error data set SE is across the 30 replicates.

Cover Type	VHF Locations Cows	VHF Locations Bulls	Error Locations Mean ± 95%CI
Regeneration / Young Forests	16.0 ± 1.4	15.4 ± 1.8	15.0 ± 0.4
Mixedwood Forest	41.1 ± 1.9	41.1 ± 2.4	41.8 ± 0.5
Deciduous Forest	2.3 ± 0.5	2.8 ± 1.1	1.7 ± 0.1
Conifer Forest	17.7 ± 1.5	19.5 ± 1.8	19.6 ± 0.3
Wet Bog	17.7 ± 1.7	19.6 ± 2.2	17.5 ± 0.2
Marsh and Fens	3.2 ± 0.5	1.5 ± 0.4	2.4 ± 0.1

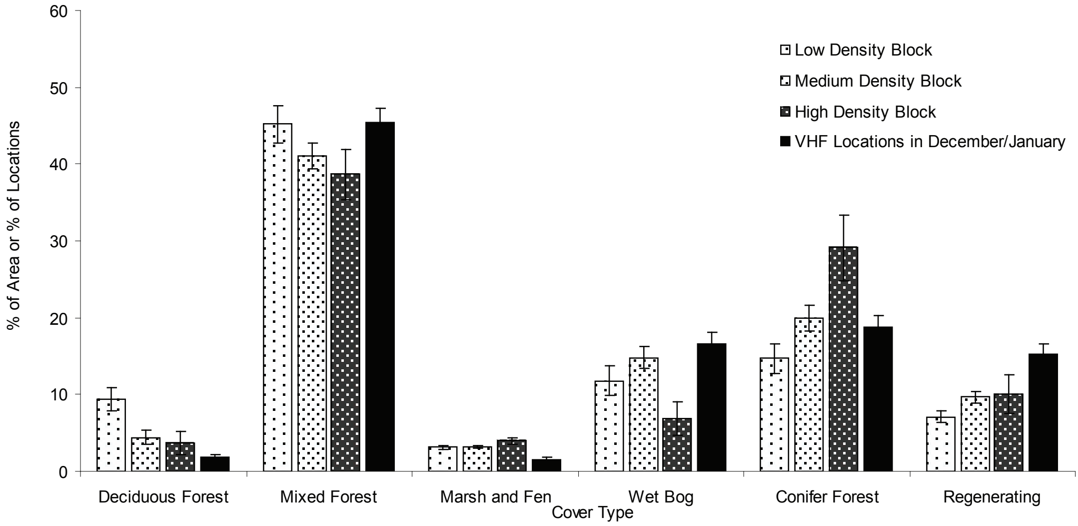

Fig. 3. Cover types in low, medium, and high density survey blocks compared to the cover types of moose locations obtained in December and January. Standard errors on survey blocks are based on cover types across the aerial survey, while standard errors on VHF locations are based on individual moose.

ers operate. Home ranges were smaller than survey blocks, and moose are not restricted to rectangular home ranges like the survey blocks. At the spatial scale of home range, a different mix of cover types can be used by moose than is possible within a survey block that could contain areas (habitats) with very low or high moose density. More precision and reduced costs were achieved in British Columbia when fixed rectangle survey blocks were modified to match habitat features (Heard et al. 2008).

The most striking difference between the aerial survey and the VHF telemetry locations was the distribution of moose among cover types in January when the aerial survey occurs. High density survey blocks contained 4x more area in the Conifer Forest type than in the Wet Bog type, yet both cover types had the same number of VHF telemetry locations in December and January. Furthermore, relatively few moose were observed in the Wet Bog and Conifer Forest types during the aerial survey, with disproportionately more observations in the Mixed Forest type.

The contrast between the relative use of

Table 4. Comparison of cover type percentage where moose were observed during the aerial survey, moose located by VHF telemetry in December and January, and the area available in each cover type across the survey area for low, medium, and high density survey blocks. Survey locations are from 2004-2011 and VHF telemetry data is from 2002-2005.

Stratification:	Low density			Medium density			High density		
Cover type	Survey	VHF	Available	Survey	VHF	Available	Survey	VHF	Available
Regeneration / Young Forest	12	17	7	13	18	10	24	15	10
Mixedwood Forest	58	43	45	64	47	41	55	42	39
Deciduous Forest	3	6	9	3	1	4	5	0	4
Conifer forest	10	17	15	10	19	20	11	23	29
Wet Bog	15	18	12	6	14	15	3	17	7
Marsh and Fen	0	0	3	1	1	3	2	3	4

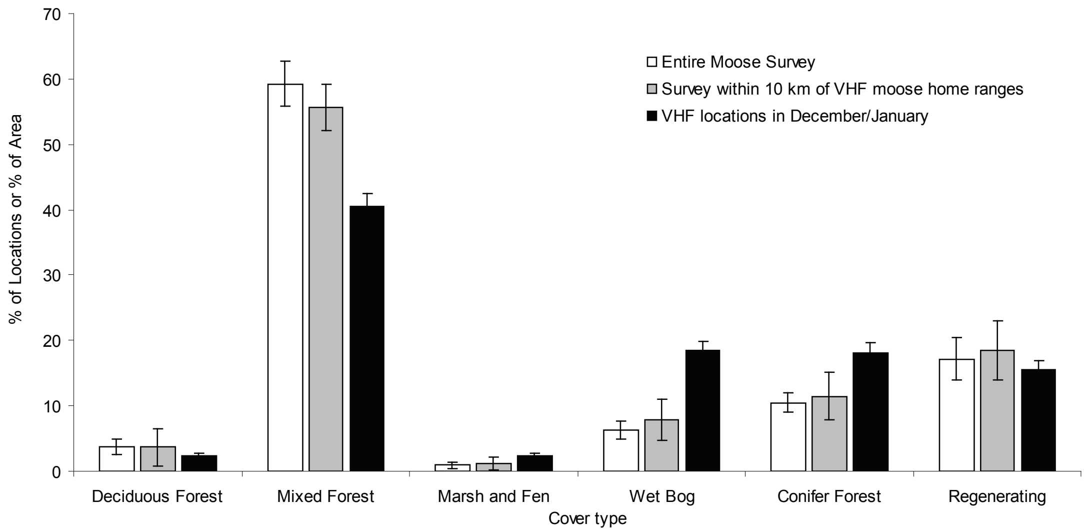

Fig. 4. Cover types of VHF telemetry locations compared to the cover types in which moose were located in during the 2004-2011 aerial surveys in Minnesota. The cover types of VHF locations are from December and January. Moose locations during the survey are either from the entire survey or from locations during the survey that were within 10 km of the composite 95% kernel home range boundary.

cover types identified in the aerial survey and VHF telemetry has important implications for survey design. Stratification of survey blocks is intended to generally reflect moose density (Lenarz 1998) and account for sightability; however, moose are difficult to observe in conifer cover during aerial surveys (Karns 1982, Peterson and Page 1993). The lower sightability of moose in conifer cover would be compensated for by a Sightability Correction Factor (SCF) if the VOC varied among cover types; however, VOC did not vary among cover types. Rather, VOC reflects the conditions at a location where moose are observed not visibility differences among cover types (Lenarz 2006). If unobserved moose in heavy conifer cover are not accounted for, the population size will be underestimated. This was recognized in the development of the VOC method in Minnesota (Lenarz 2006), and is relevant in any region where moose use conifer cover in winter unless the SCF accounts for sightability differences among cover types.

The Regenerating Forest, Conifer Forest, and Wet Bog types were important components of home range estimates, VHF locations, and locations during the survey corroborating current understanding of moose habitat needs (Peek 1997, Thompson and Stewart 1997). One surprising outcome of the home range and VHF telemetry calculations was the consistency of cover type composition at different scales. Cover type composition was not different in the MCP, the 95% Kernel, the 50% kernel, and the actual VHF locations. Patches of habitat in northeastern Minnesota are small enough that areas as big as a moose home range would include both used and unused cover types. The cumulative movements around a home range result in inclusion of each cover type, but not in proportion to availability on the landscape.

Home range sizes of moose in Minnesota were consistent with published literature (Hundertmark 1997) even though the number of locations for many moose was relatively small for calculating an annual home range. Sensitivity analysis using GPS data in Quebec indicated that an MCP home range for moose was usually underestimated with <100 annual or <30 seasonal locations (Girard et al. 2002). However, the kernel home range size would not change greatly if more locations were available each year in our data (R. Moen, unpubl. data).

Fine scale evaluations possible with GPS locations (Leblond et al. 2010) cannot be accomplished with VHF telemetry, but our estimated mean location error of 300 m would have little effect on home range calculations >10 km^2. Although such error could affect cover type composition, the cover type composition of simulated locations with position error was very close to the cover type composition of actual locations. Differences were unlikely to be biologically significant given the range of cover type composition among individual animals. Even rarely used cover types that were also rare on the landscape remained in the location data set when location error was simulated.

We evaluated many possible confounding factors that would have affected our conclusions. The years were different within the data set as the VHF telemetry data were collected in 2002-2005, and the survey data in 2004-2011. The same patterns remained when we subset the data creating a much smaller sample size for overlapping years. Group size of moose did not vary among cover types or over time; if it had this might have changed moose distribution estimates. Patterns remained consistent whether we used the entire survey area or we restricted the analysis to the part of the survey area with radio-collared moose. The analysis could be expanded by using an independently derived cover type classification, and reaching the same conclusions from independent satellite classifications increases confidence in results (Moen et al. 2008).

Management Implications

If a pre-survey flight is not possible to stratify survey blocks, home range size and cover type composition data can be used to improve survey stratification. Even if a pre-survey flight is possible, any procedure that will increase the ability to detect change in a moose population would help agencies better manage moose. Finer scale analysis of cover types and cover type composition within a survey block could be one factor affecting the decision of stratification level for each survey block, in addition to using historical understanding of moose presence. The ideas presented in this paper can be further developed and tested with ongoing and future radio-telemetry research in Minnesota. A correction factor for cover type could be developed from observation rates of radio-collared moose in different cover types. We believe that accounting for moose that are probably underestimated in Wet Bog and Conifer Forest during aerial surveys would produce a higher population estimate of moose in northeastern Minnesota.

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