MODELING MOOSE DENSITY USING REMOTELY SENSED HABITAT VARIABLES

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ABSTRACT: Models for moose density were developed using subsets of remotely sensed habitat variables in north-central Alaska. Macro-habitat factors explained from 60 to 70% of the variation in November moose densities using a regression model. Use of logistic regression allowed correct classification of most sample units into 3 moose density categories, based solely on habitat characteristics. Fire was less important to the model than anticipated, whereas river riparian zones were more important than expected. Fire was not the major determinant associated with high moose density in this interior Alaska study area. Models based on habitat alone may be useful for predicting moose density classes for some management purposes.

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Identifying and quantifying the relationship between moose *(Alces alces gigas)* density and one or several habitat variables available from modern remote sensing capabilities may provide information useful for making wildlife and habitat management decisions. It may be possible to predict the effects of changing one or more habitat variables (*e.g.*, a wildfire or prescribed burn) on moose distribution, or to develop a predictive model for habitat suitability. Such models have been developed for moose in other areas (Allen *et al.* 1988, LaPerriere *et al.* 1980) and for other cervids, such as elk *(Cervus elaphus)* (Eby and Bright 1985) and woodland caribou *(Rangifer tarandus)* (Rayner and Bennett 1988).

In recent years, the Bureau of Land Management (BLM), U.S. Fish and Wildlife Service (USFWS), and Alaska Department of Fish and Game (ADF&G) have begun to systematically inventory moose in interior Alaska. The most widely used technique is stratified random sampling from aerial surveys (Gasaway *et al.* 1986). In addition, many kinds of habitat data are now available to wildlife managers for large areas. Fire history is archived with BLM Alaska Fire Service (AFS) and classified vegetation maps from satellite imagery have been produced for most national wildlife refuges (Shasby and Carneggie 1986, Talbot and Markon 1988) and some other public lands. Other remotely sensed habitat information, including soils and digital elevation data, is becoming increasingly available. To date, there have been few attempts to correlate moose distribution and habitat characteristics on a regional scale within Alaska.

There has been much recent interest within regulatory agencies in using wildfire management or prescribed burning to improve habitat for moose (Kelleyhouse 1980, Robinson and Anderson 1990). Fires are thought to benefit moose by returning vegetation to earlier successional stages (Spencer and Hakala 1964, Bishop and Rausch 1974). Early seral communities have greater annual production of woody browse than do late successional communities (Wolff 1978). Periodic fires also establish habitats with a varied age structure (Methven and Feunekes 1987). The resulting mosaic of vegetative types is considered ideal for providing food and cover for moose (Kelleyhouse 1980).

In some locations, such as Alaska's Kenai Peninsula, fires have been associated with local increases in moose density (Bangs and Bailey 1979, Spencer and Hakala 1964). Few quantitative studies of fire-moose effects have been conducted in other parts of Alaska due to the time and expense of following a population through an appropriate period of time after the burn. Fall or early winter concentrations of moose have been noted in large burns such as the 14-year-old Farewell burn near McGrath, in central Alaska and the 12-year-old Blair Lakes burn. Gasaway *et al.* (1988) studied the initial response of radio-collared moose to the 500-km^2 Blair Lakes fire south of the Tanana River in interior Alaska. Moose that previously used the area either increased or decreased their use in the first 4 years following the fire, while there was no post-fire use by moose with home ranges in close proximity to, but outside the burn perimeter.

My initial observations of a large study area in north-central Alaska failed to detect an obvious relationship between moose concentrations and recently burned areas on a macro scale. Therefore, I decided to use computer technology to analyze existing data on moose, vegetation, occurrence of fire, and topography for correlations in an attempt to further define the relations between moose density and habitat features. My objectives were to identify the role of fire compared to other habitat factors in creating high-quality moose habitat and to test the feasibility of using a habitat model to predict moose density. The specific hypothesis to be tested was whether the distribution of moose densities over a large region in north-central Alaska can be explained by variations in remotely sensed macro-habitat factors.

STUDY AREA

The study area was located north of the Yukon River, in north-central Alaska (Fig. 1). About 75% of the area lies within the Koyukuk-Nowitna National Wildlife Refuge (NWR) with much of the remainder managed by the BLM Kobuk District or native village and regional corporations. A contiguous area of 939,000 ha with recent moose density data was subjected to spatial analysis. This area was chosen because 1/3 of the area has burned within the recorded fire history of 30-35 years, presenting a varied fire mosaic.

Most of the study area is drained by the Koyukuk River, which has an extensive flood plain. Well-drained, hilly, or sunny sites are forested with a mixture of white spruce *(Picea glauca)* and deciduous species like paper birch *(Betula papyrifera)*. Lowlands, poorly-drained sites and gentle slopes are dominated by black spruce *(P. mariana)*. On the depositing slopes of smaller meandering streams, the forest is largely white spruce, quaking aspen *(Populus tremuloides)*, willows (*Salix* spp.), and balsam poplar *(P. balsamifera)*. Treeline is about 300 m on north-facing slopes and 600 m on south slopes. Elevations >900 m are generally tundra. Soils of this region were described by Rieger *et al.* (1979).

The climate in this region is cold and continental. Galena has a mean annual temperature of -3.8° C, but the temperature can range from 38° to -56° C. The mean temperature in January is -12.6° C and the frost-free period is about 100 days (USDI 1973). Precipitation averages 37 cm annually, with an average snowfall (at Galena) of 137 cm (USDI 1973, Selkregg 1976).

Using the criteria of density, sex ratio, and recruitment of calves and yearlings, the moose population in the study area is considered healthy and vigorous (Bodkin *et al.* 1990). The average density of moose on the Koyukuk-Nowitna NWR in 1989 was 0.46 moose/km^2 with a range of 0.04 to 3.6 (Bodkin *et al.* 1990). This mean density is above average compared to other regional densities for boreal forest and taiga areas (Telfer 1984). The Koyukuk-Nowitna Refuge population averaged 19% calves, 14% yearlings, 43.5% adult females and 23.5% adult males (Bodkin *et al.* 1990).

METHODS

Moose population surveys were conducted in 1987-1989 through a cooperative effort by

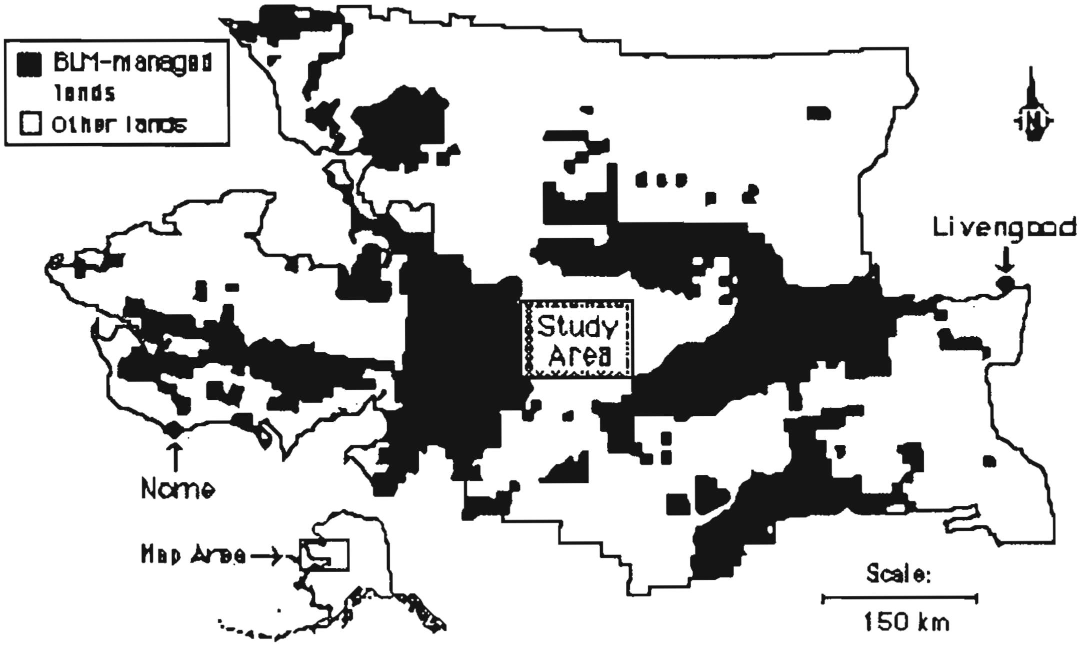


Fig. 1. General location of the study area, showing the boundaries of BLM's Kobuk District, which manages about 17 million ha of public lands in Alaska.

USFWS, ADF&G, and BLM Kobuk District (Bodkin *et al.* 1990). The area was divided into polygons of about 3,100 ha (12 mi^2) using topographic features (Fig. 2). A stratified aerial census technique was employed (Gasaway *et al.* 1986), using low-intensity searches to stratify survey units followed by intensive survey of randomly selected units. Both stratification and census counts were used as responses for models in my study. Sightability correction factors were determined for intensive surveys. Sightability in the three years of the surveys was estimated at 96% (1987), 98% (1988) and 67% (1989). All surveys were flown in November, when local snow cover, weather, daylight, and moose sightability are optimal for aerial surveys.

A land cover map for the Koyukuk-Nowitna NWR derived from 1977 Landsat imagery shows 6 major vegetation classes and 17 subclasses. Talbot and Markon (1988) described sample areas based on a combination of helicopter and ground survey, high-altitude aerial photos, and digital Landsat data. Vegetation classes were regrouped into 9 cover types for purposes of my study (Table 1). The ground resolution of Landsat (1-3) multi-spectral scanners (MSS) is 56 x 79 m, which represents 1 picture element or "pixel" (Epp 1988).

Computerized records of fires from the BLM Alaska Fire Service, maps prepared by suppression personnel, and Landsat imagery were used to map all fires $\geq$40 ha. Fires were grouped by years into 4 classes (Table 1, Fig. 3). Soil types were taken from Exploratory Soil Survey of Alaska (Rieger *et al.* 1979). These soil types are large continuous blocks of land that have been categorized using land form, cover, and soil characteristics. Three soil types proved important in modeling (Table 1).

After collection of data, the analysis proceeded in 4 stages: (1) encoding the data, (2) generating a statistics file from spatial data and moose survey polygons, (3) exploratory

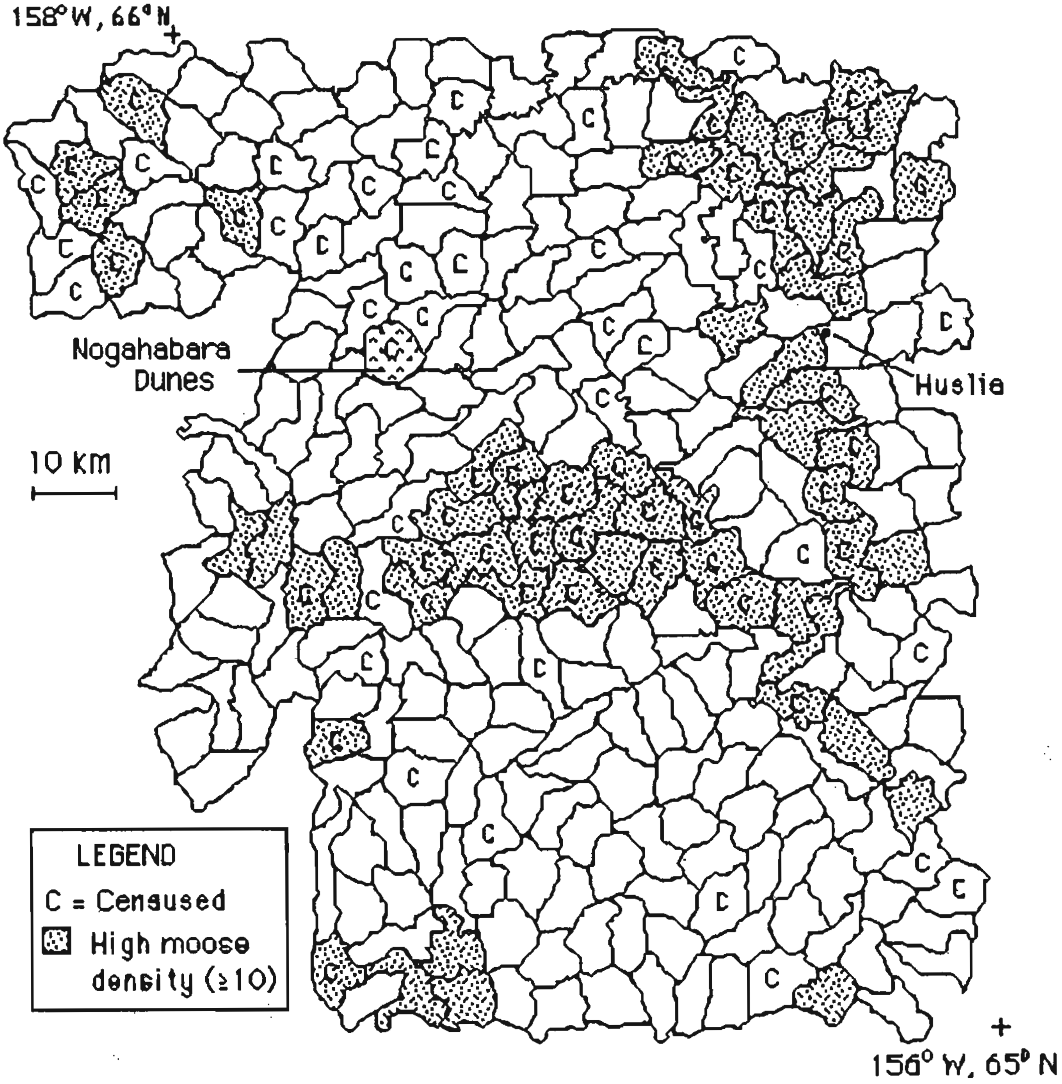


Fig. 2. Map showing the spatial distribution of moose sample units over the north-central Alaska study area. High-density units, defined as having ¯10 moose recorded during stratification survey, are stippled.

data analysis, and (4) statistical analysis and modeling. The amount of each habitat component present in individual moose survey polygons was measured using the rastor-based analysis software LAS (Land Analysis System) version 4.0 (EROS 1986). Other habitat variables, such as the "edge" between fires and "unburned" areas, were also derived using LAS software. Habitat variables were expressed as percent composition within each moose sampling unit (Tables 1 and 2). A rastor-based system was selected due to the extreme spatial heterogeneity of habitat features, particularly vegetation.

Scatter plots of habitat variables with moose density were evaluated for correlation and linearity. A Pearson correlation matrix was used to test independence of explanatory variables, and no two variables with r >|0.7| were allowed to enter regression models concurrently. Log-transformed moose densities obtained from the stratification survey were

Table 1. Definitions of several variables used during exploratory and regression analysis relating moose density to habitat factors in north-central Alaska.

Name:	Description:
DEMO	Lowest elevation class: from 36-92 m
DEMA-D	Elevation classes from 93-573 m in 120-m increments.
DEME	Highest elevation class: from 573 - 702 m
HIELE	Elevation > 332 m
FIREA	Burns from 1984-1988**
FIREB	Burns from 1977-1981
FIREC	Burns from 1969-1974
FIRED	Burns from 1957-1960
FORED	Ecotone between forested types (VEG1-3) and "open" types (all other)
MELE	Mean elevation
MSLO	Mean slope
RB1	Binary variable: RB1 = 1 if >50% burned after 1960, otherwise RB1 = 0.
OB1	Binary variable: OB1 = 1 if >50% burned before 1960, otherwise OB1=0.
RBE	Edge (ecotone) of a recent burn (since 1960)
OBE	Edge (ecotone) of an old burn (before 1960, but none before earliest fire records: 1956)
RIV	Area within 800 m of a river (river riparian zone)
NOSLO	Flat terrain.
SLP1-10	Slope classes from 1% to 10%
SLP 11	Slope of 11-19%
SLP20	Slope of 20-29%
HISLO	Slope ˉ 20%
LOSLO	Slope of 1-10%
SSE-WSW	South aspects from south-southeast to west-southwest
SOIL2	Aquept IQ3*. Histic pergelic cryaquepts (45%) and typic cryofluvents (35%). Loamy level association.
SOIL4	Umbrept IU2*. Pergelic cryumbrepts (45%) and histic pergelic cryaquepts. Very gravelly hilly to steep association.
SOIL6	Ochrept IR7*. Typic cryochrepts (35%) well-drained on low stabilized dunes and histic pergelic cryaquepts (30%).
VEG1	Needleleaf forest (>25% tree cover)
VEG2	Needleleaf woodland (10-25% tree cover), "taiga"
VEG3	Mixed forest or deciduous forest (25-100% tree cover)
VEG4	Broadleaf scrub (alluvial) or alpine/subalpine deciduous shrub
VEG5	Dwarf scrub graminoid peatland
VEG6	Prostrate dwarf shrub tundra
VEG7	Herbaceous: includes wet, moist, dry, and "fire regeneration--graminoid"
VEG8	Unvegetated, including scree, sand dunes, and floodplain
VEG9	Water (ponds, lakes, rivers or streams) or aquatic forb

*Based on Exploratory Soil Surveys of Alaska by Reiger *et al.* (1979).

**In some years, fires either did not occur, or were not recorded.

Table 2. Summary statistics for selected variables used in analysis of moose density and habitat factors, north-central Alaska. Variables are defined in Table 1.

	Moose density group (moose/sample unit)			Overall				
Variable	0-2	3-9	¯10	Mean	SD	CV	Min	Max
SOIL2	0.07	0.30	0.76	0.26	0.40	1.54	0.00	1.00
SOIL4	0.01	0.06	0.05	0.03	0.16	5.52	0.00	1.00
SOIL6	0.19	0.07	0.00	0.13	0.29	2.32	0.00	1.00
RIV	0.09	0.19	0.35	0.17	0.20	1.18	0.00	0.78
VEG3	0.02	0.04	0.10	0.04	0.05	1.28	0.00	0.29
VEG7	0.21	0.22	0.20	0.21	0.15	0.68	0.01	0.87
VEG4	0.02	0.06	0.04	0.03	0.06	1.70	0.00	0.44
ESE	0.10	0.08	0.05	0.08	0.05	0.57	0.00	0.23
FIREB	0.03	0.05	0.05	0.04	0.17	4.67	0.00	1.00
FIREC	0.26	0.12	0.01	0.18	0.34	1.86	0.00	1.00
HIELE	0.01	0.03	0.01	0.01	0.05	4.30	0.00	0.46
Count	n = 166	n = 55	n = 59	n = 280				

regressed on those habitat variables indicated by the results of exploratory analyses. The transformed variable representing stratification moose density is defined as ln [(moose seen during stratification survey + 1)/(subunit area in km^2)], and will hereafter be called "stratification moose density." Stepwise multiple linear regression (MLR) followed by all possible subsets regression (BMDP 2R, 9R) was used to determine the best model (Neter *et al.* 1985), based on the magnitude of the adjusted multiple correlation coefficient (R^2_a) and Mallows' C_p statistic (Afifi and Clark 1990). Regression models using the density of moose from the census of 76 subunits also were selected using best subsets regression (BMDP 9R). Aptness of the regression models was evaluated by formal testing and graphical examination of residuals.

Regression using ranks of stratification moose density and ranks of explanatory variables was performed to check the results of parametric multiple regression. Stepwise logistic regression (BMDP LR, PR) was used to classify sample units into density groups. The method of maximum likelihood was used iteratively to compute estimates of the parameters for an equation giving the probability of belonging to a group (Afifi and Clark 1990). Ranks regression and logistic regression require no distributional assumptions for variables (Conover and Iman 1981, Press and Wilson 1978).

The step selections for logistic regression were based on approximate asymptotic covariance estimates, an approximation of the maximum likelihood ratio (Engleman 1990). All variables having an F-to-enter with $P < 0.30$ were entered in forward stepping, then successively eliminated in backward stepping if $P \geq 0.06$ (Hosmer and Lemeshow 1989). Fit of the logistic regression model was assessed by examining C. C. Brown, chi-square, and Hosmer-Lemeshow goodness-of-fit statistics. Effectiveness of the logistic regression models in predicting outcomes was evalu-

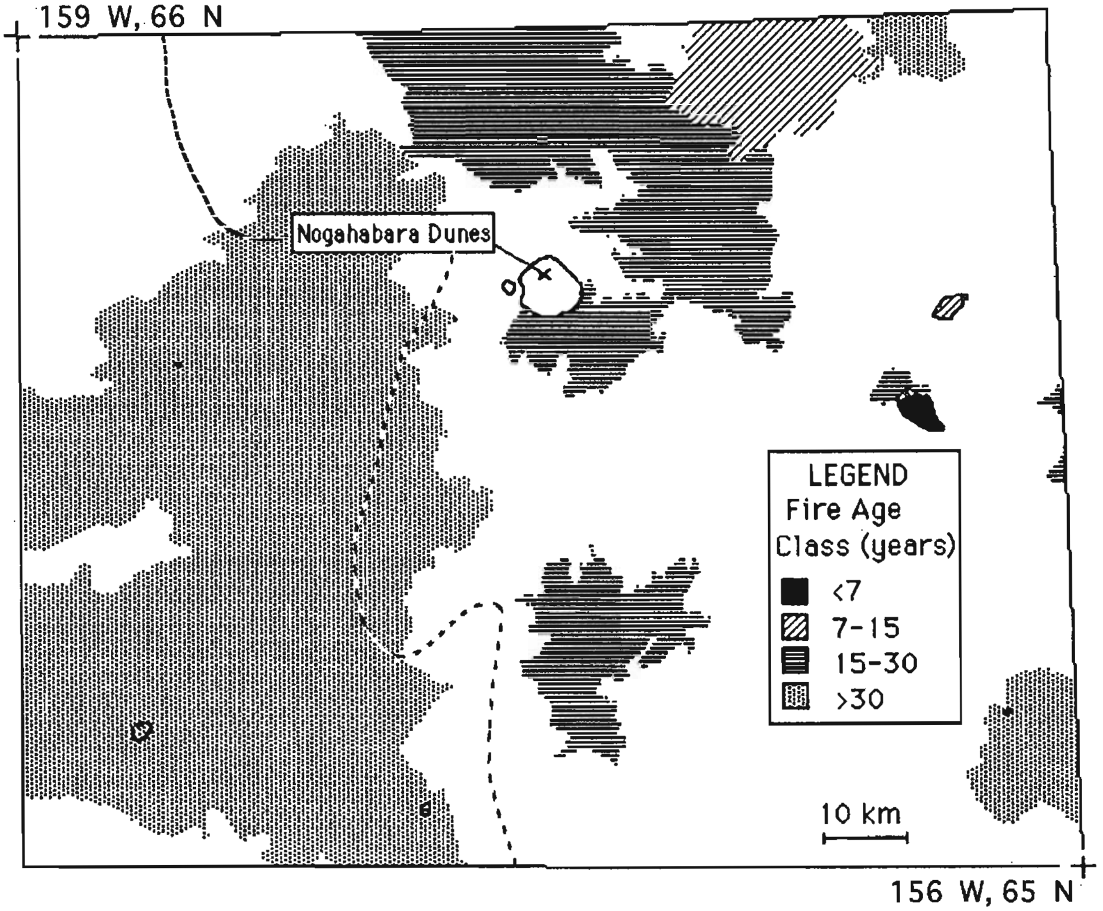


Fig. 3. Map showing recorded fires between 1956-1987. Fires <250 ha are not shown. Dotted line indicates approximate western boundary of the analysis area from Fig. 2.

ated using histograms to show classification success.

RESULTS

The original number of independent variables was reduced through elimination of redundant, highly intercorrelated, or unimportant variables. Bivariate scatter plots of individual habitat variables with moose density showed that none of the variables had strong linear relationships with moose density. A comparison of group means across 3 classes of moose density is shown in Table 2. Variables which differed most among groups and showed the most consistent increase or decrease across all groups tended to be important discriminators of moose density groups. SOIL2, RIV, and VEG3 displayed consistent increases from low to high moose density, while SOIL6, ESE, and FIREC followed a decreasing trend (Table 2).

The best relationship of habitat variables and stratification moose density was:

$$(\hat{Y})_1 = -3.27 + 1.31(\mathrm{SOIL2}) + 1.25(\mathrm{SOIL4}) + 1.23(\mathrm{RIV}) + 4.02(\mathrm{VEG3}) + 1.05(\mathrm{VEG7}) + 0.71(\mathrm{FIREB}) + 2.20(\mathrm{VEG4}) - 0.29(\mathrm{SOIL6}) - 1.84(\mathrm{ESE})$$

(See Table 1 for abbreviations). The regression is significant ($F = 48.44$, $P < 0.001$, $n = 280$) with $R^2_a = 0.60$ (Fig. 4). The sign and relative magnitude of standardized coefficients indicates the importance of habitat variables in the equation for moose density (Table

3). All coefficients except SOIL6 and ESE are significantly different than zero at the 95% confidence level (Table 3). C_p for this model, with 9 variables, was 8.38.

Excluding low-density moose units from the analysis, produced a regression equation with a poorer fit ($R^2_a = 0.48$, $F = 15.82$, $P < 0.001$), but selected most of the same variables, *i.e.* SOIL2, VEG3, SOIL4, SOIL6, VEG7, SSW, and ESE (in decreasing order of contribution to R^2). Burn variables FIREB and FIREC still did not improve the model significantly (F-enter <1.0, P >0.1). Coefficients of partial correlation were positive except for SOIL6, ESE, and FIREC.

Moose density data were tested for differences among the 3 survey years. Slopes and intercepts of regressions on habitat variables by year did not differ significantly from those of the combined data ($F = 0.992$, $P = 0.47$). Regression on ranks was used to check on the results of multiple regression. In general, the magnitude and sign of coefficients for ranked covariates was similar to that of the original covariates.

Another regression model was used to assess whether a large portion of the remaining unexplained variation in moose density from the Y_1 model could be attributed to the inaccuracy of moose counts obtained during low intensity surveys. Moose densities from the 76 sample units that were censused at standard search intensity were used as the dependent variable for regression (Y_2):

$$(\hat{Y})_2 = -2.84 + 1.43(SOIL2) + 1.90(SOIL4) + 8.22(VEG3) + 2.07(RIV) + 1.41(FIREB) + 1.85(VEG7)$$

All 6 coefficients were significant ($P < 0.05$). Changes in the magnitude of coefficients should be studied with caution, as the 76 censused units were not randomly selected from the population as a whole but represented a higher proportion of units having high moose density (Fig. 2). A larger percentage of the medium- and high-density moose units was surveyed to reduce the variance of the population estimate (Gasaway *et al.* 1986). Nevertheless, for Y_2, $R^2_a = 0.69$ ($F = 28.9$, $P < 0.001$), suggesting that habitat factors could explain more of the variation in moose numbers when more accurate density information was used.

Polychotomous logistic regression produced an equation to estimate the probability of a particular sample unit being place in low,

Table 3. Coefficient table for "best" 9-variable regression on stratification moose density. Variables are listed in decreasing order of contribution to R^2. Variables are defined in Table 2.

Variable name	Regr. coeff.	Std. error	Std. coeff.	T-stat.	Sig. level
Intercept	-3.274	0.1392	-2.795	-23.51	0.000
SOIL2	1.312	0.1486	0.451	8.83	0.000
SOIL4	1.247	0.2956	0.169	4.22	0.000
RIV	1.233	0.3077	0.206	4.01	0.000
VEG3	4.016	1.247	0.177	3.22	0.001
VEG7	1.050	0.3411	0.130	3.08	0.002
FIREB	0.707	0.2647	0.104	2.67	0.008
VEG4	2.199	0.9727	0.106	2.26	0.025
SOIL6	-0.288	0.1694	-0.072	-1.70	0.090
ESE	-1.840	1.104	-0.076	-1.67	0.097

medium, or high moose density strata, based on habitat factors:

$$P([CAT^*] > LO) = \frac{EXP(-2.410 + D)}{1 + EXP(-2.410 + D)}$$

$$P([CAT] > MED) = \frac{EXP(-4.574 + D)}{1 + EXP(-4.574 + D)}$$

$$P([CAT] > HIGH) = 0$$

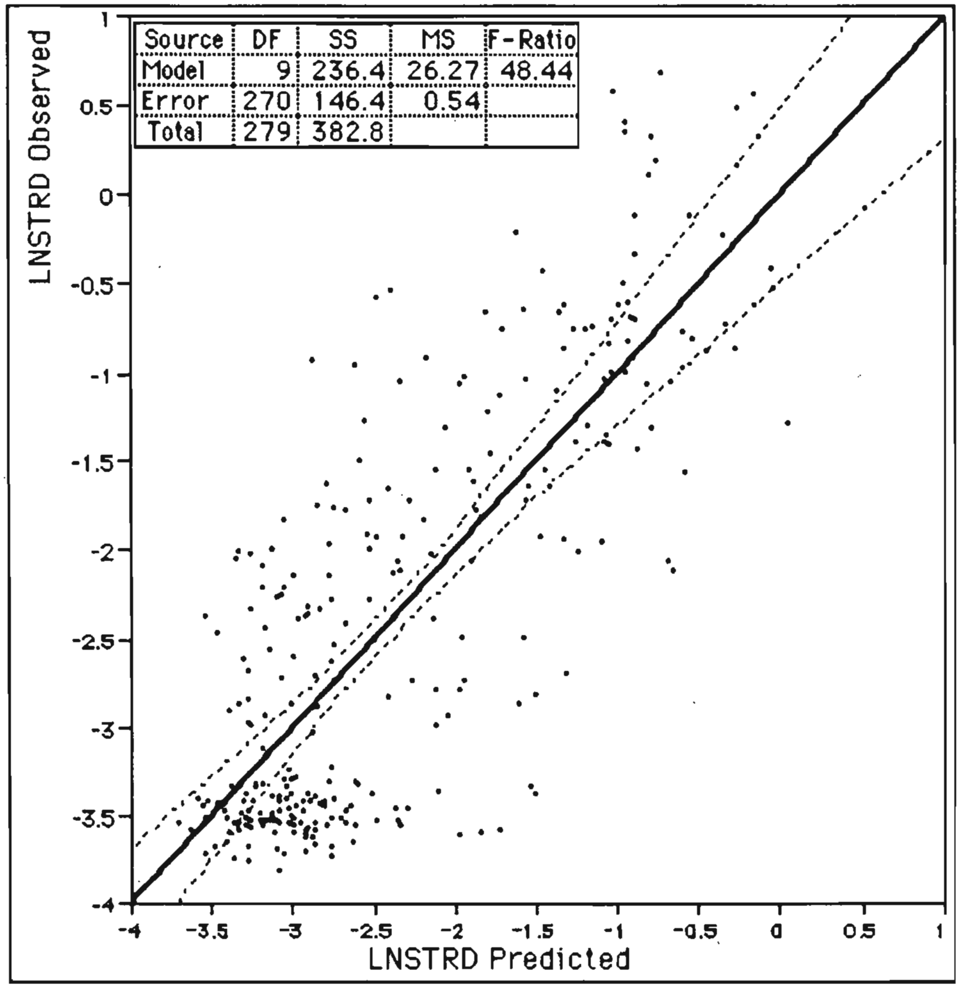
*where CAT = density category and $D = 11.15(VEG3) + 5.590(VEG4) + 2.767(RIV) + 2.463(FIREB) + 2.908(SOIL2) + 2.400(SOIL4) - 7.428(ESE) + 3.103(VEG7)$

Coefficients of the 8 input variables in the above equations were significant (*P* -0.05). The log likelihood for this model (-169.194), was highly significant ($x^2 = 338$, $P = 1.000$). Performance classification histograms show that it is possible to use this model to allocate units to LO and HIGH categories with some confidence, but allocations to MED are uncertain (Fig. 5). Overall success was about 70% (Fig. 5). When intermediate-density units were excluded, logistic regression correctly classified 93% of the remaining observations into LO or HIGH.

DISCUSSION

Habitat Factors Used to Predict Moose Density

Density of moose in November did not



Source	DF	SS	MS	F-Ratio
Model	9	236.4	26.27	48.44
Error	270	146.4	0.54	
Total	279	382.8		

Fig. 4. Fitted regression line for stratification moose density (LNSTRD) in north-central Alaska using 9 habitat factors (Table 3). Dotted lines show 95% confidence band for mean slope.

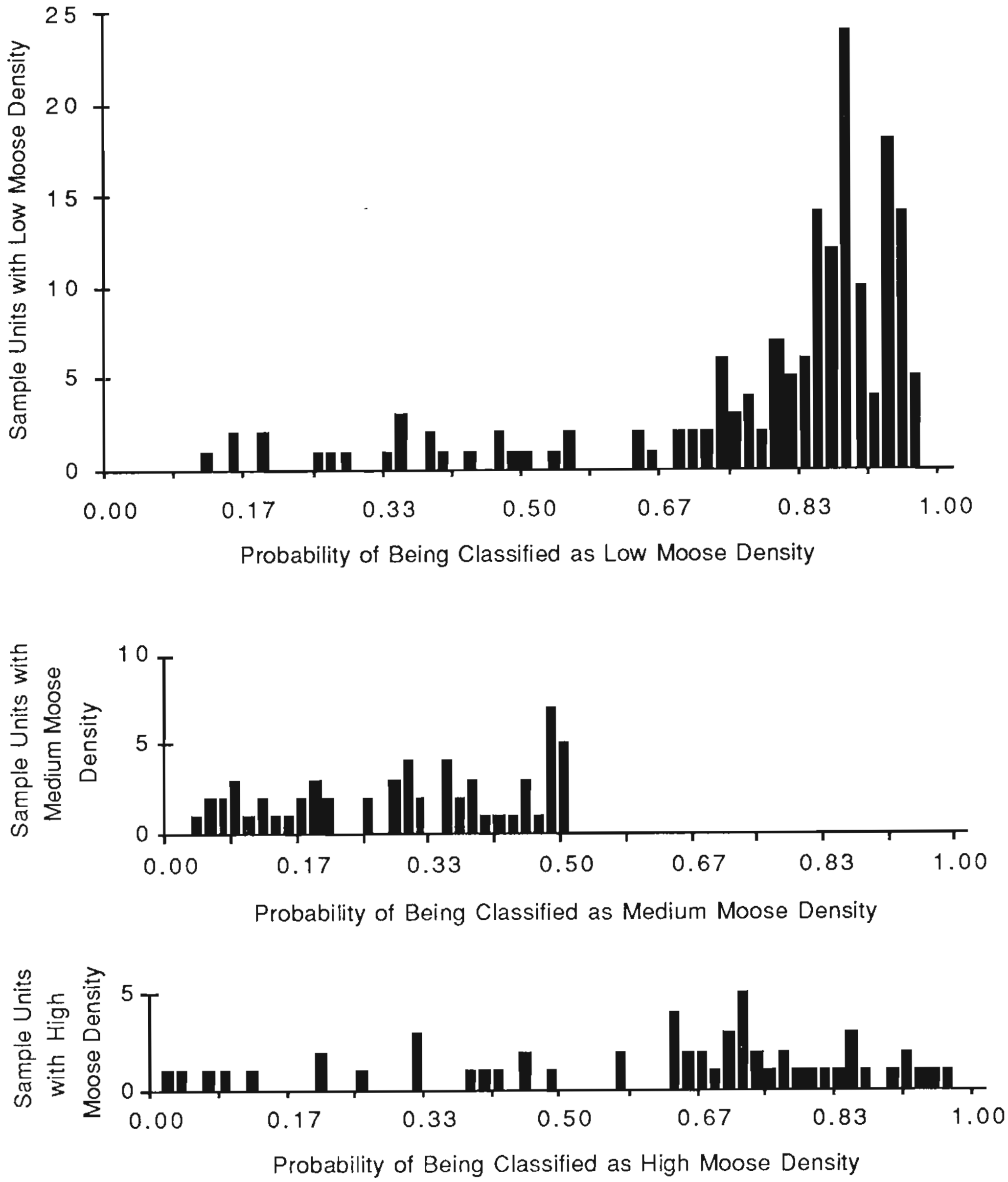


Fig. 5. Histograms of classification probabilities from polychotomous logistic regression of 3 moose density classes on 8 habitat factors in north-central Alaska.

have a direct linear relationship with the percent composition of any individual habitat factor. Habitat has many components including an adequate food source, escape cover, shelter from extremes of weather, bedding sites, and probably other components yet to be elucidated (Allen *et al.* 1988, Kowal 1977). Even though moose select for specific attributes of their total environment in a predictable manner, only a small subset of potentially important factors was used in modeling. Predator densities, harvest, traditional use patterns, competition, parasitism, and weather were not used. Consequently, failure to reject the null hypothesis of this study—that moose density is random with respect to the limited set of habitat factors considered—was a rather probable outcome. Instead, a MLR approach explained a considerable amount of the variation in moose density.

Cryofluvent soil types (SOIL2), cryumbrept soil types (SOIL4), mixed or deciduous forest (VEG3), and proximity to rivers (RIV) had the highest correlation with moose density in MLR models (Table 3). Cryofluvents are well-drained alluvial soils with alternating layers of sand and silt loam, which occur naturally along watercourses. Cryumbrepts are well-drained soils on upper slopes usually supporting growth of low shrubs, mosses, and lichens. "Soil types" as used here represent large general physiographic and ecological sites. Many of the characteristics used to define soil types (Rieger *et al.* 1979) include other variables, such as vegetation and topography. Therefore, multicollinearity among independent variables could cause important intercorrelated variables to be dropped when relying on standard t-tests for significance of the coefficients (Neter *et al.* 1985). Trial regressions with and without soil types showed that the order of other contributing variables did not change greatly, but including soils did improve the predictive ability of the model. When soil types were excluded from analysis, VEG3 and RIV were always the most important input variables, regardless of which other variables were used.

The distribution of VEG3 over the study area follows major drainages, although not closely correlated with RIV. These components can be combined into a "riverine" habitat that had components of mature forest consisting mainly of white spruce, birch, and aspen overstory. Forested riverine habitats are important for subarctic moose populations in late winter (LeResche *et al.* 1974). Such habitats provide cover and ease of movement when snow becomes deep, as well as an abundance of preferred browse species. In the high density moose units, VEG3 averaged 9.5% of total vegetative cover (Table 2). Snow depths greater than 60 cm can impede mobility (Coady 1973). Shallower snow occurs both under mature forest canopy and on frozen river channels.

Moose data used in this study were collected in November, and therefore inferences about habitat provide only a "snapshot" of year-round habitat. If habitat use were to be studied in other seasons, a different pattern might emerge. Still, it is interesting that moose density was so closely correlated to the riverine habitat in early winter. In March and April, between 50% and 98% of the moose population concentrates in river corridors on the nearby Innoko NWR, depending on snow depth (R.M. Skinner, Wildlife Biologist, USFWS Innoko NWR, pers. comm.). However, moose generally select more upland habitats during the rut and into November or December (Ballard *et al.* 1991). Individuals may begin to move onto winter ranges some time between November and January, depending on snow depth (Grauvogel 1984). Although my study looked only at factors contributing to early winter habitat quality, it is possible that moose in this study area may be dependent on "riverine" habitats for most of the winter. LeResche *et al.* (1974) found that riparian willow communities are important year-round habitats for moose, especially at more northerly latitudes.

Deciduous shrub, other than that associated with mixed forest riverine zones, was represented by VEG4 (Table 1). This cover class averaged about 3% of sample units (range 0-29%, Table 2) and consisted of a conglomerate of broadleaf species, including some rarely used by moose (such as alder). The inability to separate preferred from non preferred deciduous species is a problem inherent to the use of satellite imagery as well as aerial photography. In addition, limited resolution of Landsat MSS (0.44-0.49 ha pixels) does not allow detection of small stands of willow that occur along minor drainages or in burned areas (LaPerriere *et al.* 1980). Thematic Mapper (TM) images have a resolution of 0.09 ha and may have a better ability to detect these patches, although it also raises the question of scale of habitat selection by moose.

Association of Moose Density with Fire

Although a significant positive correlation of moose density with 7-12 year-old burns (FIREB) was found, the importance of fire in the model was relatively small. The prevailing view has been that a strong connection exists between the quality of habitat for moose in interior Alaska and the abundance fired-created early successional stands (LeResche *et al.* 1974). A considerable effort was made to identify such an association by varying the grouping of burn classes, exclusion of other variables, interactions with topography factors, and transformations. Even when the analysis was restricted to only high moose density sample units, fire factors seemed relatively unimportant. Unfortunately, sample size was inadequate to further subdivide sample units into more restrictive burn treatments which might have shown different effects of burn size or intensity. The pattern of vegetation recovery following burns is highly variable and partly depends on fire intensity, which in turn is modulated by topography, wind speed, cumulative drought, and relative humidity (Hall *et al.* 1979). Techniques used in this study would not have been able to distinguish a positive correlation of moose density with a very specific type of burn. Using a natural fire regime, it is difficult to obtain enough replications of each particular burn type, if all these factors were considered.

Burns with optimal age and characteristics for moose habitat may not have been well represented in the natural fire regime for my study area. Only about 4% of the entire region was recently burned (Table 2). Burns aged 15-30 years (FIREC) comprised 18% of the study area and should be prime for the production of moose browse based on previous studies (Spencer and Hakala 1964), yet had no significant correlation with moose density in my analysis. Indeed, the composition of FIREC across moose density groups indicates negative association (Table 2). Perhaps the natural fire regime in the study area has not provided the right mix of fire frequency, intensity and patchiness to extend good habitat conditions beyond the riverine area which is more frequently and dependably altered by water action. A carefully designed prescribed burning program might be able to extend good habitat conditions beyond the active riparian areas and provide the potential for higher moose densities. I believe a controlled study to test this idea in northern interior Alaska would be extremely valuable.

Not all fires in north-central Alaska produce the floristic changes which enhance production of moose browse. Although fires in boreal forest are commonly assumed to provide increased production of woody browse, even Spencer and Hakala (1964) recognized that some areas produced no browse subsequent to fires. Scotter (1971) did not find large amounts of browse plants in upland burn sites in northern Saskatchewan. Tundra fires do not produce increases in woody browse (Wein 1975). When "woody browse" is produced, it is not always composed of the species preferred by moose. Several studies in interior Alaska point to a strong preference for willow compared to other deciduous shrub species in winter diets (Risenhoover 1989, Steigers and Becker 1986, Cushwa and Coady 1976). Much browse in young burns consists of aspen, not willow (MacCracken and Viereck 1990). Aspen proliferates quickly after burning by means of root suckering, and produces extremely dense stands of up to 200 stems/m^2 (80 stems/milacre, Zasada 1971). Willows increase more slowly and reach their greatest density in mesic black spruce stands 5-30 years post-burn, when density is about 10 times greater than that in the 1-5 year post-burn period (Foote 1983). In addition, moose do not rapidly colonize new habitats (LeResche 1974, Andersen 1991) and may not use disturbed areas far from cover as winter range (Mound 1977). Eastman (1974) stated that the distance to cover in boreal regions should not exceed 0.5 km.

Predators affect moose abundance substantially throughout interior Alaska, and may be the primary factor limiting population growth in many areas (Gasaway et al. 1992, VanBallenberghe 1987). Fire-disturbed areas may represent potential habitat that is not used heavily until the moose population nears carrying capacity because there is little competition for the most preferred habitats at lower moose densities. The proportion of moose in low-preference types would be expected to increase in dense populations because animals would disperse into marginal habitat (Telfer 1984). If the current regional population density was low, the effect of the most preferred habitat types could be exaggerated by the fact that there would be little reason to use less preferred types. Moose densities within the study area (up to 3.6/km^2) are similar to those reported for many other locations in Alaska. However, the regression models presented here may be less useful for predicting the relationship between habitat factors, including fire, and a population nearer to carrying capacity.

Predicting Moose Density With Habitat Models

How useful is the multiple regression model? Models are considered useful for predictive purposes if the F-ratio is at least 4-5 times greater than that required for significance (Draper and Smith 1981). The *F*-ratio of 48.44 for the regression of stratification moose density is >15 times the significant *F* for a = 0.05. Yet, for individual predictions, confidence intervals were too large for satisfactorily predicting exact numbers of moose. The logistic regression model is more practical for predicting density categories, that could be used *i.e.* for stratification purposes prior to an aerial population census. The logistic regressions do not require the distributional assumptions of MLR, and they allow a category of moose density to be used as the response variable. These allow the estimation of a less exact quantity (density class) with greater accuracy (Fig. 5). Cutpoints can be chosen to minimize the overall classification error or to minimize the error in a particular density group without changing the model.

The existence of correlations between moose density and one or more habitat variables in regression models does not necessarily imply a causal relationship. Even strong statistical correlations may or may not represent meaningful ecological relationships. Although an attempt was made to select variables that have biological meaning for moose, additional studies are necessary to determine causal relationships. The relationship could be indirect, through intermediary factors not considered in the model: so-called "lurking variables" (Bowyer *et al.* 1988).

The usefulness of this model should extend to parts of interior Alaska having similar floristic, climatic, and topographic characteristics. Because of the complexity of assumptions associated with statistical techniques, however, thorough validation is required. Regression models presented here were built and tested using the same set of data. The predictive ability of this model should be tested using different data sets, for example, a neighboring quadrangle.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Moose census techniques that employ a stratification based on animal sightings are effective for providing population estimates, but are costly and provide little or no systematic information on habitat. Because habitat factors have been shown here to explain a large percentage of the variability in early winter moose numbers, it appears there is great potential for the development of a habitat-based stratification to link with population censuses. Where resource conflicts are not great, it may even be possible to derive rough population estimates at minimal cost by extrapolating habitat models from nearby areas. Habitat stratification techniques have been successfully employed in Canada (Bowles 1988, Dalton 1990). Habitat-based census should be more stable through time and may be more cost-effective than sightings-based census. By using remotely sensed data it is relatively inexpensive to sample large areas. Managers could subsequently use the habitat maps for assigning land-use priorities.

Periodic flooding and other characteristics associated with actively meandering major riverine systems make them major producers of moose browse. The zone of active meanders, which includes linear lakes and sloughs, is significantly younger than the flood plain just outside it (Drury 1956). It is in this zone, where permafrost is absent or deep, that production of preferred browse species is most prolific. These systems appear to be the most important component of high-quality moose habitat in this interior Alaska ecosystem. Disturbance by fire may not play as important a role as it does in other parts of Alaska, although burns aged 7-12 years did show a weak but consistent positive correlation with moose density. It should not be assumed that burning will significantly increase the size of the moose population in this area, even though increases have been associated with fire in other parts of Alaska.

My study suggests that conservation of riparian zones associated with major streams and rivers should receive a higher priority than habitat manipulation by broad-scale prescribed burning for moose habitat management in northern interior Alaska. However, since my study looked only at November moose distributions, and predation could be limiting this population more than habitat (Gasaway *et al.* 1992), additional studies are needed to further define the relationships between fire and moose populations. In particular, manipulative studies with controls need to be conducted in diverse parts of Alaska's vast interior. Fire does improve moose habitat under certain conditions. Careful on-site field evaluation, including distance to cover, determination of local moose density, limiting factors, stand composition and physiography should be completed prior to proposing prescribed burns for the purpose of improving moose habitat.

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