# CATCH PER UNIT EFFORT FOR MOOSE: A NEW APPROACH USING WEIBULL REGRESSION

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***Abstract:*** The relationship between hunters and their environment is a key component in managing wildlife populations. Identifying hunter's characteristics, motivations, and efforts is crucial to understanding if a hunt will be successful. We predicted that landscape characteristics and moose (*Alces alces*) densities would affect success of hunts. As in wildlife management programs elsewhere, moose hunters in interior Alaska, USA, must return harvest tickets to the Alaska Department of Fish and Game. These tickets provide location of hunts (Uniform Coding Units) and other details. Our modeling of responses (1997–2001) from harvest tickets indicated that location of hunts, mode of transportation, hunting regulations, use of commercial services, year, density of roads, hunter-to-moose ratio, moose density, and residency of hunters were important predictors of success. In addition, we documented that the linear-regression approach to measuring catch per unit effort (CPUE) was inappropriate because it produced an inverse, but not significant, relationship between hunting effort and success. This outcome occurred because most hunts, particularly for large mammals, ended with the harvesting of an animal. Likewise, modeling of hunter success with logistic regression was similarly biased by measures of hunter effort. We established that a time-to-event Weibull regression provided substantial improvement over standard models of CPUE. Weibull regression accurately represented the positive relationship between effort and success, and it can be used to model length of hunt and other covariates related to hunters and landscape characteristics for predicting success.

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Rates of hunter success are influenced by hunters' characteristics, motivations, and degree of satisfaction (Stankey 1973, Albert et al. 2001, Hayslette et al. 2001). Research related to social aspects of hunting ungulates has focused on satisfaction of hunters in relation to management (McCullough and Carmen 1982; Rollins and Romano 1989; Lauber and Knuth 1997, 1999; Fulton and Hundertmark 2004) or on general characteristics of hunters and their hunts (Miller et al. 1994, Ericsson et al. 2000). Preferences, motivations, and effort levels of hunters were directly influenced by harvest success, selection of a particular species, animal harvested, and areas hunted (Stankey et al. 1973, Getz and Haight 1989, Ericsson et al. 2000, Solberg et al. 2000, Hayslette et al. 2001, Frey et al. 2003).

Previous approaches to modeling hunter effort have typically used regression to analyze CPUE (Seber 1992, Lancia et al. 1996, Maunder and Starr 2003, Smith et al. 2003). The fishing industry commonly uses CPUE to assess the status of populations (Dupont 1983, Richards and Schnute 1992, Gould and Pollock 1997, Maunder 2001, Goodyear 2003) and to aid in development of fishing and hunting regulations (Lancia et al. 1988, Sigler and Lunsford 2001).

Results from the fishing industry indicate assessment of populations is strengthened when independent estimates of population size are used in combination with CPUE (Worthington et al. 1998, Maunder and Starr 2003). Nonetheless, CPUE for big game often is calculated as the number of animals killed per days hunted without incorporation of independent estimates of population size (Laake 1992, Lancia et al. 1996, Bowyer et al. 1999, Hatter 2001, Van Deelen and Etter 2003). This metric has been used to detect changes in moose population sizes (Mercer and Manuel 1974; Crête et al. 1981; Crête and Dussault 1987; Crichton 1993; Hatter 1998, 2001). However, Bowyer et al. (1999) and Hatter (2001) agree that CPUE is not always reliable and can lead to overestimation of increases in population size and underestimation of population decreases. Moreover, Bowyer et al. (1999) reported an unexpected inverse relationship between harvest and effort when moose densities were low.

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Despite some shortcomings, CPUE is still used widely by wildlife managers (Novak et al. 1991, Laake 1992, Lancia et al. 1996, Cooper et al. 2003). When the bag limit is only a single animal, however, traditional approaches for calculating CPUE may be inadequate. Uncertainty about the expected linear relationships between effort and hunting success has been expressed previously (Lancia et al. 1996, Bowyer et al. 1999, Hatter 2001, Maunder 2001, Van Deelen and Etter 2003). We hypothesize that this uncertainty is related to the all-or-none nature of harvesting of large mammals. In addition, uncertainty in estimates of CPUE may be associated with changes in regulations (particularly those affecting size limits), and with a nonlinear relationship between catch and effort (Worthington et al. 1998, Solberg et al. 2000).

Understanding how characteristics of hunters and landscapes influence harvest is equally as important in understanding the relationship between effort and success. We predicted that (1) choice of transportation would influence rates of success because of access, (2) increased motivation and effort of hunters, as measured by employment of guides, would increase hunt success, (3) spatial variation between game management units (GMU) would affect harvest, and (4) density of moose and the hunter-to-moose ratio would influence success, with hunters in areas of high moose density experiencing higher rates of success and reduced effort and hunters in areas of high hunter-to-moose ratio experiencing lower rates of success and more effort.

Moreover, we used Weibull regression to assess CPUE by modeling the length of a successful hunt directly. We compared standard methods used to evaluate CPUE and illustrated the inability of those procedures to cope with the censored nature of harvesting a moose. Our analyses enable prediction of future demand for resources related to moose hunting and provide insights into the motivation of individuals who hunt.

## STUDY AREA

Wildlife management by the Alaska Department of Fish and Game (ADF&G) occured on 2 primary geographic scales, the larger GMUs ($n = 26$, $\bar{x} = 72{,}952$ km$^2$, SE = 14,307 km$^2$) that may be divided into subunits (e.g., 20A, 20B). We analyzed Uniform Coding Units (UCUs, $n = 599$, $\bar{x} = 952$ km$^2$, SE = 34 km$^2$) that were nested within GMUs. Borders for UCUs were usually defined by geographic features such as ridges and river drainages. Management of wildlife within interior Alaska occurred at both levels; however, most decisions concerning harvest were made at the level of GMU.

Interior Alaska (569,694 km$^2$) is bordered by the Alaska Range (1,000–6,000 m) to the south and the Brooks Range (1,000–2,500 m) to the north (Fig. 1). The interior experienced temperature extremes, with mean summer and winter temperatures of 14°C and –30°C, respectively (Fleming et al. 2000). Average elevation in the interior is 1,120 m (range = 20 to 6,190 m). The area was dry relative to other areas in Alaska with frequent wildfires that played an important role in the diversity of the boreal forest ecosystem (Dissing and Verbyla 2003) and were of particular importance to moose (Bowyer et al. 1997, 2003; Weixelman et al. 1998). Annual precipitation was 24 cm (O'Neill et al. 2002); average snow depths were usually <70 cm and snow typically remained loose and dry (Gasaway et al. 1983, Yarie and Billings 2002). Such snow depths normally had little effect on movements or survivorship of moose (Coady 1974, 1982). Vegetation consisted of open stands of white spruce (*Picea glauca*), black spruce (*P. mariana*), and riparian habitat consisting of willow (*Salix* spp.) and birch (*Betula* spp.; Bowyer et al. 2001). We recognized 4 habitats based primarily on vegetation: nonvegetated (ice, rock, and lichens), low shrub (prostrate, dwarf, and low shrubs), deciduous and tall shrub (deciduous), and spruce (both black and white spruce).

Estimated density of moose in interior Alaska ranged from 0.0 to 0.95 moose/km$^2$ and averaged 0.25 moose/km$^2$ (SE = 0.01) for each UCU (1997 to 2001). With the exception of GMU 20A south of Fairbanks, populations of moose in interior Alaska were effectively held constant at low densities over the 5-year study period, likely because of predation (Gasaway et al. 1992, Bowyer et al. 1998, Keech et al. 2000). From 1997 to 2001, an annual average of 10,850 people hunted moose in interior Alaska with a mean harvest of 3,640 animals.

## METHODS

### Databases and Study Extent

Licensed moose hunters in Alaska must obtain a harvest tag that is returned to ADF&G whenever a moose is killed. We analyzed data from 1997 to 2001 hunting seasons. Several characteristics of moose hunting, such as transportation, residency, use of commercial services (i.e., transporter or registered guide), and length of trip were recorded on harvest tickets. Registered guides in Alaska must pass certification and become registered with the state, whereas transporters do not

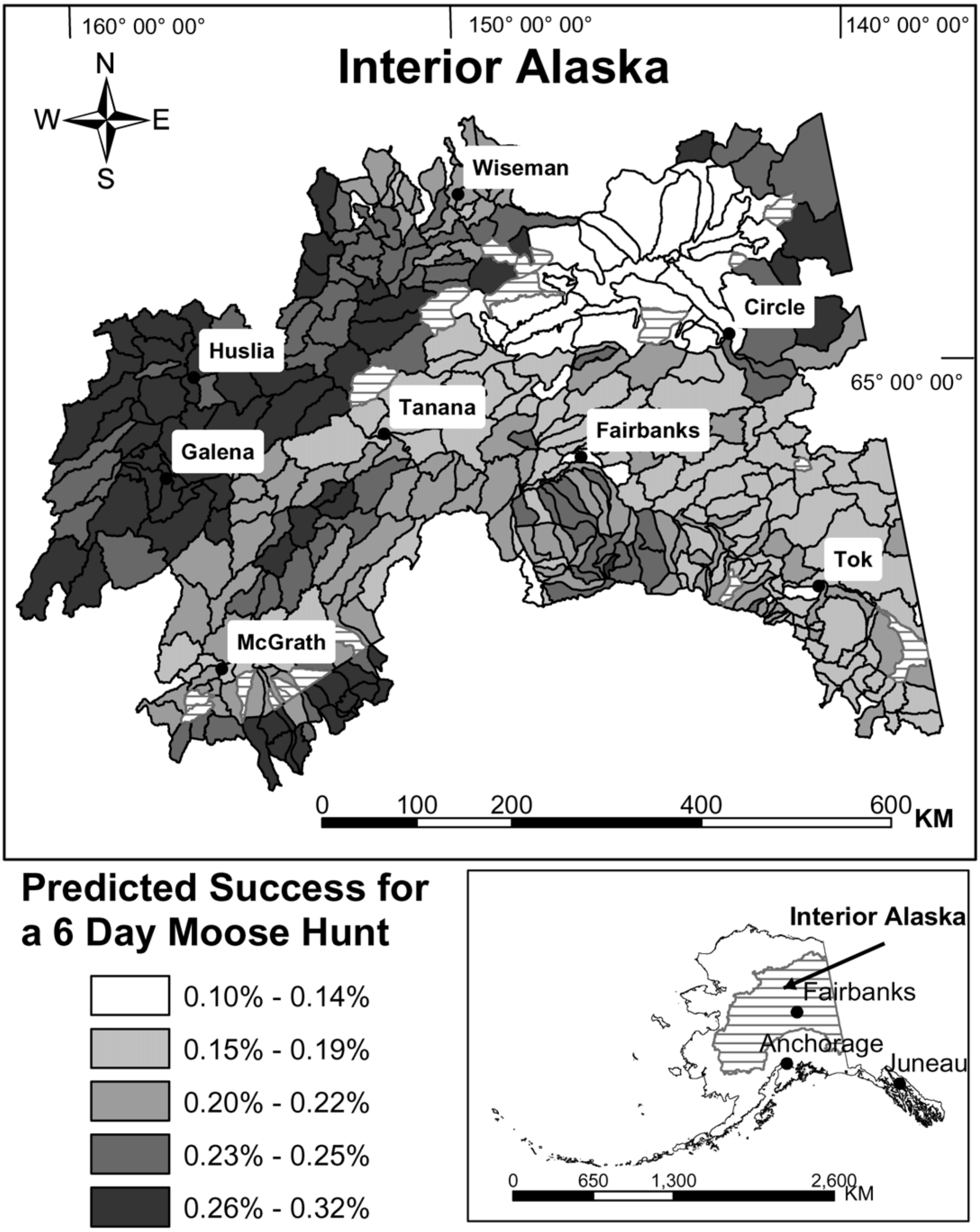

Fig. 1. Predicted moose hunt success for a 6-day hunt in 2001 by an urban, Alaskan resident with a boat, using no commercial services in interior Alaska, USA, based on hunter-harvest tickets from 1997 to 2001.

require certification and include anyone who provided travel assistance during a hunt. Returned tickets were coded by UCU that established the sampling units for most of our analyses. Although we have no independent method to verify the accuracy of moose-harvest tickets, previous research in Alaska indicates that such tickets provide a reasonable indication of characteristics of most hunters and their harvest (Albert et al. 2001). Maps for analyses of landscapes, hunter access, and management units were provided by the Alaska Department of Natural Resources and Division of Wildlife Conservation of ADF&G.

## Rivers and Roads

Rivers provide an index of how drainages influences moose habitat and access for hunters via boats during autumn. Rivers also provide trails for snowmobiles and dogsleds and landing strips for aircraft in winter and autumn. Geographic Information System (GIS) coverage of rivers was extensive and included all navigable and unnavigable waters within interior Alaska. Roads strongly affect human presence and access. Roads included primary and secondary highways, including those under construction, as well as tracks, trails, and footpaths. We calculated density values for rivers and roads by totaling the length (km) of rivers or roads encompassed by an UCU, divided by the area (km$^2$) of the UCU. Alaska contains few roads, so density estimates would have resulted in many zeros. Consequently, we represented the potential effects of roads by estimating the distance from the center point of a UCU to the nearest road. To scale and aid in comparisons of model coefficients for roads and river density values, we divided by 100 and 1,000, respectively.

## Landscape and Habitat Characteristics

Landscape characteristics included slope, aspect, and vegetation, which we obtained from the Spatial Ecology Laboratory at the University of Alaska Fairbanks. Aspect was sine- and cosine-transformed for subsequent analyses (Zar 1999). We used variation in aspect and slope to calculate terrain variability (Nicholson et al. 1997). The terrain index, as used by Nicholson et al. (1997) for modeling habitat selection by mule deer (*Odocoileus hemionus*), is a function of the deviation of the mean angular aspect multiplied by the standard deviation of slope. Hence, a higher value for terrain implies an increase in ruggedness, thereby hindering mobility and decreasing the likelihood of ungulate dispersal. Terrain grids were generated at numerous scales based on various pixel sizes. We used the grid with pixel scale of 114 km$^2$ for assessing terrain characteristics because that size was more representative of the average UCU and was likely the maximal extent to which a hunter would consider terrain when moose hunting.

## Surveys and Moose Densities

We estimated moose densities by ADF&G in aerial surveys during autumn from 1997 through 2001. We selected areas for aerial surveys based on management needs and intensity of hunter use. Survey methods involved counting all moose in randomly selected sample units of 2' latitude and 5' longitude (~12 km$^2$) within survey areas (Ver Hoef 2001, 2002). Use of this survey method helped us establish the spatial extent of our study area. We surveyed 39,332 km$^2$, with some sample units within the region sampled for multiple years. We sampled 2,665 units; when density was estimated in >1 year in a unit, we used the average.

We only used female moose in estimates of population density because they show more site fidelity than males (Ballard et al. 1991). We chose female moose because surveys were conducted after hunting season; thus, estimates of moose density would be less affected by the autumn hunt that targets mostly males (Schwartz et al. 1992). We acknowledge that moose density estimates were based on female moose when males were most likely to be harvested; however, because surveys were conducted after the autumn hunting season, estimates of males would have been confounded by hunter selection, alterations in the sex ratio, and variation in success rates. Because surveys are conducted in autumn shortly after the rut, males are likely to have been congregated around females. Thereby, sexes of moose were aggregated during autumn, and we hypothesize that the extent of females best represents the spatial distribution of both sexes prior to the hunt (Miquelle et al. 1992). We also admit that sex ratios within interior Alaska were likely to vary. We assume, however, that our estimation of moose density based on female moose was valid given the previously mentioned drawbacks of including males in estimates and our goal of quantifying overall population density of moose. Raw estimates of density were determined by totaling the number of adult females surveyed in sample units, adding 1, and dividing by the area (m$^2$) within the sample unit. The addition of 1 was necessary because we used a natural-log transformation to normalize data (McKenney et al. 1998, Rew et al. 2001, Ver Hoef 2001) and stabilize variance.

## Kriging

We used ArcGIS 8.3 Geostatistical Analysis Program (Johnston et al. 2001) to krig estimates of moose densities across interior Alaska. Our sample units for hunter characteristics were UCUs, which was larger than moose survey sample units. To aggregate to the UCU scale, we kriged all unsampled moose survey units and then averaged them for each UCU. Kriging has also been used to estimate other populations of moose (McKenney et al. 1998). The geographic area kriged was formed by all the UCUs that contained moose-survey sample units along with their adjacent UCUs (i.e., those sharing a border with an UCU that contained at least 1 sample unit). We estimated moose densities using ordinary kriging with an exponential variogram model. Because of the abundance of sample units, we used the 20 nearest neighbors of a unit to make predictions that formed a raster-based map. We overlaid predicted values of the raster map on UCUs and then averaged them within each UCU. Values then represented average moose density over our 5–year study in interior Alaska; annual surveys by ADF&G indicated that moose density was relatively stable during our study.

### Human Indices

We examined hunter density as an index to the presence of hunters and their potential interactions with moose. We calculated the number of hunters in a UCU by totaling the number of attempted hunts, regardless of success, for each year. We divided this value by area (km$^2$) to calculate yearly density of hunters in a particular UCU. We examined the influence of the ratio of hunter-to-moose density when predicting success (Cooper et al. 2003). We based predictions of moose density on a 5-year mean, so we used an equivalent 5-year average of hunter density for determining that ratio. We also explored the influence of residency of hunters on success. We assigned hunters to 3 categories related to residency: urban, rural, and nonresident (based on postal zip codes). Urban or rural communities were defined as areas with a population of 2,500 to 7,000 residents and considered community dependency, utilization of surrounding ecosystem services, and development in the local area according to the joint agreement between the Subsistence Management for Federal Public Lands in Alaska, the U.S. Department of the Interior, and the U.S. Forest Service (see also Alaska Department of Fish and Game 2000*a*).

### Statistical Analyses

We truncated the number of days hunted at 30 because of extreme outliers in our data, but 99% of our samples were retained. We also examined a Spearman rank correlation matrix to remove potentially correlated variables (Zar 1999). Hunter success is a binary response; consequently, we used stepwise logistic regression with PROC LOGISTIC and GENMOD ($\alpha = 0.15$ to enter, $\alpha = 0.10$ to remove) to select significant variables for predicting success (SAS Institute 1999). During stepwise logistic regression, we based model selection on the Akaike Information Criterion (AIC; Zar 1999). We determined goodness-of-fit with the Pearson chi-square value divided by the degrees of freedom; a value near 1 indicated a good fit (Zar 1999). Of 21 GMUs available to enter the model, we excluded 3 because of incomplete data (19A, 19B, 21E).

We used the same variables from logistic regression for modeling success and effort with Weibull regression. We assumed a Weibull distribution for CPUE. Weibull regression incorporated censored data and covariates such as landscape and hunter characteristics to estimate both time to achieve a particular rate of success and the proportion of hunters likely to succeed within an area given a specified length of hunting trip. We modeled time to success with PROC LIFEREG (SAS Institute 1999) as the probability density function. The probability of success is a function of time and is the cumulative distribution function (CDF). We treated unsuccessful hunts as censored values at the time the hunt ended. Survival models based on a Weibull distribution are 1-CDF. Parametric modeling such as Weibull regression can better handle covariates and potential interactions, and provides an approach superior to nonparametric models (i.e., Kaplan-Meier) when parametric assumptions are met (Dupont 1983, Efron 1988). Keech et al. (2000) used this parametric approach to model survivorship of moose, which also has applicability to modeling CPUE. Catch per unit effort was modeled as:

$$\text{Probability of success} = 1 - S(t) = 1 - \exp(-(te^{-\boldsymbol{\beta}'\mathbf{x}})^{1/\sigma}),$$

where $t$ is time, the values of the covariates are contained in the vector $\mathbf{x}$, the regression coefficients are contained in the vector $\boldsymbol{\beta}$, and $\sigma$ is a shape parameter (Allison 1995).

For model diagnostics, we examined the relationship between residuals and a negative log-survivorship distribution (Allison 1995), with a linear relationship indicating a good fit. We fitted all models with PROC LIFEREG (SAS Institute 1999). We used the estimated regression coefficients to examine relative effects of independent variables related to hunters and amount of time expended to kill a moose. To examine spatial patterns, we needed to hold nonspatial effects constant; thus, we created a representation of the typical hunter. For continuous hunter variables, we used the mean, and for categorical variables, we used the most frequent category. By fixing typical characteristics of a hunter and nonspatial coefficients, we analyzed effects of site-specific landscape characteristics (UCUs) on success. We also used the Weibull regression to evaluate hunter success based on use of guides to illustrate its flexibility. In addition, we used the standard approach to model CPUE and success with linear regression (PROC REG, SAS Institute 1999), with success averaged for each day hunted.

## RESULTS

### Characteristics of Hunts and Success of Hunters

Characteristics of moose hunters, their hunts, and subsequent success were affected by type of hunt, residency, whether they hunted on state or federal lands, their mode of transportation, whether they hired a guide, and the year during which they hunted (Table 1). Success was most variable among GMUs (range = 2–43%), and among modes of transportation used for hunting moose (Table 1). Use of GMUs differed with residency; 19B, 20B, and 20D were used most often by nonresidents, urban residents, and rural residents, respectively. Harvest levels remained relatively constant with a high in 1998 of 3,889 moose, a low of 3,204 moose in 2001, and 18,177 moose harvested during our 5-year study. Surprisingly, median length of hunt did not differ greatly for successful (5 days) and unsuccessful (6 days) hunters; overall the median length of a hunt was 6 days. Median days hunted was shortest for residents; urban hunters spent 5 days and rural hunters 6 days; nonresidents hunted for a median of 7 days.

### Models for Catch per Unit Effort

We modeled hunter success using logistic regression with successful hunts coded 1 and unsuccessful hunts coded zero. The value of the Pearson chi-square divided by the degrees of freedom was near 1 ($n$ = 23,956, Concordance = 69.5, $\chi^2/\mathrm{df}$ = 1.01), indicating a good fit. Remarkably, length of hunt entered the regression model with a negative coefficient (Table 2), demonstrating lower success associated with more effort. This outcome is an artifact of the successful harvest of a moose ending the hunt, and it illustrates the danger of calculating CPUE in this way. Indeed, when success was regressed with days hunted, we observed a slightly negative, but not significant, trend (Fig. 2A, $P = 0.45$). Lack of a clear relationship between effort and success further illustrates the inability to accurately depict the relationship between success and effort with this traditional approach. When we modeled hunter success with Weibull regression, a plot of residuals resulted in a linear relationship, indicating a Weibull distribution fit the data well. Weibull regression illustrated increased success with increased time to harvest, with a curvilinear and a positive relation between success and effort (Fig. 2B).

Table 1. Average success for moose hunters from 1997 to 2001 in interior Alaska, USA.

| Variables | *n* | Success (%) | *P*-value |
|---|---|---|---|
| Hunt type | | | |
| Draw | 1,335 | 48.84% | <0.0001 |
| General[a] | 48,795 | 31.92% | |
| Registration | 3,530 | 46.20% | |
| Tier II | 588 | 56.97% | |
| Residency | | | |
| Rural | 6,920 | 37.65% | <0.0001 |
| Nonrural[a] | 33,596 | 29.29% | |
| Nonresident | 13,220 | 45.15% | |
| Manager | | | |
| Federal | 103 | 51.46% | 0.0001 |
| State[a] | 54,115 | 33.49% | |
| Transportation | | | |
| Airplane | 9,007 | 44.08% | <0.0001 |
| Horse/dog/foot | 616 | 50.81% | |
| Boat[a] | 17,777 | 39.52% | |
| ATV | 9,156 | 30.13% | |
| Snowmobile | 860 | 61.40% | |
| ORV | 2313 | 31.60% | |
| Highway | 11,930 | 18.80% | |
| Airboat | 382 | 19.37% | |
| Other | 789 | 40.56% | |
| Year | | | |
| 1997 | 10,380 | 36.57% | <0.0001 |
| 1998 | 10,618 | 36.63% | |
| 1999 | 10,963 | 33.79% | |
| 2000 | 11,000 | 32.58% | |
| 2001[a] | 11,259 | 28.46% | |
| Use of guide | | | |
| Guided | 2,129 | 65.38% | <0.0001 |
| Nonguided[a] | 37,052 | 34.71% | |
| Use of transporter | | | |
| Transported | 4,138 | 45.22% | <0.0001 |
| No transporter[a] | 35,042 | 35.33% | |

[a] Variables that represent average characteristics of moose hunters.

The 5 most influential variables for predicting hunter success from stepwise logistic regression were GMU, type of transportation, length of trip, type of hunt, and whether a guide was used (Table 2). Coefficient estimates computed by logistic regression also indicated increased success with increased density of moose and distance from roads.

Table 2. Predicted success coefficients from Logistic Regression and Weibull models for moose hunters from 1997 to 2001in interior Alaska, USA. Note value estimates for categorical variables are offset by base category. Positive logistic regression coefficients indicate increased success, whereas negative Weibull coefficients represent decreased time needed to successfully harvest a moose.

| | | Logistic regression | | | | | Weibull regression | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variables | DF | Lower[a] | Est[b] | Upper[c] | $\chi^2$ | *P*-value | Lower[a] | Est[b] | Upper[c] | $\chi^2$ | *P*-value |
| Intercept | 1 | 1.257 | 1.794 | 2.332 | 42.81 | | 1.984 | 2.256 | 2.527 | 265.3 | <.0001 |
| Coefficient | | | | | | | | | | | |
| Days hunted | 1 | –0.067 | –0.060 | –0.053 | 293.89 | <.0001 | | | | | |
| Distance to road[d] | 1 | 0.572 | 0.869 | 1.167 | 32.75 | <.0001 | –0.482 | –0.339 | –0.197 | 21.77 | <.0001 |
| River density[d] | 1 | –1.002 | –0.635 | –0.268 | 11.51 | 0.001 | –0.394 | –0.200 | –0.007 | 4.11 | 0.043 |
| Moose density | 1 | 0.275 | 0.467 | 0.658 | 22.73 | <.0001 | –0.299 | –0.200 | –0.100 | 15.54 | <.0001 |
| Hunter moose ratio | 1 | –0.472 | –0.359 | –0.247 | 39.12 | <.0001 | 0.297 | 0.363 | 0.429 | 115.88 | <.0001 |
| Low shrub | 1 | –0.436 | –0.294 | –0.153 | 16.70 | <.0001 | 0.069 | 0.142 | 0.214 | 14.79 | 0.000 |
| Hunt type | 3 | | | | 154.12 | | | | | 339.16 | <.0001 |
| Draw hunt | | –1.017 | –0.736 | –0.455 | 26.39 | <.0001 | –0.043 | 0.081 | 0.206 | 1.64 | 0.201 |
| General hunt | | –1.585 | –1.330 | –1.074 | 103.74 | <.0001 | 0.486 | 0.601 | 0.716 | 104.87 | <.0001 |
| Registered hunt | | –1.495 | –1.211 | –0.927 | 69.68 | <.0001 | 0.138 | 0.266 | 0.394 | 16.50 | <.0001 |
| Tier II | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | . | . |
| Year | 4 | | | | 103.55 | | | | | 131.37 | <.0001 |
| 1997 | | 0.332 | 0.421 | 0.511 | 84.96 | <.0001 | –0.298 | –0.251 | –0.204 | 108.58 | <.0001 |
| 1998 | | 0.274 | 0.363 | 0.451 | 64.37 | <.0001 | –0.252 | –0.205 | –0.157 | 72.34 | <.0001 |
| 1999 | | 0.182 | 0.271 | 0.359 | 35.76 | <.0001 | –0.150 | –0.102 | –0.055 | 17.75 | <.0001 |
| 2000 | | 0.109 | 0.198 | 0.287 | 19.00 | <.0001 | –0.166 | –0.119 | –0.071 | 23.57 | <.0001 |
| 2001 | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | . | . |
| Residency | 2 | | | | 10.81 | | | | | 22.02 | <.0001 |
| Nonresident | | –0.166 | –0.050 | 0.067 | 0.70 | 0.403 | –0.720 | –0.505 | –0.290 | 0.00 | <.0001 |
| Nonrural | | –0.205 | –0.126 | –0.048 | 10.03 | 0.002 | –0.955 | –0.745 | –0.534 | 0.00 | <.0001 |
| Rural | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | 0.00 | <.0001 |
| GMU | 17 | | | | 404.81 | | | | | 144.40 | <.0001 |
| Transportation | 8 | | | | 184.91 | | | | | 172.47 | <.0001 |
| Airplane | | –0.382 | –0.159 | 0.064 | 1.96 | 0.162 | –0.087 | 0.028 | 0.143 | 0.23 | 0.629 |
| Horse/dog/foot | | –0.393 | –0.074 | 0.246 | 0.20 | 0.652 | –0.152 | 0.001 | 0.153 | 0.00 | 0.995 |
| Boat | | –0.601 | –0.389 | –0.177 | 12.91 | 0.000 | 0.097 | 0.208 | 0.318 | 13.59 | 0.000 |
| ATV | | –0.367 | –0.152 | 0.064 | 1.90 | 0.168 | 0.098 | 0.210 | 0.322 | 13.42 | 0.000 |
| Snowmobile | | –0.294 | 0.012 | 0.318 | 0.01 | 0.940 | –0.312 | –0.165 | –0.018 | 4.81 | 0.028 |
| ORV | | –0.376 | –0.137 | 0.101 | 1.27 | 0.260 | 0.087 | 0.214 | 0.340 | 11.00 | 0.001 |
| Highway | | –0.925 | –0.706 | –0.487 | 39.96 | <.0001 | 0.250 | 0.366 | 0.482 | 38.20 | <.0001 |
| Other | | –0.648 | –0.190 | 0.268 | 0.66 | 0.417 | –0.126 | 0.112 | 0.349 | 0.85 | 0.357 |
| Airboat | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | . | . |
| Guide usage | 1 | | | | 104.39 | | | | | 92.43 | <.0001 |
| Nonguided | | –1.246 | –1.045 | –0.845 | 104.39 | <.0001 | 0.306 | 0.385 | 0.463 | 92.43 | <.0001 |
| Guided | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | . | . |
| Transporter usage | 1 | | | | 27.53 | | | | | 0.76 | 0.383 |
| No transporter | | –0.440 | –0.320 | – 0.201 | 27.53 | <.0001 | –0.031 | 0.025 | 0.080 | 0.76 | 0.383 |
| Transported | | 0.000 | 0.000 | 0.000 | . | . | 0.000 | 0.000 | 0.000 | . | . |
| Scale of distribution | | 1.000 | 1.000 | 1.000 | | | 0.686 | 0.697 | 0.709 | 0.00 | 0 |
| Weibull shape | | | | | | | 1.411 | 1.434 | 1.458 | 0.00 | 0.000 |

[a] Lower limit of 95% confidence interval.

[b] Estimate of regression coefficient.

[c] Upper limit of 95% confidence interval.

[d] We divided distance to roads by 100 and divided river density by 1,000 to scale coefficients.

Moreover, a negative coefficient for days hunted indicated success decreased with additional days hunted. In 1997, rural residency, transportation via snowmobile, and use of a guide and transporter resulted in the highest predicted success (Table 2).

The 5 most influential variables for Weibull regression included type of hunt, mode of transportation, GMU, year, and the hunter-to-moose ratio (Table 2). Length of hunt was the response variable. Positive values for coefficients of the logistic model indicated increased success, whereas negative values for coefficients of the Weibull regression indicated shortened time to kill a moose (Table 2). Weibull regression indicated reduced time to achieve success with increased moose density, distance to road, and river density (Table 2). Attributes that decreased time to success included hunting in 1997, urban residency, use of a snowmobile, use of guide, and transporter usage (Table 2). Coefficients for GMUs in both models varied widely and reflected a strong spatial component to hunter success in interior Alaska. Major differences between the 2 regressions (i.e., logistic and Weibull) were for residency and success among years. Urban residents had the shortest time to achieve a successful hunt in the Weibull regression, whereas for logistic regression, rural hunters were most successful. Variables that did not enter the step-wise model consisted of whether a hunt was managed by federal or state agencies, amount of spruce or deciduous vegetation, slope, aspect, and ruggedness of terrain.

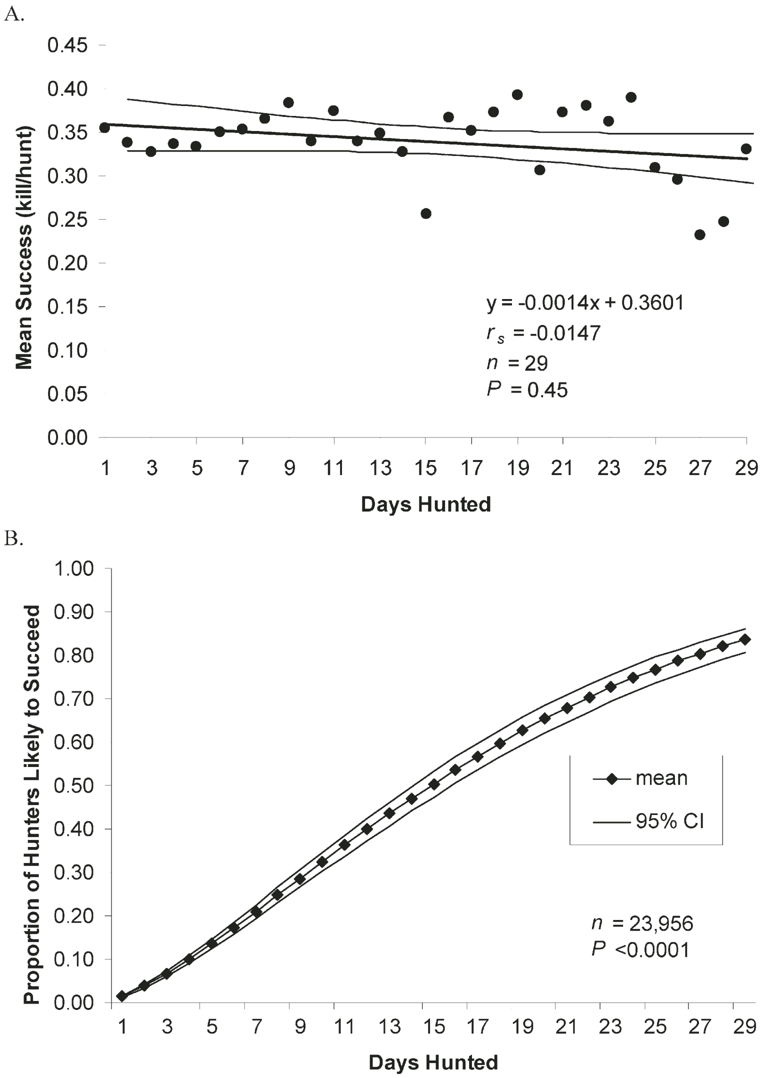

Fig. 2. Models of catch per unit effort (CPUE) for moose hunters in interior Alaska, USA, based on hunter-harvest tickets from 1997 to 2001. A= linear regression model. B= Weibull regression model.

We used Weibull regression coefficients (Table 2) to created a map of standardized hunter success (Fig. 1) by selecting characteristics of a typical hunter and variation from significant spatial components (i.e., GMU, hunter-to-moose ratio, moose density, distance to road, presence of low shrub vegetation, river density). Landscape and spatial dynamics strongly influenced predicted success for a 6-day hunt in interior Alaska by a typical moose hunter in 2001 (Fig. 1). A typical moose hunter was an urban resident who used a boat, participated in a general hunt, and contracted no guide or transporter services (Table 1).

Hunter success varied markedly within interior Alaska. Success was high near the rural communities of Huslia and Galena, approximately 50 km south of McGrath, and 100 km east and northeast of Circle (Fig. 1). Moderate levels of hunter success occurred south of Fairbanks, southwest from Wiseman toward Huslia, and southwest from Tanana to McGrath. The poorest hunting success was in the area between Circle and 100 km east of Wiseman (Fig. 1).

Although densities of moose south of Fairbanks in GMU 20A were among the highest in the state ($\bar{x}$ = 0.43 moose/km$^2$, SE = 0.08), hunting success was only moderate with other areas of the state such as the area near Hulsia experienced higher rates of success (Fig. 1). This area also possessed the second highest hunter-to-moose ratios in the state ($\bar{x}$ = 0.16, SE = 0.03); only the bordering

GMU 20B had higher ratios ($\bar{x} = 0.37$, SE = 0.07). The increase in success near the southern boundary of 20A and below McGrath in 19B corresponded with increased guiding activity and percent of hunts guided—748 of 8,074 hunts were guided in these 2 GMUs vs. 1,391 of 31,479 hunts guided for the rest of interior Alaska ($n = 32{,}227$). The area around Huslia also was also more frequently used by guides compared to other places in interior Alaska. Clearly, a guided hunt was more successful than an unguided hunt (Fig. 3).

## DISCUSSION

We hypothesize that increased effort (i.e., days spent hunting) for moose in interior Alaska was associated with lack of success, rather than the standard interpretation of effort associated with increasing success. The negative trend between days hunted and CPUE (Fig. 2A) is counter-intuitive. More important is the lack of a significant relationship between effort and success that we assume resulted from a single kill ending the hunt, which occurs frequently for harvests of large mammals. Length of a hunt was a key component of success, and it was used to quantify effort and as an index of hunt quality and status of wildlife populations (Eberhardt 1976, Novak et al. 1991, Laake 1992, Lancia et al. 1996, Bowyer et al. 1999, Van Deelen and Etter 2003). Clearly, a new approach is needed to model CPUE for moose hunting.

Logistic regression models also may not accurately represent the relationship between effort and success (Table 2). Days hunted was estimated with a negative coefficient, again indicating an unrealistic reduction in success associated with longer hunts. Because days hunted is a covariate in the logistic regression model, the negative coefficient for days hunted also influences all other covariates in the model. This outcome can confound the interpretation of other parameters in the model, including those indicated as being important in predicting hunting success. Nonetheless, amount of effort expended is an important component of hunting (Table 2). Models should reflect this key variable.

We therefore chose Weibull regression to evaluate the relationship between effort and success for moose hunters within interior Alaska, and we observed a strong relationship between hunter effort and time to success (Fig. 2B). We modeled CPUE using a Weibull distribution that has been commonly used to predict rates of failure over time (Keech et al. 2000) or, in a few instances, catch-effort models (Dupont 1983, Novak et al. 1991). Nonetheless, to our knowledge a Weibull regression approach has never been taken to evaluate hunter success for large mammals.

Weibull modeling of CPUE better reflected effort by placing length of a hunt as an outcome rather than a predictor in the model. Consequently, Weibull regression addressed and effectively removed the inherent bias resulting from confounding effects when we included length of hunt as a predictor (Fig. 2A and B). This approach depicted a more realistic relationship between CPUE and success; increases in effort that lead to improved rates of success (Fig. 2B). Weibull regression further allowed for 2 examinations of success. First, success can be predicted based on characteristics of hunters and a specified length of time in the field. For example, choosing length of hunt on the x-axis yields a prediction of success on the y-axis (Fig. 2B). Conversely, because CDFs are monotonic functions, length of time required to achieve a desired rate of success or harvest level

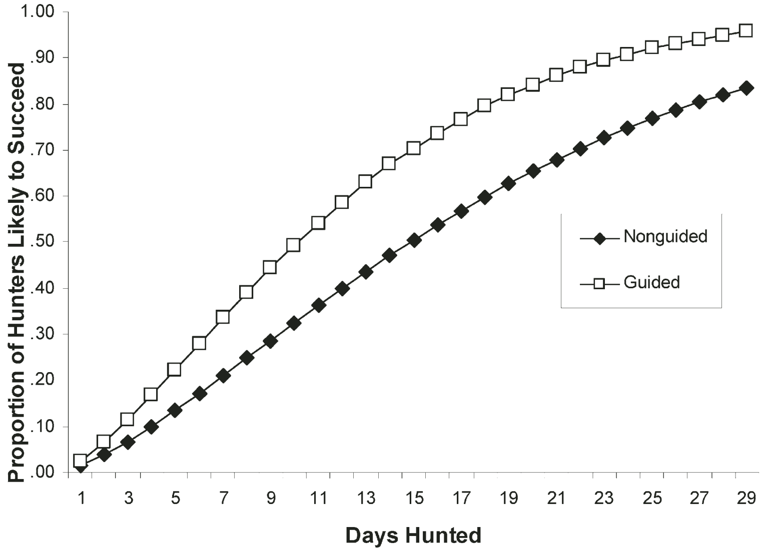

Fig. 3. Models of catch per unit effort (CPUE) for guided and nonguided hunts for moose hunters in interior Alaska, USA, based on Weibull regression coefficients in Table 2.

can be predicted. For example, choosing a success rate on the y-axis yields a predicted length on the x-axis (Fig. 2B). Success based on residency provides an example of different performance by logistic and Weibull models towards predicting success, with rural hunters being most successful in the logistic model and urban hunters more successful in the Weibull model (Table 2). We conjecture this outcome occurred for urban hunters because of the necessary preparation and expense to travel outside of the town or employment constraints. Also rural hunters could have multiple attempts to hunt, thereby reducing the time and effort to structure a hunt.

Consistent with our first prediction, rates of success were associated with modes of transportation and were extremely variable (Table 1). Transportation modes that allow access to more remote areas (i.e., boats, airplanes, and snowmobile) offer greater rates of success compared with travel via roads (Tables 1 and 2). The model already has corrected for hunter-to-moose ratio, so this effect could be explained by the presence of more naive moose in less accessible areas.

Our prediction that motivations and characteristics of hunters would influence hunting success was supported by the variability of success rates associated with different attributes of hunters (Table 1). Results indicate that increased effort improved success (Fig. 3). When modeling success and CPUE, Weibull regression exemplified the importance of hunter motivation and effort, with use of a guide or transporter strongly influencing hunting success (Table 2, Fig. 3). Covariate influences in Weibull regression indicated decreased time to success for hunters using guides and provided a quantifiable measure of the increase in effort necessary to influence success.

Game Management Unit was the most important component in predicting success (based on ≥2 values). Why GMU is so important is unclear and may reflect unmeasured local spatial effects. We speculate that variability of sex ratios among GMUs could explain some of the spatial variation. Year was also important in predicting success (Table 2). Even with use of 5-year means for some parameters, year still clearly had a significant effect on success. Such year effects may be related to fluctuations in weather, access, or regulations. In addition, this outcome implies that success is not solely driven by hunter attributes (Stankey et al. 1973). In our data, numbers of reporting hunters steadily increased (Table 1); if the number of harvested animals was constant, then rates of success decreased.

Consistent with our last prediction, density of moose significantly affected success, with increased densities improving rates of success (Table 2). Our results support those of Van Deelen and Etter (2003), who illustrated a linear relationship between deer density and effort, with hunter effort increasing as density of deer decreased. Nonetheless, they questioned whether increased effort resulted in increased success because of small sample sizes and the perception gap by hunters between actual and perceived density of deer, with hunters increasingly overestimating effort (i.e., underestimated densities of deer) as deer density decreased (Van Deelen and Etter 2003). Our results are similar, although an increase in density of moose was not the best predictor of success. Hunter-to-moose ratio was much more predictive than moose density alone (Table 2). For example, moose were at high density south of Fairbanks but this did not yield increased rates of success. This area had high densities of moose, but it also had easy access and close proximity to a substantial human population; consequently, this area attracted many moose hunters. Interference among hunters may decrease rates of success regardless of high moose densities. Other studies also report that increases in density of roads and hunter interference were associated with decreased rates of success (Cooper et al. 2002, Heberlein and Kuentzel 2002). Several authors have undertaken research incorporating hunter characteristics, motivation, and effort into management schemes (Miller et al. 1994, Albert et al. 2001, Hayslette et al. 2001, Miller and Graefe 2001, Heberlein and Kuentzel 2002); however, more research in this area is needed (Ericsson et al. 2000, Bulte and Horan 2002, Fulton and Hundertmark 2004). Moreover, Ericsson et al. (2000) stated that a better understanding of hunter characteristics could produce hunting regulations that are both economically and biologically sustainable.

## MANAGEMENT IMPLICATIONS

Our regression approach to modeling hunter success with a Weibull distribution allows for more realistic and informative predictions that wildlife managers can use to better estimate harvest levels and structure of hunts. Catch per unit effort is used widely in wildlife management, including detecting changes in population size of moose (Mercer and Manuel 1974; Crête et al. 1981; Crête and Dussault 1987; Hatter 1998, 2001). Because days hunted is more a result of success, rather than a reliable predictor of success, wildlife managers should use caution when estimating effort levels or population size based on days hunted.

Weibull estimates for CPUE provide a flexible approach to model success and harvest levels either by predicting the number of days hunted necessary to achieve a desired rate of harvest or by allowing predictions about rates of success for a particular length of trip. Predicting time needed to harvest at a particular rate provides a promising approach for managers when setting hunting seasons. Use of coefficients and covariates from Weibull regression also provides managers with a spatially explicit model that will help establish local regulations and improve site-specific conservation efforts. In addition, we suggest that to understand harvest patterns and effectively manage wildlife, information on combined effects of hunter characteristics, effort, and success are necessary; Weibull regression combines these variables into a unified statistical analysis.

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