Using snow-track surveys to determine deer winter distribution and habitat

Robert G. D'Eon

Abstract Managers require detailed distribution and habitat use information on local ungulate populations. Aerial surveys over closed-canopy coniferous forests are unreliable due to invisibility of animals from the air. I used snow-track surveys during 3 winters to determine midwinter deer distribution and habitat use in dense-canopy forests of southeastern British Columbia. Crews recorded deer tracks along straight-line transects and concurrently measured habitat plots at 50-m intervals. Deer distribution and habitat use was best explained by relative snow depth in all sampling periods. I created a relative snow-depth model delineating potential midwinter deer habitat from survey data. Advantages of snow-track surveys include delineation of seasonal ungulate use, measurement of population spatial distribution, and collection of detailed habitat information. Limitations include a geographic constraint to areas of persistent snow cover and a bias toward detecting locations of ungulate travel that are not necessarily feeding or bedding habitat.

Key words forest management, mule deer, Odocoileus hemionus, Odocoileus virginianus, snow-depth model, snow-track surveys, ungulate winter range, white-tailed deer

Public concern for native ungulates usually demands detailed forest management strategies designed to maintain population densities at acceptable levels. The onus of providing these strategies usually falls upon managers, who have little empirical information on local ungulate distributions. Despite some generalities, previous research has contributed surprisingly little to predicting distribution and habitat use of unstudied deer populations (Pauley et al. 1993) and falls short of providing the detail needed to develop fine-resolution forest management plans. Slocan Forest Products performs forest management activities within the Slocan Valley and its tributaries in southeastern British Columbia, Canada, and typifies this situation. Although anecdotal knowledge of sympatric white-tailed deer (*Odocoileus virginianus*) and mule deer (*O. hemionus*) distribution and ecology exists, local forest managers do not have accurate distribution and habitat use information at a resolution that is useful in daily decision-making.

This situation is exacerbated by difficulties in detecting deer in areas dominated by dense-canopy coniferous forest. Reliably detecting deer from the air, the most common ungulate censusing technique (Norton-Griffith 1978, Unsworth et al. 1994), under dense-canopy conditions is impractical due to invisibility of animals from the air. Accurate aerial censusing of deer is impossible in the closed-canopy forests of coastal British Columbia (Nyberg et al. 1990). Aerial census attempts within the Slocan Valley of southeastern British Columbia also have failed (R. D'Eon, unpublished data). As a result, I explored ground-based methods to provide reliable information on deer distribution and habitat use.

Several ground-based methods have been developed to gather information on ungulate abundance, including fecal pellet counts (Bennett et al. 1940, Freddy and Bowden 1983) and spotlight counts (McCullough 1982, Hatter and Janz 1994). Most of these methods are designed to obtain population trend information and are not suited to making inferences about spatial distribution and habitat use at the resolution needed for operational forest management. Snow-track surveys have been used

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commonly with species other than ungulates (Litvaitis et al. 1985, Thompson et al. 1989, Zielinski and Kucera 1995). However, track survey use with ungulates has been limited and focused particularly on dry-land surveys to obtain population indices (Kie 1988, Single et al. 1989, Fritzen et al. 1995). I know of no published account of snow-track surveys used to obtain information on ungulate spatial distribution and habitat use. My objectives were to demonstrate a management application of snow-track surveys and to provide insight into their use to determine deer spatial distribution and habitat use within dense-canopy coniferous forests.

Study area

The study area was located in the Selkirk Mountains of southeastern British Columbia, approximately 40 km north of Castlegar (49°42′N, 117°42′ W; Figure 1). It was 26,800 ha within a 65,000-ha Tree Farm License (TFL 3). Elevations within TFL 3 ranged from 750 m along the Little Slocan River to 2,500-m mountain peaks. Terrain was generally steep and broken with slope gradients exceeding 80% and slope aspects varying from 1 to 360°. Annual precipitation averaged 812 mm (Environment Canada weather station, New Denver, British Columbia). Average daily summer high and low temperatures were 26.9°C and 9.4°C, respectively; average daily winter highs and lows were 2.2°C and –4.9°C, respectively. Snow usually covered 100% of the ground from early November until late April and was deepest in mid-February.

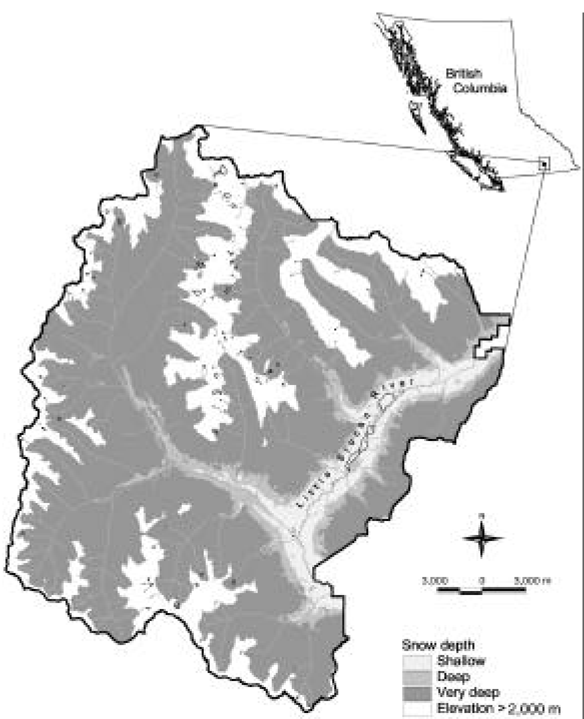

Figure 1. The Little Slocan Valley study area and a relative snow-depth model derived from snow depth, vegetation, and biophysical data collected during 1998 and 1999 snow-track surveys. Class distinction between shallow and deep snow is based on the ninetieth percentile snow depth of midwinter deer track observations and delineates potential midwinter deer habitat in the shallow zone. Deep and very deep snow depths and elevations >2,000 m reflect areas of non-midwinter habitat.

The study area was within the Interior Cedar Hemlock Moist Warm (ICHmw2) and Dry Warm (ICHdw) biogeoclimatic zones (Braumandl and Curran 1992). The ICHdw zone occurs from the lowest elevations in the study area to approximately 1,000 m, above which ICHmw2 extends beyond the 1,500-m upper boundary of the study area. Climax forest type in ICHdw and ICHmw2 was a mix of western hemlock (*Tsuga hetrophylla*) and western redcedar (*Thuja plicata*). More common were mixed seral stands of Douglas-fir (*Pseudotsuga menziesii*), white birch (*Betula papyrifera*), western larch (*Larix occidentalis*), and western white pine (*Pinus monticola*) in ICHdw, with the addition of hybrid spruce (*Picea glauca* × *P. englemannii*) in ICHmw2. Common shrubs in ICHdw were falsebox (*Pachistima myrsinites*) and Douglas maple (*Acer glabrum*); predominant herbs were twinflower (*Linnaea borealis*), prince's pine (*Chimaphila umbellata*), and queen's cup (*Clintonia uniflora*). Common shrubs in ICHmw2 were falsebox and black huckleberry (*Vaccinium membranaceum*) and predominant herbs were twinflower, prince's pine, queen's cup, and one-leaved foam flower (*Tiarella unifoliata*).

Broad-scale commercial logging in the area began in 1950. Landscapes were characterized by a mosaic of clearcuts within a mature coniferous forest matrix.

Methods

Prestratification and sample design

To assess broad-scale variability across a large area, I used a 2-stage sampling approach in which knowledge gained in early sampling was used to modify subsequent sampling (Krebs 1999). In the initial year, I defined a 26,800-ha sampling frame (i.e., extent of area considered for sampling) within TFL 3 using the 1,500-m contour as an upper elevational boundary. I selected the 1,500-m contour

One deer track in fresh snow recorded along a straight-line transect.

as an upper boundary that would capture all possible variability in deer density and abundance, including deer winter range and areas unsuitable as winter habitat (Wildstone 1994).

I used a stratified random sampling approach to select sample locations (Krebs 1999). I stratified the sample frame by terrain, aspect, and elevation to distinguish seasonal differences in ungulate winter range characteristics (Wildstone 1994). I defined terrain classes as ridgeline (i.e., vertical ridges extending from low to high elevations), riparian (i.e., areas $\leq$100 m from a creek), or face (areas not ridgeline or riparian); aspect classes by cardinal direction; and elevation classes as high (>1,060 m) or low ($\leq$1,060 m).

Combinations of terrain attributes (2 elevation classes, 3 terrain classes, and 4 aspect classes) yielded 24 unique strata. I randomly selected 64 locations among strata proportional to areal extent of each stratum. At selected locations, I established transects perpendicular to elevation contours to capture the most ecological variability within a localized area (Schemnitz 1980).

Data collection

Between 21 November 1996 and 17 February 1997 (year 1), field crews established 64 transects that were surveyed between 21 November and 10 January and again between 14 January and 17 February. These periods were selected to capture differences in early and midwinter environmental conditions. Field crews surveyed transects in the same order in each sampling period so that a similar time interval elapsed between surveys.

In the 2 subsequent winters, sampling was modified to include only 28 low and mid-elevation transects because they sufficiently covered the elevational extent used by wintering deer and potential areas beyond deer use (based on year 1 observations). Only midwinter surveys (each transect surveyed once) were performed in year 2 (3–27 February 1998) and year 3 (2 February–11 March 1999). I selected midwinter as the survey period because snow is deepest then and because of snow's relatively large influence on ungulate overwinter survival (Nyberg and Janz 1990).

Transect length varied from 300 to 1,000 m, depending on difficulty of access and terrain that terminated transects. Field crews measured horizontal distance (slope distance corrected for slope gradient) from the start of a transect and recorded all deer tracks crossing the transect centerline. Tracks were identified in the field using characteristics following Murie (1974). Tracks of white-tailed and mule deer cannot be distinguished accurately in the field and were therefore combined (Murie 1974).

Field crews established permanent plot centers at 50-m intervals along transects. At each plot they measured: slope gradient, elevation, aspect, overstory crown composition, mean overstory tree height, mean overstory tree diameter at 1.3 m from the ground, overstory crown closure, arboreal lichen abundance, horizontal cover, shrub abundance, ungulate browse activity, and snow depth. Field crews measured slope gradient with an analogue clinometer, determined plot elevation by establishing the elevation at the beginning of a transect on a digital elevation map and calculating subsequent elevations using slope gradient and distance traveled (measured with hip chains), measured aspect with a compass, determined overstory crown composition using an ocular estimate within a 20-m-radius plot, determined average overstory tree height and diameter by accurately measuring one sample tree in the 20-m-radius plot and estimating an average for all overstory trees in the plot, calculated overstory crown closure using the average of 3 spherical densiometer measurements (Lemmon 1956), assessed arboreal lichen abundance (Armleder et al. 1992), measured horizontal cover using a cover pole method (Griffith and Youtie 1988), determined deciduous shrub cover by species by ocular estimate within a 10-m-radius plot, and measured snow depth with a graduated pole. To account for microtopographic variation, field crews recorded the average of 3 snow-depth measurements concentrated around plot center. They inspected each shrub within the 10-m plot and recorded presence or absence of past ungulate browsing by shrub species.

Data analysis

For habitat use analyses, I divided transects into 50-m segments such that habitat plots were situated at midpoint along each segment. I assumed that habitat plots represented habitat conditions of the 50-m segment. I then associated tracks with the habitat conditions of the segment they intersected. In this way, I used 50-m transect segments with associated habitat conditions and deer activity as the sample unit for analytical purposes.

Measuring slope gradient, snow depth (graduated pole), and other habitat attributes at 50-m intervals along straight-line transects.

I converted track occurrence (collected as a continuous variable) to a discrete variable (i.e., presence or absence within 50-m segment). Standardizing track counts to account for animal activity between snow falls is desirable because it enables track data to be treated as a continuous variable (Thompson et al. 1989, Beauvais and Buskirk 1999). However, standardizing track counts was not appropriate in this case due to a lack of fresh snowfall during the data collection period and a low number of track observations leading to an extremely non-normal distribution that violated assumptions of standard parametric tests (Zar 1984).

I tested differences between means of continuous habitat data, grouped by presence or absence of tracks, with student's *t*-tests (Zar 1984). I determined habitat preference with log-likelihood tests of independence (*G*-test) with William's correction (G_{adj}, Fowler et al. 1998).

I used logistic regression of habitat variables to predict presence or absence of deer (Tabachnick and Fidell 1996). I used continuous and discrete habitat variables in the analysis by coding discrete variables as dummy variables (Cohen and Cohen 1983). I assessed a variety of logistic regression models based on McFadden's rho-square values and considered models with rho-square values between 0.2 and 0.4 good predictors (Tabachnick and Fidell 1996). I identified significant variables using the Wald test ($P<0.05$) and odds ratio results (variable was significant if the odds ratio 95% confidence interval did not include 1.0, Tabachnick and Fidell 1996).

I used multiple linear regression to determine significant variables in predicting snow depth and assessed a variety of models by comparing multiple R^2 values. I identified significant habitat variables using *F*-test ratios ($P<0.05$) and used these analyses to create a predictive snow-depth model using significant variables.

I derived logistic and multiple regression models using data from only years 2 and 3 because of improved field methods and consistency of data collection within these years. I then used independent data collected in year 1 to test model predictions.

Table 1. Deer tracks observed on snow-track surveys performed during 3 winters in the Little Slocan Valley, southeastern British Columbia, 1996–1999.

Survey period	Relative [a] snow depth	No. tracks[b] observed in survey period	No. Transects where tracks were observed (n = 28)	No. tracks/ 100m[c]
21 Nov 1996 to 10 Jan 1997	56	136	16	0.57
14 Jan to 17 Feb 1997	138	42	5	0.17
2 Feb to 27 Feb 1998	60	127	10	0.53
2 Feb to 11 Mar 1999	113	41	5	0.17

[a] Percent of average February levels based on long-term snow water equivalent data (British Columbia Ministry of Environment, Snow Survey Bulletins).

[b] A track is one occurrence of a deer crossing a transect line.

[c] Calculation is based on the combined length of 28 transects (23,900 m) surveyed within each sample period.

For multivariate analyses, I screened all variables for normal distributions using skewness and kurtosis indicators. I considered skewness or kurtosis extreme if ±2 times their standard error did not include zero (SPSS 1996). I transformed severely non-normal distributions using logarithm, square root, and arcsine transformations to produce more normal distributions and reduce outliers (Fowler et al. 1998). I did not use tree height in multivariate analyses due to its high correlation with tree diameter (Pearson $r > 0.7$), which violated multicolinearity assumptions (Tabachnick and Fidell 1996). I assessed discrete variables to ensure adequate cell frequencies ($\leq$5% of observations/cell, Tabachnick and Fidell 1996).

I converted aspect to a discrete variable for log-likelihood tests using the following classification: northeast = 1–90°, southeast = 91–180°, southwest = 181–270°, northwest = 271–360°. For modeling purposes, I converted aspect to an ordinal variable and treated it as continuous linear data on a solar radiation gradient ranging from northeast (45°) = 1 to southwest (225°) = 4 (Beers et al. 1966, Ohmann and Spies 1998).

Results

Sampling effort

The combined length of 64 transects sampled in early winter of year 1 was 41,800 m and resulted in 836 habitat plots. Midwinter sampling in year 1 covered 45,550 m of transects resulting in 911 habitat plots. In years 2 and 3 the subset of 28 transects accounted for 23,900 m of transect line and 478 habitat plots surveyed in each year. In year 1, plot elevations ranged from 543 m to 1,842 m; in years 2 and 3, elevation ranged from 543 m to 1,685 m.

Track observations and spatial distribution

Number of track observations and tracks/100 m ranged from 41 to 136 and 0.17 to 0.57, respectively, among sample periods (Table 1). Snow depths ranged from 56 to 138% of annual long-term averages among sampling periods (Table 1). Track presence in early winter of year 1 was spread throughout lower elevation areas in the main Little Slocan River drainage. Field crews did not observe deer tracks in higher-elevation drainages that flow into the Little Slocan River (Figure 1). In midwinter of year 1, they observed tracks on only 5 of 28 surveyed transects in the main Little Slocan drainage. The 5 transects were clustered within a single south-facing area. In midwinter of year 2, crews observed deer tracks on 10 of 28 surveyed transects. Distribution of tracks at this time was generally dispersed throughout the main Little Slocan Drainage. In midwinter of year 3, crews observed deer tracks on 5 of 28 surveyed transects. Four of these transects were clustered in the same area and in a similar fashion as in midwinter of year 1.

Habitat use

Within all 3 years, snow depth was consistently less (all $P = 0.001$), elevation was consistently lower (all $P < 0.018$), and slope was consistently greater (all $P < 0.005$) in locations where deer tracks were present versus where they were absent (Table 2). In year 3, horizontal cover was significantly greater ($t_{476} = 2.16$, $P = 0.031$) in areas where deer tracks were present. I found no significant differences or trends within or among years in tree height, tree diameter, crown closure, shrub cover, or lichen abundance (Table 2).

Consistently greater than expected track observations occurred within forest types dominated by Douglas-fir and ponderosa pine (if tracks were proportional to area representation of forest types) in mid-winter periods among all 3 years (1997: observed deer tracks in Douglas-fir–Ponderosa pine

=9, expected=1.64, $G_{adj,1}$=28.29; 1998: observed= 14, expected=4.39, $G_{adj,1}$=30.96; 1999: observed= 20, expected=5.21, $G_{adj,1}$=51.65; all P<0.001). Forest types dominated by western red cedar, western hemlock, and white birch had track observations similar to expected based on forest type area representation among all years (all $G_{adj,1}$<3.841, all P >0.064).

Mean aspects of midwinter track locations were consistently south and southeast among all years (1997: $\bar{x}$=142°, SE=10.6°, n=14; 1998: $\bar{x}$=130°, SE= 11.0°, n=24; 1999: $\bar{x}$=179°, SE=10.5°, n=28). Consistently greater than expected track observations occurred on southeast-facing slopes (if tracks were proportional to area representation by aspect) in midwinter periods among all 3 years (1997: observed tracks on southeast aspect=11, expected =3.86, $G_{adj,1}$=21.74; 1998: observed=17, expected =8.26, $G_{adj,1}$=23.72; 1999: observed=15, expected =9.31, $G_{adj,1}$=13.98; all P<0.001). In 1999, southwest slopes also had higher observed frequencies than expected (observed=11, expected=7.03, $G_{adj,1}$=9.56, P=0.002).

In year 2, the following species were browsed more than expected based on percentage cover availability: Saskatoon berry (*Amalenchier alnifolia*, $G_{adj,1}$=61.55, P<0.001), redstem ceonothus (*Ceonothus sanguineus*, $G_{adj,1}$=26.48, P<0.001), Douglas maple ($G_{adj,1}$=14.99, P<0.001), nootka rose (*Rosa nutkana*, $G_{adj,1}$=13.35, P= <0.001), ocean spray (*Holodiscus discolor*, $G_{adj,1}$=10.64, P= 0.001), wild rose (*Rosa gymnocarpa*, $G_{adj,1}$=8.15, P=0.004), and ninebark (*physocarpus malvaceus*, $G_{adj,1}$=5.25, P=0.022). Conversely, western hemlock ($G_{adj,1}$=180.78, P<0.001) and beaked hazelnut (*Corylus cornuta*; $G_{adj,1}$=11.65, P=0.001) were browsed less than expected. White birch ($G_{adj,1}$=0.83, P=0.362) and willow (*Salix* spp., $G_{adj,1}$=0.95, P=0.330) were browsed in proportion to their availability.

Model development

Deer presence and absence. Wald's test results of year 2 data indicated that presence of browse species (P=0.038), snow depth (P=0.007), elevation (P=0.042), and slope (P=0.01) were significant variables in a logistic regression model predicting presence of deer tracks (rho-square=0.351, P<0.001, Table 3). In year 3, aspect class (P= 0.007), snow depth (P<0.001), elevation (P= 0.018), slope (P=0.023), and tree diameter (P= 0.046) were significant predictors (rho-square= 0.533, P<0.001).

Snow depth. I questioned the ability of logistic regression to provide a reliable predictive model of deer presence because of low track observations.

Table 2. Mean values of continuous habitat attributes by absence (A) and presence (P) of deer tracks observed in February–March 1997, 1998, and 1999, Little Slocan Valley, southeastern British Columbia.

		1997 (n: A = 802, P = 14)				1998 (n: A = 441, P = 24)				1999 (n: A = 450, P = 28)			
Habitat attribute		$\bar{x}$	SE	t	P [a]	$\bar{x}$	SE	t	P [a]	$\bar{x}$	SE	t	P [a]
Snow depth (cm)	A	135.0	1.0	7.11	0.001*	64.0	2.0	3.71	0.001*	122.0	3.0	3.37	0.001*
	P	86.0	3.0			38.0	3.0			88.0	5.0		
Elevation (m)	A	1,083.0	9.0	3.76	0.001*	938.0	11.0	2.37	0.018*	1,013.0	10.0	2.51	0.012*
	P	1,012.0	16.0			830.0	25.0			911.0	27.0		
Slope (%)	A	40.1	0.8	5.88	0.001*	39.1	1.0	2.83	0.005*	40.2	1.0	5.15	0.001*
	P	55.6	2.4			52.0	4.2			60.2	2.6		
Tree height (m)	A	18.9	0.2	1.59	0.134	17.9	0.3	1.09	0.275	18.4	0.3	0.57	0.567
	P	20.9	1.2			19.6	1.1			17.6	0.7		
Tree diameter (cm)	A	27.4	0.4	1.07	0.302	26.0	0.6	1.40	0.161	27.2	0.6	0.84	0.398
	P	30.7	3.1			29.8	2.3			25.1	0.9		
Crown closure (%)	A	56.4	1.4	1.42	0.178	62.5	1.5	0.41	0.685	63.2	1.4	0.26	0.792
	P	48.1	6.5			60.0	5.9			61.7	3.0		
Shrub cover (%)	A	21.8	0.6	0.50	0.623	10.3	0.4	1.66	0.097	18.0	0.8	1.18	0.23
	P	20.0	3.5			13.5	1.8			21.9	3.8		
Horizontal cover (%)	A	—	—	—	—	57.8	1.2	1.33	0.196	43.7	1.2	2.16	0.031*
	P					52.4	3.9			33.9	2.7		
Lichen abundance (class)	A	—	—	—	—	1.4	0.1	0.89	0.379	1.0	0.0	0.26	0.793
	P					1.2	0.2			1.0	0.1		

[a] Statistical significance indicated (*) at α = 0.05.

Table 3. Results of logistic regression of habitat attributes collected in February–March 1998 and 1999, Little Slocan Valley, southeastern British Columbia. Dependent variable is presence or absence of deer tracks. McFadden's rho-square = 0.351 for 1998 model; 0.533 for 1999 model.

	1998 (n: absent=441, present=24)		1999 (n: absent=450, present=28)	
Habitat variable[a]	Wald's test t-ratio	P [b]	Wald's test t-ratio	P [b]
Aspect class1	1.187	0.235	–0.048	0.962
Aspect class2	–0.159	0.874	–0.378	0.705
Aspect class3	1.696	0.090	2.692	0.007*
Browse class1	2.073	0.038*	–0.714	0.475
Terrain class1	1.384	0.166	–1.083	0.279
Terrain class2	0.106	0.915	1.621	–0.105
Lichen series1	1.389	0.165	–1.885	0.059
Lichen series2	1.637	0.102	–0.760	0.447
Lichen series3	–1.505	0.132	1.235	0.217
Snow depth	2.676	0.007*	–4.164	<0.001*
Elevation	2.034	0.042*	2.358	0.018*
Lichen abundance	1.504	0.132	–1.437	0.151
Shrub cover	–0.542	0.588	0.269	0.788
Slope	–2.570	0.010*	2.269	0.023*
Diameter	0.389	0.697	–1.991	0.046*
Crown closure	–0.069	0.945	1.642	0.101
Horizontal cover	0.851	0.395	–0.564	0.573

[a] Dummy variable coding used for discrete variables. Browse class = presence or absence of preferred browse species, Terrain class = Terrain type (ridge, riparian, face), Lichen series and abundance follows Armeleder et al. (1992).

[b] Statistical significance indicated (*) at $\alpha = 0.05$.

Table 4. Analysis of variance for a multiple linear regression of habitat variables available from remotely sensed data sources in the Little Slocan Valley, southeastern British Columbia. Dependent variable is average snow depth (log transformed) from 1997, 1998, and 1999. Multiple $R^2 = 0.588$.

Source	Sum of squares	df	Mean square	F	P [a]
Forest type	0.705	5	0.141	15.117	<0.001*
Elevation	3.984	1	3.984	426.938	<0.001*
Crown closure	0.498	1	0.498	53.376	<0.001*
Slope	0.038	1	0.038	4.046	0.045*
Aspect[b]	0.136	1	0.136	14.587	<0.001*
Error	4.423	474	0.009		

[a] Statistical significance indicated (*) at $\alpha = 0.05$.

[b] Aspect data converted to ordinal variable using solar radiation gradient ranging from 1 = northeast to 4 = southwest aspect.

However, I consistently identified snow depth as the best predictor of deer presence. I therefore modeled snow depth as a surrogate using multiple linear regression.

An initial full model produced a significant regression (R^2=69.6, $F_{13,471}$=34.12, P<0.001). This analysis identified browse class (P<0.001), terrain type (P<0.001), lichen series (P=0.020), forest type (P<0.001), crown closure (P<0.001), horizontal cover (P<0.001), and aspect class (P<0.001) as significant variables associated with snow depth. To address a management objective of deriving predictive models based on readily available remotely sensed data, I performed a subsequent regression using only mapped variables to predict snow depth (Table 4). In this analysis, all variables were significant ($P \leq 0.045$) and produced a significant regression (R^2=58.8, $F_{5,479}$=66.19, P<0.001).

Results of this analysis provided regression coefficients to construct a snow-depth model that was applied to 1:20,000 British Columbia provincial forest cover and digital elevation data (Figure 1). Mapped habitat attributes in this application were: forest type, elevation, crown closure, slope, and aspect. All data layers were converted to raster data with 25-m pixels and applied within an ARCINFO platform.

The model predicted absolute snow depth. To assign relative snow-depth classes, I used a 3-year average of the ninetieth percentile snow depth where deer tracks were found (year 1=112.5 cm, year 2=52.0 cm, year 3=113.6 cm, 3-yr mean=92.7 cm) to distinguish between shallow and deep snow. The shallow snow-depth zone thereby delineated potential midwinter deer habitat. The very deep zone was delineated using model predictions of 120 cm and deeper (upper limit of observed tracks). A test of model predictions against year 1 data resulted in 77.6% (586/755) of observations classified correctly as shallow- or deep-snow locations.

Discussion

With sufficient data, snow-depth zones can be related directly to deer survival and management prescriptions (Nyberg et al. 1990). Similarly, snow depth can be used to predict white-tailed deer presence in ecosystems similar to those found in the Little Slocan Valley (Pauley et al. 1993). Deer in the Little Slocan study area demonstrated consistent winter-range patterns largely explained by relative snow depth. In 2 periods of relatively shallow snow depth (early winter in year 1 and midwinter in year 2), deer were dispersed widely throughout a larger area as compared to 2 periods of relatively deep snow (midwinter in years 1 and 3). In periods of relatively deep snow, deer displayed an aggregated pattern in one localized area within the study area, presumably in response to snow depth. These findings are consistent with the literature on influence of snow depth on ungulate distribution (Edwards 1956, Gilbert et al. 1970, Telfer 1978, Kirchoff and Schoen 1987, Pauley et al. 1993).

Management implications

Snow-track surveys provided indirect observations of deer presence during a specific time interval. This is an advantage over spring pellet counts, which typically do not permit seasonal differentiation (i.e., early, mid, or late winter) of data. The surveys also provided a measure of population distribution, an advantage over radiotelemetry methods, which require that information on radiocollared individuals be extrapolated to the population (White and Garrott 1990). Also, site-specific snow-depth data were effectively collected and related to vegetation and biophysical attributes, unlike most alternatives.

A limitation of snow-track surveys is the logistical resources required to conduct broad-scale field surveys in winter, especially in areas with limited road access. Surveys of this kind also are limited to areas of complete and persistent snow cover. An area with partial snow coverage would not provide meaningful results due to the inability of observing tracks in snow-free patches.

Another limitation of snow-track surveys is a bias toward quantifying locations where deer travel and not necessarily where deer spend most time feeding or bedding. As well, deer movement is reduced by increased snow depth (Gilbert et al. 1970, Parker et al. 1984). Therefore, areas with deeper snow may have fewer tracks due to reduced movement, even if deer density is equal to areas with less snow.

Finally, a potential pseudoreplication problem through a lack of independence among sample units (50-m transect segments in this study) is recognized (Hurlbert 1984). In this study, I used continuous rather than discontinuous transects to elevate the probability of intersecting ungulate tracks and reducing travel time between transects. A 50-m distance between habitat plots was judged to be an optimal balance between sample independence and capturing differences in changing habitat conditions along transects. Conversely, it was not feasible to randomly intersperse all sample plots within the study area to completely eliminate any dependence between plots and sufficiently cover the sample frame. Hurlbert (1984) recognizes that adequate interspersion can sometimes be assured only by dispensing with strict randomization. However, if feasible (e.g., small study area with adequate access), a greater number of shorter transects would reduce the concerns surrounding independence of sample units. The optimal design in this case would be randomly interspersed sample units consisting of a single short transect entirely within one habitat.

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