Research Report

BC Journal of Ecosystems and Management

Snow depth as a function of canopy cover and other site attributes in a forested ungulate winter range in southeast British Columbia

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Abstract

Snow depth is considered a major influence on deer (*Odocoileus* spp.) winter distribution and abundance in northern parts of their range. Overstorey canopy cover is often considered a principal variable governing snow depths in forests and has implications for managers who wish to achieve reduced snow depths by manipulating canopy closure in forests. I used three years of snow-depth data collected in forested ungulate winter range in southeast British Columbia to determine the relative influence of canopy closure and other site attributes on snow depth. Although canopy closure was a major factor in determining snow depth, it was outweighed by elevation and aspect. I found a close relationship between canopy closure and snow depth at low-elevation sites, but this relationship diminished or disappeared at higher elevations and on cooler aspects supporting the hypothesis that the influence of canopy closure depends on overall snow accumulation. At low elevations, forest managers could use canopy closure to influence snow depths. I offer the generalization that, on similar sites, maintaining 50% canopy closure will reduce snow depths by approximately 20%; 100% canopy closure will reduce snow depths by up to 40%.

KEYWORDS: *canopy cover, southeast British Columbia, snow depth, ungulate winter range, wildlife habitat management.*

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Introduction

Snow depth is generally considered a major factor influencing the winter distribution and abundance of deer (*Odocoileus spp.*) in the northern parts of their range (Edwards 1956; Gilbert *et al.* 1970; Bunnell *et al.* 1990; Pauley *et al.* 1993; Armleder *et al.* 1994; D'Eon 2001). This notion is especially relevant to the mountainous regions of western North America where mid-winter snow depths can vary from zero to many metres depending on location and site attributes. Wintering deer in these regions typically seek out areas of shallower snow. This behaviour is believed to decrease energy expenditures because of easier locomotion and higher food availability, and ultimately leads to greater overwinter survival (Parker *et al.* 1984).

The relationship between snow depth and deer distribution in forested winter range has received considerable attention in the published literature, especially in the coastal ecosystems of British Columbia (e.g., McNay 1985; Bunnell *et al.* 1990). However, the factors directly influencing snow depth in these areas have received less consideration, despite the management implications of understanding the relative influence of site attributes on snow depth in ungulate winter range. For example, many forest management jurisdictions employ varying canopy-cover prescriptions (e.g., partial cutting) that are designed to maintain or improve ungulate winter range habitat (e.g., Armleder and Dawson 1992). Many assume that a general inverse relationship exists between overstorey canopy cover and snow depth in forests. This is typically attributed to the higher rates of snow interception by thicker canopies, which can ultimately reduce snow depth (e.g., Kirchoff and Schoen 1987; Armleder *et al.* 1994). However, this relationship likely varies widely depending on site attributes, habitat conditions, and environmental variability. Indeed, Harestad and Bunnell (1981) found inconsistent relationships between studies in a meta-analysis and suggested that canopy cover has a relatively smaller effect on snow accumulations in areas with deep snowpacks than in areas with shallower snowpacks. Golding and Swanson (1978) identified several confounding factors, such as opening shape, topography, and annual variability, in a study of snow depth in forest openings. Finally, Kirchoff and Schoen (1987) found tree height and net inventory volume better correlates with snow deposition than canopy cover. This variability suggests that the relationship between canopy cover and snow depth in forested ungulate winter range is not well understood, probably varies with environmental factors, and, therefore, cannot be assumed under local conditions.

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I collected mid-winter snow-depth measurements along with a suite of biophysical and habitat attribute data over three winters in a forested ungulate winter range in southeast British Columbia. These data were gathered in conjunction with data collection for other ungulate winter range studies (D'Eon 2001). My objectives were to:

- determine the relative influence of canopy cover and other site attributes on mid-winter snow depths, and
- provide predictive relationships between canopy cover and snow depths for use by forest managers.

Study Area

Field data were collected in the Little Slocan Valley, in southeast British Columbia, approximately 40 km north of Castlegar (49°42' N, 117°42' W; a 26 800-ha study area described by D'Eon [2001]). This valley has been used historically as ungulate winter range, primarily by mule deer (*Odocoileus hemionus*) and to a lesser extent by white-tailed deer (*O. virginianus*) and elk (*Cervus elaphus*). The area is part of a Slocan Forest Products Ltd. (Slocan, B.C.) Tree Farm License (TFL3) tenure, which is actively managed for timber and other non-timber resources. This forest landscape is characterized by a mosaic of clearcuts within a mature coniferous forest matrix. The study area is within the Interior Cedar-Hemlock Moist Warm (ICHmw2) and Dry Warm (ICHdw) biogeoclimatic zones described by Braumandl and Curran (1992). The ICHdw zone occurs from the lowest elevations in the study area (approx. 500 m) to approximately 1000 m on cool aspects and 1200 m on warm aspects, above which the ICHmw2 extends to approximately 1450 m. Climax forest type in the ICHdw and ICHmw2 is a mix of western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*).

More common in the ICHdw are mixed seral stands of Douglas-fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), western larch (*Larix occidentalis*), and white birch (*Betula papyrifera*).

Terrain is generally steep and broken with slope gradients exceeding 80% and slope aspects varying from 1° to 360°. Annual precipitation averages 812 mm (Environment Canada weather station, New Denver, B.C.). Average daily summer high and low temperatures are 26.9°C and 9.4°C, respectively; average daily winter highs and lows are 2.2°C and –4.9°C, respectively. Snow usually covers 100% of the ground from late November until mid-April and is typically deepest at low elevations in mid-February.

Methods

Data Collection

Snow depth and other site attribute data were collected in conjunction with data collection for other ungulate winter range studies during February from 1997 to 1999 (see D'Eon [2001] for exact dates and details). Surveys were performed in the shortest possible time (given logistical constraints) to alleviate the influence of snow accumulation during the sample periods. Twenty-seven straight-line transects, between 300 m and 1000 m long, were established using a stratified random design, and surveyed annually using methods described by D'Eon (2001). These transects were a subset of 67 transects originally established for other ungulate winter range studies and were selected because they contained consistent snow-depth data collected from three consecutive mid-winter periods (other transects had different sampling intervals or were sampled at different times of year). I selected the transect locations on the basis of a stratified random approach that confined the sampling area to a region which represented the total extent of possible ungulate winter range in the Little Slocan Valley (see D'Eon [2001] for further details). At 100-m intervals along the transects, field crews measured the following site attributes: snow depth, slope gradient, elevation, aspect, canopy cover, canopy composition by tree species, average diameter (DBH) of main canopy, average height of main canopy, and biogeoclimatic ecosystem classification subzone (or "BEC"; Braumandl and Curran 1992).

Snow depth was calculated as the average of three measurements taken with a graduated pole concentrated around plot centre (i.e., 1 m from plot centre in three cardinal directions). The average was used to avoid anomalous depth measurements (e.g., when the pole hit a stump). Other site attributes were measured in the following way.

- Slope gradient: measured with an analogue clinometer
- Plot elevation: determined by establishing the elevation at the beginning of a transect on a digital elevation map and calculating subsequent elevations using slope gradient and distance travelled (measured with hip chains)
- Aspect: measured with a compass
- Overstorey canopy composition: determined using an ocular estimate within a 20-m radius plot
- Average overstorey tree height and diameter (DBH): determined by measuring one sample tree in the 20-m radius plot and estimating an average for all overstorey trees in the plot
- Overstorey coniferous canopy cover: calculated using the average of three spherical densiometer measurements at plot centre (i.e., 1 m from plot centre in three cardinal directions; as recommended by Lemmon [1956])

I chose an angular method over vertical methods of measuring canopy cover because angular measures are believed to better capture ecological factors related to solar radiation and snow depth (Bunnell and Vales 1990; Nuttle 1997). While methods and terminology for measuring forest canopy cover lack consistency (see Bunnell and Vales [1990] for a review), I refer to canopy cover in this study as the proportion of the sky obstructed by tree foliage from a point on the ground (also referred to as "crown completeness" by Bunnell and Vales [1990]).

Snow depth and canopy cover were measured during each visit because I considered them variable; all other attributes were measured on the first visit only.

Data Analysis

I averaged snow depth and canopy cover measurements for each plot among the three annual visits. I combined the three years of data to provide generalized predictions that better reflect average conditions. This also avoided modelling an anomalous and, therefore, unrepresentative winter. I created two new variables from canopy composition observations in the field:

1. % Douglas-fir/ponderosa pine ("FIRPINE") in the main canopy, and
2. % western redcedar/western hemlock ("CEDHEM") in the main canopy.

I chose these two variables to represent habitat types as they are the two predominant forest types in the study area. I converted aspect, recorded as a continuous circular variable, to a nominal variable based on solar incidence classes; that is, 1 = 286–59°, 2 = 60–135°, 3 = 241–285°, and 4 = 136–240°. In this way, I constructed a data set with 3-year average snow depth and canopy cover in association with other site attributes for each plot along all transects. The final data set contained the following variables: snow depth, canopy cover, slope, aspect class, elevation, BEC subzone, DBH, height, FIRPINE, and CEDHEM.

To investigate the relative influence of all attributes in determining snow depth, I calculated Akaike's Information Criterion (AIC) and associated values for a set of *a priori* multiple linear regression models that predicted snow depth (Burnham and Anderson 1998; Anderson and Burnham 2002). Akaike's Information Criterion is a relatively new method of data analysis based on an extension of likelihood theory (see Anderson *et al.* [2000] for details). In light of criticisms in the ecological literature against the use of statistical hypothesis testing (Cherry 1998; Johnson 1999; Guthery *et al*. 2001; Ander-son and Burnham 2002), AIC has been strongly advocated by some as an alternative to null-hypothesis testing and associated *P*-values. Briefly, AIC is a model-selection technique that focuses on providing the relative evidence for a set of models based on a formal expression of likelihood rather than a statistical test of a null hypothesis. Anderson *et al.* (2001) described the presentation of AIC results.

I used the least squares method for calculating AIC values (Burnham and Anderson 1998:48). I ranked models based on ΔAIC values (i.e., smaller numbers indicated better models) and used AIC weights (AICω) and evidence ratios to gauge the relative importance of model parameters in predicting snow depth (Burnham and Anderson 1998:123). Before modelling, all variables were assessed for normality using skewness and kurtosis indicators and transformed using logarithmic, square-root, or arcsine transformations to obtain more normal distributions, if warranted. As well, all variables were tested for multi-colinearity and rejected for multivariate analyses, if highly correlated ($r > 0.7$; Tabachnick and Fidell 1996).

To quantify the relationship between snow depth and canopy cover and to provide useable information to managers, I stratified data by biogeoclimatic subzone (ICHdw and ICHmw2), which is closely associated with elevation, and aspect (warm: ≥ 136° and ≤ 285°; cool: ≥ 286° and ≤ 135°). I further stratified each subzone and aspect stratum into high- and low-elevation classes based on the midpoint of the data. I did this to further account for the influence of elevation on snow depth. I used simple linear regression to obtain snow-depth models within strata using canopy cover as the independent variable.

Data screening and linear regression analyses were performed using SYSTAT 8.0 statistical software (SPSS 1998); AIC values were calculated within a spreadsheet.

Results

A total of 455 plots from 27 transects were sampled annually within the ICHdw and ICHmw2. Plots at elevations above the ICHmw2 were not included in the analyses as wintering deer rarely use elevations above this zone (D'Eon 2001). Plot elevations ranged from 543 to 1459 m. Plot slope gradients ranged from 0 to 110%. Aspect class distribution was: 1 = 125 plots, 2 = 77 plots, 3 = 64 plots, and 4 = 189 plots.

For modelling purposes, tree height was omitted from multivariate analyses because of high correlation with DBH ($r = 0.767$), and BEC subzone was omitted because of high correlation with elevation ($r = 0.723$). I chose to retain DBH because it is more accurately measured in the field, and elevation because of its vital role in snow-depth modelling. To obtain more normal distributions, snow depth and elevation were square root-transformed, canopy cover was arcsine-transformed, and FIRPINE was logarithmic-transformed.

Model selection analyses using AIC methods demonstrated that the full model contained the most parsimonious set of predictors for snow depth compared to all other models explored (ΔAIC = 0, $R^2 = 0.536$; Table 1). However, the DBH and CEDHEM variables contributed relatively minor amounts to AIC weights, and the full model was only 1.6 times more likely to predict snow depth than a model without DBH (based on evidence ratio calculations [i.e., $\text{AIC}\omega_i/\text{AIC}\omega_j = 0.5107/0.3118 = 1.637$]; Anderson and Burnham 2002), and 3.2 times more likely than a model without CEDHEM. The FIRPINE and aspect variables contributed more to the model with evidence ratios of 56.7 and 81.0, respectively, for models without those variables compared to the full model (Table 1). Slope, elevation, and canopy cover contributed very heavily with evidence ratios in the thousands. Elevation had the single heaviest contribution to the full model. A model of only biophysical attributes (elevation, slope, aspect; ΔAIC = 115.409) was much more likely to predict snow depth than a model of only habitat suitability (i.e., habitat variables that change through time such as forest cover) attributes (e.g., canopy cover, DBH, FIRPINE, CEDHEM; ΔAIC = 289.411).

Simple linear regression analyses between snow depth and canopy cover were significant ($P > 0.05$) within three of the ICHdw strata, the exception being high-elevation cool aspects (Figure 1). No significant regressions occurred among the ICHmw2 strata (all $R^2 < 0.069$; all $P > 0.194$). Models for significant regressions (from Figure 1) are the following:

- ICHdw warm–low: $SD = -0.319 \times CC + 95.395$,
- ICHdw cool–low: $SD = -0.475 \times CC + 113.343$, and
- ICHdw warm–high: $SD = -0.177 \times CC + 98.168$,

where: SD = snow depth in centimetres, and CC = canopy cover in percent. These three models predict that increasing canopy cover (under similar environmental conditions) to 50% will, on average, decrease snow depths between 9.0 and 20.7%; increasing canopy cover to 100% will decrease snow depths between 18.0 and 41.6% (Table 2).

TABLE 1. Model selection results for 11 linear regression models using site attributes to predict February snow depths in a southeast British Columbia forested landscape

Model[a]	K	RSS	AIC[b]	ΔAIC	AICω
Full model: elevation, slope, aspect, CC, FIRPINE, CEDHEM, DBH	9	414.81	–24.07	0.00	0.5107
Full model without DBH	8	417.54	–23.08	0.98	0.3118
Full model without CEDHEM	8	418.74	–21.77	2.29	0.1618
Full model without FIRPINE	8	424.08	–16.01	8.05	0.0090
Full model without aspect	8	424.74	–15.30	8.77	0.0063
Full model without slope	8	441.48	2.28	26.35	< 0.0001
Elevation, slope, aspect, CC	6	459.31	16.29	40.37	< 0.0001
Full model without CC	8	467.19	28.03	52.10	< 0.0001
Elevation, slope, aspect	5	544.05	91.33	115.40	< 0.0001
Full model without elevation	8	764.11	251.87	275.95	< 0.0001
Canopy cover, FIRPINE, CEDHEM, DBH	6	793.99	265.33	289.41	< 0.0001

[a] Aspect = 4-class nominal variable; CC = evergreen canopy cover; FIRPINE = % Douglas-fir/ponderosa pine in stand; CEDHEM = % western redcedar/western hemlock in stand; DBH = average diameter at breast height of leading tree species.

[b] Akaike's Information Criterion (AIC) values calculated using the least squares method (Burnham and Anderson 1998:48); RSS = residual sum of squares; K = number of model parameters; ΔAIC = change in AIC value from the best model; AICω = AIC weights; R^2 for full model = 0.536; n = 455.

TABLE 2. Percent decrease in snow depth with increasing coniferous canopy cover predicted by snow depth models in a forested ungulate winter in southeast British Columbia (see text for models)[a]

ICHdw strata		Canopy cover (%)				
Aspect	Elevation	0	25	50	75	100
Warm (136–285°)	Low (543–850 m)	0	8	17	25	33
Cool (286–135°)	Low (561–800 m)	0	11	21	31	42
Warm (136–285°)	High (851–1195 m)	0	5	9	14	18

[a] Data derived from forests within the Interior Cedar-Hemlock dry warm (ICHdw) biogeoclimatic subzone variant described by Braumandl and Curran (1992).

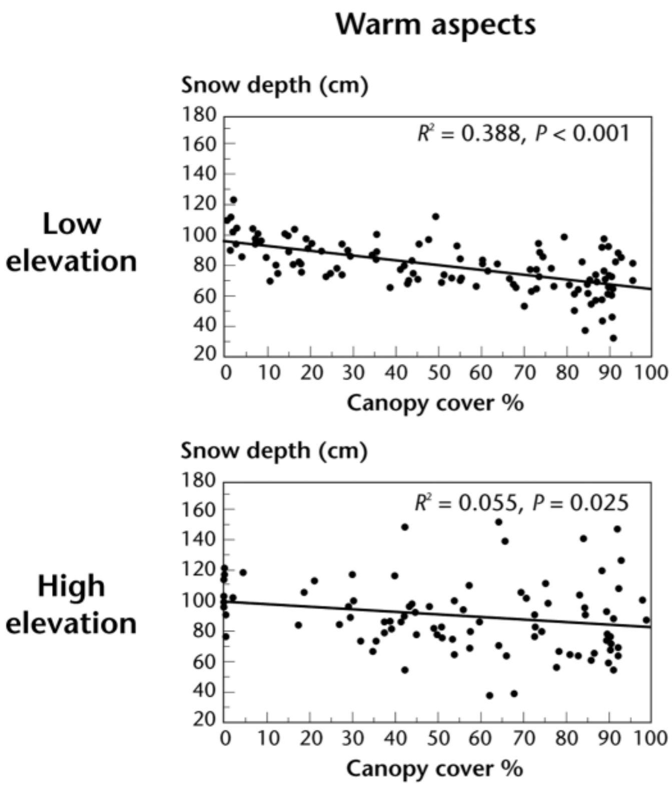

FIGURE 1. February snow depths versus coniferous canopy cover for Interior Cedar-Hemlock (dry, warm) forested sites in southeast British Columbia from 1997 to 1999. Data was stratified by warm (≥ 136° and ≤ 285°) and cool (≥ 286° and ≤ 135°) aspects, and elevation (warm aspects: low = 543–850 m, high = 851–1195 m; cool aspects: low = 561–800 m, high = 801–1069 m). Regression lines signify the line of best fit for significant regressions.

Discussion

Model selection analyses demonstrated that all variables I considered contributed to a better model of snow depth. This supports the hypothesis that snow depth results from the complex interaction of a large suite of variables. Accurately predicting snow depth at any particular location based on one or a few variables would be difficult, if not impossible. However, as expected, the results of this study clearly indicate that elevation is the most influential variable for snow-depth predictions in my study area. Interestingly though, elevation was followed by (in order of importance) aspect, canopy cover, and slope. Thus canopy cover, although demonstrated as an important predictor of snow depth, was outweighed by elevation and aspect. This has significant management implications: forest managers attempting to obtain reductions in snow depths by manipulating forest canopy cover must account for the differing effects of elevation and aspect on snow depth, rather than assuming a direct and universal relationship between canopy cover and snow depth. This is especially true given that the worst performing model I explored lacked biophysical attributes, again underscoring the importance of biophysical attributes in snow-depth prediction.

On the basis of snow–water equivalent studies conducted primarily in California, Harestad and Bunnell (1981) showed that canopy cover had a relatively smaller effect on snow accumulation in areas with deep snow than in areas with shallow snow. This hypothesis held true in my study—where snow depths are shallower, I found relatively close relationships between canopy cover and snow depth at lower elevations (ICHdw; Figure 1). This relationship diminished with increasing elevation (which results in increasing snow depth) and disappeared (based on non-significant regression analyses) at the highest elevations (ICHmw2). In addition, cooler aspects (which typically have greater snow depths) at the highest elevations in the ICHdw failed to demonstrate a significant relationship between canopy cover and snow depth (Figure

1). Harestad and Bunnell's (1981) work held true in my study area, where canopy cover strongly influenced snow depths at lower elevations (warm aspects up to 1200 m; cool aspects up to 800 m), but the effect of canopy cover on snow depth diminished with increasing elevation and cooler aspects. However, I am unable to speculate on the ultimate mechanisms and processes (e.g., climatic and meteorological) that produce greater snow depths under forest canopies at higher elevations and cooler aspects, although it is likely related to reduced rates of snow melt and dispersion from forest canopies in those areas (e.g., see, Bunnell *et al.* 1985; Gluns 2001; and Winkler 2001).

I consider the data collected in this study very robust. Most data from similar studies are collected in a single season and from few sites. In this study, I presented data from 455 sample locations dispersed within a 26 800-ha sampling area. A major advantage of these data is that they represent 3-year average snow depths, which diminishes the effects of an anomalous winter. However, since snow accumulation is a highly variable and dynamic process, generalizations beyond my study area must be done with caution. Indeed, the best canopy closure model in this study explained 39% of the variability in snow depth and, therefore, suggests that many other factors are involved; these other factors will have variable effects depending on local site conditions.

Management Implications

Ungulate winter range management in the Pacific Northwest of North America typically focuses on manipulating the amount of mature coniferous forest cover through landscape- and stand-level harvest prescriptions (e.g., Armleder and Dawson 1992). The underlying assumption is that mature coniferous forest cover provides necessary habitat for wintering deer. Reduced snow depth is considered one of the major benefits of mature coniferous forest habitat because deep snow buries food and impedes deer movement, which increases energy costs (Parker *et al.* 1984). In this study, I have demonstrated that canopy cover had a significant influence on snow depths at low elevations and on warmer aspects; therefore, forest managers can influence snow depths on these sites by manipulating canopy cover through stand retention or partial harvesting techniques. The empirical relationships demonstrated here can be used to more directly and precisely reach snow-depth objectives by employing preharvest prescriptions. Table 2 illustrates the percentage of decreased snow depth that can be expected as canopy cover of forest stands increases (i.e., as predicted from the models). In a hypothetical example, if a manager working on a cool, low-elevation site (as defined in Table 2) ensured 50% canopy cover, the resulting mid-winter snow depths could be 21% lower than in an opening (i.e., a clearcut) on a similar site; increasing canopy cover to 75% on this site could result in a 31% decrease in snow depth, and so on. Since the relationships appear linear (Figure 1), other canopy-cover values and resulting decreases in snow depth could be safely interpolated or calculated from the model equations provided. Note, however, that this effect diminishes with increased elevation, and beyond 1000 m becomes questionable.

This study demonstrates that canopy cover had a significant influence on snow depths at low elevations and on warmer aspects.

An important consideration in applied work that involves the measurement of forest cover is the distinction between canopy cover measured from a point on the ground versus crown closure, which is typically measured or estimated from aerial photographs across an entire stand. In this study, all measurements and predictions involved field measurements of canopy cover, or the amount of the sky that is obstructed by tree foliage from a point on the ground. Crown closure, on the other hand, is a measure of the proportion of ground surface encompassed by vertical projections of the outer edges of tree crowns. Although related, canopy cover and crown closure provide dissimilar measures and, therefore, caution must be exercised when interpreting data from studies using these two different measurement techniques. Managers or researchers working with stand-level measures (e.g., crown closure taken from forest-cover mapping) must consider this difference when interpreting the data presented in this study. As well, ground-based measurements of canopy closure or snow depth underneath the crown of a large conifer will likely be different than those taken beyond the influence of the crown. These and other scale-related measurement issues must be considered in light of project objectives.

Finally, I caution that the focus of this work was solely on the benefits of mature forest cover for wintering deer. Recent work suggests that other factors, such as summer precipitation and food availability, may be more important variables in explaining population trends in mule deer (Peek *et al.* 2002). This strongly suggests that managers should consider many factors, especially food availability (which tends to grow more abundantly in openings) in addition to mature coniferous forest cover when managing for ungulate winter range.

Acknowledgements

I thank R. Serrouya for a review of a previous draft, especially for his insight into AIC modelling. I am also grateful to my field staff, particularly the efforts of C. Bialkowski, D. Lutz, P. Lindgren, and T. Merriman. Funding to collect the data used in this study was provided by Forest Renewal BC to Slocan Forest Products. I thank R. Winkler, R. Scherer, and one anonymous reviewer for very useful comments on a previous draft.

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