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Réimpression du

Canadian Journal of Forest Research

Journal canadien de recherche forestière

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Volume 18 • Number 5 • 1988

Pages 566–573

Printed in Canada/Imprimé au Canada

The influence of forest stand characteristics on snow interception in the coastal forests of British Columbia

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Received July 14, 1987

Accepted January 15, 1988

MCNAY, R. S., PETERSON, L. D., and NYBERG, J. B. 1988. The influence of forest stand characteristics on snow interception in the coastal forests of British Columbia. Can. J. For. Res. **18**: 566–573.

The capability of forest stands to intercept snow is an important factor in determining management prescriptions for such hydrologically related phenomenon as avalanches, floods, and water supply as well as suitability for ungulate winter habitat. This study tested the hypothesis that snow interception can be predicted as a function of various stand characteristics and storm sizes. The dependent variable was fresh snow depth under the forest canopy; the independent variables were crown completeness, crown length, crown width, basal area per hectare, tree height, tree density, and storm size. Ten stands were selected for study from two locations on Vancouver Island. Snow depth was monitored over 24 storms ranging from 1.4 to 38.0 cm. The best simple linear regression models that incorporated forest variables were those for individual storms, with fresh snow expressed as a function of mean crown completeness. The best assessments of a particular stand's capability to intercept snow were made using an equation with both storm size and mean crown completeness as independent variables.

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La capacité des peuplements forestiers d'intercepter la neige est un élément important à considérer dans l'élaboration des prescriptions d'aménagement lorsqu'on a affaire à divers phénomènes hydrologiques comme les avalanches, les inondations et la fourniture d'eau tout comme lorsqu'il s'agit de créer des habitats hivernaux pour les ongulés. Cette étude avait pour but de vérifier l'hypothèse suivant laquelle on peut prédire l'interception de la neige d'après diverses caractéristiques des peuplements et l'intensité des tempêtes de neige. La variable dépendante était l'épaisseur de neige récente sous le couvert forestier; les variables indépendantes étaient la densité des cimes, la longueur des cimes, la largeur des cimes, la surface terrière par hectare, la hauteur des arbres, la densité du feuillage ainsi que l'intensité des tempêtes. Dix peuplements ont été choisis pour l'étude, répartis à deux endroits de l'île de Vancouver. L'épaisseur de la neige fut mesurée périodiquement pendant 24 tempêtes de neige allant de 1,4 à 38,0 cm. Les meilleurs modèles de régression linéaire simples incorporant des variables forestières ont été ceux applicables à des tempêtes individuelles, basés sur la neige récente en fonction de la densité moyenne des cimes. Les meilleures évaluations de la capacité d'un peuplement individuel à intercepter la neige ont été faites en utilisant une équation prenant en compte l'intensité des tempêtes et la densité moyenne des cimes comme variables indépendantes.

[Traduit par la revue]

Introduction

Hydrology literature, particularly from northern latitudes and mountainous regions, abounds with studies that document the relationships between forests and characteristics of their associated snowpacks (for reviews see Kittredge 1953; Miller 1966; Shank and Bunnell 1982; Bunnell *et al.* 1985). The interest derives from snowpack management objectives concerned with avalanche control, flood control, or the timing and quality of water reserves (Haupt 1972; Golding and Swanson 1978; Strobel 1978; Harr and Berris 1983). Wildlife ecologists are also interested in snowpack management because the interception of snow by forest canopies is an important element in the management of winter habitats for ungulates. As snow accumulates on the ground the energetic cost of locomotion increases exponentially (Parker *et al.* 1984) and food resources become buried and therefore inaccessible (Jones 1974; Bunnell and Jones 1984).

The goal of this study was to provide a method for evaluating the capability of forest stands to intercept snow, as an aid to the management of ungulate winter habitats. Models reported in previous work (e.g., Harestad and Bunnell 1981; McNay 1985) were based on measures of snow depth in centimetres of snow water equivalent (cm SWE), which is also the unit of measure reported in most other studies of snow accumulation or interception (Shank and Bunnell 1982). However, energy expenditure for deer locomotion and the rate at which forage is buried are both more frequently related to snow depth than to SWE (Parker *et al.* 1984; Hovey 1987[1]). We therefore chose to measure snow depth in centimetres to achieve our objective, which was to investigate the relationships of snow deposition in

[1]Hovey, F. 1987. Shrub burial in coastal immature forests: a review and recommendations. Unpublished manuscript on file at the Faculty of Forestry, University of British Columbia, Vancouver, B.C.

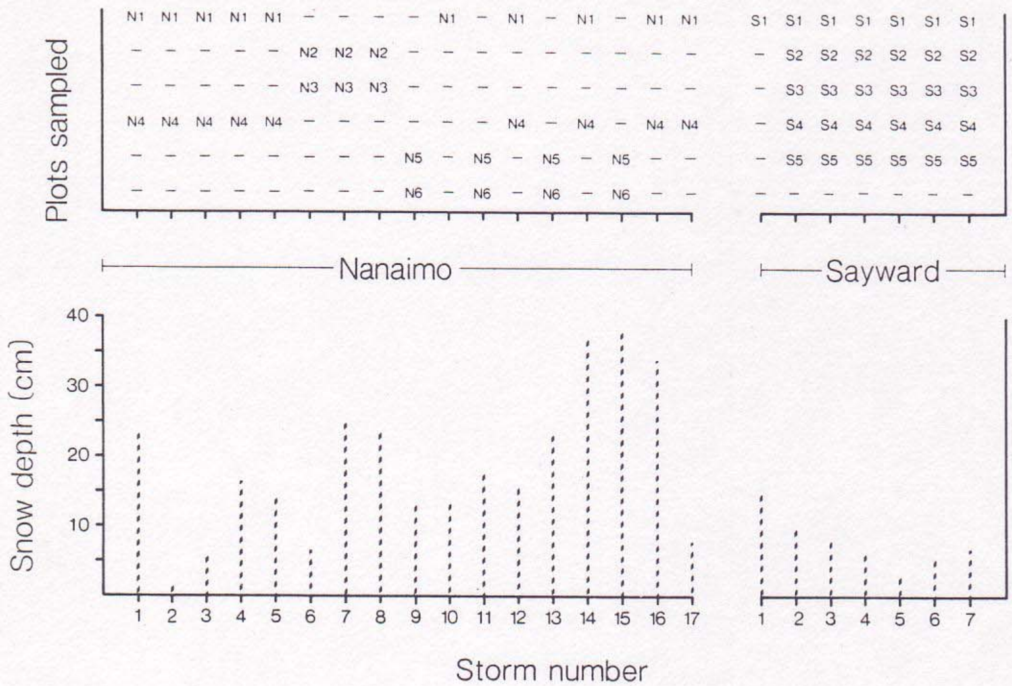

FIG. 1. The distribution of sampled snow storms.

forest stands to the magnitude of snowfall and to forest stand characteristics.

Methods

Forest stands were chosen for sampling based on several criteria: (*i*) terrain: level topography was chosen to reduce the effect of slope on apparent snow depth (Bunnell *et al.* 1985; p. 132); (*ii*) area: stands greater than 5 ha in area were chosen to limit the influence of adjacent stands on snow deposition (Bunnell *et al.* 1985); (*iii*) stand proximity: comparisons of snow interception for individual storm sizes could only be made among stands experiencing the same storm; (*iv*) proximity to a large open area: large openings that experienced the same storm were needed nearby to allow measurement of storm size (storm size being measured as that amount of fresh snow falling from the onset of snowfall until its cessation); and (*v*) stand characteristics: a range of stand characteristics (e.g., age, crown structure, tree density) was needed to ensure robustness of the results.

Representative stands with canopies of Douglas-fir (*Pseudotsuga menziesii* Mirb.) and western hemlock (*Tsuga heterophylla* Raf.) were chosen at two locations on Vancouver Island, British Columbia. Permanent measurement plots were established using a systematic sampling design. Five stands were chosen in the Sayward Provincial Forest near the city of Campbell River and five on private land in the Nanaimo River drainage. All plots were located between 170 and 700 m elevation. The five Sayward Forest stands and two of the Nanaimo River stands were in the wetter portion of the Coastal Douglas-fir Biogeoclimatic zone (*sensu* Klinka *et al.* 1984). The remaining three Nanaimo River stands were in the drier maritime portion of the Coastal Western Hemlock Biogeoclimatic Zone. On each plot, 66 sampling points were arranged at 1-m intervals on parallel lines 5 m apart. Sample size was calculated, using data from McNay (1985), to yield a mean snow depth within 5% of the true mean 90% of the time (95% confidence with PE = 10%; after Stauffer 1983). The Sayward Forest samples were arranged in six 10-m lines, while those in the Nanaimo River stands were in four 14-m lines and one 5-m line.

Crown completeness, defined as the proportion of the sky obscured by tree crowns within a specified angle viewed from the ground (Bunnell *et al.* 1985), was measured by hemispherical photography and the moosehorn technique (Bonnor 1967). The moosehorn projects a viewing angle of approximately 10°. The same angle was used to assess hemispherical photographs. Both techniques were chosen over other crown measurement techniques because of their relative precision and lack of bias (McNay 1985; Vales and Bunnell 1985). Moosehorn readings, centred on the zenith, were taken at each of the 66 snow sampling points per plot; photographs were taken at every second point. Crown completeness data, when measured with the moosehorn or with photography, are henceforth referred to as CCm and CCphoto, respectively. Whenever plot means are discussed, MCCm and MCCphoto are used. Tree measurements were collected using standard forest inventory techniques (Bell *et al.* 1984). The geometric mean of the minimum and maximum crown diameter was used as the measurement of crown width. Plot size was adjusted to include all those trees with canopies extending within 2 m of a sampling point. Tree densities and means calculated from tree measurements were based only on trees greater than 7.5 cm in diameter at breast height (dbh).

Snow depth was measured to the nearest centimetre. When snow fell on an existing snowpack, the depth of new (fresh) snow could be determined by measuring to the crust that was usually present at the surface of the old pack. Storm size was determined by measuring new snow deposited on the open sites.

The literature shows that the term "snow interception" is often used indiscriminately. It is correctly defined as the amount of snow or proportion of a snowfall that does not reach the ground during a given single storm (Gray and Male 1981). We estimated interception by measuring the difference in depths of new snow between the open and canopied sites after each storm. Fresh snow at the open sites was assumed to be an effective index of true storm size.

Both the hydrology literature (Bunnell *et al.* 1985) and previous investigations (McNay 1985) have suggested that temperatures causing melt, and wind causing redistribution of snow, have confounding effects on the prediction of snow interception as a function of forest crown attributes. To reduce these effects, we attempted to sample immediately (usually 6–12 h) after snow storms, when there was no wind and the temperature was at or below freezing. In addition, we sampled only when the sky was overcast and without appreciable precipitation.

During the winters of 1984–1985 and 1985–1986, fresh snow was measured after 18 snow events. Because of differences in weather patterns between sites, this sampling resulted in data on 24 dif-

TABLE 1. Mean plot characteristics at the Nanaimo River and Sayward Forest study site

Stand	Plot no.	Age (years)	MCCm (%)	MCCphoto (%)	Density (stems/ha)	Basal area (m^2/ha)	dbh (cm)	Height (m)	Live crown length (m)	Crown width (m)
Old growth	S1	200	61.2 (3.9)	68.6 (4.5)	448	85.5	45.7 (3.4)	27.8 (1.6)	16.1 (1.2)	5.6 (0.3)
Unthinned commercial	S2	40–45	82.1 (1.8)	89.9 (2.0)	742	47.4	25.7 (1.8)	23.9 (1.1)	10.3 (0.8)	4.7 (0.2)
Commercially thinned	S3	40–45	42.7 (3.7)	54.1 (6.2)	335	30.7	32.9 (2.0)	28.8 (0.7)	13.6 (0.9)	4.9 (0.3)
Unthinned young growth	S4	40–45	75.5 (2.9)	86.6 (3.5)	1376	33.9	16.5 (0.6)	15.8 (0.4)	6.4 (0.2)	3.1 (0.1)
Non commercially thinned	S5	40–45	52.2 (4.1)	67.5 (6.4)	833	20.5	18.4 (0.4)	15.4 (0.2)	7.8 (0.3)	3.2 (0.1)
Old growth	N1	200	62.1 (3.9)	79.2 (5.0)	540	65.7	36.8 (2.6)	23.2 (1.3)	12.6 (1.0)	6.2 (0.2)
Old growth	N2	200	89.1 (1.2)	97.1 (1.0)	698	88.3	31.8 (3.7)	19.3 (1.77)	12.4 (1.3)	5.4 (0.3)
Old growth	N3	200	88.7 (1.1)	95.2 (0.8)	386	93.5	50.9 (4.7)	31.3 (2.6)	20.8 (2.0)	7.1 (0.4)
Unthinned young growth	N4	28	78.1 (3.8)	86.6 (1.5)	1610	29.8	13.6 (0.8)	10.8 (0.4)	8.7 (0.4)	3.7 (0.1)
Closed, thinned young growth	N5	20–30	71.5 (2.9)	91.4 (3.2)	719	46.5	28.8 (1.6)	23.6 (0.9)	13.0 (0.8)	5.9 (0.2)
Open, thinned young growth	N6	20–30	37.4 (3.9)	57.0 (6.5)	548	17.1	19.7 (0.7)	17.1 (0.4)	10.9 (0.4)	4.5 (0.1)

NOTE: MCCm and MCCphoto are plot means of crown completeness data measured with the moosehorn or by photography, respectively. Values in parentheses are standard errors of the means.

ferent storm sizes. We measured seven snowfalls from 2.9 to 15.1 cm in the Sayward Forest and 17 snowsfalls from 1.4 to 38.0 cm at the Nanaimo River site (Fig. 1).

Statistical analyses were carried out using Statpro (Wadsworth Inc. 1983) or SAS (SAS Institute Inc. 1985). Simple and multiple linear regressions were computed for the dependence of fresh snow on means of storm sizes, tree crowns, and stand variables. Crown completeness, tree density, basal area per hectare, and seven different geometric calculations of crown area and crown volume were used as independent variables in the analyses (see Table 3). Regressions from different storms and stands were compared using procedures described in Zar (1974). Multiple regressions (RSQUARE; SAS Institute Inc. 1985) were computed incorporating all independent variables.

Results

Plot characteristics are summarized in Table 1. MCCm ranged from 37.4% in a noncommercially thinned stand to 89.1% in one of the old-growth stands. Tree density varied from 335 to 1610 stems/ha and basal area from 17.1 to 93.5 m^2/ha.

Fresh snow depths in the open were normally distributed, and in the forest they were near normal in distribution as well. Greatest variance in depth in the Sayward Forest occurred in the unthinned commercial-age plot (Table 1), while the unthinned young-growth stand had the highest variance in the Nanaimo River area. The sample size (66) in these two stands was not always adequate to provide a mean within our desired confidence limits.

CCm was not normally distributed, showing a binomial pattern characteristic of percentage data (Vales and Bunnell 1985). Various data transformations failed to normalize the data appreciably. Because CCm was to be used as the independent variable in regression analyses, however, we felt that the distribution of the data was of minor importance.

Using storm size as the independent variable, we constructed simple linear regression models that predicted mean fresh snow deposition under the canopies of our sample plots (Fig. 2). Regression values were high (Table 2). Examination of the regression slopes shows a general decrease from a slope of 1.0, which occurs when MCCm = 0% (represented by broken lines in Fig. 2), to slopes that progressively tend toward zero at the highest MCCm. Storm size alone explained 83% of the variation in fresh snow accumulation:

$$[1] \quad FS = -1.62 + 0.67SS \qquad (n = 64;\ r^2 = 0.83;\ s_{Y \cdot X} = 1.54;\ P < 0.05)$$

where FS represents fresh snow (cm) under a forest crown, and SS is storm size (cm).

Regression analyses were also used to explore relationships between fresh snow deposited by individual storms and various stand characteristics. Only data from the Sayward Forest (n = 6 sites per storm) were analysed because regressions from the Nanaimo River site included only three sites per storm. In total, 11 variables were individually tested (Table 3). Regressions were computed twice for each variable, once including the open site values and once excluding them. All regressions were significant at $P < 0.10$; only two were not significant at $P < 0.05$. The best predictor of fresh snow depth was MCCm (the only forest variable retained for later analyses). MCCm always ranked as one of the three best independent variables (the highest mean coefficient of determination and the lowest standard error of the regression). For most regressions calculated without

TABLE 2. Simple linear regression results for fresh snow (FS) deposits under forest canopies expressed as a function of storm size (SS)

Plot No.	n^a	Equation	r^2	$s_{Y \cdot X}$	P (slope = 0)
S1	5	FS = 0.70 + 0.45SS	0.73	0.15	0.10
S2	6	FS = −0.47 + 0.43SS	0.88	0.08	0.01
S3	7	FS = −0.74 + 0.85SS	0.95	0.09	0.0005
S4	6	FS = −0.53 + 0.48SS	0.70	0.15	0.05
S5	6	FS = 0.49 + 0.59SS	0.70	0.20	0.05
N1	10	FS = −3.86 + 0.79SS	0.94	0.07	0.005
N4	9	FS = −3.55 + 0.68SS	0.92	0.07	0.0005
N5	4	FS = −3.84 + 0.72SS	0.99	0.02	0.0001
N6	4	FS = −1.55 + 0.93SS	0.99	0.04	0.0001

[a]Only regressions for $n > 3$ are included.

the open site values, the intercept approximated storm size, the expected value when the independent variable is 0 (Table 3). Regression lines predicting fresh snow depth from MCCm are shown in Fig. 3. They show a trend of increasingly negative slope with greater storm size.

The general model for fresh snow depth as a function of MCCm was

$$[2] \quad FS = 8.21 - 0.07MCCm \quad (n = 38; r^2 = 0.40, s_{Y \cdot X} = 2.42; P < 0.05)$$

The consistent change in slope of the individual FS = f (SS) regressions (see Fig. 2) reflected the results of Harestad and Bunnell (1981) and prompted us to plot the slopes of the regression equations against MCCm (Fig. 4). The equation for the Sayward Forest data failed to reveal the expected curvilinear form and instead was significant in a linear form (eq. 3).

$$[3] \quad b = 1.12 - 0.009MCCm \quad (n = 5; r^2 = 0.71; s_{Y \cdot X} = 0.21; P < 0.07)$$

where b represents the slope of the regressions between fresh snow and storm size.

The Nanaimo River regression was highly significant in the curvilinear form (eq. 4).

$$[4] \quad b = -0.22 + 0.28 \ln(100 - MCCm) \quad (n = 6; r^2 = 0.99; s_{Y \cdot X} = 0.05; P < 0.0001)$$

To help choose a two-variable regression model we summarized the best multiple regressions (Table 4). Because of the apparent interaction between storm size and mean crown completeness, we added a 13th variable, SS × MCCm, to the analysis. Judged by Mallows' Cp statistic (Mallows 1973), the best models used storm size, the product of storm size and MCCm, and two other crown indices: crown volume and crown width × crown length. However, neither the standard error of the regression nor the variance explained by the independent variables changed appreciably by adding the third and fourth variables and therefore they were dropped from the model (Table 4).

Discussion

Snow depth in the forest was highly variable, reflecting the variation in forest structure because of individual tree form and the interspersion of small openings (Golding 1982; Bunnell *et al.* 1985, p. 333; Woo and Steer 1986). The average snow depth under forest canopies, however, was strongly related to many characteristics of the forest, as well as to storm size (Table 3; eqs. 1 and 2).

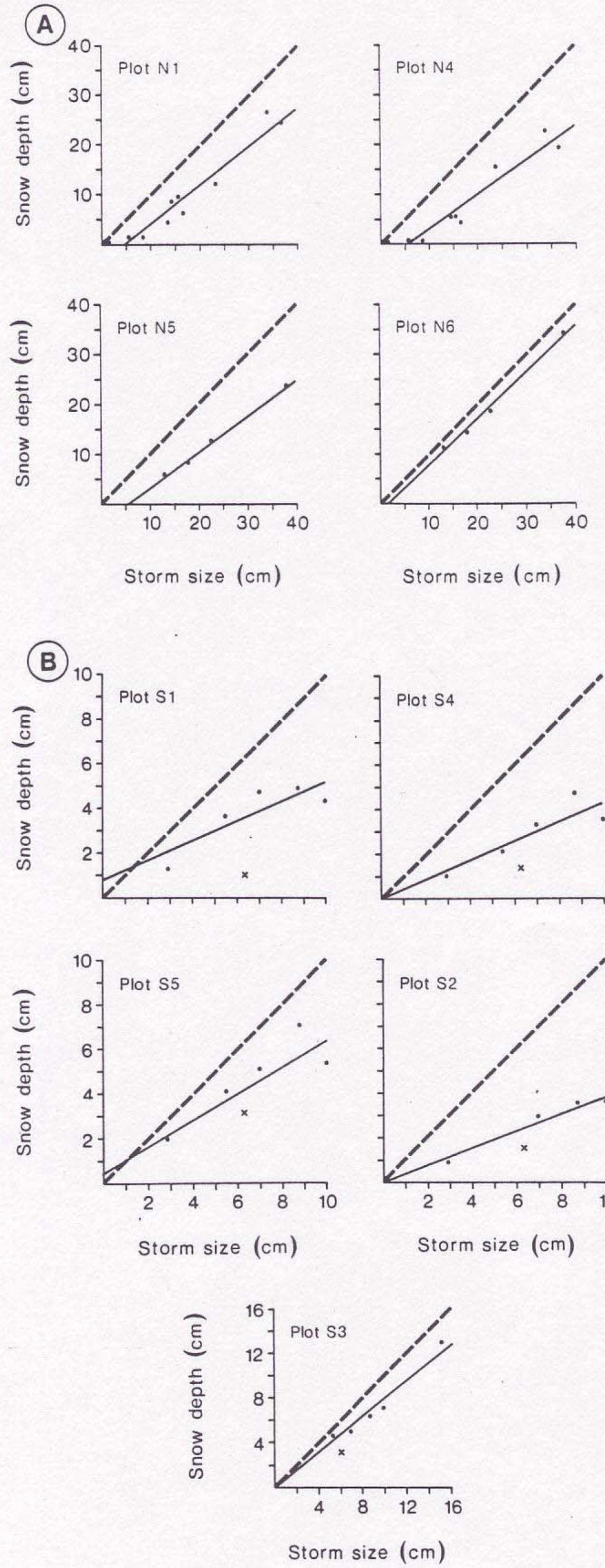

FIG. 2. Simple linear regression results of fresh snow deposited under a crown as a function of storm size for (A) the Nanaimo River and (B) the Sayward Forest sample plots.

Both unthinned young-growth stands (N4, S4) and the old-growth stand at Nanaimo River (N1) showed slightly curvilinear forms for the regression of fresh snow on storm

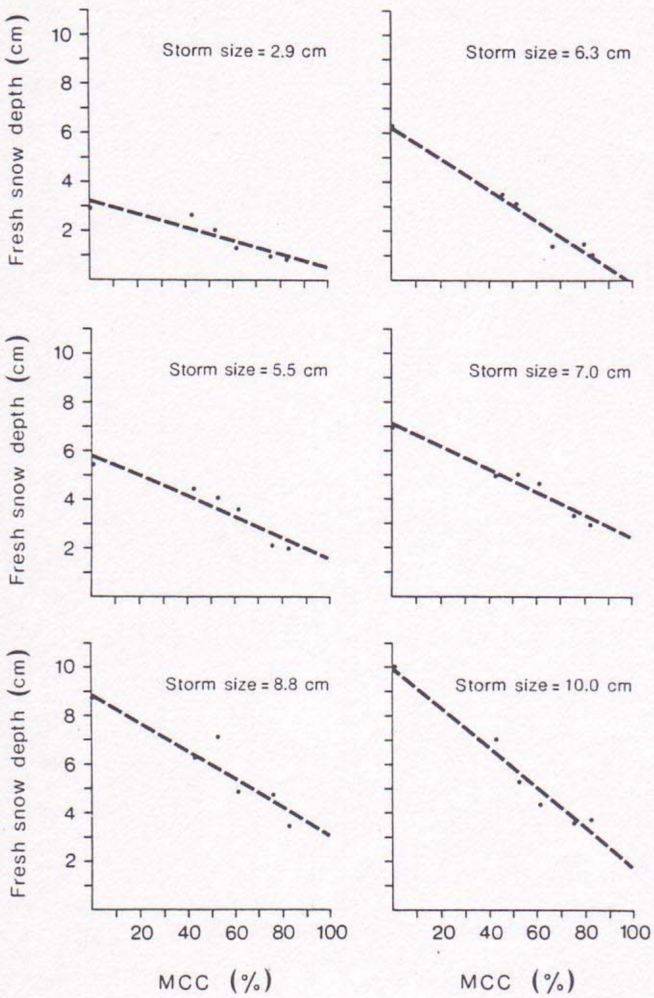

FIG. 3. Simple linear regression results of fresh snow found under a canopy expressed as a function of mean crown completeness (moosehorn).

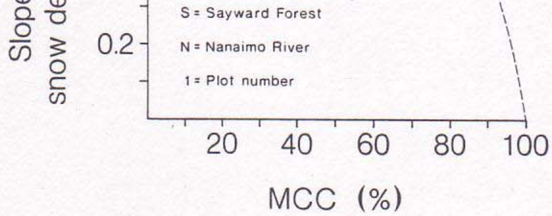

FIG. 4. The relationship between slope of the fresh snow and storm size regressions and mean crown completeness for the two study sites.

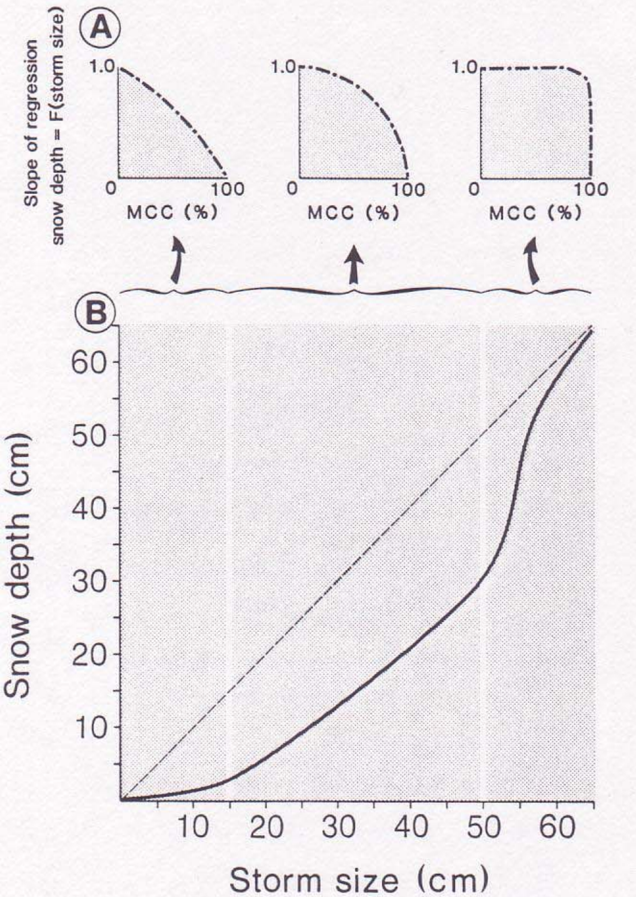

FIG. 5. A conceptual model of snow deposition under forest crowns expressed as a function of storm size (A), and the resulting relationships with mean crown completeness (B).

size (Fig. 2). The curved form indicates that interception was greater than would be expected from a linear model until storm size reached approximately 15 cm in magnitude, at which point the relationship became strongly linear. That phenomenon is well documented for individual tree crowns (e.g., Satterlund and Haupt 1967; for a review see Bunnell *et al.* 1985, p. 241), but has rarely been documented for forest stands (Kittredge 1953). With pooled data, the linear form of the relationship (eq. 1) was strongest, probably because of the low sample of small storms' sizes.

We were unable to document the curvilinear form at higher storm sizes as reported by Satterlund and Haupt (1967) for individual trees and by Strobel (1978) for forest stands. Strobel's data showed that a stand's ability to intercept snow reaches a maximum at a storm size of 10 cm SWE, or 50 cm depth (using a snow density of 0.2 g/cm^3). The maximum storm size measured in this study was below that required to overpower the interceptive ability of forest crowns.

Our conceptual model of snow deposition, which was derived from Satterlund and Haupt (1967), Strobel (1978), and this study, is depicted in Fig. 5. The variation in slopes of the simple linear regression equations caused by changes in MCCm and storm size (Figs. 2 and 3) implies that the snow deposition curve presented in Fig. 5 would be specific for any given MCCm and that both variables are necessary for the prediction of snow deposition under forest crowns.

TABLE 3. Simple linear regression statistics for fresh snow (FS) expressed as a function of plot variables, measured on the Sayward Forest, when (*a*) open site values were included ($n = 6$); and when (*b*) open site values were excluded ($n = 5$)

Independent variables	SS 2.93 cm			SS 5.45 cm			SS 6.27 cm			SS 6.98 cm			SS 8.75 cm			SS 10.00 cm		
	r^2	$s_{Y \cdot X}$	a	r^2	$s_{Y \cdot X}$	a	r^2	$s_{Y \cdot X}$	a	r^2	$s_{Y \cdot X}$	a	r^2	$s_{Y \cdot X}$	a	r^2	$s_{Y \cdot X}$	a
(*a*)																		
MCC (moosehorn)	0.837	0.3985	3.24	0.886	0.5070	5.87	0.974	0.3556	6.21	0.947	0.3714	7.15	0.873	0.7593	9.02	0.964	0.5286	9.98
MCC (photo)	0.745	0.4945	3.23	0.818	0.6405	5.89	0.913	0.6532	6.35	0.908	0.4866	7.22	0.789	0.9778	9.02	0.953	0.6000	10.17
Crown area/ha (2D)	0.863	0.3654	3.12	0.862	0.5571	5.63	0.895	0.7183	5.83	0.910	0.4830	6.87	0.987	0.2465	8.91	0.871	0.9953	9.38
Crown area/ha (3D)	0.726	0.5164	3.05	0.638	0.9022	5.41	0.915	0.6473	5.97	0.723	0.8460	6.70	0.912	0.6320	8.89	0.794	1.2572	9.33
Crown volume/ha	0.457	0.7272	2.60	0.340	1.2184	4.67	0.650	1.3102	4.95	0.421	1.2234	5.91	0.720	1.1248	8.02	0.466	2.0263	7.91
Tree density (SPH)	0.532	0.6750	2.65	0.657	0.8780	5.05	0.459	1.6287	4.58	0.612	1.0012	6.14	0.336	1.7332	7.33	0.648	1.6458	8.27
Basal area/ha	0.429	0.7458	2.53	0.232	1.316	4.44	0.604	1.2451	4.88	0.270	1.3732	5.61	0.538	1.4455	7.63	0.459	2.0395	7.77
Height × SPH	0.772	0.4715	3.09	0.891	0.4959	5.73	0.776	1.0468	5.73	0.912	0.4766	6.95	0.713	1.1396	8.55	0.901	0.8712	9.58
Crown length × SPH	0.778	0.4656	3.22	0.778	0.7071	5.79	0.912	0.6571	6.28	0.829	0.6639	7.06	0.728	1.1105	8.84	0.982	0.3758	10.15
CL × CW	0.086	0.7435	2.13	0.037	1.4711	3.95	0.361	1.7696	4.31	0.107	1.5193	5.26	0.297	1.7833	7.17	0.177	2.5148	6.97
CL × CW × SPH	0.676	0.5619	3.05	0.556	0.9986	5.35	0.921	0.6221	6.09	0.647	0.9545	6.65	0.832	0.8723	8.85	0.795	1.2565	9.46
(*b*)																		
MCC (moosehorn)	0.925	0.2425	4.43	0.965	0.2422	7.50	0.907	0.4048	6.02	0.895	0.3705	8.82	0.762	0.8030	10.10	0.862	0.6095	9.88
MCC (photo)	0.860	0.3325	5.11	0.953	0.2788	8.66	0.688	0.7428	6.89	0.865	0.4190	8.75	0.597	1.0453	10.75	0.849	0.6383	11.26
Crown area/ha (2D)	0.824	0.3730	3.54	0.772	0.6161	6.02	0.725	0.6980	4.89	0.770	0.5467	6.64	0.980	0.2308	9.26	0.660	0.9560	8.03
Crown area/ha (3D)	0.572	0.5808	3.37	0.350	1.0408	5.30	0.745	0.6721	5.20	0.339	0.9278	5.98	0.813	0.7123	9.26	0.415	1.2551	7.61
Crown volume/ha	0.204	0.7921	2.23	0.068	1.2455	3.81	0.398	1.0323	3.50	0.083	1.0927	4.74	0.515	1.1471	7.22	0.099	1.5574	5.63
Tree density (SPH)	0.300	0.7432	2.35	0.448	0.9586	4.63	0.105	1.2590	2.81	0.343	0.9249	3.26	0.037	1.6163	5.81	0.416	1.2540	6.47
Basal area/ha	0.191	0.7990	2.15	0.014	1.2812	3.49	0.534	0.9081	3.58	0.004	1.1383	4.32	0.272	1.4051	6.58	0.132	1.5282	5.67
Height × SPH	0.666	0.5133	3.52	0.861	0.4810	6.47	0.375	1.0517	4.31	0.768	0.5495	6.88	0.380	1.2968	8.02	0.704	0.8924	8.48
Crown length × SPH	0.864	0.3277	4.75	0.741	0.6563	7.53	0.675	0.7586	6.33	0.559	0.7575	7.48	0.400	1.2759	9.30	0.947	0.3765	10.93
CL × CW	0.023	0.8778	1.58	0.137	1.1986	2.55	0.033	1.3081	2.49	0.108	1.0772	3.64	0.028	1.6241	5.70	0.072	1.5808	4.13
CL × CW × SPH	0.491	0.6334	3.42	0.211	1.1466	5.02	0.734	0.6856	5.51	0.179	1.0339	5.63	0.632	0.9998	9.18	0.370	1.3025	7.75

NOTE: SS, storm size (depth of snow accumulation on open sites); SPH, stems per hectare; CL, crown length; CW, crown width. Regression statistics: r^2, coefficient of determination; $s_{Y \cdot X}$, standard error of the regression; *a*, intercept at dependent variable axis.

TABLE 4. Stepwise multiple regression results for the dependent variable, fresh snow (FS) deposited under forest plot canopies during individual storms (SS)

Sample stratification	b_0	SS b_1	SS × MCC b_2	CV/ha b_3	CW × CL b_4	$R^2_{adj.}$	$s_{Y \cdot X}$	C_p	n
All data	−0.24	1.02	−0.005	−0.001	−0.03	0.98	1.37	5.06	88
	−0.22	1.03	−0.005	−0.0001	—	0.97	1.45	14.38	88
	−1.29	1.08	−0.006	—	—	0.97	1.58	31.57	88
	−1.54	0.80	—	—	—	0.79	4.13	698.62	88
Sayward Forest	−0.34	1.07	−0.008	—	—	0.94	0.81	3.74	38
	−1.46	0.84	—	—	—	0.63	1.91	167.78	38
Nanaimo River	−0.01	1.01	−0.004	0.0001	0.03	0.97	1.66	4.67	50
	−0.50	1.04	0.005	0.0001	—	0.97	1.73	7.34	50
	−2.30	1.11	0.006	—	—	0.97	1.89	16.14	50
	−2.43	0.83	—	—	—	0.74	5.25	426.91	50

NOTE: SS, storm size; MCC, mean crown completeness data; CV, crown volume; CW, crown width; CL, crown length; C_p, Mallows' C_p statistic (Mallows 1973).

MCCm was the best single forest variable in explaining the deposition of snow in forests. The relatively high standard error of these regressions (Table 3) indicates, however, that MCCm by itself is insufficient to provide predictive power. The low MCCm plots (N6 and S3) were both relatively inefficient at intercepting snow (Fig. 4). At the middle range of MCCm interception efficiency varied most between the Sayward Forest and the Nanaimo River sites. The difference between slopes for stands of similar age and structure (e.g., S1 and N1) reflects differences in storm sizes at the two study sites. All but four storms from Nanaimo River were greater than 10 cm whereas only one storm at Sayward Forest was greater than 10 cm (Fig. 1). The Sayward Forest data represent only the lower curvilinear portion of the snow deposition curve depicted in Fig. 5 (compare regressions plotted for N1 and S1 in Fig. 2).

If the difference between eqs. 3 and 4 can be attributed to sampling different portions of a theoretical snow deposition curve (Kittredge 1953; Satterlund and Haupt 1967; Strobel 1978) and not to area climatic differences, then we would expect the relationship depicted in Fig. 4 to be a family of three or more curves; one line for each portion of the sigmoidal snow deposition curve (Fig. 5). All curves should intersect the dependent axis at 1.0 and the independent axis at 100% MCCm. Regions that experience infrequent and (or) small snow storms should be characterised by efficient snow interception (Harestad and Bunnell 1981; McNay 1985) over a relatively wide range of MCCm (Fig. 5). Regions that experience frequent and large snow storms should show less efficient interception of snow, and only the stands at the upper range of MCCm (e.g., 80–100%) should intercept significant amounts.

At the lower and middle portions of the snow deposition curve, which our data are felt to best represent, snow depth was adequately reflected by MCCm (an index of the potential for throughfall to occur) combined with storm size (Table 4). As storm size or accumulated snow in the canopy increases, however, there could be a change in interceptive abilities among stands with equal MCCm. Stands with large crown surface areas (e.g., plot N3) may reach maximal snow load much later than stands such as N4 with high MCCm but low crown surface area (Bunnell *et al.* 1985, p. 309).

During mild winters with relatively small and infrequent snowfalls, MCCm is probably a sufficient index of the interceptive ability of different forest canopies. Crown width and crown length may become useful or necessary additional indices when large (>40 cm) or frequent storms occur.

Acknowledgements

The research was funded through the Integrated Wildlife—Intensive Forestry Research (IWIFR) program, which is cooperatively sponsored by the B.C. Ministry of Environment and Parks, the B.C. Ministry of Forests and Lands, and the University of British Columbia. Comments and suggestions from F. Bunnell and W. Bergerud concerning study design were greatly appreciated. Reviews of the draft manuscript were provided by W. Bergerud, F. Bunnell, D. Golding, G. Montgomery, and D. Spittlehouse.

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