SNOW *accumulation* and MELT *under certain forest conditions in the Adirondacks*

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The Spring Snowpack

THE Adirondack region of New York is a land of many lakes and streams. It feeds water into Lake Champlain, Lake Ontario, the St. Lawrence River, and the Hudson River. Much of this streamflow comes from the melting of the spring snowpack in the Adirondacks.

About a fourth of the regions' annual precipitation of 35 to 50 inches accumulates in this spring snowpack. In some areas snowfall averages 140 inches a year. As a whole, the Plateau receives 80 to 100 inches of snowfall a year. Part of this comes in the fall, and melts; but the winter snowfall accumulates so that by March 15 snow depth may reach 30 inches. This is equivalent to about 10 inches of water.

The amount of snow that accumulates, and its rate of melt, depend in part on the type and condition of forest cover. The Adirondacks possess a great variety of forest types, ranging from pure conifer stands to hardwood stands occurring under virgin, cut-over, and burned conditions. The purpose of this study was to compare snow accumulation and melt under certain of these types and conditions.

Previous Studies

Only three studies of forest-snow relationships have been made in the Northeast.

One Northeastern study, Made by Maule (1934) near New Haven, Connecticut, showed that snow accumulation was greatest in open fields and progressively less in hardwood, white pine, hemlock, red pine, and Norway spruce forest stands. Snow remained the longest under white pine, and for progressively shorter periods in red pine, Norway spruce, hemlock, and hardwood forests, and open fields. White pine ranked first in snow retention because it shaded the snow, slowing its melt, and yet, of the conifers, permitted the greatest depth to accumulate on the ground.

A second (and recent) study at Bartlett, New Hampshire, showed that snow accumulation was greater under sawtimber hardwood stands than under pole-sized hardwood stands (Sartz and Trimble, 1956). At time of maximum snowpack the snow-water depth was 7 to 10 percent less in pole stands than in openings in the stands. Sawtimber stands contained 3 to 4 percent less snow water than small openings. Snow depth ranged from 25 to 40 inches and water content from 9 to 10 inches.

In a third study of comparative snow depth under different forest conditions in the Northeast, as determined at six widely-separated experimental areas, Pierce, Lull, and Storey (1958) reported that average seasonal snow depth in hardwoods was 1.75 times greater than that in conifers, and 1.50 times that in the open. For the two winters of measurement snow depth in hardwood stands averaged 2.7 inches deeper than in conifer stands.

Methods

Snow depth and water content were measured at 32 snow-survey courses in the spring of 1959 at three areas within 10 miles of Paul Smiths, New York. At Areas 1 and 2 (elevations 1,710 and 1,550 feet, respectively) duplicate courses were laid out to sample five conditions: conifer sawtimber, conifer sapling, hardwood sawtimber, hardwood sapling, and open fields (table 1).

At Area 3 (elevation 1,660 feet), duplicate courses were located in six cutting-practice-level experimental

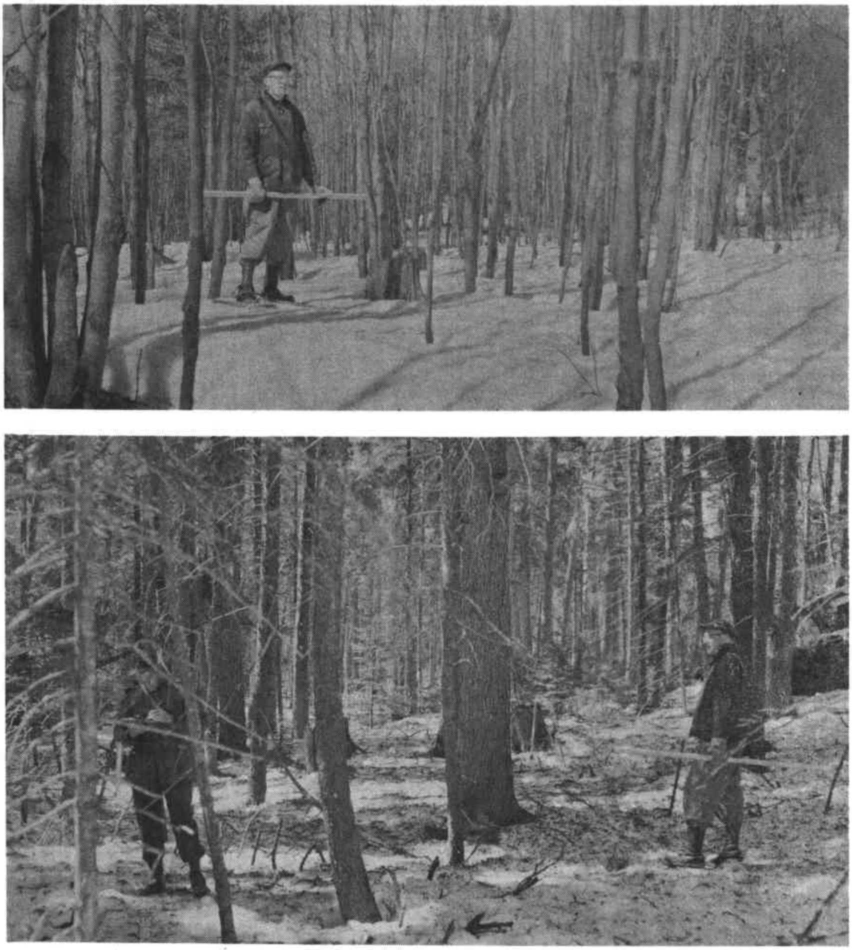

Figure 1.--*Surveying the Adirondack snowpack. Above, in a hardwood sapling stand. Below, in a conifer sawtimber stand.*

plots of the Paul Smiths Research Center. These plots were located in a mature stand of mixed hardwoods and conifers and consisted of a control, a commercial clearcut, a selective cut on a 5-10 year cycle, a selective cut on a 15-20 year cycle, a selective cut on a 25-35 year cycle, and a semi-open area along a woods road (table 1).

Each snow course was 200 feet long and had 10 measuring points 20 feet apart. To minimize effects of slope and aspect, courses were located as nearly as possible on level areas.

Snow depth and water content were measured with a Mount Rose snow sampler and a tubular scale. Snow depths were read to the nearest inch and water contents to the nearest one-half inch.

Measurements were taken at the time of maximum accumulation on March 16-18 and thereafter to record the progress of melt on April 2-3, 13-14, 16-17, 20, 24, 29, and on May 4 and May 8.

At each course the locations of trees over 4 inches in diameter were plotted and diameters and species were noted for a strip 10-feet on each side of the survey line. The locations of conifers 1 to 4 inches in diameter within

Table 1.--Forest conditions studied

Area	Condition	Principal species	Conifers		Hardwood	
			Trees per acre	Average diameter	Trees per acre	Average diameter
			No.	Inches	No.	Inches
1	Hardwood sawtimber	Hard maple, beech, yellow birch	5	2.0	452	8.2
	Hardwood sapling	Hard maple, yellow birch	6	12.0	404	6.8
	Conifer sawtimber	Red spruce	477	7.0	31	7.5
	Conifer sapling	Balsam fir, red spruce	1,446	3.3	57	6.1
2	Hardwood sawtimber	Red maple, hard maple, yellow birch	42	4.2	176	11.8
	Hardwood sapling	Red maple, beech	16	5.5	280	5.6
	Conifer sawtimber	Red spruce, balsam fir	690	6.8	57	11.8
	Conifer sapling	Balsam fir, red spruce	2,188	2.4	62	8.8
3	Forest road, semi-open	Beech, red maple, yellow birch	5	4.2	58	13.2
	Commercial clearcutting	Beech, yellow birch, red maple	72	3.6	104	10.4
	Selective cutting, 25-35 year cycle	Red maple, beech, yellow birch	166	3.1	160	9.2
	Selective cutting, 15-20 year cycle	Hemlock, beech, red maple	140	9.2	32	9.0
	Selective cutting, 5-10 year cycle	Red spruce, hemlock. balsam fir	301	5.4	68	10.0
	Control	Red spruce, balsam fir, birch	441	4.6	68	13.0

5-foot strips were also plotted. At each snow-measuring point the canopy opening was estimated with the spherical densiometer (Lemmon, 1957). Four readings were taken at each point, two facing opposite ends of the survey course and two at right angles to the survey line. Daily records of precipitation and maximum and minimum air temperatures were obtained from a weather station at Paul Smiths, New York.

Lower-than-normal temperatures during the winter of 1958-59 with no prolonged thaws led to greater snow accumulations than normal. On March 16-18 the average snow depth for all courses was 34 inches, 5 to 10 inches deeper than expected. After measurements began, about 5 inches of snow fell in a series of small storms.

Principal Results

Snow-water contents by conditions and dates are given in figure 2. Areas 1 and 2 follow much the same pattern: in both, the snow in the open disappeared by April 16-17, whereas snow under the conifers persisted until May 4. Greatest accumulations of snow water were in the hardwood stands, averaging 8.28 inches in Area 1 as compared to 6.16 in the conifers, and 9.74 vs. 7.66 inches for Area 2--in each area about a 2-inch difference.

Between March 16-18 and April 13-14 the greater melt rate in the hardwoods had virtually erased this difference: comparable values were then 4.52 and 4.50 inches for Area 1 and 4.50 and 5.28 for Area 2. Thereafter the conifer areas possessed the greater snow-water content.

An analysis of variance of the Area 1 data clearly revealed this trend. On March 16-18, when accumulations in the hardwoods were greater, differences between the forest conditions were highly significant. By April 13-14 differences between conditions were not significant. Three days later the snow accumulations under conifers were distinctly greater and differences were again significant.

In Area 3 (the cutting-practice-level plots) differences were not so pronounced (partly because of their mixture of hardwoods and conifers as compared to the almost pure stand composition of Areas 1 and 2). On March 16-18 the average snow-water content was 9.45 inches and ranged between 8.25 and 10.12 inches; differences were highly significant with some trend towards greater accumulation in the

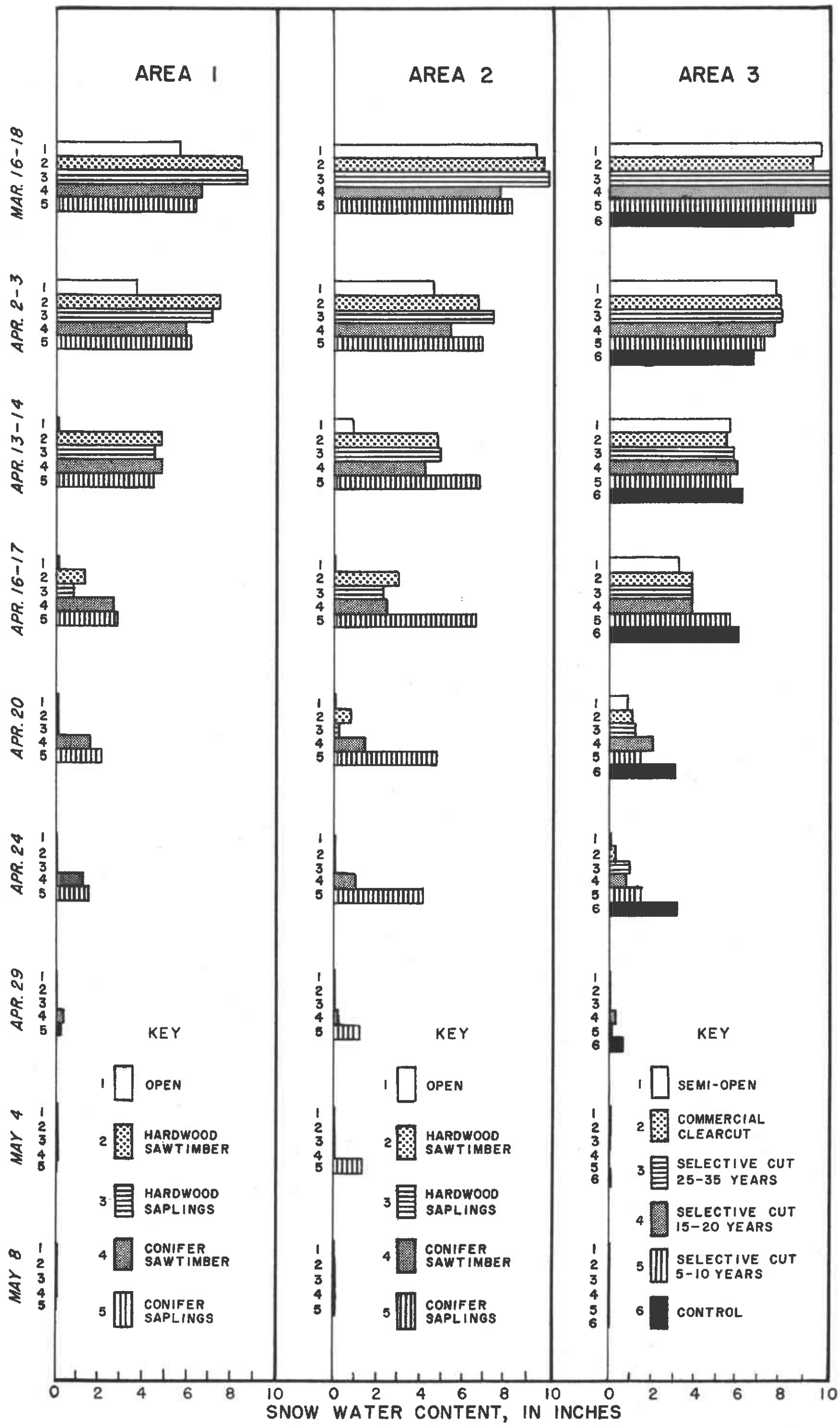
AREA 1
AREA 2
AREA 3
MAR. 16-18
APR. 2-3
APR. 13-14
APR. 16-17
APR. 20
APR. 24
APR. 29
MAY 4
MAY 8
KEY
1 OPEN
2 HARDWOOD SAWTIMBER
3 HARDWOOD SAPLINGS
4 CONIFER SAWTIMBER
5 CONIFER SAPLINGS
KEY
1 OPEN
2 HARDWOOD SAWTIMBER
3 HARDWOOD SAPLINGS
4 CONIFER SAWTIMBER
5 CONIFER SAPLINGS
KEY
1 SEMI-OPEN
2 COMMERCIAL CLEARCUT
3 SELECTIVE CUT 25-35 YEARS
4 SELECTIVE CUT 15-20 YEARS
5 SELECTIVE CUT 5-10 YEARS
6 CONTROL
0 2 4 6 8 10
SNOW WATER CONTENT, IN INCHES

Table 2.--Snow-water content at time of maximum accumulation, and number of days to melt

Area	Condition	Snow-water content	Percent of maximum (by areas)	Days to melt
		Inches	Percent	Days
1	Hardwood sawtimber	8.22	98	34
	Hardwood sapling	8.35	100	33
	Conifer sawtimber	6.28	75	40
	Conifer sapling	6.05	72	43
	Least significant difference	2.05	--	--
2	Hardwood sawtimber	9.62	98	35
	Hardwood sapling	9.85	100	34
	Conifer sawtimber	7.42	75	40
	Conifer sapling	7.90	80	50
	Least significant difference	1.25	--	--
3	Forest road, semi-open	9.68	96	36
	Commercial clearcutting	9.25	91	36
	Selective cutting, 25-35 year cycle	10.08	100	36
	Selective cutting 15-20 year cycle	10.12	100	38
	Selective cutting, 5-10 year cycle	9.30	92	38
	Control	8.25	82	41
	Least significant difference	1.73	--	--

more heavily cut areas. By April 13-14 average water content had dropped to 5.63 inches, ranging from 5.30 to 6.05 inches; and differences were not significant. A week later differences were significant, and the effect of the greater number of conifers in slowing snow melt was evident in the control plot and intensive-selection plots.

Figure 2.--*Snow-water content of the snowpack, by cover conditions and dates.*

Accumulation and melt for the conditions studied and weather experienced are summarized in table 2. Snow accumulation was greatest in the hardwood stands; conifer stands averaged 75 percent of the hardwood-sapling snow catch, a significant difference. Snow melted in the hardwood stands in 34 days, and in the conifer stands in 43 days.

In the cutting-practice-level plots there were significant differences between maximum accumulation in the more heavily-cut selection plots and the least accumulation in the uncut control. Differences in accumulations between the other plots, though not significant, indicated a response to treatment or an effect of conifer distribution. For instance, smaller accumulations in the clearcut area and road area may have occurred because of their greater exposure and consequent greater melting of initial snow accumulations; on the other hand, lesser accumulations in the most lightly cut plot and the uncut control may have been due to increased interception by their greater conifer component. The differential in days of melt amounted to 5 days at the most, and the control plot retained snow longest, 41 days.

After snow had disappeared on all courses, a reconnaissance was made of higher elevations. This showed much snow remaining on northerly aspects: large patches were found at 3,500 feet, and at 3,900 feet the cover was nearly complete.

Supplementary Observations

These findings substantiate general knowledge that snow accumulation is greater in hardwood than in conifer forests, but that it melts slower in conifers. These findings provided quantitative evidence of these results based on weather conditions experienced during the winter of 1958-59.

More enlightening and useful results require study of causative factors that could lead to the development of prediction methods to permit estimates of snow accumulation and melt based on measurable characteristics of the forest stand. To initiate a more basic approach, supplementary analysis of such snow characteristics as density, variation in water content, and rate of melt were made and the relation of accumulation and melt to canopy closure was explored.

Snow Density

Snow densities on four dates are given in table 3. At the time of maximum accumulation, March 16-18, they averaged 24 percent, varying for individual conditions from 23 to 26 percent. By April 2-3, average density had increased to 29 percent, and by April 13-14 to 31 percent. Three days later, April 16-17, after rapid melt, the density was 29 percent. Differences between dates were highly significant; differences between conditions were not significant.

Table 3.--Snow density, in percent, by dates

Area	Condition	March 16-18	April 2-3	April 13-14	April 16-17
1	Hardwood sawtimber	24	31	32	30
	Hardwood sapling	25	32	31	27
	Conifer sawtimber	23	29	31	28
	Conifer sapling	24	30	31	26
2	Hardwood sawtimber	25	27	31	33
	Hardwood sapling	24	30	34	27
	Conifer sawtimber	24	29	31	28
	Conifer sapling	26	27	30	27
3	Forest road, semi-open	24	28	33	30
	Commercial clearcutting	23	29	31	33
	Selective cutting, 25-35 year cycle	25	29	32	30
	Selective cutting, 15-20 year cycle	26	28	32	29
	Selective cutting, 5-10 year cycle	25	26	28	28
	Control	25	27	31	29

Most of the melting occurred when snowpack densities were between 28 and 31 percent. This ties in with Sartz and Trimble's (1956) observation in New Hampshire that the snowpack apparently began to lose water by melting when the density of the snow reached about 30 percent. This also points up the difference that Gerdel (1945) noted between snow-melting densities in the East and those of the mountainous West, which range between 40 and 50 percent. The relation of snow density to snow melt, rates of changes in density, and variation of density within the snow profile are subjects for further research.

Variation in Snow-Water Content

Average standard deviations *(s)* and coefficients of variations *(CV)* of snow-water content for the courses were as follows:

	March 16-18		*April 16-17*	
	s (*inches*)	*CV* (*percent*)	*s* (*inches*	*CV* (*percent*)
Hardwood sawtimber	0.89	10	1.02	52
Hardwood saplings	.78	9	.83	61
Conifer sawtimber	1.92	31	1.79	93
Conifer saplings	2.02	29	1.31	33
Cutting-practice-level plots	1.51	16	1.86	48

Standard deviations in the hardwood courses increased slightly during the melt period, and conifer sawtimber variations decreased slightly, while variations within conifer sapling courses dropped about one-third. The marked reduction in the last-named courses could be due to differential melting: areas of deeper snow between crowns melting more rapidly than the shallower, shaded accumulations beneath the crowns.

Coefficients of variations reflect the depth-variation relationship and were greater for conifer than hardwood courses in mid-March and increased for all conditions by mid-April.

Rate of Melt per Day

Two melt-rate values are given in table 4 for each forest condition. The average melt rate in inches of water per day, during the month-long measurement period when snow cover was almost complete, shows that hardwood melt rates were about twice those of conifer stands, with hardwood-conifer rates occupying a midway position; the three rates averaged 0.23, 0.12, and 0.19 inches respectively.

In degree-days (as derived from air-temperature measurements at Paul Smiths College) average values for the three types are 0.06, 0.03, and 0.05 inches per degree-day above 32°F. For comparison, Horton (1945) found degree-day

Table 4.--Melt rates, in inches

Area	Condition	Melt from March 16-18 to April 16-17	
		Mean daily rate	Mean degree-day rate
1	Hardwood sawtimber	0.22	0.06
	Hardwood sapling	.24	.06
	Conifer sawtimber	.12	.03
	Conifer sapling	.10	.03
2	Hardwood sawtimber	.21	.06
	Hardwood sapling	.24	.07
	Conifer sawtimber	.16	.04
	Conifer sapling	.10	.02
3	Forest road, semi-open	.21	.06
	Commercial clearcut	.18	.05
	Selective cutting, 25-35 year cycle	.22	.06
	Selective cutting, 15-20 year cycle	.21	.06
	Selective cutting, 5-10 year cycle	.17	.05
	Control	.13	.03

(above 32°F.) melt rates of 0.08 and 0.09 inches per day from heavily cutover and burned areas and 0.06 inches for good stands of northern hardwoods and hemlock in western Pennsylvania.

Influence of Canopy Opening on Accumulation and Melt

In figure 3 the average canopy closure for each snow course is plotted against the average accumulation and melt for the course. From the accumulation regression, for each 10 percent increase in canopy closure, snow-water content decreased about one-third of an inch (or in terms of snow depth at 30 percent density, about 1 inch). The correlation coefficient of 0.794 signifies that this relationship accounts for 63 percent of the variation in accumulation.

The snow-melt relationship is such that it decreased at the rate of about 0.005 inches per degree-day for each

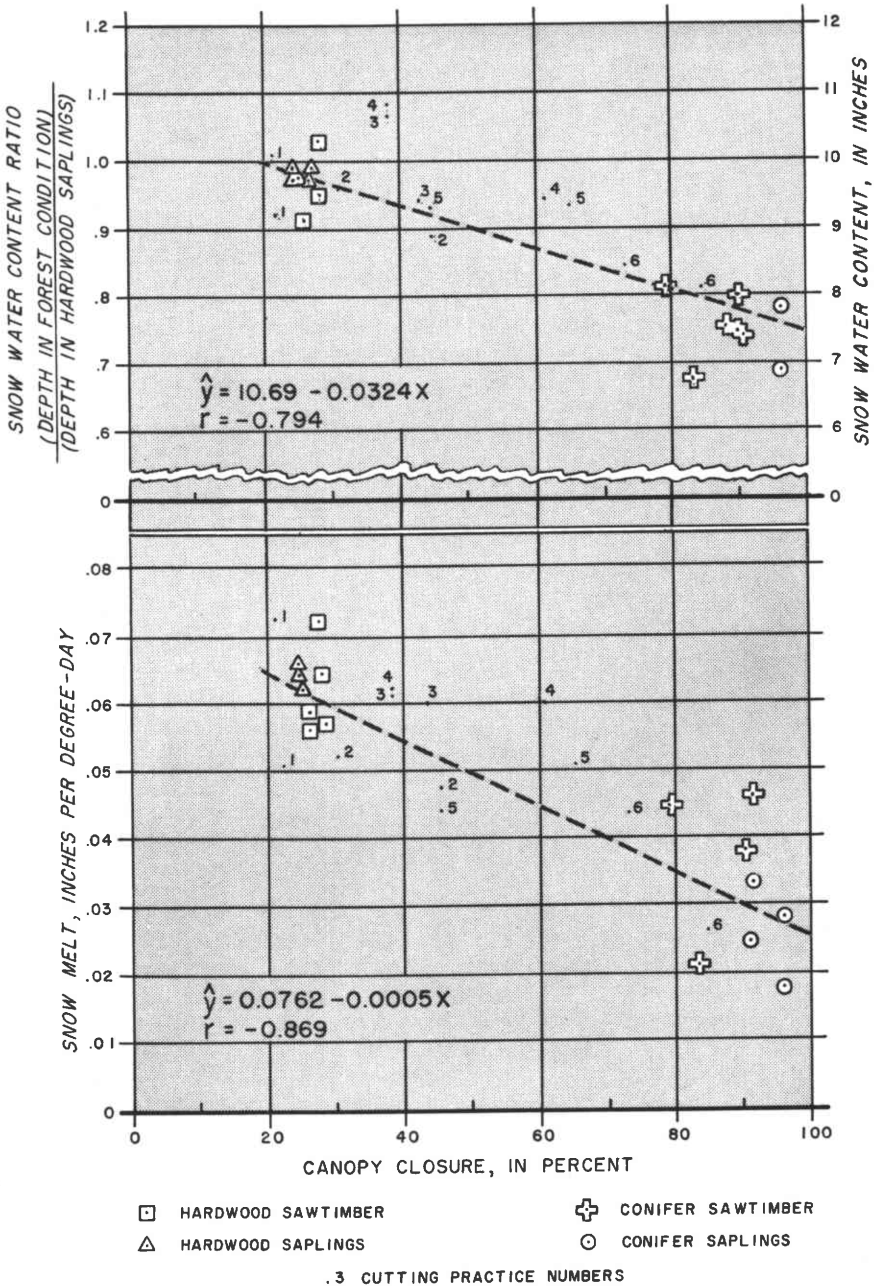

Figure 3.--*Snow water content at maximum accumulation, and snow melt rate in relation to canopy closure.*

Table 5.--Within-course correlations of accumulation and melt with canopy closure

Area	Condition	Course number	Coefficient of correlation	
			Accumulation	Melt
1	Conifer sawtimber	16 17	-0.869 - .629	0.480 - .924
1	Conifer sapling	13 14	- .389 - .177	- .096 - .225
2	Conifer sawtimber	26 27	- .429 - .890	- .053 - .744
2	Conifer sapling	24 25	- .054 - .324	- .152 - .119
3	Selective cutting, 15-20 year cycle	9	- .797	- .408
3	Control	1 2	- .480 - .591	.245 .118

10 percent increase in canopy closure. With a correlation coefficient of 0.869, this accounts for 76 percent of the variation in melt-rate.

These correlations provoked the question: can a simple measurement of tree density be correlated with canopy closure and then with snow behavior? Wellner (1948) and Miller (1955) have pointed out that the amount of light that is received beneath the canopy is related to the summation in inches of tree diameter per acre. For our data, this relationship is given in figure 4. Subtracting an average hardwood canopy closure of 25 percent from the regression for the cutting-practice-plot closure gives a canopy regression that follows closely the relationship that Wellner (1948) reported between percent of full sunlight (midday light intensity) and summation of diameter per acre for small-crowned western white pine.

Correlation between snow accumulation and melt at sampling points within courses and canopy openings over the points was also computed. In table 5 are given coefficients for selected courses (those with coefficients of variation of more than 20 percent) where a relationship might be expected. Results were variable. Apparently, at any one point

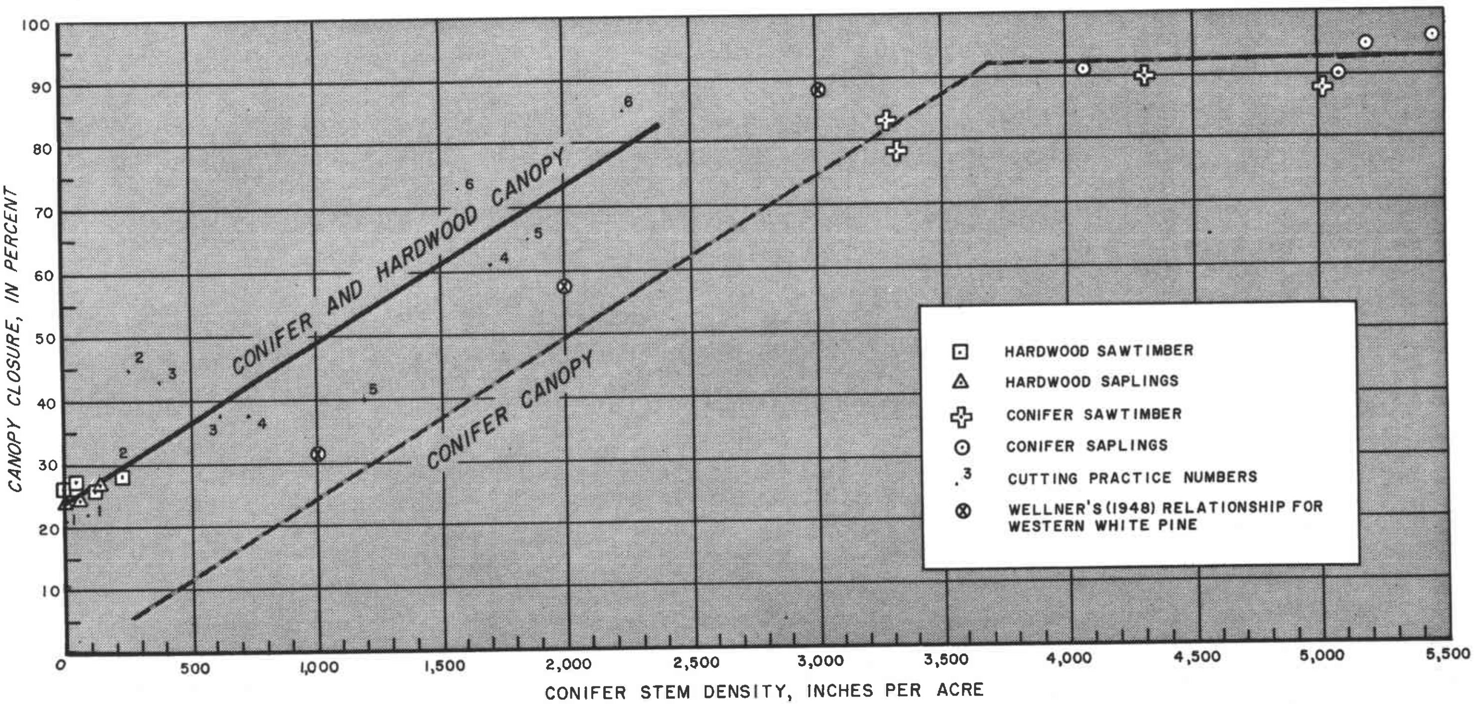
CANOPY CLOSURE, IN PERCENT
CONIFER STEM DENSITY, INCHES PER ACRE
CONIFER AND HARDWOOD CANOPY
CONIFER CANOPY
HARDWOOD SAWTIMBER
HARDWOOD SAPLINGS
CONIFER SAWTIMBER
CONIFER SAPLINGS
CUTTING PRACTICE NUMBERS
WELLNER'S (1948) RELATIONSHIP FOR WESTERN WHITE PINE

Figure 4.--*Relation of canopy closure to stem density.*

in a forest stand, accumulation or melt is not consistently related to the amount of overhead canopy; yet there is a consistent and rather close relationship for average accumulation and melt within a stand and average canopy opening. Put another way, point accumulation and melt is a function of a canopy area either greater or less than that measured by the densiometer. No correlation was apparent between accumulation or melt and number and location of trees within 10 feet of the sampling point. Thus this study produced little information on the factors governing snow accumulation and melt at any one sampling point.

Interception and Snow Frost

A feature of the forest snow cover were the wells beneath sapling conifers. These are formed by interception. We excavated a snow profile beneath a 3-inch balsam fir about 20 feet tall. The snow depth at the well bottom, directly beneath the tree, measured 16 inches. Just outside the area covered by the crown, snow depth was 56 inches. This particular well was 40-inches deep. Beneath the 16-inch snow, concrete frost extended to a depth greater than 6 inches. But at the crown edge, unfrozen soil was picked up at the bottom of a snow-tube sample. Sakharov (1945) has attributed the occurrence of deeper frost beneath spruce understory to interception. Frost formations of this kind under a tree may delay its growth in the spring.

Summary

Snow measurements taken in the Adirondacks in the spring of 1959 showed that the snowpack in hardwood sapling and sawtimber stands contained two more inches of water than the snowpack in balsam fir and red spruce stands. In hardwood stands snow melted about twice as fast as in conifer stands, and snow disappeared about 9 days earlier. In mixed conifer and hardwood stands, snow accumulation and melt were intermediate. Average accumulation and melt values for the snow courses were correlated with canopy closure; and canopy closure, in turn, appeared to be correlated with the summation of inches of tree diameter per acre.

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