THE EFFECT OF FOREST ON SNOW COVER

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Presented at the 13th Eastern Snow Conference, Hanover, N.H., February 9, 1956

There is an intimate relation between forests and snow in the north temperate zone. While each can exist without the other, regions of heavy snowfall in medium latitudes are commonly densely forested. Examples are the Northeastern, Lake States and Rocky Mountain regions in the U.S.; Eastern Canada, Scandinavia, the mountainous regions of Europe, and less typically, Siberia and Alaska. Before going into details of the effect of forests on snow the opposite influence of snow on forests will be considered briefly.

INFLUENCE OF SNOW ON FORESTS

Trees are vulnerable to dry cold winters, hence the treeless great plains, but they can survive dry summers quite well if soil moisture is stored, and soil freezing mitigated by deep winter snow. The depth of snow cover determines the wealth of vegetation. Snow prevents or modifies soil freezing and consequent drying. It reduces frost heaving by preventing change in soil volume and thus makes possible survival of tree seedlings. It also protects from freezing tree parts below the snow line, diminishing moisture loss by transpiration in dry winter winds that can be more desiccating than summer winds. Erosion is prevented during the time soil is snow covered. Erosion is more severe when alternate freezing and thawing occurs, hence a long and steady snow cover is of great benefit. On the other hand several unfavourable effects of snow on forests may be mentioned, including a shortened growing season, mechanical injury by breaking branches, tops, bending and avalanche damage (Curtis '36). Restriction of air circulation may be conducive to snow mould *(Phacidium infestans)*. All these effects have a profound influence on natural selection and snow is an important factor controlling forest types and forest composition. It also influences the choice of species for planting in regions of heavy snowfall. Source of seed is important since much heavier snow damage occurs to trees grown from seed collected in regions of scanty snow (Engler '05).

EFFECT OF FOREST ON SNOW COVER

Forests affect snow cover chiefly by interception, shading and by acting as insulators and wind barriers. Trees affect both accumulation, density and the rates of evaporation and melting. The main influences may be stated as follows:

1. Forests influence accumulation by intercepting snow on the crowns, resulting in less snow beneath trees after a fresh snow fall. Some of the intercepted snow evaporates or blows away without reaching the forest floor. Snow depth in the open is influenced to a considerable distance on the lee side of stands because of drifting.
2. Forests influence snow density by shading and protection from wind.
3. Forests retard evaporation or sublimation.
4. Melting of snow beneath trees is retarded.

All these influences commonly work together and there are many indirect effects on snow such as depth of soil freezing, type of soil cover (litter). The effects vary widely with the type of snowfall, duration, snow density, the weather following the snowfall such as wind direction and velocity, humidity and other factors.

1. EFFECT ON ACCUMULATION OF SNOW ON THE GROUND

Dense tree crowns intercept more precipitation than light, open crowns. Since deciduous trees are bare in winter it is the evergreen conifers that are the most efficient snow catchers. It is a familiar sight to see the ground completely bare beneath a hemlock or spruce after a moderate wet snow storm when the snow adheres readily to the twigs and needles. Fully stocked stands intercept more than open stands with scattered trees. While spruce, fir and hemlock are effective umbrellas, their drooping branches cause shedding of deep accumulated snow, whereas stiff pine branches may be able to retain their burden longer. Thus the net effect of interception is less snow accumulation directly under the crowns but a greater depth in openings due both to shedding and reduced evaporation.

Some intercepted snow may melt on the branches and reach the ground as stem-flow (much less than in the case of rain) or drip. With steady cold weather these amounts are small. More probably evaporates or blows away and adds to the depth in openings. The result is that soil may freeze deeply under thick evergreens because of scanty snow cover and this retards snow melt and growth in the spring.

Interception in coniferous stands may be very great but is always extremely variable. It may be so complete that only 0.1% of a light snow reaches the ground under dense young spruce (Mayr '25). A thick or deep crown canopy is more efficient than a thin cover. Connaughton ('35) found the annual interception in virgin ponderosa pine 24.5% but when advance reproduction was present beneath the older trees it was 29.8%.

Maule ('34) found that next to leafless hardwoods, white pine allowed the greatest depth to accumulate because its flexible needles and branches shed snow. Red pine was about equally effective in letting snow penetrate to the forest floor but Norway spruce because of its stiff branches and needles was able to hold snow longer on the crown where it was exposed to evaporation.

Harrington ('93) observed that when snow is blown horizontally against the sides of the crowns it encounters a greater surface for interception but measurements of this are lacking.

Not only the species of trees and their age but the stand density or presence of openings influences the extent of interception and accumulation. Korhonen ('26) in Finland found greater accumulation in forest openings and less in the forest itself compared to open stations.

Niederhof and Dunford ('42) found small openings about 16′ in diameter provided the optimum storage of snow in young lodgepole pine. The size of crown opening definitely influenced both the amount of storage and rate of melting.

Haupt ('51) measured the water content of snow in Idaho and found the greatest water storage on February

15th in the open but on March 1st under forest. The greatest water storage was found in sapling stands while there was low accumulation in mature ponderosa pine due, he believed, to interception.

The type of storm and snow density affect the degree of interception. Alter ('11) stated that a fall of 4 to 5 in. may be almost entirely supported by evergreen branches even when deposited in a high wind, provided the snow is sufficiently moist when it falls. After freezing it may cling to the branches a long time and the proportion evaporated is very great. Zon ('12) cites Russian experiments to show that 30 year spruce stands were more efficient in intercepting snow than older pine or mixed stands.

As a wind barrier, the forest can exert much influence on the snow depth in openings on the lee side due to drifting. The greatest excess accumulation occurs where the width of the opening is equal to the height of the trees. This then would be a good forest pattern for water conservation, for instance, around reservoirs. The water equivalent of the snow in openings is usually greatest about 10 to 12 ft. from the trees. The shelterbelt effect may extend to a distance of 7 to 8 times the tree height. Betts ('16) observed drifting at high elevations in Colorado where trees caused the snow to be held in pockets and glades. Church ('12) had proposed storing snow by use of drift fences. Lull and Orr ('50) reported doing this in Utah. Drifts in the lee of fir clumps were 4 ft. high and 70 ft. long and double sections of snow fence were used effectively where trees were lacking in order to provide water storage.

2. INFLUENCE OF SNOW DENSITY

Density is defined as the volume of water contained in a unit volume of snow or the ratio of the water equivalent of snow to its depth. Freshly fallen snow varies in density from 4 to 17% and increases with age due to freezing and thawing. Forest cover protects snow from the temperature extremes of the open and modifies both the thawing and freezing. The result is that snow retains a lower density in the forest than in the open. After a light rain or thaw ski-runners know they can still find powder snow under the forest. Kittredge ('48) reports an increase of snow density of 2% per day in the forest compared to 2.5-3% in clearings. The thicker the forest cover, i.e. the greater the forest density, the lower the snow density. However, neither Jaenicke and Foerster ('15) nor Maule ('34) found any marked difference in snow density in winter within the forest and in the open, and Kittredge ('53) reported slightly higher density of new snow under the tree crowns.

3. INFLUENCE OF FOREST ON EVAPORATION FROM A SNOW COVER

Evaporation is here used to include sublimation or any ablation of the snow surface where moisture passes off as vapour. Evaporation increases with air temperature and since forest stands by shading and windbreak reduce temperature in the woods evaporation is diminished. While rates may vary widely from almost no difference to 10 to 100 times more in the open than in the forest, condensation may occasionally exceed evaporation in the forest. (Kittredge loc. cit.)

Miller ('55) approached the problem from the viewpoint of heat exchange. Recognizing the high insolation associated with a snow cover he found forest offers a striking contrast. "The low albedo of the forest results in part from the low albedo of needles . . . Insolation is trapped and absorbed in a deep layer of interstices among needles." . . .

"Most of the light transmitted to the snow under the trees and reflected upward is absorbed in the branches; little escapes to the sky. Trees form excellent heat-exchangers. Insolation absorbed by them is rapidly transferred to the air through convection." . . . "The net loss of heat by long wave radiation from snow in forest stands is only ½ to ⅓ of that from snowfields in unforested sites."

4. THE CONSERVATION OF SNOW COVER BY FORESTS

The most conspicuous effect of forests on snow is the retardation of snow melt under a stand compared to the open. Snow remains longer under trees than in the open despite the much greater accumulation in the open. This is a result of shading and wind protection lowering temperature and hence evaporation as mentioned above. Further, rain may be partially intercepted and prevented from reaching the snow in the woods. Where interception is great in early winter allowing soil to freeze the cold soil helps preserve snow from melting.

Carpenter ('01) was one of the first in the U.S. to record the protective effect of forests on snow in Colorado. Recognizing the connection between snow on the mountains and agriculture in the dry valleys, he found that in mid-summer snow was to be found at moderate elevations only in the forests were sheltered from the direct rays of the sun. He also observed that the greater the forest cover on the mountains the less violent the daily fluctuation of stream flow and concluded that the presence of forests was an absolute necessity for irrigated agriculture.

Mattoon ('09) observed a greater total snowfall in ponderosa pine forests in Arizona "due chiefly to higher wind velocity in the open, resulting in a lighter deposition of snow, a case similar to the deposition of silt in stream courses". Melting was more rapid in winter within the forest and by March the cover in the forest was broken by open patches while a uniform snow cover prevailed in the open.

Jaenicke and Foerster ('15) measured snowfall on paired stakes, one in the forest and one in an open park-like area in the ponderosa pine of Arizona. Like Mattoon they noted that during winter melting was greater in the forest than in the open due (they believed) to radiation from tree trunks. Because of this and to a minor degree, interception, depth was less in the forest. When rapid melting in the open began in the spring, the melting rate in the forest was only slightly accelerated so that snow remained under the trees two weeks after it had disappeared in the open. Incidentally there was less surface runoff in the forest because the soil thawed with the gradual snow melt and allowed melt water to seep into the soil.

Griffin ('18) also used paired snow stakes in Oregon and Washington. Snow in the forest decreased in spring from a maximum of 70″ to 28″ by the time snow had disappeared completely in the open. Snow remained in the forest an average of 17 days longer than in the open. Snow was retained to a greater extent in dense than in open forest. Snow that accumulated in small openings in Douglas fir was late in melting. It was calculated that an average square mile of forest retained an equivalent of 400 acre feet of water after open areas became bare.

Old uncut stands may be superior as snow protectors to open forest according to Meagher ('38) who measured snow in virgin stands, in partially cut Douglas fir, and in the open there was no drifting and a uniform snow depth was found in the virgin forest. Snow disappeared in the open one week before that in the partially cut stand and two weeks before that in the virgin forest where the snow depth was two to four times as great in April as in the open. During one week of warm weather in late March the following equivalent depths of water were released from the surface by melting:

Virgin Forest	1.5″
Partially Cut	2.7″
Open	4.8″

In the open 70% of the snow cover melted in this week but four weeks were required for the same amount to melt in the forest. Connaughton (loc. cit.) found melting occurred eight days earlier on open and sagebrush plots than in ponderosa pine. He found the greatest snow accumulation in the open but small openings were found to be as efficient as large denuded areas and the conservation of snow was superior.

Maule (loc. cit.) considered that white pine ranked above red pine and Norway spruce in its capacity to retain snow. Usually spruce and fir are considered the most efficient snow conservers.

A striking example of the influence of forests in conserving snow and thus reducing flood runoff from forest-covered land was afforded by the March 1936 flood in New England. (Baldwin and Brooks '36). (Anon. '36, '37). (Meagher '38). Prior to the flood a deep snow blanket covered both forest and open but after the torrential rains and thaw snow remained only in the woods. Open fields were completely bare even in northernmost New Hampshire and on the summit of Mt. Washington all but one inch of the 20.5 in. of dense snow and ice melted. In the forest on the other hand, while the snow level sank to less than one-half the original depth, this snow layer absorbed and held not only much of the melt water but some of the rain that fell. Conduction and latent heat of condensation contributed to the melting as well as sun and rain. If a dense forest cut the sun and wind to a third of the effect in the open and conserved the snow cover, this may well have reduced the flood water from the forest covered area by two-thirds.

Snow frequently disappears early on south and west borders of forest stands and individual trees due to the reflected heat from the boles causing melting. Interception plays a part also but the same phenomenon of melting around a pole will be noticed in the case of fence posts and telegraph poles where interception is practically nil.

OBSERVATIONS OF SNOW UNDER FOREST AT FOX STATE FOREST, HILLSBORO, N.H.

Following the March 1936 flood, interest in the effect of forests on snow resulted in the following observations at the Fox Forest. Upwards of 50 stations located both within and without the forest were under observation for five winters from 1937 to 1942 after which the war interrupted the project. The purpose was to determine the effect on accumulation and conservation of snow exerted by different forest types and stand ages. Preliminary results have been reported by a brief note (Baldwin '38a).

METHOD

Forest stations were selected that had an average branch cover directly over the stake. In closed stands stakes were midway between trees, in no case near the trunks. Open stations were more than the tree height distance from the woods. Wherever possible paired stations were selected, one in the forest and one in the open. In the fall before the ground froze a level space was cleared to bare mineral soil and a two ft. square of celotex or "Nu-wood" placed flat in contact with the soil; the upper surface of the insulating board was painted white. This gave a uniform base at all stations on which to collect the snow. Through a 1″ hole in the center of the wallboard a bamboo pole was inserted in a crowbar hole into the soil below frost level. The pole was painted with aluminum paint and graduated in inches with black paint. The zero mark was adjusted flush with the top surface of the wallboard. Rain gauges were placed at 20 stations, 10 in the forest and 10 outside. Snow depth on the stakes was read at weekly intervals.

The results, as might be expected, were extremely variable. It is obvious that as far as interception is concerned one square foot under a stand can experience almost complete interception and have no snow whereas another square foot a few feet distant may get a load of snow dumped from branches. The difficulties in reporting an average snow depth in the open have been pointed out by the writer (Baldwin '38b). In the woods there may be even more variation. However, in the range of conditions investigated the following results were obtained:

1. Interception was usually greater in young than in middle-aged white pine stands. Young stands were also more effective in retaining snow in the spring.

2. The greater the fall of snow in any one storm, the higher the percentage intercepted.

3. Snow with a high density was more fully intercepted than low density snow.

4. In one case under a middle-aged white pine stand there was only 38% the snow depth of adjacent open land on January 1 but by mid-April this had risen to 400% of the open depth. On May 1st there was no snow in the open but still over ½ ft. in the forest. (See Table 1.)

5. Results were far from uniform and in many cases contradictory. When 15 to 20 or more stations were averaged differences between forest and open became less striking.

6. Differences between forest and open varied in different years in the same location and with the conditions attending each storm and with differences in the march of seasonal weather.

SUMMARY

Forests have a profound effect on the distribution, character and duration of snow cover. In forested regions snow is less subject to drifting and the rate of melting is retarded compared to tree-less regions.

Evaporation from the snow cover is less in the woods than in the open.

Accumulation, while less, directly under the crowns due to interception, is greater in openings because of protection from wind and sun. The result is greater accumulation in old forests of low density or in younger stands with openings.

There is less accumulation in fully stocked young pole stands at ages of maximum density.

Evergreens influence snow more than deciduous trees. Trees with dense stiff foliage and branches intercept snow

and hold it from falling longer than long flexible needles and branches. Tall trees with long crowns intercept a higher percentage of snow than short flat crowns. The amount of interception varies with the type of snowstorm and snow density.

Density of snow decreases from a maximum in the open to a minimum under dense forest in proportion to increase in stand density.

The rate of melting of snow is retarded by forest, and the date snow disappears from the ground is later in the forest than the open, sometimes as much as six weeks.

The effect of forests in retarding snow melt increases with density of the forest, the depth of crown and abundance of advance reproduction.

TABLE I

AVERAGE DEPTH OF SNOW IN THE FOREST IN PERCENT OF THE DEPTH ON ADJACENT OPEN LAND

		11-20 White Pine Saplings				41-50 Yr. Middle-Aged White Pine			
YEAR		38-39	39-40	40-41	41-42	38-39	39-40	40-41	41-42
		Number of Stations				Number of Stations			
Month and Week		10	11	10	10	10	33	33	40
Dec. (Start of)	1	79		54				98	
	2			45	68			90	48
	3			50	65			87	60
	4			54	61			91	56
Jan.	1	63		38	74			93	100
	2	66	32	51	79		38	79	54
	3	66		51	70	59	68	83	No Snow
	4		56	61	—		66	89	No Snow
Feb.	1	82	67	67	73	75	74	88	87
	2	82	100	68	70	73	90	96	84
	3	80	88	63	76		88	96	89
	4	92	81	62	76	76	85	105	89
Mar.	1	104	87	59	82	93	88	107	96
	2	100	93	82	90	88	90	99	95
	3	84	87	77	100		97	104	110
	4		94	85	229	110	93	104	161
Apr.	1		138	135	333		106	250	163
	2	140	248			120	154		
	3						385		
	4						400		
May	1								
	2								

TABLE II

Fox Forest

Hillsboro, N.H.

SNOW MEASUREMENTS 1940

Series B — White Pine Stand — 41-50 years

Date	Under Stand	Adjacent Open	Snow Under Stand in % of Adjacent Open
	Av. depth of snow in inches		
1/10	1.2	3.2	38
1/17	5.4	7.9	68
1/31	4.7	7.1	66
2/7	6.1	8.2	74
2/15	17.9	19.8	90
2/21	23.1	26.4	88
2/28	21.3	24.7	85
3/6	23.7	26.7	88
3/13	21.0	23.4	90
3/20	24.1	24.9	97
3/27	24.1	26.1	93
4/5	15.5	14.7	106
4/9	10.5	6.8	154
4/17	7.3	1.9	384
4/24	5.6	1.4	400
5/1	0.6	0	inf.

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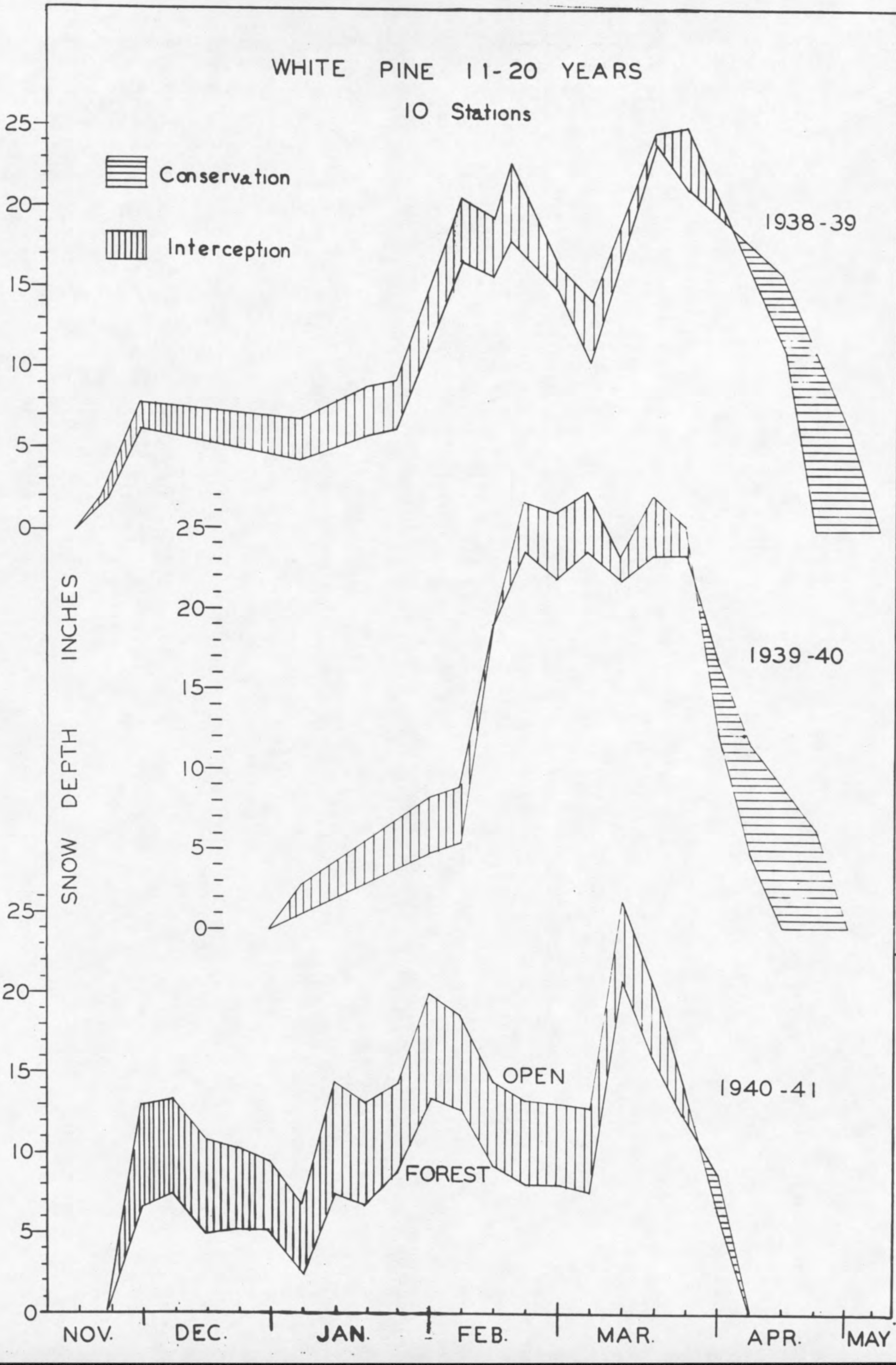
WHITE PINE 11-20 YEARS
10 Stations
Conservation
Interception
1938-39
1939-40
1940-41
OPEN
FOREST
SNOW DEPTH INCHES
25
20
15
10
5
0
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY

SNOW DEPTH IN FOREST

IN PERCENT OF DEPTH IN THE OPEN

WHITE PINE- 4 YEAR AVER.

HILLSBORO N.H.