THE SIGNIFICANCE OF THE EFFECT OF STAND DENSITY UPON THE WEATHER BENEATH THE CANOPY

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During the middle of the nineteenth century forests were believed to have important influences on climate. As climate was more thoroughly understood it became evident that the major climatic controls were beyond the influence of forest cover, a finding which wholly discredited the earlier conclusions. It was evident to the forester and student of ecology, however, that a forest stand has important and under certain conditions critical influence upon plant succession. Accordingly, attention was given to local climate, or micro-climate. An understanding of the significance of the influence of the forest in micro-climate is dependent on comparative measurements which the paper of Mr. Jemison clearly sets forth.

FORESTERS generally recognize that stand density influences the weather, but the magnitude and reliability of apparent differences in soil, air, and duff temperature, air and fuel moisture, wind, and evaporation following complete or partial removal of dense virgin timber have long been matters of speculation for American forest conditions. The significance of real differences in the weather elements is enlightening when their application is considered in the fields of silviculture and fire protection. Information on this subject is of value to the forester in explaining the survival and growth of seedlings, the invasion or succession of vegetation after cutting, and the relative forest fire danger on areas of varying amounts of forest cover.

Relatively few publications are available on the subject. Pearson (7 and 8) emphasized the importance of recognizing the effect of silvicultural systems on the physical factors directly concerned with tree growth. He stated that "too often the forester thinks of the method of cutting as acting directly instead of through its effect on basic physical conditions." Munger (6) compared the evaporation and surface soil temperatures of timbered and open areas in the Douglas fir region. Stickel (9) showed the modifying effect of a forest cover on fire danger in New England, and Larsen (5) made a study of the effect of the removal of a virgin western white pine stand upon the site factors.

The effect of stand density upon the weather and inflammability beneath the canopy has been measured at the Priest River Forest Experiment Station, near Priest River, Idaho, since 1924. Beginning in late 1930 comparable data have been obtained for three sites: one located under dense virgin timber, one under partial cover where about one-half of the canopy has been removed, and the other in the open where there is virtually no forest cover but merely small and widely scattered patches of reproduction. These stations, which are termed the full-timbered, half-cut, and clear-cut areas, respectively, are located within 1,400 feet of each other on a topographic bench where all conditions are comparable except the density of the forest cover. Data obtained on the three areas, through a carefully developed technique, include twice-daily measurements throughout each fire season of maximum and minimum air temperature, relative humidity, wind, evaporation, soil temperature, maximum duff temperature, precipitation, and duff and slash moisture content, as well as automatic records of relative humidity and duff and air temperature.

In a study of the influence of stand density upon the weather elements beneath the canopy, averages or a comparison of averages fail to tell the story completely unless the reliability of means and of the differences between means is investigated. The average relative humidity on the half-cut area might be three per cent higher than that on the clear-cut area, for instance, but it is possible that these two means do not differ significantly one from the other because of large sampling errors associated with the data.

Using the detailed records, which were available for July and August of 1931, 1932, and 1933, averages and their standard errors were computed, and the results are presented in Table 1.

The standard errors of the means were computed by the formula $\sigma_M = \frac{\sigma_X}{\sqrt{N}}$, in which

σ_M = Standard error of the mean of the variable X.

σ_X = Standard deviation of the variable X.

N = Number of observations.

Thus the full-timbered average maximum air temperature of 79.3° ± 0.6° indicates that means of similar samples of maximum air temperature would fall between 78.7° and 79.9° two times out of three.

The significance of the difference between two means can be tested by determining the magnitude of the standard error of the difference and comparing it to the difference itself. The observed difference between the mean relative humidities of the clear-cut and half-cut areas was 1.7 per cent with a standard error of ±0.3 per cent. This difference, almost six times its error, was undoubtedly real because in statistical work two or three times the standard error is taken as the level of significance. Three times the standard error was adopted as the level of significance for this study.

An investigation reveals that the differences between the clear-cut and half-cut averages and all differences between the half-cut and full-timbered averages are significant because they are at least three times the corresponding standard errors. These differences are shown in Table 2.

The following formula was used to compute the standard errors of differences between the means of the dependent events:

$\sigma_{X-Y} = \sqrt{\sigma^2_X + \sigma^2_Y - 2r_{XY}\sigma_X\sigma_Y}$ in which

σ_{X-Y} = Standard error of the difference between the means of variables X and Y.

σ_X = Standard error of the mean of X.

TABLE 1

AVERAGES OF WEATHER AND FUEL MOISTURE ON THREE SITES AT THE PRIEST RIVER FOREST EXPERIMENT STATION

Factor measured	Full-timbered area Mean	Full-timbered area Std. error	Half-cut area Mean	Half-cut area Std. error	Clear-cut area Mean	Clear-cut area Std. error
Maximum air temperature, °F.	79.3	±0.6	81.7	±0.7	84.1	±0.7
Soil temp., 1-foot depth, °F.	51.4	±0.1	53.9	±0.1	59.6	±0.1
Max. surface duff temp., °F.	77.0	±0.7	91.6	±1.0	126.9	±1.3
Rel. humidity, 4:30 p.m., per cent	35.8	±1.1	29.0	±1.1	27.3	±1.1
Abso. hum'ty, 4:30 p.m., grs./cu.ft.	3.343	±0.057	2.886	±0.057	2.817	±0.052
Wind movement during day, miles	3.8	±0.2	18.8	±0.6	32.6	±0.7
[1]Evap. rate, grams	40.0	±2.0	77.0	±8.0	163.0	±11.0
Duff moisture, per cent	18.8	±0.9	16.5	±0.9	8.2	±0.6
Branchwood moist. 2" di., per cent	11.1	±0.2	9.5	±0.2	6.4	±0.2

[1]Average evaporation based on measurements taken every 10 days during 1931 and 1932 only.

σ_Y = Standard error of the mean of Y.
r_{YX} = Correlation coefficient of the variables X and Y.

As the foregoing tests of the significance of the differences between means indicate that all differences are real, the averages for July and August, shown in Table 1, can be taken as reliable indicators of the effect of stand density upon weather and fuel moisture beneath the canopy. Knowing that these differences are significant, the results of partial or complete removal of the forest cover are quite striking. It becomes apparent that partial cutting increased the average maximum air temperature two and one-half degrees, while clear cutting raised it five degrees. Soil temperature was increased from two and one-half to eight degrees, and maximum temperature of surface duff as much as 50 degrees. These cutting practices also lowered relative humidity seven to eight and one-half per cent, increased wind movement five to eight times, at least doubled the evaporation, and reduced fuel moisture contents as much as ten per cent.

These averages for a two-month period fail, however, to indicate the extreme conditions which, while they may not last long, have important effects upon seedling survival and upon inflammability. Tables 3 and 4 were therefore prepared to show extremes of duff temperature and fuel moisture. They show emphatically that clear cutting results in extremely dangerous conditions.

One of the most striking features of these tabulations is the extremely high temperature of 158° measured just under the surface of the duff on the clear-cut area. Right at the surface, in the full blast of the sun, the temperature must have been even higher than 158° which in itself is sufficient to kill young seedlings. The danger in such high temperatures has been proved by Baker (1) who found that surface temperatures of 130° F. quickly kill young coniferous seedlings. Toumey and Neethling (10) found that lesions occur on coniferous plants whenever the topsoil temperature exceeds 122° F. for a period of two hours, even if the roots are in contact with abundant soil moisture. Haig (4), studying seedling survival on the three Priest River areas, found surface soil temperature to be the most important single physical factor causing first-year seedling mortality on the clear-cut area.

Averages show that during July and August on the clear-cut area there were 44 days when the duff temperature exceeded 120° F., the average period of duration being over four hours each day. On 26 days the temperature was at least 130° for an average period of three hours, and on four days temperatures greater than 140° were

TABLE 2

SIGNIFICANCE OF THE DIFFERENCES BETWEEN THE MEANS OF THE CLEAR-CUT AND HALF-CUT AREAS, AND OF THE HALF-CUT AND FULL-TIMBERED AREAS

Factor measured	Difference between the means of the Clear-cut and half-cut areas		Half-cut and full-tbr. areas	
	Diff.	Std. Error	Diff.	Std. Error
Maximum air temperature, °F.	2.4	±0.1	2.4	±0.1
Soil temperature, 1-ft. depth, °F.	5.7	±0.1	2.5	±0.1
Maximum sur. duff temperature, °F.	35.3	±0.9	14.6	±0.6
Relative humidity, 4:30 p.m., per cent	1.7	±0.3	6.8	±0.4
Abso. humidity, 4:30 p.m., grs./cu. ft.	0.069	±0.022	0.457	±0.028
Wind movement during day, miles	13.8	±0.4	15.0	±0.5
Evaporation rate, grams	86.0	±7.0	37.0	±7.0
Duff moisture, per cent	8.3	±0.7	2.3	±0.4
Branchwood moisture, 2" diam., per cent	3.1	±0.1	1.6	±0.1

recorded for periods of two hours. Temperatures of this magnitude no doubt cause the death of young trees on planted areas and of reproduction on the more exposed sites, as well as tremendous mortality among young seedlings. Wahlenberg (11) studied the effect of the shade of ceanothus brush on ponderosa pine seedlings, but attributed the better survival of transplants under the bushes largely to more favorable moisture conditions. Often the beneficial effect of shade is realized in planting operations and young trees are placed in the shade of stumps and logs, and the wisdom of this practice is clearly shown by the present data. An outstanding example of the effect of the shade of some small object can be found in the Priest River records for August 5, 1930, when the shade of a fence post on the duff caused the temperature to drop from a fatal 142° to 122° in about 20 minutes.

In contrast to these dangerous conditions brought about by clear-cutting, only once in three years has the duff temperature on the half-cut area exceeded 120° F. and then it reached 122° F. for only a few minutes. The highest record of duff temperature on the full-timbered area was 94° F.

The effect of the timber canopy on fire danger, as shown by the moisture contents of duff and wood, is so obvious in Table 3 that it needs little comment here. By influencing temperature, humidity, wind, and evaporation the forest overwood makes moisture-holding conditions much more favorable and cuts down the inflammability, hence the danger from rapid spread of fire. A full forest cover eliminates 90 per cent of the critical days during July and August, while half cover cuts out more than one half.

Absolute humidity has been purposely omitted from the discussion so far. From Table 2 the half-cut average absolute humidity is shown to be just barely significantly different from the clear-cut value. The former area had an average of $.069 \pm .022$ more grains of water per cubic foot of space than the open area. While in this case the small difference is real, conditions can be readily visualized, and actual records are available where absolute humidity under a timber canopy is the same as out in the open although *relative* humidities are higher and temperatures are lower in the timber. In this connection it is desirable to remember that relative humidity is the ratio of the amount of moisture in space to the amount that space could hold, temperature and pressure being constant. It is possible that the relative humidity under timber is greater because the temperature is lower, hence the *capacity* of space to hold moisture here is less. This observation is supported by Cummings (2), who states that "the direct effect of (relative) humidity changes on evaporation should not be confused with the indirect effect caused by changes in insolation which usually accompany humidity changes."

The importance of a timber cover in decreasing inflammability by lowering temperature and raising relative humidity is no doubt overemphasized. Applying the averages of Table 1 to the equilibrium relations between relative humidity and

TABLE 3

EXTREMES OF WEATHER AND INFLAMMABILITY DURING JULY AND AUGUST ON THREE SITES AT THE PRIEST RIVER FOREST EXPERIMENT STATION

	Clear-cut area	Half-cut area	Full-tbr. area
Highest duff temperature measured, °F.	158.0	122.0	94.0
Lowest duff moisture measured, per cent	3.5	8.0	8.5
Lowest 2" branchwood moisture measured, per cent	3.5	7.0	7.5
Average per cent of critical days (when duff moisture was below 10 per cent)	88.7	32.3	8.1

fuel moisture derived by Dunlap of the Forest Products Laboratory and reproduced by Gisborne (3), the lower temperature and higher humidity on the half-cut area accounted for a fuel moisture greater than the clear-cut moisture by only four-tenths of one per cent. The contribution of temperature and relative humidity to the greater fuel moistures that exist under forest canopies, therefore, may be relatively small in comparison to the effect of wind, sun, and other factors.

SUMMARY

All of the observed differences, in the weather and inflammability, between the full-timbered, half-cut, and clear-cut areas were found, by making statistical tests of significance, to be real.

The influence of a forest cover as shown by the Priest River records benefits the survival of seedlings and planted stock by creating more favorable conditions of temperature.

Inflammability is greatly reduced under the canopy because of a lower evaporation rate. A full stand of timber eliminated 90 per cent of the critical days during July and August.

Absolute humidity is a better index of differences in atmospheric moisture on areas where the temperature is not the same. Relative humidity, when used alone, may be misleading.

CONCLUSIONS

Definite information on the requirements of tree species is somewhat meager at the present. However, to make use of the data now available it is necessary to have equally specific data on the physical factors of sites. The forester may strengthen the foundations of silviculture by recognizing the influence of stand density upon the weather under the canopy and by correlating it with the requirements of various tree species. He may well realize the important effect of varying canopy density upon inflammability and formulate his plans for successful fire control accordingly.

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TABLE 4

DAYS AND HOURS WHEN SURFACE DUFF TEMPERATURE EXCEEDS 120°, 130°, AND 140° F. ON THE CLEAR-CUT AREA

	Duff temperature above: 120°	130°	140°
Average number of days during July and August	44	26	4
Average number of hours	4.2	2.9	2.0

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To the man in the street most forms of scientific research are regarded as an expensive luxury, although there are occasional cases where a successful pioneer is given an unexpected share of limelight when his scientific toy has become the civilized world's latest necessity. . . . .

Until a healthy public opinion has been built up amongst the educated classes with an appreciation of the economics of plantation work and the replacement of felled crops, timber treatment and seasoning, the development of our minor forest products, and of forest protection in its widest sense, our research programme will remain at the mercy of whomsoever happens to hold the purse-strings of government.—*Indian Forester,* February, 1934.