A Spherical Densiometer For Estimating Forest Overstory Density

BY

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FORESTERS, ecologists, range scientists and many others recognize that forest overstory is important to the plant community. It affects such basic habitat factors as light, moisture, wind and temperature.

Light is required for the growth of most plants and is characterized by four attributes: quality, direction, intensity, and duration (Weaver and Clements, 1929). When a forest overstory is present it may alter one or more attributes of the light that penetrates into lower portions of the tree crowns, to the understory plants, and to the forest floor.

A forest overstory may intercept snow and rain causing a loss of potential soil moisture due to evaporation from exposed and greatly increased surface areas. It may have an important influence upon the accumulation and melting of snow and ice (Craddock, 1954).

Interception of rainfall by a forest overstory and increased evaporation result in a cooling effect on the temperature. Insulation against direct radiation from the sun, moderation of wind currents, and cooling due to shading, reduce transpiration from plants and evaporation from both soil and plants.

Many instruments and methods have been used to study the influences of forest overstory. Examples of such instruments and methods are: photometers (Weaver and Clements, 1929; Matusz, 1953), light meters (Jackson and Harper, 1955), photographic methods (Suzuki and Satoo, 1955), densiometers and ceptometers (Robinson, 1947; Ingebo, 1955), vertical crown projection methods, and ocular estimations of overstory density.

Studies of forest overstory density are made by foresters to establish spacing standards in forest thinnings and to determine light requirements for regeneration. Soil Conservation Service technicians record measurements of overstory density during field studies made to relate soil and other environmental factors to growth of trees and grasses. The author designed an instrument to make measurements of overstory density easily and accurately. This paper describes the instrument and gives some data on its reliability in use.

Development and Description of Instrument

Ocular estimations of overstory density were used in preliminary work. These were intended to estimate relative area of crown coverage by vertical crown projection methods. The first instrument used by the author was a densiometer patterned after that described by Robinson (1947). A flat mirror was used in this instrument which limited the size of the overstory sample being measured. A large number of measurements was therefore needed to get a reliable estimation. The instrument was also large and inconvenient to carry. Study and discussion of the problem suggested the use of a curved or spherical mirror to reflect a larger segment of the overstory. Ingebo (1955) employed this principle in his ceptometer. An improved method of delineating an area of overstory on the mirror for density estimations was sought. After much study and trial, spherical densiometers described briefly in a discussion of Ingebo's paper were devised.[1]

Two models, A (Fig. 1) and B (Fig. 2), have been adopted as standard. Each employs a highly polished chrome mirror 2½ inches in diameter and having the curvature of a 6-inch sphere. The convex side of the mirror is used in Model A and the concave side in Model B. Each has some advantages over the other. Concave mirrors invert the reflected image. The reflection is less clear than in convex mirrors unless the viewer closes one eye. The area of overstory being measured by a concave mirror can be more nearly overhead because the head of the viewer may be easily kept outside the angle of reflection. Identification of reflected objects is more difficult in the concave mirror due mainly to image inversion.

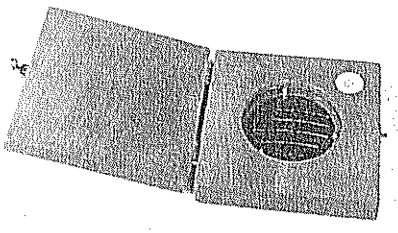

FIGURE 1. *Spherical densiometer, Model A, with estimating grid scratched on the surface of the convex mirror.*

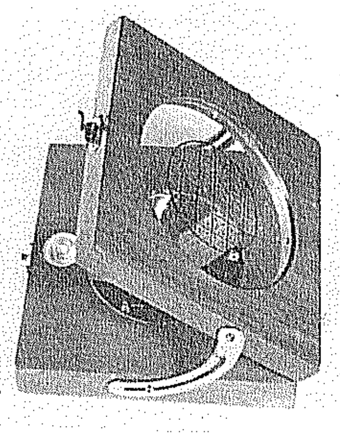

FIGURE 2. *Spherical densiometer, Model B, with estimating grid superimposed between the eye and the surface of the concave mirror.*

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[1] The first spherical densiometer was a 6-inch hemisphere with a mirror surface and a flange at the base like the brim of a hat. It was fixed to a camera tripod. Many kinds of grids for estimating area were tested. One was a wire hoop with square cross-sectional markers held about one to two feet above the hemisphere in such a way that its reflection fell precisely on a circle marked on the surface of the mirror. This grid could be superimposed at will on the mirror at any point representing changes in direction of incoming light through the overstory. This grid is perhaps the most accurate and has several interesting possibilities. However, there are some mechanical problems of support and the instrument is cumbersome. In fact, the hemispherical mirror itself is larger than necessary because it reflects side and even ground areas as well as overstory. Only a small part of a spherical mirror is needed to reflect a large enough area of overstory for measurement.

TABLE 1. Analysis of variance: test of spherical densiometer.

Source of variation	Degrees of freedom	Sums of squares	Mean squares	Variance ratios (f)
Instruments	1	480	480	3.38
Forests	6	63,792	10,632	74.87**
Operators	3	308	103	0.73
Interactions:				
Instruments and forests	6	1,917	320	2.25
Forests and operators	18	3,302	183	1.29
Instruments & operators	3	346	115	0.81
Error	18	2,552	142	
Total	55	72,351		

**Significant at 99% level.

The mirrors are mounted in small wooden recessed boxes with hinged lids similar to compass boxes. The over-all dimensions are about 3½ × 3½ × 1⅛ inches. A circular spirit level is mounted (recessed) beside the mirrors. Positive slide fasteners are provided in Model B which allows the lid to open to an angle of about 45 degrees.

Cross-shaped and circular grids with squares and dots are used to estimate overstory coverage by tree crowns. Grids are of two kinds: (1) those scratched upon the surface of the mirror, Model A, and (2) those superimposed between the mirror and the eye, Model B.[2]

The cross-shaped grid scratched upon the convex surface of the mirror in Model A has 24 quarter-inch squares (Fig. 3A). Instructions for using the densiometer and cumulative values for the squares on the grid are shown on a chart that is attached to the inside of the box lid (Fig. 3B). It is easier and faster to estimate the relative amount of overstory coverage with this instrument by assuming the presence of 4 equi-spaced dots in each square and by counting dots representing openings in the canopy. The percentage of overstory density is then assumed to be the complement of this number. Each assumed dot is assigned a value of one percent in this case. A slight discrepancy exists between estimations using the squares and estimations by counting assumed dots, because there are only 96 dots in the entire grid area. Cumulative values of the squares shown in the chart add up to 100 percent for the entire area within the grid. If desired, one may calculate the exact percentage values for each assumed dot and thereby make the two methods of use exactly comparable. Data presented for this instrument were based on cumulative values of the grid squares.

Model B has a circular grid. The circle is one and one-half inches in diameter superimposed over quarter-inch squares. Each square has four equi-spaced dots (Fig. 4A). This grid is made from a positive print of a photographic film mounted between thin sheets of plexiglass and fitted into the window of the box lid. Instructions for operating Model B are given on a chart mounted on the bottom of the instrument box (Fig. 4B). The operator estimates overstory density by counting the dots representing overstory openings and assuming this to represent the percentage of non-covered overstory area. Here again a slight discrepancy exists because there are only 96 dots included within the area of the circular grid. Exact percentage values for each dot may be calculated to estimate the entire circular area as 100 percent. This refinement is not considered necessary for ordinary use of the instrument.

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[2] Grids superimposed between the mirror and the overstory have been used by Ingebo, 1955 and Robinson, 1947, and were tried by the author. (See footnote 1).

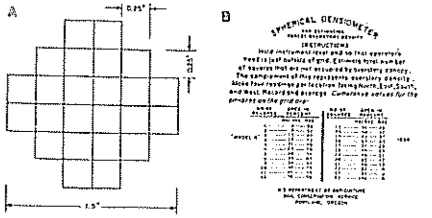

FIGURE 3. A. *Cross-shaptd grid scratched on the convex surface of the mirror in Model A. Each square is ¼ inch o na side.* B. *Instructions for using Model A. This is fastened to the inside of the lid of the mounting box.*

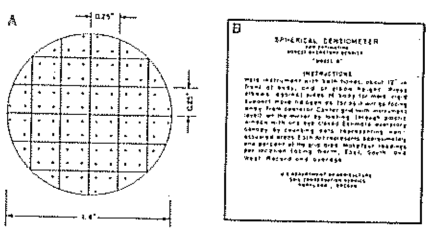

FIGURE 4. A. *Circular grid superimposed between the eye and the concave mirror in Model B. Each square is ¼ inch on a side.* B. *Instructions for using Model B. This is fastened to the bottom of the mounting box.*

The kind, size, and shape of the grid may be designed to meet the needs. Such things as amount of lateral coverage, desire for sampling specific overstory areas from a point, and ease in making the estimation are considerations in designing the grid. Small aberrations in the cross-shaped grid scratched on the surface of the curved mirror are thought to be within the accuracy of the instrument and are not important sources of error.

The degree of curvature of the mirror may be selected within limits to meet the needs of the investigator. It seems important, however, to have mirrors with known physical properties of curvature. Mirrors with curvature of a 6-inch sphere have been satisfactory in work with Douglas fir, ponderosa pine, lodgepole pine and other western conifers. They reflect an area of overstory large enough for accurate estimations of covered and non-covered areas. Curvature has not caused appreciable inaccuracy due to scratching a grid on the surface, reading the instrument, or fitting it into small compact portable units. Standardization of mirror curvature, grid size and design and methods of using the instrument are necessary to provide comparable information that can be duplicated. Operators need a little training to become consistent in the use of the instrument. Judgment and experience is needed to differentiate between overstory areas that are considered completely covered by the overstory and those that have thin but uniformly distributed coverage. In the latter case it may be necessary to estimate the area of many small irregular openings and reduce the percentage overstory density by the sum of these. Training and experience are needed for each different forest species or type because of the differences in overstory characteristics. The season of the year is important when making measurements in forests containing deciduous species.

Experience has shown that sufficient accuracy can be attained with the spherical densiometer by holding it as nearly level as possible in the hand. This is made possible by installing a circular spirit level in the mounting box. No mechanical support, such as a tripod, is needed. This adds to the practicability of the instrument in use.

Using the spherical densiometer, Soil Conservation Service technicians measure overstory density facing each of the four cardinal directions at each sample point. Since the overstory area measured by the spherical densiometer is not directly overhead, this gives added information about overstory density in different directions. Slope percentage and aspect are always measured by supplementary equipment. It has not been necessary to install compasses in the densiometers currently in use although this could easily be done if desired.

Variations in Overstory Density

Overstory density measurements were made in several ponderosa pine forests in south central Oregon and south central Washington. Each of four different operators used both Model A and B instruments. Each operator measured the overstory density at four points, north, east, south, and west around a reference tree. The reference tree in each case represented a typical dominant or codominant in the stand. The points selected around each reference tree were far enough away so that the crown of the reference tree was just outside the overstory area being estimated. This is equivalent to 28 forest measurements made by each of four different operators by each of two different instruments. Care was taken to prevent one operator from knowing the results of any previous measurement during the work.

The data were subjected to an analysis of variance by standard procedures (Table 1). There proved to be no significant difference among measurements made by different operators or with different instruments. None of the interactions were significant. The only variable showing significance was that of forests. All other sources of variation were therefore pooled. When the error term was thus increased to 49 degrees of freedom, the variance ratio due to forests was 60.9, a value significant at the 99 percent level.

Fiducial limits of the mean of total means were set up for different levels of probability based on this latter analysis. These fiducial limits were based on means of four measurements.[3] Division by four would show expected variations at the different probability levels for actual overstory density measurements. For instance, the overstory in forest 42 (instrument A, direction N and instrument B, direction N) was measured 8 times with the following results: 71, 71, 67, 67, 71, 65, 74, and 66. The mean of these measurements is 69 percent. At the 70 percent level of probability results are reliable within ± 1.3 percent—a coefficient of variation of 2 percent of the mean. At the 95 percent level of probability the results are reliable within ± 2.4 percent—a coefficient of variation of a little over 3 percent. At the 99 percent level of probability the results are reliable within ± 3.1 percent—a coefficient of variation of a little over 4 percent. Both instruments apparently give consistently accurate measurements of forest overstory density, regardless of operator. The spherical densiometer is therefore a practical and reliable instrument for obtaining comparative information about forest overstory density for whatever purpose this information may be sought.

In the past, overstory density usually has been estimated and assigned to classes, both in accumulating field information and in analyzing results. With the spherical densiometer this is not necessary, for overstory density can be measured easily, quickly and accurately. If overstory density classes are needed to simplify calculations and analyses the class interval can be more narrowly defined by data obtained with this instrument.

Tests have been made to show reliability when forests are assigned to 5 percent overstory density classes by the spherical densiometer. Data used in computing Table 1 have been combined with additional data for this test (Fig. 5). Each of the 416 single measurements was allocated to a density class established by the average of the 4 measurements of each individual forest overstory sample. These included measurements by four different operators. For instance, forest 42, instrument B, direction N; the measurement 71 by operator 1 was placed into density class 66 to 70 established for the average (69) of 71, 65, 74, and 66, the measurements of operators 1, 2, 3, and 4, respectively. Variation shown in Fig. 5 has been calculated around the mean of all the measurements within each class and not from the central class value. The data include all 224 single measurements used in Table 1 and 192 additional measurements all made with instruments of the Model A type. These additional measurements were equally divided among four different operators and included, as before, readings facing N, E, S, and W at each point in 9 additional forests. These forests included coast Douglas fir in western Washington, ponderosa pine and mixed coniferous forests in northeastern Washington.

The standard deviation and coefficient of variation of the mean of all measurements within each class were plotted against the mean (Fig. 5). Harmonized, freehand curves were drawn among the points. These curves indicate that variation among measurements increases as the overstory density decreases. This seems to agree with the findings of Jackson and Harper (1955). There is little significant change in consistency of measurements above about 60 percent overstory density. Actually, the reliability of measurements in forests of only 50 percent overstory density is entirely satisfactory for most purposes. In use, the reliability would be reflected by that portion of the curves to the right of the 50 percent overstory density class because an operator will naturally tally the areas that are covered with overstory instead of the areas that are not covered when measuring forests of low overstory density.

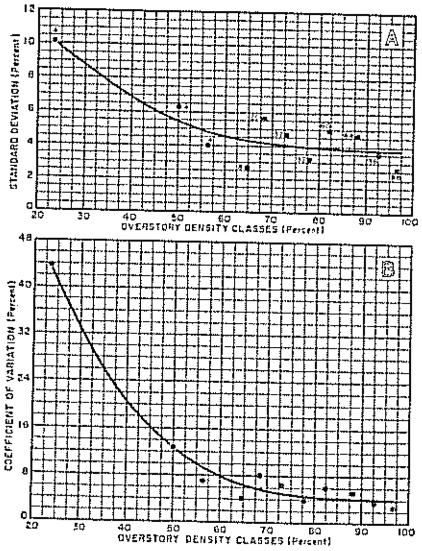

FIGURE 5. *Relation of standard deviation and variation coefficient to overstory density classes.*

When assigning forest overstory to density classes by means of the spherical densiometer some loss in accuracy results. If 5 percent classes are used as in Fig. 5A, reliability of measurements of about the order of ± 5 percent can be expected (with a probability at about the 68 percent level) for all density classes above 50 percent. This is in contrast to a reliability of about ± 1.3 percent when actual measurements with the spherical densiometer are tabulated. The coefficient of variation (Fig. 5B,) amounts to about 5 percent for all density classes above 70 percent and increases to about 13 percent for classes down to 50 percent overstory density.

Summary

The spherical densiometer has been designed as a pocket type, easily used, highly accurate and practical instrument for determining from a point the relative amount of light that is cut off by specific areas of the forest overstory. It can be used equally well by the scientist doing highly technical research work, or by the practicing forester, range conservationist or plant ecologist.

Two models of the spherical densiometer, A and B, have been standardized. Both are based on the use of curved (spherical) mirrors which reflect the overstory conditions at a point and make possible the estimation of relative amounts of area covered and not covered. Measurements

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[3] The limits are ± 5.3 at the 70% level, ± 9.4 at the 5% level, and ± 12.5 at the 1% level.

are made by means of various kinds of grids. Model A has a cross-shaped grid with ¼-inch squares scratched upon the surface of the mirror. Model B is provided with a circular grid superimposed over ¼-inch squares, each of which contains 4 equispaced dots. This is mounted in the lid of the mounting box to be superimposed between the mirror and the eye of the operator.

Trials by different operators with both instruments have shown that there is no significant difference among measurements of overstory density made by different operators or with different instruments. Differences in forest overstory density, however, can be assessed with an unusually high degree of fidelity. For instance, at the probability levels of 70, 95 and 99 percent, average measurements of the same overstory area can be expected to be within ± 1.3, ± 2.4 and ± 3.1 percent respectively. These variations are about 2, 3, and 4 percent of the average overstory density measurements respectively (the coefficients of variation.)

Tests were made to show the influence upon expected variability of measurement when assigning overstory density to class. Two conclusions are obvious: (1) Variation among replicated measurements increases with a decrease in the overstory density. This is important in forests with overstory density varying from 100 down to about 50 percent. In forests with lower overstory density the operator naturally tallys the area covered with overstory instead of the area not covered. The variation in reliability, therefore, never exceeds that shown for about 50 percent overstory density. (2) There is a loss in reliability of measurements when forest overstory is assigned to an overstory density class by the spherical densiometer over that of using each measurement directly.

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Germination of Slash Pine Pollen in Vitro

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FOR MANY SPECIES of plants, tests of pollen germination *in vitro* are used to indicate their pollen viability. Variation in germination percentage may be caused by factors such as drying methods, methods of extraction, conditions during pollen extraction, storage conditions, germination techniques, temperature, relative humidity, and organic and inorganic nature of media (Lidforss, 1899; Brink, 1925; O'Connor, 1927; Dengler and Scamoni, 1939; Smith, 1939, 1942; Saarnljoki, 1941; O'Kelley, 1954; Duffield, 1954). Different tree species show so much variation in chemical requirements for germination of their pollen that a given medium can be considered standard for only a few. Two widely used media are 5 to 10 percent sucrose solutions (or sucrose-agar blocks), and distilled water (liquid or vapor). In view of the fact that many species respond to varying media combinations, a study of the effect of various inorganic and organic additives on germination of pollen is of interest from both a physiological and cytological point of view.

In this study, the stimulation or inhibition effect of different concentrations of inorganic and organic compounds, the effect of a flower extract, and the effect of a short storage period on the germination of slash pine (*Pinus elliottii* Engelm.) pollen were investigated.

Review of Literature

Investigations into the phenomena of pollen germination and pollen-tube growth were initiated prior to 1900 (Lidfross, 1899). Brink (1925) introduced the hanging drop method of growing pollen *in vitro*. He reported that potassium, sodium, and lithium salts prevented germination at concentrations near M/100, whereas magnesium and barium salts were equally toxic at M/1500. Calcium salts considerably enhanced growth of pollen tubes at concentrations of M/50 to M/500.

Dengler and Scamoni (1939) used sucrose solutions for germination of pollen from twelve tree species. They reported optimum concentrations ranging from 5 percent for *Pinus*, to 40 percent for *Tilia* and other species. The addition of 1 ppm of 3-indoleacetic acid to germination media was found by Smith (1939) to produce favorable effects. He later tested four additional organic compounds and concluded that auxins in concentrations weaker than 20 ppm were favorable additions to a culture medium. All stronger concentrations

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