Study of Errors Involved Using
Proposed Cubic Foot Rules in
Scaling Ponderosa Pine

by

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Introduction

Although cubic foot scaling is not widely used in this country at present, it is the general consensus of opinion among foresters who have given any thought to the matter that for many purposes it would be superior to the board foot unit of measurement. The industries most in need of such a method of scaling are pulp and veneer. It is the purpose of this paper to show the need for such a method of scaling, to review some of the work that has already been conducted in this field, and to show the relative value of the various cubic foot rules proposed for use.

Why Cubic Foot Scaling is Needed

In the United States the three units of measurement that are used to express log volumes are the board foot, the cubic foot, and the cord. Each has its advantages when applied to certain classes of materials and when the final product is considered. Various board foot rules have been in use for over one hundred years and some of them have served their purpose, that being to give a fairly accurate estimate of the amount of lumber that can be cut from a certain size log in the mill.

Most of the board foot rules that are in use do not consider the taper in a log and consequently underestimate the amount of actual wood content. When the log is being cut into lumber, this error is not of great magnitude as there is a tremendous amount of wood wasted that cannot be avoided. The board foot, however, has been and is being used as a unit of measurement for logs that are to be used for pulpwood and veneer. In these cases the board foot unit is not satisfactory as a measure of the amount of pulpwood or plywood obtainable from the log. In these industries the error of the board foot unit is magnified, as the wood that is wasted in cutting lumber can be used in the pulp and veneer industries. These operators are interested in the actual volume of wood in the log and not in the theoretical yield of boards that can be cut from it. The cord unit ban be used satisfactorily for pulpwood when the logs are small and can be cut and stacked in cords. In cutting larger timher it would be impracticable to harvest it by stacked cord methods, and it is in this class of material that the cubic unit of measurement could be used to its best advantage.

Cubic Foot Rules Examined

The cubic foot rules studied in this report are Newton's, Huber's, Smalian's, Rapraeger's, and Sorensen's. Each has its advantages and disadvantages which will be discussed.

Newton's rule is based on an engineering formula and the log is assumed to be a frustum of a solid having a curvilinear form. Considering the length of the logs to be thirty-two feet, the formula resolves itself into the following form. $V = 0.02909 \times (D_b^2 + 4D_m^2 + D_t^2)$ where V equals the volume in cubic feet, D_b the diameter at the butt of the log in inches, D_m the diameter at the middle of the log in inches, and D_t the diameter at the top of the log in inches. All of the diameters in this report are diameters inside the bark. This rule has the advantage of more nearly approaching the absolute volume of a log and thus is used as the standard in this discussion to which the other rules are compared. It would not be practical of application in actual scaling practice due to the amount of time that would be consumed in obtaining the three separate measurements for each log that the formula calls for.

Huber's formula gives the volume of a cylinder of the same length as the log and a diameter equal to that at its middle. It can be simplified so as to take the following form. $V = .174528 \times D_m^2$. Its advantage is that only one measurement need be taken. This may prove to be a disadvantage in some cases instead of an advantage. When it is necessary to scale the logs when they are decked, the middle diameter measurement is impossible to ascertain on all but the top logs of the pile. Another disadvantage is that in addition to the diameter outside bark measurement, the bark thickness must be measured in order to determine the diameter inside bark which is the figure needed to substitute in the formula.

Smalian's formula averages the basal area of the two ends and multiplies by the length to get the volume. It can be stated as $V = .087264 \times (D_b^2 + D_t^2)$. It requires the diameter inside bark at both ends of the log.

Rapraeger's one-in-eight rule provides for a taper of one inch in eight feet from the top diameter in calculating the middle diameter. Once this diameter is obtained the computations are the same as for the Huber rule. Rapraeger's rule for logs of thirty-two feet may be stated as follows: $V = .174528 \times (D_t + 2)^2$. It has the advantage of requiring only one measurement, that being the diameter inside bark at the top. Its usefulness is doubtful as the assumed taper is probably not accurate for more than one given set of conditions.

Sorensen's rule provides for a taper on one inch in ten feet so that only one measurement need be taken and the diameter of the other end can then be computed. It assumes the log as the frustum of a cone and the formula thus becomes $V = .0582 \times (D_b^2 + D_t^2) + (D_b \times D_t)$.

Review of Work Accomplished

Some considerable amount of literature is available to those who are interested, on various phases of cubic foot scaling. Articles have been written and research conducted by men who are well-known in the forestry profession, such as Munger (1) and Rapraeger (2) (3) (4).

A list of articles which should be consulted by anyone who is contemplating doing any work in this field will be found in the bibliography of this report.

Preece (5) investigated application of the same five rules to western hemlock logs and came to the following conclusions. The most promising of these rules from a standpoint of practical application are the Huber, Smalian, Rapraeger's one-in-eight, and Sorensen's one-in-ten rules. Three log groups were investigated these being butt logs, intermediate logs, and top logs. In an investigation of the errors involved in applying the above rules, the Huber rule proved to be the most accurate considering all log groups in general. The aggregate cubic foot volume errors in percentage using the Huber rule was -5.6 per cent for 26 butt logs, +0.5 per cent for 51 intermediate logs, and -2.1 per cent for 23 top logs. The Smalian rule gave errors twice as great and of the opposite sign as those incurred by using the Huber rule. Rapraeger's one-in-eight rule was very accurate except in the top log group. The errors in percentage using this rule were +0.5 per cent for 26 butt logs, +0.3 per cent for 51 intermediate logs and -23. per cent for 23 top logs. Sorensen's one-in-ten rule gave values lower than the Newton rule in all log groups and can therefore be discounted as an accurate method to use. The aggregate cubic foot volume errors in percentages for the Sorensen rule were -2.7 per cent for 26 butt logs, -3.7 per cent for 51 intermediate logs, and -28.6 per cent for 23 top logs.

Henri Roy (6) in an article on "Log Scaling in Quebec" explained the system used to scale logs to be used for pulpwood in that province. The Quebec Forest Service has adopted the cubic foot unit in such a way as to do away with the necessity of identifying the log at both ends and consequently is more economical in operation. It had been found that the identification of a log at both ends to record the top diameter often was not possible in piles of small logs. Both ends of the logs in the piles are tallied by their diameter but not recorded as either a top or a butt diameter. Short logs are tallied only from one end of the pile, the total cross-sectional areas at one end are assumed to be equal to the total cross-sectional areas at the other end. The volume of the short logs is then computed by totaling the cross-sectional areas and multiplying by the length. In scaling long logs, both ends of the logs in the piles are scaled, but the logs are tallied by using half their length. The volume for the long logs is then computed by summing the total cross-sectional areas at both ends and multiplying by half the lengths. Alexander (7) in reviewing the work of the Quebec Forest Service made the following observation which adds to what Henri Roy has written. "An investigation by the Quebec Society of Forest

Engineers in cooperation with the industry indicated that Smalian's formula applied to twelve foot camp run logs gave aggregate positive errors up to seven per cent. However, much of the pulp material is now being cut in four foot and eight foot lengths which will reduce the error."

Alexander (7) has also summarized the investigations of the B. C. Forest Service. "The aggregate deviation in cubic volume of a spruce stand in the Interior was +2.0 per cent for Smalian's formula and -2.6 per cent for Huber's formula. A check on 20 butt logs showed that Smalian's formula was 6.1 per cent high and Huber's 3.1 per cent low. The error in either formula is not great for entire trees on account of the relatively small amount of butt flare and either formula might be used except for butt logs, when Huber's formula is superior."

Source of Data

The measurements upon which this paper is based were taken by the author during September of 1946 on the Mendocino National Forest in Northern California. Eighteen Ponderosa Pine trees were measured, these trees being down trees along a logging road right-of-way. A diameter tape was used to determine diameter and length of logs. Diameter and bark thickness were recorded at 1.5 feet above the base of the tree, breast height, and at sections of 8.15 feet measured from the 1.5 foot point to a point where the diameter inside bark was less than six inches. From that point the distance to the top of the tree was measured.

Analysis of Computed Volumes

The 18 trees yielded 19 thirty-two foot logs and the volume of each log was computed by the five rules to be tested. The total errors were based on the difference between the total volume of the logs by the Newton formula and the total volume by each of the other four rules. Table I in the appendix gives the total volume for each rule, the total errors for each rule, and the error for each rule in per cent. Table II gives the volume in cubic feet and the error in cubic feet for each individual log by each of the rules tested.

As the trees were measured in 8.15 foot sections, it was possible to compute the volume of the logs by the Newton formula using both sixteen and thirty-two foot sections. As the Newton volumes were used as a standard with which to compare the volumes computed by the other rules, it was desirable to see how much accuracy was lost by using thirty-two foot logs instead of sixteen. The error proved to be negligible amounting to + 5.998 cubic feet. Expressed on a percentage basis, using the volumes computed for sixteen foot logs as the base, the error amounted to + 1.5 per cent.

The total error was -4.5 per cent in scaling by Huber's formula. As practically all the trees measured were small they yielded only one thirty-two foot log. In other words almost every log was a butt log. This accounts for as large an error as did occur, as more volume is present in butt logs than the Huber formula would indicate, as only the middle diameter is used.

The error by the Smalian formula was +9.1 per cent or approximately twice as great and in the opposite direction as that of the Huber formula. Again the fact that each log was a butt log accounts for the size of the error to some extent. As the two end areas are averaged, it is evident from this data, at least, that for butt logs the Smalian formula overestimates the volume by a considerable amount.

The error by Rapraeger's formula was a -11. per cent. This shows that Rapraeger's taper allowance of one inch in eight feet is not enough in scaling Ponderosa Pine trees of this size class. The error by the Sorensen rule was a -18.7 per cent which shows that a taper of one inch in ten feet is even more inadequate. The trees that were measured had been growing on an area of poor to medium site. It is possible that on a good site the taper that these two rules allow would have been more nearly correct and the error would not have been so great.

A Suggested Method of Scaling

Probably the best results would be obtained by determining actual average taper on an area that is to be cut and then scaled. Only the top diameter of each log would need to be taken, and the average taper would be applied to obtain the middle diameter. The Huber formula could then be used to obtain the volume of the log.

With this in mind the average taper for the nineteen logs measured was determined by totaling the taper for all logs and dividing by 32. This taper proved to be 5.44 for each thirty-two foot log. Dividing by 32 gave 0.17 as the taper per foot and multiplying by 16 gave 2.72 as the taper in inches for a sixteen foot section. This was rounded off to 2.7 inches for ease in computation. The volume of the logs was then obtained by applying the above taper allowance and then using the Huber formula. The error using this taper allowance was +1.2 per cent.

This error would undoubtedly be greater when applied to logs other than those from which the taper was determined, but it still would give greater accuracy than either the Rapraeger or Sorensen rules when applied to the same group of logs.

It is doubtful if this method would ever be adopted on a large scale,however, as the seller and the buyer would have to agree on the taper to be used and there would be the time involved in making taper studies on individual areas.

Conclusions

Of the rules tested the Huber and Smalian gave the best results on Ponderosa Pine logs, which bears out conclusions other authors have drawn for other species. The Rapraeger and Sorensen rules show relatively large errors and should not be used unless it has already been determined that the taper for the logs to be scaled is approximately equal to that allowed in either the Rapraeger or Sorensen rules. Though the errors which occurred in this study are of some value, they should not be used as an indication of the errors that might result in trees other than those of the species and size class that were studied.

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APPENDIX

TABLE I

Total Volumes in Cubic Feet and
Total Errors in Cubic Feet and Per Cent

	Total Volumes (Cu. Ft.)	Total Errors (Cu. Ft.)	Per Cent Error	Total Volume Using 16' Logs
Newton	383.640	+5.998	+1.5	377.642
Huber	366.206	-17.434	-4.5	
Smalian	418.489	+34.849	+9.1	
Rapraeger	341.494	-42.052	-11.0	
Sorensen	311.708	-71.932	-18.7	
Average Taper 2.7"-16'	388.158	+4.518	+ 1.2	

TABLE II

Individual Log Volumes and Errors in Cubic Feet

Log No.	Newton Vol. 16' Logs	Error	Newton Vol. 32' Logs	Huber Vol.	Error	Smalian Vol.	Error	Rapraeger Vol.	Error	Sorensen Vol.	Error	2.7"-16' Vol.	Error
1	35.785	-.431	35.354	34.207	-1.147	37.640	+ 2.286	28.150	- 7.204	26.564	-8.790	31.338	-4.016
2	14.233	+.580	14.813	14.453	-.360	15.530	+ .717	15.421	+ .608	14.292	-.521	17.804	+2.991
3	11.565	+.219	11.784	10.892	-.892	13.565	+1.781	12.315	+ .531	11.323	-.461	14.453	+2.669
4	15.344	+.315	15.659	14.453	-1.206	18.068	+2.409	15.095	-.564	13.979	-1.680	17.453	+1.794
5	9.778	+.456	10.234	8.798	-1.436	13.104	+2.870	10.081	-.153	9.200	-1.034	12.023	+1.789
6	18.497	+.493	18.980	17.453	-1.537	22.061	+3.071	18.877	-.113	17.609	-1.381	21.504	+2.514
7	24.538	-.276	24.262	23.891	-.371	24.989	+.727	24.301	+.039	22.840	-1.422	27.270	+3.008
8	9.693	+.325	10.018	8.798	-1.220	12.456	+2.438	10.348	+.330	9.454	-.564	12.315	+2.297
9	21.000	-1.293	19.707	19.610	-.097	19.898	+.191	10.892	-8.815	9.970	-9.737	12.908	-6.799
10	47.829	+.633	48.462	48.093	-.369	49.190	+.728	47.515	-.947	44.407	-4.055	51.632	+3.170
11	18.129	+1.599	19.728	19.610	-.118	19.961	+.233	6.927	-12.801	6.227	-13.501	8.552	-11.176
12	36.718	+.794	37.512	34.207	-3.305	44.115	+6.603	32.757	-4.755	31.034	-6.478	36.190	-1.322
13	10.202	-.412	9.790	9.557	-.233	10.255	+.465	9.557	-.233	8.704	-1.086	11.451	+1.661
14	22.317	+.580	22.897	21.504	-1.393	25.678	+2.781	19.242	-3.655	17.960	-4.937	21.893	-1.004
15	12.938	+.805	13.743	12.908	-.835	15.409	+1.666	12.023	-1.720	11.046	-2.697	14.138	+.395
16	11.106	+.094	11.200	10.618	-.582	12.360	+1.160	8.552	-2.648	7.755	-3.445	10.348	-.852
17	32.021	+.570	32.591	31.338	-1.253	35.089	+2.498	30.410	-2.181	22.490	-10.101	33.237	+.646
18	13.536	+.379	13.915	12.908	-1.007	15.926	+2.011	16.421	+2.506	15.250	+1.335	18.877	+4.962
19	12.413	+.568	12.981	12.908	- .073	13.195	+ .214	12.610	-.371	11.604	-1.377	14.772	+1.791