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Challenges in Converting Among Log Scaling Methods

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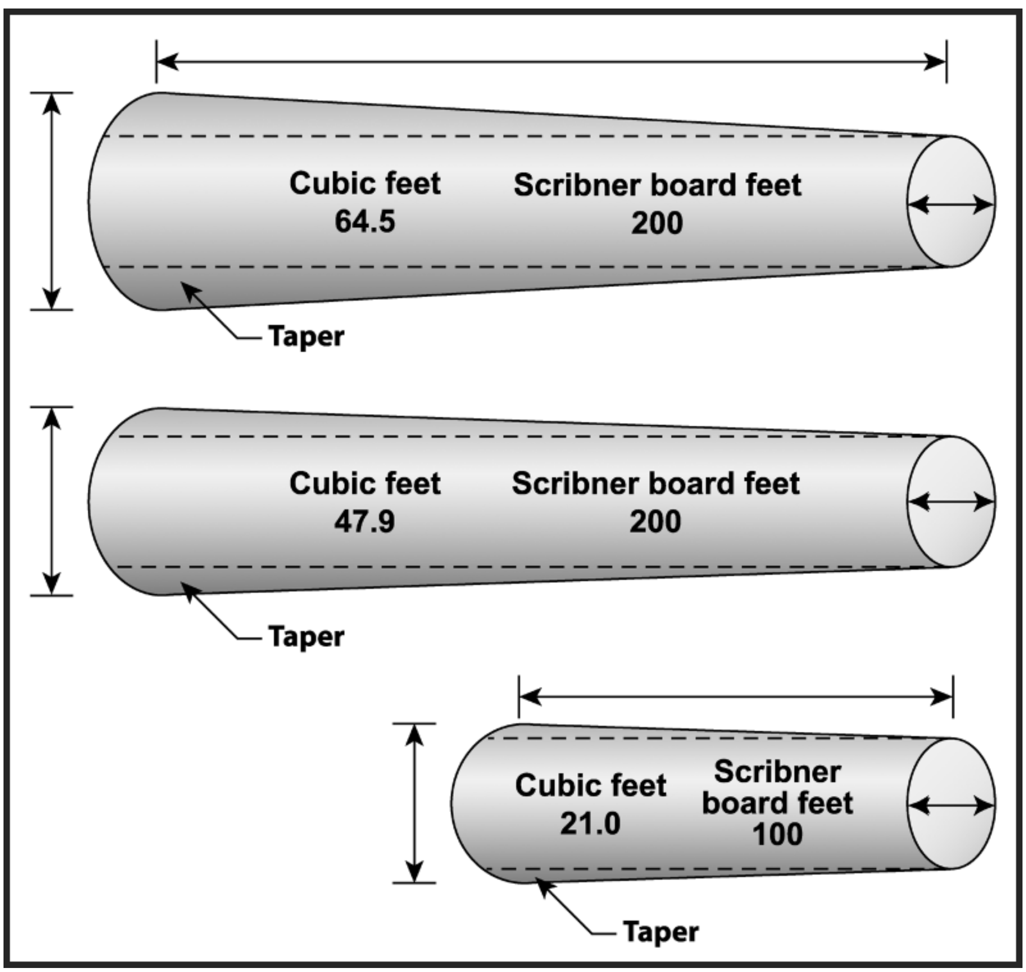

Abstract

The traditional method of measuring log volume in North America is the board foot log scale, which uses simple assumptions about how much of a log's volume is recoverable. This underestimates the true recovery potential and leads to difficulties in comparing volumes measured with the traditional board foot system and those measured with the cubic scaling systems used in most of the world. The relationships among these different scaling systems vary systematically with log diameter, as well as length, taper, defects, and measurement and utilization conventions. As average log size has declined in North America due to the replacement of virgin wood by plantation-grown timber, the discrepancies have become larger. This article deals with the factors that affect the translation of traditional board foot log volumes to cubic volume and weight equivalents.

Keywords: log rules, conversion factors, board feet, cubic volume

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Challenges in Converting Among Log Scaling Methods

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Background

Accurately measuring logs for their potential yield of salable products has challenged generations of foresters. Logs are irregular, roughly round, conically tapered objects from which mostly standardized rectangular lumber products are made. Yet sizing up infinitely variable logs for their lumber yield is necessary to estimate their fair value. Over the years, many rules have been developed, but the large number is testimony to their failure to give adequate results (Rapraeger 1950).

Log scales created in 19th century North America reflected the prevailing conditions of the time. Logs tended to come from virgin, old growth trees of large girth, and residues obtained in the course of milling them for lumber had little value. Thus, the main goal of scaling was to assess logs for their lumber potential. Of the many scales developed, the Scribner rule remains the most widely used. This is based on the number of 1-in.- (25.4-mm-) thick boards, spaced 1/4 in. (6.4 mm) apart, that can fit into a circle defined by the diameter of a log's small end. By summing the widths of the individual boards, dividing by 12, and multiplying by the log length, an estimate of the board foot yield from within the log's scaling cylinder is obtained. It is immediately apparent, however, that since logs are tapered, the approach overlooks volumes outside of the scaling cylinder. Thus, the longer a log is, the greater the amount of full width though shorter lumber that is unaccounted for. For a given taper, the omission becomes proportionately larger as diameter declines (Matson 1947).

These shortcomings posed relatively few practical problems while the resource was predominantly large and diameters were in a range where the systematic bias in the scale was relatively constant. But in recent decades, the log supply in the United States has been changing as old growth forests have been gradually cut over or placed in reserves. At the same time, the residues that once were considered waste to be disposed of in wigwam burners or left in the woods acquired value as furnish for pulp and boards. Thus, accounting for the full value of logs meant imputing the value of the missing volumes into the fraction of the log that the rule was designed to calculate, which itself was shrinking due to smaller logs.

Methods of determining log volume have also been changing. Log measurement and grading used to be done in the woods where they were felled. But this is costly and impractical to do on small logs of relatively low quality. Consequently, the U.S. industry has been increasingly conducting commerce of such logs by weighing them at the mill and converting weights to cords, board feet, or cubic volume using factors derived from small-scale samples. Likewise, the USDA Forest Service has transitioned to cubic scaling but, bowing to tradition, continues to report volumes and values in board feet using rule of thumb conversion factors. Proper conversions, however, depend on log characteristics such as diameter, length, taper, and defects. Consequently, conversion factors are a moving target, varying as log characteristics change.

Although using conversion factors to estimate cubic volume can be an adequate approach if both buyers and sellers know log characteristics, the use of general conversion factors for comparing log production, prices, and trade among regions where log characteristics are not uniform is fraught with the possibility of error. It is timely then to review conversions to cubic and weight measurements, with particular focus on published conversion factors that are often applied in policy, trade, and academic studies.

Board Foot to Cubic Volume Relationships

Calculated relationships between board foot and cubic scales can be derived from values found in scaling handbooks (for example, Northwest Log Rules Advisory Group 1982). For board feet, volumes from the Scribner log rule are most widely used in the United States. In practice, volumes are often expressed in units rounded to the nearest ten (Decimal C), which lead to the notable stepwise changes in volumes that are especially significant at diameters of less than about 12 in. (0.3 m). The Scribner rule comes in two variations, the westside rule practiced in the coastal regions of the Pacific Northwest and the eastside rule applied in the rest of the country. There are also differences among published versions of the rule (for example, Northwest Log Rules Advisory Group (1982) and Forest Service (1973) show different values for some logs).

For cubic volumes, Smalian's formula is most common. It is the official rule of the USDA Forest Service as well as in Canada, although the manner in which log measurements are recorded in applying it vary in different regions and for different users. Volumes are determined using diameter measurements taken at both ends of a log. Thus, in contrast with most board foot rules, the effect of taper on volume is accounted for.

Effect of Changing Length at Three Diameters

Figure 1 illustrates the effect of changing log length on the conversion factor of cubic meters to board feet. Three log diameters are shown. The number of cubic meters (Smalian's formula) per thousand board feet (Scribner's formula) generally increases with increasing log length. This tendency is periodically interrupted due to the relatively large discontinuous jumps in the Scribner system. On average, conversion factors are highest for small diameters. Thus, a log mix dominated by small-diameter, long logs will have higher factors than a mix of large-diameter, short pieces.

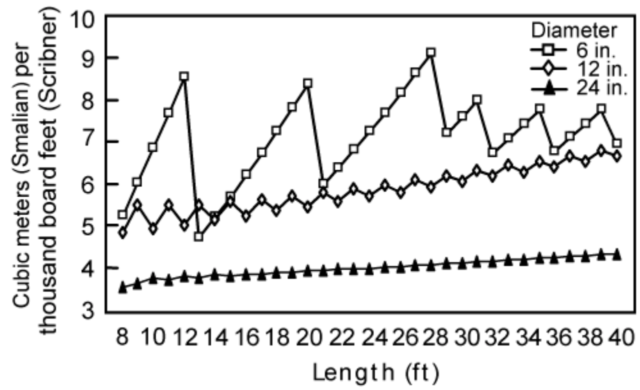

Figure 1—Effect of changing log length at three log diameters on cubic volume to board foot conversion (no defects, no trim, taper 0.125 in/ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

Effect of Changing Diameter at Three Lengths

Figure 2 isolates the effect of changing log diameter on the conversion factor. Three log lengths are shown. The number of cubic meters per thousand board feet generally decreases with increasing diameter. Some exceptions occur at small diameters due to the uneven increases in board foot volumes. Compared with the effect of length in Figure 1, it is apparent that diameter is generally more influential on the conversion factor.

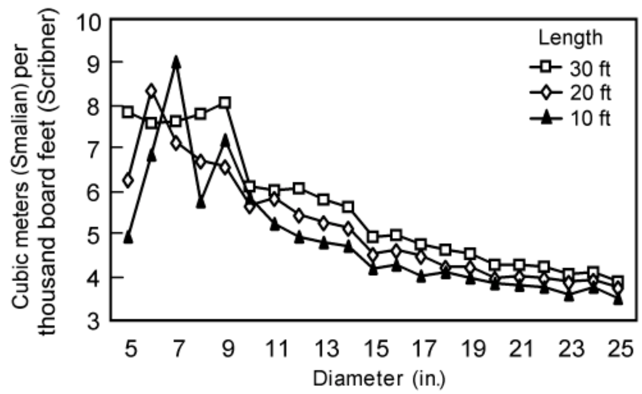

Figure 2—Effect of changing log diameter at three log lengths on cubic volume to board foot conversion (no defects, no trim, taper 0.125 in/ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

Effect of Taper

Figure 3 illustrates the effect of different tapers on the conversion factor with increasing log diameter. The effect of taper is relatively small and consistent, always increasing the conversion factor with increasing tapers. At smaller diameters, however, its influence is magnified and can become quite significant.

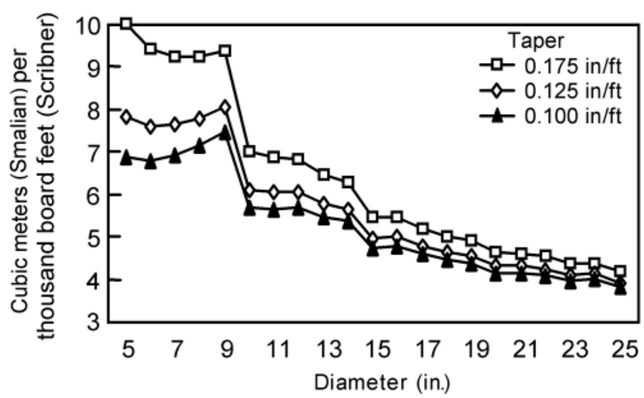

Figure 3—Effect of log diameter and taper on cubic volume to board foot conversion (no defects, no trim, length 30 ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

Effect of Measurement Conventions

When board foot to cubic volume conversions are made, it is often assumed that the diameter and length measurements are identical. Although the Forest Service's version of the cubic scale follows Scribner measurement conventions for diameter and length, in other jurisdictions, practices differ. In Canada, diameter measurements are rounded up or down, which is in contrast to the Pacific Coast region where Scribner scaling diameters are truncated. Consequently, the same logs measured by the two systems are, on average, recorded as being about 1/2 in. (12.7 mm) smaller under the long-log Scribner rule. Likewise, when logs are measured for length in Canadian cubic scaling, the entire length is recorded, inclusive of trim, as well as along the contour for crooked

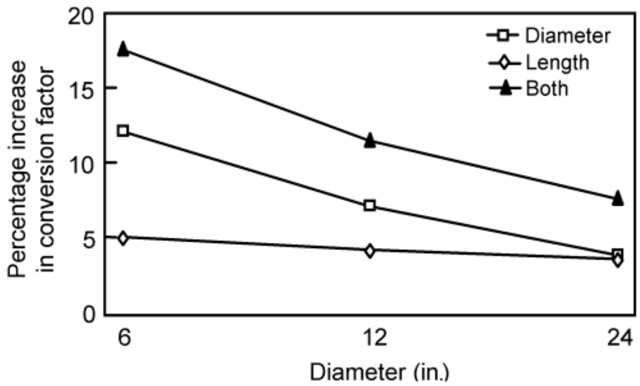

Figure 4—Effect of ½-in. diameter and 1-ft length differences on cubic volume to board foot conversion (no defects, no trim, length 32 ft, taper 0.125 in/ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

logs. In Scribner, trim allowances are excluded and length is measured in a straight line from end to end. These differences extend cubic scale lengths for the same log by an average of about a foot, depending on log length. Figure 4 illustrates the effect of 1/2-in. (12.7-mm) width and 1-ft (0.3-m) length differences (for 32-ft (9.75-m) logs) on conversion factors for three diameters. Thus, if the average log is 12 in. (0.3 m) in scaling diameter when scaled in Scribner and a conversion factor based on tabulated values of 6.2 m^3 per thousand board feet is used to convert it to cubic volume, then that factor would understate a cubic-based conversion of 6.9 m^3 per thousand board feet by about 10% if measurement conventions differ by the above amounts.

Effect of Defect Deduction Conventions

Defects can be classified as sound (shake, ring splits, checks, excessive knots, crook, break, butt flare) and unsound (rot, decay, scar). While sound defects affect lumber yields, they tend not to hurt fiber utility for pulping. Accordingly, cubic rules often allow fewer deductions for sound wood defects. Such differences affect volume conversion ratios. Forest Service studies conducted on the basis of then proposed cubic scaling practices in the early 1980s increased gross to net conversion factors ratios from less than 1% at small diameters to more than 10% for large-diameter logs where defects are more prevalent (Cahill 1984). Different jurisdictions treat defects differently and therefore when comparisons are made, conversions should be based on net rather than gross volume measurements.

Effect of Utilization Standards on Log Valuations

A factor further confounding comparisons is differences in utilization standards. In most of the United States, a live tree is scaled for sawlog valuation purposes down to a minimum diameter of 5 or 6 in. (127 to 152 mm). The remaining portion is available free or at a lower pulpwood rate. In Canada, the minimum scalable volume is around 4 in. (102 mm). (Minimum scaling diameters for valuation are 4.33, 3.94, 3.94, and 3.5 in. (110, 100, 100, and 89 mm) for Alberta, British Columbia, Ontario, and Quebec, respectively.) Thus, even if all the proper resource characteristics were taken into account in converting from board feet to cubic volume, the resulting volume would still not be equivalent to Canadian jurisdictions because the latter contain a different mix of wood sizes. In cases where differences on the above scale exist, conversion factors can be boosted by 2% to 4% because of the missing volumes.

Board Foot and Cord to Weight Relationships

Many of the same factors that affect board foot to cubic volume relationships also influence volume to weight equivalents. One can observe this by converting log volumes to weights using fundamental wood property data on specific gravity, moisture content, sapwood to heartwood ratios, and bark volumes. The data used here are for Southern Pine.

The juvenile wood core of a log was set as a cylinder with diameter of 4 in. (102 mm) and a specific gravity of 0.39. The rest of the log was defined as mature wood with a specific gravity of 0.59 (Zobel and others 1972). Log specific gravity is therefore the average of these values weighted by the respective volume shares.

An outer ring 5 in. (127 mm) wide, running the length of a log, was set as the sapwood portion with a moisture content ratio of 2.1 (that is, 110% of the dried weight of the wood). The rest of the log was set as the heartwood with a moisture content ratio of 1.32 (Forest Products Laboratory 1999). The moisture content ratio of a log is therefore the average of these values weighted by the respective shares of their volumes.

The green weight of the bark was calculated from an empirical equation derived by Guttenberg and others (1960).

The weight of a log is therefore its volume times its specific gravity, times the weight of water, times the moisture content ratio, plus the weight of the bark.

Figure 5 illustrates the relationship between weight and Scribner board feet with increasing log diameter using three log lengths. The relationships mimic those between board feet and cubic volume due to the close correlation between weight and volume. The range per thousand board feet varies from more than 20,000 lb (10 tons) per thousand board feet for small diameters to less than 10,000 lb (5 tons) per thousand board feet for large diameters. In the 7- to 13-in. (179- to 330-mm) range, which includes most contemporary Southern Pine sawlogs, the average weight is about 15,000 lb (7.5 tons) per thousand board feet.

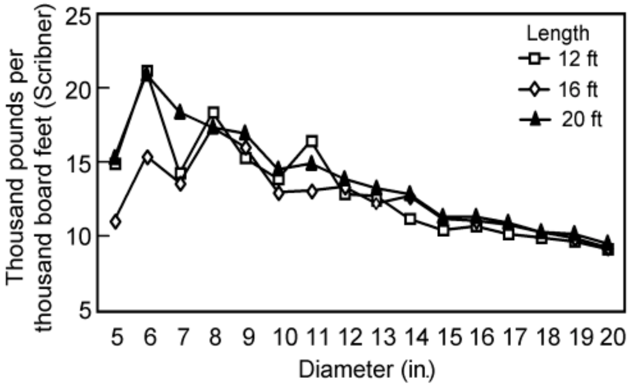

Figure 5—Effect of log diameter and length on weight to board foot conversion (no defects, taper 0.125 in/ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

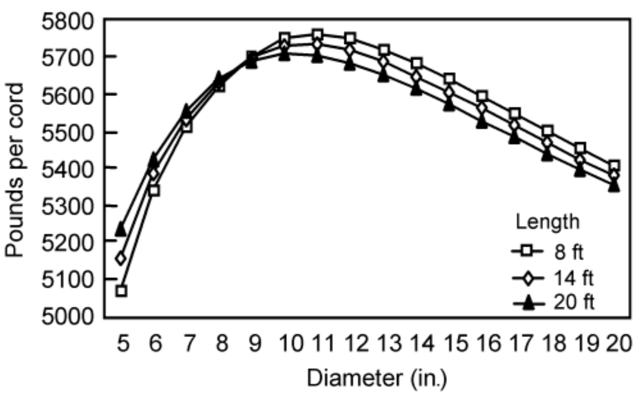

Figure 6—Effect of log diameter and length on weight to cord conversion (no defects, no trim, taper 0.125 in/ft). (1 in. = 25.4 mm; 1 ft = 0.3048 m)

Figure 6 illustrates the relationship between weight and cords (using 76 ft^3 (2.15 m^3) of solid wood per cord) as diameter increases. The conversion factor ranges from 5,800 lb (2.9 tons) per cord for medium diameters to less than 5,200 lb (2.6 tons) per cord for small diameters, where most pulpwood is found. The initial increase is due to the rising proportion of high-density mature wood. Then, the increasing proportion of drier heartwood causes a decline in the conversion factor.

Diameter, length, and taper also affect the packing of a cord, which means that the 76 ft^3 (2.15 m^3) per cord used here is itself variable. The smaller, longer, and more tapered the logs are, the lower the solid wood content of a standard cord is. Weight scaling also needs to factor in seasonality, especially for smaller, younger trees with a high proportion of sapwood. Not only does sapwood have a much higher moisture content than heartwood, but also, the percentage of moisture fluctuates with the seasons (Besley 1967).

Widely Used General Conversion Factors

For trade reporting, policy assessments, or general statistical presentations, various organizations need to convert U.S. measurements to metric or weight equivalents. Table 1 compares some of the theoretical conversion factors derived here with published empirical and rule of thumb conversion factors.

The first row in Table 1 contains a standard conversion factor found in many sources and applied widely to volumes traded internationally. This factor is traced to a committee of experts organized by the United Nations Food and Agriculture Organization (FAO) after World War II to harmonize reporting of international trade data. They determined that 4.53 m^3 per thousand board feet was a fairly representative factor for the size of saw and veneer logs typical for that time. This has been used ever since to translate board feet log volumes to cubic meters (Canadian Forest Service 1996, Howard 2001) even though log sizes have changed in North America. Ideally, this outdated factor should be modified periodically to reflect changes in the resource, but no formal inquiry has been made and FAO continues to use this number.

Another source for conversion factors is Random Lengths Publications (Eugene, OR), publishers of widely read market reports. Besides making general use of the standard factor in their reporting, they have also circulated a set of factors for converting various diameters of nominal 32-ft (9.75-m) logs (unpublished data by D. Bartel). These estimates are lower than gross factors derived from tabulated values and for gross and net empirical factors estimated from field measurements, especially at the low end of the diameter range.

A focal reference for forest products conversion factors is the work of Binek (1973). The factors for logs in this source have been the cause of confusion because the author attempted to replicate in cubic volume the intent of the board foot rules, which defined log volumes solely in terms of the central cylinder. However, he did not explicitly state this, and over the years, his factors have gained wide circulation (USDA 1990, Northeastern Loggers Association 2000, Smith and others 2001). These factors significantly understate both tabulated and field-based conversion factors where volumes include log taper.

Conversion factors derived from tabulated values make no allowance for different defect accounting conventions. Deductions for defects are often more lenient in cubic volume than in board foot scaling as evidenced by two sets of empirical equations, one gross and the other net (defects deducted), derived from a population of dual-scaled logs (Cahill 1984). The equations based on net volumes relating conversion factors to log scaling diameter provide one basis for calculating contemporary conversion factors if the

Table 1—Theoretical and empirical board foot to cubic volume conversion factors compared with some published estimates

	Conversion factor (m^3/thousand board feet)				
	Theoretical gross[a]	Empirical gross[b]	Empirical net[c]	Random lengths data[d]	Binek (1973)
Scribner					
Standard				4.53	4.53
Log diameter					
8 in.	7.34	8.30	8.44		
12 in.	6.18	6.27	6.51	5.6	
16 in.	5.07	5.24	5.51	4.7	
20 in.	4.31	4.70	4.99	4.3	
24 in.	4.15	4.39	4.70	4.1	
15 in.	4.42[e]	4.66[f]	4.99[f]		3.90[g]
International ¼ in.					
Log diameter					
15 in.	3.87[e]				3.48[g]

[a]No defects or allowance for trim, average taper 0.125 in/ft, log length 32 ft.
[b]Cahill (1984); based on westside Scribner rule with log lengths up to 40 ft, no defects.
[c]Cahill (1984); same as empirical gross except allowances taken for defects.
[d]Unpublished data (obtainable from the author); log length 33 ft, taper 0.125 in/ft.
[e]Same as theoretical gross but based on log length 16 ft.
[f]Based on eastside Scribner rule with log lengths up to 20 ft.
[g]Based on log length 16 ft and no taper.

average diameter of current logs can be determined. More universal formulas that incorporate length, taper, and defects as additional variables would improve accuracy, because different species, ages, and growing conditions result in variable conversion factors.

Table 2 contains some typical published board foot and cord to weight conversion factors compared with those derived-here for specific diameters (for Southern Pine). Calculated weight conversion factors (column 1) decline with increasing log size because of less moisture in older, bigger trees. This trend is reflected in field measurements showing a similar decline from smaller second growth to larger old growth trees (Lang 1962).

Contemporary Conversion Factors

With changes in U.S. timber resource from old growth to second growth and plantation-grown timber, the traditional standard conversion factor from board feet to cubic volume is outdated. Moreover, because of differences in regional scaling practices and timber sizes, a national conversion factor is of no practical use. Regional conversion factors, where the same scales are employed and timber characteristics are more uniform, offer a more useful avenue to obtain at least rough approximations of contemporary board foot to cubic volume relationships.

One recent study derived conversion factors for Washington State for the period 1970 to 1998 (Spelter 2002). Average log diameters through time were estimated from data on log characteristics reported by sawmills. Substituting these diameters into Cahill's empirical equation, based on net log scales (Cahill 1984), allowed the derivation of conversion factors over time (Table 3). These indicated that the conversion factor increased, from around 4.7 in the 1970s to more than 6.7 (coast) and 5.9 (interior) by 1998.

Spelter (2002) can be validated by comparing the derived diameters with survey data (Larsen 2002). A direct comparison is not possible because the survey data were aggregated into broad size categories (Table 4), but a more general comparison can be made by calculating the highest and lowest possible values for the population using the extreme value of each cell. This shows that the derived estimates fell within the ranges and very close to the medians for both regions.

Table 2—Theoretical board foot and cord to weight conversion factors for Southern Pine compared with published estimates

	Theoretical gross[a]	University of Georgia (2002)	Williams and Hopkins (1969)[b]	Williams and Hopkins (1969)[c]	Williams and Hopkins (1969)[d]	Lang (1962)[e]	Lang (1962)[f]
			Pounds per thousand board feet				
Standard		15,000	15,500	14,900	14,700	15,210	12,110
Log diameter							
6 in.	15,490						
9 in.	16,510						
12 in.	13,930						
16 in.	11,550						
			Pounds per cord				
Standard		5,350	5,200	5,550	5,200		
Log diameter							
6 in.	5,400						
8 in.	5,630						
10 in.	5,720						
12 in.	5,710						

[a]No defects or allowance for trim, average taper 0.125 in/ft, length 16 ft (1 in. = 25.4 mm; 1 ft = 0.3048 m; 1 lb = 0.045 kg).
[b]Loblolly pine.
[c]Slash pine.
[d]Shortleaf pine.
[e]Second growth Southern Pine.
[f]Old growth Southern Pine.

Table 3—Estimated sawlog sizes and conversion factors for Spelter (2002)

	Diameter[a] (in.)		Conversion factor[b] (m^3/thousand board feet)	
Year	Coast	Interior	Coast	Interior
1970	22.1	16.2	4.81	4.84
1972	22.6	18.1	4.78	4.64
1974	21.8	18.0	4.83	4.66
1976	21.5	17.3	4.86	4.73
1978	20.2	17.8	4.97	4.67
1980	21.2	16.9	4.88	4.77
1982	18.1	15.3	5.20	4.96
1984	17.8	15.9	5.23	4.88
1986	17.9	16.0	5.22	4.86
1988	17.6	16.0	5.26	4.87
1990	15.6	12.6	5.58	5.35
1992	14.2	13.2	5.87	5.25
1996	11.8	11.1	6.60	6.64
1998	11.4	10.0	6.74	5.93

[a]See Spelter (2002) for derivation of log diameters (1 in. = 25.4 mm).
[b]Conversion factors obtained by inserting diameters into net-based formulas derived by Cahill (1984).

Discussion and Recommendations

The change in size characteristics of the U.S. timber supply in recent decades has magnified the inadequacies of traditional log scaling systems for the purpose of comparing production, prices, and trade among regions and countries. Even when trees were bigger, scaling and measurement inconsistencies existed. A previous generation of foresters recognized this and advocated a change to less variable cubic volume scaling (Rapraeger 1950, Orchard 1953). That need remains and is greater than ever in an environment of declining log sizes where, due to the eccentricities of U.S. board foot scales, conversion factors are especially sensitive even to small changes in timber size. Traditional factors, developed in another era characterized by large logs, are inaccurate for today's smaller diameter trees.

Cubic volume scaling based on the metric system is almost universally practiced in forestry. In the United States, the metric system was officially introduced in 1964, but many sectors, like logging, continue to use traditional measures. This leaves the United States, along with Liberia and Myanmar at last count, as the lone holdouts in a metric world.

Table 4—Sawlog distribution by diameter class from Larsen (2002)

	Sawlogs (million board feet)				Sawlog diameter (in.)[a]		
	<5 in.	5 to 10 in.	11 to 20 in.	>20 in.	High	Low	Median
Coastal	124	909	812	137	14.1	8.4	11.2
Interior	22	200	173	39	13.7	6.9	10.3

[a]High and low values were made by taking the extreme value of each cell, converting board feet to cubic volume using the conversion factor for that diameter, and weighting the diameter values by those volumes (1 in. = 25.4 mm).

This leads to confusion and misunderstandings, and in an increasingly globalized economy, it saddles the United States with a self-inflicted disadvantage.

A logical solution would be to convert wholly to cubic volume and weight scaling systems. Although these have become established to varying degrees in U.S. forestry, residual use of the board foot scale continues. Thus, to know where U.S. log prices are in relation to world markets, accurate conversion factors to translate logs scaled in board feet into cubic volume or weight measures are still needed.

In any attempt at conversions, factors should first be tailored to the board foot rule involved, of which four are still used in the United States. Ideally, log scale data on diameter, length, taper, and defects should be the basis for conversions, but on a region-wide scale, such data are seldom reported nor easily obtained. In the absence of population-wide data, sampling should be used to narrow the likely range of these variables, the most important of which is log diameter. Then, if the purpose of the exercise is comparative evaluation, further adjustments should be made for differences in measurement conventions and utilization standards in the regions being compared. Ultimately, one has to recognize that wide variances exist in the scaling methods and practices of the regions of North America, which can easily lead to confusion and misconceptions. Thus, a need exists in forestry to harmonize these practices in the interests of log market transparency.

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