Hardwood Log Grading in the United States—Part 1: A Historical Perspective

Curt C. Hassler
Shawn T. Grushecky
Lawrence E. Osborn
Joseph F. McNeel

Abstract

The ability to efficiently and consistently characterize the quality of hardwood sawlogs is an indispensable part of operating a hardwood sawmill. And it is equally important for buyers and sellers of hardwood logs to negotiate prices on a uniform basis of both scale and grade. While scaling of logs is relatively straightforward, assuming buyer and seller agree on a specific log rule to use (e.g., Doyle, Scriber, International), grading logs for the purposes of evaluating quality is more complex.

Hardwood log grading is an essential component of any hardwood sawmill's operation and effectively sets the stage for profit or loss. Various efforts have been made to develop a standardized log grading system by both the forest products industry and the US Department of Agriculture Forest Service (USDAFS) since the beginning of the 20th century. However, even after over a century of effort, there is still no broadly accepted standard for grading hardwood logs.

The purpose of this article is to document the historical evolution of hardwood log grading systems. Understanding the development of hardwood log grading systems over time can help to produce a better log grading standard in the future.

The first formal efforts to establish standard hardwood log grades occurred early in the 20th century. In the 1930s and 1940s, the initial development efforts in log grading were undertaken through an intense effort to collect and analyze empirical data. Over the next three decades, hardwood log grading standards were further refined and finalized by the US Department of Agriculture Forest Service (USDAFS). Based on empirical analyses of individual hardwood logs and the lumber produced from those logs, the USDAFS developed and refined a hardwood log grading system that defined log grade based on the prediction of clear lumber yield. A limited number of competing hardwood log grading systems surfaced during this period but did not survive the USDAFS system. With the final refinements of the USDAFS log grading system in 1966, little additional documented development has occurred.

Beyond internal use of the system by the USDAFS, the system has seen widespread use by the research community as a means of classifying hardwood logs for analysis purposes. However, there is little documented evidence that the USDAFS log grades have been widely adopted or used by the hardwood industry to any significant degree. Reasons for this nonadoption by industry range from issues with ease/difficulty of use, to individual log grades covering wide ranges of log characteristics/quality, to overlapping grades for a given set of log attributes, among others. In contrast, while mills recognize the need for pricing based on log grades, most mills use proprietary grades that do not compare with the developed USDAFS grades.

One of the key components of profitability when operating a hardwood sawmill is purchasing raw materials

The authors are, respectively, Visiting Research Scientist, Appalachian Hardwood Center (chasslerwv@gmail.com), Assistant Professor, Energy and Land Manag. (shawn.grushecky@mail.wvu.edu), Research Associate, Appalachian Hardwood Center (losborn2@wvu.edu), and Professor and Director, Appalachian Hardwood Center (jmcneel@wvu.edu [corresponding author]), Div. of Forestry and Natural Resources, West Virginia Univ., Morgantown. The work upon which this publication is based was funded in whole or in part through a grant awarded by the Northeastern Area State and Private Forestry, USDA Forest Serv. This article was received for publication in May 2018. Article no. 18-00023.

Forest Prod. J. 69(2):110–123.
doi:10.13073/FPJ-D-18-00023

(logs) at an appropriate price. Since both the raw material and resulting lumber are considered commodities, price pressures on the inputs and outputs are intense. The cost of the inputs is often cited as the barrier to increased profits by this industry sector because that is the largest contributing cost to operating the mill. Raw material for softwood lumber can be >70 percent of the total cost of production (Fonseca 2005). In a 2010 survey of production costs for Appalachian hardwood sawmills, the cost of logs sawn represented 52.1 percent of total production costs (Hassler 2010).

Historical Background

Early efforts to create a log grading system

During the early decades of the 20th century, hardwood log grading began receiving increased attention. One of the earliest references was in 1913 (Bryant 1913). Six log grades were developed by the Nashville (Tennessee) Lumbermen's Association based on diameter and defect characteristics. Defects were specified mainly as knots and had quantity and size limits for each grade. For example, the rules specified that ''No. 3 logs shall be 24 to 26 inches in diameter inclusive, fresh cut, green, straight and free from knots, windshakes and other defects, except that this grade may take logs 27 inches and up in diameter with one to three small solid knots not exceeding 3 inches in diameter'' (Bryant 1913, p. 525). A log that was downgraded from a higher class because of knots but was of sufficient diameter could be placed in the next highest class as long as it had fewer than three solid knots smaller than 3 inches in diameter. Logs with larger defects, such as dote (early stage of decay) or rot, or showing effects of age had their scaling diameters reduced based on the situation that applied. Diameter cutoffs for the log grades varied for several species, and all crooked logs were specified as log grade No. 6.

In a USDAFS Forest Products Laboratory (FPL) review of hardwood log grading proposals, Wollin and Vaughan (1949a, p. 2) report that, in 1915, the Southern Log Association of Memphis, Tennessee developed a system for grading southern hardwood logs. Unfortunately, little or no information exists that describes this log grading system, other than it was among the first systems to incorporate the principle of limiting the size and frequency of defects.

Establishing defined log grades

In 1933, the FPL, in cooperation with the USDAFS Southern Forest Experiment Station, produced a report entitled *Lumber and Log Grades for Southern Hardwoods* authored by Garver and Miller (1933). Wollin and Vaughan (1959) note that Garver and Miller documented a method of grading logs based on the amount of clear area between defects, mirroring the basic principle underlying hardwood lumber grading, which was carried throughout the ensuing development of hardwood lumber grades by the USDAFS. In addition, the classification of logs into grades was based on No. 1 Common and better lumber yields.

Similar log grades were then introduced to the northern hardwood region in 1938 (White 1938). In this effort, White classified the quality of standing timber in the Lake States. Three log grades were developed, each distinguished mainly by diameter and total number of defects. Likewise, logs of particular grades needed to saw out a certain percentage of grade lumber. For instance, White determined that logs meeting a Grade 1 specification needed to saw out at least 60 percent Common and better lumber. Two years after this article, Bromley (1941) used similar methods to show how these grades could be used to appraise timber in the northern hardwood region.

As thinking progressed about hardwood log grading, Benson and Wollin (1938) developed a working plan for a new system of grading hardwood logs, arguing that log grades should not be determined in advance of mill studies. That is, log grades should be developed based on grouping of the lumber yield results. Log characteristics that were considered important centered on defects on the log faces, as well as diameter and species. This effort was justified at the time because of a perceived scarcity of ''good logs'' and the diversity of raw material suppliers (Benson 1941).

While log grading was practiced at this time, its acceptance in hardwood producing areas was not universal. Regional organizations developed log grade specifications; however, it was noted that only the buyer made use of some form of quality specification (Benson 1941). This practice is as true today as it was then—although standards exist, during the buying and selling of logs, log grading standards are as variable as those making the transactions. This makes intuitive sense because those making purchases are doing so based on the product markets they are accessing. This is one of the main contributing factors to the multitude of mill-specific grading decisions that were common then and now.

Following the development of the log grading proposal, Benson (1941) described the common practice of assessing log grades based on defects and what problems this created. Those logs with fewer defects are assessed higher grades than those that are ''surface clear.'' Benson further argued that this method was not appropriate because it did not correspond to how the resulting lumber was graded. The end users of hardwood lumber based their grades on the number of clear cuttings that resulted from the raw lumber. These pieces were then used as raw material in the secondary wood products industry. Benson asserted that log grades should follow the same clear-cutting approach used with lumber grades. He also postulated that a grading system needed to be simple enough that those who did not have the experience seeing logs ''open up'' could still assign grades in such a way that the highest specifications resulted in the highest quality lumber and those with the lowest grades resulted in the lower yields of quality lumber. To remove the subjectivity associated with identifying defects, Benson felt that the clear areas between defects should be the underlying basis for a log grading system—most could identify areas free of defects. Thus, the concept of standardized log grades based on clear cuttings was initiated.

Grading of Northern Hardwood Logs (Benson and Wollin 1941) became the first attempt by the USDAFS to develop a standardized system for grading hardwood logs, based on the resulting lumber grade yields. Approximately 7,000 logs representing 15 species were included in this work, and this number represented only logs that were sawn purely for lumber and none that produced industrial products in cant form. The field data were collected between 1938 and 1940 in both circular and band mills in New York, Michigan, Wisconsin, Massachusetts, Vermont, and New Hampshire. Mills were selected based on their size and production. An

effort was made to collect data at smaller, low-production mills so as to simplify the collection of field data.

Log defects were identified on each of the four log faces, and detailed sketches of the faces and corresponding defects were recorded. These logs were then followed through the production process, and the resulting lumber grades and yield information were recorded. Grade yields were recorded for each of the study logs, and this information was used to segregate the logs into quality classes. Quality segregations were then made based on the yield of No. 1 Common and better lumber. For example, all logs that yielded 60 percent No. 1 Common and better lumber were classified as No. 1 grade logs. Those that yielded less than 25 percent No. 1 Common or better lumber were classed as No. 3 grade logs. This relationship was not held constant across log sizes. Some logs that met minimum lumber grade-yield specifications were placed in different log grade classes based on scaling diameter, in order to recognize the influence of log size on log quality.

Once the quality classes were defined, grade specifications were developed using a clear-cutting approach. Log grades were chosen to follow existing lumber grade specifications as closely as possible. Benson and Wollin (1941) decided to mirror the lumber grades in an effort to simplify the grading process. Originally, all four log faces were used to distinguish grades; however, after field trials, the authors decided that narrowing the grading faces to three caused no appreciable loss in grading effectiveness. The authors' goal throughout development of the log grading system was to reduce the complexity so that it would be more easily applied in a production environment.

While the original delineation of log grades was developed based on a clear-cutting approach that followed standard lumber grades, other factors were then introduced to further segregate the developed log grades. These included defects, log diameter, and log length. Defect characteristics that were considered when developing guidelines included interior defects (shake and decay), sweep, mineral stain, dote, bird peck, tap holes, flutes, frost cracks, grub and worm holes, bumps, double pith forked top, gum streaks, encased metal, and knots (five types).

The majority of these defects impacted grading by reducing the number and size of clear cuttings on each of the graded faces. When present, each of these defects has its own impact on the resulting log grade. Although not defined in the report, it is assumed that the authors were using a method that estimated defect volume as a percentage of gross log volume similar to the methods published later by Grosenbaugh (1952). Mineral stain was recorded as a function of log diameter and allowable limits developed. The majority of the remaining defects either limited the grade of a log or the number of clear cuttings that could be obtained.

Log diameter and length impacted grades in a slightly different fashion. Minimum diameters and lengths were developed for each log grade and varied slightly among species. Diameter cutoffs were assigned primarily due to the authors' realization that larger logs from a given age class tended to yield higher levels of quality lumber. Likewise, even though shorter logs had the potential to yield high grade lumber, lumber grades imposed length restrictions, and thus logs had to be of a certain length to be considered.

Developing log grades was not a simple task in the early- to mid-20th century, before the advent of computing technology. Benson and Wollin (1941) delineated grades by calculating lumber yields for each of the logs studied. The logs were then grouped based on their yields of First and Seconds (FAS), Select, 1 Common, 2 Common, and 3 Common lumber. During the groupings, tentative restrictions on sweep, cull, diameter, and length were incorporated to further segregate the authors' log grades. This process required an immense amount of cutting and trying.

Throughout the development of the grades, the portions of the log grade specification developed based on lumber cuttings were held fairly constant. The authors felt that since the yield of quality lumber resulting from a log is the most important factor, lumber grade yields needed to be the basis of any grading mechanism. When changes in specification were needed, defect, diameter, and length restriction were the three parameters that were adjusted to help define final log grades. A simplified grading table was developed, as illustrated in Table 1, by Benson and Wollin (1941, p. 24) and became the basis for ultimately implementing USDAFS log grades. While this format could be used in most circumstances, the authors included instructions for specific species. These instructions included new diameter ranges for log grades of certain species.

The incorporation of mill studies into the development of log grades

Subsequent to this was the original work on central US hardwood species published by Wollin and Vaughan (1947). For this report the authors conducted 14 mill studies in Indiana, Missouri, Illinois, and Ohio. The majority of the mill studies were conducted at four mills—two circular and two band mills. During the studies, 2,886 logs were sampled representing 15 species, mainly white, black, and red oak (*Quercus alba, Quercus velutina, Quercus rubra*) as well as cottonwood (*Populus deltoides*). As with Benson and Wollin (1941), mills selected for study only cut grade lumber and not industrial products. The grading formulations were similar to the earlier work on northern hardwoods, with the major change being the minimum length of clear cuttings in the No. 1 grade.

In this 1947 paper (Wollin and Vaughan 1947, p. 2), the authors also discussed six factors, summarized below, that ultimately define what a log classification should be able to address:

1. Segregate logs into high-, medium-, and low-quality groups according to the grade yields and value of the lumber produced.
2. Complement standard methods for appraising and evaluating timber where large volumes are involved and errors associated with appraising individual logs average themselves out.
3. Be applicable to relatively small lots of logs where balancing errors associated with individual logs cannot be relied upon.
4. Classify logs based on similar lumber grade yields so that any one grade is made up of logs having a fixed range of quality with as little overlap among grades as possible.
5. Apply to all species that are covered by the lumber grading system that is used and reflect the characteristics of the individual species and their effect on grade yields.

Table 1.—Basic grade specifications for northern hardwood logs as developed by Benson and Wollin (1941).

Log grade	Log length (feet)	Log diameter (inches)	Deduction from gross scale: Cull permitted (%)	Deduction from gross scale: Sweep permitted (%)	Surface requirements on each of three faces of log
1	10+	12–15, logs under 15 must be butts	40	15	5/6 yield in cuttings not less than 7 feet long
		16+			5/6 yield in not more than two cuttings not less than 5 feet long
2	8 and 9	12+	50	30	3/4 yield in not more than two cuttings not less than 3 feet long
	10+	10+			Logs under 12 feet long, 2/3 yield in not more than two cuttings not less than 3 feet long; in logs 12 feet and over three cuttings permitted
3	8+	8+	33 1/3 sound	Not over 4 inches in logs up to 12 inches and 6 inches in logs over 12 inches	No restrictions
3A (ties)	8 1/2 or 17				

6. Make use of common terms and methods of measurement typical to the industry.

At each mill during the study, logs were diagrammed and photos were taken of all sides and each end. They were then followed through the sawing process, and the lumber yield was recorded for each individual log. Data were summarized for each log and results placed on punch cards for sorting and tabulating results. The actual log grade specifications were made by ''trying various methods of analysis until what appeared to be the best was found'' (Wollin and Vaughan 1947, p. 4). To take into account varying thicknesses of the lumber produced, the authors used the dollar value for each of the lumber grades as the common denominator. Actual dollar values were not used; instead, value ratios were developed based on the differences among lumber prices and thickness. Herrick (1946) used a similar method; however, only value ratios developed for 4/4 lumber were used in his report. Wollin and Vaughan (1947) felt that this was an acceptable method because the price relationships between grades and thicknesses were relatively constant, even though the actual prices varied.

Although the authors felt that it was important, they did not attempt to define a ''limit of merchantability'' for Grade 3 logs. Based on the analyses performed for their report, they suggested that this limit should be addressed to better determine values when conducting timber surveys. The authors felt that the criteria developed for Grade 3 logs would need to be addressed, indicating that logs should be suitable to produce an industrial product or yield at least 50 percent on each of three faces, with any clear cuttings being at least 2 feet long (Wollin and Vaughan 1947).

To further refine log grades within red oak, white oak, and cottonwood, a grade-yield range was developed among diameter ranges within an individual log grade. These species were selected because there was sufficient representation within each of the diameter classes to infer results. The grade yields for each diameter class were constructed by removing the upper and lower 10 percent logs (in terms of yields) from the diameter ranges. Likewise, yields of 1 Common and better were weighted by giving those graded as First and Seconds (FAS) a weighting of 1.5 against a weighting of 1 for Selects and 1 Common lumber. The weighting system was based on the approximate differential in monetary value among the lumber grades.

This basic grading system developed by Wollin and Vaughan (1947) was similar to the system published by Benson and Wollin (1941). In the new standard table, information was presented in a different fashion with few alterations of the original. Again, deviations were made among grade factors based on the species being graded as illustrated in Table 2 (Wollin and Vaughan 1947, p. 9).

Defining USDAFS Hardwood Log Grades

After the culmination of the Northern and Central States log grading reports, industry groups and academics began making use of the proposed log grading system. One of the first adoptions by an industry group was the Northern Hemlock and Hardwood Manufacturer's Association (NHHMA), which published the *Official Grading Rules for Northern Hardwood and Softwood Logs, Tie Cuts, Box Bolts, Chemical Logs, Bolts, and Cordwood* (NHHMA 1947), which was based on a slightly modified version of the original grading work (Wollin and Vaughan 1947). These rules were accepted by the association on September 24, 1947, and recognized log grades Prime, No. 1, No. 2, and No. 3. The NHHMA took a clear-cuttings approach similar to the USDAFS grades; however, it was much less elaborate. It should be noted that the NHHMA also provided a log inspection service at the time, much like the National Hardwood Lumber Association (NHLA), for disputes on log grades among buyers and sellers.

During this period, a parallel effort was being undertaken by researchers at Duke University. Rather than concentrating on log grades, Schumacher and Young (1943) were studying the relationship between empirical log rules among species and lumber grades. In particular, their work predicting the proportion of lumber in each of three lumber grade groups (First and Seconds, No. 1 Common, and No. 2 Common) was a new approach at assigning value classes to logs. Rather than focus on log defect characteristics, they concentrated on determining the impact that log size and length (as represented by a log volume equation) had on

Table 2.—Basic hardwood sawlog grade specifications developed for hardwoods in 1947. Reproduced based on report developed by Wollin and Vaughan (1947).

Grade factors	Grade No. 1			Grade No. 2		Grade No. 3
	Butt only[a]	Butt and upper[b]		Butt and upper		Butt and upper
Diameter, minimum (inches)	13–15	16–19	20+	11+		8+
Length, minimum (feet)	10+	10+		8–11	12+	8+
Clear cuttings on the 3 best faces,[c] portion of face,[d] minimum	5/6	5/6		4/6		No cutting
Number on face, maximum	2	2		2	3	requirement
Length, minimum (feet)	7	5	3	3		
Sweep[e] and crook deduction, maximum (%)	15	15		30		—
Cull deduction including sweep, maximum (%)	40	40		50[f]		67[g]
Sound end defects, area affected by slight dote, mineral stain, bark pockets, etc., diameter in percent of small-end diameter not more than (%)	50	50		50[h]		Unlimited

[a] 12 inches minimum for ash, basswood.
[b] 10 inches minimum if of No. 1 surface quality for ash, basswood, cottonwood (central states data analyzed on basis of 8 foot and 9 foot lengths to be 12 inch + diameter and yield 9/12 of log length in not over two cuttings 3 feet + long).
[c] Definitions: *Face* = one-fourth of the circumference of the log surface, longitudinally; *Cutting* = that portion of the face extending for the entire width of the face, either from the end of the log and a defect or between defects; *Clear* = excluded from clear cuttings are knots, bark-covered elevated defects, such as bumps, or recessed defects covering overgrown knots, grub holes, etc. (any defects, such as light scars, etc., found outside the right cylinder of the log are not considered).
[d] Required yield based on nominal log lengths, that is, 12.4 feet = 12 feet.
[e] Maximum sweep reduced one-third on log having over one-fourth diameter in sound end defects.
[f] No. 1 logs with not over 60 percent cull deduction will be admitted in the No. 2 grade.
[g] Maximum cull allowance optional between buyer and seller.
[h] 16 inches and larger will admit 3/5 of diameter.

lumber grades produced. They had three main findings regarding the relationship between log scale and lumber produced:

1. Lumber graded as First and Seconds was restricted to sawlogs equal to or greater than 18 inches in diameter, and lumber volume in First and Seconds varied directly with diameter in larger logs.
2. Lumber volume in No. 1 Common runs about 7 board feet to the foot of log length, for logs with scaling diameters between 18 and 25 inches.
3. Lumber volume in No. 2 Common averages about 5 board feet to each foot of log length, regardless of sawlog diameter.

Herrick (1946) published a set of log grades based on work he conducted at Purdue University. The Purdue system does not place logs into end use categories, but rather applies a set of defined rules applicable to any sawlog. Grading is then based on the distance between defects and evaluated on the three visible faces without turning the log. The down face is assumed to look like the three visible faces.

One of the main reasons cited for the development of a new log grading system was that many of those in development at the time were too complicated, and a simpler system was needed. Herrick (1946) conducted mill studies at 13 hardwood sawmills in Indiana during 1943 and 1944. The majority of logs tallied (80%) were from band headrigs, while most of the lumber sawn was 4/4. The log grades were chosen to work for both logs and standing trees. This was accomplished because the log grades only required an observation of three visible faces, where a ''face'' was defined as any one quarter of the surface of the log.

Herrick considered his log grades an adaptation of the USDAFS grades being developed; however, they were much less complex. Although Herrick admitted that the simplicity of the developed grades did not allow for precise estimation of lumber grade recovery, they did work well enough that they could be adopted as a standard throughout the central hardwood region. The following characteristics were used to distinguish among the Purdue log grades (Herrick 1946, p. 8):

Prime.—Practically (90%) surface clear on three visible faces. Must be 16 inches or larger in diameter inside bark (dib).

Number 1.—At least 3/4 (75%) of length on three visible faces must be surface clear in one cutting. Must be at least 14 inches dib.

Number 2.—At least 1/2 (50%) of length on three visible faces must be surface clear in two cuttings, neither of which is less than 3 feet long. Must be at least 10 inches dib.

Number 3.—Will not meet Number 2 specifications.

In further defining the Purdue log grades, Herrick developed a log quality index, which was used as a means of quickly assessing the value of a log. It was a linear combination of lumber volume sawn from a particular log with weights assigned to the various lumber grades. This quality index was then used by Herrick (1946) to further justify the log grading system that he had developed—the quality index was directly correlated to the Purdue log grades. A follow-up extension publication was developed that served as a field guide for these log grades (Herrick 1949).

Other attempts to develop universal log grades occurred during the same time. Wallace (1948) continued on Herrick's (1946) line of reasoning that the USDAFS grades were too complex. He developed a log grading system that he felt ''needed a minimum amount of skill and practically no computations'' (Wallace 1948, p. 378). He again broke logs down into four faces. However, he only looked at the whole face and determined whether it was clear. Log grades

were then formed based on the number of clear faces a log exhibited. Four basic grades were developed:

Grade I.—Contains logs with four clear faces.
Grade II.—Contains logs with three clear faces.
Grade III.—Contains logs with one and two clear faces.
Grade IV.—Contains logs with 0 clear faces.

The size classes were further segregated by scaling diameter. A similar grading system forms the basis by which most buyers and sellers grade hardwood sawlogs in Appalachia today, based on the senior author's observations while conducting hardwood sawmill studies throughout the Appalachian region.

Following this work, Wallace (1955) published more research related to his log grades. His introductory statement suggests that others had perhaps criticized his log grading system. He stated that ''the development of simple log grades was not intended for scientific use nor for conditions where intensive management of individual species or trees is applied'' (Wallace 1955, p. 2). Additionally, he questioned the FPL approach because the USDAFS grading system did not define the overlap in grades or the volume or number of logs needed to obtain a statistically valid average for each log grade. He developed this research project to understand these metrics.

Wallace (1955) obtained 1,000 log diagrams from the FPL to conduct his research. He classified the logs into his grades based on the diagrams and assigned a quality index (Herrick 1946) for each log. The quality index (QI) was used to test for overlap and mean dispersion for each log grade. Using the QI and the FPL logs, he felt that he had adequately substantiated his original grading system. The QIs for each grade showed little overlap—which is the desired condition. He noted in his results that there was serious overlap in the FPL log grades, especially the 16 inch and larger grade No. 1 logs. Wallace also showed in his work the merits of growing big trees. Even though they all had four clear faces, logs in the 10 inch to 14 inch diameter groups did not have the highest QIs. Wallace again reiterated that his log grading system was simple to apply and was not difficult to remember.

Herrick (1956) also continued development on his quality index approach to log grading. As referenced, several researchers were using the quality index approach. However, each was using a different reference grade for developing the QI. In his original article, Herrick (1946) based the price relatives with FAS as the reference grade (price relatives were the proportional deviation of lumber grade prices from the reference grade price).

A symposium was held in 1952 at Purdue University to discuss reference grade selection and the price relatives approach. Participants at this meeting agreed that the reference grade for the QI would be 4/4 plain sawn No. 1 Common lumber. The QIs for all of the original logs sawn at Indiana mills were recalculated based on the No. 1 common reference grade and presented (Herrick 1956). In this article, he also applied the QI to tree grades and stumpage appraisal. Although the QI is a logical approach for grouping logs based on their product characteristics, its use only shows up two additional times in the literature—both in Wisconsin. Bentley and Streeby (1968) presented projected QIs for hardwood logs from 1967 to 1976. Likewise, a computer program was developed that computed the QI for three log grades (Streeby and Bentley 1968). The software computed the price differentials and projected them forward in time based on a simple linear regression model.

Finally, in 1965, the Ohio Forestry Association published *Ohio Standard Saw Log Grades* (Ohio Forestry Association 1965). The grades included four specific log grades (Prime, No. 1, No. 2, and No. 3) and a cull grade. The cull grade included logs that would not meet a No. 3 grade. Criteria for classifying logs included diameter and clear cuttings on the three poorest faces.

Formal Adoption of Log Grading Standards by the USDAFS

The culmination of this evolving work was the development and promulgation of Report No. D1737, *Hardwood Log Grades for Standard Lumber—Proposals and Results* (Wollin and Vaughn 1949a). A shorter version was also published at the same time in a regional journal (Wollin and Vaughan 1949b). Likewise, a pocket edition entitled *Hardwood Log Grades for Standard Lumber and How to Apply Them* was published as FPL 1737A in 1949 (USDAFS 1949). The original D1737 published in 1949 was republished in 1959 by Wollin and Vaughan (1959) as FPL Report 1737, with the subtitle *Information Reviewed and Reaffirmed*. This publication was developed as a reiterative follow-up of the original work. In 1952, the grades were officially adopted by the USDAFS to serve as the organization's official hardwood log grades.

Wollin and Vaughan (1949a, 1959) combined logs sawn in Northern, Central, and Southern Hardwood Forest Service regions into a comprehensive description of hardwood log grades. For these articles, approximately 11,000 logs sawn at 28 sawmills were included in the analyses of log grades.

Lumber yield tables were developed for 19 species—some individual species were separated into subgroups to take into account regional variation in log quality (for example—lowland and upland red and white oak). The standard grading table was similar to the one proposed by Wollin and Vaughan (1947) with a few notable exceptions (Table 3).

Previously, Wollin and Vaughan (1949a) did not specify cutting requirements for Grade 3 logs. However, in the new table, 3/6 of the length of each of the three best faces needed to be clear. Likewise, a 50 percent maximum sweep and crook deduction was added, as well as reducing the cull deduction from 67 to 50 percent for Grade 3 logs. Wollin and Vaughan (1959) also allowed unlimited sound end defects, whereas previously only 60 percent was allowed for Grade 3 logs.

A case was made by Wollin and Vaughan (1959) that the three grades developed were sufficient for commercial evaluation of logs. The methodology leading up to these grades was reaffirmed and discussed in this work. A series of 44 tables was developed showing lumber yields and values for various diameter classes and log grades for individual species. It is also important to note that the log values reported in this publication were developed based on lumber prices as of June 1948 (Wollin and Vaughan 1959). The system formalized by Wollin and Vaughan (1949a) was formally adopted as the official hardwood log grades for the USDAFS (Wollin and Vaughan 1959, Vaughan et al. 1966).

The development of a log grading system to this point that included only three categories reduced the complexity of assigning grades. To help those attempting to adopt the

Table 3.—Basic hardwood sawlog grade specifications developed for hardwoods. Reproduced based on report developed by Wollin and Vaughan (1959).

Grade factors[a]	Grade No. 1			Grade No. 2		Grade No. 3
	Butts only	Butts and uppers		Butts and uppers		Butts and uppers
Diameter, minimum (inches)	13–15	16–19	20+	11+		8+
Length, minimum (feet)		10+		8–11	12+	8+
Clear cuttings (on the 3 best faces)						
Length, minimum (feet)	7	5	3	3		2
Number on face (maximum)	2	2		2	3	Unlimited
Yield in face length (minimum)	5/6	5/6		4/6		3/6
Sweep and crook deduction (maximum) (%)	15	15		30		50
Cull deduction including sweep, maximum (%)	40	40		50		50
Sound end defects	See instructions					

[a] Exceptions: In ash and basswood 12 inch diameter inside bark (dib) for Grade 1 butts. Grade 2 with 10 inch dib must be Grade 1 surface quality. Grade 2 with 11 inch dib limited to two cuttings. Grade 2 with 8 and 9 foot lengths limited to 12 inch dib; 3/4 yield in not more than two 3 foot cuttings. Sweep and crook allowance reduced 1/3 in logs with more than 1/4 diameter in sound end defects. Sixty percent cull deduction permitted in Grade 2 if otherwise of Grade 1 quality. Sixty percent cull deduction permitted in Grade 3 if otherwise of Grade 2 quality.

USDAFS log grades, Ostrander (1952) developed a visual outline of the log grading system that could be attached to a standard scaling stick. This was considered to be an aid for those with some familiarity with the grading system and not a replacement for formalized training. This grading ''cheat sheet'' was further refined when changes were incorporated based on work performed at the Southern Research Station (Ostrander and Englerth 1953).

Lockard (1957) developed a manual to ''amplify and interpret'' the grades devised by the FPL. He was one of the first, if not the first, to develop specific use classes for hardwood logs. These included factory, construction, and local-use classes. Factory class was developed for logs that will be sawn to produce lumber that would be later recut into smaller pieces, which would be nearly free of defects. The resulting lumber would be graded under NHLA standards. Construction class included logs used for the production of ties and timbers and other items that might be used for weight bearing purposes. The main difference in defect allotments for construction class products was due to lumber strength and not appearance. Local-use class included logs suitable for products not covered by any standard specifications.

High strength, durability, or fine appearance is typically not needed for a local-use class log. Lockard (1957) provided grading specifications for both construction and local-use class logs as well as reiterating the grade specifications for factory class logs under the FPL grading system. He also provided a number of illustrations (cull descriptions, defects, end conditions, etc.) to help those applying log grades understand their intricacies.

At the same time, two models were competing for specifying log grades—the FPL and Purdue classification systems. A research project was initiated to investigate the differences between these methods (Walters and Herrick 1956). In total, 308 logs were graded and scaled based on the FPL and Purdue log grades and followed through four mills in Indiana and Illinois. Only 207 logs could be used for comparison purposes because several of the species sawn were not applicable under FPL grades. Likewise, 28 of the logs fell below FPL factory log status and could not be graded. Three methods were used by the authors to predict the value of each log: FPL log grades and percentage grade yields; Purdue log grades and percentage grade yields; and Purdue log grades and quality indexes (QIs). Results indicated that the FPL and Purdue log grading systems were comparable when used on the highest and lowest quality logs; however, they had significantly less agreement on medium-quality logs. They also determined that even though the FPL grades underestimated lumber recovery, they gave the best mean predicted log value. Thus, the FPL system was better than the Purdue system for stratifying logs into value categories. Walters and Herrick (1956) concluded that, because of the amount of variability in lumber yields among logs, no more than three log grades appear to be necessary for developing value classes.

In early June of 1957, a hardwood log grading symposium was held to try to focus the efforts of those working on log grades (Callahan et al. 1957). It was hosted by the Central States Section of the Society of American Foresters (SAF) and included numerous participants who were at the forefront of log grading systems. While it was mentioned during the symposium that the purpose was not to decide whether the Purdue or FPL log grading system was best, these were the primary log grading methods discussed. A list of six points was developed by the participants at the symposium and was voted for by a majority of those in attendance, as detailed below:

1. There is a real need for a quality judging technique for hardwood logs and trees.
2. The grading or judging scheme should be based on recovery of 4/4 factory lumber.
3. The grading scheme should cover all logs from best to poorest.
4. Forestry schools should give basic instruction in the reasons or importance of quality grading.
5. Research workers need an accurate and precise system of grading as is possible to obtain.
6. For field application by practicing foresters and lumbermen the system should be as simple or fool-proof as the required limits of accuracy permit. (Callahan et al. 1957, p. 105)

Also, during this same period, the FPL produced an internal document, *Overall Work Plan for Development of Log and Bolt Grades for Hardwoods* (USDAFS 1958). The stated purpose of the Work Plan was to present ''procedures for conducting research aimed at developing or checking the

accuracy of specifications for grading hardwood logs'' (USDAFS 1958, p. 1). And the intent was to provide information and guidance to Forest Service personnel engaged in work related to hardwood log grading. The report goes on to indicate that at the time ''there is no one system of grading hardwood logs or timber that has been universally accepted and used throughout the hardwood region. The nearest approach is the system of log grades for factory lumber developed by the USDAFS and adopted as their official standard Service-wide'' (USDAFS 1958, p. 2).

National Log Grade Committee and Working Group Efforts

In the late 1950s the Chief of the Forest Service requested the National Log Grade Committee ''advise him regarding an action program in log and tree grading research as a solution to part of the timber quality problem'' and ''what could be done to give foresters and timber users all the same definition of timber quality'' (Newport et. al 1959, p. 1). At the time, the Committee recommended a permanent Task Force, which was not established.

Instead, a temporary working group of three USDAFS researchers was established to address a more limited set of objectives, including: (1) formulate a clear statement of the problem of measuring log quality and to set up uniform objectives for research in log and tree grading; (2) establish basic concepts and standards of performance to be used in developing, testing, and applying any system for measuring timber quality; (3) suggest uniform research techniques to be used in the analysis of timber quality data; and (4) recommend a program for service-wide action in log and tree grading research, which is realistic in terms of the magnitude of the problem, the difficulty of its solution, and the availability of funds and personnel (Newport et al. 1959, p. 1).

The group reviewed a number of different tree and log grading systems in use at the time in the United States and graded each according to a number of criteria related to the committee's objectives, standards of performance, and basic concepts. It is interesting to note that, of the 15 hardwood and softwood grading systems analyzed, the FPL grading system was the one most in conformance to their criteria. Although not measured against the committee's criteria, the Purdue log grading system was referenced, as well as 14 other mixed hardwood grading systems in use across the country (Newport et al. 1959).

In their report, the committee stated that,

> [T]his report is the proper beginning for a program of research to establish adequate timber quality measures. The report is intended to provide the framework within which the development, testing, and application of grading systems must be carried on. Those who have worked with timber grading for any length of time will recognize that this report simply presents in one place and in an organized manner the things which many foresters have been saying and doing for many years. (Newport et al. 1959, p. 2)

It would appear that this language implies that the USDAFS, through the National Log Grade Committee, was hoping to resolve the issues surrounding hardwood log grading in the United States through a USDAFS directed and funded research program.

For purposes of clarity, the committee established a distinction between classifying and grading: classifying being the placement of logs or trees into use classes, while grading placed a log or tree into quality groups within a use classification. Quality was categorized as ''the property or group of properties exhibited by a log or tree which make it physically suitable for conversion into end-products'' (Newport et al. 1959, p. 3).

The report confirms that only prior to 1930, in a few very specific instances, had any advanced standards for log grading been developed, and more importantly there was no broadly accepted concept of timber quality. After 1930, and particularly during World War II, interest in quality and grading accelerated.

The working group identified three types of grading systems that had developed over time:

1. Judgment Grading Systems—In these systems graders must use their judgment in estimating whether a log will produce the stipulated or desired volume of key products. As time passes, surface indicators or characteristics are added to the specifications so that less experienced graders can perform the grading function. The grading rules of various West Coast Log Scaling and Grading Bureaus (Columbia River LSGB 1951, Puget Sound LSGB et al. 1954) and other regional LSGBs are cited in the report as being judgment rules.
2. Arbitrary Grading Systems—In this case the developmental step is in writing a set of specifications based on experience and the more obvious visual characteristics, including size, clearness, knot size, and distribution. Those developing the grading system recognize the correlation between these characteristics and the quality of the products produced, but the interactions are not a result of direct study. Average product yields are generally determined after the specifications have been written. Company grades are cited as generally being of the arbitrary grading system variety.
3. Analytical Grading Systems—Here the results of direct study are used to establish specifications. The yields for a grade are then determined and used as a performance measure of the grade. The Hardwood Log Grades for Standard Lumber (D1737) were developed according to this methodology.

The report goes on to identify 32 different log grading systems and classifies them by application—industry or other federal or state: 10 were used by both, 16 used by industry only, and 6 used by other federal or state only.

The Working Group (Newport et al. 1959) also laid out three major objectives that any log grading system must meet:

1. To determine the gross market value of a log or group of logs—Gross market value is the actual dollar value of the products produced from the logs, before cost of conversion is taken into account.
2. To determine the relative gross value of a log or group of logs—Relative value means ranking of the material produced from a log or group of logs into a category(s) other than dollar value (e.g., lumber grade yields).
3. To determine the amounts of the various classes of end products and/or grades of a given end-product class that can be obtained from a log or group of logs. By assigning current market values to the various classes or grades of

end product in the proportions in which they are estimated or produced, either gross or relative market value can be determined.

The Working Group then recommended that two types of standards must be met in developing and applying grades: (1) variability limitations and (2) application standards.

The grades in a grading system must group the logs so that the variability in value and/or product yields is reduced to a reasonable limit. They wanted the variation due to the grouping of logs to be less than the variation without the grouping, so that the effectiveness of a log grading system could be judged by the reduction in variability resulting from the grouping of logs. Three sources of variation were cited: natural variability of individual logs, range of log sizes in the sample, and number in the sample. If the sample size and log sizes can be controlled adequately, then the grouping of logs can minimize the effects due to natural variability.

The Working Group went on to recommend that the square root of the variance per unit volume should be 7 percent of the mean value per unit volume for each grade within a grading system.

Value and/or product differences between grades are necessary within a grading system. Thus, the grading system should

> segregate the logs into grades that have differences in value or end-product performance that are statistically significant and of large enough real magnitude to justify the time and effort of applying the system. For a given log size one grade should differ from another by not less than 10% of the mean value of the higher of the two grades under consideration. The differences in mean value between the several grades should be approximately equal (Newport et al. 1959, p. 20).

The Working Group recommended the following Application Standards:

1. Grade specification must be clear, concise, and understandable, in terms that persons with experience or training in timber growing and harvesting can be expected to understand.
2. There should be a limited number of grades within any grading system. Six grades should be set as a maximum standard.
3. A given grading system should be applicable to a particular species over its entire commercial range.
4. A grading system should cover, within a species or a species group, all of the trees or bole segments that are physically suitable for conversion into the end product under consideration.
5. In the application of any grading system, it is highly desirable that the same set of specifications be used for all species producing end products of a similar or the same use class.
6. If several grading systems are developed for a species, each for a different class of end product, it will be possible for a log to have several grades, one for each use class in which it can be placed. Such overlapping grading systems should be combined when possible by making appropriate adjustments in the specifications.

Finally, the Working Group identified five basic concepts that should guide the development of any grading system:

1. Gross valuation should be made on an end-product basis.
2. Minimum specifications are needed.
3. Grading specifications should include only the visible and important indicators.
4. The conversion system is important in controlling the end-product yields.
5. A grading system should remain unchanged as long as possible.

On the last point, in order to make any grading system useful over the widest area for the longest period of time, adjustments for such changes must be made only in the performance data after the system has received acceptance in the field. This means that the specifications should remain the same as much as possible, but the performance criteria (i.e., the yield or value tables) will be changed (Newport et al. 1959, p. 20).

The USDAFS system has remained relatively unchanged since its introduction in 1949, in part because there has been no industry impetus to drive the process toward another system and because the USDAFS has not considered it necessary to alter or change their system, since it meets the internal needs of the agency.

Application of the Forest Service Log Grading System

The original USDAFS log grading rules were republished by Vaughan et al. (1966). This publication was the first to refer to the grades as the ''official US Forest Service Hardwood Log Grades for Standard Lumber.'' Although never officially stated, the log grades and lumber yields were again based on the same log and yield data collected during previous studies in the northern, southern, and central hardwoods regions. This publication's justification and methodology mirror earlier efforts; however, several changes were made to the standard grading rules (Table 4).

One of the obvious changes to the grading system is the adoption of ''Factory'' in reference to each of the log grades, as first introduced by Lockard (1957). As opposed to Log Grade No. 1, No. 2, and No. 3, the authors refer to the classifications as F1, F2, and F3. This appears to be the first time that the Factory specification appears in the USDAFS log grading system. The authors also expanded the log length classes for F2 grade logs from two to four. The differentiation in these length classes was with respect to the length and number of clear cuttings as well as the fraction of the log length required in clear cuttings. Sweep and crook allowance was also split into two categories in the new standard grade table. The categories were differentiated based on the portion of the end in sound defects—those above and below 1/4. The final apparent change was a decrease in total scaling deduction from 40 to 30 percent for 13 to 15 inch F1 butt logs.

In 1957, the USDAFS Northeastern Forest Experiment Station issued a Preliminary Edition of a *Manual for Hardwood Log Grading in the Northeast* (Lockard 1957), which was revised and reissued in 1965 as *A Guide to Hardwood Log Grading* (Ostrander 1965), based on Publication D1737. It was developed primarily as a teaching aid and reference publication in connection with training sessions and demonstrations of hardwood log classing and grading processes. It includes material that amplifies information presented in a different form elsewhere. It also presents material developed especially for the demonstra-

Table 4.—Official US Department of Agriculture Forest Service hardwood log grades for standard lumber. Reproduced based on report developed by Vaughan et al. (1966).

Grading factors		F1			F2				F3
Position in tree		Butts only	Butts and uppers		Butts and uppers				Butts and uppers
Diameter, scaling, minimum (inches)		13–15[a]	16–19	20+	11[b]		12+		8+
Length, minimum (feet)			10+		10+	8–9	10–11	12+	8+
Clear cuttings[c] on each 3 best faces	Length, minimum (feet)	7	5	3	3	3	3	3	2
	Number on face (maximum)	2	2	2	2	2	2	3	No limit
	Fraction of log length required in clear cuttings[d]		5/6		2/3	3/4	2/3	2/3	1/2
Sweep and crook allowance (maximum) in percentage gross volume	For logs with less than 1/4 of end in sound defects (%)		15			30			50
	For logs with more than 1/4 of end in sound defects (%)		10			20			35
Total scaling deduction including sweep and crook (%)			30[e]			50[f]			50
End defects						See instructions			

[a] Ash and basswood butts can be 12 inches if otherwise meeting requirements for small No. 1s.
[b] Ten-inch logs of all species can be No. 2 if otherwise meeting requirements for small No. 1s.
[c] A clear cutting is a portion of a face free of defects, extending the width of the face.
[d] See table 46 in Vaughan et al. (1966).
[e] Otherwise No. 1 logs with 41 to 60 percent deductions can be No. 2.
[f] Otherwise No. 2 logs with 51 to 60 percent deductions can be No. 3.

tions and not published elsewhere. The stated purpose was to ''simplify and interpret specifications for grading hardwood logs as set forth in the Forest Products Laboratory Publication No. D1737'' (Ostrander 1965, Foreward). In 1966 Vaughan et al. updated Publication 1737 by adding a limited amount of lumber yield data and making some adjustments in the original yield data.

While the USDAFS originally only reported log yields and return for factory class logs, USDAFS researchers began looking at the yields from ''sub-factory'' or ''local-use'' class logs. Schroeder (1968) was the first to develop yield tables for sub-factory class red oak logs. An argument was made that a large portion of the standing inventory that could be considered lower quality meets sub-factory class standards.

Schroeder (1968) followed 235 below factory Class 3 logs through a sawmill in the Kaskaskia Experimental Forest in Illinois. The logs were sawn in such a way as to isolate the majority of the defects along the outer edge of the resulting boards. The boards were graded and the resulting lumber was dried. This publication included kiln-dried lumber yield tables for red oak logs between 9 and 19 inch scaling diameters. He provided these results so that users could determine the marginal sawlog specifications for their own applications.

Hanks (1973) continued the work on sub-factory class logs by adding data for nine additional hardwood species. He did not collect additional information, rather he used logs that had not met factory Class 3 designations in the FPL log yield studies (e.g., Vaughan et al. 1966). While this work differed from Schroeder (1968) because the logs were not sawn based on the locations of maximum defects, it did give users more information on grade yields for important hardwood species. Yield equations were developed for each lumber grade within a species so that a wide range of diameter classes could be represented. This was because only 600 logs were available to represent all of the nine species included in this report.

The last major milestone of the USDAFS Hardwood Log Grades was the publication of *Lumber Grade Yields for Factory Sawlogs* in 1980 (Hanks et al. 1980). This report summarizes the results of sawing nearly 20,000 logs at 75 sawmills in the eastern United States for the following species: basswood (*Tilia* spp.), paper birch (*Betula papyrifera*), yellow birch (*Betula lutea*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), black oak (*Quercus velutina*), chestnut oak (*Quercus montana*), northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), white oak (*Quercus alba*), yellow-poplar (*Liriodendron tulipifera*), beech (*Fagus grandifolia*), cottonwood (*Populus deltoides*), elm (*Ulmus* spp.), sap gum (*Liquidambar stryraciflua*), and lowland red oak (*Quercus* spp.). Lumber grade yields, according to NHLA lumber grades, were tabulated by species, log grade (USDAFS log grade), and diameter class. This publication represented about 40 years of research on logs and lumber grade yields.

After the FPL system (Wollin and Vaughan 1949a, 1959) became the USDAFS log grading standard, scientists appeared to focus their efforts on supporting it. Cole (1965) initiated a study to compare various log grading methods to assess differences in overall valuations. Logs were graded and sawn at five circular sawmills in eastern Kentucky and southern Ohio during the summer of 1962. Three basic grading systems were investigated: Mill using adaptation of USDAFS Hardwood Log Grades or Ohio Forestry Association Log Grades; Mill varying price according to an estimate of quality; and Mill grading system developed by operator for own use. Logs graded at each of the study mills were compared with grades assigned by the study team using the USDAFS Log Grades (Wollin and Vaughan 1959).

Cole (1965) reported that the mill graders tended to show bias in grading logs. Logs of preferred species were graded higher than similar logs of less desired species. Likewise, it was found that scaling diameter was far more important to the mills than log defects. Defects that reduced volume and defects that reduce volume and degrade were not differentiated. Overall, it was determined that mill operators tended to over-grade logs. The author argued that this has the

potential to create a large discrepancy in log values and that log sellers could not validly compare board-foot prices paid for logs by competing mills. Thus, a system of log grade adjustments would be needed to standardize mill grades. These adjustments, argued Cole (1965), would not be needed if standardized log grades were accepted.

Work by Martens (1965) illustrated the benefits of the USDAFS log grades. In order for sawmill operators to understand their profits, they needed to determine more precisely the maximum their mill could pay for logs of different grades and/or by conducting an accurate evaluation of their conversion technique. In order to illustrate these criteria, he compared trends in log recovery value ($/MBF) for each of the three grades for three separate species (red oak, white oak, and yellow-poplar) between 1954 and 1964. Through discussion of the resulting trends (which were quite stable over the time period) he argued that using log grades along with lumber prices the mills were receiving was a means to determine the value that could be expected from logs of different species and grade.

The cost of grading logs was then discussed by Church (1965). He argued that grading logs helped determine precise sawlog values, predict lumber volumes and grades, and evaluate sawmill efficiency. He felt that the costs associated with grading were much lower than the cost to scale logs, and that grading could be easily incorporated with scaling through training. At the time, Church (1965) estimated that grading cost approximately $0.30 per MBF, whereas both scaling and grading cost $1.35 per MBF.

Other researchers began investigating the impacts of FPL log grades on other aspects of the industry. Researchers used the FPL log grades to determine the efficiency of log bucking decisions for log value. Stump et al. (1953) followed timber cutters in southern Michigan while they bucked 78 trees. They determined that a 12 percent increase in the volume of No. 1 grade logs could have been attained if standard log grading rules had been properly applied in the woods. It was felt that an opportunity existed for increasing the yield of higher grade logs through proper training and conscientious effort in the use of log grading rules.

There was also a timely introduction of the log grades proposed by Wollin and Vaughan (1949a) into eastern Canada in 1959. Calvert (1956) formally recognized the USDAFS log grading system. He explained the derivation of the FPL grades and how they might apply to Canadian hardwoods. It was argued that some form of a log grading system was needed in Canada, especially when logs were being sold from private woodlands.

There are many instances in the literature where an attempt was made to discuss USDAFS log grades in more concise terms. Several publications/manuals are in print covering the basics of USDAFS rules for presentation purposes (Screpetis [undated], Lockard and Carpenter 1951, Lockard 1960, and Rast et al. 1973).

Another example of a new use for FPL grades was for the valuation of the standing timber resource. Quinney (1955) measured 501 trees in hardwood stands in Minnesota. He found that over 67 percent of their timber volume would be classified as Log Grade No. 3—suitable for the manufacture of box and crate material, short rough boards, or small timbers.

Walters and Harrick (1956) conducted a comparison of the USDAFS and Purdue Log Grading Systems. In general, results of this study showed the Forest Service system to outperform the Purdue system. The final published result stated, ''Because of inherent variability in the quality of lumber yields, no more than three grades appear to be necessary for sorting hardwood sawlogs into quality classes'' (Walters and Harrick 1956, p. 22). Interestingly, the Purdue system does not appear in the literature much after this time period.

Kramer (1952) explored the feasibility of developing log grades for the poorer quality logs that are predominant in east Texas upland hardwood stands. The reasoning was that the USDAFS Factory Lumber Grades did not adequately address the low-quality hardwood logs in east Texas. Three alternative grades were developed for red oak, post oak, and sweet gum.

King (1958) presented a system for black walnut that included four log quality classes (Prime, Select, Common, and Cull), based on clear cuttings. A Prime log required two clear faces and one 5/6 clear; Select required one clear face and two faces 2/3 clear; and Common required no clear sides and three 2/3 clear. Cull logs were those not meeting the minimum specifications for a Common grade. Findings showed that Prime logs yielded 60 percent F1F and better lumber and 80 percent 1 Common and better lumber. Select logs yielded 40 percent F1F and Better and 70 percent 1 Common and better. Common logs yielded about 20 percent F1F and better lumber and 60 percent 1 Common and better.

A further sampling of research studies using the USDAFS Hardwood Log Grades to classify logs as part of research studies included, in chronological order: Doverspike and Camp (1951) tested the USDAFS Factory Log Grading system at four mills, two in Maine, one in Pennsylvania, and one in West Virginia. Arbogast (1953) studied lumber and log grade yields from second growth Northern hardwoods. Calvert (1960) tested the USDAFS system to determine its applicability to Eastern Canadian hardwood species. Petro (1962) amplified and interpreted the log grade specifications set forth by Calvert (1960), which in turn were based on USDAFS D1737 hardwood log grades. Schroeder and Hanks (1967) explored lumber grade yields for factory grade northern red oak sawlogs. Neilson et al. (1970) compared sawing patterns and their effect on the yield of furniture components produced from hard maple logs. Dunmire (1971) developed a series of tables for predicting yields of graded lumber and dimension stock from red oak logs based on the USDAFS system. Stayton et al. (1971) used the USDAFS system to predict lumber grade yields from standing trees and then compared the results with lumber sawn from sample sugar maple trees. Kersavage (1972) compared the production of cherry logs using two different sawing methods—grade and live sawing. Burry et al. (1977) conducted sawmill improvement projects at mills in New York in an effort to generate a higher percentage of lumber out of each log. Koch and Rousis (1977) investigated the yield of yellow-poplar structural dimension from low-grade sawlogs. Yaussy (1987) predicted lumber yields for sugar maple and basswood logs graded based on the USDAFS system. Kluender et al. (1988) explored product yield and recovery at an Arkansas hardwood sawmill. Lin et al. (1994) studied the impact of log sawing patterns and cutting sequences on the dimension yields of factory grade No. 2 and No. 3 logs. Perkins et al. (2008) used the USDAFS sub-factory grade sawlogs to assess wood and residue yields from small diameter red oak logs.

Summary and Discussion

The major development work in log grades occurred roughly from 1940 through 1970, with the primary driver of that development being the federal government. The USDAFS contributed 45 percent of the log grading publications during the time period (Fig. 1). And, even though the log grade development process has been going on since the early 20th century, most of the activity occurred between the 1930s and 1970s (Fig. 2).

At its base, the USDAFS system is designed to first classify each log as to its best end use (factory lumber, structural material, and local use). And, by definition, a log grading system is ''a set of specifications that is used to segregate a given lot of cut logs into two or more log grades'' (Hanks et al. 1980, p. 1). Moreover, there is the added requirement that there be significant differences in unit value or in end-product yield between log grades (Hanks et al. 1980). Once placed in an end use category, the grading is based on the distance between defects on the second worst face, with grade improving with increasing proportion of log length in clear cuttings. The distance between defects is directly related to NHLA lumber grading rules for clear cuttings and lumber grades. Since the publication and reaffirmation of Hardwood Log Grades for Standard Lumber (Wollin and Vaughan 1949a, 1959), there has been little evolution in log grading, evidenced by a lack of any significant publications in the pertinent literature, beyond the Hanks et al. (1980) publication.

Although some competing systems were developed during the timeframe in which the USDAFS system was developed, those competitors showed no long-term sustainability. There is no evidence that these systems have survived and are in use today. The only log grading system to survive over the long term has been the USDAFS system.

The USDAFS system has primarily flourished within the Forest Service, particularly with its use in some of the Forest Inventory Analysis work and in Forest Service and university research. Whenever log grades are an important consideration in research work, the USDAFS grades are used. This is well documented in the literature, some of

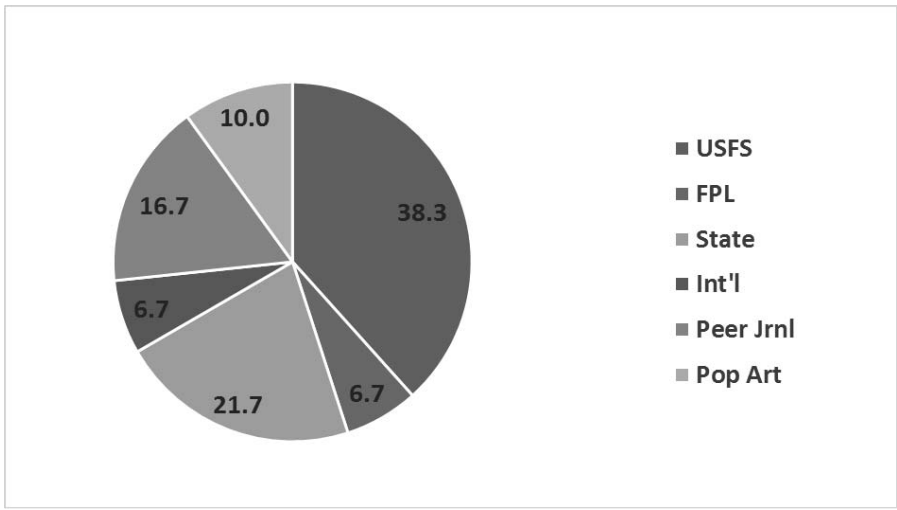

Figure 1.—Hardwood log grading articles referenced by source (percent).

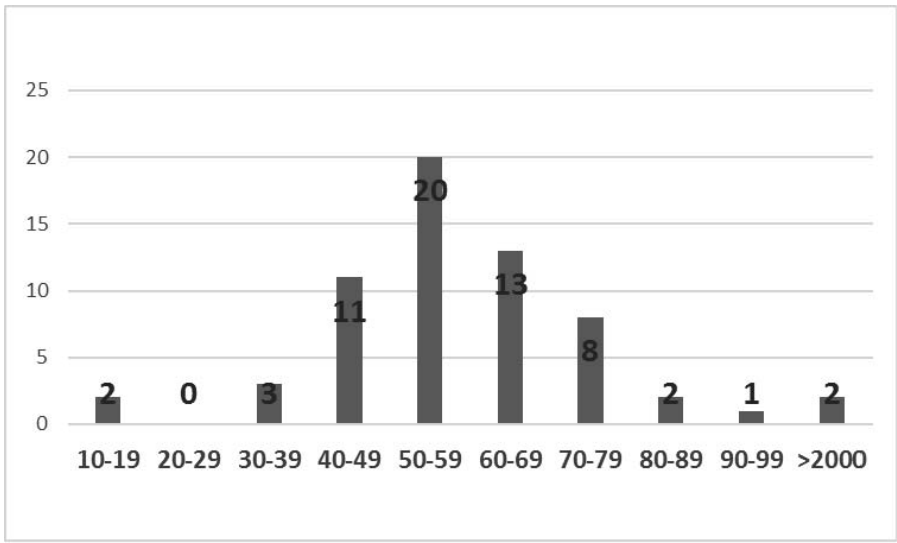

Figure 2.—Hardwood log grading articles referenced by decade (number).

which is cited in this article. And finally, whenever log grading workshops are offered, the USDAFS log grading system is generally the one that is taught.

However, from a hardwood industry perspective, there has never been a broad acceptance of the USDAFS Hardwood Log Grades. As recently as 2012, McConnell (2012) stated that no set standards exist for grading hardwood logs and trees. His short discussion of the log grading process suggested that, even though the USDAFS produced a comprehensive rule for hardwood log grading, other more simplified grading systems exist and are used more commonly by the industry than the USDAFS system.

More detail on current hardwood log grading methods will be provided in forthcoming articles that address the current status of log grading within the industry and evaluate the USDAFS log grading system from an industry perspective.

Literature Cited

Arbogast, C., Jr. 1953. Lumber and log grade yields from second growth northern hardwoods. *J. Forest Prod*. 3:25–27, 79.

Benson, A. O. 1941. Something new in hardwood log grades. *J. Forestry* 39(1):13–15.

Benson, A. O. and A. C. Wollin. 1938. Grading Hardwood Logs. Project L-260-2, Working Plan. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin.

Benson, A. O. and A. C. Wollin. 1941. Grading northern hardwood logs. USDA Forest Service Report, Forest Products Laboratory, Madison, Wisconsin. 34 pp.

Bentley, W. R. and L. L. Streeby. 1968. Projected quality indexes for estimating hardwood log values. Research Note No. 142. Wisconsin Forestry, Madison.

Bromley, W. S. 1941. The use of log grades in appraising lumber values of selectively cut northern hardwood timber. *Papers Michigan Acad. Sci., Arts Lett*. XXVI:135–142.

Bryant, C. B. 1913. Logging—The Principles and General Methods of Operation in the United States. John Wiley & Sons, New York. 547 pp.

Burry, H. W., G. M. Bliss, and K. F. Burns. 1977. Hardwood lumber recovery and sawmill efficiency in New York. AFRI Research Report No. 33. SUNY, Applied Forestry Institute, Syracuse, New York. 24 pp.

Callahan, J. C., A. M. Herrick, E. R. Martell, and C. S. Walters. 1957. Proceedings of hardwood sawlog-grading symposium. Sponsored by Central States Section Society of American Foresters. June 10–11, 1957, Indianapolis, Indiana. University of Illinois Agricultural Experiment Station and Purdue University Agricultural Experiment Station. 107 pp.

Calvert, W. W. 1956. Grading hardwood logs for factory lumber. Forest Products Laboratories of Canada, Ottawa Laboratory. 4 pp.

Calvert, W. W. 1960. Grading hardwood logs for factory lumber. FPL Technical Note No. 18. Forest Products Laboratories of Canada, Ottawa Laboratory. 27 pp.

Church, T. W. 1965. Can you afford to grade your hardwood logs? *Northern Logger and Timber Processor* 14(12):12–13.

Cole, A. B. 1965. Hardwood log grading at circular sawmills. USDA Forest Service Research Note CS-41. Central States Forest Experiment Station, Columbus, Ohio. 4 pp.

Columbia River Log Scaling and Grading Bureau (LSGB). 1951. Official log scaling and grading rules. Columbia River LGSB, Portland, Oregon. 33 pp.

Doverspike, G. E. and H. W. Camp, Jr. 1951. Four test-demonstrations of hardwood log grades in the Northeast. Station Paper No. 42. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 19 pp.

Dunmire, D. E. 1971. Predicting yields from Appalachian red oak logs and lumber. *In:* Oak Symposium Proceedings, August 16–20, 1971; USDA Forest Service Northeastern Forest Exp. Station, Upper Darby, Pennsylvania. pp. 94–99.

Fonseca, M. A. 2005. The Measurement of Round-Wood; Methodologies and Conversion Ratios. CABI Publishing, Wallingford, UK. 288 pp.

Garver, R. D. and R. H. Miller. 1933. Lumber and log grades for southern hardwoods. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 26 pp.

Grosenbaugh, L. R. 1952. Shortcuts for cruisers and scalers. Occasional Paper 126. USDA Forest Service, Southern Forest Experiment Station, Asheville, North Carolina. 24 pp.

Hanks, L. F. 1973. Green lumber grade yields for sub-factory class hardwood logs. Research Paper NE-256. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 8 pp.

Hanks, L. F., G. L. Gammon, R. L. Brisbin, and E. D. Rast. 1980. Hardwood log grades and lumber grade yields for factory lumber logs. FS Research Paper NE-468. USDA Forest Service, Northeastern Forest Experiment Station, Broomall, Pennsylvania. 92 pp.

Hassler, C. C. 2010. 2009 Sawmill production and cost survey—Executive summary. Appalachian Hardwood Manufacturer's Inc., High Point, North Carolina. 7 pp.

Herrick, A. M. 1946. Grade yields and overrun from Indiana hardwood sawlogs. Agricultural Experiment Station Bulletin 516. Purdue University Agricultural Experiment Station, Lafayette, Indiana. 60 pp.

Herrick, A. M. 1949. How to grade hardwood sawlogs. Agricultural Extension Bulletin 346. Purdue University Agricultural Extension Service, Lafayette, Indiana. 8 pp.

Herrick, A. M. 1956. The quality index in hardwood sawtimber management. Station Bulletin 632. Purdue University Agricultural Experiment Station, Lafayette, Indiana. 26 pp.

Kersavage, P. C. 1972. Sawing method effect on the production of cherry lumber. *Forest Prod. J*. 22(8):33–40.

King, W. W. 1958. Evaluating quality of black walnut sawlogs. *Forest Prod. J*. 8:243–248.

Kluender, R. A., E. W. McCoy, and V. O. Harding. 1988. Product yield and recovery of an Arkansas hardwood sawmill. Report Series No. 306. Arkansas Agricultural Experiment Station, Clarksville, Arkansas. 10 pp.

Koch, C. B. and W. T. Rousis. 1977. Yield of yellow-poplar structural dimension from low-grade saw logs. *Forest Prod. J*. 27(4):44–48.

Kramer, P. R. 1952. Log grade classification based on standard lumber recovery for inferior upland hardwoods in East Texas. Technical Report No. 4. Texas Forest Service, Forest Products Department, Lufkin, Texas. 34 pp.

Lin, W., D. E. Kline, and P. A. Araman. 1994. Dimension yields from Factory Grade 2 and 3 red oak logs. *Forest Prod. J*. 44(9):19–25.

Lockard, C. R. 1957. Manual for hardwood log grading in the northeast (Preliminary edition). USDA Forest Service, Northeastern Forest Experimental Station Forest Service, Upper Darby, Pennsylvania. 41 pp.

Lockard, C. R. 1960. Manual for hardwood log grading in the Northeast (Preliminary Edition), Revised May 1958; Reprinted with minor revisions June 1960. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 46 pp.

Lockard, C. R. and R. D. Carpenter. 1951. Hardwood log grading course. USDA Forest Service, Southern Forest Experiment Station, New Orleans. 21 pp.

Martens, D. G. 1965. Log grades—A key to predicting sawmill profits. *Southern Lumberman* 210(2612):29–34.

McConnell, T. E. 2012. Hardwood log and tree quality. The Ohio State University. Fact Sheet F-74. https://ohioline.osu.edu/factsheet/F-74-12. Accessed April 12, 2019.

Neilson, R. W., D. W. Bousquet, and S. M. Pnevmaticos. 1970. Sawing pattern effect on the yield of furniture components from high quality hard maple logs. *Forest Prod. J*. 20(9):92–98.

Newport, C. A., C. R. Lockard, and C. L. Vaughan. 1959. Log and tree grading as a means of measuring quality—Report of the Working Group. USDA Forest Service, Washington, D.C. 31 pp.

Northern Hemlock and Hardwood Manufacturer's Association (NHHMA). 1947. Official grading rules for northern hardwood and softwood logs, tie cuts, box bolts, chemical logs, bolts, and cordwood. NHHMA, Oshkosh, Wisconsin. 12 pp.

Ohio Forestry Association. 1965. Ohio standard saw log grades. Ohio Forestry Association, Inc., Columbus, Ohio. 8 pp.

Ostrander, M. D. 1952. A handy aid for hardwood log graders. Forest

Research Note NE-13. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 5 pp.
Ostrander, M. D. 1965. A guide to hardwood log grading. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 50 pp.
Ostrander, M. D. and G. H. Englerth. 1953. Hardwood log grading scale stick improved. Forest Research Note No. 24. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 2 pp.
Perkins, B., R. L. Smith, and B. Bond. 2008. Solid wood and residue yield analysis of small-diameter red oak logs. *Forest Prod. J*. 58(1/2):97–100.
Petro, F. J. 1962. How to evaluate the quality of hardwood logs for factory lumber. Technical Note No. 34. Forest Products Research Branch, Ottawa Laboratory. 33 pp.
Puget Sound Log Scaling and Grading Bureau (LSGB). 1954. Official Log Scaling and Grading Rules for the Puget Sound Log Scaling and Grading Bureau, Grays Harbor Log Scaling and Grading Bureau, Southern Oregon Log Scaling and Grading Bureau, and Northern California Log Scaling and Grading Bureau. Puget Sound LSGB, Seattle. 38 pp.
Quinney, D. N. 1955. Log grades of Minnesota hardwoods. Technical Note No. 435. Lake States Forest Experiment Station, St. Paul, Minnesota. 1 p.
Rast, E. D., D. L. Sonderman, and G. L. Gammon. 1973. A guide to hardwood log grading. General Technical Report NE-1. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 32 pp.
Schroeder, J. G. 1968. Lumber grade yields for sub-factory class red oak logs. USDA Forest Service Research Paper NE-114. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 15 pp.
Schroeder, J. G. and L. F. Hanks. 1967. Lumber grade yields for factory-grade northern red oak sawlogs. Research Note NE-65. USDA Forest Service, Northeastern Forest Experiment Station, Upper Darby, Pennsylvania. 13 pp.
Schumacher, F. X. and H. E. Young. 1943. Empirical log rules according to species groups and lumber grades. *J. Forestry* 41(7):511–518.
Screpetis, G. D. Undated. Teaching the basics of hardwood and lumber grading. USDA Forest Service, Southeastern Area State and Private Forestry, Pineville, Louisiana. 15 pp.
Stayton, C. L., R. M. Marden, and G. L. Gammon. 1971. Predicting lumber grade yields for standing hardwood trees. Research Paper NC-50. USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota. 8 pp.
Streeby, L. L. and W. R. Bentley. 1968. QUINDEX—A program to estimate and project quality indexes for log grades. Forestry Research Note. University of Wisconsin, Madison. 8 pp.
Stump, W. G., R. Ralston, and J. L. Arend. 1953. Log grading starts in the woods. Technical Note No. 406. Lake States Forest Experiment Station, St. Paul, Minnesota. 1 p.
USDA Forest Service. 1949. Hardwood log grades for standard lumber and how to apply them—Pocket edition, No. D1737A. Forest Products Laboratory, Madison, Wisconsin. 18 pp.
USDA Forest Service. 1958. Overall work plan for development of log and bolt grades for hardwoods. TGUR-16. Forest Products Laboratory, Madison, Wisconsin. 61 pp.
Vaughan, C. L., A. C. Wollin, K. A. McDonald, and E. H. Bulgrin. 1966. Hardwood log grades for standard lumber. Research Paper FPL 63. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 54 pp.
Wallace, O. P. 1948. A simple method for grading hardwood logs and determining log values for New Hampshire. *J. Forestry* 46:377–379.
Wallace, O. P. 1955. A simple method for grading hardwood logs. Station Technical Bulletin 94. University of New Hampshire, Agricultural Experiment Station, Durham, New Hampshire. 7 pp.
Walters, C. S. and A. M. Herrick. 1956. A comparison of two log-grading systems. Bulletin 603. University of Illinois, Agricultural Experiment Station, Champaign, Illinois. 23 pp.
White, H. G. 1938. An introduction to the study of timber quality in Lake States hardwoods. *Papers Michigan Acad. Sci., Arts Lett*. XXIII:339–348.
Wollin, A. C. and C. L. Vaughan. 1947. Sawlog grades for hardwoods—Central states studies, No. D1699. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 22 pp.
Wollin, A. C. and C. L. Vaughan. 1949a. Hardwood log grades and standard lumber—Proposals and results, D1737. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 15 pp.
Wollin, A. C. and C. L. Vaughan. 1949b. Hardwood log grades for standard lumber—Results of studies of proposed methods on northern, central and southern hardwoods. *Southern Lumberman* 178(2237):60, 62, 64, 66, 68–69, 72.
Wollin, A. C. and C. L. Vaughan. 1959. Hardwood log grades and standard lumber—Proposals and results (information reviewed and reaffirmed), D1737. USDA Forest Service, Forest Products Laboratory, Madison, Wisconsin. 15 pp.
Yaussy, D. A. 1987. Green lumber grade yields from sugar maple and basswood factory grade logs. *North. J. Appl. Forestry* 4:154–157.