History of Forest Survey Sampling Designs in the United States

W.E. Frayer and George M. Furnival

Abstract.—Extensive forest inventories of forested lands in the United States were begun in the early part of the 20th century, but widespread, frequent use was not common until after WWII. Throughout the development of inventory techniques and their application to assess the status of the nation's forests, most of the work has been done by the USDA Forest Service through regional centers. Various sampling designs have been tried: some have proved efficient for estimation of certain parameters but not others. Some designs, though efficient in many respects, have been abandoned due to the complexity of application. Others, while possibly not demonstrating high efficiency, have been adopted because of the simplicity of application. This is a history of these applications. We start with the early compilations of western data and line-plot cruises for statewide inventories. Much discussion is presented on the development of specialized designs for regional applications that mushroomed from the 1940's through the 1970's. We conclude with descriptions of the various designs now in common use or being tested today.

One of the first notices of the awareness of a need for a national forest inventory is found in "Timber Depletion and the Answer" (Greeley 1920). This report stated that "The original forests of the United States are estimated to have covered 822 million acres and to have contained 5,200 billion board feet of timber....There are left today about 137 million acres of virgin timber, 112 million acres of culled and second-growth timber large enough for sawing, 133 million acres partially stocked with smaller growth, and 81 million acres of devastated and practically waste land....Three-fifths of the timber originally in the United States is gone." The main point of the report is a call for legislation to protect forest land from fire and to increase the area of public land. One small section of the report does suggest that "legislation is needed, with an appropriation of $3,000,000, to be available for from 2 to 4 years as the work may require, which will permit the Secretary of Agriculture to survey the forest resources of the United States, determine the present volume together with the present and possible production of each class of timber in every important forest region...". These remarks are given in more detail in a report of the same year known as "The Capper Report." The USDA Forest Service views this report as the first of a series that incorporated new data and it was considered a milestone in appraising our timber supply.

Although the Capper Report is a milestone, our main consideration in this paper is the historical development of sampling methods to collect data and to make inferences. This report includes many inferences as summarized in the Chief's report, but it includes the admission that "A comprehensive and fully adequate report...would require an exhaustive survey of the forest resources of the country...No such survey has ever been made." It was pointed out that "data...have been compiled from a great variety of sources secured for different purposes by different organizations with varying degrees of accuracy."

The second milestone report, the Copeland Report, was prepared by the Forest Service in 1930 and presented to Congress in 1933. It included such new data as had become available to supplement the data of the Capper Report, but there was still no "grand sampling design" to acquire data.

The McSweeney-McNary Forest Research Act of 1928 had earlier authorized the Forest Service to conduct a national forest survey. It called for "a determination of the present and potential productivity of forest land therein (the United States)." Because the main concern in those days was the timber situation, it was understandable that the survey was primarily a timber inventory. The survey began in 1930 (Andrews 1932, Wilcox 1938) in Oregon, McNary's home state, as described by Doig (1976). Planning had begun in 1929 when Thornton T. Munger, the first Director of the Pacific Northwest Forest Experiment Station, received $30,000 in funding (Van Hooser *et al.* 1992). The first approach in the Pacific Northwest was to use available private data with some field work for verification and supplementation. Doig described an experiment carried out in 1930-1931 in Lewis County, WA, in which a line-plot survey was run to compare it with compilations made for the area and to

Dean, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI, USA, and Professor Emeritus, Yale School of Forestry and Environmental Studies, New Haven, CT, USA, respectively.

assess its potential for use in the South. Plots were one-quarter acre in size and spaced at 10-chain intervals on east-west strips run through forested areas. About 486 miles of survey line had been run by the end of June 1931. The field work had included 3,888 sample plots at a cost of $10,448. It was decided not to use the method in the Douglas-fir region because of the rugged terrain, but it was adopted for the East.

Some results for Oregon and Washington were published in 1932 (Cowlin). A later report was published for the Douglas-fir region (Anonymous 1934). Wieslander (1935), who was head of Forest Survey at the California Forest and Range Experiment Station from 1935 until 1950, described the first steps of Forest Survey in California. He said that mapping was in progress, and there was a plan to take 35,000 field plots, but this was not done until after 1950. Wijkstrom (1930) described a sample plot method used in a land economic survey for Minnesota. It's not clear whether this was part of the new nationwide Forest Survey.

"Cap" Eldredge was placed in charge of Forest Survey in the South, headquartered at the Southern Forest Experiment Station in New Orleans in 1930. Two reports in 1931 (Anonymous, Lentz) described the line-plot sample method (based on the Lewis County, WA, experiment) that was proposed for 25 million acres of bottomland area in the Mississippi Delta states. Two interim reports on this were made in 1932 (Anonymous, Lentz). Lentz' report stated that 5,815 plots had been taken on 4,425,000 bottomland acres; Eldredge (1935) noted that field inventory of 75 million acres in the South would be completed by April 1, 1935. A second report by Eldredge (1937) described methodology consisting of three-man crews on parallel compass lines 10 miles apart taking quarter-acre plots at 10-chain intervals. He stated that analysis had begun and that some results had been published.

In 1938, Garver reported that the forest inventory phase was well along in the South, Pacific Northwest, and the Lake States. He said the job was half done—289 million acres of forest land had already been examined. There was no information on sampling design, intensity, etc. Cunningham (1939a,b) reported that the inventory phase of Forest Survey in the Lake States had been completed in 1937, and he reported preliminary statistics on areas and volumes. Forest Service Chief F. A. Wilcox stated in his annual report (1938) that "We need in forests all the 630 million acres we now have and that are most valuable for forest growth. Yet unless it is abused and neglected, we probably do not and will not need more forest land. For 300 years our forests have been chopped, burned, and depleted. Yet with care and forethought there seems no excuse for a timber famine of national proportions." He also stated that "The Forest Survey indicates that we have more forests than we thought,...and more forest growth." It was also pointed out that the Forest Survey had begun in 1930, and about one-half of the forests of the United States had been surveyed—with about 60 percent of the resulting data compiled. This was the status that remained for several years, due to the war. Several tables of information on the status of the nation's forests were presented by R. E. Marsh, Acting Chief, and William H. Gibbons, Senior Forester, Division of Forest Economics, Forest Service, in the 1940 Yearbook of Agriculture. They noted that reports and unpublished manuscripts by many members of the Forest Service had been drawn upon. "Where authoritative data on forest conditions such as those so far furnished by the Forest Survey have been available, they have been used. Where such data were not available, the best approximations possible, which are believed to be substantially near the truth, have been made." This is considered by the Forest Service as the third milestone report.

Shortly after the war, Forest Survey began in earnest. In two reports in 1946, Chief Lyle F. Watts said that "during 1945 and 1946 the Forest Service has been making a reappraisal of the Nation's forest situation." Several tables were presented, and the general conclusion was that there was enough forest land, but not enough timber. The survey was credited to R. E. Marsh, and the data were compiled and presented by C. Edward Behre and S. Blair Hutchison. These reports make up the fourth milestone report.

The four milestone reports portrayed national results, but there is little information on how they were obtained. The purpose of this paper is to present the historical development of sampling as used in the national Forest Survey. Most survey efforts based on extensive sampling of the nation's forests began in 1930 or later. The actual sampling designs used began to appear more commonly in the literature in the 1950's. As pointed out in an excellent portrayal of the roots of forest inventory in America by Gregoire (1992), one of the first (if not the first) sampling texts was prepared specifically for forestry by Schumacher and Chapman (1942).

Becker (1950) described the Forest Survey procedures used in the Central States. This effort was a function of the Central States Forest Experiment Station in Columbus, OH, where Becker was Field Supervisor for Forest Survey. He said that the first field work began in the Pacific Northwest in 1930 and was gradually extended to other areas. As indicated earlier in this paper, he explained that most of the effort in the West was based on compilation of available data. He indicated that a line-plot system was used in other areas, including the central states where the effort began in 1946. He explained that

area estimates in the central states were based on aerial photo plots and that a subsample of these plots were field-sampled to obtain volume estimates. He also indicated that a type of optimum allocation was used (at least a disproportional allocation). A higher intensity of field plots was used in sawtimber stands than in poletimber stands, and a higher intensity in poletimber than in seedling/sapling stands.

The reference to line-plot field inventory brings to mind a story related 40 years ago by Fred Hampf, who took part in the first Forest Survey of Virginia. He said that he walked across Virginia three times (east-west). He said that as he was approaching the Natural Bridge, he offset his line so that he would go directly under it. He claimed to be doing "government work" so that he wouldn't have to pay admission. Hundreds of foresters who have taken part in Forest Survey work over the past several decades most certainly have their memories of favorite plots and stories.

In the Pacific Northwest, the problems of estimating volumes in old-growth stands presented a different type of challenge than faced in the East. Floyd Johnson, a statistician at the Pacific Northwest Forest and Range Experiment Station, began working on this (Johnson 1950, Johnson and Hixon 1952). At that time—and up to current times—the approaches taken in Forest Survey differed somewhat at the different experiment stations. Some of this difference was needed. The large ownerships and high volumes in parts of the West seemed to necessitate a cooperative approach between agencies and private owners with most wanting the survey results to be useful in management planning. The smaller ownerships and generally lesser volumes by individual owners east of the Rockies enabled the stations in the East to design broad inventories, produce state reports, and—for the most part—leave management planning for individual owners as a separate problem faced by those owners. Much of this was good, but it presented problems that also have continued to this day. The autonomy of the individual stations meant that differences in techniques appeared even when there would have been advantages gained by standardization.

The approach of using aerial photo plots and ground plots in combination to estimate areas and volumes had been apparent for some time and was probably best described by Bickford (1952). He pointed out that the use of photo plots to form strata and to estimate their sizes, along with a subsample of those plots being measured as field plots, is a double sampling design. Specifically, it could be called stratified sampling with estimated stratum weights. He relied heavily on Neyman (1938), and shortly after on Cochran (1953), when the first edition of his popular textbook was published. It's interesting to note that the formula for estimating variance in Cochran's earliest edition was incorrect. It was corrected in a later edition and was extended to the case of n-phase sampling by Frayer *et al.* (1979) and Jeyaratnam *et al.* (1984). These later works were among many in the literature in the 1970's when it appeared that some combination of satellite imagery, aerial photos, and ground plots would be useful in multiphase or multistage estimators.

The use of aerial photos to set up strata, simple as it seems, sometimes was confusing and was not always done to best advantage. Of course, the more recent the photographs, the higher the correlation between what could be interpreted from them and what was found on the field plots. Some people just would refuse to believe that photos a few years old could help to provide estimates of today's areas and volumes. Inefficiencies occurred when many strata were used, and photo interpreters spent a long time classifying the photo plots. Take, for example, the case where only two strata are used: nonforest and forest. Plots that interpreters were uncertain of often resulted in long discussions, and sometimes it was a tossup where they went. Because only a small portion of plots fell in this category, it was much more efficient to place them in an "unknown" third stratum (Frayer 1978). Early work by Bickford showed the advantages of optimum allocation. However, over time, strata change, objectives may change, personnel most certainly change; and all of these factors argue for a simple, easily understood approach. Proportional allocation became more common over time.

Wheeler and Cruikshank published an article in 1956 titled "The South's Forest Resource." Wheeler and Cruikshank were, respectively, Chiefs of the Division of Forest Economics at the Southern Forest Experiment Station, New Orleans, LA, and the Southeastern Forest Experiment Station, Asheville, NC. It was a report for the combined station territories. The two stations later went somewhat their own ways, and it was only recently (culminating with the combination of the two Forest Survey units) that data and information could be easily combined for the states covered in the earlier report.

Several things happened in the early 1960's that resulted in changes in design and measurement techniques at several experiment stations. Point sampling had become very popular (Bitterlich 1948; Grosenbaugh 1952,1958; Beers and Miller 1964). The realization that remeasured plots were the most precise way to estimate growth and change was acknowledged (Hall 1959). Shiue (1960) and Shiue and John (1962) proposed systematic sampling with multiple random starts. To the purist, this had some appeal because it satisfied statistical theory and, at the same time, provided a consistent way of locating plots on maps, topo sheets, and photos. Over time, however, it had been used only at the North Central Forest Experiment Station, and they abandoned it to be more consistent with

other stations. Sampling with partial replacement, the most complicated design ever used by Forest Survey, was implemented at the Northeastern Research Station (Ware 1960, Ware and Cunia 1962, Bickford *et al.* 1963). In time, sampling with partial replacement was dropped, primarily because of its complexity (Scott and Kohl 1992). Foresters in the West were adopting some of the eastern procedures, such as combining aerial photo information and ground plots (MacLean 1963).

Fixed-radius plots were abandoned in most places in favor of point samples. This was an especially interesting development that provided for precise estimates of volume by sampling trees with probability proportional to basal area. At the same time, components of change were receiving prime attention (Hall 1959, Beers 1962). A sweeping change to point sampling was accompanied by development of estimation procedures for growth components on remeasured points. Most stations were now using a cluster of 10 points roughly covering an acre. In the East, it was decided that it would be reasonable to sample approximately 20 trees on each cluster. Because it was generally accepted that 75 square feet of basal area was the minimum for a fully stocked stand, some stations started using 37.5-factor prisms (75 ft^2 divided by 20 trees times 10 points = 37.5).

All these activities in the early 1960's may have been the result of the fifth milestone report prepared by the USDA Forest Service (USDA 1958). To prepare information for this 713- page report, data were compiled in a number of ways: states that had been surveyed since January 1, 1947, were based on the survey data; for 10 states in which the survey was in progress, the data collected were supplemented with some additional data; and for other states, special surveys were conducted to gather some information. This large effort, coupled with the fact that there were now competent statisticians at the experiment stations and forestry schools, probably helped provide the impetus for the myriad studies and publications of the early 1960's.

Another USDA Forest Service milestone report was released in 1965. Titled "Timber Trends in the United States," it was based on more complete data than any previous report. It includes description of a stand-projection procedure used to standardize data to a common year for publication and to provide projections for the future. Some simulation studies using this procedure later showed that rates of change (harvest and growth components) are especially critical for such a projection procedure to have any precision (Frayer and Jones 1970).

The 1970's saw continued emphasis placed on Forest Survey. The original enabling legislation, the McSweeney-McNary Forest Research Act of 1928, was first amended by the Forest and Rangeland Renewable Resources Planning Act of 1974 and later by the National Forest Management Planning Act of 1976. The overall result was more responsibility and more funding for Forest Survey. Forest Survey by this time was known as Forest Resources Evaluation Research and later as Forest Inventory and Analysis. For the purposes of this paper, we use the term Forest Survey throughout. Satellite data were now readily available (Langley 1971). It was shown that combinations of high-altitude photography, low-altitude photography, and field samples could form the basis for effective three-phase sampling in Forest Survey (Kent *et al.* 1979, Johnston 1982). It was assumed that sampling of many resources—not just timber—was needed (Frayer 1974, 1978; McClure *et al.* 1979; Furnival 1979). Some (Scott 1979) thought that interim data were needed (survey cycles ranged from less than 10 years in some states to almost 20 years in others). There was talk about producing estimates on an annual basis (Frayer 1978), an idea that is at the forefront of two ongoing Forest Survey studies (AFIS and SAFIS) described later. Another milestone report was published titled "Outlook for Timber in the United States" (USDA Forest Service 1973). A stand projection system was again used to bring data to a common year (Larson and Goforth 1974). Peden *et al.* (1973) described how variance estimators could be used with these projections.

Forest Survey in many ways had matured. Many studies were carried out over the next 2 decades. Some were done within the Survey units, and many were done in conjunction with the Survey Techniques Project, which has been located at the Rocky Mountain Research Station since the late 1970's. Two of the studies currently being conducted and which will be described later have already been mentioned (AFIS and SAFIS).

The maturity of Forest Survey was evidenced by publications for states, parts of states, and periodic milestone reports for the nation, as required by enabling legislation. Sampling designs were now mostly in place for the various stations, although there continued to be differences among stations. The information in the following several paragraphs describes the procedure in place for each station and is based largely on an excellent in-house report of the Forest Service (USDA Forest Service 1992).

Pacific Northwest Research Station

The PNW Station covers the West Coast, including Alaska and California. Responsibility for California had originally been assigned to the station in California (now the Pacific Southwest Research Station). Two approaches are used. In Alaska, sample populations are first identified by broad vegetation classification based on satellite

digital data. Within these populations, the primary sample consists of a random selection of satellite pixels transferred to aerial photographs. Items classified on the primary photo samples include land class, ownership, forest type, and timber volume class. Secondary samples for ground examination are selected from the primary samples. All strata are sampled, but the sampling intensity on non-forest strata is less than in forested strata. In other Pacific Coast states, the primary sample is defined by a systematic grid of permanent, mapped points. At each grid point, aerial photos are used to classify the land into strata similar to those used for Alaska. Secondary samples for ground examination are selected systematically from the primary sample locations. Secondary sample intensity can be varied to meet special objectives.

Intermountain Research Station

This Station has had responsibility for the Rocky Mountain West and the Southwest. The general approach is a stratified double sampling design. The primary sample is defined by points on a systematic 1,000-m grid. Each grid point is located on an aerial photograph for interpretation. Items identified for stratification include ownership, land class, and forest type group. The interpreted items are used to define sampling strata. The secondary ground sample is a subset of the primary sample at 5,000-m intervals. A supplemental 5,000-m field grid is available for sampling intensification as required by cooperators, and additional samples can be selected from the 1,000-m primary grid.

North Central Research Station

The North Central Station has responsibility for the midwestern states and lake states (the Central States Station was phased out in the 1960's). Using a systematic grid of 121 plots per township (36 square miles or 9,324 ha) on aerial photographs, each photo plot is classified stereoscopically based on land use, forest type, size, and density. Areas are allocated to ground locations, which are a systematic subsample of the photo plots using random allocation. The total number of ground plots sampled in an inventory is a function of the expected variability of the resource, the expected accuracy of the aerial photo interpretation, and the desired sampling errors.

Southern Research Station

Until recently, the Southern Station has had responsibility for states in the mid-South. This station was recently combined with the Southeastern Station, and the work handled by both will now be headquartered in Asheville, NC.

Estimates of timberland area are based on forest-nonforest interpretation of plots on aerial photographs. These plots represent approximately 230 acres (93 ha). The land-use interpretations are checked in the field at sample locations representing approximately 3,840 acres (1,554 ha). After these checks are used to adjust the photo interpretations, an estimate of the proportion of forest to non-forest area is then made for each county. The proportion of forest area is combined with U.S. Census land area data to derive county-level forest area statistics.

Descriptive forest resource statistics are derived from measurements at permanent sample plots located at the intersections of a 3- by 3-mile (4.8- x 4.8-km) grid; each plot represents, on average, 5,760 acres (2,331 ha). The sample plots are remeasured at each survey to allow assessment of change (i.e., growth, removals, and mortality estimates) and of current resource status.

At each forested sample plot on the 3-mile (4.8-km) grid, trees are measured on a cluster of 10 sample points. Trees at least 5.0-in. (12.7-cm) dbh are selected using a 37.5-factor prism; each sample tree thus represents 3.75 ft^2 (0.35 m^2) of basal area. Trees smaller than 5.0-in. (12.7-cm) dbh are sampled on a 1 /275-acre (0.0015-ha) circular plot at the first three points of the 10-point cluster. Using several tree measurements, volumes are computed using Smalian's formula.

Southeastern Research Station

In the first phase (of a two-phase design), a large number of 16-point cluster samples are interpreted from aerial photographs for forest, non-forest, and non-census water land use. In phase 2, a smaller set of 16-point cluster samples are centered over each permanent ground sample and classified in the same manner as described above and then checked on the ground. The 16-point clusters checked on the ground are used to adjust the area estimates from the photo sample. A linear regression is fitted to develop a relationship between the photo and ground classification of the subsample. The entire photo estimate in phase 1 is adjusted for change in land use since the date of photography and for misclassifications.

The inventory volume design consists of all the permanent sample points that fall on timberland. These are used for volume per acre estimates, number of trees, and stand attributes. Each permanent forest inventory sample that is relocated and remeasured is used to estimate growth, removals, and mortality.

Northeastern Research Station

Responsibility for northeastern states, including west to and including Ohio and south including Maryland. A primary sample is obtained from a grid of photo points

overlaid on aerial photographs of the inventory area. Interpretation of each photo point is for land use and timber volume class stratification. A secondary sample is taken for on-the-ground examination; samples include all ground plots measured at the last occasion and new ground plots that are added to make the ground sample proportional to the primary sample. Data from all plots, new and remeasured, are combined to calculate a combined estimate of current volume.

If you were to try to characterize the descriptions, you could say that most states are inventoried with a double sampling design, using photo plots for stratification and ground plots for volume measurements. You can readily see many differences. This is one factor that led to the formation of a Blue Ribbon Panel on Forest Inventory and Analysis. Its report (Anonymous 1992) had many recommendations, including to "increase consistency and compatibility among FIA (formerly Forest Survey) units." A second Blue Ribbon Panel was assembled in 1997. Its report is in the review process. It is expected that two of the things to be stressed are support for an annual inventory system and strong support for standardizing plot configuration.

The Forest Service has already moved to standardize plots to a cluster of four fixed-radius plots. This may end an era lasting close to 40 years in which the most popular plot was a cluster of 10-point samples.

AFIS and SAFIS Studies

We'll close with a discussion of two important studies now underway. The first of these, being tried in northern Minnesota, is the Annual Inventory System (AFIS). Briefly, it is an attempt to use remote sensing (satellite data in this case) to stratify plots into classes with different probabilities of disturbance. Those with higher probabilities of disturbance would have a higher probability of being sampled in a given year, while other plots would be updated using models.

The Southern Annual Inventory System (SAFIS), being tested in Georgia, is similar, but probabilities of field plot selection will be equal (proportional allocation). Values for unmeasured plots may be inputted or estimated from models. Thus, the results at first may not be as precise (for a given effort) as the AFIS approach if the stratification by satellite imagery is successful, but the SAFIS group is avoiding the long-term complexities of using unequal probabilities with stratum boundaries changing over time. Plus, the more rapid changes (in land uses as well as volumes) in the South probably reduce the gains possible from optimum allocation. For example, one possible approach that was voiced at the Southeastern Station in the 1960's was to fly over forested plots in a light plane and then remeasure those that appeared disturbed. This could have been a reasonable way of estimating volume change. However, for determination of forest area, the changes from non-forest to forest area might be of more importance than the disturbed forested plots.

SUMMARY

We have described the development of inventory techniques to assess the nation's forest resources. We have mentioned some of the national reports and some of the personnel who were involved in the early days of Forest Survey. We have concentrated more on the sampling designs used than on the development of measurement procedures and their changes over time. Current emphasis in Forest Survey is on development of sampling designs and models that will provide annual information.

LITERATURE CITED

Andrews, H.J. 1932. Forest survey in the Douglas fir region. Journal of Forestry. 30: 264-275.

Anonymous. 1931. Second phase of forest survey gets under way. Journal of Forestry. 29: 616-617.

Anonymous. 1932. Preliminary forest survey completed in south. Journal of Forestry. 30: 624-625.

Anonymous. 1934. Forest survey statistics available. Journal of Forestry. 32: 879.

Anonymous. 1992. Report of the blue ribbon panel on forest inventory and analysis. 14 p.

Becker, M.E. 1950. Forest survey procedures for area and volume determination. Journal of Forestry. 48: 465-469

Beers, T.W. (1962) Components of forest growth. Journal of Forestry. 60: 245-248.

Beers, T.W.; Miller, C.I. (1964) Point sampling: research results, theory and applications. Res. Bull. 786. Purdue University.

Bickford, C.A. (1952) The sampling design used in the forest survey of the northeast. Journal of Forestry. 50: 290-293.

Bickford, C.A.; Mayer, C.E.; Ware, K.D. (1963) An efficient sampling design for forest inventory: the Northeastern forest resurvey. Journal of Forestry. 61: 826-833.

Bitterlich, W. 1948. Die winkelzahlprobe. Allgemeine Forst-und Holzwirtschaftliche Zeitang 59: 4-5.

Cochran, W.G. 1953. Sampling techniques. New York, NY: John Wiley & Sons. 320 p.

Cowlin, R.W. 1932. Areas of types in Oregon and Washington counties. Journal of Forestry. 30: 504-505.

Cunningham, R.N. 1939a. Preliminary forest survey figures from the lake states. Journal of Forestry. 37: 66-69.

Cunningham, R.N. 1939b. Lake states forest survey. Journal of Forestry. 37: 698-700.

Doig, I. 1976. When the Douglas-firs were counted: the beginning of the forest survey. Journal of Forest History. 20: 21-27.

Eldredge, I.F. 1935. The south's forest survey. Journal of Forestry. 33: 406-411.

Eldredge, I.F. 1937. Sawtimber and cordwood volumes in central and southwestern Mississippi. Journal of Forestry. 35: 504-505.

Frayer, W.E. 1974. The increasing complexity of large forest inventories. Journal of Forestry. 72: 578-579.

Frayer, W.E. 1978. Objectives of multi-resource inventories in relation to design considerations. In: Integrated inventories of renewable natural resources. Gen. Tech. Rep. RM-55. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station: 267-269.

Frayer, W.E. 1978. Stratification in double sampling — the easy way out may sometimes be the best way. Resour. Inven. Notes 10: 1-3. Denver. CO: U.S. Department of Interior, Bureau of Land Management.

Frayer, W.E. 1978. Potential uses of sampling with partial replacement in national inventories. In: Proceedings of IUFRO conference on forest inventories. Bucaresti, Rumania.

Frayer, W.E.; Jones, D.B. 1970. Effect of estimated inputs on the output of a stand-projection system—a Monte Carlo approach. Department of Forest and Wood Sciences, Colorado State University. 8 p. (Also, Abstracts, Society of American Foresters Annual Meeting, 1968).

Frayer, W.E.; Graybill, F.A.; Jeyaratnam, S.; Bowden, D.C.; Kent, B.M.; Johnston, D.C. 1979. Multilevel sampling designs for resource inventories. Colorado State University. 113 p.

Furnival, G.M. (1979) Forest sampling - past performance and future expectations. In: Forest resource inventories proceedings. Colorado State University: 320-326.

Garver, R.D. 1938. The nationwide forest survey. Journal of Forestry. 36: 889-892.

Greeley, W.B. 1920. Timber depletion and the answer. Dept. Circ. 112. Washington, DC: U.S. Department of Agriculture.

Gregoire, T.G. 1992. Roots of forest inventory in North America. Paper presented at the Inventory Working Group session of the 1992 Society of American Foresters National Convention.

Grosenbaugh, L.R. 1952. Plotless timber estimates. New-fast-easy. Journal of Forestry. 50: 32-37.

Grosenbaugh, L.R. (1958) Point sampling and line sampling. Probability theory, geometric implications, synthesis. Occas. Pap. 160. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 34 p.

Hall, O.F. 1959. The contribution of remeasured sample plots to the precision of growth estimates. 1959. Journal of Forestry. 57: 807-810.

Jeyaratnam, S.; Bowden, D.C.; Graybill, F.A.; Frayer, W.E. 1984. Estimation in multiphase designs for stratification. Forest Science. 30: 484-491.

Johnson, F. (1950) Estimating forest areas and volumes of large tracts. Journal of Forestry. 48: 340-342.

Johnson, F.A.; Hixon, H.J. (1952) The most efficient size and shape of plot to use for cruising in old growth Douglas-fir timber. Journal of Forestry. 50: 17-20.

Johnston, D.C. (1982) Theory and application of selected multilevel sampling designs. Colorado State University. 194 p. Ph.d. dissertation.

Kent, B.; Johnston, D.; Frayer, W.E. (1979) Application of three-phase sampling for stratification to multi-resource inventories. In: Forest resource inventories proceedings. Colorado State University: 993-1000

Langley, P.G. (1971) Multistage sampling of earth resources with aerial and space photography. In: Monitoring earth resources from aircraft and spacecraft. NASA SP-275, Washington, DC: 129-141.

Larson, R.W.; Goforth, M.H. (1974) TRAS: a timber volume projection model. Tech. Bull. 1508. Washington, DC: U.S. Department of Agriculture, Forest Service. 15 p.

Lentz, G.H. 1931. The forest survey in the bottom-land hardwoods of the Mississippi delta. Journal of Forestry 29: 1046-1059.

Lentz, G.H. 1932. Forest Survey of the Mississippi delta region. Journal of Forestry. 30: 1015.

MacLean, C.D. 1963. Improving forest inventory area statistics through supplementary photo interpretation. Journal of Forestry. 61: 512-516

Marsh, R.E.; Gibbons, W.H. 1940. In: 1940 Yearbook of Agriculture: 458-488.

McClure, J.P.; Cost, N.D.; Knight, H.A. (1979) Multiresource inventories-a new concept for forest survey. Res. Pap. SE-191. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 68 p.

Neyman, J. 1938. Contribution to theory of sampling human populations. Journal of American Statistics Association. 33: 101-116.

Peden, L.M.; Williams, J.S.; Frayer, W.E. 1973. A Markov model for stand projection. Forest Science. 19: 303-314.

Schumacher, F.X.; Chapman, R.A. 1942. Sampling methods in forestry and range management. Bull. 7. Duke University, School of Forestry. 213 p.

Scott, C.T. (1979) Midcycle updating: some practical suggestions. In: Forest resource inventories proceedings. Colorado State University: 362-370.

Scott, C.T.; Kohl, M. 1992. Experiences with designing the forest survey of the northeastern United States. In: Proceedings of the 100th I. U. F. R. O. World Congress, Berlin.

Shiue, C.J. (1960) Systematic sampling with multiple random starts. Forest Science. 6: 42-50.

Shiue, Cherng-Jiann; John, H.H. 1962. A proposed sampling design for extensive forest inventory: double systematic sampling for regression with multiple random starts. Journal of Forestry. 60: 607-610.

USDA Forest Service. 1920. Timber depletion, lumber prices, lumber exports, and concentration of timber ownership. Report on Senate Resolution 311, 66th Congress, 2nd session. 71 p. [The Capper Report]

USDA Forest Service. 1933. A national plan for American forestry. Senate Document 12, 73rd Congress, 1st session. 2 volumes, 1,677p. [The Copeland Report]

USDA Forest Service 1958. Timber resources for America's future. For. Resour. Rep. 14. Washington, DC: U.S. Department of Agriculture. 713 p.

USDA Forest Service 1965. Timber trends in the United States. For. Resour. Rep. 17. Washington, DC: U.S. Department of Agriculture. 235 p.

USDA Forest Service 1973. Outlook for timber in the United States. For. Resour. Rep. 20. Washington, DC: U.S. Department of Agriculture. 367 p.

USDA Forest Service 1992. Forest resource inventories: an overview. Washington, DC: U.S. Department of Agriculture, Forest Service. 39 p.

Van Hooser, D.D.; Cost, N.D.; Lund, H.G. 1992. The history of the forest survey program in the United States. In: Proceedings of the 100th I. U. F. R. O. World Congress, Berlin.

Ware, K.D. (1960) Optimum regression sampling design for sampling of forest populations on successive occasions. Yale University. Ph.D. dissertation.

Ware, K.D.; Cunia, T. (1962) Continuous forest inventory with partial replacement of samples. Forest Science Monograph. 3.

Watts, L.F. 1946. Timber shortage or timber abundance? Report of the Chief of the Forest Service. Washington, DC: U.S. Department of Agriculture, Forest Service.

Watts, L.F. 1946. Gaging the timber resource of the United States. Washington, DC: U.S. Department of Agriculture, Forest Service. 66 p.

Wheeler, P.R.; Cruikshank, J.W. 1956. The south's forest resource. Journal of Forestry. 54: 629-632.

Wieslander, A.G. 1935. First steps of the forest survey in California. Journal of Forestry. 33: 877-884.

Wijkstrom, S. 1930. Sample plot method of the Minnesota land economic survey for determining growth and yield. Journal of Forestry. 28: 734-738.

Wilcox, F. A. 1938. Report of the Chief of the Forest Service. Washington, DC: U.S. Department of Agriculture, Forest Service.