Final Report

Periodic Remeasurement of the Gus Pearson Natural Area

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Repeated photographs from the Gus Pearson Natural Area in 1909 (top right, G.A. Pearson), 1938 (below, G.A. Pearson), and 2000 (bottom right, J.D. Waskiewicz).

Contents

Executive Summary

The 240-acre Gus Pearson Natural Area in Fort Valley Experimental Forest, Arizona, comprises an important historical and ecological site because of the presence of dense stands of old-growth trees and detailed records of stand growth and mortality since 1920. Permanently tagged trees were remeasured after the 2000 growing season. This measurement is the twelfth decadal or bi-decadal measurement since establishment of the study area. This report includes electronic files with tree data and data summaries for selected subplots. Inventory procedures and tree condition codes used in 2000 are documented. The major trends in the 80-year measurement period were: (1) long-term decline in basal area growth, (2) shifts in the relative growth of larger versus smaller trees, and (3) reduced growth and increased mortality, especially since 1945. These trends are consistent with other research findings at the site.

Introduction

A 240-acre area of never-harvested ponderosa pine forest in Fort Valley Experimental Forest, near Flagstaff, Arizona, was selected by Gustav A. Pearson to serve as a control unit for silvicultural experiments (Avery et al. 1976). Tree measurements were taken every five years from 1920 to 1960, then at decadal intervals to the present. The 80-year record from the Gus Pearson Natural Area (GPNA) is the longest period of repeatedly measured tree growth in the Southwest, providing a unique data set for assessing long-term patterns.

Franco Biondi applied the GPNA data to show that increased tree crowding through the twentieth century led to reduced growth rates (Biondi 1994, Biondi et al. 1994). The large pines that grew more rapidly than small pines in 1920-1930 came to grow more slowly than smaller trees by 1980-1990, a reversal that was attributed to declining ability of large trees to compete for resources (Biondi 1996). Biondi (1999) also compared the relative strengths of repeated inventory versus dendrochronology as long-term measurement tools.

As a small preserve of old-growth trees in an otherwise heavily logged region, the GPNA has been a valuable site for investigating a variety of ecosystem processes. White (1985) and Savage et al. (1996) studied age structure and regeneration patterns in GPNA. In 1987, an 8-acre area of GPNA next to the Fort Valley Experimental Forest headquarters was decommissioned from Natural Area designation because high forest density posed a fire hazard to the historic wooden buildings. Beginning in 1992, an experiment in ecological restoration was initiated to test thinning of young trees and reintroduction of surface fire (Dieterich 1980, Edminster and Olsen 1996, Covington et al. 1997, Moore et al. 1999). Studies were done to reconstruct past forest conditions (Mast et al. 1999), measure tree physiological responses to treatments (Feeney et al. 1998, Stone et al. 1999), and compare a variety of belowground variables including soil moisture, soil respiration rates, and nutrient transport and transformations (Kaye and Hart 1998a, 1998b, Kaye et al. 1999).

The permanently tagged trees at GPNA were last measured after the 1990 growing season, in October 20 to November 9, 1990. After the 2000 growing season, we carried out the decadal remeasurement from February 28 to March 28, 2001, with funding provided by the USDA Forest Service, Rocky Mountain Research Station (Research Joint Venture Agreement No. 01-JV-11221615-075). This report presents the data summaries and brief interpretation of trends. Data are attached in electronic form on a CD. English units are used throughout, matching the format of Avery et al. (1976).

Methods

Study site

The study site is described by Avery et al. (1976) and Biondi (1996, 1999). Briefly, the GPNA is a 240-acre tract located about 9 miles NW of Flagstaff, Arizona, in a pure stand of never-harvested ponderosa pine forest (longitude 111° 45' west, latitude 35° 16' north). Soils are derived from flow and cinder basalt, classified as Brolliar stony clay loam, a fine, smectitic, Typic Argiboroll (Kaye and Hart 1998a). Weather data is available from the Fort Valley weather station adjacent to GPNA at 7,400' elevation (1909-2000). Average annual precipitation is 22.4 inches, with average annual snowfall of 85.3 inches. Average maximum July temperature is 80.1° and average minimum January temperature is 9.8°. Avery et al. (1976) gave additional information about stand structure and productivity. Olberding (undated) described the historical context of the Experimental Forest and its founders.

Inventory Establishment and Repeated Measurements 1920-1990

In 1915 the larger trees in the GPNA were tallied (Myers and Martin 1961). Beginning in 1920, all trees greater than or equal to 3.6 inches in diameter at breast height (dbh) were permanently tagged and measured. Ingrowth of trees reaching 3.5" dbh was measured until 1960, after which the minimum ingrowth diameter was raised to 6" (Biondi 1996)[1]. Ingrowth was not measured after 1970. Inventories appear to have been generally conducted in the fall after the growing season[2]. Avery et al. (1976) gave additional information about inventory procedures.

[1] Avery et al. (1976) stated that 1920 minimum diameter was 3.5" and the minimum diameter for ingrowth was raised to 7.6" dbh from 1940 on. The individual tree data do not agree with this statement; instead, they are consistent with the diameter limits of Biondi (1996) as stated above.

[2] "Plot S6A [now GPNA] has been measured at 5-year intervals (in the fall) since 1915" (Myers and Martin 1965).

2000 Inventory

This section presents detailed information on the 2000 inventory. We hope that these details will be useful to the people who carry out future inventories.

The 2000 Gus Pearson Natural Area tree inventory took place in late winter and early spring of 2001, prior to the 2001 growing season. Fieldwork was begun on February 28, 2001 when John Paul Roccaforte, Pete Fulé, and Justin Waskiewicz located subplot corners NE 29, NE 28, NE 21, NE 22 and began measuring trees in subplot 22. On March 2, Justin Waskiewicz and Sam Bourque located and photographed the remaining subplot corners. All located subplot corner monuments were photographed from 5 m south using a 38mm lens centered on the subject. Subplot corners NE 4, NE 14, NE 26, NE 30, NE 31, NE 32, NE 33, and NE 34 were neither located nor photographed. Tree measurement began again on March 7 and continued until March 21, with Justin Waskiewicz, Annika Buck, Tim Hudelson, and Stephen Fountain (March 8 and 9 only). On March 22, 26, and 28, mistakes were corrected and missing trees were found when possible. Photographs were taken facing south, southwest, and west from every subplot's NE corner. We also relocated points where photographs had been taken in 1990 in subplot 12, and in 1909, 1938, 1944, 1949, and 1990 in subplot 17. We re-photographed these points, attempting to frame our photos as nearly the same as possible. Data entry of tree diameters and conditions began on March 30, 2001.

All trees having inventory tags (xx-yyy, where xx = subplot number and yyy = tree number) were re-measured at the tag height. Some tags were found far below, and a few almost a foot above, but measurements were always taken at the tag's nail for the sake of consistency with previous inventories. English-unit diameter tapes were used, rounding down to the nearest tenth-inch. Our data sheets listed each tree's 1990 inventory size and condition. These data were used to help locate and re-tag trees which had lost their original tags, as well as to identify errors such as "shrinking" trees. Not all trees appearing on the 1990 inventory were relocated. Many were killed and all evidence of their existence was obliterated by highway widening in 1999. Many trees in subplots 25, 26, 27, 28, 29, 30, 31, 32, 33, and 34 were cut as part of a forest ecosystem restoration project in 1994 (Covington et al. 1997). Some trees lost their tags and could not be identified with certainty. A few trees were simply not found.

A number of irregularities were found in tagging and measurements from previous inventories. Tagging within each subplot generally begins at the NE corner (NW for subplot 6) and proceeds south and west in moderately logical sequence. Tagging in subplot 1, however, showed no logical order. The trees are all there, just scattered nearly randomly. Three pairs of trees had switched tags, which we corrected. Trees 16-83 and 85, 18-114 and 115, and 24-77 and 78 were retagged to match the data. Two trees were found to have the tag number 3-32. The larger is the correct tree, matching the historical measurements. It is unknown why the smaller was tagged, but it was left as found. Tree 16-53 was another peculiar case. It "shrank" ten inches between 1990 and the present, during which interval it also died. While it is not unusual for diameter measurements to decrease by as much as a few tenths following mortality (bark begins to scale off, and is not replaced), ten inches is too much. Historical measurements for the tree date back to 1920 and record it as being always over 39 inches, but it was measured this year at exactly ten inches smaller than 1990. It seems impossible that so much wood could be lost in just ten years; it seems more likely that the diameter has been mis-recorded or mis-entered in previous years. A number of trees have grown together at breast height, making measurement difficult. When it was not possible to measure trees at the tag height for this reason, we measured them as low as possible, in some cases 15 inches above the original tag. In one case, trees 9-212 and 213, we found that the diameters given for 212 in all previous inventories were in fact of both trees together measured at the tag, while the diameter for 213 was taken at the lowest possible point above the tag. We felt it important to remain consistent with the error, but would like to mention here that the correct diameter for 212 alone is 23.8 inches, not 35.0. There are two trees in subplot 4, tagged 4-249 and 4-250. These tagged trees are NOT 4-249 and 4-250, as 4-249 and 4-250 died in 1970 and 1960, respectively, at which time they were quite larger than the trees now bearing their tags. We did not measure these trees.

Table 1. Tree code list. Detailed explanations of tree codes are given in Appendix 1.

Code	Explanation	Code	Explanation
00	No apparent defect or fault	46	Other heart rot
01	Unmerchantable -- fork or crotch	50	Tipmoth -- light
02	Fork or crotch below 18 feet	51	Tipmoth -- heavy
03	Fork or crotch above 18 feet	52	*Dendroctonus* present
04	Suppressed	53	*Ips* present
05	Pruned	54	Turpentine beetles present
09	Merchantable -- spike top	55	Shoot moth present
10	Unmerchantable -- spike top or complete girdle below 18 feet	60	Lightning -- top dead
11	Unmerchantable -- crook or sweep	61	Lightning -- bole split
12	Unmerchantable -- limby	62	Lightning -- scar on one-quarter bole
13	Leans more than 4 deg. from vertical	63	Lightning -- scar on over one-quarter bole
14	Merchantable -- crook or sweep	64	Fire scar on one-quarter bole at base
15	Limby -- merchantable	65	Fire scar on over one-quarter bole at base
16	Grown together at BH	66	Fire -- bark burnt on one-half bole at base
20	Mistletoe -- light in crown	67	Fire -- bark burnt completerly at base
21	Mistletoe -- heavy in crown	70	Snow bend -- less than 30 deg. from vertical
22	Mistletoe -- light on bole	71	Snow bend -- from 30 to 45 deg from vertical
23	Mistletoe -- heavy on bole	72	Snow bend -- more than 45 deg from vertical
24	Mistletoe -- on bole and crown	73	Snow -- top broken
25	Mistletoe -- top dead	74	Wind --top broken
30	Squirrel -- light damage	76	Lightning -- top broken
31	Squirrel -- medium damage	77	Mechanical damage -- kind
32	Squirrel -- heavy damage	90	Killing agent -- lightning
33	Porcupine -- partial girdle in crown	91	Killing agent -- wind
34	Porcupine -- partial girdle below crown	92	Killing agent -- insects
35	Porcupine -- complete girdle	93	Killing agent -- rust
36	Squirrel -- nest tree	94	Killing agent -- dwarf mistletoe
37	Squirrel -- food tree	95	Killing agent -- suppressed
40	Rust -- new in crown	96	Killing agent -- root rot
41	Rust -- advanced in crown	98	Killing agent -- other identifiable agents (squirrel, snow bend)
42	Rust -- new in bole	99	Killing agent -- unidentified agent
43	Rust -- advanced in bole		
44	*Elytroderma* (needle blight) in crown		
45	Red rot		

In taking the 2000 inventory, we discovered the condition code list (Table 1) to be rather long and confusing, containing 65 different codes, some seeming to overlap. Every tree was assigned a code from the list. When we were unsure how to identify a certain defect or disease, we sometimes coded trees as they were in 1990. We found that the 1990 inventory seemed to overuse some codes – assigning mistletoe or forks to trees with no such defects. To be fair, we may have overused some codes ourselves, code 14 especially. Our data sheets showed only one code assigned to each tree in 1990, presumably the most prominent, while we gave ourselves space to enter up to 5 codes. In 1990, a code interpretation sheet was made for some of the codes, and we found it somewhat helpful. Appendix 1 contains the original code interpretations (and our additions in parentheses).

Data analysis was done in a MS-Excel spreadsheet (version Excel 2002). Data were presented and summarized following the examples in Avery et al. (1976). As the data tables were developed, they were continually checked for agreement with the Avery et al. (1976) publication. Results did not agree perfectly but are quite close. The differences are within what would be expected for the errors encountered in the original (typos, missed trees, twice-recorded trees) and whatever other such errors may exist unnoticed.

Results

Tree and Stand Data

Inventory results are presented in several ways, as described below.

1) First, all individual tree data for all subplots is contained in the MS-Excel spreadsheet GPNA_Tree_Data_2000.xls, enclosed with this report.

2) Second, data for trees on 16 selected subplots 1-14, 16, and 27, and summary data for these subplots is presented in Sections 1 through 3 of this document, following the same format used by Avery et al. (1976).

3) Third, data for trees on 16 subplots with minimal disturbance (subplots 1, 2, 4, 5, 7-10, 12, 13, 16, 17, 19-22) and summary data for these subplots is presented in Section 4 of this document.

4) Fourth, the summary tables for Sections 1 through 4 are contained in the MS-Excel spreadsheet GPNA_Data_Summaries_2000.xls, enclosed with this report.

5) Finally, comparisons of tree growth are presented at the end of the results section.

Sections 1 through 3 appended to this report present individual tree data (section 1) and summary data (section 4) following the same format used by Avery et al. (1976). Sections 1, 2, and 3 are based on data only from subplots 1-14, 16, and 27, as in Avery et al. (1976). Section 4 is a new summary of plot data from the 16 subplots that have been least affected by road construction or the restoration experiment, subplots 1, 2, 4, 5, 7-10, 12, 13, 16, 17, 19-22. A detailed description of each section is presented below.

Section 1. Individual Tree Data

This list includes records for each individual tree in subplots 1-14, 16 and 27. Diameter recorded in each inventory year and condition code in each inventory year is given for each tree. Each tree was assigned to an "age class" in 1920, 40, and 60, reflecting whether the tree was judged to be a "blackjack" (code 1) or "yellow pine" (code 2). There is no age class data from 1980 or 2000 inventories. "Age-vigor" is also given for each tree for four periods. Period I is 1925-40, II is 1940-55, III is 1955-70, and IV/V is 1970-2000 (an average of two 15-year periods). Age-vigor is a two digit code: the first classifies trees by "Age Code" and the second by "Vigor-Code" (Avery et al. 1976). There was no data on "Age Code" after 1970 so that digit blank was left blank in Period IV/V. Since there was no inventory in 1985, vigor code in Period IV/V was estimated as half the difference in diameter between 2000 and 1970. Each tree also received a number in its row for plot number (all are plot 61), subplot number (1-14, 16 and 27), and individual tree number (consecutive for each subplot).

Section 2. Subplot Summary Data

This section includes summaries of each of the 16 subplots 1-14, 16 and 27. Each subplot has two tables, the first giving the stem count per acre for each one inch diameter class (4"-50") in each inventory year. Diameter classes are defined as including all trees with diameters from 0.4 below to 0.5 above the class label (for example: the 4 inch class includes all trees 3.6 to 4.5 inches in diameter). The second table gives basal area per acre for each diameter class in each inventory year. The final row of each table gives the sum total for each inventory year. In these tables, dead trees were included in the first inventory after death (but not after). When no diameter was given after death, diameters for dead trees were estimated to be the same as in their last live inventory.

SECTION 3. COMPOSITE STAND AND STOCK TABLES

This section includes four sub-sections:

Stand Tables (Sub-section 3.1). Tables for each inventory year give the number, square foot basal area, cubic foot volume, and board foot volume of trees in each one inch diameter class (4"-45"). Following Avery et al. (1976), we used volume equations from Myers (1972) -- pages 6 and 7 for cubic volume and pages 14 and 15 for board foot volume. "Age Class" (see Section 1 description) was used to classify trees as blackjack or old growth pine for use of Myers' equations. Age Class given in 1960 was used for all following inventory years. The final row of each table gives a sum total for each inventory year. Dead trees were not included in these tables.

Mortality Tables (Sub-section 3.2). Tables for each period between inventories give the number, square foot basal area, cubic foot volume and board foot volume per acre of dead trees in each one inch diameter class (4"-45"). Mortality was calculated from diameters in the inventory year a tree is first recorded as dead (using its last live recorded diameter if no diameter is given in the year of death). The same volume equations as above were used. Again, the final row of each table gives a sum total for each between-inventory period.

Net Periodic Growth Tables (Sub-section 3.3). These tables provide change in number, square foot basal area, cubic foot volume, and board foot volume per acre between inventory years for each one-inch diameter class (4-45). The values in these tables are equal to the difference between the values in their respective bracketing stand tables (for example: Basal Area Per Acre net periodic growth for 12 inch trees in the period 1940 to 1945 equals Basal Area Per Acre for 12 inch trees in 1945 minus Basal Area Per Acre for 12 inch trees in 1940). Negative values indicate that growth for the class was outweighed by mortality or growth of trees into the next class. The final row of each table gives a sum total for each between-inventories period.

Summary Tables (Sub-section 3.4):

Average Annual Diameter Growth by Size Classes (Table 3.4.1). This table shows the average annual diameter growth for all 12 inter-inventory periods by one-inch diameter class (4"-45"). Contrary to the intuitive interpretation, the values reflect the average annual growth of each class to the label diameter, not from, and so include the ingrowth of first-marked trees from 0 (unrecorded) to their diameter when first inventoried. Therefore, the numbers in at least the first two size classes are misleading; they reflect the addition of trees to the survey rather than very large annual growth rates among smaller trees.

Percent of Trees in a Diameter Class Advancing to the Next Diameter Class during the Growth Period (Table 3.4.2). This table could have been more accurately titled "Percent of Trees in a Diameter Class that Advanced from the Previous Diameter Class during the Growth Period." It is outlined like table 3.4.1, and, similarly, reflects percent advancement to the label diameter, not from, and includes first-marked trees.

Mortality for the Period 1920 to 2000 by Diameter Class and Killing Agent (Table 3.4.3). Values in the columns of this table equal the number of trees killed by each agent in each diameter class divided by the total number of trees ever to be included in that diameter class between 1920 and 2000. For example, of all the trees that ever were in the 12 inch diameter class, 1.09 % died in that class, 0.00% because of lightning, 0.17% because of wind, 0.17% because of insects, 0.00% because of rust, etc. The final two rows of the table are labeled "weighted avg" and "percentage." The meaning of "weighted average" remained elusive. We were not able to reproduce the values for 1920-70 printed in Avery et al. (1976). The total number of dead trees under each column heading divided by the total number of trees (3335) was used for the values in this row (this method gave the closest number to that in Avery et al. [1976] when applied to 1920-1970). "Percentage" is the number of trees killed by each cause divided by the total number of dead trees. Note that the percentages in Avery et al.

(1976) do not add up to 100%, so there is a possibility that the numbers printed in the publication are erroneous for both of the final rows.

Stand Table Summary (Table 3.4.4), Mortality Table Summary (Table 3.4.5), and Net Growth Summary (Table 3.4.6). These three tables present as rows the sum total lines of their namesake sub-section tables. Table 3.4.4's final row gives the total change in values from 1920 to 2000 (2000 values minus 1920 values); tables 3.4.5 and 6's final rows give the sum total of all inter-inventory intervals.

Section 4. Composite Stand and Stock Tables for 16 Undisturbed Subplots

This section includes four sub-sections. Sub-sections 4.1, 2, and 3 are organized and calculated identically to their counterparts in Section 3, but use data from the relatively undisturbed subplots only, subplots 1, 2, 4, 5, 7-10, 12, 13, 16, 17, 19-22. Counterparts to the summary tables 3.4.2 or 3.4.3 were not repeated in Section 4. Table 4.4.1 was not calculated the same way as 3.4.1. Instead, we used the average radial growth of trees beginning the period at the given diameter class (for example: trees of the 10 inch class in 1925 grew, on average, 0.20 inches until 1930). This method eliminates the problem of ingrowth explained above, and therefore reflects more realistic growth rates for the smaller trees. Tables 4.4.4-6 are identical to their section 3 counterparts, but with data from undisturbed plots only.

Comparison of tree growth

Mean annual radial growth by size class and inventory period is shown in Figure 1. Radial growth was greatest in small-diameter tree classes. There was a general trend toward declining growth from 1920 to 2000.

Mean annual basal area growth by size class and inventory period is shown in Figure 2. Basal area growth was generally highest in large-diameter tree classes. Like radial growth, basal area growth showed a declining trend from 1920 to 2000.

Growth slowed over the twentieth century from 1920 to 2000. Mean basal area growth by size class in each inventory period is compared in Figure 3. Polynomial curves were fit to the 1920-1925 data and the 1970-1980 data to illustrate the change. In 1920-1925, mean annual basal area growth exceeded 0.02 ft^2 per year for all size classes of trees below 40" dbh. The peak of basal area growth occurred around the 30" dbh class. By the end of the twentieth century, growth had slowed considerably. The decades 1970-1980, 1980-1990, and 1990-2000 had the lowest growth rates, with no size class in 1970-1980 exceeding 0.01 ft^2 per year. Peak growth shifted toward smaller trees; maximal growth occurred around the 16" dbh class.

Discussion

Across all inventory periods, mean annual radial growth was greatest in smaller diameter trees, while basal area growth was highest in larger diameter trees (Figures 1 and 2). These differences are consistent with the geometric effect of adding wood to an increasingly larger stem diameter: much more total wood growth is required to add 1" of tree ring width to a 40" tree than to a 6" tree.

In contrast to radial growth, which varies more with tree size and age, basal area increment provides a relatively stable variable for growth comparison (Biondi 1999). The long-term basal area growth reduction we observed (Figure 3) matched the findings of Biondi et al. (1994) and Biondi (1994). Since no changes in temperature or precipitation were found from 1920 to 1990, Biondi (1996) attributed the growth decline to increased competition as the numerous young trees grew.

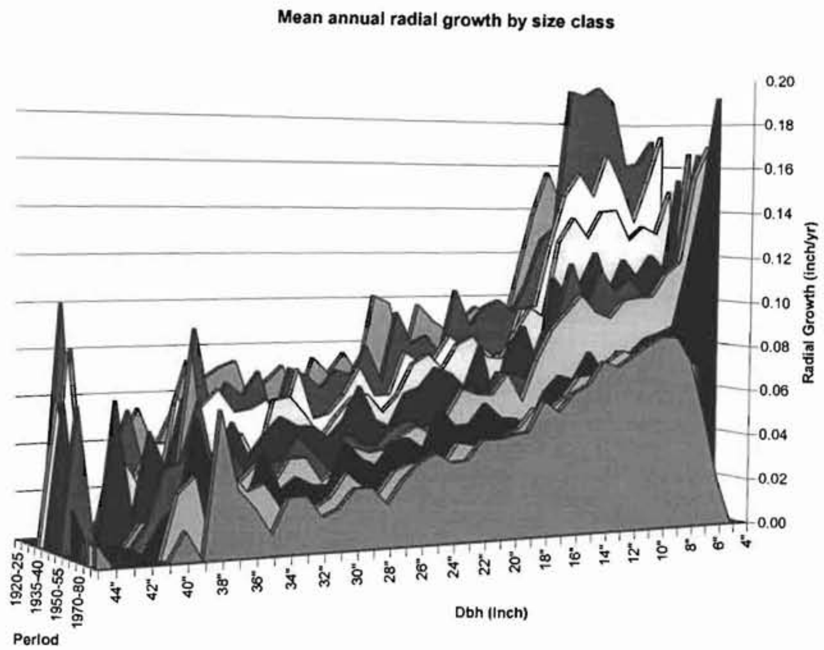

Figure 1. Mean annual radial growth by size class by measurement period.

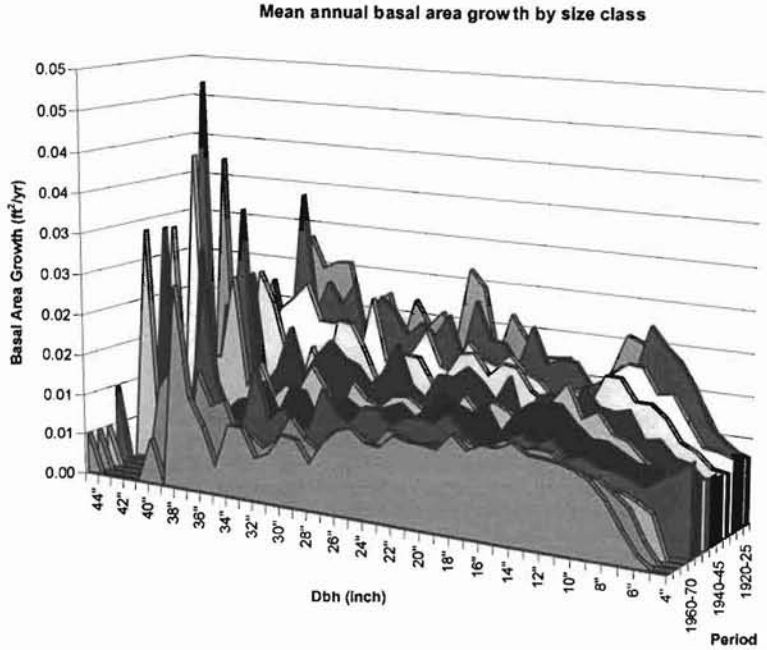

Figure 2. Mean annual basal area growth by size class by measurement period. In contrast to radial growth patterns shown in Figure 1, basal area declined less during the twentieth century. Large trees contributed a relatively greater proportion of basal area growth than radial growth.

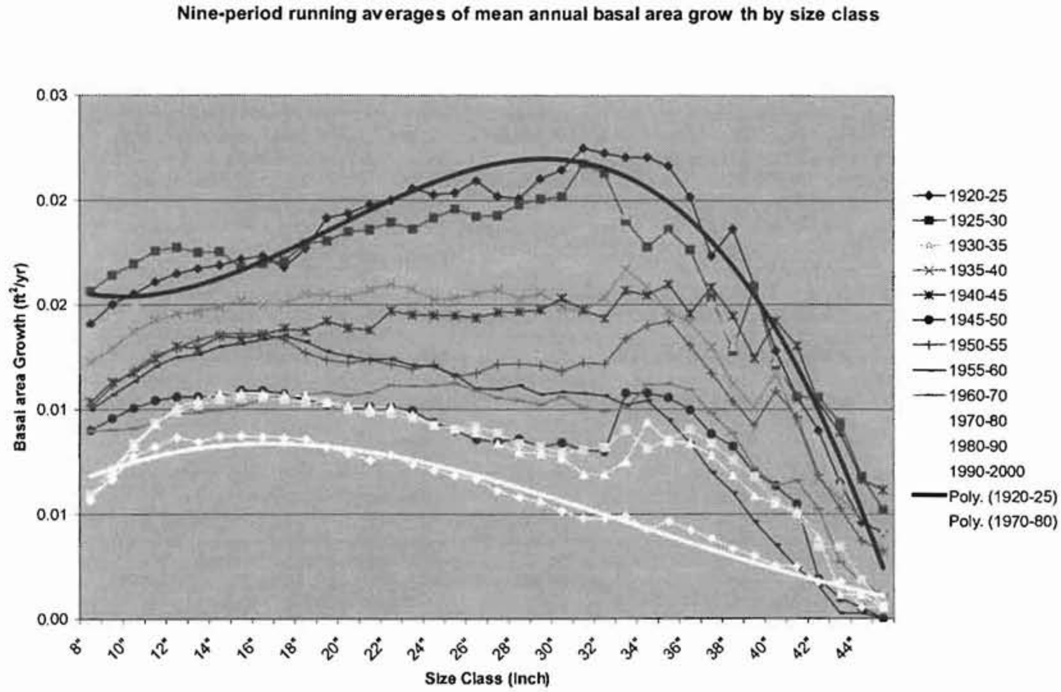

Figure 3. Changes in patterns of basal area growth from 1920 to 1990. Growth declined throughout the twentieth century and peak growth shifted from larger to smaller trees.

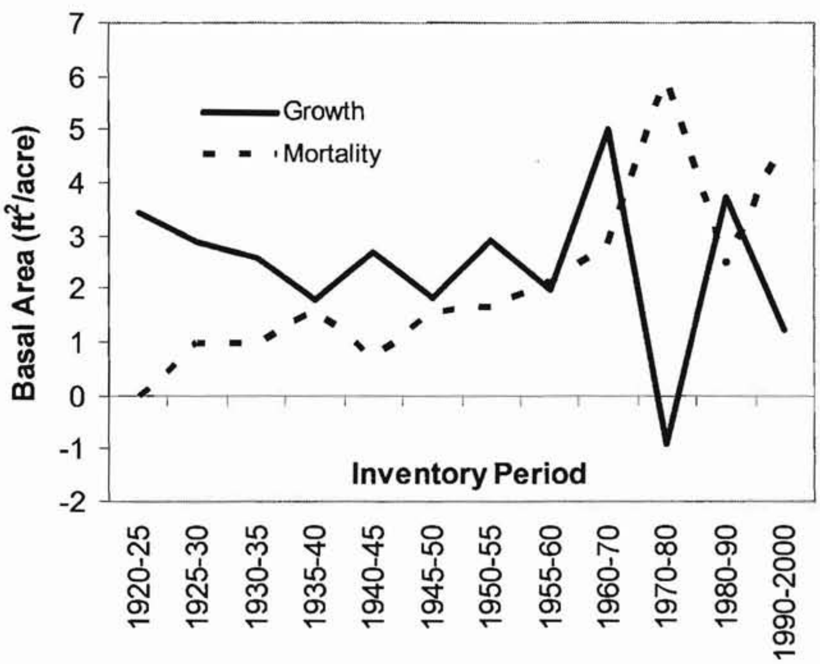

Figure 4. Changes in growth and mortality 1920-2000 in sixteen relatively undisturbed subplots (data from Section 4).

Gus Pearson (1944) foresaw the effects of competition while the young trees were still small:

> "Notwithstanding a marked superiority of the cut-over stand, growth in the virgin stand was by no means negligible. Even in diameter classes above 30 inches, growth continued at a rate well over a half-inch per decade, which in trees of this size means considerable volume increment.... The reason is that most of them are partially isolated. Now that reproduction has come in, young trees will claim an ever increasing share of the meager moisture supply which the veterans were able to monopolize as long as fire and grazing prevented regeneration. It is to be expected that another 20 years will witness a marked decline in the growth of large trees."

On the 16 relatively undisturbed subplots (Section 4), basal area growth per acre fluctuated widely after 1960 (Figure 4). Peaks in mortality coincided with minimal growth in the 1970-80 and 1990-2000 periods. Mortality on the undisturbed subplots peaked at about 6 ft^2/acre in 1970-80 (see Figure 5 and Mast et al. 1999).

In 2001, the Fort Valley area might be nearly unrecognizable to the forest research pioneers of 1909. Housing developments now butt up against the Experimental Forest headquarters, U.S. highway 180 is a major route to Grand Canyon (Figure 6), and recreationists crowd the forest roads. But the period that has brought so much human-caused change to northern Arizona is short in the lifespan of the ponderosa pines. The foresight of the foresters who created the long-term studies in Fort Valley has produced benefits for those who seek to understand ecological change and restore sustainable conditions.

Figure 5. Repeated photographs from 1938 (G.A. Pearson, photo number 365735) and 2000 (J.D. Waskiewicz) illustrate mortality of several of the mature trees. Trees numbered 1 and 3 in the 1938 photograph are now snags. Trees numbered 2 and 6 are dead and down.

Figure 6. Widening of U.S. highway 180 obliterated many Gus Pearson Natural Area trees along the right-of-way.

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Appendix 1: Code interpretations, 2000 inventory

This list was developed for the 1990 inventory directed by C.C. Avery. Our comments from the 2000 inventory are in parentheses.

Code

00 - No apparent defect or fault; (We used this code if a tree showed no defect or damage covered by the other codes. Note that there is no code for flat-topped or sparsely foliated. An 00 tree isn't necessarily perfect, it just isn't inflicted by anything covered by the other codes.)

01 - Unmerchantable – fork or crotch; Unable to get at least one 18 foot section of straight board out of it. (We used this code rarely, since code 02 seems to cover forks and crotches below 18 feet. We reserved 01 for particularly low or ugly forks)

02 - Fork or crotch below 18 feet; (See below. 18 feet was not measured, just estimated.)

03 - Fork or crotch above 18 feet; (See above. "Fork or crotch" was never clearly defined for us, so it was left somewhat to subjective interpretation. We determined that a fork or crotch must do one of two things: either compete at the tree top with the main leader stem, such that the two can't be distinguished by height, or cause the main stem to curve, bend, or change angle at the point of the fork. These things distinguish a fork or crotch from a mere large or high-angle branch. We felt that many trees coded as forked in 1990 were mis-coded in this way.)

04 - Suppressed; A tree that has been overtopped and shows signs of competition from other trees for light and water. (We generally used this only for trees that were clearly overtopped and appeared to be having their growth hindered by bigger trees.)

05 - Pruned (natural); (We really don't understand what this is supposed to mean, and we didn't use it.)

09 - Merchantable – spike top; (A tree having a dead main stem starting at least 18 feet above the ground.)

10 - Unmerchantable – spike top or complete girdle below 18 feet; (This is self-explanatory.)

11 - Unmerchantable – crook or sweep; Less than 18 feet of merchantable wood. (Not being entirely sure what constitutes "merchantable" wood, this was a fairly subjective interpretation for us. We used it only for the worst trees – those that we couldn't imagine going through a sawmill.)

12 - Unmerchantable – limby; We decided to only use this as a secondary condition rather than a primary one. (We never actually used this one, but suspect that it could only be for a tree that is clothed in large diameter branches all the way to ground. It appears to have been used only once or twice in 1990, and inconsistently at that.)

13 - Leans more that 4 degrees from vertical; (This is pretty self-explanatory. A leaning tree is straight, but diagonal [vs. a sweep, which is often diagonal, but not straight]. We did not measure actual lean on any trees, however, just estimated visually.)

14 - Merchantable – crook or sweep; (If we overused a code, it was this one. This tends to be a rather subjective call. We used it for anything that was not crooked enough to be a code 11, but still clearly not straight. A crook is a relatively sharp bend in the trunk; a sweep is a long bow over the bole's whole length.)

15 - Limby – merchantable; Those trees that have an excessive number of limbs all the way down the tree but still has a merchantable, straight bole. (This code was added in 1990, and only really used once or twice in that inventory, very inconsistently. We did not use it at all.)

16 - Grown together at DBH; Those trees which have grown together and are unable to be measured individually at DBH (tag height). The individual trees should be measured at the lowest point possible if feasible. (This code was added in 1990. It was used a number of times, and, except for tree 9-212, the given directions were followed.)

20 - Mistletoe – light in crown; (This and the other mistletoe codes seem to have been much overused by previous inventory crews. We found these codes on many trees that showed no evidence whatsoever of having ever hosted the dwarf-mistletoe parasite. We found mistletoe only in a few subplots, mostly on the northern end of the natural area. We used mistletoe codes only when the plant was actually visible to the eye. We drew the line between light and heavy subjectively at an approximate estimated DMR of 3).

21 - Mistletoe – heavy in crown; (See above.)

22 - Mistletoe – light on bole; (See above. We drew the line between light and heavy subjectively based on the number of plants seen on the bole.)

23 - Mistletoe – heavy on bole; (See above.)

24 - Mistletoe – on bole and crown; (See above.)

25 - Mistletoe – top dead; (We did not actually use this. Must be certain that cause of top death was mistletoe.)

30 - Squirrel – light damage; We would base this on the amount of activity seen from a squirrel as evidenced by numbers of squirrel eaten twigs on the ground. (We used code 30 and 37 whenever any squirrel clippings were found underneath a tree, regardless of whether there was any visible damage to the tree's crown. Must be certain the clippings come from the tree being given the code, however, and not a tree next to it. We drew the line between code 30 and 31 subjectively based on the number of clippings seen. Note: in the 2000 inventory, snow covered squirrel damage evidence for much of the survey period.)

31 - Squirrel – medium damage; There would have to be an exorbitant amount of twigs and "bones" on the ground – more than a dozen. (See above.)

32 - Squirrel – heavy damage; Chose not to use this code. (We did not use it either.)

33 - Porcupine – partial girdle in crown; (We used this code when bark was chewed off part – way around the stem within the tree crown.)

34 - Porcupine – partial girdle below crown; (We used this code when bark was chewed off part – way around the stem below the tree crown.)

35 - Porcupine – complete girdle; (Used when the porky chewed bark off all the way around the stem, either within or below the crown. We actually caught one of the critters in the act in the 2000 inventory.)

36 - Squirrel – nest tree; When a squirrel nest is seen in the tree. (This code was added in 1990. A squirrel nest looks like a big, loose, sloppy ball of twigs and needles, about basketball size or a little bigger.)

37 - Squirrel – food tree; (This code was also added in 1990. We used it for any tree coded 30 or 31.)

38 - Bird – excavated cavities; (We added this code in 2000 to indicate if a tree had cavity-nesting sites. Excavated cavities differ from natural ones in that they have smooth, round edges and are not knotholes.)

39 - Bird – drilling on bole; (We added this code in 2000 to indicate if a tree had been used by a bole-foraging bird. We included sapsucker well drillings as well as deeper woodpecker drillings.)

40 - Rust – new in crown; Ascertained that this referred to limb rust. Important Note: When limb rust and mistletoe are present in same tree, limb rust will take precedence in condition class because it is a direct cause of mortality. Mistletoe is predominantly responsible for growth reduction. (We used this code on trees that showed dead limbs in the crown that did not appear to have other cause to be dead (not overshadowed). We drew the line between new and old in crown by a subjective assessment of the number of dead branches in the crown.)

41 - Rust – advanced in crown; Same as in code 40. (See above.)

42 - Rust – new in bole; Chose not to use this code as bole rust is very unlikely to be seen (Information from Dr. Wagner, NAU). (We did not use this one either.)

43 - Rust – advanced in bole; Same as in code 42. (See above.)

44 - *Elytroderma* (needle blight) in crown; (We did not know what this is. A tree coded in 1990 as having it displayed an odd witches' broom in the crown (not mistletoe – induced), and we used this as an indicator for other trees.)

45 - Red rot (white conks on bole); (Used for trees with white conks on bole.)

46 - Other heart rot; (Did not use, but would have for conks not of red rot.)

50 - Tipmoth – light; Chose not to use this code as it only affects smaller trees that are not present in our inventory. (We did not use this code either.)

51 - Tipmoth – heavy; Same as in code 50. (See above.)

52 - *Dendroctonus* present; Small pitch tubes (1/8") from DBH on up the bole (Information from Dr. Wagner, NAU). (We used this code when pitch tubes generally extended above BH.)

53 - *Ips* present; Top of crown yellowing or dead (Information from Dr. Wagner, NAU). (Since many things can cause a treetop to die, we did not use this unless we felt certain it was caused by pine engraver, which we never did.)

54 - Turpentine beetles present; Pitch tubes (1/4") with grass around base of tree on up to DBH (Information from Dr. Wagner, NAU). (Used this code when pitch tubes found generally below BH.)

55 - Shoot moth present; Chose not to use this code as they are very unlikely to occur (Information from Dr. Wagner, NAU). (We did not use this code either.)

60 - Lightning – top dead; (Must be certain that top was killed by lightning.)

61 - Lightning – bole split; (Used when lightning has actually split out a chunk of bole, not merely killing a streak of bark.)

62 - Lightning – scar on one-quarter bole; The scar is <= one quarter of the bole in circumference, not height. (Used when width of lightning streak covers up to a quarter of the tree's circumference.)

63 - Lightning – scar on over one-quarter bole; The scar is greater than one quarter of the bole in circumference, not height. (Used when width of lightning streak covers over a quarter of the tree's circumference.)

64 - Fire scar on one-quarter bole at base; (Wood must be exposed to be a fire scar – mere char on a bole does NOT constitute a scar. Width of scar covers up to one quarter of tree's basal circumference.)

65 - Fire scar on over one-quarter bole at base; (See above. Width of scar covers over a quarter of tree's basal circumference.)

66 - Fire – bark burnt on one-half bole at base; (We felt that this should refer to fire-caused damage, so, again, mere char doesn't count – the tree has to be damaged. For code 66, the damage must extend around about a half of the tree's basal circumference.)

67 - Fire – bark burnt completely at base; (See above. Damage must extend completely around tree base.)

70 - Snowbend – less than 30 degrees from vertical; This is hard to determine because it usually affects smaller trees not in our inventory. Must be certain beyond a doubt that snow was the causal factor of bend. (It is hard to be certain beyond a doubt of any such thing, especially without snow on the ground. We used snowbend codes only for trees that were so coded in 1990, or that we could see were pinned under a load of snow.)

71 - Snowbend – from 30 to 45 degrees from vertical; Same as in 70. (See above.)

72 - Snowbend – more than 45 degrees from vertical; Same as in 70. (See above.)

73 - Snow – top broken; Must be certain beyond a doubt that snow broke top. (See above).

74 - Wind – top broken; Must be certain beyond a doubt that wind broke top. Other trees in immediate area having same condition is good indication. (Used only when so coded in 1990.)

76 - Lightning – top broken; Must be certain beyond a doubt that lightning broke top. (See above.)

77 - Mechanical damage – kind; When a tree has a scar on it from an automobile, another tree falling on it, or any other form of physical damage (abiotic). Source of mechanical damage should be noted in comments column of data sheet. (Used for any mechanical damage not covered in other codes. Specified when we could. Must be actual damage. Scuffed up bark doesn't count – must actually wound tree.)

90 - Killing agent – lightning; Use only if lightning is the most obvious killing agent. (This and other killing agent codes were applied only to trees having died between the previous inventory and ours. Must be certain that cause of death is the killing agent specified.)

91 - Killing agent – wind; (See above.)

92 - Killing agent – insects; (See above.)

93 - Killing agent – rust; (See above.)

94 - Killing agent – dwarf mistletoe; (See above.)

95 - Killing agent – suppressed; (See above.)

96 - Killing agent – root rot; (See above.)

98 - Killing agent – other identifiable agents (squirrel, snowbend); (Specify. May include fire, cutting, mechanical damage...)

99 - Killing agent – unidentified agent; Use when no single killing agent can be absolutely determined. (Most commonly used killing agent code – usually we couldn't tell at all, let alone with certainty.)

Sections 1-4: Individual Tree and Summary Data

The following sections 1 through 3 present individual tree data (section 1) and summary data (section 4) following the same format used by Avery et al. (1976). Sections 1, 2, and 3 are based on data only from subplots 1-14, 16, and 27, as in Avery et al. (1976). Section 4 is a new summary of plot data from the 16 subplots that have been least affected by road construction or the restoration experiment, subplots 1, 2, 4, 5, 7-10, 12, 13, 16, 17, 19-22. A detailed description of each section is presented below.

Section 1. Individual Tree Data

This list includes records for each individual tree in subplots 1-14, 16 and 27. Diameter recorded in each inventory year and condition code in each inventory year is given for each tree. Each tree was assigned to an "age class" in 1920, 40, and 60, reflecting whether the tree was judged to be a "blackjack" (code 1) or "yellow pine" (code 2). There is no age class data from 1980 or 2000 inventories. "Age-vigor" is also given for each tree for four periods. Period I is 1925-40, II is 1940-55, III is 1955-70, and IV/V is 1970-2000 (an average of two 15-year periods). Age-vigor is a two digit code: the first classifies trees by "Age Code" and the second by "Vigor-Code" (Avery et al. 1976). There was no data on "Age Code" after 1970 so that digit blank was left blank in Period IV/V. Since there was no inventory in 1985, vigor code in Period IV/V was estimated as half the difference in diameter between 2000 and 1970. Each tree also received a number in its row for plot number (all are plot 61), subplot number (1-14, 16 and 27), and individual tree number (consecutive for each subplot).

Section 2. Subplot Summary Data

This section includes summaries of each of the 16 subplots 1-14, 16 and 27. Each subplot has two tables, the first giving the stem count per acre for each one inch diameter class (4"-50") in each inventory year. Diameter classes are defined as including all trees with diameters from 0.4 below to 0.5 above the class label (for example: the 4 inch class includes all trees 3.6 to 4.5 inches in diameter). The second table gives basal area per acre for each diameter class in each inventory year. The final row of each table gives the sum total for each inventory year. In these tables, dead trees were included in the first inventory after death (but not after). When no diameter was given after death, diameters for dead trees were estimated to be the same as in their last live inventory.

Section 3. Composite Stand and Stock Tables

This section includes four sub-sections:

Stand Tables (Sub-section 3.1). Tables for each inventory year give the number, square foot basal area, cubic foot volume, and board foot volume of trees in each one inch diameter class (4"-45"). Following Avery et al. (1976), we used volume equations from Myers (1972) -- pages 6 and 7 for cubic volume and pages 14 and 15 for board foot volume. "Age Class" (see Section 1 description) was used to classify trees as blackjack or old growth pine for use of Myers' equations. Age Class given in 1960 was used for all following inventory years. The final row of each table gives a sum total for each inventory year. Dead trees were not included in these tables.

Mortality Tables (Sub-section 3.2). Tables for each period between inventories give the number, square foot basal area, cubic foot volume and board foot volume per acre of dead trees in each one inch diameter class (4"-45"). Mortality was calculated from diameters in the inventory year a tree is first recorded as dead (using its last live recorded diameter if no diameter is given in the year of death). The same volume equations as above were used. Again, the final row of each table gives a sum total for each between-inventory period.

Net Periodic Growth Tables (Sub-section 3.3). These tables provide change in number, square foot basal area, cubic foot volume, and board foot volume per acre between inventory years for each one-inch diameter class (4-45). The values in these tables are equal to the difference between the values in their respective bracketing stand tables (for example: Basal Area Per Acre net periodic growth for 12 inch trees in the period 1940 to 1945 equals Basal Area Per Acre for 12 inch trees in 1945 minus Basal Area Per Acre for 12 inch trees in 1940). Negative values indicate that growth for the class was outweighed by mortality or growth of trees into the next class. The final row of each table gives a sum total for each between-inventories period.

Summary Tables (Sub-section 3.4):

Average Annual Diameter Growth by Size Classes (Table 3.4.1). This table shows the average annual diameter growth for all 12 inter-inventory periods by one-inch diameter class (4"-45"). Contrary to the intuitive interpretation, the values reflect the average annual growth of each class *to* the label diameter, not from, and so include the ingrowth of first-marked trees from 0 (unrecorded) to their diameter when first inventoried. Therefore, the numbers in at least the first two size classes are misleading; they reflect the addition of trees to the survey rather than very large annual growth rates among smaller trees.

Percent of Trees in a Diameter Class Advancing to the Next Diameter Class during the Growth Period (Table 3.4.2). This table could have been more accurately titled "Percent of Trees in a Diameter Class *that Advanced from* the *Previous* Diameter Class during the Growth Period." It is outlined like table 3.4.1, and, similarly, reflects percent advancement *to* the label diameter, not from, and includes first-marked trees.

Mortality for the Period 1920 to 2000 by Diameter Class and Killing Agent (Table 3.4.3). Values in the columns of this table equal the number of trees killed by each agent in each diameter class divided by the total number of trees ever to be included in that diameter class between 1920 and 2000. For example, of all the trees that ever were in the 12 inch diameter class, 1.09 % died in that class, 0.00% because of lightning, 0.17% because of wind, 0.17% because of insects, 0.00% because of rust, etc. The final two rows of the table are labeled "weighted avg" and "percentage." The meaning of "weighted average" remained elusive. We were not able to reproduce the values for 1920-70 printed in Avery et al. (1976). The total number of dead trees under each column heading divided by the total number of trees (3335) was used for the values in this row (this method gave the closest number to that in Avery et al. [1976] when applied to 1920-1970). "Percentage" is the number of trees killed by each cause divided by the total number of dead trees. Note that the percentages in Avery et al. (1976) do not add up to 100%, so there is a possibility that the numbers printed in the publication are erroneous for both of the final rows.

Stand Table Summary (Table 3.4.4), Mortality Table Summary (Table 3.4.5), and Net Growth Summary (Table 3.4.6). These three tables present as rows the sum total lines of their namesake sub-section tables. Table 3.4.4's final row gives the total change in values from 1920 to 2000 (2000 values minus 1920 values); tables 3.4.5 and 6's final rows give the sum total of all inter-inventory intervals.

Section 4. Composite Stand and Stock Tables for 16 Undisturbed Subplots

This section includes four sub-sections. Sub-sections 4.1, 2, and 3 are organized and calculated identically to their counterparts in Section 3, but use data from the relatively undisturbed subplots only, subplots 1, 2, 4, 5, 7-10, 12, 13, 16, 17, 19-22. Counterparts to the summary tables 3.4.2 or 3.4.3 were not repeated in Section 4. Table 4.4.1 was not calculated the same way as 3.4.1. Instead, we used the average radial growth of trees beginning the period at the given diameter class (for example: trees of the 10 inch class in 1925 grew, on average, 0.20 inches until 1930). This method eliminates the problem of ingrowth explained above, and therefore reflects more realistic growth rates for the smaller trees. Tables 4.4.4-6 are identical to their section 3 counterparts, but with data from undisturbed plots only.