GROWTH AND YIELD OF UPLAND HARDWOODS IN SOUTHERN INDIANA

James D. Schroering and Burnell C. Fischer[1/]

Abstract.--Although growth and yield parameters are valuable tools in estimating growth and assessing management strategies, they are rarely available for upland hardwoods. In 1953, 69 - 1/5 acre continuous forest inventory (CFI) plots were established at the Southern Indiana Purdue Agricultural Center (SIPAC). The 69 CFI plots were remeasured in 1956, 1962, 1966 and 1980. The objectives of this study were to analyze the 27 years of growth data from the SIPAC plots.

The SIPAC woodlands are typical of the unmanaged woodlands in the area. The old growth was harvested in 1914, with two additional high-grading harvests in 1932 and 1952. Timber stand improvement with herbicides was performed in the late 1950's, and subsequently, limited timber sales and cultural activities have been periodically conducted to improve the woodlands and stocking.

The total number of trees 9.0" DBH and greater at SIPAC increased 71 percent from 8,605 trees in 1953 to 14,735 trees in 1980. Although the number of red and white oak stems increased, their corresponding percent of the total trees decreased slightly. The percentage of maple increased dramatically, while the percentage of beech declined. Initially, the average stocking was 1,224 Doyle and 2,139 International 1/4" bd. ft. per acre. By 1980, the average stocking had increased to 2,709 Doyle and 4,334 International 1/4" bd. ft. per acre. Annual per acre board foot growth averaged 60 Doyle and 86 International 1/4" in the 1953-56 growth period and increased to 97 and 137 board feet respectively in the 1966-80 growth period. These board foot growth rates are similar to another southern Indiana study but much lower than the Soil Conservation Service productive potentials for the site.

Keywords: Upland hardwoods, growth and yield, CFI.

INTRODUCTION

Woodlands in southern Indiana are typically undermanaged and found on sites unsuitable for agriculture. The history of such woodlands has been periodic grazing, burning and high grading. The current management strategy to reverse the long term degradation process resulting from this past mis-

---

[1/] Graduate Research Assistant and Associate Professor, Department of Forestry and Natural Resources, Purdue University, West Lafayette, Indiana

management involves "improving" the existing stand conditions through time by various combinations of timber stand improvement and partial ("selective") cutting.

Although growth and yield parameters are valuable tools in estimating growth and assessing management strategies, they are rarely available for upland hardwoods. This is unfortunate, because present day management practices have "evolved" to a point where new or "radical" departures from "normal" management procedures are difficult to evaluate or promote. Thus, the objectives of this study were to summarize and analyze the 27 years of growth data from a continuous forest inventory system at the Southern Indiana Purdue Agricultural Center.

LITERATURE REVIEW

Land managers require continuous, accurate data from field inventories in order to properly manage forest resources. Data essential for modern forest management include estimations of growth, stocking, numbers of trees present and species composition. A scientific, practical and efficient method of obtaining these parameters is through the implementation of a continuous forest inventory system.

Continuous forest inventory (CFI) was originally developed in Europe, but was first applied in the United States in the Midwest in 1937. Stott and Semmens (1960) define CFI as follows:

> Continuous forest inventory is a precise, frequently repeated, and directly comparable measurement of all commercial trees in systematically placed sample plots. These plots have fixed radii and are permanently located in the forest. Their treatment, and the treatment of the surrounding forest must be analogous.

Although Stott and Semmens, in conjunction with Region 9 of the U.S. Forest Service's State and Private Sector, had a strong influence on the circulation, expansion and improvement of CFI, a literature search has failed to locate a significant number of published results of growth and yield of typical stands of upland Central Hardwoods. An even fewer number of researchers have published their results in the Doyle Log Rule, the log rule most commonly used by industrial, private and state foresters in the Central Hardwood Region.

Schnur (1937) developed a comprehensive set of yield, stand and volume tables for even-aged upland oak forests in the Midwest and Appalachian regions. However, none of the study plots were located in Indiana. In an unpublished report, Beers and Hall (1960), utilizing a system of continuous forest inventory plots, reported stocking, growth and statistical results for the Morgan-Monroe State Forest in south-central Indiana, and the Harrison-Crawford State Forest in southern Indiana.

Although not directly addressing the subject of board foot growth of unmanaged upland hardwood stands, several researchers have published results of studies dealing with yield from stands under various stages of management. Dale (1972) developed regression equations for growth and yield estimates of

upland oak stands in the Midwest. However, his work dealt with growth responses 10 years after initial thinning. Gingrich (1971a) documented yields by stand age and site index for both thinned and unthinned upland oak stands as part of a field guide for the management of young and intermediate upland hardwood stands. Gingrich (1971b) also summarized expected net basal area growth per acre per year for even-aged upland oak stands by stocking percent and stand age. Results showed net basal area growth decreased with stand age and was greatest between 50-60 percent stocking.

Smith and Lamson (1977) reported board foot, cubic foot and basal area yield results in conjunction with a 9.0 inch diameter limit first cutting in Appalachian hardwoods. Beck and Della-Bianca (1970) developed yield estimates for unthinned, natural stands of yellow poplar by an analysis of diameter distributions, tree heights and tree volumes based on height and diameter. In another study, Watson (1979) summarized growth data from a large system of CFI plots established on woodlands owned by the University of Tennessee, and utilized a summary procedure similar to that of Beers and Hall (1960) and Beers (1962).

All the previously mentioned authors summarized their board foot stocking and growth results in the International 1/4" board foot log rule. Bramble and Fix (1980), however, published their findings on the productivity of a managed woodland in the Doyle log rule, using repeated 100% inventories of a 38.3 acre northern Indiana woodland. Their justification for evaluating board foot volume and growth in this particular log rule was familiarity of the Doyle log rule by foresters, loggers and mill operators.

STUDY AREA

The study woodlands are located on the Southern Indiana Purdue Agricultural Center in Dubois County, in southern Indiana. SIPAC is presently 1,321 acres, of which 635 acres are forested. The 13 woodlands in this project make up the majority of the original forest acreage on the farm when Purdue University acquired the property in 1953.

The SIPAC woodlands are typical of the unmanaged woodlands in the area. The old growth was harvested in 1914, with two additional high-grading harvests in 1932 and 1952. The area had a history of fire and livestock grazing prior to 1953. Since Purdue University acquired the property in 1953, the overall woodland management objectives have been to protect the woodlands from fire and grazing and to increase the stocking of high quality pole and sawtimber trees. The former objective has been achieved through an extensive fencing program on the property and good landowner cooperation. The later objective has been partially accomplished through unevenaged stand management involving timber stand improvement in the late 1950's, and subsequently, with limited timber sales to remove mature, cull and undesirable trees.

The soils of SIPAC belong to the Gilpin-Zanesville-Berkes association. These soils are well drained and moderately deep to deep, found on moderately sloping to very steep upland sites. Slopes on the study area range from 0 to 30 percent. These soils are commonly found in the unglaciated sandstone-shale soils region of south-central Indiana. The soils in this region formed in residuum of sandstone, siltstone and shale from the early Pennsylvania age. During Late Wisconsin time, loess, ranging in depth from a few inches to

several feet, was deposited over the entire area. Most of the silt was washed away on the steeper slopes, but on the less sloping soils it remained and is part of the soil profile (Wingard 1980).

Gilpin silt loams and the Gilpin-Berkes complex are moderately deep, well drained upland soils occurring on 18 to 50 percent slopes. The silt loam surface layer, typically 6 inches thick, has a moderate organic matter content and is friable. In many areas, the original surface layer has been eroded away, resulting in a surface layer composed of channery clay loam. The subsoil is about 22 inches thick and composed of friable channery silt loam, firm channery clay loam, friable clay loam and friable channery loam. Rippable sandstone and shale bedrock are found below depths of 26 to 28 inches. Most areas of the Gilpin-Berkes complex are forested.

Zanesville silt loams are deep, well drained upland soils occurring on 6 to 12 percent slopes. The silt loam surface layer, typically 5 to 9 inches thick, has a low to moderate organic matter content. Due to severe erosion of the original surface layer, the present surface layer in many areas is composed of silty clay loam. The subsoil ranges from 47 to 56 inches in depth and is composed of firm, friable silt loam, silty clay loam and loam. A very firm, brittle fragipan composed of silty clay loam, located at a depth of 24 to 42 inches, restricts the downward movement of roots and water, often causing saturation in winter and spring. Stratified sandstone, shale bedrock and clay shale are found below depths of 61 to 79 inches (Wingard 1980).

The Soil Conservation Service (SCS) estimates the site index (age 50) ranges of these soils to be the following:

Soils Series	Common Trees	Site Index
Gilpin	Upland Oak	70-80
	Yellow Poplar	75-95
Zanesville	Upland oak	60-80
	Yellow Poplar	85-95
Berkes	Upland Oak	60-80
	Yellow Poplar	70-80

Collected site index data for these woodlands are: 1) white oak- 70; and 2) red oak- 69. Ages of sampled white oaks ranged from 44-79 years, while red oaks ranged from 50-65 years. Site index curves by Carmean (1971) were used.

The SCS also estimates the productive potential (Doyle board feet per acre per year) of these soils by timber type. The productive potentials apply to fully stocked, evenaged, unmanaged stands, and are estimated for the major timber types found on the associated soils. The two SCS timber types found on upland soils in Dubois County are upland oak and yellow poplar. Upland oak is the dominant timber type and is found on moderately well and well drained upland soils. It consists of mixtures of all upland oaks and includes various mixtures of hickory, ash, sugar maple and yellow poplar. The yellow poplar type is more restricted and found mainly on cooler north and northeast facing slopes and in narrow valleys and coves. Other species associated with this type are the red and white oaks, hickory, beech, ash, black walnut and sugar

maple. The SIPAC woodlands reflect a mixture of these two SCS timber types, with upland oak predominating.

The productive potentials for the soils series found at SIPAC are as follows:

Soil Series	Timber Types	Productive Potential (Doyle Rule) Bd. Ft./A./Yr.
Gilpin	Upland Oak	185-260
	Yellow Poplar	220-370
Zanesville	Upland Oak	185-260
	Yellow Poplar	300-375
Berkes	Upland Oak	185-260
	Yellow Poplar	185-260

METHODS

The CFI plots at SIPAC were established in 1953. The 0.2 acre circular plots were laid out in a systematic fashion, with a random starting point for each of 13 separate woodlands. The original 69 plots represent 5.5% of the total acreage in the sampled woodlands. The plot centers and accompanying milacre regeneration plots were permanently marked. Distance between plots ranges from 1 1/2 to 8 chains.

The initial tree measurements were recorded in the winter of 1953-1954. Four subsequent remeasurements were made in the winters of 1956-1957, 1962-63, 1966-67 and 1980-81. Data collected at each plot included: 1) plot data - wood's number, plot number, aspect, slope and other site factors; 2) tree data (for trees 9.0 inches DBH and greater) - tree number, species code, diameter, pulpwood height to a 4" diameter, sawtimber height to a 10" top d.i.b. or major defect, log characteristics (d.i.b., length, Purdue log grade), tree class, soundness and tree status; 3) sapling/pole-sized tree data (for trees 3.0 to 9.0 inches DBH) - species code and diameter class (4, 6 or 8 inch class); and 4) regeneration data from milacre plot located in each CFI plot - species code, diameter, height, origin, form and vigor.

The sapling/pole-sized tree data were collected only in 1962 and 1980. Regeneration data were collected in 1953-54, 1966-67 and 1980-81, but were not analyzed in this study. All other data were recorded for each measurement. Data were stored and processed on the Purdue University Computer System.

Prior to 1980, no attempt had been made to correct inventory errors made in the field or processing and keypunching errors made in the office. However, in 1980, an error check program was written to search through the comparisons of the measurements between 1953-1956, 1956-1962, 1962-1966 and 1966-1980, and enumerate specific data elements that were incorrect. Absolute errors found included incorrect woods', plot and tree numbers, decreases in diameter, impossible status code combinations and incorrect species' codes. Errors of this type were easily identified and corrected.

Another set of "questionable" errors was found by the error check program. These errors included decreases in both merchantable height and soundness. If an error of this type was found, a separate listing of that tree's individual characteristics was generated over its life history since 1953. If a definite trend was seen in the data, no corrections were made. However, if the tree characteristic displayed sporadic increment and decrement, the tree parameter was adjusted in a logical manner. Most of these "questionable" errors were the result of employing eight different individuals over the past 27 years for the field inventory work.

Sawlog merchantability limits were changed during the 27 year measurement period. In 1953 and 1956, merchantable sawlog material was recorded to an 8" top d.i.b. However, from 1962 to the present, merchantability was raised to a 10" top d.i.b. in order to more correctly reflect local sawlog utilization standards. The problem was corrected by adjusting the 1953 and 1956 sawlog heights in conjunction with taper correction tables and procedures adapted from Mesavage and Girald (1946) and Husch et al. (1972). If sawlog heights had not been adjusted, volume of ingrowth would have been underestimated and survivor growth volume would have been overestimated.

Summary programs were written in response to specific problems relating to woodland management and the study of growth and yield of upland hardwoods. Specific programs written included individual tree, plot, woods' and species' summaries. Each program summarized the changes in number of trees, basal area, cubic feet and Doyle and International 1/4" Board Feet by the following status codes: mortality, timber stand improvement (TSI), ingrowth, pulpwood, sawtimber, cull, and cut. Woods', plot and per acre totals for each category were summarized according to the following types and components of forest growth (Beers 1962):

Types of Growth;

Gross growth of initial volume (i.e. survivor growth) (Gg)

Gross growth including ingrowth (Gg+I)

Net growth of initial volume (Gn)

Net growth including ingrowth (Gn+I)

Net increase (Gd)

Components of Growth;

V_{S1} = initial volume of survivor trees

V_{S2} = final volume of survivor trees

M = initial volume of trees dying during the period between inventories

C = initial volume of trees which were cut during the period between inventories

I = volume of trees at the second inventory which were below merchantable size at the first inventory

Growth Equations;

$Gg = V_{S2} - V_{S1}$

$Gg+I = Gg + I$

$Gn = Gg - M$

$Gn+I = Gn + I$

$Gd = Gg + I - M - C$

Formulas for specific volumes used include:

BASAL AREA (BA)

$BA = .005454D^2$ (Husch et al. 1972)

where: D = diameter at breast height

CUBIC FOOT VOLUME (CF)

$$CF = 92 \cdot \frac{D^2(D+190)}{100,000} \cdot \frac{1}{100} \cdot \frac{H(168-H)}{64} + \frac{32}{H}$$ (Beers 1964)

where: H = height in feet; and
D = diameter at breast height

DOYLE BOARD FOOT VOLUME (DBF)

$$DBF = (0.55743L^2 + 41.51275L - 29.37337) + (2.78043 - 0.04516L^2 - 8.77272L)D + (0.04177 - 0.01578L^2 + 0.59042L)D^2$$

(Mesavage and Girald 1946; Wiant and Castaneda 1977)

where: L = number of 16 foot logs; and
D = diameter at breast height

INTERNATIONAL BOARD FOOT VOLUME (IBF)

$$IBF = (1.52968L^2 + 9.58615L - 13.35212) + (1.79620 - 0.27465L^2 - 2.59995L)D + (.04482 - 0.00961L^2 + 0.45997L)D^2$$

(Mesavage and Girald 1946; Wiant and Castaneda 1977)

where: L = number of 16 foot logs; and
D = diameter at breast height

The summary programs compiled information on the following parameters: 1) number of trees by woods, species and year; 2) stocking (basal area, cubic feet and board ft./acre) by woods, species and year; and 3) growth (Doyle bd. ft., Int. 1/4" bd. ft., cubic ft. and basal area/acre/year) by woods, species and measurement period. Peripheral programs used in this project were developed to calculate plot slope correction factors, diameter distributions for each woods and measurement period, and stocking of the sapling/pole-sized trees for the 1962 and 1980 measurements.

For management purposes, all data were summarized by individual woodland and then averaged for the 13 separate woodlands. This was done since each woodland is physically separate and each has been treated as a unique management and record keeping unit. Data were also summarized by individual tree and plot tallies for use in future growth and yield projects.

RESULTS

Tables 1A and 1B present the 1953 and 1980 stocking of the CFI plots. As would be expected in stands with an initially low stocking such as those at SIPAC, stocking has greatly increased following 27 years of growth and development. The average basal area per acre for all trees ($\geq$ 9.0 inches DBH) increased from 36 to 66 sq. ft. per acre. Average basal area per acre in 1980 for all trees ($\geq$3.0 inches DBH) was 92 sq. ft. per acre.

Table 1A. Status of CFI plots in 1953 (trees ≥ 9.0 inches DBH) by woodland for SIPAC. All data are expressed on a per acre basis.

Woods	B.A.	No. of Trees	Cubic Feet	Volume Bd. Ft. Doyle	Volume Bd. Ft. Int 1/4"
1	56	32	735	1512	2461
2	14	13	385	557	1034
3	33	23	836	1136	2071
4	19	25	512	419	778
5	29	25	590	648	1277
6	32	42	937	631	1243
7	44	44	1267	1493	2803
8	24	30	761	730	1366
9	45	51	1076	1005	1948
10	41	46	1023	1269	2362
11	38	44	901	1022	1743
12	42	39	1121	1946	3299
13	54	37	1536	3546	5416
Average	36	35	898	1224	2139

Table 1B. Status of CFI plots in 1980 (trees ≥ 9.0 inches DBH) by woodland for SIPAC. All data are expressed on a per acre basis.

Woods	B.A.	No. of Trees	Cubic Feet	Volume Bd. Ft. Doyle	Volume Bd. Ft. Int 1/4"
1	63	49	1749	3265	4801
2	55	54	1724	1969	3110
3	48	52	1534	1639	2742
4	70	72	1904	2078	3195
5	74	69	2462	3180	4905
6	93	98	2827	3128	5253
7	80	71	2612	3738	5781
8	53	55	1658	2066	3414
9	74	65	2205	2759	4570
10	73	65	2180	3150	4991
11	58	54	1849	2487	4278
12	66	52	2217	3222	5233
13	50	43	1510	2534	4071
Average	66	61	2033	2709	4334

Stocking percent was calculated for each woodlot in 1962 and 1980 for all trees greater than 3.0 inches DBH from the guidelines of Gingrich (1971a). Average percent stocking in 1962 was 62 percent, increasing to 83 percent in 1980. In 1962, 5 woodlands were classified as understocked. These were less than 58 percent stocked - below the B line - for the upland hardwood stocking guide. Eight woodlots were classified as fully stocked - between 58 percent and 100 percent stocking. In 1980, 12 woodlots were classified as fully stocked, while 1 woodlot was classified as overstocked - greater than 100 per cent stocking. Average Doyle board foot stocking in 1953 was 1224 bd. ft./acre, while the average International 1/4" board foot stocking was 2139 bd. ft./acre. By 1980, average Doyle board foot stocking increased to 2709 bd. ft./ acre and 4334 International 1/4" bd. ft./acre.

Table 2 gives the gross growth including ingrowth for basal area, board feet and cubic feet averaged for the 13 woodlands. Basal area growth was highest for the first measurement period, declined for the second and third measurement periods and increased again for the fourth period. Cubic foot growth followed the same pattern. Species contributing substantial basal area and cubic foot growth were the white oaks, red oaks and sugar maple.

Board foot growth has shown a continuing increase, reflecting the increasing number of potential merchantable sawtimber sized trees on the plots over time (Table 2). Board foot growth averaged 60 bd. ft. per acre per year Doyle and 86 bd. ft. International 1/4" in the 1953-1956 growth period and increased to 97 and 137 bd. ft., respectively, per acre per year in the 1966-1980 growth period.

Board foot growth per acre per year by measurement period is separated into growth components in Table 3a for Doyle board feet and Table 3b for International 1/4" board feet. Measurement periods with the least cutting, 1953-56 and 1966-80, had the highest mortality.

Table 2. Gross growth including ingrowth (Gg+i) per acre per year by measurement period for basal area, board feet and cubic feet averaged for 13 SIPAC woodlands for trees 9.0 inches DBH and greater. Standard deviation in parentheses.

Growth Measurement	Measurement Period			
	1953-56	1956-62	1962-66	1966-80
Basal Area (Ft^2)	2.4 (0.6)	1.1 (0.3)	1.1 (0.3)	2.3 (0.5)
Doyle Bd. Ft.	60.2(29.3)	61.2(26.7)	65.5(20.9)	96.6(29.3)
Int 1/4" Bd. Ft.	85.9(38.2)	102.1(44.8)	101.6(40.2)	137.1(35.5)
Cubic Ft. (Ft^3)	66.0(16.9)	32.4(10.8)	40.5 (8.0)	75.6(18.3)

Table 4 summarizes species composition for all trees ≥9.0 inches DBH in 1953 and 1980. Total number of trees at SIPAC increased 71 percent from 8605 trees in 1953 to 14,735 trees in 1980. Although the number of red and white oaks increased, their corresponding percent of the total trees decreased slightly. Percentage of maple increased from 9.6 in 1953 to 18.7 in 1980, while the percentage of beech declined during the same period from 19.0 to 9.6.

Table 3A. Doyle board foot growth per acre per year by growth period and component for SIPAC.

Growth Component	Measurement Period			
	1953-1956	1956-1962	1962-1966	1966-1980
Survivor Growth (Gg)	60.2	61.2	65.5	84.5
Ingrowth (I)	0.0	0.0	0.0	12.1
Mortality (M)	18.4	7.1	9.4	16.9
Cut (C)	18.0	50.0	41.5	6.5
Gross growth + ingrowth (Gg+i)	60.2	61.3	65.5	96.6
Net growth (Gn)	41.8	54.1	56.1	67.6
Net growth + ingrowth (Gn+i)	41.8	54.1	56.1	79.7
Net increase (Gd)	23.8	4.1	14.6	73.2

Table 3B. International 1/4" board foot growth per acre per year by growth period and component for SIPAC.

Growth Component	Measurement Period			
	1953-1956	1956-1962	1962-1966	1966-1980
Survivor growth	85.9	102.1	101.6	114.4
Ingrowth	0.0	0.0	0.0	22.7
Mortality	34.9	14.3	16.4	29.3
Cut	33.1	75.2	67.0	11.3
Gross growth + ingrowth	85.9	102.1	101.6	137.1
Net growth	51.0	87.8	85.2	85.1
Net growth + ingrowth	51.0	87.8	85.2	107.8
Net increase	17.9	12.6	18.2	96.5

Table 4. Species composition for trees 9.0 inches DBH and greater on SIPAC for 1953 and 1980, and percent change in number of trees by species.

Species	1953 No. of Trees	1953 Percent of Total	1980 No. of Trees	1980 Percent of Total	% Change in Number
Am. Beech	1631	19.0	1416	9.6	-13
Elm	843	9.8	825	5.6	-2
Hickory	645	7.5	1793	12.2	+178
Red Oak	1094	12.7	1631	11.1	+49
Sugar Maple	825	9.6	2761	18.7	+235
White Ash	376	4.4	1147	7.8	+205
White Oak	1685	19.6	2617	17.8	+55
Yellow Poplar	645	7.5	914	6.4	+42
Misc.*	861	10.0	1631	11.1	+89
Total	8605	100.0	14735	100.0	

Table 5. Average Annual Periodic Diameter Increment by Species and Diameter Class.

DBH CLASS (in.)	SPECIES Am. Beech	Elm	Hick-ory	Red Oak	Sugar Maple	White Ash	White Oak	Yellow Poplar	Misc.*	Average
10	.154	.131	.155	.265	.177	.196	.186	.236	.178	.190
12	.180	.161	.140	.310	.166	.221	.190	.272	.158	.193
14	.217	.182	.157	.331	.202	.218	.200	.297	.212	.225
16	.230	.215	.190	.292	.191	.141	.204	.295	.162	.226
18	.180	.152	.244	.247	.233		.193	.335	.247	.217
20	.152	.106	.250	.237	.333		.197	.421	.138	.196
22	.222			.246	.157	.200	.141		.307	.195
24	.176						.187			.180
26	.129									.129
28	.333									.333
30	.127			.167						.134
Ave.	.182	.157	.152	.288	.178	.208	.193	.270	.177	.202

* Misc. includes American Sycamore, Black Cherry, Black Walnut, Kentucky Coffeetree, Sassafras and Sweetgum.

Average annual periodic diameter increment by species and diameter class is summarized in Table 5. Red oak had the highest annual diameter increment with .288 inches, while hickory had the lowest annual diameter increment of .152 inches. Yellow poplar, white ash and white oak had relatively high diameter growth rates.

Table 6 is a summarization of basal area ingrowth and mortality by species group. Sugar maple (19.2%) had the highest ingrowth (as a pecentage of total basal area), followed by white ash, hickory and the miscellaneous species group. Lower rates, ranging from 8-12% occurred for American beech, white oak, elm, yellow poplar and red oak. The highest mortality (as a percentage of initial basal area) occurred in the elm, beech and miscellaneous species' groups. The lowest mortality occurred in the white oak, white ash, red oak and hickory species' groups. In reference to diameter classes, the highest mortality occurred in a range from 22 to 32 inches, while the lowest mortality occurred in the 10 to 22 inch diameter classes.

Table 6. Average Basal Area Ingrowth and Mortality Per Acre Per Year by Species

Species	Average BA Ingrowth (Per Acre/Yr)	Ingrowth as a % of species BA	Average BA Mortality (Per Acre/Yr)	Mortality as a % of initial species BA
Am. Beech	.067	7.8	.235	15.7
Elm	.037	9.6	.064	14.8
Hickory	.106	17.3	.014	4.9
Red Oak	.132	11.1	.050	5.7
Sugar Maple	.156	19.2	.039	7.9
White Ash	.073	17.8	.004	2.6
White Oak	.138	8.4	.011	1.0
Yellow Poplar	.064	10.3	.039	6.7
Misc.*	.107	16.1	.072	11.8

* Misc. includes American Sycamore, Black Cherry, Black Walnut, Kentucky Coffeetree, Sassafras and Sweetgum

DISCUSSION AND CONCLUSIONS

It is apparent from the results that the stocking of the SIPAC CFI plots has increased in the past 27 years and that the management objective of increased stand volume is being achieved.

Roach and Gingrich (1968) indicate that upland hardwood stands with acceptable growing stock above the C level (greater than 40 percent stocking) should be retained and managed. Despite years of mismanagement prior to 1953 and timber stand improvement activities in the 1950's, the stocking percent in 1962 was acceptable - above the C level - in 12 of the 13 woodlands. No direct measure of acceptable growing stock is availble at SIPAC, as suggested

by Roach and Gingrich (1968) or demonstrated for 23 private nonindustrial woodlands by Callahan and Fischer (1982). However, the timber stand improvement and harvesting activities in the 1950's removed primarily unacceptable growing stock and cull trees so that much of the stocking percentage in 1962 and 1980 is acceptable growing stock.

Changes in species composition have been influenced by survivor growth, ingrowth and mortality. Elm and American beech were the only species that declined in number between 1953 and 1980. Elm had an intermediate amount of ingrowth (9.6%) while American beech had the smallest percentage (7.8). However, both species had high mortality rates (Elm: 14.8%; Beech: 15.7%).

The species having the largest increase in numbers of stems $\geq$ 9.0 inches DBH were sugar maple, white ash and hickory. All three species had high rates of ingrowth and relatively low rates of mortality. In 1980, an average stand was composed of 19% sugar maple, 12% hickory and 8% white ash.

Other species increasing in numbers were white oak, red oak, yellow poplar and the miscellaneous species group. In 1953, oak species composed 32% of an average stand, while in 1980 this figure dropped to 29%. The oak group had relatively low rates of both ingrowth and mortality. Although the number of oak stems has increased, the percentage of the total stand composed of oak had declined slightly over the past 27 years. Typical sawtimber stands at SIPAC are becoming increasingly dominanted by sugar maple, hickory, white ash and miscellaneous species, at the expense of the higher valued white oaks, red oaks and yellow poplar.

The initial average stocking at SIPAC of 2,139 (Table 1A) International 1/4" board feet per acre and periodic annual gross growth including ingrowth of 86, 102, 102 and 137 International 1/4" board feet per acre per year (Table 2) compare favorably to that found by Beers and Hall (1960). They determined International 1/4" board foot stocking and growth for two state forests in Indiana between 1949 and 1959. These forests exhibited much of the same stand conditions, management history and objectives as SIPAC. Harrison-Crawford State Forest, which has an average site quality somewhat lower than SIPAC, had an initial stocking of 1,821 board feet per acre (1950) and a final stocking 8 years later of 2,301 board feet per acre. Gross growth plus ingrowth averaged 87.4 Int. 1/4" board feet per acre per year. Morgan-Monroe State Forest, which has better site quality than SIPAC, had an initial stocking of 1,963 Int. 1/4" board feet per acre (1949), and in 10 years had increased to 3,392 board feet per acre. Gross growth plus ingrowth averaged 168.7 Int. 1/4" board feet per acre per year.

Bramble and Fix (1980) reported the net annual growth plus ingrowth for an 18 year period for an unevenaged mixed hardwood woodland in northern Indiana to be 306 Doyle board feet per acre per year. This is considerably higher than the net growth plus ingrowth values of 42, 54, 56 and 80 Doyle board feet per acre per year by growth period for SIPAC (Table 3A). These large differences are due to two factors: initial stocking and site quality. The woodland studied by Bramble and Fix had an initial stocking of 8700 Doyle board feet per acre. This is seven times the initial stocking at SIPAC.

Also, although white oak site index was reported by Bramble and Fix (1980) to be 60 to 70 feet, site index values exceeding 75 feet are commonly associated with the woodland.[2/]

A comparison of growth rates at SIPAC with published research by Schnur (1937), Gingrich (1971b), Dale (1972) and others is quite difficult and discouraging. Each study used different utilization standards. Also, stand and site conditions such as initial stocking levels, diameter distributions, species composition and geographic locations varied greatly.

This problem is illustrated by a review of the woodland productive potentials reported by the Soil Conservation Service. These values are reported for woodland soils throughout Indiana and are widely utilized by foresters and other land managers to estimate growth rates for forest management planning. The productive potentials for upland oak stands at SIPAC range from 185-260 Doyle board feet per acre per year (Wingard 1980). Although no mention is made as to whether these values are mean or periodic annual increment values, it is stated that these figures are for fully stocked, unmanaged, evenaged stands, indicating a periodic annual increment value. Also, the rather wide range in values for potential productivity and the national and regional data bases for soil classification and interpretation work would indicate that these values are from a amalgamation of growth and yield studies.

The relatively low Doyle board foot growth rates for Morgan-Monroe and Harrison-Crawford State Forests (Beers and Hall 1960) and SIPAC, when compared to the SCS potential productivity values, reflect "real world" conditions for southern Indiana. Southern Indiana foresters are continually confronted with revising (lowering) growth projections in forest management plans to correspond with actual growth and yield situations which do not approach higher predicted values.

Accurate growth data obtained from permanent plot inventories on a wide spectrum of sites are vital for effective hardwood management. It is obvious that published growth and yield data from the Central Hardwoods Region has been collected from well stocked and/or well managed evenaged stands. These productive potentials should not be extended to the more "typical" evenaged situations in the region or to stands managed by unevenaged systems. There is a definite need for additional summaries of permanent plot inventories from stands varying in management strategies and stand conditions.

[2/] Personal communication, W. L. Fix, Department of Forestry and Natural Resources, Purdue University.

LITERATURE CITED

Beck, D. E. and L. Della-Bianca. 1970. Yield of unthinned yellow-poplar. USDA For. Serv. Res. Pap. SE-58, 20 p.

Beers, T. W. and O. F. Hall. 1960. Summary of forest growth and stocking on the Morgan-Monroe and Harrison State Forests. Unpublished Report. Dept. of Forestry and Conservation, Purdue University. 43 p.

Beers, T. W. 1962. Components of forest growth. J. For. 60(4): 245-248.

Beers, T. W. 1964. Composite hardwood volume tables. Purdue University Ag. Exp. Sta. Res. Bull. No. 787, 12 p.

Bramble, W. C. and W. L. Fix. 1980. Productivity of a managed woodland in the central states. J. For. 78(9): 553-556.

Callahan, J. C. and B. C. Fischer. 1982. Economic and silvicultural potentials of 23 harvested Indiana woodlands. Purdue University Ag. Exp. Sta. Station Bull. No. 362, 23 p.

Carmean, W. H. 1971. Site index curves for black, white, scarlet, and chestnut oaks in the central states. USDA For. Serv. Res. Pap. NC-62, 8 p.

Dale, M. E. 1972. Growth and yield predictions for upland oak stands 10 years after initial thinning. USDA For. Serv. Res. Pap. NE-241, 21 p.

Gingrich, S. F. 1971a. Management of young and intermediate stands of upland hardwoods. USDA For. Serv. Res. Pap. NE-195, 26 p.

Gingrich, S. F. 1971b. Stocking, growth and yield of oak stands. In: Proceedings of the oak symposium. Morgantown, WV. p. 65-73.

Husch, B., C. I. Miller, and T. W. Beers. 1972. Forest mensuration. Ronald Press, New York, 410 p.

Mesavage, C. and J. V. Girard. 1946. Tables for estimating board-foot volume of timber. USDA For. Serv., Wash., D. C. 94 p.

Roach, B. A. and S. F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. USDA For. Serv. Ag. Handbook 355, 39 p.

Schnur, G. L. 1937. Yield, stand and volume tables for even-aged upland oak forests. USDA Tech. Bull. 560, 87 p.

Smith, H. C. and N. I. Lamson. 1977. Stand development 25 years after a 9.0 inch diameter-limit first cutting in Appalachian hardwoods. USDA For. Serv. Res. Pap. NE-379, 4 p.

Stott, C. B. and G. Semmens. 1960. Our changing inventory methods and the CFI system in North America. Forest Control by Continuous Inventory, No. 80.

Watson, E. E. 1979. Analysis of 15 years of University of Tennessee continuous forest inventory data. Unpublished Master's thesis. University of Tennessee, Knoxville. 135 p.

Wiant, H. V., Jr. and F. Castaneda. 1977. Mesavage and Girard's volume tables formulated. USDI, Bureau of Land Management. Resource Inventory Notes. No. 4, 4 p.

Wingard, R. C. Jr. 1980. Soil survey of Dubois County, Indiana. USDA Soil Conservation Service. 117 p.