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DESCRIPTION AND GROWTH SIMULATION OF DOUGLAS-FIR STANDS

by
K. J. Mitchell

**PACIFIC FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
VICTORIA, BRITISH COLUMBIA**

INTERNAL REPORT BC-25

**DEPARTMENT OF THE ENVIRONMENT
JULY, 1971**

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This illustrative report introduces a technique of describing stands in mensurational terms that makes it relatively easy to predict the growth and yield of managed stands. It may also allow foresters to compare the outcome of alternative silvicultural practices without resorting to expensive and time-consuming field trials. The procedure outlined is designed for single-storied stands of coniferous species and is currently being applied to Douglas fir (Pseudotsuga menziesii (Mirb.) Franco). (Background information and objectives were reported earlier) (Mitchell 1970). White spruce (Picea glauca (Moench) Voss) has also been studied (Mitchell 1969) and the investigation of hemlock (Tsuga heterophylla (Raf.) Sarg.) is in the planning stage.

The basic information is obtained from photo-plots rather than conventional field plots. Low-level stereo-photographs are taken 350 feet above the forest canopy, from a helicopter equipped with a photographic system developed by the B.C. Forest Service. The height, ground level, crown dimensions and relative location of each tree are determined with the aid of a Wild A40 Autograph provided by the B.C. Forest Service. This instrument is similar to those used to construct contour maps from aerial photographs. A plotter attached to the A40 Autograph produces a map of each plot (Fig. 1) and a keypunch automatically records the X Y Z coordinates on cards (Fig. 2B). A computer is programmed to reference the A40 coordinates to one corner of

the plot and a point of known elevation (Figs. 2A and 2C). The new coordinates are illustrated in Figure 3, which corresponds to the subplot in Figure 1. Note that the plot is visualized as having an overlying grid that divides it into units of one-square foot. The 0.225-acre plot in Figure 1 has $99 \times 99 = 9801$ discrete units of growing space. Trees can be located in any unit to simulate a hypothetical or actual spacing regime (intersection points of the grid represent the actual center of each unit in Fig. 3).

A second computer program elaborates upon the description of the trees in the plot by outlining the crown of each tree (Fig. 4) and filling the interior (Fig. 5). Tree 3 shows that branches radiate from the bole in such a pattern as to occupy all growing space in the plot if competition and time are not limiting. To avoid measuring surrounding trees, it is assumed that the plot is simply replicated to simulate outside competition. This means that a person looking north from point A would see exactly the same stand as he would looking north from B. Consequently, any portion of a tree crown that extends beyond the boundary appears to enter the plot on the opposite side as in the case of tree 5 (Fig. 6). That portion transposed from one side to the other is of the same area but not necessarily of the same shape, as is evident by comparing Figures 4 and 6. If sufficient growing space cannot be occupied (e.g. tree 3), that portion of the crown within the plot is increased in size and will occupy those locations denoted by small circles. This method of simulating outside competition gives good results when the plots are of a realistic size (e.g. Fig. 1). A three-dimensional description of the surface of the crown of each tree is shown in Figure 7. The numbers represent the height a particular point on the

surface of the crown is above a reference plane. Cross-sections through the stand along rows 5 and 24 are plotted in Figure 8. The information displayed in Figures 6 and 7 is coded and stored on cards (Fig. 9) or tape for later use.

A third program projects the growth of the plot forward in time to obtain estimates of yield at various points in time. The process is demonstrated in Figures 10 to 27, with the data cards listed in Figure 9. The trees are Douglas fir but two are assumed to be of a species that adds most of its height growth in the first 50 years. This hypothetical species, the removal of one tree in a thinning and the growth of a young tree are introduced solely to illustrate features of the program. The results shown are probably not biologically correct because some of the growth relationships used in the simulation are based on incomplete data. The main purpose of this trial is to demonstrate the capabilities of the program.

The program that simulates the development of the stand is comprised of empirical growth models and a variety of techniques that allow variables to operate as they do in nature. The height growth of a particular tree is based on the site index curve of the plot (input information listed in Fig. 10), estimated vigor (Fig. 11) and current inter-tree competition defined by STATUS in Figure 12. Branch growth and crown size are dependent upon height increment and the availability of growing space. Estimates of bole diameter and volume are based on crown size and tree height. The description of the plot prior to growth simulation is shown in Figure 12. Figures 13 to 26 follow the development of the stand to age 45.

A series of physical models depict the simulation of another plot from age 0 to 45 (Fig. 27). Note that branches are growing out of the bole

at various heights. Growth ceases when a branch meets the crown of another tree but other branches located slightly higher up the bole may grow over the leading edge of the competing crown or vice versa, depending on the relative rates of branch growth. Consequently, crowns may decrease or increase in size in response to competition and available growing space.

LITERATURE CITED

- Mitchell, K. J. 1969. Simulation of the growth of even-aged stands of white spruce. Yale Univ. School of Forestry Bul. 75.
- _____. 1970. Growth prediction in managed Douglas-fir stands. Department of Fisheries and Forestry, Forest Research Laboratory, Victoria, B. C. Internal Report BC-20.

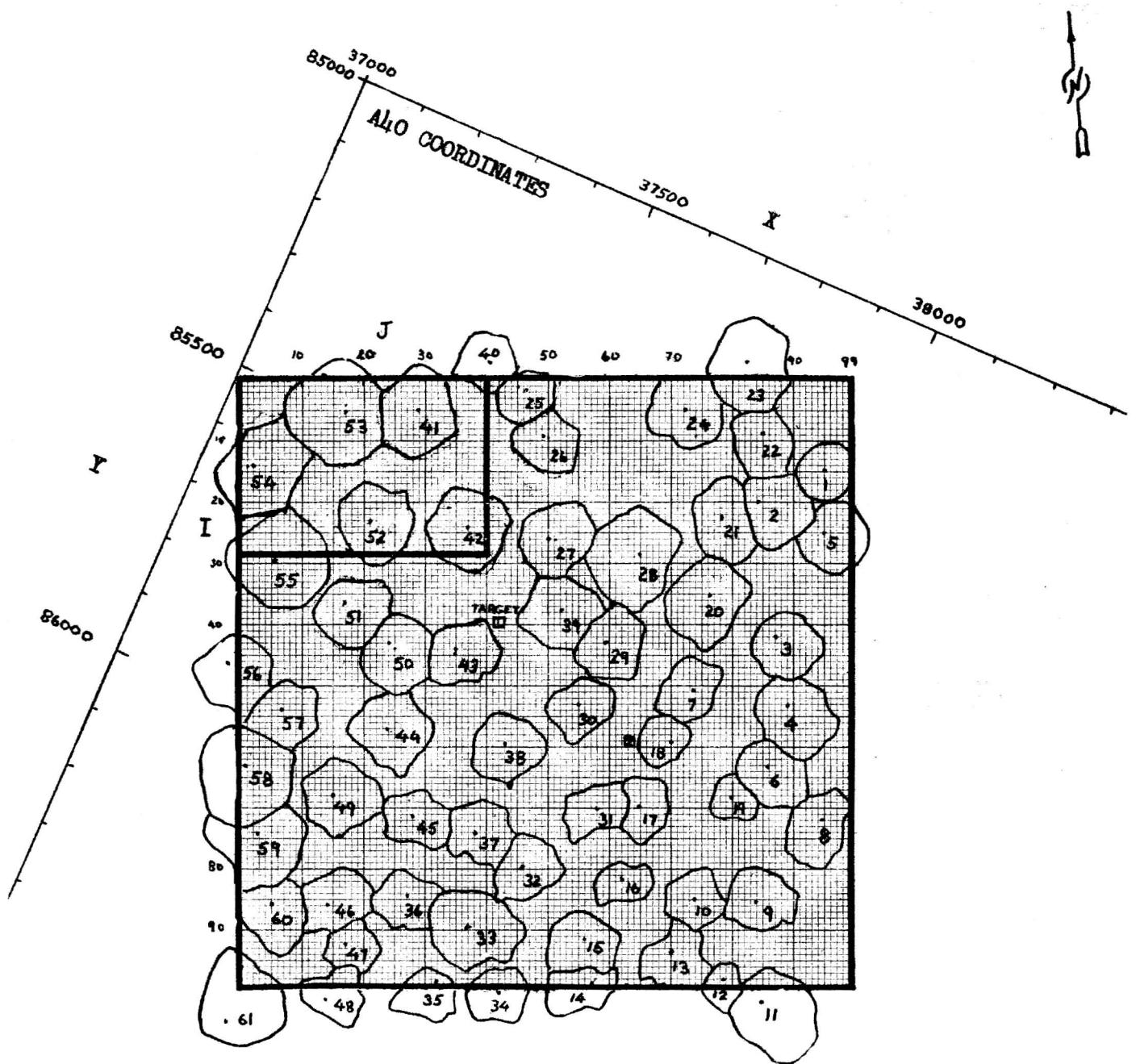


Figure 1.

CROWN MAP DRAWN BY THE A40 PLOTTER FOR PLOT 5 (FAIRSERVICE CREEK)

The X Y Z coordinates at the top and near the base of each tree, and at points around the perimeter of the crown are punched on cards and later expressed in relation to the upper lefthand corner of the plot. The coordinates for a small part of the plot (outlined by a broken line) are shown on the next two pages. A 28 x 40 foot subplot is used for demonstration because it can be conveniently displayed on a single page by the computer.

ANGLE OF ROTATION		REFERENCE CORNER																
PLOT	AGE SPP.	X	Y	Z	TARGET 1			TARGET 2			CENTER			CALCULATED				
22.5	3701.6	8552.4	918.8		x	y	z	x	y	z	x	y	z			(A)		
51	301	37930	8514509235	375728571	7091	883786295816	09103	37660	85796	09161								
TREE		TOP	BASE		MAX. CROWN RADIUS													
5 41	301	37244	8546308638	373498552	2091	90372398553	208779											
5 42	301	37391	8560706637	373498552	2091	90374058555	208779											
5 52	301	37245	8566508672	371584553	3109231	372758543408779												
5 53	301	37130	855008573	3715845631	09231	371528558008779												
5 54	301	37034	856540851	371585631	09231	370623560308779												
COORDINATES AROUND PERIMETER OF CROWN																		
5 41	301	37307	85420082537321	8545409026	372718554209055	372328553408994												
5 41	301	1	37198	854560890926	37228453960890	7372838539808967-2												
5 42	301	1	37367	85549090723	74398554109077	374663556709012374668562608935												
5 42	301	1	37456	85566108761	374038567508933	373498553708977373508556509040												
5 42	301	2	37371	8554709040-2														
5 52	301	1	37292	855930911737314	8561909021	373258566708981372928571408880												
5 52	301	1	37251	857250880372128568308815	372048554409073	372268560509079												
5 52	301	2	3728	855909079-2														
5 53	301	1	3723	8552708911372078557608911	371598560308911370808557708910													
5 53	301	1	3704	8552308910371028544408910371	708544708910372078545808910													
5 53	301	2	-1															
5 54	301	1	37133	8558708910371258569508910370598573908910	370308572408744													
5 54	301	1	36991	856860869837012	37061856008945	370728555208945												
5 54	301	2	-1															
POINT OF																		
		TOP	J	I	K	J	I	K	J	I	K	J	I	K				
5 41	301		29	5	155	35	14	100	24	11	141							
5 42	301		37	24	155	35	14	100	39	19	141							
5 52	301		21	23	152	13	17	96	23	22	141							
5 53	301	changed for purpose of demonstration	17	5	162	13	17	96	14	12	141							
5 54	302		2	14	167	13	17	96	7	11	141							
COORDINATES AROUND PERIMETER OF CROWN																		
5 41	1		34	4	135	35	8	116	27	13	113	23	11	119				
5 41	1		1	23	2	26	28	-1	119	33	0	122	-200					
5 42	1		35	17	112	42	19	112	44	23	118	41	28	125				
5 42	1		1	39	31	123	34	30	126	30	25	121	33	18	115			
5 42	1		2	-200														
5 52	1		27	18	107	28	22	117	27	27	121	22	30	131				
5 52	1		1	18	29	131	16	24	137	16	20	112	20	17	111			
5 52	1		2	26	18	111	-200											
5 53	1		24	10	128	19	14	128	14	14	128	8	9	128				
5 53	1		1	7	3	128	15	-2	128	21	0	128	24	3	128			
5 53	1		2	-100														
5 54	1		12	12	128	7	22	128	0	23	128	-2	21	144				
5 54	1		1	-4	16	149	1	8	149	6	7	24	8	6	124			
5 54	1		2	100														

Figure 2.

LISTING OF COORDINATES

The axes were rotated 22.5° and translated 3701.6', 8552.4' and 918.8' for the X,Y&Z axes respectively.

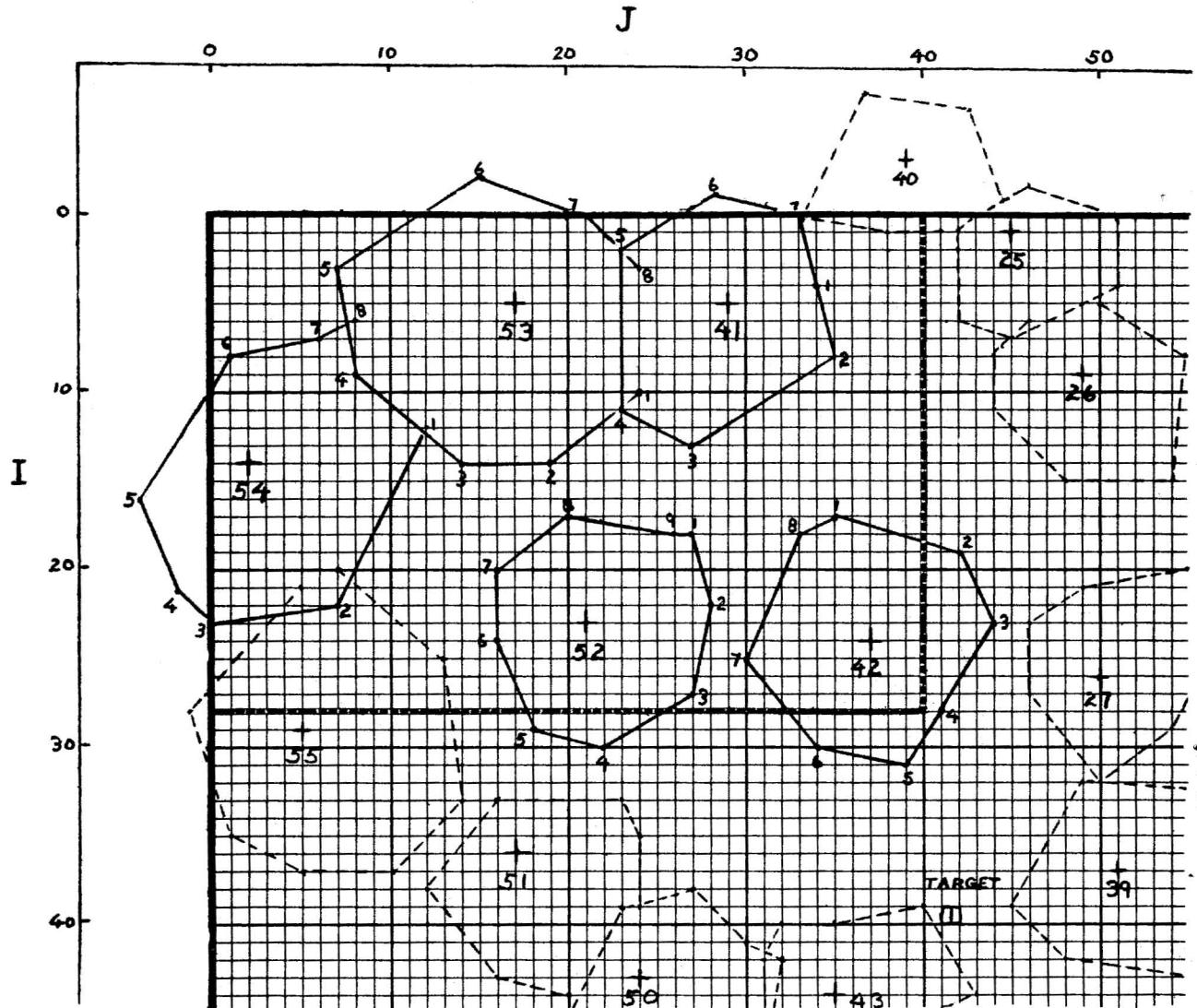


Figure 3

CROWN MAP BASED ON COMPUTED COORDINATES

The numbers around the perimeter of each crown show the location of each X Y Z coordinate and the sequence in which they were recorded on the A40 plotter.

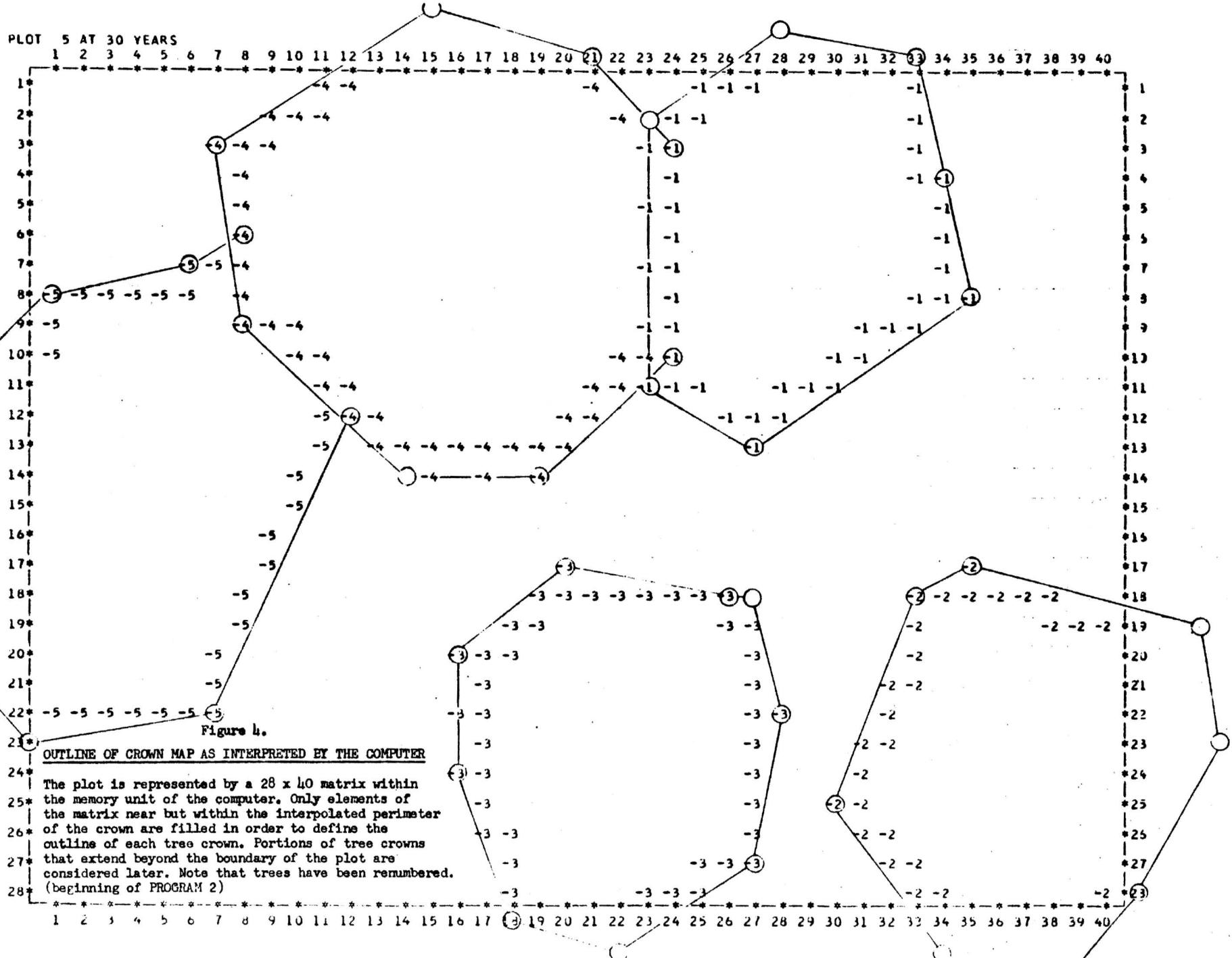


Figure b.

OUTLINE OF CROWN MAP AS INTERPRETED BY THE COMPUTER

24* The plot is represented by a 28×40 matrix within
 25* the memory unit of the computer. Only elements of
 26* the matrix near but within the interpolated perimeter
 27* of the crown are filled in order to define the
 28* outline of each tree crown. Portions of tree crowns
 that extend beyond the boundary of the plot are
 considered later. Note that trees have been renumbered.
 (beginning of PROGRAM 2)

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

PLOT 5 AT 30 YEARS

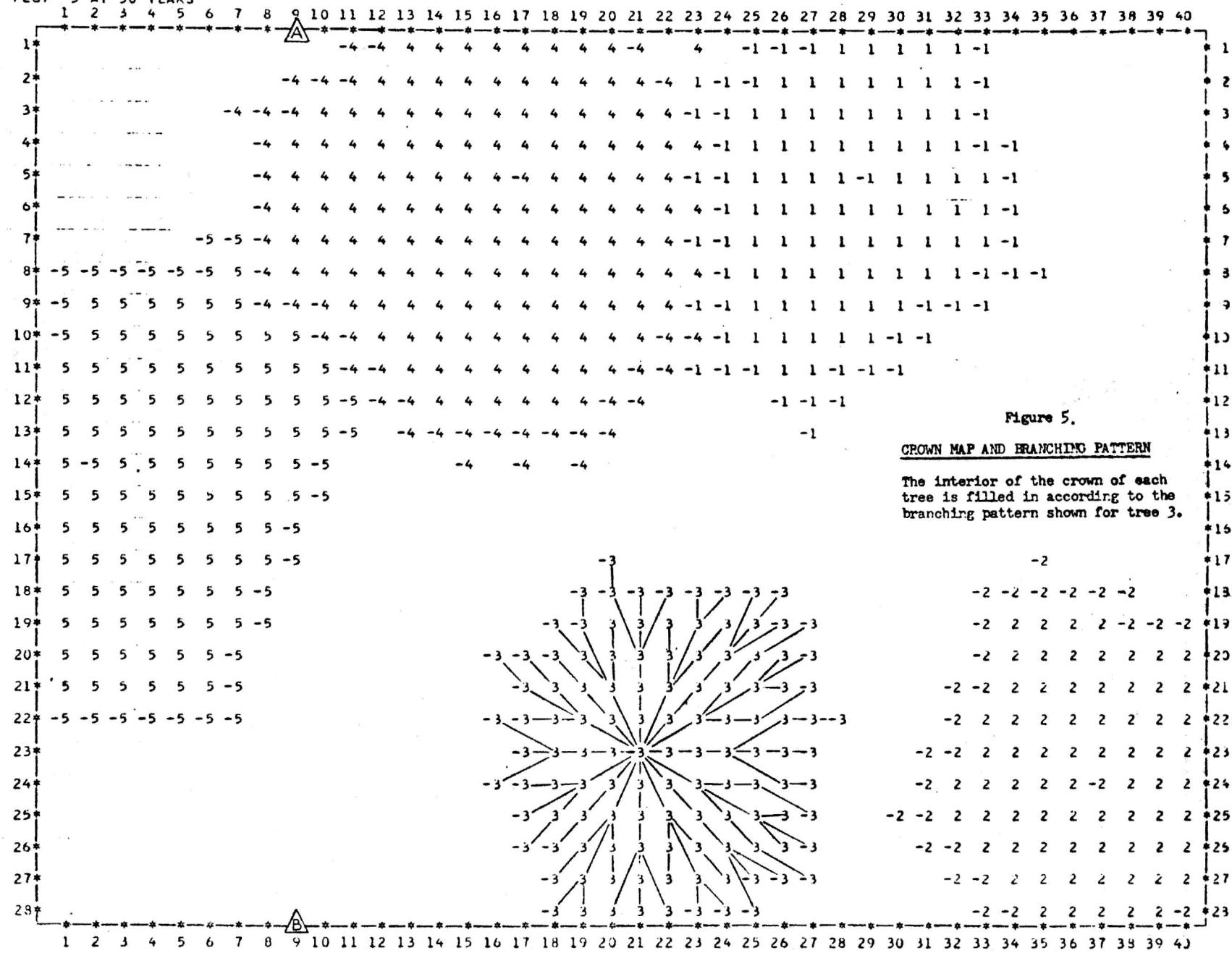
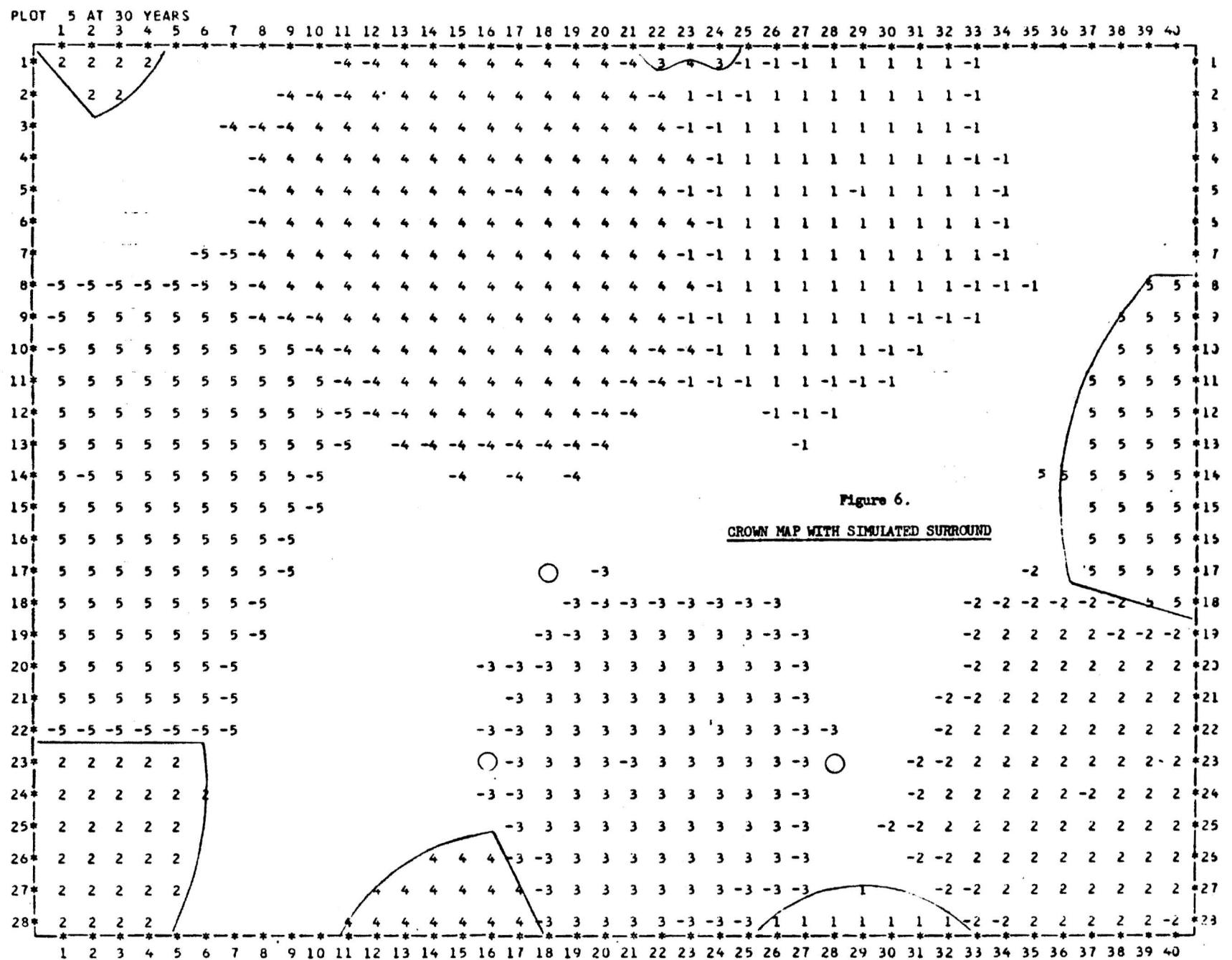


Figure 5.

CROWN MAP AND BRANCHING PATTERN

The interior of the crown of each tree is filled in according to the branching pattern shown for tree 3.



30 YEARS

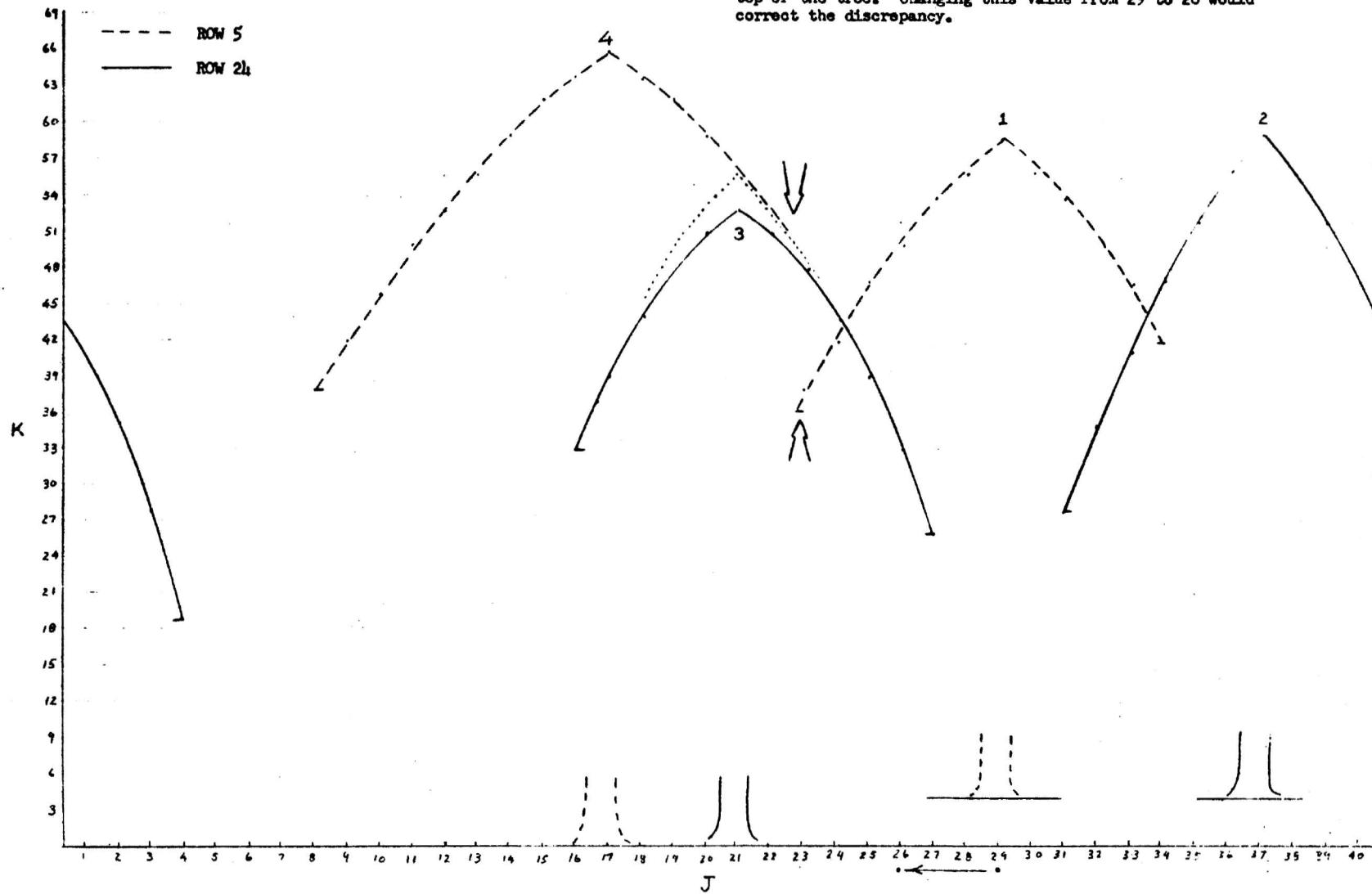
Figure 8.

VERTICAL PROFILES THROUGH THE STAND

Note that the cross-section does not pass through the top of tree 3 giving it a slightly flatter than normal profile.

The bases of trees 1 and 2 are four feet above the reference plane as illustrated on the lower right.

The crowns of trees 1 and 4 do not meet at the same level probably because of an error in the J coordinates at the top of the tree. Changing this value from 29 to 26 would correct the discrepancy.



PLOT	GRID	ROWS	COL	SPP.	TREES	NUMBER OF TOP HEIGHT
5	1.000	28	40	2	6	68.5

TREE	SPP.	CROWN		A40		NO. AGE				
		ROW	COL	AREA	TREE					
1	1	5	29	128	0	0	0	41	30	0
2	1	24	37	135	0	0	0	42	30	0
3	1	23	21	125	0	0	0	52	30	0
4	2	5	17	193	0	0	0	53	30	0
5	2	14	2	172	0	0	0	54	30	0
6	2	24	35	0	0	0	0	99	-10	0

[6] ADDED FOR PURPOSE OF DEMONSTRATION

CROWN VICOUR COEFF.	MAXIMUM BRANCH LENGTH	HEIGHT COEFF.	INDEX		MAXIMUM OF SUP- PRESSION	CROWN AREA	GROUND DBH VOLUME	LEVEL			
			MAXIMUM VIGOUR	INDEX							
			COEFF.	HEIGHT							
1	8.241	8.485	0.0.898	0.	55.0	-0.442	309.9	7.9	7.6	0.	4.
2	6.345	7.280	0.0.842	0.	55.0	-0.154	183.7	8.1	7.9	0.	4.
3	6.626	7.810	0.0.910	0.	56.0	-0.245	204.6	8.0	7.8	0.	-0.
4	10.267	10.198	0.0.957	0.	66.0	-0.547	591.4	11.3	17.1	0.	-0.
5	5.427	10.198	0.0.1068	0.	71.0	-0.572	539.9	11.3	18.8	0.	-0.
6	10.000	0.0	0.1.0000	0.	0.0	0.0	0.0	0.0	0.0	0.	4.

[6] ADDED

ROW	COLUMN	1	2	3	4	5	6	7	8	
		HEIGHT	BRANCH LENGTH	TREE	0	0	0	0	0	0
1	1	24083002	18000002	0	0	0	0	0	0	
2	1	20	0	0	0	0	0	0	0	
3	1	0	0	0	0	0	0	32000004	37000004	
4	1	0	0	0	0	0	0	0	38000004	
5	1	0	0	0	0	0	0	0	38000004	
6	1	0	0	0	0	0	0	0	38000004	
7	1	0	0	0	0	0	0	44000005	41000005	37000004
8	1	53000005	53000005	53000005	52000005	50000005	48000005	45000005	36000004	
9	1	57065005	57000005	57065005	56058005	54085005	52083005	49000005	34103004	
10	1	60000005	60000005	59000005	57000005	55000005	52069005	48000005		
11	1	63068005	64000005	63068005	62091005	59000005	57000005	54085005	50000005	
12	1	66072005	66000005	66072005	64000005	62077005	59000005	56090005	52000005	
13	1	68061005	69065005	68075005	66072005	63087005	60000005	57097005	53000005	
14	1	69075005	71000005	69085005	66000005	64000005	60000005	57000005	53000005	
15	1	68047005	69035005	68075005	66072005	63077005	60000005	57075005	53000005	
16	1	66049005	66000005	66034005	64100005	62077005	59000005	56081005	52000005	
17	1	63046005	64000005	63087005	62091005	60000005	57000005	54063005	50000005	
18	1	60000005	60000005	60000005	59000005	57000005	55000005	52083005	48000005	
19	1	57075005	57000005	57075005	56030005	54099005	52083005	49000005	45000005	
20	1	53000005	53000005	53000005	52000005	50100005	48000005	45000005	0	
21	1	49000005	49000005	49000005	48000005	46000005	44000005	41000005	0	
22	1	44085005	44000005	44085005	43000005	41000005	39000005	37000005	0	
23	1	41000002	34075002	27000002	18000002	0	0	0	0	
24	1	41000002	35000002	28000002	19000002	0	0	0	0	
25	1	41000002	34075002	27000002	18000002	0	0	0	0	
26	1	41000002	32090002	25000002	16000002	0	0	0	0	
27	1	35000002	29085002	21000002	13000002	0	0	0	0	
28	1	30100002	24083002	17000002	0	0	0	0	0	

REMAINING 112 CARDS FOR COLUMNS 9 - 40 ARE NOT SHOWN

Figure 9.

INPUT DECK REQUIRED TO INITIATE SIMULATION

This listing contains the preceding information in a format suitable to initiate simulation of stand growth. The trees are 30 years old with the exception of one which is not scheduled to start growing for 10 years - hence its age is -10 years.

Figure 10.
INPUT INFORMATION

(beginning of PROGRAM 3)

This page displays information which is provided at the beginning of the simulation (e.g., height-age curves) or passed on from the previous program. It also shows the various options requested. The three digits across from "STAND SUMMARY REQUEST" under a particular age cause a tally, tree characteristics and stand characteristics respectively to be printed. Note that a thinning was requested at age 40.

The following output which is mostly self-explanatory describes the simulated development of the stand.

Figure 11. Listing of growth coefficients and tree numbers.

TREE	ROW	COL	SPECIES	GROWTH VIGOUR	TREE NUMBERS FOR		
				COEFFICIENT	CROWN	HEIGHT	CROSS REFERENCE
						440	PSP
1	5	29	1	8.241	0.893	41	0
2	24	37	1	6.345	0.842	42	0
3	23	21	1	6.626	0.910	52	0
4	5	17	2	10.267	0.957	53	0
5	14	2	2	9.427	1.063	54	0
6	24	35	2	10.000	1.000	99	0

stochastic variable which expresses the rate of height growth (inherent vigour) relative to site index curve
expresses the amount of branch growth added per unit of height growth (after transformation)

Figure 12. Summary of the stand at age 30.

AGE 30 SPECIES 1												
TREE	ROW	COL	AGE	CROWN	CROWN	CROWN	BASAL	DBH	HEIGHT	(different vol. equations) BCFS		
				AREA	WIDTH	LENGTH	AREA					
1	5	29	30	128.0	12.8	23.4	0.34	7.9	55.0	7.60	7.52	-0.442
2	24	37	30	135.0	13.1	36.2	0.36	8.1	55.0	7.90	7.85	-0.154
3	23	21	30	125.0	12.6	31.8	0.35	8.0	56.0	7.80	7.85	-0.246
TOTAL	3 TREES		388.0	38.5	91.4	1.05	24.0	166.0	23.30	23.21		
AVERAGE				129.3	12.8	30.5	0.35	8.0	55.3	7.77	7.74	
/ACRE	117 TREES					40.73		906.20	902.84			

AGE 30 SPECIES 2												
TREE	ROW	COL	AGE	CROWN	CROWN	CROWN	BASAL	DBH	HEIGHT	(different vol. equations) BCFS		
				AREA	WIDTH	LENGTH	AREA					
4	5	17	30	198.0	15.9	23.3	0.70	11.3	66.0	17.10	17.22	-0.547
5	14	2	30	172.0	14.8	23.8	0.70	11.3	71.0	18.80	18.71	-0.572
TOTAL	2 TREES		370.0	30.7	47.2	1.39	22.6	137.0	35.90	35.93		
AVERAGE				185.0	15.3	23.6	0.70	11.3	68.5	17.95	17.97	
/ACRE	78 TREES					54.17		1396.25	1397.58			

AGE 30 SUMMARY OF ALL SPECIES										
TREE	ROW	COL	AGE	CROWN	CROWN	CROWN	BASAL	DBH	HEIGHT	VOLUME1
				AREA	WIDTH	LENGTH	AREA			
TOTAL	5	TREES	758.0	69.2	138.6	2.44	46.6	303.0	59.20	59.15
AVERAGE			151.6	13.8	27.7	0.49	9.3	60.6	11.84	11.83
/ACRE	194 TREES					94.90		2302.46	2300.42	

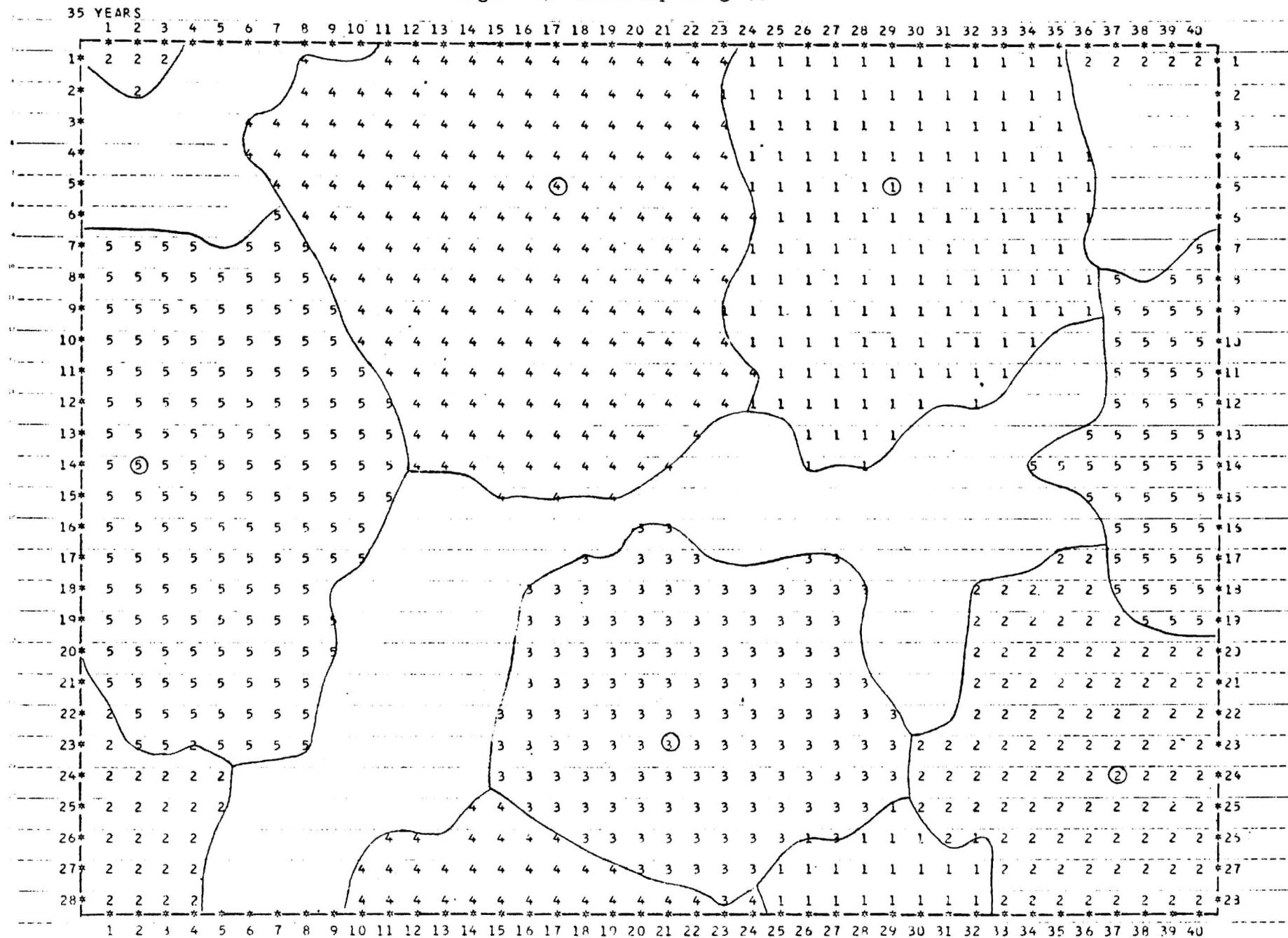
Figure 13. Summary of the stand at age 35.

AGE 35 SPECIES 1												
TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
1	5	29	35	170.0	14.7	28.8	0.57	10.2	63.6	18.26	13.77	-0.456
2	24	37	35	143.0	13.5	37.9	0.51	9.7	65.1	17.43	13.00	-0.247
3	23	21	35	131.0	12.9	33.0	0.48	9.4	65.5	16.42	12.40	-0.376
TOTAL	3	TREES		444.0	41.1	99.7	1.56	29.2	194.2	52.51	39.17	
AVERAGE				148.0	13.7	33.2	0.52	9.7	64.7	17.50	13.06	
/ACRE	117	TREES					60.53			2042.40	1523.43	

AGE 35 SPECIES 2												
TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
4	5	17	35	237.0	17.4	26.6	0.91	12.9	70.2	27.98	23.33	-0.510
5	14	2	35	207.0	16.2	27.3	0.92	13.0	75.5	30.47	25.66	-0.550
TOTAL	2	TREES		444.0	33.6	53.9	1.83	25.9	145.7	58.45	48.99	
AVERAGE				222.0	16.8	27.0	0.92	13.0	72.9	29.23	24.50	
/ACRE	78	TREES					71.35			2273.36	1905.44	

AGE 35 SUMMARY OF ALL SPECIES												
TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
TOTAL	5	TREES		886.0	74.7	153.7	3.39	55.2	339.9	110.97	83.16	
AVERAGE				177.6	14.9	30.7	0.68	11.0	68.0	22.19	17.63	
/ACRE	194	TREES					131.88			4315.76	3429.79	

Figure 14. Crown map at age 35.



35 YEARS

Figure 15. Crown profiles at age 35.

5* -0 -0 -0 -0 -0 -0 39 44 48 52 56 59 62 65 67 70 72 70 67 65 62 59 56 53 57 61 64 67 70 67 64 61 57 53 48 43 -0 -0 -0 -0 * 5

24* 52 45 38 29 19 -0 -0 -0 -0 -0 -0 -0 -0 37 44 50 55 59 62 64 62 59 55 50 44 37 29 19 29 38 45 52 57 62 66 69 66 62 57 *24

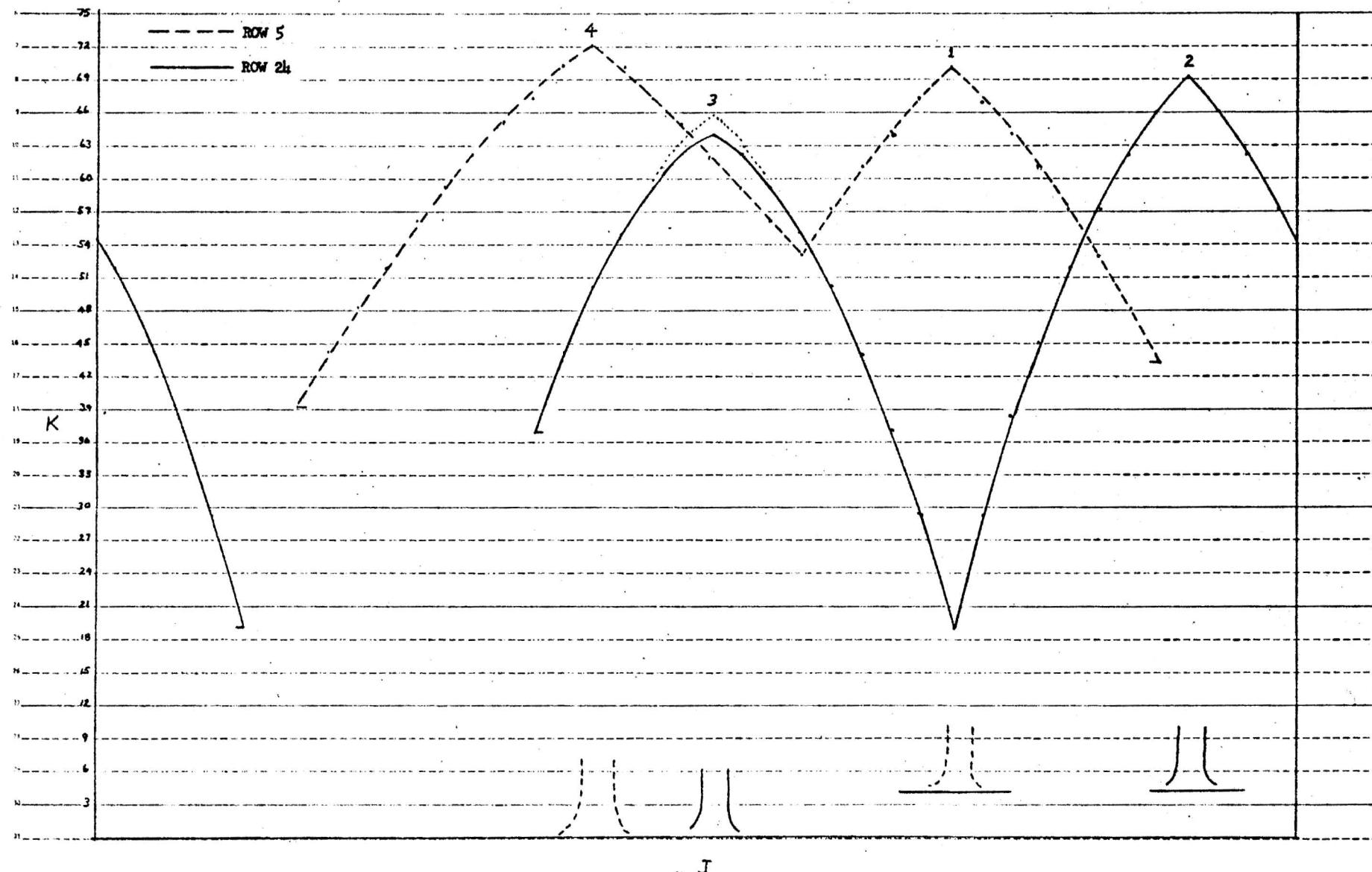


Figure 16. Summary of the stand at age 40.

AGE 40 SPECIES 1

TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
1	5	29	40	190.0	15.6	31.4	0.77	11.9	71.3	25.39	20.51	-0.468
2	24	37	40	152.0	13.9	39.9	0.68	11.2	74.0	24.30	19.31	-0.284
3	23	21	40	151.0	13.9	36.9	0.68	11.2	74.3	24.43	19.40	-0.371
TOTAL		3 TREES		493.0	43.3	108.2	2.13	34.2	219.7	74.12	59.22	
AVERAGE				164.3	14.4	36.1	0.71	11.4	73.2	24.71	19.74	
/ACRE		117 TREES					82.95		2882.75	2303.23		

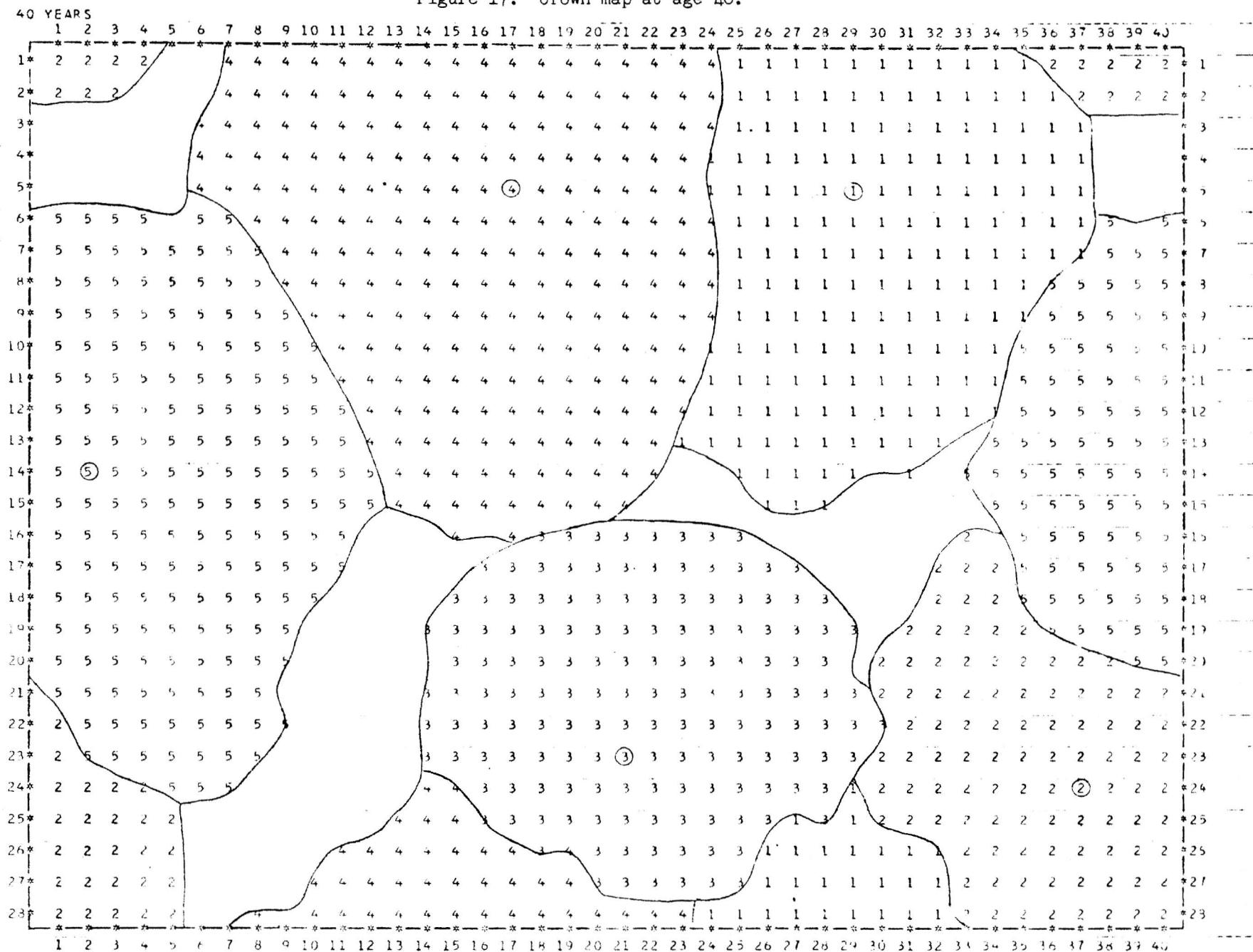
AGE 40 SPECIES 2

TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
4	5	17	40	263.0	18.3	28.8	1.10	14.2	73.9	33.40	29.09	-0.492
5	14	2	40	253.0	17.9	31.8	1.22	15.0	79.6	38.74	34.74	-0.483
TOTAL		2 TREES		516.0	36.2	60.6	2.32	29.2	153.5	72.14	63.83	
AVERAGE				258.0	18.1	30.3	1.16	14.6	76.7	36.07	31.91	
/ACRE		78 TREES					90.26		2805.80	2482.48		

AGE 40 SUMMARY OF ALL SPECIES

TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
TOTAL		5 TREES		1009.0	79.6	168.8	4.45	63.4	373.1	146.26	123.05	
AVERAGE				201.8	15.9	33.8	0.89	12.7	74.6	29.25	24.61	
/ACRE		154 TREES					173.21		5688.55	4785.77		

Figure 17. Crown map at age 40.



40 YEARS

Figure 18. Crown profiles at age 40.

5* - 0 - 0 - 0 - 0 - 0 37 42 47 51 55 59 62 66 68 71 73 75 73 71 58 66 62 59 61 65 69 72 75 77 75 72 69 65 61 51 44 - 3 - 3 - 3
24* 61 54 47 33 40 36 25 - 0 - 0 - 0 - 0 - 0 45 46 52 58 53 68 71 72 71 68 63 58 52 45 37 34 38 47 54 61 66 71 75 72 75 71 - 5 - 2+

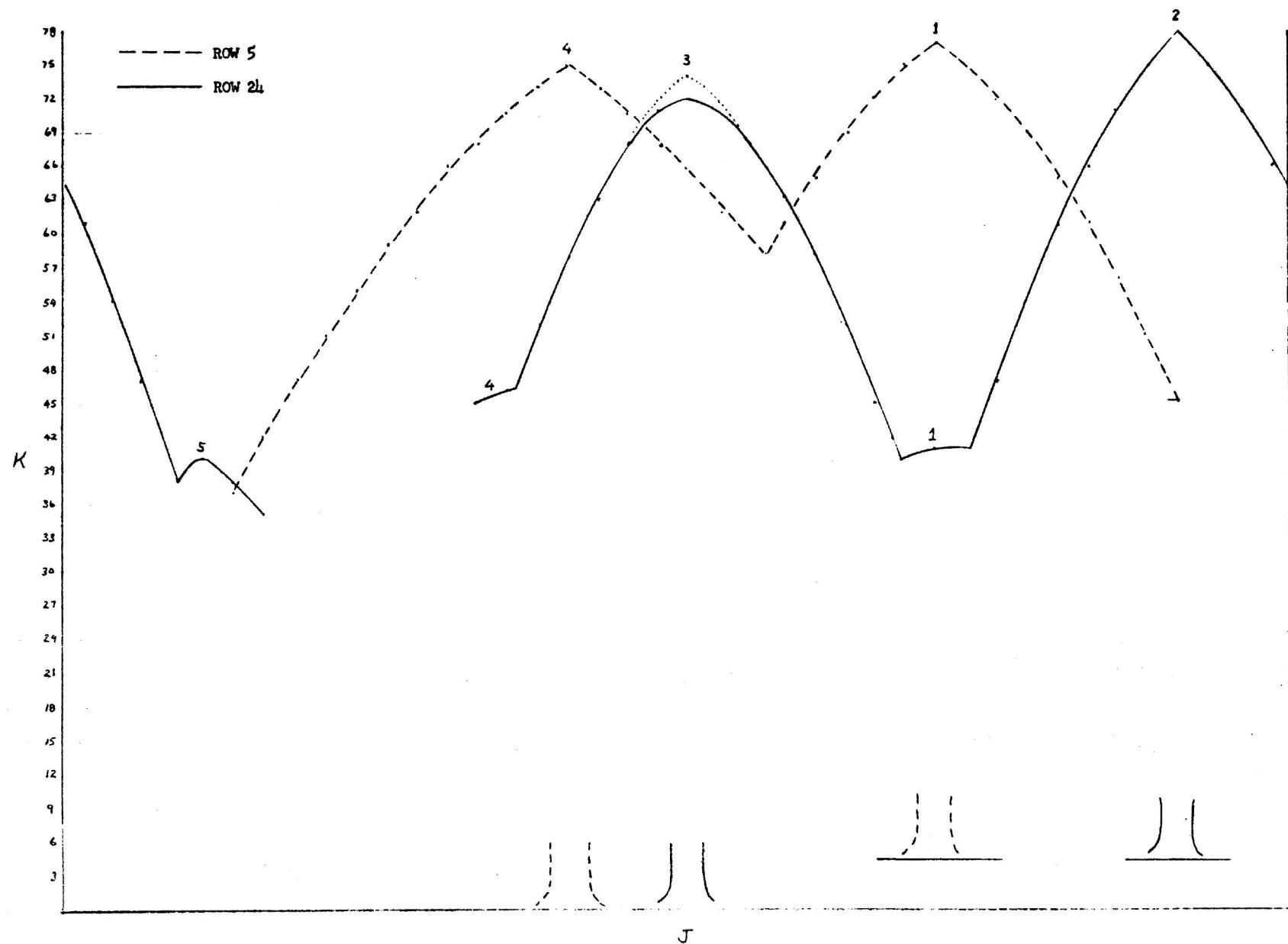


Figure 19. Summary of trees thinned at age 40 (only one tree removed).

TREES THINNED AT AGE 40 REGIME 1						
(SPECIFICATIONS 0.1 -0 3-0 1 125.0 7.0 11.5 0. 0. 0. 0.)						
TREE	ROW	COLUMN	DBH	BASAL AREA	HEIGHT	VOLUME1 VOLUME2 STATUS
2	24	37	11.2	0.68	74.0	24.3 -0.294
TOTAL			11.2	0.68	74.0	24.3
AVERAGE			11.2	0.68	74.0	24.3
(CUT %			15.29		16.61	
TOTAL PER ACRE			26.48		945.1	

{ Instruction to reduce the basal area to 125 sq.ft./acre
by removing the trees having diameters between 7.0 and
11.5 inches - starting with the smallest trees

Figure 20. Crown map after thinning.

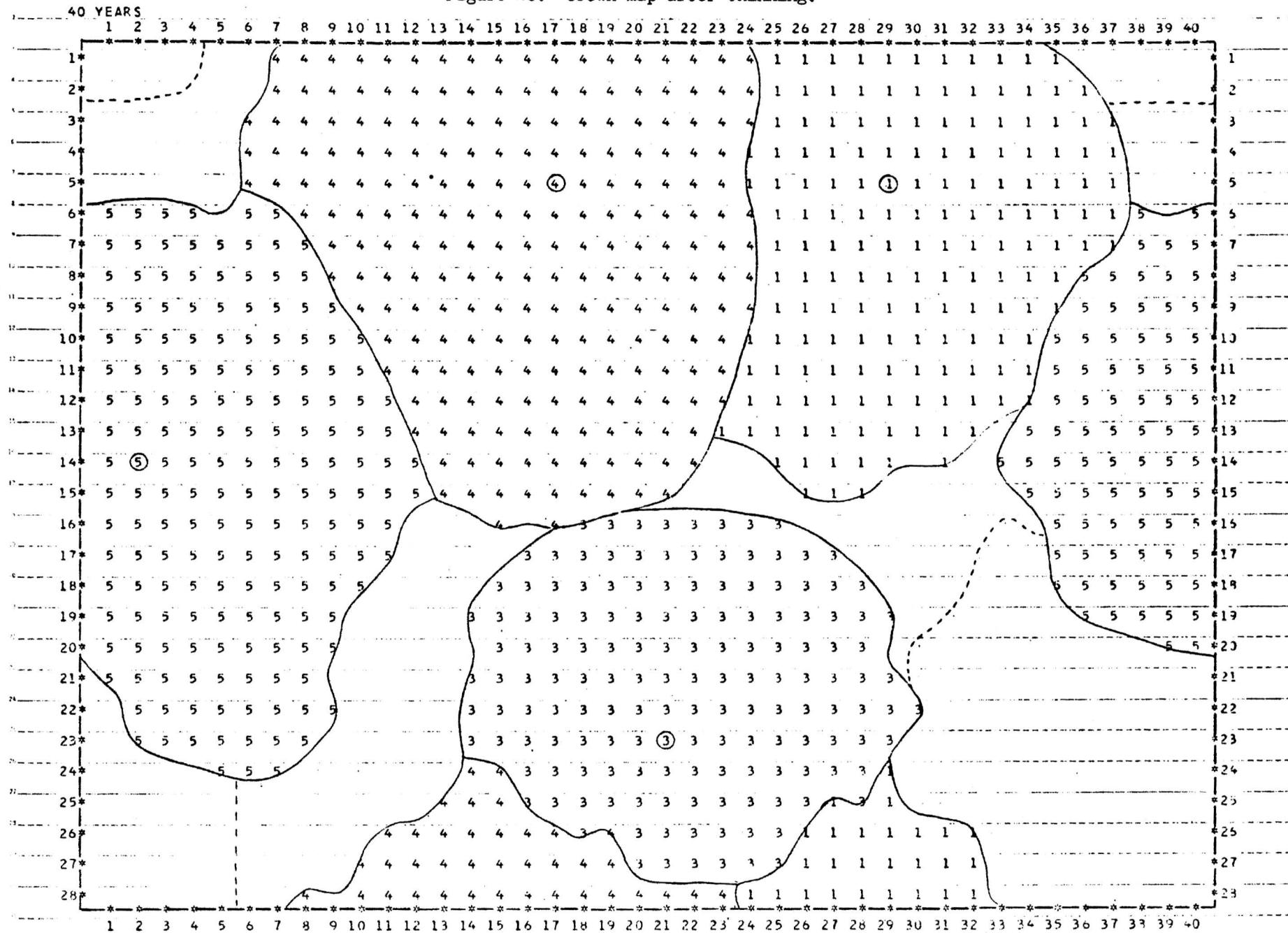


Figure 21. Summary of the stand at age 45.

AGE 45 SPECIES 1

TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
1	5	29	45	217.0	16.6	34.8	1.04	13.8	78.4	34.22	29.59	-0.454
3	23	21	45	169.0	14.7	40.5	0.91	12.9	82.4	33.05	27.89	-0.367
TOTAL	2 TREES			386.0	31.3	75.3	1.95	26.7	160.8	67.27	57.48	
AVERAGE				193.0	15.6	37.7	0.97	13.4	80.4	33.63	28.74	
/ACRE	78 TREES				75.71				2616.28	2235.56		

DBH HEIGHT VOLUME1

CLASS TALLY CLASS TALLY CLASS TALLY

13	1	52	0	13	0
14	1	56	0	14	0
15	0	60	0	15	0
16	0	64	0	16	0
17	0	68	0	17	0
18	0	72	0	18	0
19	0	76	0	19	0
20	0	80	1	20	0
21	0	84	1	21	0
22	0	88	0	22	0
23	0	92	0	23	0
24	0	96	0	24	0
25	0	100	0	25	0
26	0	104	0	26	0
27	0	108	0	27	0
28	0	112	0	28	0
29	0	116	0	29	0
30	0	120	0	30	0
31	0	124	0	31	0
32	0	128	0	32	0
33	0	132	0	33	1
34	0	136	0	34	1
TOTAL	2	2	2		

AGE 45 SPECIES 2

TREE	ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
4	5	17	45	269.0	18.5	29.3	1.20	14.9	76.7	36.93	32.91	-0.506
5	14	2	45	235.0	19.0	34.9	1.48	16.5	83.0	45.79	42.93	-0.444
6	24	35	5	38.0	7.0	8.3	0.02	1.9	10.5	0.12	0.10	-1.481
TOTAL	3 TREES			592.0	44.5	72.5	2.70	32.2	170.2	82.84	75.94	
AVERAGE				197.3	14.8	24.2	0.90	11.1	56.7	27.61	25.31	
/ACRE	117 TREES				105.01				3221.88	2953.52		

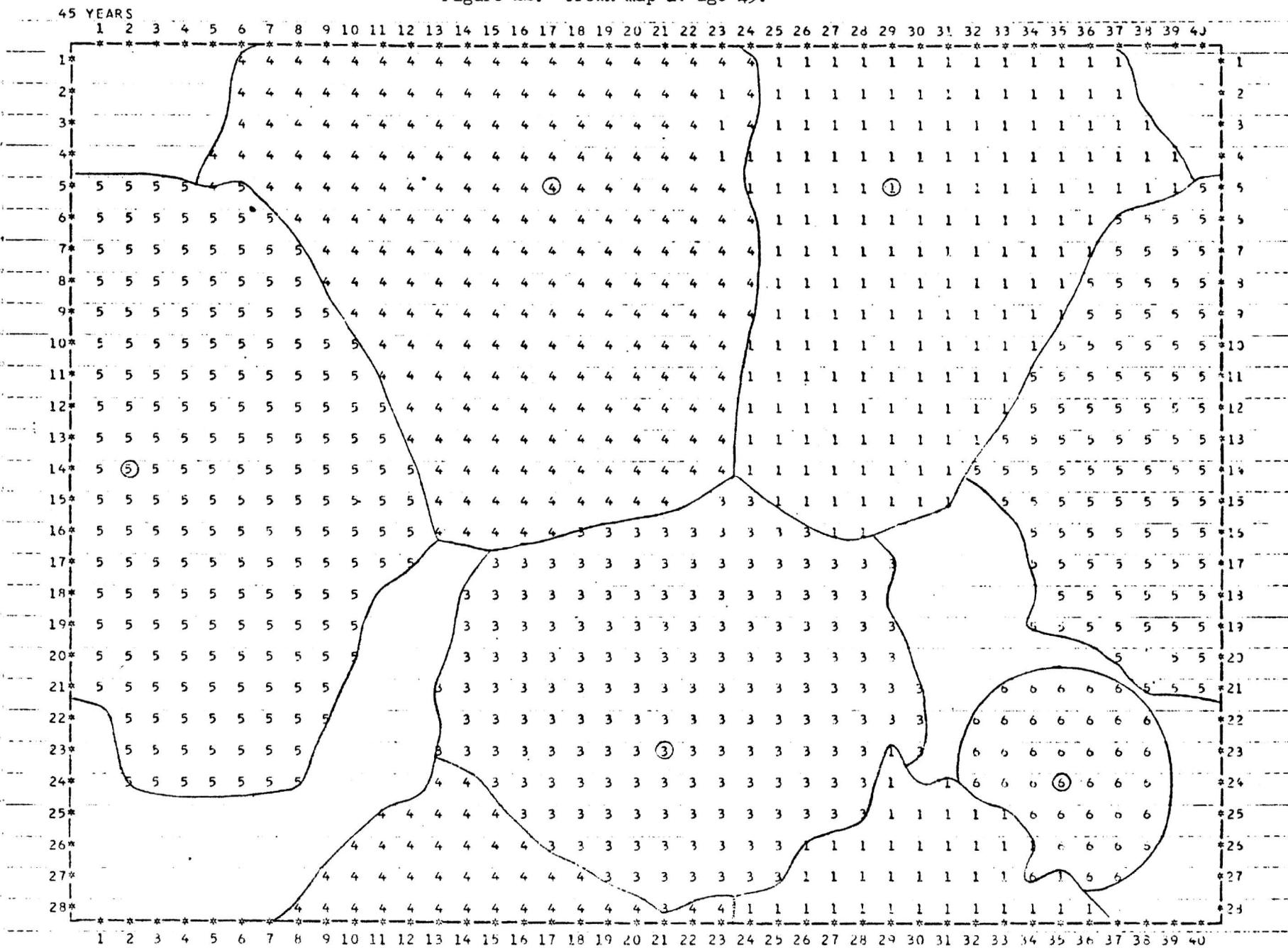
(Tally not shown)

----- Figure 21. (Continued). -----

AGE 45 SUMMARY OF ALL SPECIES

TREE ROW	COL	AGE	CROWN AREA	CROWN WIDTH	CROWN LENGTH	BASAL AREA	DBH	HEIGHT	VOLUME1	VOLUME2	STATUS
TOTAL	5 TREES		578.0	75.8	147.8	4.65	59.9	321.0	150.11	133.42	
AVERAGE			195.6	15.2	29.6	0.93	12.0	66.2	30.02	26.68	
/ACRE	194 TREES					180.85			5838.21	5189.08	

Figure 22. Crown map at age 45.



45 YEARS

Figure 23. Crown profiles at age 45.

5* 52 52 52 51 53 47 45 50 54 53 62 65 63 71 73 76 78 76 73 71 68 65 62 68 72 75 79 82 84 82 79 75 72 69 69 57 51 47 37 51 + 5
24* -0 46 45 45 43 41 38 35 -0 -0 -0 -0 46 47 53 60 65 71 75 79 80 79 75 71 66 60 53 45 45 -0 43 8 13 12 15 11 10 1 -9 -9 24

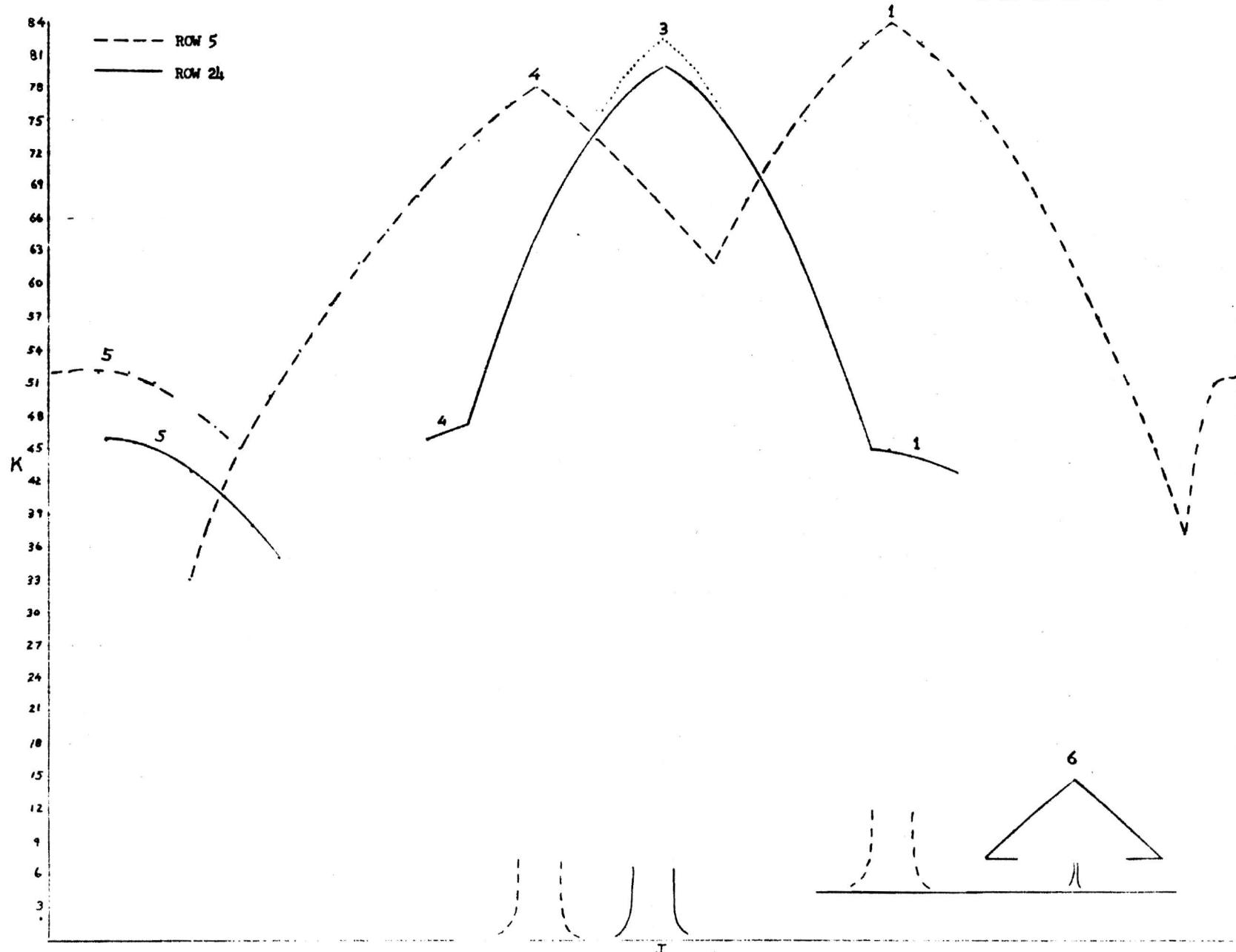


Figure 24. Change in crown profiles from age 30 to 45 (Row 5).

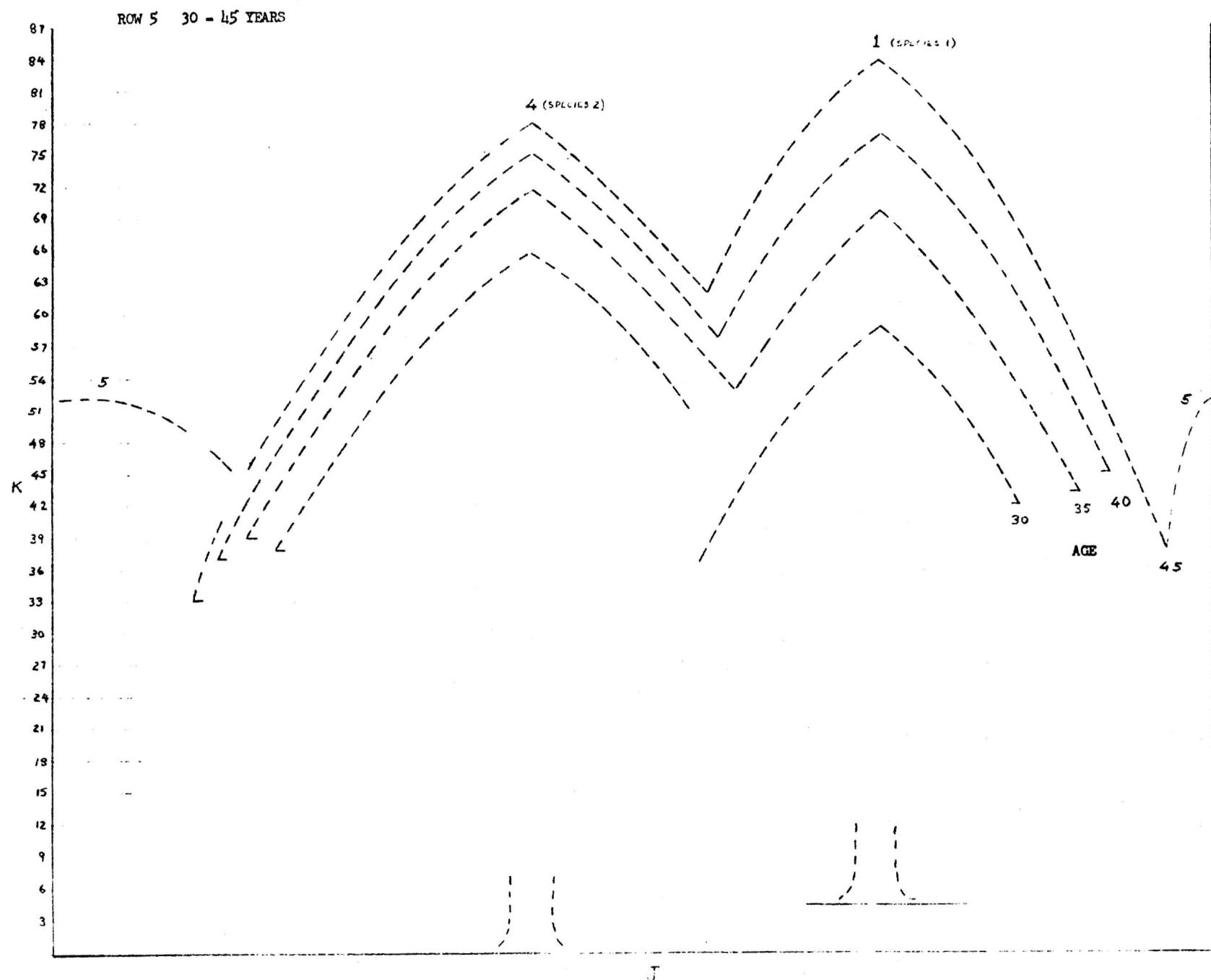


Figure 25. Change in crown profiles from age 30 to 45 (Row 24).

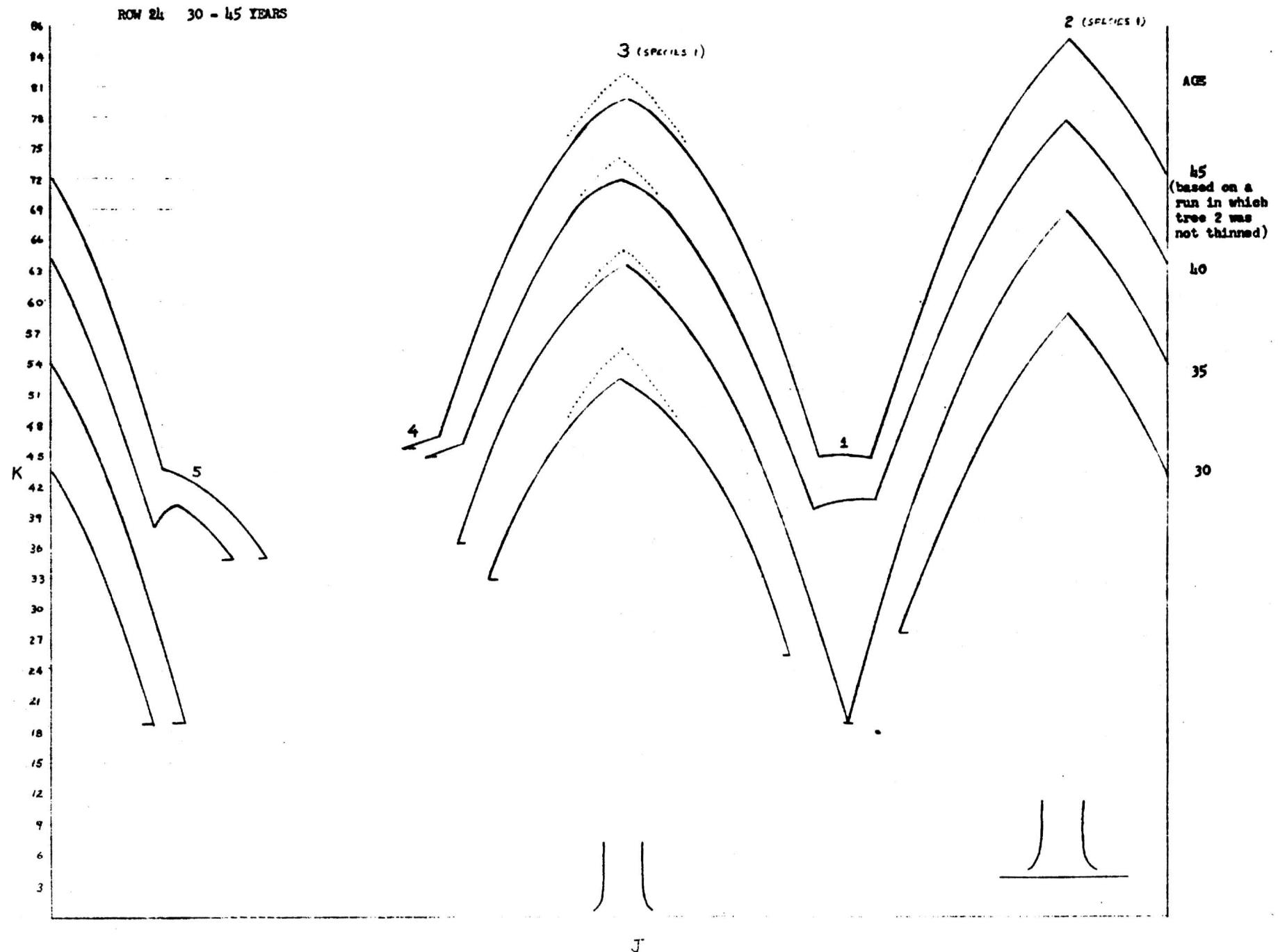


Figure 26. Expansion of the crown from age 30 to 45.

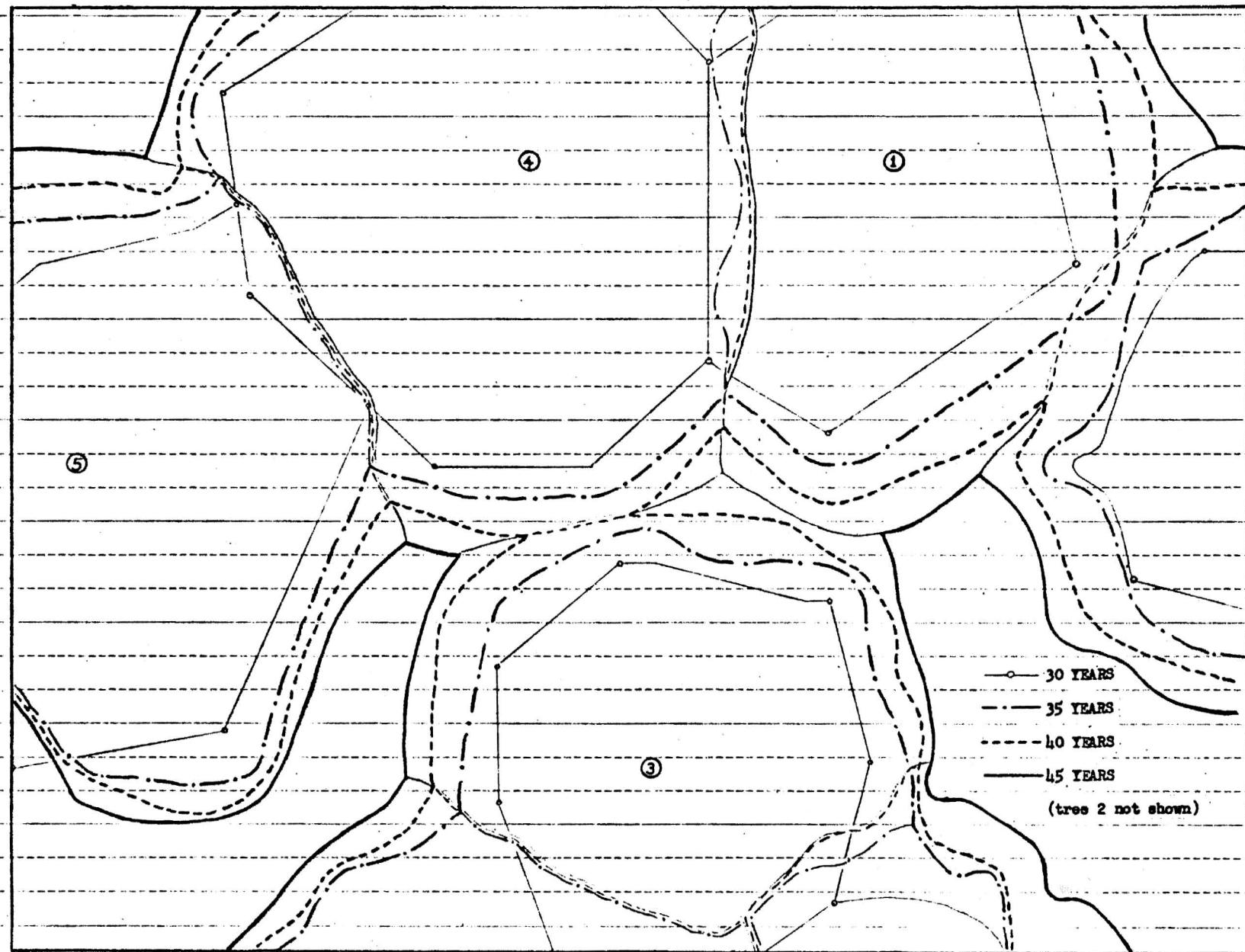


FIGURE 27. PHYSICAL MODELS DEPICTING THE SIMULATION PROCESS.

