FINAL REPORT

to the

CALIFORNIA DEPARTMENT of FORESTRY

THE EFFECT OF SILVICULTURAL SYSTEM AND STOCKING LEVEL ON PRODUCTIVITY, COSTS, AND SITE DISTURBANCE

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June 1984

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to the
CALIFORNIA DEPARTMENT OF FORESTRY

Supplement to Master Agreement for Conducting Cooperative
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Contents

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INTRODUCTION

In the redwood/Douglas-fir region of Northern California there is a lack of information on the potential benefits and costs to society stemming from the adoption of alternative silvicultural prescriptions for forest management. Long-term growth data are not available documenting differences in productivity associated with different management strategies. This knowledge gap is particularly important to the small private landowner and general public who need specific quantitative information and examples of alternative approaches to guide decision making.

The small forest landowner commonly needs guidance on three major issues:

1) What are the effects of choosing alternative residual growing stock levels representing light to heavy harvests?

2) What are the effects of reaching a given level of residual growing stock by alternative silvicultural prescriptions?

3) What are the effects of varying decisions on residual growing stock and silvicultural prescription on biological productivity, value and cash flow, and site disturbance?

The study was implemented in the Summer of 1983. Details on the methodology and results are available in a Master of Forestry Professional Paper by Clifton Kennedy, 1983, Forestry Library, Department of Forestry and Resource Management, U.C. Berkeley.

STUDY OBJECTIVES

The three specific study objectives (revised, Jan. 1983) were:

1. To quantify the relationship between level of stocking and stand growth.

2. To evaluate financial costs and benefits of alternative silvicultural strategies.

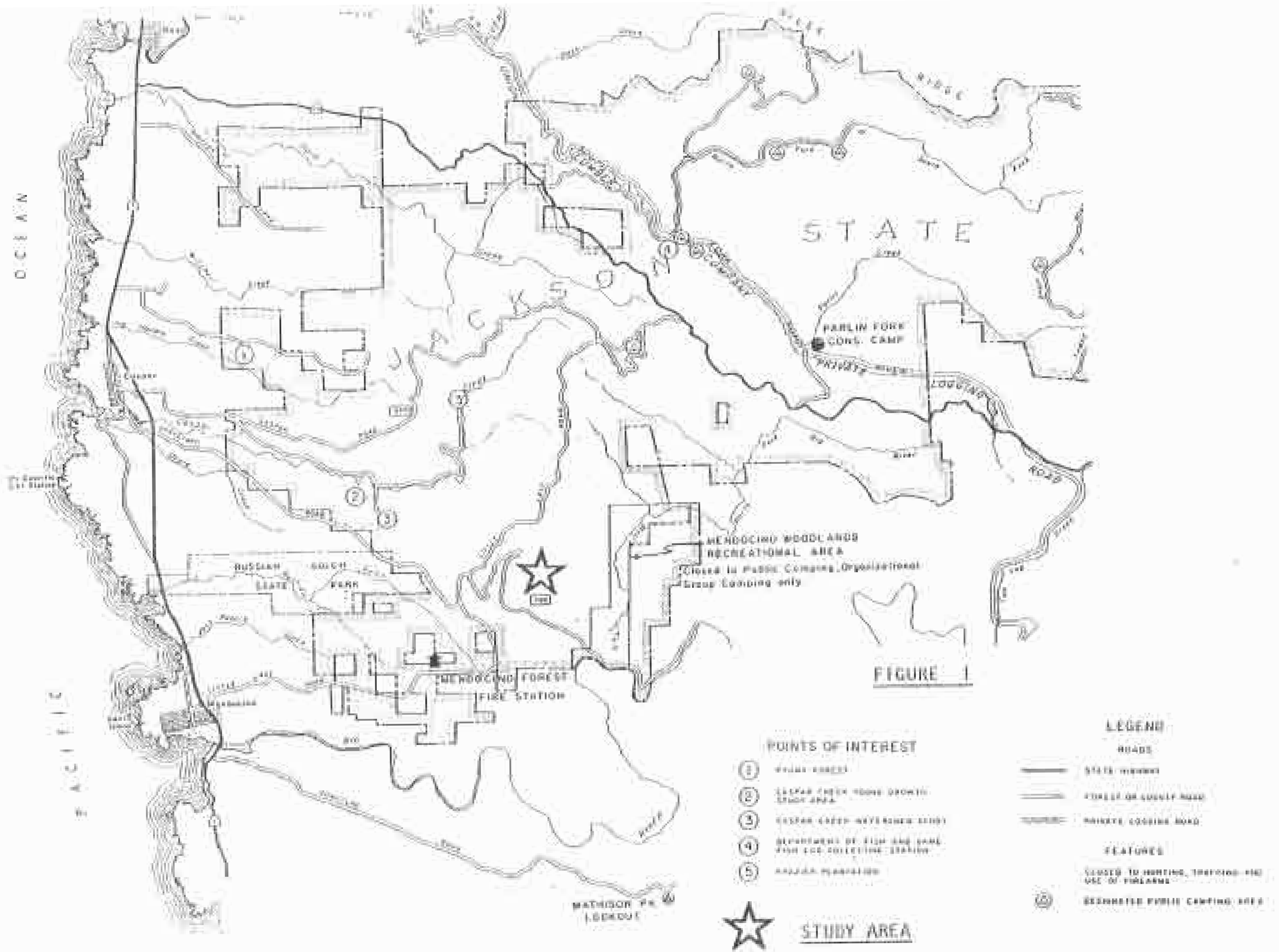
3. To quantify the effects of alternative silvicultural prescriptions on understory growth and soil surface displacement.

METHODS

1. Location: The study was located on 260 ac in Railroad Gulch, Jackson Demonstration State Forest (Figure 1). This area was selected because it was readily accessible to the public, and because the medium-quality of the forest stand most closely approximated that of small private ownerships. The area is about 5 miles from the coast, has an elevation of 160 to 880 feet, and slopes varying up to 80 percent. Soils are of the Hugo Series, and are gravelly to sandy clay loams 3-5 feet deep. Vegetation consisted of clumps of 55-60 year-old redwood intermixed with Douglas-fir, grand fir, tanoak, and lesser amounts of associated species.

2. Study Design: Thirteen 20-ac and one 10-ac study plots were established (Figure 2). One 20-ac and one 10-ac plot were selected as controls and the remaining 12 plots assigned treatments. Plot size was chosen to provide an adequate area for the demonstration of alternative uneven-aged stand structures.

Four levels of residual growing stock level were tested involving the



OCEAN
PACIFIC
STATE
JACKSON
PARLIN FORK
CONS. CAMP
MENDOCINO WOODLANDS
RECREATIONAL AREA
Closed to Public Camping, Organizational
Group Camping only
RUSSIAN GULCH
STATE PARK
MENDOCINO FOREST
FIRE STATION
MATHISON PK.
LOOKOUT
POINTS OF INTEREST
LEGEND
ROADS
FEATURES
STUDY AREA

FIGURE 1

RAILROAD GULCH 1983

TREATMENT AREAS and
PERCENT BASAL AREA REMOVED

I = Indiv. Tree Selection
G = Group Selection
G/I = Group + Indiv. Tree

FIGURE 2

removal of approximately 20, 30, 40 and 50 percent of existing basal area.

Three uneven-aged structures were evaluated: single-tree selection, group selection, and a combination prescription involving group selection and thinning between the groups. The three methods were chosen to create quite different stand structures. They vary in difficulty of implementation, and in resulting growth and development of trees, sprouts and understory.

Treatments were allocated as shown in Figure 2. Table 1 lists the treatment characteristics.

Table 1: Treatment Area Characteristics

Treatment Area	Prescription
0-1	Control
1-1	Indiv. Tree Selection, remove 30% BA
1-2	" remove 40% BA
1-3	" remove 50% BA
1-4	" remove 20% BA
2-1	Group Selection, remove 30% BA
2-2	" remove 40% BA
2-3	" remove 20% BA
2-4	" remove 50% BA
2-5	Control
3-1	Group/Individual, remove 30% BA
3-2	" remove 40% BA
3-3	" remove 50% BA
3-4	" remove 20% BA

3. Inventory: A random-systematic inventory was done at 10 percent sampling intensity (20 plots per treatment area). Circular plots were 1/10 ac in size. Minimum-sized trees measured were ≤ 2 in dbh for conifers and ≥ 4 in for hardwoods. Trees were numbered with aluminum tags. Measurements taken were dbh, live crown ratio, 5- and 10-yr radial growth at breast height, and height to the nearest foot on 8 trees per plot. A total of 260 permanent plots were established and 8000 trees measured.

Site indexes for redwood and for Douglas-fir were obtained by measuring height and breast-height age on 2 dominant trees of each species on each plot, (Krumland and Wensel, 1977).

Within each plot, three 1/100 ac plots were established to record presence, abundance, cover of understory species, and ground cover disturbance.

Within each treatment area 6-8 permanent photo points were established to record the development of vegetation over time.

4. Prescriptions: To control the structure of regulated uneven-aged stands it is usual to define the number of trees to be present in each diameter class in terms of an inverse J-shaped curve. The position and slope of the curve within its axes is controlled by three parameters: 1) the largest tree size to be retained. Using a criterion of that sized tree which will maintain a 6% value growth rate, the largest-sized tree was calculated to be 34 in dbh for both species. 2) diminution quotient. This quotient determines the slope of the diameter distribution curve. A "q" factor of 1.2 was chosen based on previous work done in coast redwood and mixed conifer forests (Adams 1980, Alden 1977). 3) residual growing stock. Four levels of cut were identified in the treatments. These three parameters identify the position of the desired frequency distribution of diameter classes. The difference between existing and desired distributions identifies the ideal numbers of trees that should be harvested in each diameter class.

Species composition was maintained at current levels - redwood 68 percent, Douglas-fir 22 percent, and tanoak 10 percent.

As shown in Figure 2, the shaded area above the road was harvested by cable, and the area below the road was tractor-skidded.

a) Individual Tree Selection

Trees were marked for harvest to bring the existing stand towards the desired distribution of diameter classes for each level of residual basal area. In anticipation of harvesting damage, marking for harvest was reduced by 7 percent to allow for removal of non-marked trees that were anticipated to be damaged during falling and skidding operations. The hardwood component was not included in the mark. The objective was to develop a stand of evenly-distributed, high-quality trees. As far as possible, trees marked included those which were of poorer quality. It was recognized that trees marked for cutting had to be merchantable and capable of being safely felled from within a clump.

b) Group Selection.

To achieve the desired residual growing stock levels, between 8 and 20 1/2 ac groups were cut within each treatment area. The number of groups cut reflected the proportion of basal area to be removed. Group cuts were distributed evenly within each treatment area except for avoiding unstocked areas.

c) Group/Individual Tree Selection.

Within a given treatment area, half the basal area needed to be removed to achieve the desired level of residual growing stock was removed by group cuts and the other half was removed by individual tree selection between the groups.

5. Determination of Harvest Levels and Growth Projection

Determination of harvest levels and growth projections were made using the CRYPTOS redwood/Douglas-fir growth model (Krumland and Wensel, 1982).

This distance-independent tree model is based on data collected throughout the north coast region. A comparison of basal area growth from the study area with that utilized within the model showed that the model over-estimated growth in this specific area by 25 percent. Consequently the model was calibrated to the study area by reducing projected growth by 25 percent.

RESULTS

1. Inventory Summary

Table 2 provides a comparison of stand characteristics of each treatment area.

Table 2: Inventory Summary by Treatment Area

Treatment Area	dbh (in)	Trees /ac	BA (ft^2/ac)	Volume (bd ft/ac)	Site (50 yr) DF	Site (50 yr) Redwood	Area (ac)
1-1	15.2	234	293	57,630	142	121	21.8
1-2	17.4	218	362	68,840	134	109	20.0
1-4	15.3	253	323	57,360	137	115	18.9
2-1	16.4	240	350	49,160	118	93	20.1
2-2	14.7	194	230	38,200	136	112	18.7
2-3	16.0	224	312	79,020	148	123	17.8
2-4	16.0	231	324	47,560	121	97	21.4
2-5	15.1	223	277	48,690	136	110	20.0
3-1	17.8	181	315	55,620	126	102	21.2
3-2	13.5	187	187	26,650	129	103	20.6
3-3	16.6	167	233	51,410	140	120	20.4
3-4	13.9	198	209	22,090	117	87	21.9
Average	15.8 ±1.2	210.9 ±24.7	286 ±54	50,210 ±15,200	132	108	260.5

This table shows the considerable variability between treatment areas. Average stand basal area ranged from 187 to 362 ft^2/ac. Standing volume varied from 22,090 to 79,020 bd ft/ac. Similarly site quality ranged from 87 to 123 feet in 50 years. Because of the variability in site and stocking, residual basal area levels were based on the removal of a percent of existing basal area rather than common absolute levels.

2. 1983 Harvest Levels

Table 3 shows the proportion of basal area removed in each treatment area.

Table 3: Comparison of desired and actual harvest levels

Treatment Area	BA before harvest (ft^2/ac)	BA after harvest (ft^2/ac)	Percent BA removed	Desired cut (%)
1-1	293	176	40	30
1-2	362	191	47	40
1-4	323	261	19	20
2-1	350	261	25	30
2-2	230	156	32	40
2-3	312	256	18	20
2-4	324	161	44	50
3-1	315	180	36	30
3-2	187	117	37	40
3-3	233	136	41	50
3-4	209	121	24	20

This table indicates differences between the percent of basal removed and the desired proportion to be cut. These differences could be due to four main factors: 1) difficulty in marking to a precise target harvest, 2) allowances for 7 percent harvest of damaged trees which may or may not have occurred, 3) trees marked but not cut due to falling difficulties, and 4) estimates of basal area removed being based on re-examination of permanent plots after harvest. This approach is not well-suited to evaluating group selection where an accurate estimate of the harvest cut would require the proportion of permanent plots falling in group cuts to be exactly the same as the proportion of basal area removed. The probability of nearly all the group cuts falling on permanent plots is equal to the probability of nearly all the group cuts falling between the permanent plots.

3. Stand Prescriptions and Growth Projections

A. Individual Tree Selection

1) Treatment Area 1-1

Removing 30% of existing basal area.

Figure 3a shows the diameter distribution of the stand before and after the 1983 harvest and the desired distribution reflecting the specified q-factor, size of largest tree, and residual growing stock level.

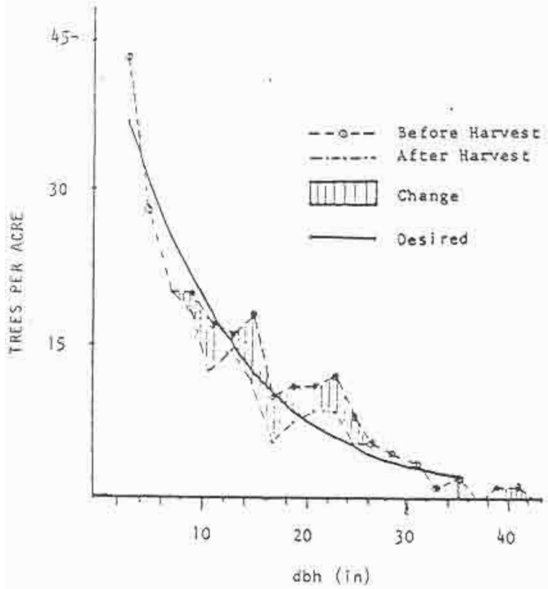


Fig. 3a. Treatment 1-1, 1983 harvest

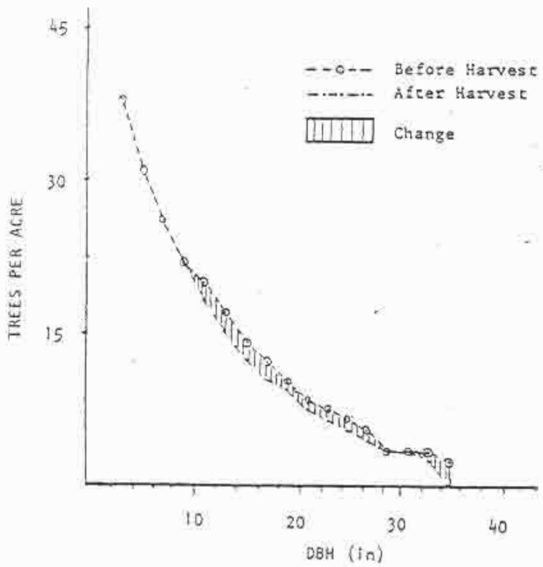


Fig. 3b. Treatment 1-1, 10-year harvest after regulation.

Differences between the desired distribution and the distribution after harvest reflect the same factors mentioned on page _ plus the deliberate marking of trees in the lower diameter classes which had slow growth rates, poor form, and low live-crown ratios.

Using the CRYPTOS growth model, stand growth and projected harvests were simulated until the stand was fully regulated. Although in the 1983 harvest

40 percent of the basal area was estimated as being cut rather than the desired 30%, the projection reverts back to 30 percent at the third entry. Table 4 shows the harvest sequence required to achieve the regulated condition.

Table 4: Harvest sequence in treatment 1-1 during conversion period.

Year	BA Before	BA After	Volume Before	Volume After	Harvest
	---(ft^2/ac)---		---(bd ft/ac)---		(bd ft/ac)
1983	293	177	57,630	35,120	22,500
1993	221	205	53,520	36,000	17,500
2003	255	200	54,500	38,600	15,900
2013	251	201	51,800	37,300	14,500

Each harvest removes the least vigorous trees in each size class subject to achieving the desired diameter distribution (Figure 3a) and a basal area of 200 ft^2/ac.

After harvest in year 2013, treatment area 1-1 will contain a stand with the desired number of trees in each size class capable of providing a sustainable yield. This situation is illustrated in Figure 3b. The shaded portion in this figure shows the proportion of trees in size classes >11 inches dbh which are harvested in order to return the stand to the desired diameter distribution.

The 10-year harvests in the regulated stand are shown in Table 5.

Table 5: 10-year harvest in treatment 1-1 after regulation.

	dbh (in)	Trees /ac	BA (ft^2/ac)	Standing Volume bd ft/ac)	Harvest Volume (bd ft/ac)
Before Harvest	14.3	298	263	51,500	
After Harvest	13.5	283	200	35,000	16,500

2) Treatment Area 1-2

Removing 40 percent of existing basal area.

Figure 4a shows the diameter distribution before and after the 1983 harvest plus the desired distribution.

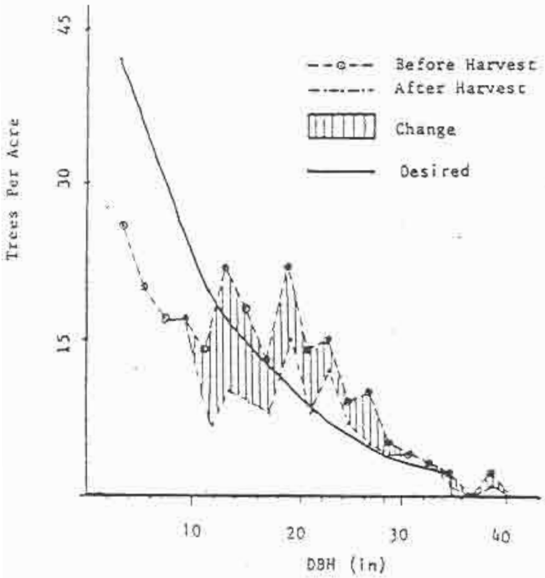


Fig. 4a. Treatment 1-2, 1983 harvest

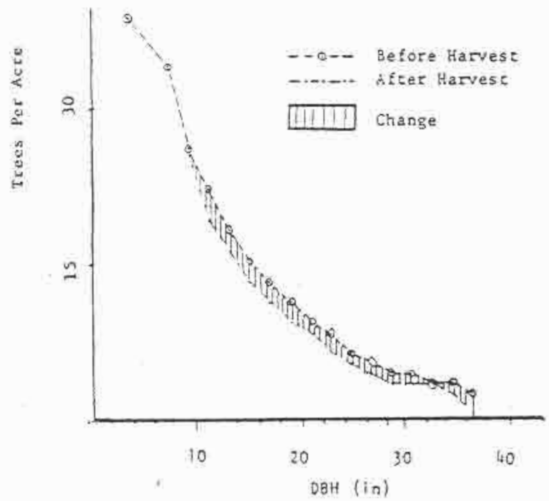


Fig. 4b. Treatment 1-2, 10-year harvest after regulation.

Table 6 shows the harvest sequence required to achieve the regulated condition.

Table 6: Harvest sequence in treatment 1-2 during conversion period.

Year	BA Before	BA After	Volume Before	Volume After	Harvest
	---ft^2/ac---		---bd ft/ac---		(bd ft/ac)
1983	362	191	68,840	34,950	33,890
1993	222	232	46,700	46,200	16,500
2003	260	236	59,200	45,200	14,200
2013	275	235	60,900	43,800	17,100
2023	270	235	55,600	40,000	15,600

The desired residual basal area after each simulated harvest is about 235

ft^2/ac. By the year 2023, the deficient number of trees in size classes ≤17 in dbh will be replenished by ingrowth. The frequency distribution and 10-year growth at the time of regulation in the year 2023 is shown in Figure 4b.

The 10-year harvests of the fully-regulated stand after the year 2023 are shown in Table 7.

Table 7: 10-year harvest in treatment 1-2 after regulation

	dbh (in)	Trees /ac	BA (ft^2ac)	Standing Volume (bd ft/ac)	Harvest Volume (bd ft/ac)
Before Harvest	14.9	302	291	55,600	
After Harvest	12.6	240	234	40,400	15,200

3) Treatment Area 1-3

This treatment area included an old trail which, late in the study, became a politically-sensitive issue. At the time of timber falling, a decision was made to exclude the northeast 1/3 of the area above the road from the project. During the summer of 1984, this lower area will be surveyed, additional permanent plots will be installed, and determination made of standing volume 1983 harvest, and projections of future growth and yield.

4) Treatment Area 1-4

Removing 20 percent of existing basal area.

Figure 5a shows the diameter distribution before and after the 1983 harvest plus the desired distribution.

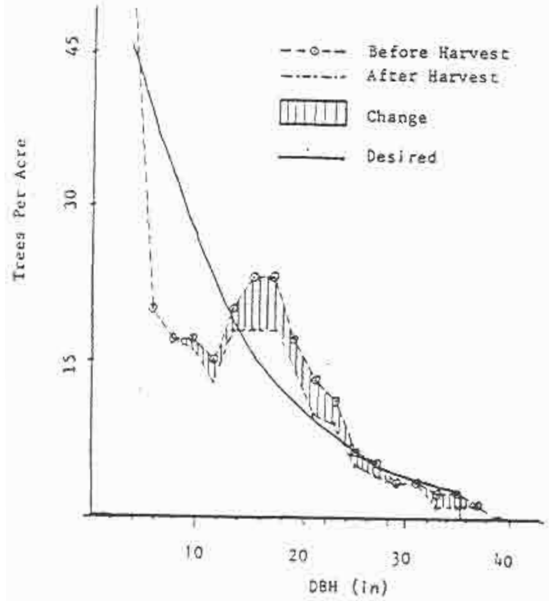


Fig. 5a. Treatment 1-2, 1983 harvest

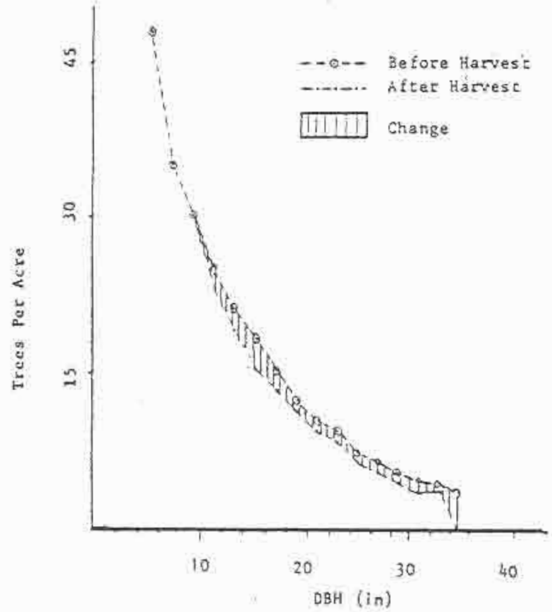


Fig. 5b. Treatment 1-2, 10-year harvest after regulation.

Table 8 shows the harvest sequence required to achieve the regulated condition:

Table 8: Harvest sequence in treatment 1-4 during conversion period.

Year	BA Before	BA After	Volume Before	Volume After	Harvest
	---ft^2/ac---		---bd ft/ac---		(bd ft/ac)
1983	323	267	57,400	47,700	9,700
1993	309	259	64,300	50,900	13,400
2003	300	252	60,200	45,000	15,200

After the stand is fully regulated in year 2003, the 10-year growth will be as shown in Figure 5b.

The 10-year harvest after the year 2003 is shown in Table 9.

Table 9: 10-year harvest in treatment 1-4 after regulation.

	dbh (in)	Trees /ac	BA (ft^2/ac)	Standing Volume (bd ft/ac)	Harvest Volume (bd ft/ac)
Before Harvest	15.0	330	314	62,300	
After Harvest	13.5	265	253	43,500	18,800

B. Group Selection

The management of treatment areas 2-1 through 2-4 involves the periodic harvesting of trees in a mosaic of 1/2-acre groups. The harvesting of each group establishes a new age class which remains unthinned until it is mature and harvested. The number of groups cut in one harvest depends on the proportion of basal area that is required to be cut. At each entry, a new set of groups is cut and a new age class developed until the stand develops into a fully regulated condition. The residual basal area after each entry is an average of all group types within the stand, varying from unstocked to fully stocked.

1) Treatment Area 2-1

Removing 30 percent of existing basal area.

The prescription called for a reduction in stand basal area from 350 ft^2/ac to 240 ft^2/ac. This was accomplished by harvesting 12 1/2-acre groups which totalled 30 percent of the area.

To achieve a regulated stand with a 10-year cutting cycle and 240 ft^2 basal area, CRYPTOS projections indicated a need for 12 entries creating 12 group types of equal area. Figure 6 shows the frequency and the projection of growth over a subsequent 10-year period. The distribution is not a regular J-shaped curve because no thinning will take place between the groups.

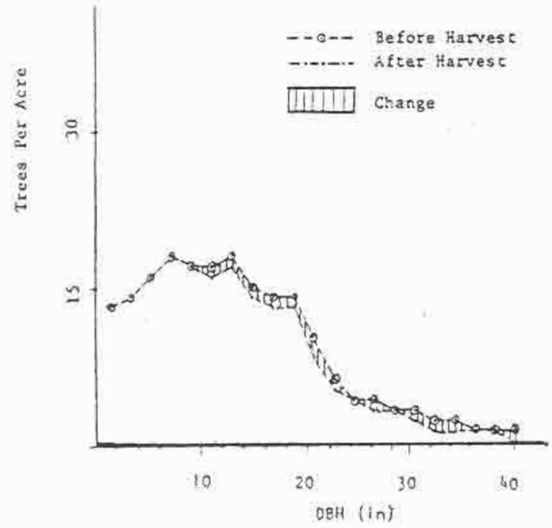


Fig. 6. Treatment 2-1,
10-year harvest after regulation.

Table 10 shows the stand characteristics and volume harvested over the entire stand every 10 years to achieve the fully-regulated condition in year 2093.

Table 10: Harvest sequency in treatment 2-1 during conversion period.

Year	Area Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	6.00	350	262	49,200	34,400	14,800
1993	1.67	300	248	46,300	38,900	7,400
2003	1.67	295	260	49,900	43,300	6,600
2013	1.67	307	268	55,000	46,900	8,100
2023	1.67	314	272	58,800	49,100	9,700
2033	1.67	316	271	61,300	50,100	11,200
2043	1.67	314	266	62,300	49,600	12,800
2053	1.67	309	257	61,800	47,400	14,400
2063	1.67	299	245	59,600	43,600	16,000
2073	1.67	285	242	57,000	39,400	17,600
2083	1.67	270	234	50,700	42,200	8,500
2093	1.67	275	237	53,500	43,600	9,900

The requirement of removing 30 percent of existing basal area in the 1983 harvest results in a large harvest cut in that year. In subsequent years, 1.67 ac are cut in each entry. Harvests drop in the second entry and then gradually increase due to the continued growth of the uncut portion of the stand. The harvest in year 2073 removes the last 0.70 ac from the uncut stand and 0.98 ac from the 6 ac group type regenerated after the 1983 harvest. In the year 2083, harvests will be entirely from regenerated group cuts, consequently volumes drop appreciably to the stable yield levels of the regulated stand.

Table 11 shows the condition of the stand after regulation. It contains 12 group types each occupying 1.67 ac.

Table 11: Harvest sequence in treatment area 2-1 after regulation.

Group Type	Age (yrs)	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)
1a	-	-	-	-	-
2	10	3.2	272	16	-
3	20	7.6	233	74	1,900
4	30	10.5	219	132	7,500
5	40	12.7	208	184	15,900
6	50	14.6	200	231	26,900
7	60	16.1	193	274	39,900
8	70	17.6	187	315	54,400
9	80	18.8	182	353	69,800
10	90	20.0	178	389	85,900
11	100	21.1	174	424	102,200
12	110	22.2	170	456	118,600
		Harvested Group Type			
1b	120	23.1	167	488	134,900
Avg*		13.7	214	237.3	237

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest (excludes group type 1b)

The total volume harvested is determined by multiplying 1.67 ac harvested by the volume per ac in the particular group type. The average volume removed per ac will be 43,600 bd ft/ac.

2) Treatment Area 2-2

Removing 40 percent of the basal area.

This harvest was done by cutting 40 percent of the area in 15 1/2 ac groups.

CRYPTOS projections indicate that a fully-regulated condition can be obtained in 7 entries, each removing 2.67 ac of group cuts. Table 12 shows the condition of the stand at each 10-year entry to the year 2043 when regulation is anticipated.

Table 12: Harvest sequency in treatment 2-2 during conversion period.

Year	Area Cut (ac)	BA Volume Before (ft^2/ac)	BA Volume After (ft^2/ac)	Standing Harvest Before (bd ft/ac)	Standing Harvest After (bd ft/ac)	Volume (bd ft/ac)
1983	7.50	230	156	38,200	25,100	13,100
1993	2.67	194	128	37,700	23,900	13,800
2003	2.67	169	128	32,000	22,400	9,600
2013	2.67	173	128	31,000	19,100	11,900
2023	2.67	176	126	28,000	13,900	14,400
2033	2.67	169	134	20,100	15,000	5,100
2043	2.67	183	140	25,200	17,500	7,700

After the stand is fully regulated, it will consist of 7 group types with the characteristics shown in Table 13.

Table 13: Harvest sequence in treatment area 2-2 after regulation.

Group Type	Age (yrs)	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)
1a	-	-	-	-	-
2	10	3.2	272	16	-
3	20	7.9	233	79	2,500
4	30	10.9	218	141	9,600
5	40	13.2	207	198	20,500
6	50	15.2	199	251	36,000
7	60	16.9	192	300	54,000
		Harvested Group Type			
1b	70	18.5	185	345	70,200
Avg*		9.6	188	140	17,500

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest (excluding group type 1b).

At the conclusion of each 10-year period, group type 1b (age 70 yrs) will be removed involving a harvest of 2.67 ac carrying 70,200 bd ft/ac. The diameter distribution of the regulated stand before and after harvest is shown in Figure 7.

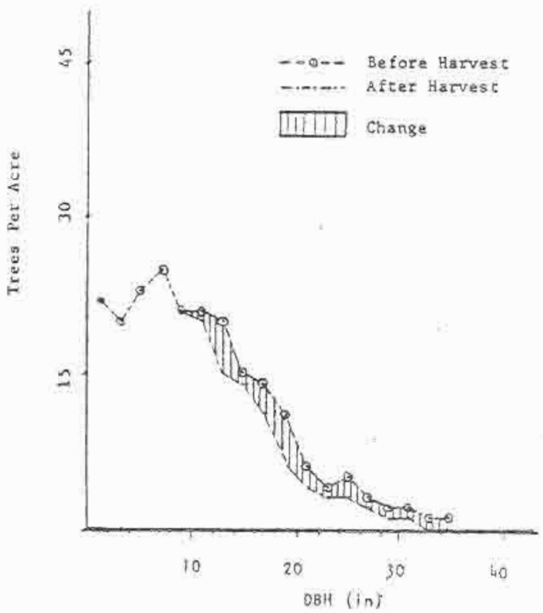


Fig. 7. Treatment 2-2,
10-year harvest after regulation.

3) Treatment Area 2-3

Removing 20 percent of existing basal area.

The 1983 harvest was done by cutting 20 percent of the area in 7 1/2 ac groups.

CRYPTOS projections indicate that a fully-regulated condition can be obtained in 10 entries, each entry after 1983 removing 1/10 of the total area or 1.78 ac. Table 14 shows the condition of the stand at each 10-year entry to the year 2073 when full regulation is anticipated.

Table 14: Harvest sequence in treatment 2-3 during conversion period.

		BA		Standing Volume		Harvest Volume
Year	Cut (ac)	Before (ft^2/ac)	After	Before (bd ft/ac)	After	(bd ft/ac)
1983	3.50	312	256	79,000	63,600	15,400
1993	1.78	297	240	85,000	68,500	16,500
2003	1.78	283	245	85,900	73,700	12,200
2013	1.78	290	248	91,300	76,600	14,700
2023	1.78	298	253	94,400	77,000	17,400
2033	1.78	303	254	95,000	75,000	20,000
2043	1.78	305	252	92,800	70,100	22,700
2053	1.78	304	248	88,300	63,000	25,300
2063	1.78	300	242	81,600	53,600	28,000
2073	1.78	297	247	72,700	56,500	16,200

After the stand is fully regulated, it will consist of 10 group types with the characteristics shown in Table 15.

Table 15: Harvest sequence in treatment 2-3 after regulation.

Group Type	Age (yrs)	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)
1a	-	-	-	-	-
2	10	3.2	272	16	-
3	20	8.3	232	87	3,700
4	30	11.6	217	159	13,900
5	40	14.2	206	226	29,400
6	50	16.3	198	288	50,400
7	60	18.2	190	345	74,800
8	70	19.9	184	400	101,900
9	80	21.5	179	451	131,000
10	90	22.9	174	299	161,600
		Harvested Group Type			
1b	100	24.2	170	546	192,800
Avg*		13.6	212	247	56,600

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest (excluding group type 1b).

At the conclusion of each 10-year period, group type 1b (age 100 yr) will be removed involving a harvest of 1.78 ac carrying 192,800 bd ft/ac. The diameter distribution of the regulated stand before and after harvest is shown in Figure 8.

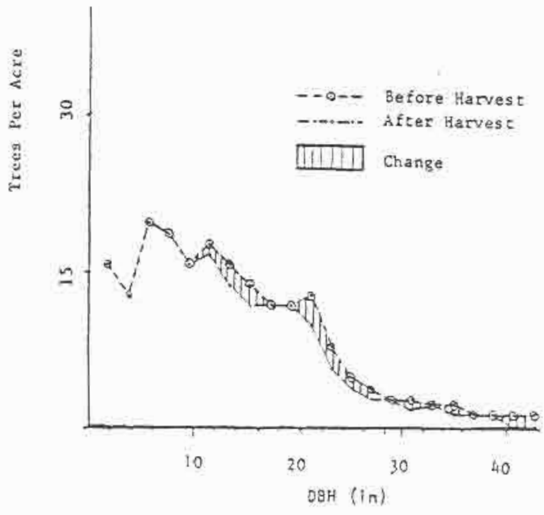


Fig. 8. Treatment 2-3
10-year harvest after regulation.

4) Treatment Area 2-4

Removing 50 percent of the basal area.

The 1983 harvest was done by cutting 50 percent of the area in 21 1/2 ac groups.

CRYPTOS projections indicate that a fully-regulated condition can be obtained in 8 entries, each entry after 1983 removing 2.67 ac. Table 16 shows the condition of the stand of each 10-year entry to the year 2053 when full regulation is anticipated.

Table 16: Harvest sequence in treatment 2-4 during conversion period.

Year	Area Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	10.50	324	261	47,600	37,400	10,200
1993	2.67	300	142	50,900	22,900	28,000
2003	2.67	188	136	30,000	20,200	9,800
2013	2.67	184	136	27,300	15,300	12,000
2023	2.67	186	125	24,900	10,700	14,200
2033	2.67	173	143	18,200	13,200	5,000
2043	2.67	190	154	23,700	18,200	5,500
2053	2.67	201	159	26,700	20,100	7,500

After the stand is fully regulated, it will consist of 8 group types with the characteristics shown in Table 17.

Table 17: Harvest sequence in treatment 2-4 after regulation.

Group Type	Age (yrs)	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)
1a	-	-	-	-	-
2	10	3.2	272	16	-
3	20	7.7	233	76	2,100
4	30	10.7	219	136	8,100
5	40	13.0	208	190	17,400
6	50	14.9	200	241	29,600
7	60	16.5	193	288	44,000
8	70	18.0	187	331	60,000
		Harvested Group Type			
1b	80	19.3	182	372	77,300
Avg*		11.3	229	159	20,100

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest (excluding group type 1b).

At the conclusion of each 10-year period, group type 1b (age 80 yr) will be removed involving a harvest of 1.67 ac carrying 77.300 bd ft/ac. The diameter distribution of the regulated stand before and after harvest is shown in Figure 9.

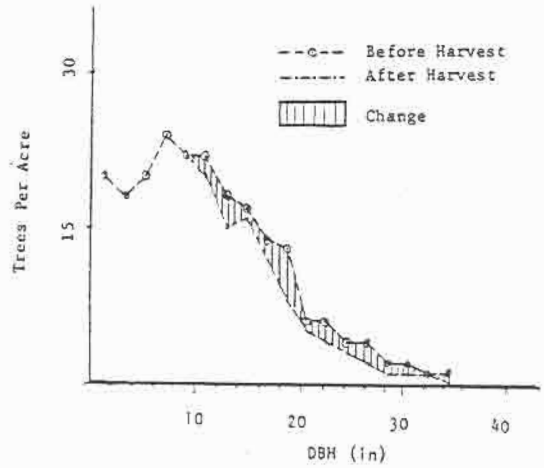


Fig. 9. Treatment 2-4,
10-year harvest after regulation.

C. Group Selection with Thinning Between Groups

Thinning between groups at each entry permits more intensive management and the maintenance of stands with higher vigor. In each treatment, half of the basal area to be harvested was allocated to 1/2 ac group cuts and the other half to individual tree selection between the groups.

Because of the more intensive procedure, including pre-commercial thinnings in the regenerated groups, the sprouts coming from harvested redwood stumps and natural regeneration of Douglas-fir were both anticipated as developing into vigorous ingrowth. Consequently, 40 redwood sprouts per ac and 10 Douglas-fir seedlings per acre were added as ingrowth after each 10-year entry. Growth of the ingrowth was reduced during the first decade prior to precommercial thinning to 75 percent of normal for redwood and 60 percent for Douglas-fir to account for competitive effects of the overstory. Growth projection, ingrowth, and harvests are projected until the accumulated average basal area equals the desired level.

1) Treatment Area 3-1

Removing 30 percent of existing basal area.

The 1983 harvest was done by cutting 15 percent of the basal area using 1/2 ac groups, and 15 percent of the basal area using individual tree selection between the groups. Figure 10a shows the distribution of diameters before and after the 1983 harvest and the desired J-shaped distribution of the regulated stand.

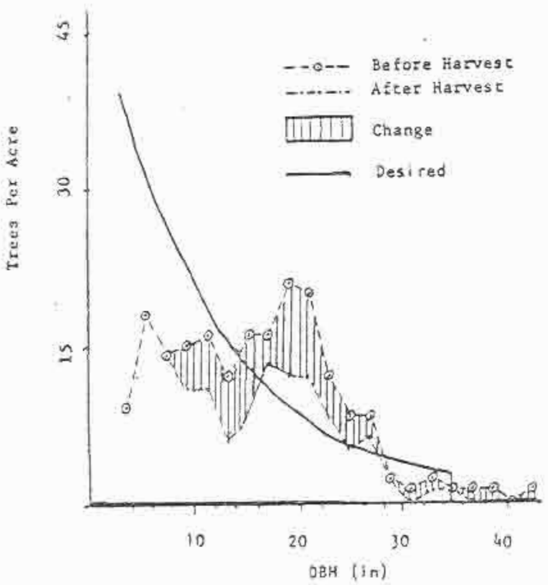


Fig. 10a. Treatment 3-1, 1983 harvest.

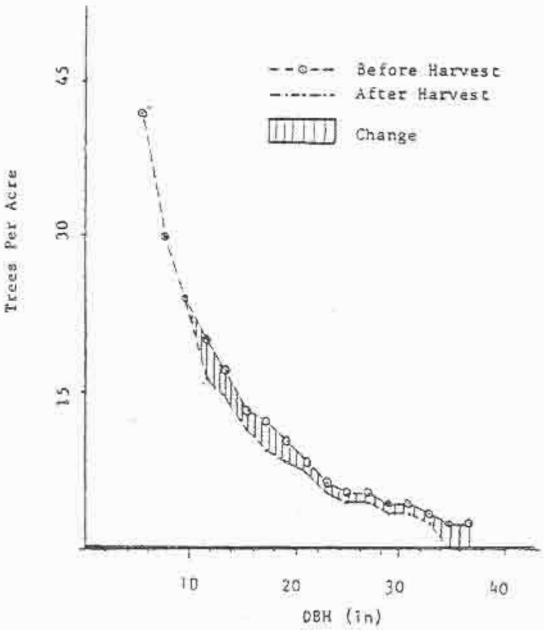


Fig. 10b. Treatment 3-1, 10-year harvest after regulations.

Using the CRYPTOS model, growth and projected harvests were simulated until the stand was fully regulated. Table 18 shows the condition of the stand at each 10-year entry to the year 2083 when regulation is anticipated.

Table 18: Harvest sequence in treatment 3-1 during conversion period.

Year	Area Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	3.00	315	180	55,600	31,600	24,000
1993	1.93	213	217	43,100	41,200	1,900
2003	1.93	257	214	53,700	42,600	11,100
2013	1.93	256	214	53,900	43,600	10,300
2023	1.93	254	210	54,000	43,200	10,800
2033	1.93	253	208	54,000	43,600	10,500
2043	1.93	250	203	54,100	42,700	11,400
2053	1.93	247	203	53,800	42,100	11,600
2063	1.93	251	202	50,100	40,600	9,500
2073	1.93	257	207	52,800	45,300	7,400
2083	1.93	270	211	49,000	37,400	11,600

After the stand is fully regulated, (figure 10b) it will consist of 11 group types with the characteristics shown in Table 19.

Table 19: Stand condition in treatment 3-1 before and after harvesting after regulation.

Group Type	Age (yrs)	Status	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)	Vol Cut (bd ft/ac)
1a	0	After	-	-	-	-	133,700
2	10	Before	3.2	272	16	-	
		After	3.2	272	16	-	-
3	20	Before	7.8	232	76	2,700	
		After	7.8	232	76	2,700	-
4	30	Before	10.7	216	136	9,100	
		After	10.7	216	126	9,100	-
5	40	Before	13.1	208	192	19,300	
		After	15.4	134	173	18,300	1,000
6	50	Before	15.1	181	226	30,900	
		After	18.0	118	209	29,200	1,700
7	60	Before	16.8	166	257	43,300	
		After	19.5	114	237	40,700	2,600
8	70	Before	18.1	160	286	56,800	
		After	18.8	138	266	54,000	2,800
9	80	Before	17.0	212	336	71,900	
		After	16.9	202	316	68,100	3,800
10	90	Before	18.9	208	407	88,300	
		After	19.1	195	387	84,500	3,800
11	100	Before	20.3	231	520	108,400	
		After	20.4	221	504	104,300	4,100
			Harvested Group Type				
1b	110	Before	22.0	258	683	133,700	
Avg*		After	13.6	167	211	37,400	13,900

1a Description of group type 1 after harvest.
1b Description of group type 1 before havest.
* Description of the average stand after harvest.

At the conclusion of each 10-year period, group type 1b (at age 110 yr) will be removed involving a harvest of 133,700 bd ft/ac. In addition, thinning will remove between 1,000 and 4,100 bd ft/ac from group types 5 through 11. Expressed in terms of the entire treatment area, the average volume removed over the 21.2 ac stand each 10-year entry will average 13,900 bd ft/ac.

2) Treatment Area 3-2

Removing 40 percent of existing basal area.

The 1983 harvest removed 20 percent of the basal area using 1/2 ac groups and 20 percent using individual tree selection between the groups. Figure 11a shows the distribution of diameters before and after the 1983 harvest and the desired J-shaped distribution of the regulated stand.

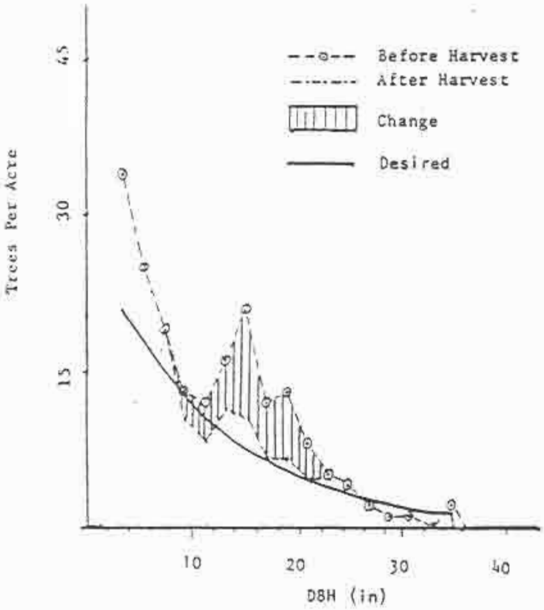


Fig. 11a. Treatment 3-2, 1983 harvest.

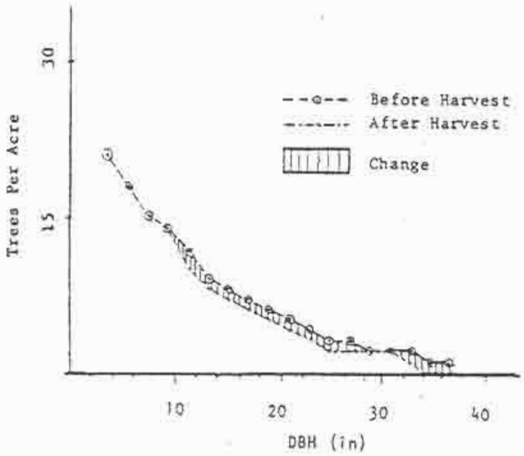


Fig. 11b. Treatment 3-2, 10-year harvest after regulation.

Using CRYPTOS, growth and projected harvests were simulated until the stand was fully regulated. Table 20 shows the condition of the stand at each 10-year entry to the year 2043 when regulation is anticipated.

Table 20: Harvest sequence in treatment 3-2 during conversion period.

Year	Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	4.00	187	117	26,600	16,800	9,800
1993	2.94	151	107	26,600	17,100	9,500
2003	2.94	140	98	23,000	15,900	7,200
2013	2.94	133	97	20,400	13,800	6,600
2023	2.94	135	100	20,200	13,400	6,800
2033	2.94	153	112	20,900	13,200	7,700
2043	2.94	159	114	21,400	13,800	7,600

After the stand is fully regulated (Figure 11b) it will consist of 7 group types with the characteristics shown in Table 21.

Table 21: Stand condition in treatment 3-2 before and after harvesting after regulation.

Group Type	Age (yrs)	Status	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)	Vol Cut (bd ft/ac)
1a	0	After	-	-	-	-	53,900
2	10	Before	3.2	272	16	-	
		After	3.2	272	16	-	-
3	20	Before	7.8	232	77	2,700	
		After	7.8	232	77	2,700	-
4	30	Before	10.8	216	137	9,500	
		After	10.8	216	137	9,500	-
5	40	Before	13.2	205	194	19,900	
		After	15.7	124	167	18,300	1,600
6	50	Before	15.3	172	220	30,900	
		After	17.9	108	190	27,600	3,300
7	60	Before	16.9	154	238	41,600	
		After	21.4	84	209	28,300	3,300
			Harvested Group Type				
1b	70	Before	18.9	131	255	53,900	
Avg*		After	11.0	148	114	13,800	8,900

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest.

At the conclusion of each 10-year period, group type 1b (age 70 yr) will be harvested involving the removal of 53,900 bd ft/ac. In addition, thinning will remove between 1,600 and 3,300 bd ft/ac from group types 5 through 7. The average volume removed over the whole 20.6 ac of the treatment area each

10-year entry will average 8,900 bd ft/ac.

3) Treatment Area 3-3

Removing 50 percent of existing basal area.

The 1983 harvest removed 25 percent of the basal area using 1/2 ac groups and 25 percent using individual tree selection between the groups. Figure 12a shows the distribution of diameters before and after the 1983 harvest and the desired J-shaped distribution of the regulated stand.

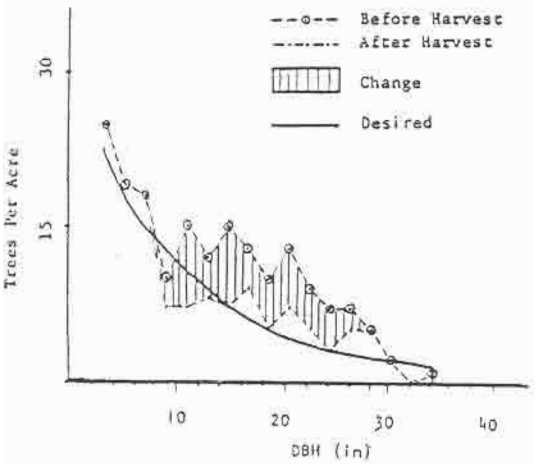


Fig. 12a. Treatment 3-3, 1983 harvest.

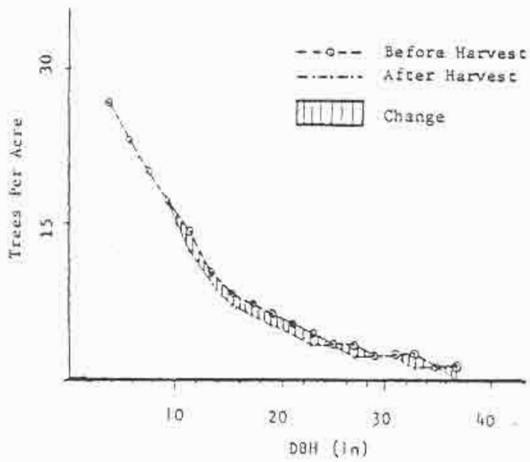


Fig. 12b. Treatment 3-3, 10-year harvest after regulation.

Using CRYPTOS, growth and projected harvests were simulated until the stand was fully regulated. Table 22 shows the condition of the stand at each 10-year entry to the year 2043 when regulation is anticipated.

Table 22: Stand condition in treatment 3-3 during conversion period.

Year	Area Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	5.00	233	136	51,400	30,400	21,000
1993	2.91	171	100	46,600	23,300	23,300
2003	2.91	133	92	31,500	19,400	12,100
2013	2.91	130	87	27,100	15,700	11,400
2023	2.91	130	88	23,800	12,800	11,000
2033	2.91	134	100	21,500	13,800	7,700
2043	2.91	147	118	27,400	17,600	9,800

After the stand is fully regulated (Figure 12b) it will consist of 7 group types with the characteristics shown in Table 23.

Table 23: Stand condition in treatment 3-3 before and after harvesting after regulation.

Group Type	Age (yrs)	Status	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)	Vol Cut (bd ft/ac)
1a	0	After	-	-	-	-	70,800
2	10	Before	3.2	272	16	-	
		After	3.2	272	16	-	-
3	20	Before	8.2	232	85	3,500	
		After	8.2	232	85	3,500	-
4	30	Before	11.4	217	155	12,900	
		After	13.9	119	127	11,600	1,300
5	40	Before	14.5	167	190	25,300	
		After	17.1	100	161	22,400	2,900
6	50	Before	16.6	146	218	39,200	
		After	23.2	65	189	35,400	3,700
7	60	Before	19.7	114	241	54,600	
		After	19.4	108	222	50,100	4,500
			Harvested Group Type				
1b	70	Before	19.0	144	282	70,800	
Avg*		After	12.1	128	118	17,600	11,900

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest.

At the conclusion of each 10-year period, group type 1b (age 70 yr) will be harvested involving the removal of 70,800 bd ft/ac. In addition, thinning will remove between 1,300 and 4,500 bd ft/ac from group types 5 through 7. The average volume removed over the whole 20.4 ac of the treatment area each

10-year period will average 11,900 bd ft/ac.

4) Treatment Area 3-4

Removing 20 percent of existing basal area.

The 1983 harvest removed 10 percent of the basal area using 1/2 ac groups and 10 percent using individual tree selection between the groups. Figure 13a shows the distribution of diameters before and after the 1983 harvest and the desired J-shaped distribution of the regulated stand.

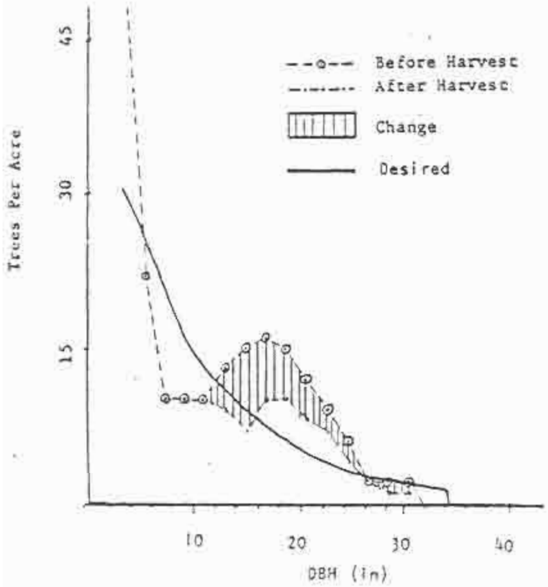


Fig. 13a. Treatment 3-4, 1983 harvest.

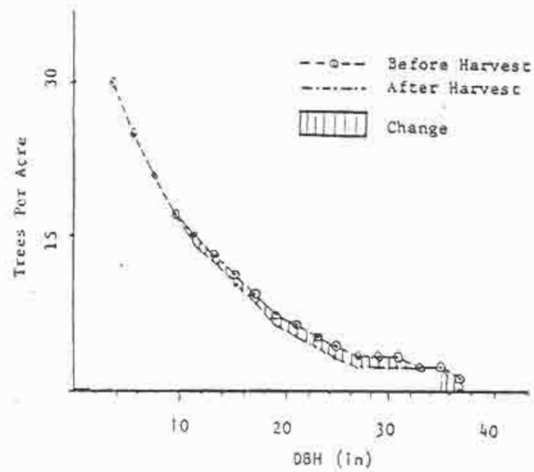


Fig. 13b. Treatment 3-4, 10-year harvest after regulation.

Using CRYPTOS, growth and projected harvests were simulated until the stand was fully regulated. Table 24 shows the condition of the stand at each 10-year entry to the year 2083 when regulation is anticipated.

Table 24: Harvest sequence in treatment 3-4 during conversion period.

Year	Area Cut (ac)	BA Before (ft^2/ac)	BA After (ft^2/ac)	Standing Volume Before (bd ft/ac)	Standing Volume After (bd ft/ac)	Harvest Volume (bd ft/ac)
1983	2.00	209	121	22,100	11,900	10,200
1993	2.00	141	142	16,400	17,100	400
2003	2.00	169	136	22,900	17,300	5,600
2013	2.00	164	133	22,200	17,100	5,100
2023	2.00	161	129	22,700	17,500	5,200
2033	2.00	159	127	22,600	17,300	5,200
2043	2.00	157	125	23,000	17,800	5,200
2053	2.00	157	125	23,500	17,900	5,600
2063	2.00	158	127	23,800	18,000	5,800
2073	2.00	163	132	24,400	18,900	5,500
2083	2.00	208	164	32,700	25,000	7,700

After the stand is fully regulated (Fig 13b) it will consist of 11 group types with the characteristics shown in Table 25.

Table 25: Stand condition in treatment 3-4 before and after harvesting after regulation.

Group Type	Age (yrs)	Status	dbh (in)	TPA	BA (ft^2/ac)	Vol. (bd ft/ac)	Vol Cut (bd ft/ac)
1a	0	After	-	-	-	-	81,400
2	10	Before	3.2	272	16	-	
		After	3.2	272	16	-	-
3	20	Before	7.4	232	69	2,000	
		After	7.4	232	69	2,000	-
4	30	Before	10.1	216	121	6,900	
		After	10.1	216	120	6,900	-
5	40	Before	12.3	204	168	14,000	
		After	14.4	133	151	13,200	800
6	50	Before	14.2	180	197	22,000	
		After	16.7	117	179	20,300	1,700
7	60	Before	15.8	163	221	30,200	
		After	19.3	98	201	28,600	2,600
8	70	Before	17.4	145	240	39,400	
		After	22.1	82	220	37,200	2,200
9	80	Before	18.9	132	258	58,900	
		After	19.3	117	239	46,600	2,400
10	90	Before	18.5	154	286	58,900	
		After	18.3	148	266	55,000	3,900
11	100	Before	18.9	184	358	68,900	
		After	18.7	179	337	65,200	3,700
			Harvested	Group Type			
1b	110	Before	19.6	214	451	81,400	
Avg*		After	13.6	145	164	25,000	9,000

1a Description of group type 1 after harvest.
1b Description of group type 1 before harvest.
* Description of the average stand after harvest.

At the conclusion of each 10-year period, group type 1b (age 110 yr) will be harvested involving the removal of 81,400 bd ft/ac. In addition, thinning will remove between 800 and 3,700 bd ft/ac from group types 5 through 11. The average volume removed over the whole 21.9 ac. of the treatment area each 10-year period will average 9,000 bd ft/ac.

4. Comparison of Alternative Prescriptions

The objective of the study was to achieve particular levels of residual stand basal area by methods that create markedly different stand structures. The alternative prescriptions have different characteristics from an operational and silvicultural standpoint.

1. Individual Tree Selection

It was assumed that adequate regeneration would occur and that 70 redwood sprouts and 40 Douglas-fir seedlings per acre would become established after each 10-year entry. Because of competition from neighboring trees, growth of the regeneration was reduced by 50 percent. No pre-commercial thinning of redwood sprouts was prescribed.

The time required to convert stands to a fully-regulated condition was short, only 20-40 years. This results in little fluctuation in yields during the conversion period.

2. Group Selection

To create the simplest possible structure, the prescription did not incorporate any thinnings within or between the groups. This results in the development of high basal areas and marked mortality in the regenerated groups with increasing age. The groups were assumed to be regenerated with 350 conifers per acre - 75% redwood sprouts and 25% Douglas-fir seedlings.

Using this prescription, stands will consist of a series of even-aged group types. Each group type has a typical bell-shaped distribution of diameter classes. The entire treatment area however would have a diameter distribution similar to a J-shaped curve. The diminution quotient will differ somewhat from the desired q = 1.2 due to the structure created by even-aged groups.

Operationally the group selection prescription has several advantages. The volume to be harvested is concentrated in space which reduces costs of marking and tractor logging. Where cables are used, problems may occur in securing adequate tail-holds and in damaging residual trees adjacent to the extraction corridors. Harvesting in small groups also facilitates site preparation, regeneration, and brush control. It also permits planting of preferred stock.

CRYPTOS projections indicate wide fluctuations in yield during the conversion period. This is particularly true when the initial cuts allow future harvests to be extended longer in the original stand, allowing more time for the regenerated groups to increase in volume before being included in harvest cuts.

3. Group/Individual Tree Selection

This prescription allowed more control over stocking and spacing. Group cuts were assumed to regenerate with 350 conifers per acre - 75 percent redwood sprouts and 25 percent Douglas-fir seedlings. These groups are presumed to be pre-commercially thinned and growth during the first decade was set at 75 percent of normal for redwood sprouts and 60 percent for Douglas-fir seedlings. In the second decade after pre-commercial thinning, growth of all regeneration was assumed to equal normal growth for the region. Low thinning was scheduled when average diameter of the group type equalled between 11-13 in (between ages 30-40 yr). After thinning 40 redwood sprouts and 10 Douglas-fir seedlings per acre were added as ingrowth. Growth of these seedlings was assumed to be influenced by competition from neighboring trees and reduced by 75 percent for redwood and 60 percent for Douglas-fir compared with growth of regeneration in the group cuts.

Total yield from these prescriptions was not significantly different from the other two systems. However thinning would capture potential mortality while concentrating growth on larger trees.

5. Comparison of Growth

Table 26 compares the treatment areas in terms of residual growing stock, annual growth, and volume growth percent.

Table 26: Volume growth and volume growth percent in the regulated stand.

Treatment Area	Residual Growing Stock (bd ft/ac)	Annual Growth (bd ft/ac)	Volume Growth Percent (%)
1-1	35,000	1,650	4.7
1-2	40,400	1,520	3.8
1-4	43,500	1,880	4.3
2-1	43,600	1,120	2.6
2-2	17,500	1,000	5.7
2-3	56,600	1,930	3.4
2-4	20,100	970	4.8
3-1	37,400	1,390	3.7
3-2	13,800	890	6.4
3-3	17,600	1,190	6.8
3-4	25,000	900	3.6

It can be seen from this table that volume growth increases as residual growing stock level increases. Conversely, volume growth percent decreases as residual growing stock increases. This relationship is also shown in Figure 14.

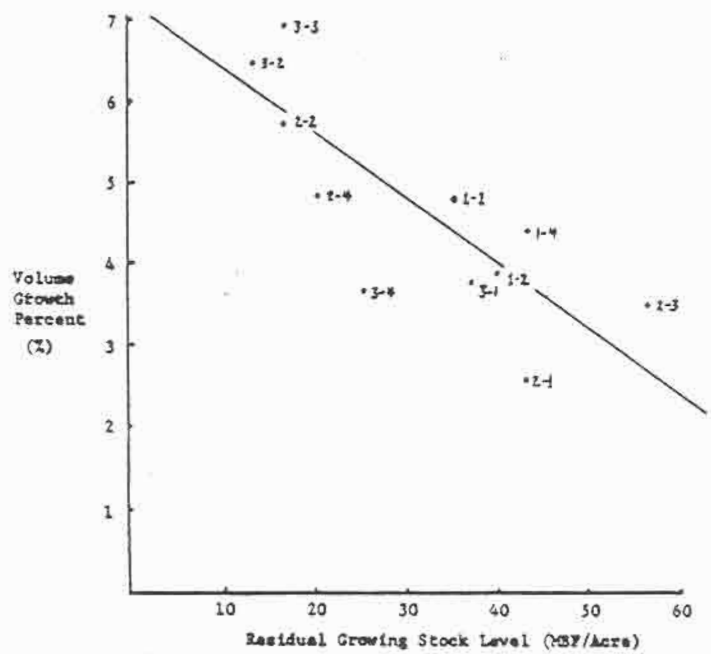


Fig. 14. Relation between volume growth percent and residual growing stock level for each prescription.

Figure 14 also shows that in comparing treatment areas 3-3 and 2-2, which have the same residual growing stock (17,500 bd ft/ac) group selection plus individual tree selection (3-3) may yield a higher volume than group selection (2-2). Also, the value growth of treatment 3-3 was 6 to 8 percent compared with 5.7 percent for treatment 2-2. A similar comparison could be made between individual tree selection (treatment 1-4, 4.3 percent) and group selection (treatment 2-1, 2.6 percent) at a common residual growing stock level of 43,500 bd ft/ac.

6. Financial Analysis

In general, a small woodland owner has the choice of:

a) heavier initial harvest, raising more capital, but resulting in lower yields and income in subsequent harvests, or

b) lighter initial harvest, raising less capital, but resulting in greater yields and income in subsequent harvests.

The financial analysis can be divided into two parts:

a) a comparison of present net worth (PNW) of each prescription in terms of converting the stands to a fully-regulated state. Here, the analysis is sensitive to the length of the conversion period with high PNW being associated with low residual stocking and short conversion periods.

b) a comparison of PNW of each prescription in terms of the growth of stands after they have been fully regulated. Here, the value of the residual growing stock is treated as a sunk cost and not included in the calculation.

In both analyses the values of PNW are determined by:

volume cut per acre

value of residual stand after initial 1983 harvest

cutting cycle

years to reach regulation

discount rate

management costs

stumpage rate (includes falling, skidding, and loading, assumed to be $150/MBF, and allowed to increase from 4.5% in 1993 to 1.8% in 2033 after which it was held constant.

Table 27 compares the present net worth for each prescription in 1983 for the conversion period and for the regulated stand.

Table 27: Present net worth for each prescription in 1983.

Treatment area	Volume after 1983 harvest	Length of conversion	PNW for converting to regulation		PNW for regulated stand		Aggregate PNW	
	MBF/acre	years	dollars/acre	rank	dollars/acre	rank	dollars/acre	rank
1-1	41.5	30	2100	3	1060	2	3160	2
1-2	46.9	40	1891	4	447	3	2338	4
1-4	46.5	20	-2431	10	2232	1	-199	9
2-1	35.5	110	-551	9	10	10	-541	10
2-2	26.3	60	923	6	91	5	1014	6
2-3	63.2	90	-2586	11	31	8	-2555	11
2-4	23.8	70	3168	1	40	7	3208	1
3-1	33.7	100	1632	5	12	9	1644	5
3-2	19.4	60	618	7	82	6	700	7
3-3	32.7	60	2500	2	110	4	2610	3
3-4	15.7	100	557	8	8	11	565	8

The aggregate PNW is the net of the PNW of a series of entries to conversion, and that of a perpetual series of entries in the regulated state. Due to the effects of discounting, PNW for conversion period has more impact on the aggregate PNW than the PNW for the period after regulation. Table 27 shows that treatments 2-4 (Group selection, removing 50 percent of existing basal area), 1-1 (individual tree removing 30 percent of the basal area), and 3-3 (group plus individual tree, removing 50 percent of the basal area) have the highest aggregate PNW. In other words, the financial attractiveness of the treatments increase with: 1) low residual stocking, 2) heavy initial harvests, and 3) short conversion periods.

FUTURE EVALUATIONS

Silvicultural analyses based on one entry can only be based on theoretical projections. Simulation models such as CRYPTOS can be used to aid these projections. Validation of these projections can only be made by collecting time-series data. This project has established an excellent base enabling quantitative comparison of the effect of alternative prescriptions on growth and yield. Base-line data are also available that will permit an analysis of growth of understory vegetation and recovery of areas disturbed by timber harvesting.

If at all possible, the University would like to cooperate with Jackson Demonstration State Forest in continuing the collection of growth data over time. Significant information of value to small woodland owners would be obtained if growth on these treatment areas was monitored on a 5-year basis to determine the accuracy of CRYPTOS projections. Furthermore, it would be desirable to periodically harvest the growth on each treatment area in conformance with the schedule described in the CRYPTOS projections. If this was done, Jackson Demonstration State Forest would have a unique set of case examples quantifying the outcomes of alternative silvicultural prescriptions in comparison with simulated projections. In addition, the alternative stand structures created permit comparisons from the standpoints of other values such as wildlife habitat, aesthetic considerations, watershed protection, and growth of understory species.

Literature Cited

Adams, D.D. 1980. A case study of young-growth redwood management of a small non-industrial private forest in Santa Cruz County. Professional Paper. Dept. Forestry and Res. Mgt., University of California, Berkeley.

Alden, H. 1977. Selection management in the central Sierra: financial analysis. Professional Paper. Dept. Forestry and Res. Mgt., University of California, Berkeley.

Kennedy, C.E. 1983. A study of uneven-aged management strategies in young-growth redwood at Jackson Demonstration State Forest. Master of Forestry Professional Paper, Dept. Forestry and Res. Mgt., U.C. Berkeley. 128 p.

Krumland B. and L.C. Wensel. 1977. Procedures for estimating redwood and Douglas-fir Site Indexes in the North Coast Region of California. Res. Note 5, Coop Redwood Yield Research Project. Dept. Forestry and Res. Mgt., U.C. Berkeley. 12 p.

Krumland, B. and L.C. Wensel. 1982. Cryptos/Crypt2 User's Guide: Cooperative redwood yield project output simulator. Version 4.0. Res. Note No. 20, Coop Redwood Yield Res. Project, Dept. Forestry and Res. Mgt., U.C. Berkeley, Mimeo.