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The Most Efficient Size and Shape of Plot to Use for Cruising in Old-Growth Douglas-Fir Timber

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A STUDY CONDUCTED in an old-growth Douglas-fir stand in Oregon has indicated that a 1-chain by 3-chain (3/10-acre) rectangular plot is the most efficient size and shape of sample plot to use for intensive cruise work in old-growth Douglas-fir timber. This conclusion was reached after 12 different kinds of plots were tested.

In general, rectangular plots were more efficient than circular plots, and plots 1/5-acre to ⅓-acre in size were more efficient than either larger or smaller ones. Among circular plots alone, the ¼-acre size was found to be most efficient.

This information on the relative efficiencies of various kinds of plots should be looked upon only as evidence and not as proof. The findings could differ considerably in other forest types where the number of stems per acre, tree size, brush cover, and other factors are different. It should also be noted that if cruising techniques other than those used for this study were adopted, the order of the relative efficiencies of the various kinds of plots might have been altered. However, the cruising conditions were quite typical for the Douglas-fir subregion of Oregon and Washington, and the techniques employed were standard ones used in cruising national forest timber.

The general purpose of this study was to increase the effectiveness of intensive cruise work in old-growth Douglas-fir timber. A more specific purpose and the subject of this report was to determine which of several kinds of plots is the most efficient to use in cruising old-growth Douglas-fir timber.

The Study Area

A 40-acre tract of old-growth Douglas-fir timber on the Blue River Experimental Forest within the Willamette National Forest in Lane County, Oregon, was selected for the study. This area lies about 50 miles east of Eugene and just north of the McKenzie River. The topography on the 40 acres varied from level to steep, and the ground was relatively free of brush. The average volume per acre for all species was 91,000 board feet. Except for a small amount of hemlock, sugar pine, and cedar, the volume was almost entirely in Douglas-fir trees which had an average diameter of about 45 inches.

Basic Data

Two kinds of data were obtained for the study:

1. *Cruising time data.*—Two time studies were conducted on the 40-acre study area. One of these time studies was made to determine the average time required per chain of travel between plot boundaries. A two-man crew traveling 40 chains over various degrees of slope and using the staff compass and trailer tape was used for this study. The average time per chain of such travel was 1.84 minutes.

The other time study resulted in averages of the times required to take ten kinds of plots (Table 1). For this second time study there were ten lines of plots, each line containing all the plots listed in Table 1. The different kinds of plots were located at random within each line.

The average times required for two additional plots, the circular ¼-acre and the circular 1/5-acre plots, were obtained from the data of the other circular plots by curving plot time over plot area. These averages were 10.6 minutes for the circular ¼-acre plot and 8.8 minutes for the circular 1/5-acre plot.

TABLE 1.—AVERAGE CRUISING TIME REQUIRED ON PLOTS OF VARIOUS KINDS

Kind of plot	Average time required on one plot
	Minutes
Circular .100-acre	5.413
Circular .225-acre	9.663
Circular .400-acre	16.083
Rectangular ½-chain by 1-chain	2.360
Rectangular ½-chain by 2-chain	5.369
Rectangular ½-chain by 4-chain	10.224
Rectangular ½-chain by 6-chain	15.837
Rectangular 1-chain by 2-chain	8.202
Rectangular 1-chain by 3-chain	11.582
Rectangular 1-chain by 4-chain	16.840

Less time was required on the average to cruise the 1-chain by 2-chain rectangular plot than the ½-chain by 4-chain plot, although both kinds of plots have the same area. Apparently a compact rectangular plot is more efficient from the standpoint of cruising time than a longer and narrower rectangular plot.

Similarly it took less time to cruise 3/10-acre in the form of a 1-chain by 3-chain plot than in the form of a ½-chain by 6-chain plot.

2. *Coefficients of variation.*—The 40-acre study area was divided into 1600 square 1/40-acre units (½-chain by ½-chain) by stretching string along compass lines in the woods. A 100-percent cruise was then made to determine the total net saw-timber volume[2] in each of the 1600 units (Fig. 1). Later, in the office, the volumes on the 1/40-acre units were combined in ten different ways (Fig. 2) to provide ten different universes of plots.

For example, they were combined by twos to provide a universe of 800 rectangular plots (½-chain by 1-chain), and they were combined by fours to provide a universe of 400 square 1/10-acre plots. Ten coefficients of variation,[3] one for each of the ten universes of plots, were then calculated (Table 2).

It will be noted that the coefficients of variation listed in Table 2 are for rectangular and circular

[1]Field work by Otto Hanel and Roy A. Silen.

[2]This is the so-called "woods" net. It excludes volume in live cull trees and the cull logs of merchantable saw-timber trees. It includes all other volume in merchantable saw-timber trees which are 12 inches d.b.h. and over.

[3]Standard deviation divided by average plot volume.

190	0	386	0	46	5	273	8	9	16	244	0	226	0	202	0	0	0	0	0	444	0	28	0	0	0	4	53	77	107	38	438	0	7	0	0	493	0	22	582
10	62	120	9	434	0	252	8	0	24	246	762	0	306	306	288	718	35	22	0	0	0	582	0	0	0	0	61	706	0	226	12	444	553	32	322	916	201	204	48
15	46	170	0	0	58	10	31	30	215	0	406	153	299	0	0	16	0	0	0	0	29	538	29	0	7	26	65	0	425	603	8	16	448	268	224	23	299	28	0
7	37	75	435	58	158	134	20	34	0	0	14	21	120	210	0	12	0	376	0	484	7	0	73	0	498	65	0	832	8	0	10	10	0	0	63	379	246	291	277
332	0	531	286	226	0	478	0	9	9	236	344	562	20	0	0	136	0	565	19	0	14	551	853	0	0	0	22	0	20	0	619	488	169	27	7	45	79	47	446
6	0	105	238	313	264	82	0	0	272	0	0	124	0	138	416	558	467	0	0	412	0	18	0	0	0	496	12	14	59	925	0	0	10	9	123	126	600	37	58
41	97	157	0	68	0	46	0	375	0	10	0	516	593	14	238	268	725	0	17	0	15	7	0	0	0	13	516	655	0	9	1379	210	0	32	12	133	35	80	589
169	294	259	299	41	0	0	587	268	714	0	0	0	0	4	207	0	0	16	0	244	0	28	34	0	686	16	0	238	11	160	184	49	33	12	56	191	409	0	99
375	0	441	37	0	438	16	591	282	66	148	381	16	272	528	794	31	387	0	0	236	18	87	7	0	31	9	557	353	342	224	105	344	0	28	41	0	25	509	156
10	38	0	0	316	16	1087	128	290	0	0	34	0	214	0	27	0	491	18	0	0	23	0	603	0	417	11	278	10	171	262	0	708	10	387	596	1171	301	22	387
290	220	0	466	0	80	432	24	73	446	0	0	87	313	183	762	23	461	0	0	0	14	754	32	124	216	66	66	772	29	328	38	545	10	306	46	19	0	161	575
108	0	27	158	0	0	656	580	0	0	0	0	0	42	142	26	20	0	0	802	480	281	19	0	0	108	307	66	9	649	18	21	0	496	90	25	19	452	12	299
379	39	51	168	56	281	0	290	87	0	7	0	820	0	0	18	0	0	0	0	9	0	0	48	427	16	0	31	373	647	666	34	170	41	21	0	70	195	50	41
106	72	906	0	28	395	400	0	0	546	268	0	366	0	291	0	858	0	18	26	16	23	497	403	0	8	456	388	32	0	13	28	10	21	49	327	26	46	33	8
230	0	94	392	0	75	54	0	655	332	380	290	551	183	0	12	31	0	122	0	0	78	10	112	953	492	0	562	0	705	1005	34	39	36	28	61	46	20	30	25
226	425	0	355	24	0	67	0	0	0	285	182	7	565	303	20	100	0	885	9	633	65	474	225	7	627	1018	49	10	50	111	42	346	0	85	70	75	258	1312	230
138	404	13	0	0	157	332	502	281	326	14	260	737	0	0	48	62	0	7	0	16	559	8	62	536	434	246	221	34	18	34	45	45	22	42	0	503	35	10	12
86	112	0	0	216	460	152	508	160	184	0	0	696	452	565	30	53	690	10	580	0	366	7	168	0	47	416	34	0	0	0	46	0	0	0	224	42	624	21	777
10	0	366	7	0	0	0	145	0	56	611	453	11	582	0	22	423	0	0	16	101	14	402	36	273	627	412	339	618	25	16	14	911	24	192	480	403	7	682	11
0	112	0	0	0	24	179	213	0	335	0	0	25	0	168	47	27	28	33	26	41	281	301	313	0	230	0	299	0	0	574	137	688	939	738	0	0	18	16	16
392	7	514	0	389	31	131	354	407	621	11	0	874	322	513	11	0	799	10	747	702	869	10	336	680	251	694	864	34	0	755	180	0	9	9	0	125	60	22	41
30	467	597	509	0	31	0	0	0	251	27	349	0	451	0	0	24	0	0	492	508	0	0	10	464	660	0	45	179	29	10	0	65	21	22	431	884	0	0	766
707	290	0	322	0	13	0	0	0	345	0	437	108	0	16	16	922	13	465	521	313	856	55	22	0	0	622	52	28	655	0	404	466	0	197	62	0	27	0	80
313	476	344	11	557	610	0	480	0	251	321	483	438	828	586	1131	503	968	0	0	230	13	872	18	10	878	42	0	7	0	801	1309	412	748	3	34	23	521	22	467
26	0	0	0	0	834	0	285	0	21	0	251	445	1252	16	467	1266	717	80	0	350	24	1206	507	91	0	23	7	0	43	114	658	651	0	729	23	0	413	492	7
0	0	0	58	0	52	0	94	0	762	374	42	807	0	551	22	0	0	763	18	0	16	818	0	59	12	24	63	366	0	547	1371	0	7	0	0	19	517	446	0
24	105	94	0	0	246	0	0	468	1355	0	25	1562	376	637	42	431	0	503	507	18	0	28	26	0	57	11	10	31	16	7	6	0	238	565	492	19	0	12	35
37	26	26	46	10	24	702	544	316	0	823	761	15	9	606	0	0	0	663	652	0	0	0	32	0	55	29	57	543	0	249	588	10	17	0	131	732	0	251	538
87	42	22	30	419	0	7	34	16	423	730	258	0	647	0	857	0	974	1518	0	0	39	200	524	0	0	26	646	50	292	0	319	735	0	1215	795	503	0	150	0
0	0	48	480	34	399	607	16	795	0	336	0	868	0	1194	0	582	520	0	600	1242	0	20	0	214	603	26	615	770	22	823	575	0	0	10	0	646	58	366	0
1012	8	743	214	158	78	117	16	409	711	468	503	0	582	580	426	423	0	238	0	205	877	734	0	468	1043	709	0	8	0	0	251	87	602	611	13	480	991	0	0
339	524	707	16	989	0	194	0	468	641	0	0	430	0	190	0	576	344	0	662	0	0	551	322	551	0	0	565	22	719	1555	197	533	11	418	10	66	175	32	33
273	384	200	689	467	191	647	382	31	0	10	654	944	0	7	1043	0	0	415	820	615	0	738	0	0	770	1218	474	10	100	838	546	1019	36	66	28	139	58	100	201
275	0	0	160	336	10	0	0	0	737	0	290	0	402	352	10	313	181	431	0	517	820	0	477	942	0	0	503	0	1259	503	610	0	34	66	19	587	103	66	67
401	403	686	96	465	380	698	21	4	415	698	536	0	737	646	439	0	416	15	834	18	1224	197	10	968	930	8	0	609	0	1397	20	224	235	266	71	96	22	319	0
23	19	0	565	197	14	21	124	120	10	0	570	1326	0	0	299	0	7	25	832	609	551	811	0	32	971	822	652	6	624	292	0	565	238	0	65	0	256	24	8
458	0	373	706	7	681	911	1015	4	341	306	474	756	7	14	1142	1390	10	16	0	0	0	18	0	1285	321	0	755	20	615	0	379	0	6	62	141	0	289	82	7
882	734	615	354	1032	11	7	0	288	8	503	28	615	34	469	0	685	506	541	0	1393	10	0	2721	442	0	551	0	694	0	1762	303	436	124	136	92	178	26	446	102
509	0	96	0	0	16	1127	349	401	16	268	1224	412	618	7	28	55	888	1124	0	780	0	87	0	0	603	1073	0	0	622	343	662	0	12	16	0	33	0	138	57
0	8	147	14	78	430	899	603	0	529	401	10	28	0	635	681	939	0	673	11	2220	0	54	53	1503	0	366	856	256	0	46	1027	153	42	24	0	19	131	100	209

FIG. 1.—100-percent cruise of 40 acres of old-growth Douglas-fir timber. Each cell represents a square 1/40-acre on the ground. The number in each cell is the total timber volume (Scribner Decimal C) of the 1/40 acre unit.

plots, although coefficients of variation were calculated only for rectangular and square plots. Since a 100 percent cruise by circular plots could not be made, and since the issue was considered to be between rectangular and circular plots, it was necessary to assume that the variation among circular plots of a given area is the same as the variation among square plots of the same area.

It will also be noted that 12 kinds of plots are listed in Table 2, whereas only 10 universes were established and only 10 coefficients of variation were calculated. The two additional plots are the ¼-acre and 1/5-acre circular plots. They were included because they are so commonly used in cruising. Their coefficients of variation were taken from a curve of coefficient of variation over plot area which was established from the data of the other three circular plots.

The coefficients of variation listed in Table 2 show a tendency to decrease as the plot area increases, and for different rectangular plots of equal area there is a tendency for the longer and narrower plots to have smaller coefficients of variation.

How the Most Efficient Plot was Picked

An estimate of the total net sawtimber volume, which is obtained by measuring and otherwise observing trees on a portion of the entire tract for which the estimate is required, is exposed to two principal types of error; sampling error and technique error. Sampling er-

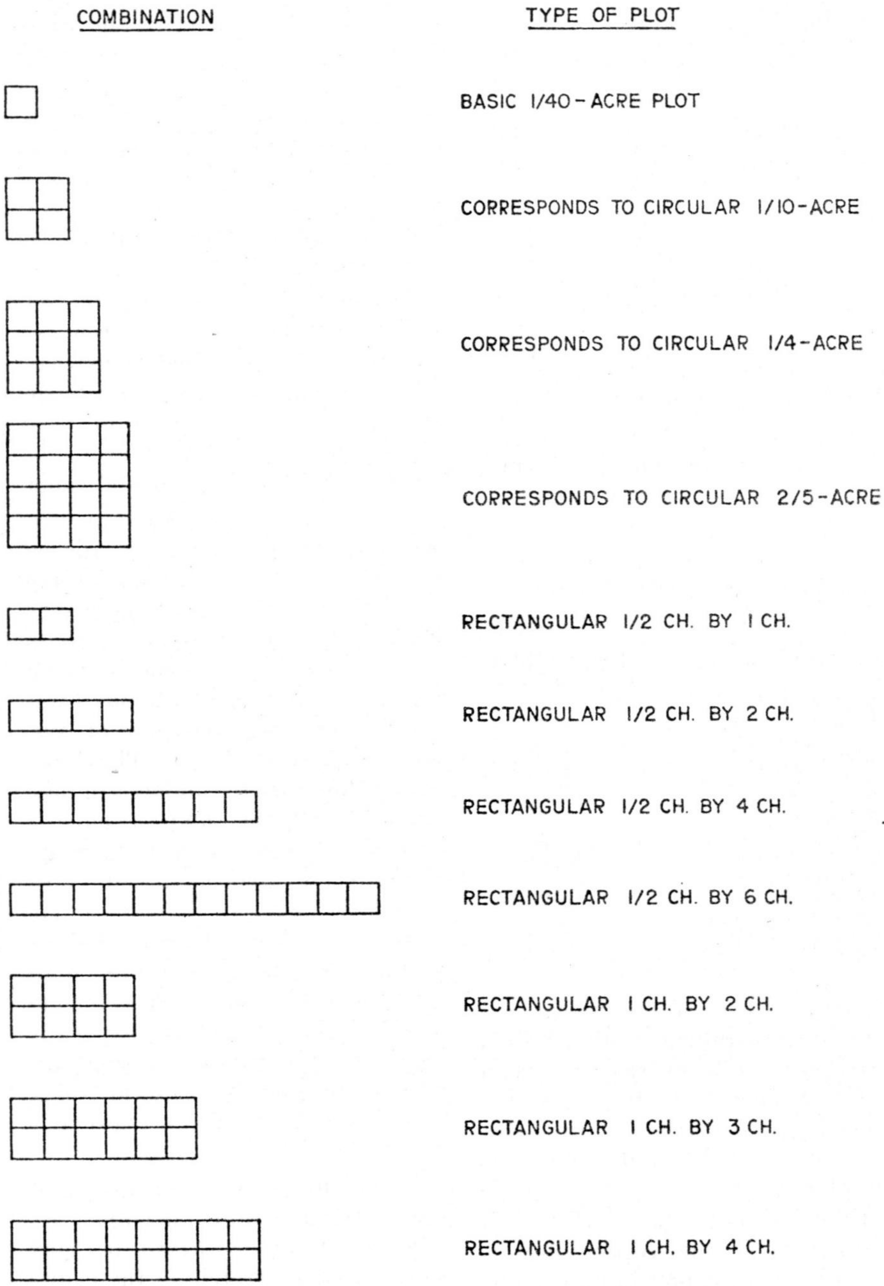

FIG. 2.—Basic 1/40-acre plot and various combinations.

ror is the difference between the total volume of the tract as estimated from the sample and the total volume that would have resulted if a 100-percent cruise of the tract had been made. Technique error is the difference between the total volume that would have resulted from a 100-percent cruise and the *true* total volume on the tract.

The amount of technique error depends upon the accuracy of the cruiser's measurements and observations and on the reliability of his volume tables. It is not usually possible to provide an objective estimate of the amount of technique error to which the estimate of total volume is exposed.

The amount of sampling error, on the other hand, can be estimated by using the appropriate statistical methods and by making certain minor assumptions. It varies inversely with the square root of the number of plots which have been included in the sample; directly with the square root of the proportion of the total number of possible plots *not* included in the sample; and directly with an index of the variation among the volumes recorded for the various plots of the sample. These relationships are expressed in symbols as follows:

$$E = C\sqrt{1/n}\sqrt{N-n/N}$$

Where E = Sampling error of an estimate of total volume on a given tract expressed in percent of the total volume and in terms of one standard error.

C = The coefficient of variation appropriate to a particular kind of plot.

N = Total number of possible plots of a given kind in the tract of timber for which an estimate of total volume is required.

n = Number of plots of a given kind in a sample.

Obviously if plots of one kind vary greatly among themselves, that kind of plot is likely to be inefficient. But it is not necessarily true that the kind of plot with the least amount of variation is the most efficient. One kind of plot might, for example, have the smallest coefficient of variation and yet be so difficult to take that, for a given amount of work, only a few plots could be included in a sample. It is apparent from the formula given above that the amount of sampling error will be small if the sample is large. For maximum efficiency, therefore, a plot must provide the best compromise between variation and time.

The most efficient kind of plot may be defined as *the one which will give the smallest sampling error for a given amount of work*, and in order to determine the most efficient kind of plot for this study, it was necessary to calculate a sampling error for each kind of plot.

The time study information was used to calculate, for each kind of plot, the number of systematically spaced plots which could be taken in a 4-hour cruise of a 40-acre tract of timber. These are the values of "n" listed in Table 2. Both time spent on the plot and time spent going between plots were taken into consideration in

TABLE 2.—SAMPLING ERRORS FOR 12 KINDS OF PLOTS

Kind of plot	C	n	N	E
	Percent			*Percent*
1. Rect. 1-ch. by 3-ch.	50.09	13.18	133	13.10
2. Rect. 1-ch. by 2-ch.	58.40	16.50	200	13.77
3. Circ. 1/4-acre	56.00[1]	14.21[1]	160	14.15
4. Rect. 1/2 by 6-ch.	48.95	10.83	133	14.26
5. Rect. 1/2 by 4-ch.	57.56	14.87	200	14.36
6. Circ. .225-acre	58.05	14.93	178	14.38
7. Circ. 2/5-acre	49.00	10.25	100	14.50
8. Circ. 1/5-acre	60.00[1]	15.68[1]	200	14.55
9. Rect. 1-ch. by 4-ch.	48.84	9.89	100	14.74
10. Circ. 1/10-acre	71.09	21.16	400	15.04
11. Rect. 1/2 by 2-ch.	74.58	21.62	400	15.60
12. Rect. 1/2 by 1-ch.	96.08	31.99	800	16.64

[1]Not computed directly from basic data but determined from curves of values from other plots.
C.—Population coefficient of variation in percent.
n.—Number of systematically spaced plots which can be taken in a 4-hour cruise of 40 acres.
N.—Total possible number of plots in 40 acres.
E.—Sampling error resulting from 4 hours' work.

TABLE 3.—SAMPLING ERRORS FOR 3- AND FOR 5-HOUR CRUISES OF 40 ACRES

Kind of plot	For 3-hrs. work on 40-acres	Kind of plot	For 5-hrs. work on 40-acres
	Percent		*Percent*
Rect. 1 × 3-ch.	16.31	Rect. 1 × 3-ch.	11.03
Rect. 1 × 2-ch.	17.30	Rect. 1 × 2-ch.	11.54
Rect. 1/2 × 6-ch.	17.46	Circ. 1/4-acre	11.93
Circ. 1/4-acre	17.70	Circ. .225-acre	12.10
Rect. 1/2 × 4-ch.	17.86	Rect. 1/2 × 4-ch.	12.16
Circ. 2/5-acre	17.93	Rect. 1/2 × 6-ch.	12.17
Circ. .225-acre	17.98	Circ. 1/5-acre	12.28
Rect. 1 × 4-ch.	18.17	Circ. 2/5-acre	12.29
Circ. 1/5-acre	18.26	Circ. 1/10-acre	12.53
Circ. 1/10-acre	19.05	Rect. 1 × 4-ch.	12.53
Rect. 1/2 × 2-ch.	19.77	Rect. 1/2 × 2-ch.	13.03
Rect. 1/2 × 1-ch.	21.70	Rect. 1/2 × 1-ch.	13.57

calculating "n." A 40-acre tract was specified because that is a typical cruising unit, and 4-hours were specified because that is a reasonable average time for cruising 40 acres of old-growth Douglas-fir timber.

Values for "C," "n," and "N" were substituted in the formula for sampling error given above, and 12 sampling errors, one for each kind of plot were calculated (Table 2).

The plots in Table 2 are listed in the order of their efficiency. It may be noted that three kinds of plots had lower coefficients of variation than the rectangular 1-chain by 3-chain plot which was the most efficient. In each of these three cases the advantage resulting from decreased variation was more than counterbalanced by the disadvantage arising from the fact that fewer plots were available for the sample.

Eight kinds of plots had an advantage over the rectangular 1-chain by 3-chain plot in that it was possible to include more units in the sample for a given amount of work. In these cases the advantage in terms of sample size could not compensate for the disadvantage in terms of variation.

The rectangular 1-chain by 3-chain plot provided the best compromise between variation and time.

New values of "n" and "N" were determined for a 3-hour cruise of 40-acres and also for a 5-hour cruise of 40-acres. They were substituted in the formula and new values of sampling error were calculated. In each case (Table 3) the 1-chain by 3-chain rectangular plot retained its lead, but the order of efficiency for the remaining plots was changed somewhat. This change, of course, results directly from the influence of total cruise time on the total travel time among systematically spaced plots.

The foregoing discussion on how the most efficient plot was picked requires an additional qualifying statement which is made necessary by the fact that the "n" used in the formula for calculating sampling errors for Tables 2 and 3 was determined from samples of systematically spaced plots. The formula applies only to random samples, since systematic samples have a tendency to give biased estimates of universe coefficients of variation.[4] In order to defend the superiority of the 1-chain by 3-chain rectangular plot, therefore, it is necessary to *assume* that the 12 kinds of plots tested in this study would be affected in the same degree by this tendency toward bias. This is believed to be a reasonable assumption.

The results of this study suggest that similar studies in other regions and in other forest types may show ways of stretching the cruise dollar under different circumstances. For old-growth Douglas-fir the evidence favors use of a 1-chain by 3-chain rectangular plot.

[4]Hasel, A. A. 1938. Sampling error in timber surveys. Jour. Agric. Research 57:713-736.