AERIAL PHOTO-CRUISE TESTS

Tests of Several Types of Aerial Photo-Cruises on a 133-acre Area in Central New England

By
Robert B. Pope

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Submitted in partial fulfillment of the requirements for the degree of Master in Forestry at Harvard University

Harvard Forest
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CONTENTS

SECTION 1 -- INTRODUCTION

CONTENTS (CONT.)

CONTENTS (CONT.)

MAPS

(All are at a scale of 1:4800 except where Otherwise specified)

FIGURES

Page

SECTION 1 -- INTRODUCTION

SECTION 3 -- AERIAL CRUISE NO. 1

TABLES

Table Page

TABLES (CONT.)

AERIAL VOLUME TABLES

SECTION 1

INTRODUCTION

SECTION 1 -- INTRODUCTION

PROBLEM

In designing a timber cruise using aerial photographs, either alone or in combination with ground field work, the number of possible systems is almost infinite. A great variety of scales and types of aerial photographs exist. The photographs alone may be used in a variety of ways and they may be combined with various types of ground cruise in any possible combination. A large number of different designs have been and are being used in the United States and Canada. In some cases the results of these cruises have been checked against cutting records or fairly heavy ground cruises but in many cases there has either been no check or else only a low-percentage ground cruise which could not be regarded as very accurate. Furthermore, a comparison between different cruises actually carried out has been difficult because of differences in forest conditions between the areas to which they were applied. To the writer's knowledge there has been no case where different designs of aerial photo cruises have been applied to the same area and compared with accurate ground results. It is felt that there is a need for such comparisons in order to better understand the use of aerial photographs in forest mensuration.

PURPOSE

The purpose of this project, then, is to obtain some concrete comparisons of several types of cruises as applied to a single area on which the volumes are accurately known. As previously pointed out, the number of imaginable cruise designs is infinite and it would be impossible to try them all. However, it is hoped that by testing several varied systems, certain trends can be ascertained. The area which is studied in this project is so small that the results cannot be considered decisive. The purpose, therefore, is not to determine conclusively the best type of cruise design but to ascertain the trends in order to point the way towards further experimentation along this line.

DESCRIPTION OF THE AREA

The area treated in this report is part of the Harvard Forest known as Slab City, Compartments IX and X, and consists of 133 acres located about three miles south of the village of Petersham, Massachusetts. The general location is shown in Map No. 1. It will be noticed that the area is bounded on the west by the Swift River and that a highway (State Routes 32 and 122) runs through the eastern portion thus making it extremely accessible.

Map No. 2 shows the topography of the area at a scale of 1:4800. Contours are taken from the U.S.G.S. Petersham Quadrangle. Elevations range from 670 feet in the southwest corner to slightly over 1000 feet near the southeast corner. Slopes are nowhere precipitous but are moderately steep over much of the southern half and there are very few flat portions within the area.

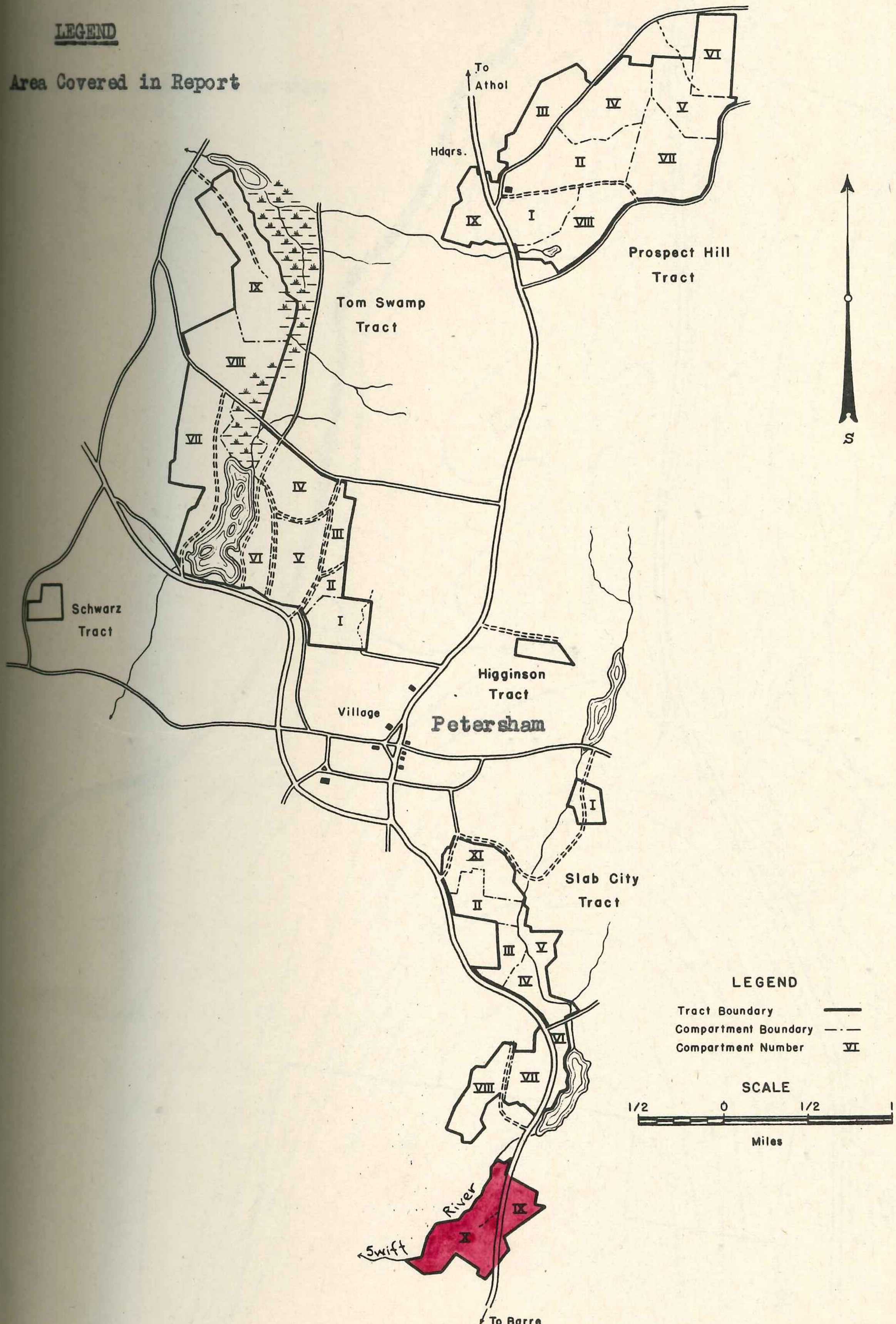
The complete history of this tract is not known in detail. Certain portions give evidence of having once been cleared for cultivation but it is fairly certain that the bulk of the area was never used for crops. A large portion appears to have been very heavily cut about 1885 and probably was used as pasture for some time afterwards. The present stand consists principally of stemwise mixtures of hardwoods, hemlock and white pine, mostly about 50 to 60 years old. Exceptions to

MAP NO. 1

Vicinity Petersham, Massachusetts

LEGEND

Area Covered in Report



Willett Rowlands

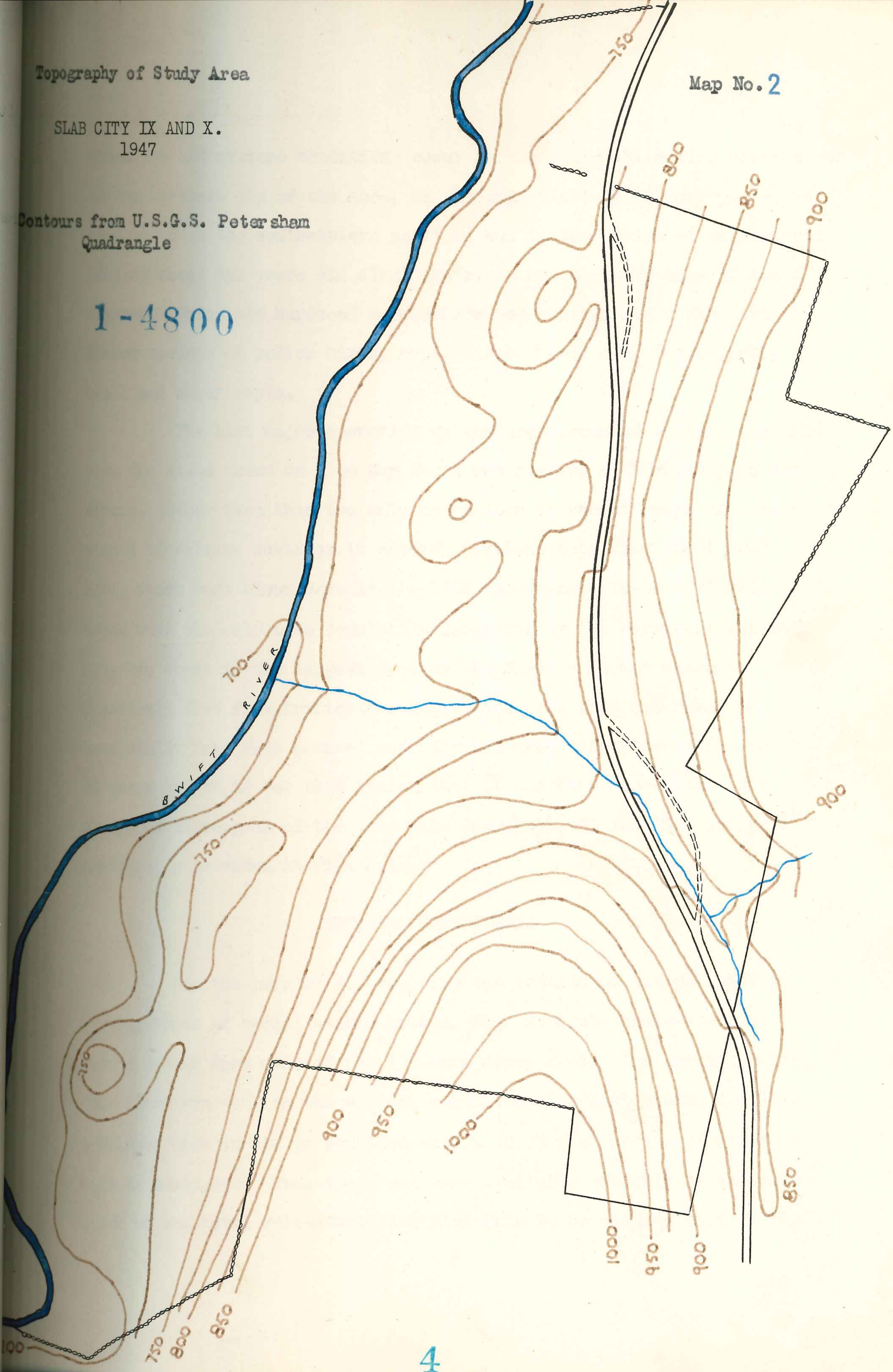
Topography of Study Area

Map No. 2

SLAB CITY IX AND X.
1947

Contours from U.S.G.S. Petersham Quadrangle

1-4800



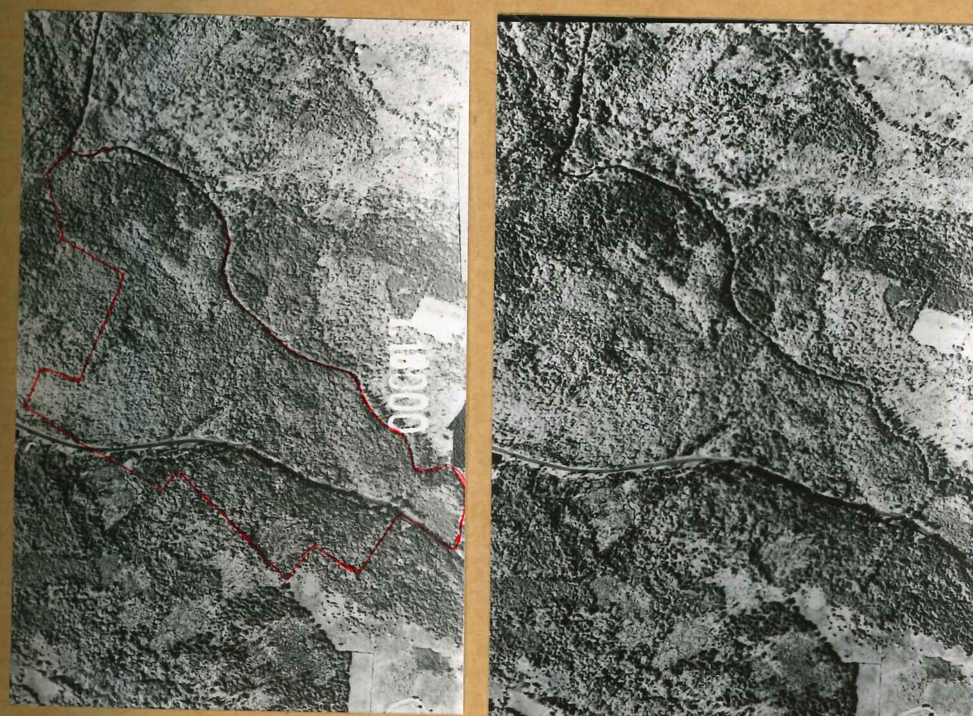
these age and mixture conditions occur in the young white pine plantations at the northern tip of the area, in the approximately 80-year pure white pine stand in the southeastern portion, and in the strips of nearly pure hemlock about 150 years old along the river and the east edge of the highway. Principle hardwood species are red oak and red maple with lesser amounts of yellow birch, paper birch, black oak, black birch, beech and sugar maple.

The last major operation on the area occurred in 1914 and 1915 when the stand shown as 1 on Map No. 3 was planted with white pine and spruce. Other than this the only operations in recent years have consisted of salvage cuttings in several portions totalling about four acres which were blown down in the 1938 hurricane. These few small areas were the only ones completely destroyed by the hurricane and this 133-acre tract is the largest area on the Harvard Forest which is relatively free from hurricane damage. The area then has remained essentially free from natural and silvicultural disturbances for 50 or 60 years and it is for this reason that it has been chosen for this study. A stereogram of the area made from 1:18,000 modified infrared photographs is shown in Figure 1.

OUTLINE OF PROCEDURE

For the purpose of comparing the results of several widely varying types of aerial timber cruise, four separate cruises and a ground cruise were made of the 133-acre study area. The ground cruise, made after the work on the photos, consisted of a 100% cruise of all sawtimber made in strips combined with a 10.7% plot cruise of poles as well as sawtimber. Thus there was made available not only an accurate check of the total volume but also plot data to be used as part of the

Figure 1



Stereogram of Study Area from 1:18,000 Modified Infrared Photographs.

Approximate Boundaries of Study Area Shown in Red.

aerial cruises.

Aerial Cruise No. 1 consisted of a very intensive use of 1:5300 modified infrared photographs with no supplementary ground data. Aerial Cruise No. 2 is a moderately intensive use of 1:18,000 modified infrared photographs combined with ground data. Aerial Cruise No. 3 is a less-intensive use of the 1:5300 photographs combined with ground data. Aerial Cruise No. 4 uses the 1:18,000 photographs in an extensive manner involving the location of plots on the photographs.

Analyses were made of all cruises to determine the chief sources of error and to enable comparisons to be made of relative costs and accuracies. In order to better understand these comparisons the various cruises were expanded to cover a hypothetical township of 23,040 acres, assumed to be similar to the 133-acre study area.

Conclusions were then drawn regarding the chief errors made and the relative merits of the various types of cruise, and suggestions made for further research along this line.

VOLUME TABLES USED

The volume tables used in the ground cruise are described in SECTION 2 -- GROUND CRUISES.

The volume tables used in the aerial cruises consisted of all the aerial volume tables that could be assembled for this region plus a local yield table adapted for aerial use. Copies of the tables are included in this section and are described below.

Aerial Volume Table No. 1 is a local yield table for hardwoods based on cutting records of the Harvard Forest. The original table gave the yield in cords per acre for the best stocked stands of various heights. The figures for cubic feet per acre were derived from the cords per acre by assuming the number of cubic feet per cord shown in the last column of the table. The figures for board feet per acre were derived from the cords per acre by determining a relationship of board feet per cord for stands of various heights. This relationship was derived by curving several tables obtained from U.S.D.A. Technical Bulletin No. 560 by Schnur.

Aerial Volume Tables No. 2 to 8 are self-explanatory. All available information concerning them may be obtained from the tables themselves which follow.

Hardwood Volume Table, Site Index 65 Volume Table No. 1.

Based on Cutting Data on the Harvard Forest

Average Height Dom. Trees	Cords Per Acre	Cubic Feet Per Acre	Board Feet Per Acre	Cubic Feet / Cords
35	4.2	250	150	60
40	7.0	490	365	70
45	10.2	816	850	80
50	13.2	1120	1450	85
55	16.5	1400	2450	85
60	19.8	1680	3650	85
65	23.0	2070	4900	90
70	26.5	2385	6450	90
75	30.5	2740	8300	90
80	34.5	3100	10250	90

Cords per acre from Harvard Forest data.

Cubic feet per acre converted from cords per acre by assumed conversion shown in last column.

Board feet per acre converted from cords per acre by conversions derived from U.S.D.A. Technical Bulletin No. 560, by Schnur.

Stand Volume for Normally Stocked Stands

Total tree Height Feet	Volume per Acre in Board Feet Oak
40	700
50	2,700
60	6,000
70	12,000
80	22,000

Aerial Volume Table No. 3

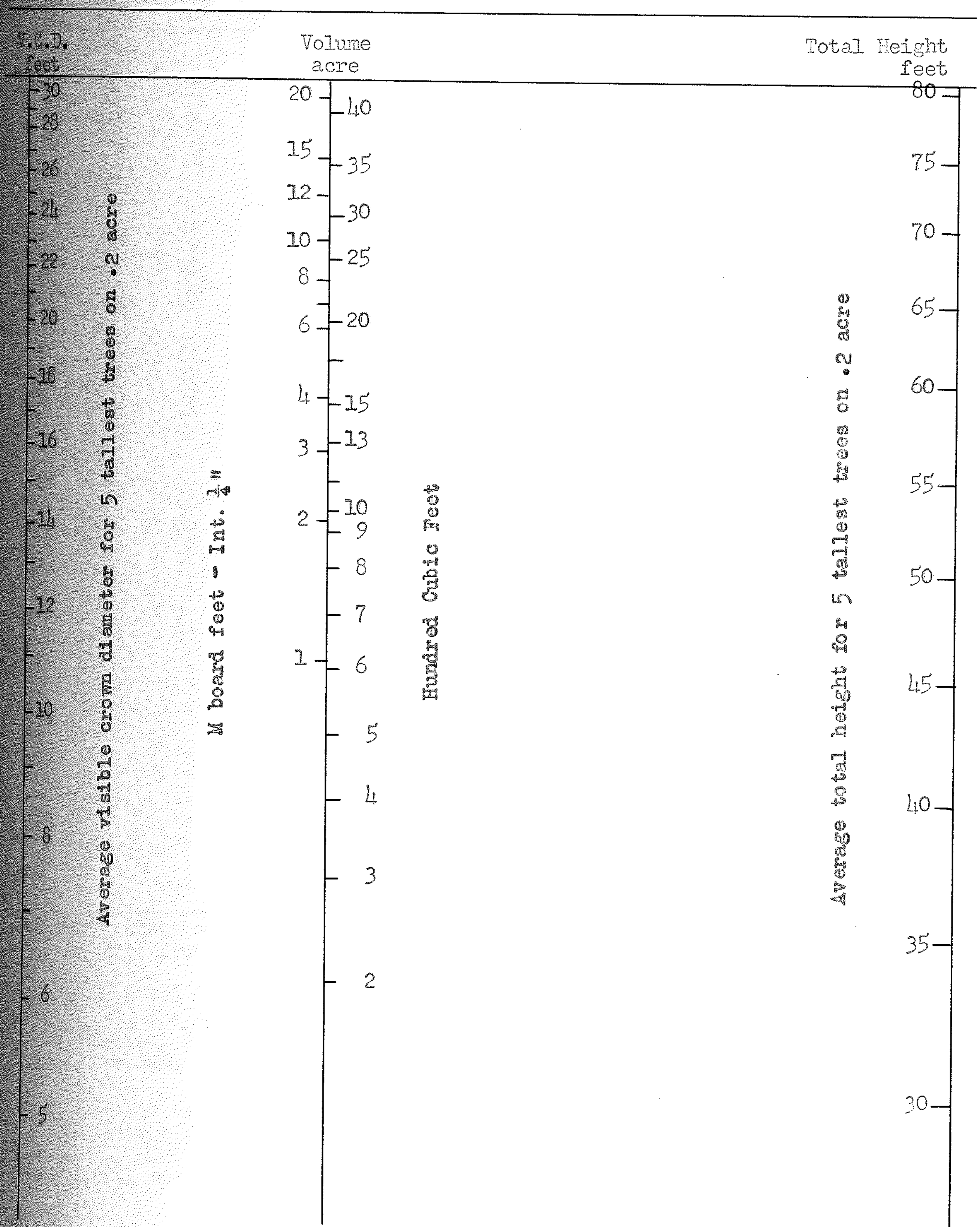
Volume per Acre Estimate from Aerial Photographs
Based upon Visible Crown Diameter (VCD)

Average VCD Five Largest Trees on 1/5 Acre Feet	Net Volume per Acre C ubic Feet	Net Volume per Acre Board Feet
7.5	0	0
9.0	220	0
10.5	450	375
12.0	670	850
13.5	900	1500
15.0	1120	2500
16.5	1250	3500
18.0	1570	4800
19.5	1800	6000
21.0	2000	7200
22.5	2220	8800
24.0	2430	10000
25.5	2650	11700

For use with hardwoods, and hardwoods and softwoods.
Not satisfactory for softwoods alone.

Both tables from U.S.F.S. Northeastern Forest Experiment Station, Forest Survey.

Alinement Chart for Northern Hardwoods, and Spruce-Fir Types
Wild River, Coos County, New Hampshire



Aerial Photo Volume Table
Yellow Birch, Beech and Sugar Maple
Wild River, Coos County, New Hampshire

Board Foot Volume by International 1/4 Inch Rule

Visible Crown Diameter	Total Height of Tree in Feet: 35	40	45	50	55	60	65	70	75	80
Feet	Volume - board feet									
6...	...	1	1	2	2	3	4	...	...	...
7...	1	2	2	3	4	5	14	26	52	...
8...	2	3	3	4	6	9	24	35	66	...
9...	3	4	5	7	9	14	33	47	82	...
10...	5	6	8	10	13	20	42	60	96	...
11...	7	9	11	14	18	28	52	73	111	...
12...	10	12	15	19	25	36	61	85	124	169
13...	14	16	20	25	32	45	70	96	139	194
14...	17	21	25	31	40	56	78	107	155	219
15...	22	26	30	37	50	66	88	117	172	239
16...	26	31	35	43	58	75	96	130	189	266
17...	30	35	40	51	68	85	108	144	209	289
18...	33	39	46	58	75	94	120	158	230	308
19...	37	44	52	65	85	104	133	173	249	327
20...	41	50	59	74	95	113	147	189	267	342
21...	...	55	65	82	103	123	159	207	285	356
22...	...	60	72	91	112	134	169	221	301	368
23...	...	66	79	102	123	145	182	238	317	380
24...	...	70	86	112	134	158	195	254	329	395
25...	...	74	92	125	147	171	209	268	341	406
26...	...	77	97	138	159	183	221	281	349	417
27...	...	80	102	155	171	197	235	295	356	427
28...	...	83	107	166	183	211	248	306	365	436
29...	...	...	111	179	198	226	262	318	370	441
30...	...	...	116	196	212	240	278	330	376	445
31...	...	...	...	209	227	256	289	341	383	450
32...	...	...	...	219	238	269	299	355	398	458
33...	...	...	...	229	256	279	309	366	408	463
34...	...	...	...	237	260	289	318	377	417	473
35...	...	...	...	...	269	298	327	385	425	478
36...	...	...	...	...	279	305	336	397	435	484

Based on measurements of 1,646 trees by the Northeastern Forest Experiment Station, 1946, on the White Mountain National Forest.

Volumes are above 1.0 foot stump for trees 11.0 inches d.b.h. and larger to a usable top, i.e., the point on stem at which merchantability for saw timber is limited by branches, deformity, defect or by a diameter of less than 6.0 inches inside bark. No deduction made for defect.

Aggregate deviation for 1,646 trees; Table 0.085% high. Standard error of estimate for individual tree, based on 110 trees mechanically selected from the total number, is 107% of the average sample tree volume. Determintion index based on 110 tree sample is 0.72.

Empirical Stand Volume Table -- White Pine

Visible Height	Board Feet per Acre	Visible Crown Diameter	Visible Number of Trees per Acre	Basal Area per Acre
25	--	10.1	250	75
30	2,100	10.5	246	95
35	6,500	10.8	242	119
40	9,800	11.3	237	133
45	12,600	11.8	231	145
50	15,300	12.3	224	154
55	17,900	13.0	210	161
60	21,000	13.7	180	166
65	24,600	14.5	150	170
70	28,700	15.4	138	174
75	33,700	16.2	131	178
80	40,000	17.1	125	181
85	47,000	18.0	120	184
90	54,600	19.0	116	186

Based on 18 plots taken cooperatively in August, 1945 by Harvard Forest and Northeastern Forest Experiment Station, U.S.F.S. Board Foot Volumes computed from Girard form point table (Mesavage and Gerard, 1945). International $\frac{1}{4}$" log rule. Minimum merchantable D.B.H. is 9 inches. Minimum merchantable top is 5 inches.

Correlation Index: Board foot volumes with height--0.937

Individual Tree Volume Table -- White Pine

Crown Diameter	Total Visible Height 40	50	60	70	80	90	100
	Board Foot Volumes (Int. ¼")						
10	40	60	90	110	140	180	210
12	60	80	110	150	180	220	270
14	70	100	140	180	220	270	330
16	80	120	160	210	260	320	390
18	90	140	190	250	310	380	450
20	110	150	220	280	350	430	520
22	120	180	240	320	400	490	590
24	140	200	270	360	450	550	650
26	150	220	300	390	500	610	720
28	170	250	340	430	550	670	800
30	180	270	370	480	600	730	870
32	200	290	400	530	650	790	950
34	210	320	430	560	700	860	1030
36	230	340	460	600	750	920	1110
38	250	360	500	640	810	990	1180

Developed in cooperation with U.S. Forest Service from measurements of 324 trees on 18 fifth acre plots in Petersham, Mass., August, 1945.

Values derived from alinement chart of equation: log V-1.298 log. c + 1.701 log. H -2.38. C.I. = 0.83.

Aerial Photo Volume Table
Red Spruce, Balsam fir, and Eastern Hemlock
Wild River, Coos County, New Hampshire

Board Foot Volume by International $\frac{1}{4}$ inch Rule

Visible Crown Diameter	Total Height of Tree in Feet										
	30	35	40	45	50	55	60	65	70	75	80
Feet				Volume - board feet							
2...	0	0	0.2	1.0	1.7	2.2	2.9	3.8	...	...	...
3...	0	0	0.6	1.6	2.6	3.7	5.1	8.4	...	...	...
4...	0	0	0.9	2.5	4.2	6.0	8.6	15.7	27.5	...	...
5...	0	0	1.7	4.0	6.8	9.7	14.5	25.0	41.0	...	...
6...	0	0	3.1	6.2	10.4	15.0	22.3	35.7	52.5	70.0	...
7...	0	1.1	5.4	9.7	15.5	22.5	31.8	46.0	63.4	81.0	...
8...	0	2.8	8.9	15.0	22.6	32.2	42.8	58.7	75.0	93.0	...
9...	0	5.7	14.0	22.4	32.5	43.0	55.5	73.0	89.0	107	120
10...	0	10.0	20.2	31.1	43.3	56.0	70.0	87.5	102	121	137
11...	0	15.7	26.0	41.5	57.0	70.0	86.0	103	117	137	155
12...	...	22.7	36.2	52.1	70.8	83.8	99.0	115	133	153	175
13...	...	...	46.0	65.0	85.0	99.0	112	128	148	172	199
14...	...	...	...	...	100	112	124	141	165	190	223
15...	...	...	...	...	113	126	136	155	181	212	250
16...	...	...	...	...	123	136	147	167	197	230	284
17...	...	...	...	...	134	145	157	179	213	251	300
18...	...	...	...	...	143	153	167	190	228	270	324
19...	...	...	...	...	150	161	176	200	242	289	345
20...	...	...	...	...	158	167	183	210	255	306	360
21...	...	...	...	...	163	174	192	218	268	321	373
22...	...	...	...	...	169	180	200	224	278	336	388
23...	...	...	...	...	173	185	205	230	285	348	400
24...	...	...	...	...	178	189	210	235	292	360	408
25...	...	...	...	...	181	191	214	239	300	367	415
26...	...	...	...	...	184	193	218	241	305	374	420
27...	...	...	...	...	187	197	220	243	310	380	423
28...	...	...	...	...	189	199	222	245	314	386	426
29...	...	...	...	...	...	...	...	...	318	392	429
30...	...	...	...	...	...	...	...	...	322	397	432

Based on measurements of 1,479 trees by the Northeastern Forest Experiment Station, 1946 on the White Mountain National Forest.

Volumes are above 1.0 foot stump up to 18 inches D.B.H. and 1.5 foot stump over 18 inches D.B.H. to a useable top, i.e., the point on stem at which merchantability for saw-timber is limited by branches, deformity, defect or by a diameter of less than 6.0 inches inside bark. Minimum D.B.H. is 9.0 inches. No deductions made for defect.

Aggregate deviation for 1,479: Table 1.0% low.
Standard error of estimate for individual tree, based on 149 trees mechanically selected from the total number, is 51% of the average sample tree volume.

Determination index based on 149 tree sample is 0.80.

SECTION 2 -- GROUND CRUISES

A 100% Cruise of Sawtimber and a 10.7% Plot Cruise

of Poles and Sawtimber

SECTION 2 — GROUND CRUISES

A 100% Cruise of Sawtimber and a 10.7% Plot Cruise of Poles and Sawtimber

INTRODUCTION

Although the ground cruises were executed after the aerial photo work on the aerial cruises, they are here considered first so as to establish a basis for comparing the results of the aerial cruises and so that a better understanding may be had of the source of the ground data for the aerial cruises. In order to provide a check on the results of the various aerial cruises, a 100% ground cruise of all sawtimber on the area was made. In conjunction with this, to provide ground data for use in the aerial cruises, an 11% plot cruise of both pole-size and sawtimber was made. It was necessary to organize the cruise so as to provide certain types of data, and yet complete it in as short a time as possible since it was only a part of the general problem. Consequently, this ground cruise differs from normal cruises in a number of ways, as for example, in containing no cull or growth data. In evaluating the results of the ground cruise the design must be borne in mind, particularly when considering such things as cost.

PROCEDURE

A base line was laid out with compass and chain and perpendicular to it a series of parallel strips one chain wide were run. On these strips the diameter of all sawtimber trees was measured and the merchantable height estimated. Along the leading edge of each strip, trees were frequently marked so as to prevent the overlapping of any strips or the missing of any trees. Separate tally sheets were used for each strip so that in addition to the 100% cruise, various combinations of these would provide strip cruises of different percentages.

At three-chain intervals on every third strip a tenth-acre sample plot one chain square was established. At the beginning of each strip a random choice was made to decide whether the first plot in that strip should fall in the first, second, or third chain. This design resulted in 142 1/10-acre plots or a 10.7% plot cruise. On these plots, in addition to sawtimber, poles down to 6 inches d.b.h. were measured and their merchantable heights estimated. Also, on each plot the average height of the dominant and codominant trees was estimated by the field crew members to the nearest five feet, occasionally checked with an Abney level. The percentage of crown closure was ocularly estimated to the nearest 10%. The purpose of these two estimates was to provide information for checking the photo-interpretation. The approximate location of these plots is shown in Map No. 3.

Trees were measured at d.b.h. with diameter tapes to the nearest tenth-inch and tallied by one-inch classes up to 18 inches and by two-inch classes for 20 inches and larger. Sawtimber trees were defined as those in the eleven-inch class or larger for hardwoods, and nine-inches or larger for softwoods.

Merchantable heights for sawtimber trees were estimated to the nearest half-log and occasional checks were made with an Abney level. The limits of top merchantability for sawtimber trees were defined as 8 inches inside the bark for hardwoods and 6 inches inside the bark for softwoods. Merchantable heights for pole-size trees were estimated to the nearest four feet, the limit of merchantability being four-inches inside bark for all species.

Sawtimber trees forking above 16 feet were tallied as one tree

Map No. 3

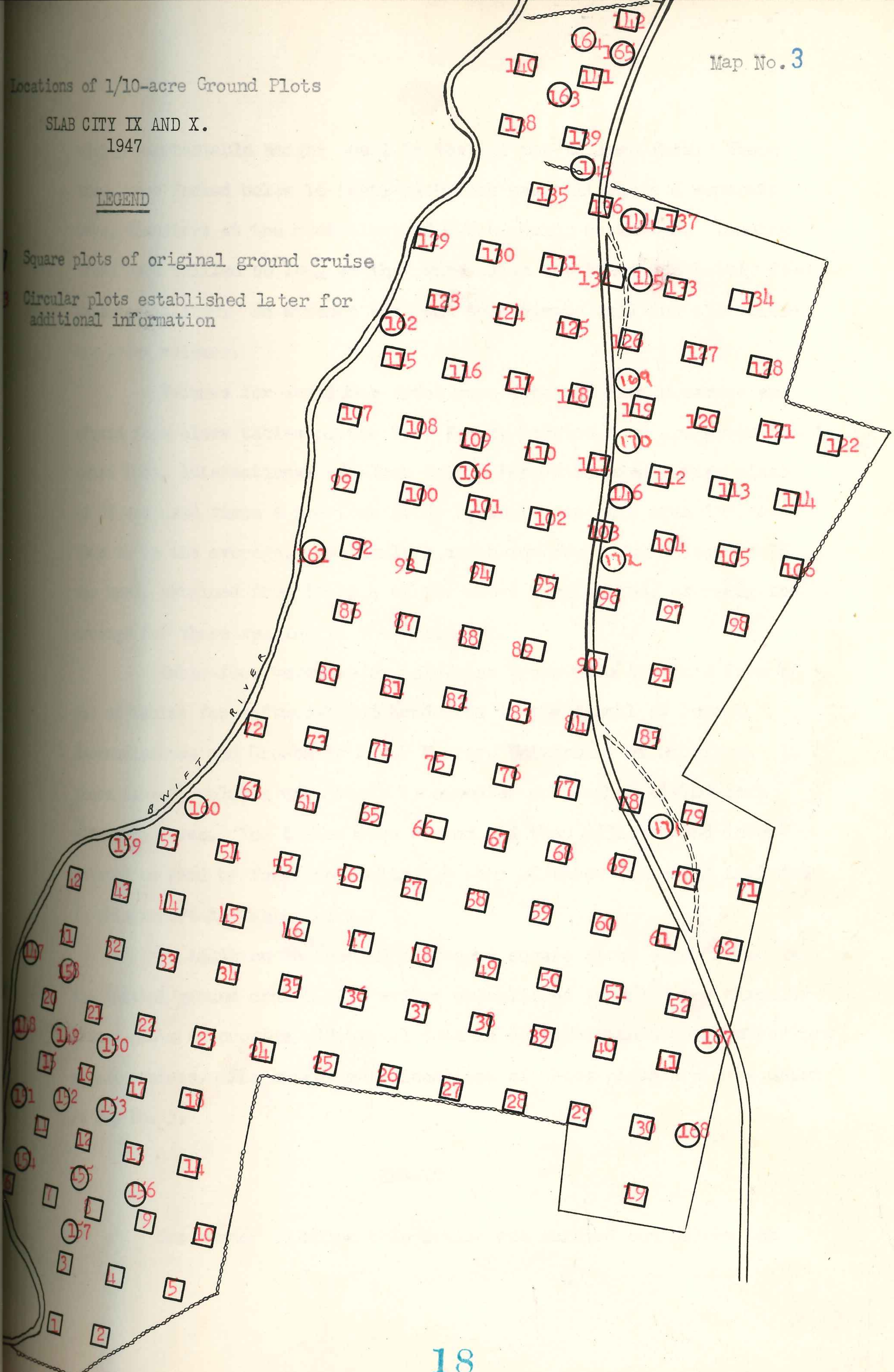
Locations of 1/10-acre Ground Plots

SLAB CITY IX AND X.
1947

LEGEND

Square plots of original ground cruise

Circular plots established later for additional information



with a merchantable height equal to that of the tallest fork. Where trees were forked below 16 feet, each fork was tallied as a separate tree, diameters at the equivalent of d.b.h. being estimated. Leaning trees were tallied so long as they were alive but trees completely dead were not tallied. No attempt was made to estimate cull and all volumes are gross volumes.

Volumes for sawtimber trees were obtained from Mesavage and Girard form class tables of the U.S. Forest Service, and are given in board feet, International 1/4-Inch Rule. For white pine a form class of 82 was used since a previous study conducted in this area indicated this to be the average. For hemlock and hardwoods a form class of 78 was used, obtained from Table 4 of the above publication, as being the average for these species in the Northeast.

Cubic-foot volumes for pole-size trees were obtained from a set of tables for softwoods and hardwoods in the Manual of Forest Reconnaissance and Growth by Frank Murray, University of Michigan. In these tables, volumes were shown by diameter and number of 100-inch sticks per tree. The tables were curved and then adjusted and interpolated to read by four-foot bolts. A copy of these tables is included in this report as Table No. 1.

In addition to the 142 1/10-acre square plots established in the initial ground cruise, the writer established 30 1/10-acre circular ground plots to provide additional data in certain stands for the various aerial cruises. The approximate locations of these plots are also shown in Map No. 3.

RESULTS

The manner in which this cruise was carried out allows the

Cubic-foot Volumes for Pole Timber

HARDWOODS

DBH	Merchantable Height - Feet 8	12	16	20	24	28	32	36	40
6	1.5	2.0	2.5	3.1	3.6	4.2	4.7	5.3	--
7	2.2	2.8	3.4	4.1	4.7	5.3	5.9	6.5	7.1
8	2.9	3.6	4.4	5.1	5.9	6.6	7.4	8.2	9.0
9	3.9	4.8	5.7	6.5	7.4	8.3	9.2	10.0	10.9
10	5.3	6.3	7.3	8.3	9.4	10.3	11.3	12.4	13.4

SOFTWOODS

DBH	Merchantable Height - Feet 8	12	16	20	24	28	32	36	40
6	1.5	2.0	2.6	3.2	3.7	4.3	4.9	--	--
7	2.2	2.8	3.5	4.1	4,8	5.4	6.1	6.7	7.3
8	3.3	4.1	4.8	5.5	6.2	6.9	7.7	8.4	9.1

Adapted from Manual of Forest Reconnaissance and Growth by Frank Murry, University of Michigan.

Volumes are given in cubic feet of merchantable wood inside bark to a top diameter limit of 4-inches i.b.

data to be combined in a number of different ways. Since the tally was kept separate by one-chain strips it was possible to assemble strip cruises of varying percentages. Volumes for the area were computed for all possible 5, 10, 20, 25, 33 1/3 and 50 percent cruises, and for the 100% cruise. In any cruise less than 100% there is naturally an error in an area estimate which is based upon the length of the lines run. Consequently, the data was worked up in two ways for each cruise--one without any correction for error in area and one with a correction for error in area. Table No. 2 is a summary of the results of the various ground cruises. The standard error of the estimate is shown for the 5, 10 and 20 percent cruises only, because the remaining cruises have such a small number of degrees of freedom. It will be noted that there is a regular decrease in the standard error of the estimate from the 5% to the 20% cruises. Average errors are shown for all cruises. In general these errors decrease from the 5% cruises up through the 20%, but beyond this the results are erratic and there is no noticeable trend. A tabulation of the least errors of any individual cruise shows that some of the cruises were accurate to within less than 1% of the true total volume. Examination of the greatest errors on any one cruise shows that considerable errors can be obtained on any one cruise. Maximum errors for the 5% cruises were 55% for the total volume and 92% for the volume of only one species.

The actual error of the one 10.7% plot cruise was 5.7%, while the standard error of the mean was 9.3%, based on an unlimited population, and 8.8% when based on the formula for a limited population.

COSTS

In determining the costs of a project of this nature a number

Table No. 2

Standard Errors and Average Errors

for the Various Ground Cruises

	STRIP CRUISES											
	5%		10%		20%		25%		33-1/3%		50%	
*	Unc.	Corr.	Unc.	Corr.	Unc.	Corr	Unc.	Corr.	Unc.	Corr	Unc	Corr
Standard Error of Estimate (%)												
For Total Volumes	21.2	23.7	12.8	11.8	6.9	6.8						
For Hardwood Volumes	29.7	23.0	20.9	15.8	6.9	5.4						
For Hemlock Volumes	23.0	24.7	16.0	12.9	6.5	5.2						
For White Pine Volumes	34.5	39.0	20.0	21.7	13.9	14.5						
Average Error (%)												
For Total Volumes	17.3	20.6	9.9	8.9	5.9	5.8	6.0	5.8	4.7	3.7	6.0	5.5
For Hardwood Volumes	19.3	16.3	16.9	13.2	6.5	5.2	4.7	3.4	3.1	2.2	0.2	0.3
For Hemlock Volumes	17.6	20.1	13.7	11.5	5.6	4.5	9.4	9.3	2.3	1.3	9.3	8.8
For White Pine Volumes	29.7	33.5	14.4	16.4	12.7	13.0	6.9	7.9	7.0	6.0	5.4	4.9
Least Error of Individual Cruise												
For Total Volumes	0.7	0.3	0.6	1.9	0.8	1.6	2.1	0.8	2.2	2.7	-	-
For Any Indiv.Spec.Vol.	0.7	0.2	0.7	0.3	2.3	1.1	0.5	0.1	1.2	0.3	-	-
Greatest Error of Individual Cruise												
For Total Volumes	55.2	39.1	23.9	24.5	10.5	10.1	10.0	11.6	7.0	5.6	-	-
For Any Indiv.Spec.Vol.	92.3	72.4	44.5	43.5	18.7	19.4	19.0	18.5	10.5	9.1	-	-

10.7% Ground Plot Cruise

	Hardwood	Hemlock	White Pine	Total
Error (%)	-13.1	-14.7	+ 4.5	-5.7

Standard Error of Mean = 9.3% **(Based on formula for unlimited population)**
" " " " = 8.8% **(Based on formula for limited population)**

* Unc. columns are based on volumes uncorrected for exact area.
Corr.columns are based on volumes corrected for exact area.

of assumptions must necessarily be made. Furthermore, in considering these costs the design of the survey must be kept in mind. The purpose of estimating the costs of the various cruises is solely for comparison with the cost of other cruises determined in a like manner. For several reasons the costs of these surveys do not reflect the costs of surveys actually carried out for timber inventory. For example, no cull or growth data was collected, and a straight 10% for overhead has been assumed for all cruises. Furthermore, the area is particularly accessible to roads.

Nevertheless, time records have been kept on all of the surveys and by making several assumptions it is felt that valid comparisons between the costs of the various ground cruises and between the costs of ground cruises and aerial photo cruises can be made.

Following are the assumptions regarding costs of the ground cruises:

Salary (field and office work done by same personnel)	$2660 / annum
Car mileage	$0.05 / mile
Overhead	10%
Distance between office and field area	6 miles
Cost of travel time one way to be borne by cruise.	

The estimated costs of certain of the cruises for the 133-acres are:

Cruise	Total Cost	Cost per acre, cents
5% Strip	$ 36.47	27.41
10% Strip	59.97	45.09
20% Strip	91.20	68.57
10.7% Plot	101.87	76.59

CRUISE OF A TOWNSHIP

In order to better visualize the comparisons of the various cruises, it is of interest to expand them and see how they apply to a larger area. In SECTION 7 is a comparison of the number of plots and the costs of the various cruises as applied to a six-mile-square township of 23,040 acres. Since there was no sampling unit in the strip cruises they are not subject to statistical treatment and the expansion of the ground cruises to a township area is confined to the one 10.7% ground plot cruise.

CONCLUSIONS

It is not the purpose of this project to make detailed comparisons of various types of ground cruises but since the 100% cruise was made in strips it was possible to combine the data into strip cruises of various percentages and this was done as an incidental matter of interest. The results are of passing interest but the conclusions far from decisive, principally because of the small size of the area involved.

Examination of the table of errors shows that for an area this small it is necessary to employ a strip cruise of about 20% in order to be assured of a standard error of the mean below 10%. On the other hand, the evidence available indicates that an increase in strip cruise percentage above 20% does not necessarily result in an appreciable increase of accuracy. Therefore, it may be concluded that for an area this small and of this type a cruise of about 20% is the best by the strip method.

Although the accuracy of the 10.7% plot cruise was somewhat better than that of the 10% strip cruise, the cost is considerably more. The 20% strip cruise appears slightly cheaper and more accurate than the plot cruise. Part of the high cost of the plot cruise is due to the rectangular spacing of the plots and costs could be reduced considerably by a closer spacing of plots on lines farther apart. However, this is not very practical on such a small area and probably would result in some decrease in accuracy. The results, then, indicate that for an area of this type and size a 20% strip cruise is likely to give the most satisfactory results.

SUMMARY

For the purpose of providing an accurate volume check on the various aerial and ground cruises a 100% ground cruise of the area was made. In addition, in order to acquire data for adjusting certain of the aerial cruises, 142 tenth-acre ground plots were mechanically spaced in the area, thus providing a 10.7% plot cruise. Thirty additional tenth-acre plots were established to provide further data in certain stands. Time records were kept and costs of certain of the cruises computed for purposes of comparison.

Results indicate that for an area of this type and size, a 20% strip cruise is the cheapest that will provide results of acceptable accuracy. That is, a standard error of the mean of less than 10%.

SECTION 3 — AERIAL CRUISE NO. 1

An Intensive Use of Large Scale Photographs Involving a Detailed Stand Map but No Supplementary Ground Data

SECTION 3 -- AERIAL CRUISE NO. 1

An Intensive Use of Large-scale Photographs Involving a Detailed Stand Map but no Supplementary Ground Data

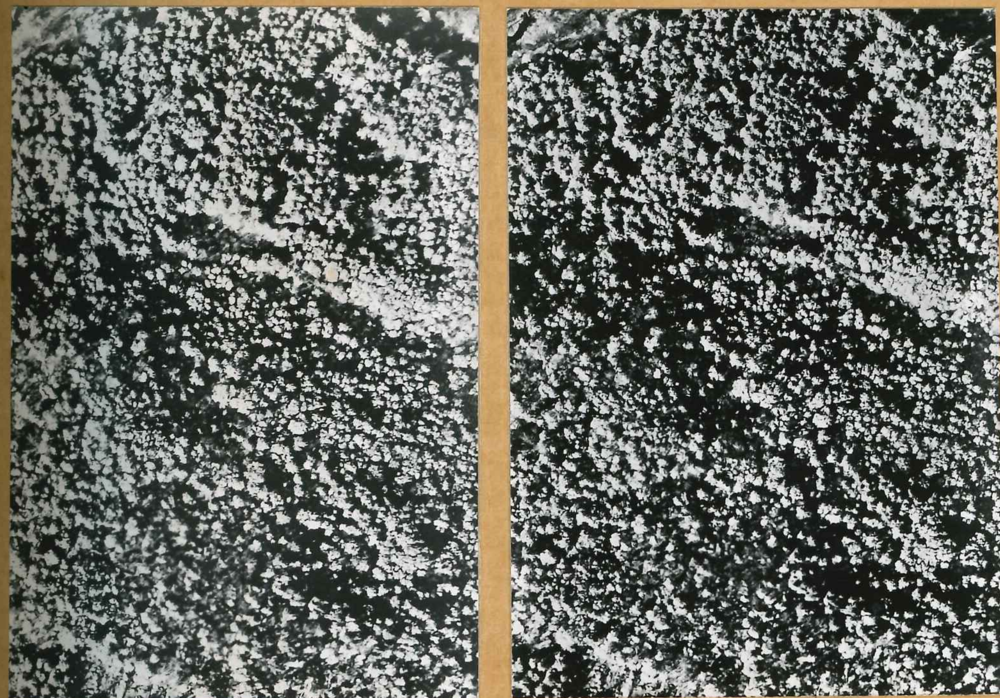
INTRODUCTION

This cruise is an intensive one using large scale photographs with the primary objective of determining how accurate a volume estimate it is possible to make from such photos alone without the use of ground data. It was hoped that some indication might thus be gained as to whether or not it would pay to use large scale photographs intensively for timber inventory purposes. Additional objectives were to gain experience in making measurements on the photographs, and to determine about how accurately these measurements could be made.

PHOTOGRAPHS

The photographs used were HF - 3 - 8 to 11, taken on October 20, 1946, about a year before this survey, using infrared film with a minus blue filter. The theoretical scale was supposed to be about 1:4800 but a scale check revealed the actual scale to be 1:5300. Although the pictures were clear and of an unusually large scale, a preliminary examination revealed serious shortcomings. Chief of these was the extreme contrast which caused the photographs to be composed almost entirely of bright whites and opaque blacks with no intermediate tones. This appeared to be caused by the combination of the early hour of the photography (9:30 A.M.) and late season (October 20), which produced long shadows; the infrared film which made these shadows particularly black; and probably some fault in the exposure, developing or printing. The result is that each tree is composed of a blank white portion on the sunny side and an opaque black portion on the shadow side. This causes the tone differentiation between species, which generally

Examples of the 1:5300 Photographs Used in Aerial Cruises No. 1 and 3.



Stereogram - Southwest Portion of Study Area

Stereogram - Northern tip of Study Area

shows up well on infrared photographs, to be entirely lacking. In addition, the photographs were taken at such a late date that many of the hardwoods were partially defoliated and some were completely defoliated. Stereograms from these photos covering portions of the study area are shown in Figure 2 and reveal the aforementioned shortcomings.

PROCEDURE

Design of the Cruise

Since the purpose of this cruise was to secure the best volume estimate possible, the cruise was designed to extract the maximum amount of detail from the photos without regard to the time or cost involved. To accomplish this purpose the design called for a detailed type map with no minimum area limit set. Within each type the percentage of all distinguishable species were estimated, the height or height range of each species component estimated to the nearest five feet, the average crown diameter of each species estimated to the nearest foot, the total and merchantable number of trees per acre estimated, and the crown closure or density estimated to the nearest five percent. Per-acre volumes were then obtained by roughly averaging the figures given by the several volume tables available and these volumes were applied to the areas of the various types to obtain the total volume figures.

Preliminary Computations

The first step was to calculate the photo scale and prepare graphs for such factors as parallax, shadow length, area corrections, etc.

In order to determine the actual scale of the photographs a number of lines were measured on each photo and checked against the U.S.G.S.

topographic map. Here an unexpected difficulty was encountered. The various scale checks when plotted on graph paper showed little or no correlation between scale and elevation. The results of the scale check are shown in Figure 3. Included is a line showing the theoretical slope of the ratio between scale and ground elevation as determined from the relationship of focal length, flying height and photo scale. That there is little correlation between the slope of this line and that of the actual scale checks is immediately apparent. The most logical answer seems to be that the difficulty lies in the points chosen for the scale check. Since the scale of the photographs is large they cover too small an area on the topographic sheet to include many accurately located control points. The points necessarily chosen for the scale check consisted, in large part, of such features as stream junctions, road bends and farm houses which probably were not too accurately located on the topographic sheet. An additional possible cause, of course, is distortion due to camera tilt but it is beyond the scope of this report to analyze this. To solve the problem of scale discrepancies, the average scale and average elevation of all the check points were determined and approximately through this point a line was drawn at the proper slope to indicate the photo scale at various elevations. This is shown in Figure 4. As can be seen, the scale at an elevation of 800 feet, which is about average for the area, is 1:5300. A single check made by chaining a distance along the road indicated that the assumed scale was approximately correct.

By means of the parallax formula, computations were made to form a graph showing the parallax factor, or tree height in feet per .001-inch of parallax, for the various elevations. In order to compute this, corrections for the absolute parallax at different elevations were

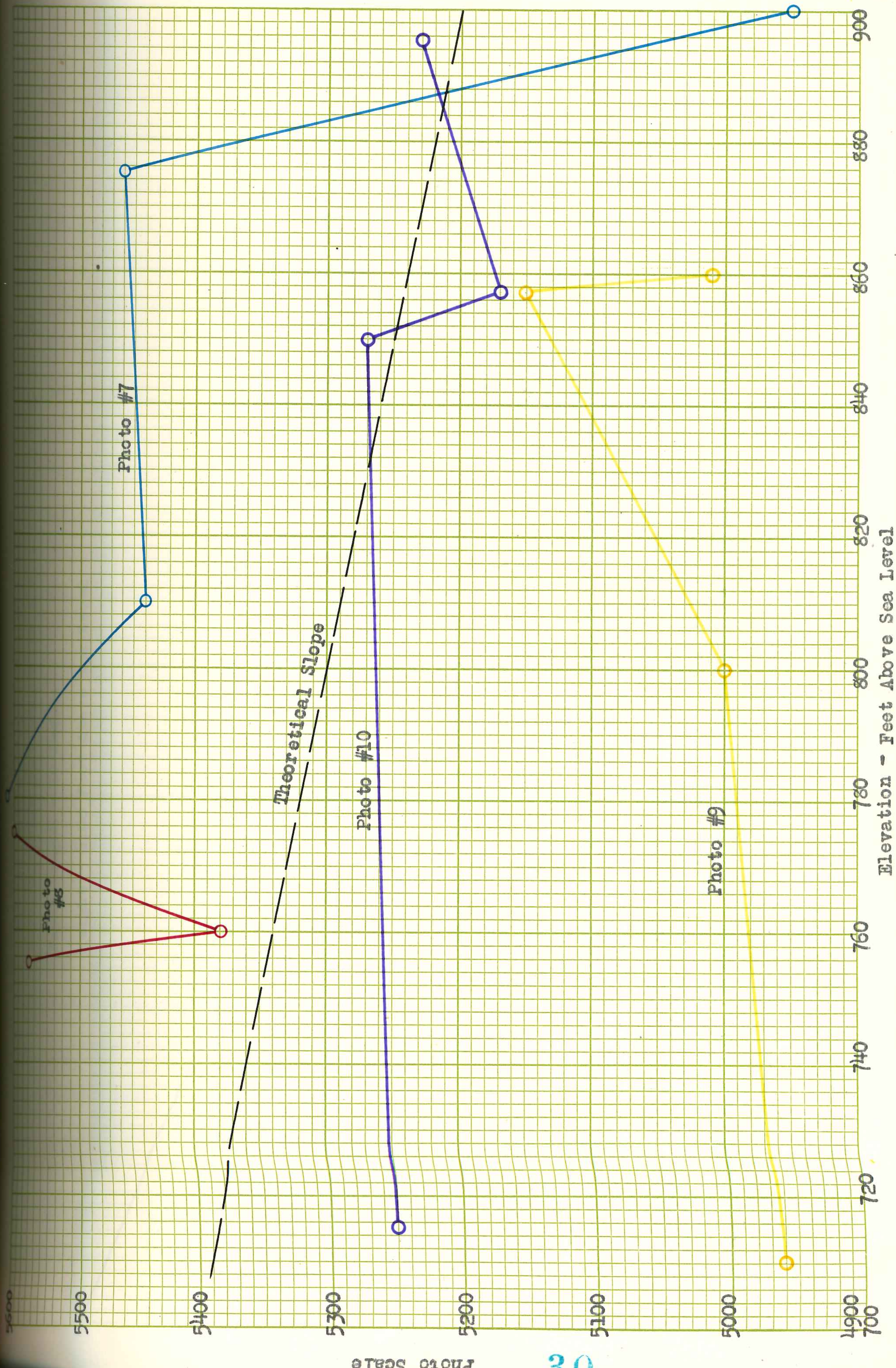
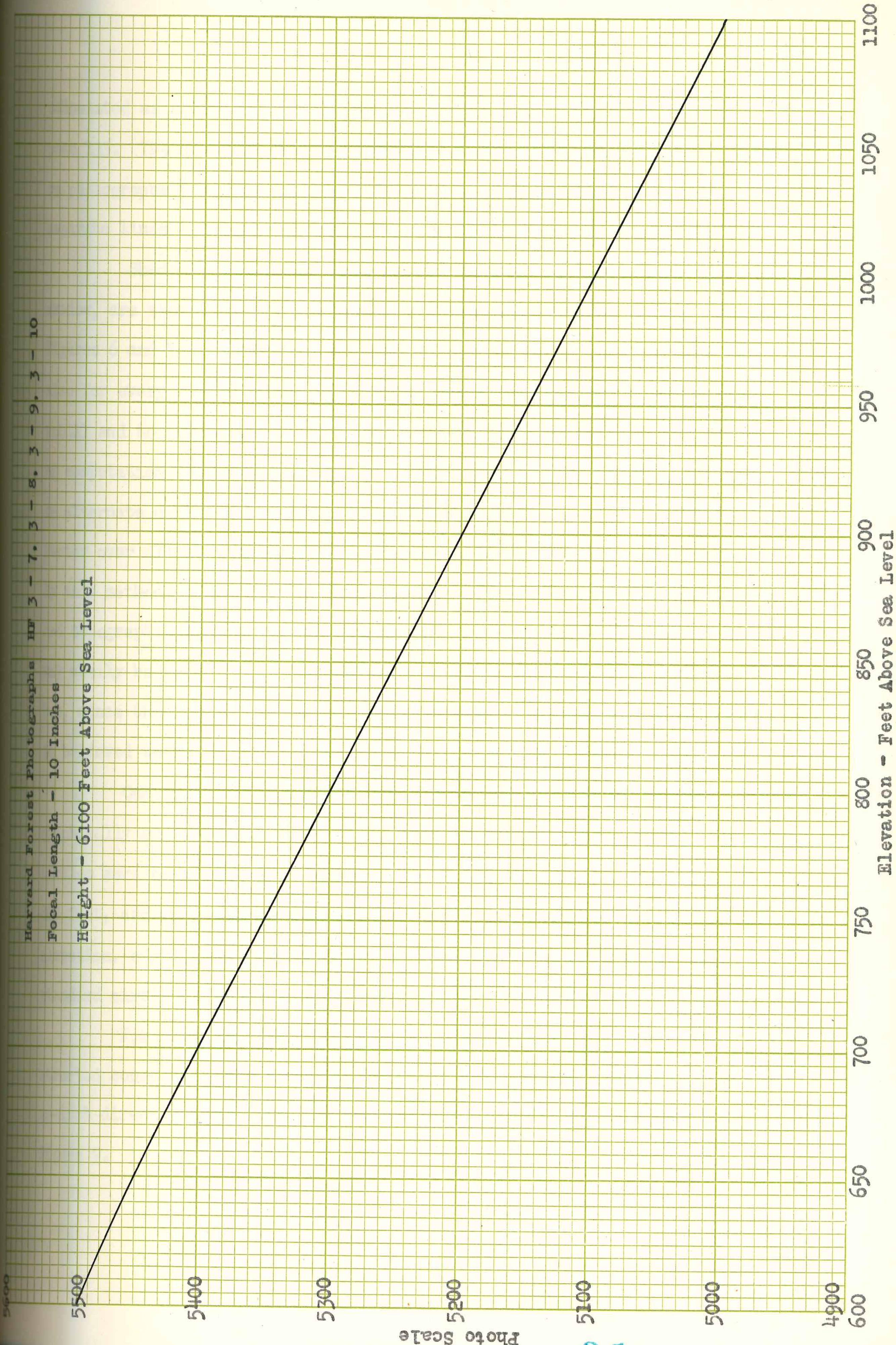


Photo #7
Photo #8
Photo #9
Photo #10
Theoretical Slope
Elevation - Feet Above Sea Level
900
880
860
840
820
800
780
760
740
720
700
Photo Scale
5600
5500
5400
5300
5200
5100
5000
4900

Aerial Cruise No.1. Photo Scale Graph Figure 4

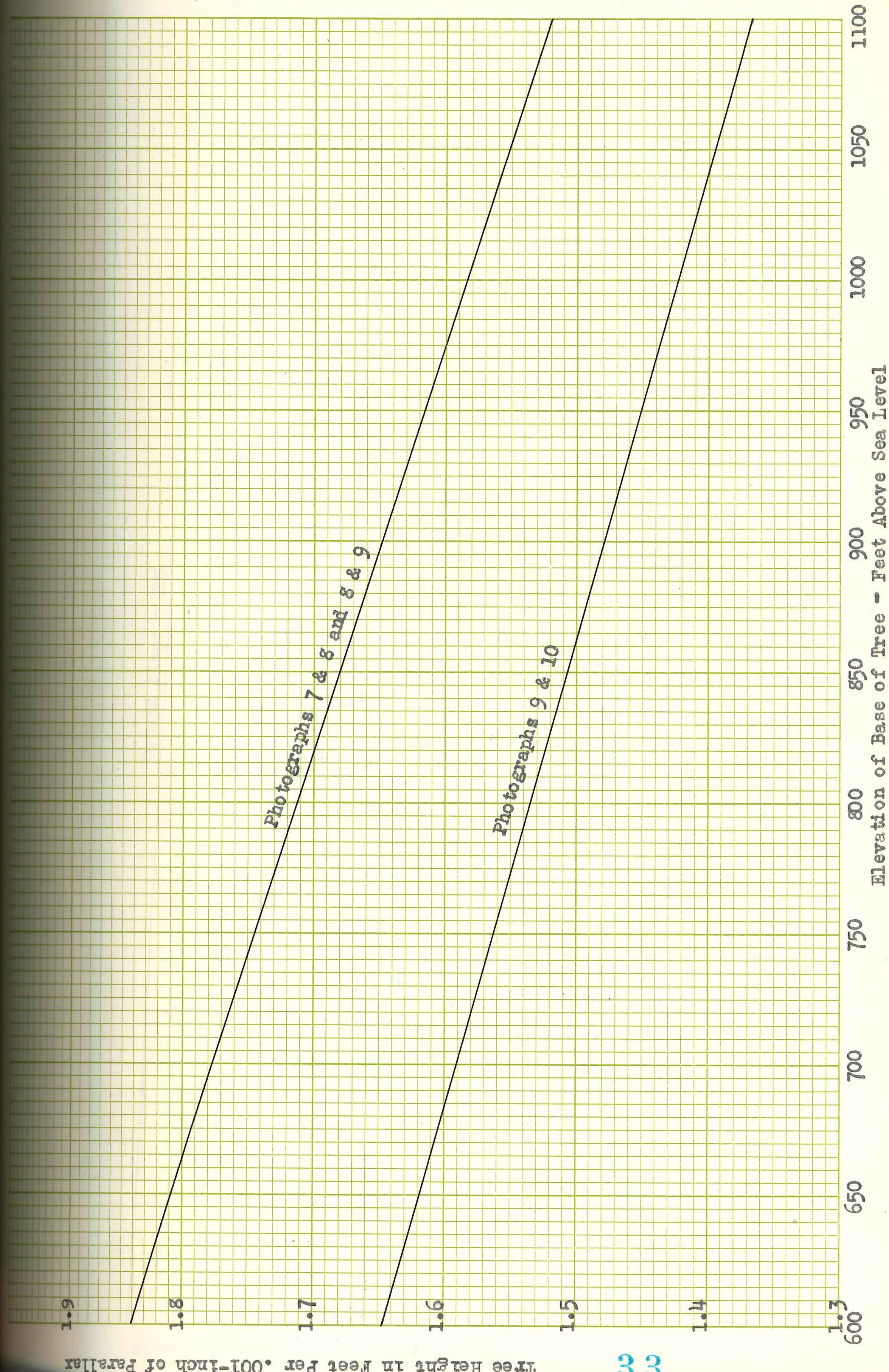


calculated as shown in Aerial Photographs in Forestry, by S. Spurr, page 135. The distance between principle and conjugate principle points on photographs 9 and 10 differed from that of the other paris and so separate lines had to be drawn. This graph is shown in Figure 5.

Shadow factors, or tree height in feet per .001-inch of shadow, are shown for the various elevations encountered on the area in Figures 6 and 7. Factors were computed not only for level ground but also for every 20% of slope up to 100% where the shadows were falling uphill and to 40% where the shadows were falling downhill. The method of computation is described in the aforementioned reference, page 240. An alternate method of constructing this graph is to show the shadow factor over slope, graphing lines for each 50 or 100 feet of elevation. By this method, slope can be expressed in terms of degrees, percent and topographic units, and the factor for intermediate amounts of slope may easily be read off. Interpolation must be made between elevations but, since the factor varies only slightly with elevation, this method is believed to be easier to use than that shown in Figures 6 and 7.

One-fifth acre circles were drawn and reproduced photographically on transparencies to be used in making tree counts. The circles were constructed to measure one-fifth acre at an elevation of 800 feet, and in order to correct for differences caused by changes in elevation, a graph was constructed to show the area covered by this standard circle at other elevations. (Figure 8)

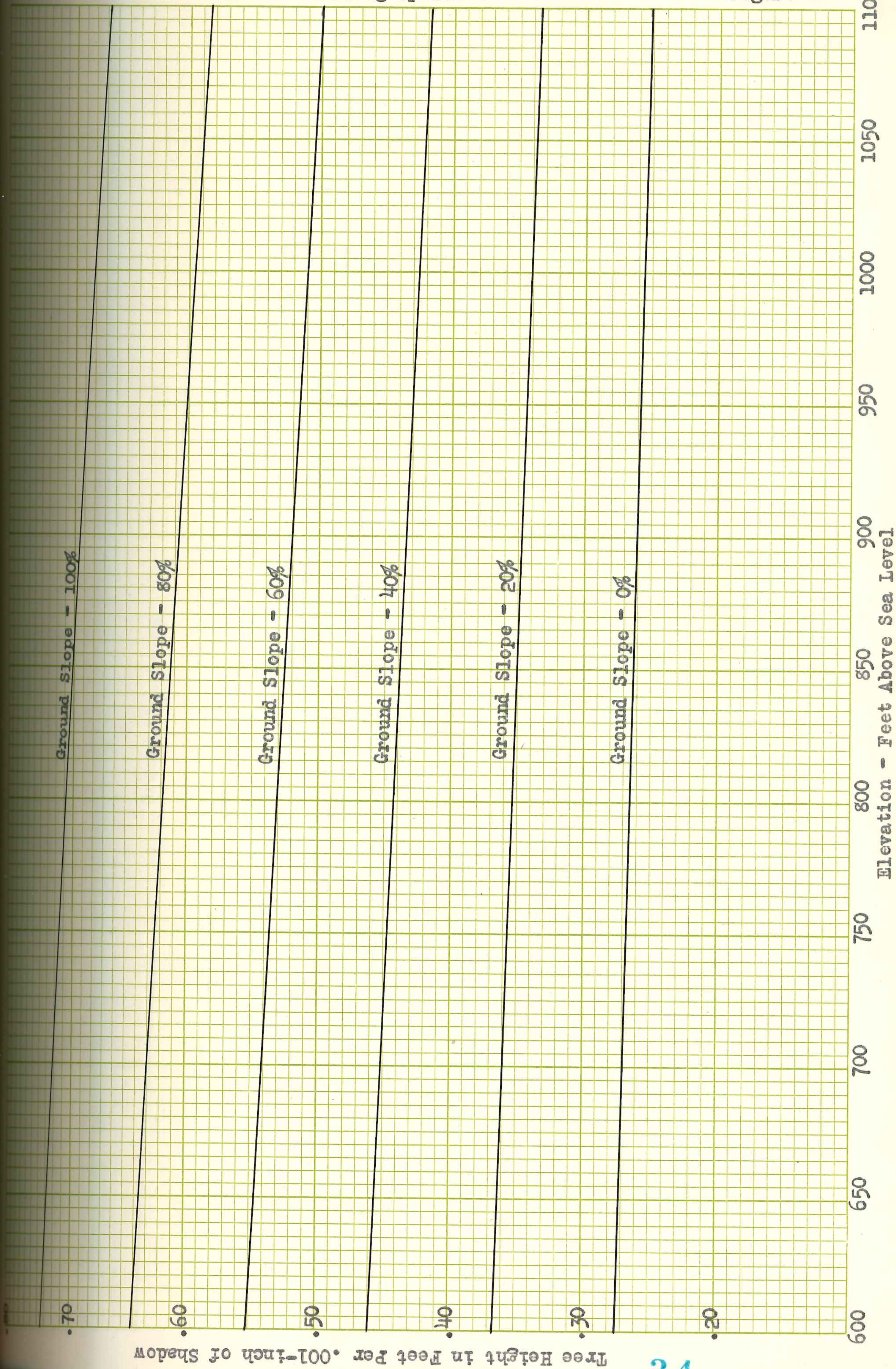
For ease in determining crown diameters a graph was constructed converting the crown diameter as measured in thousandths-of-an-inch directly into feet for the various elevations, as shown in Figure 9.


Photographs 7 & 8 and 8 & 9
Photographs 9 & 10
Elevation of Base of Tree - Feet Above Sea Level
600
650
700
750
800
850
900
950
1000
1050
1100
Tree Height in Feet Per .001-inch of Parallax
1.9
1.8
1.7
1.6
1.5
1.4
1.3

Aerial Cruise No. 1.

Shadow Factor Graph
Shadows Falling Uphill

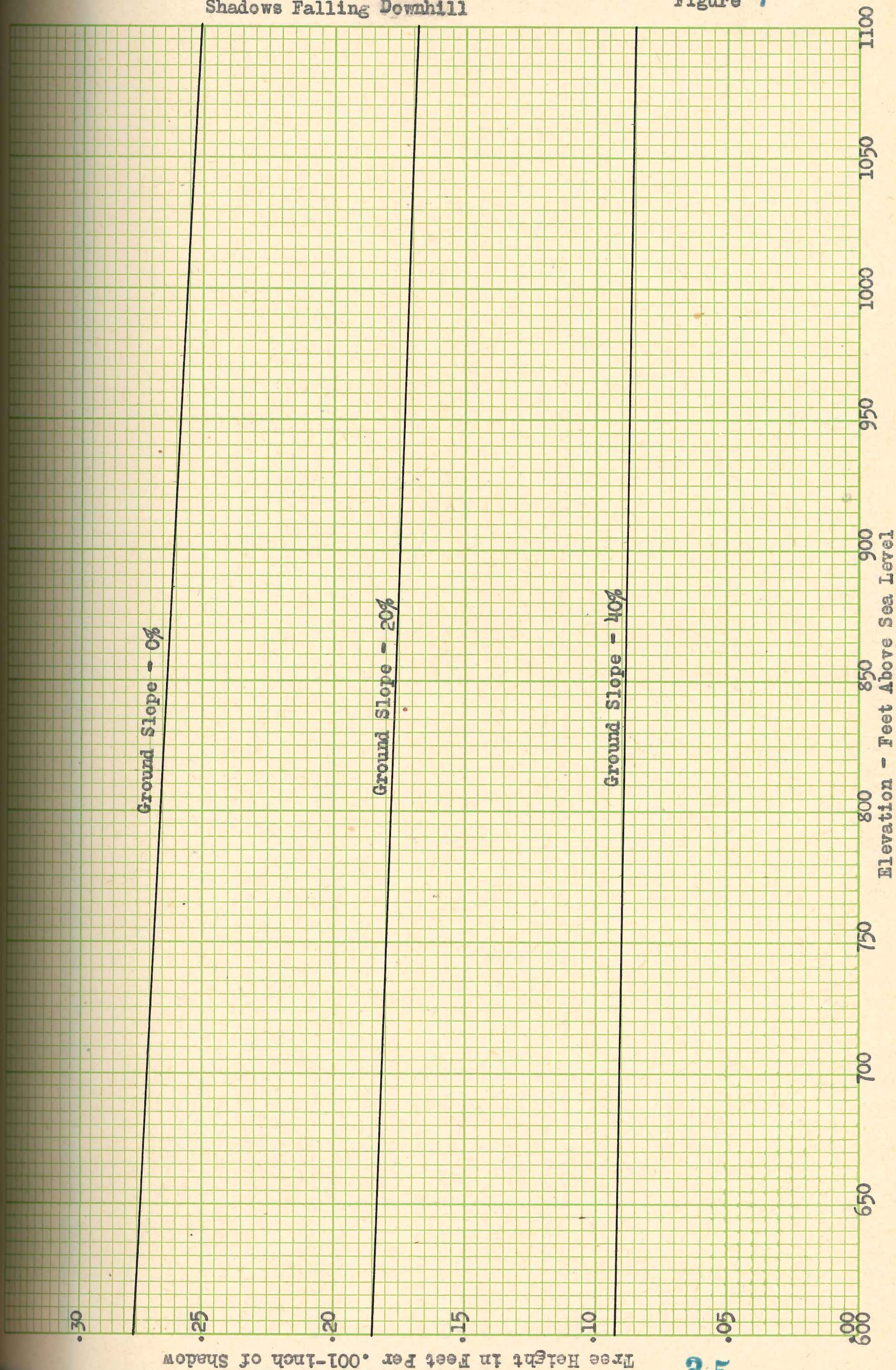
Figure 6



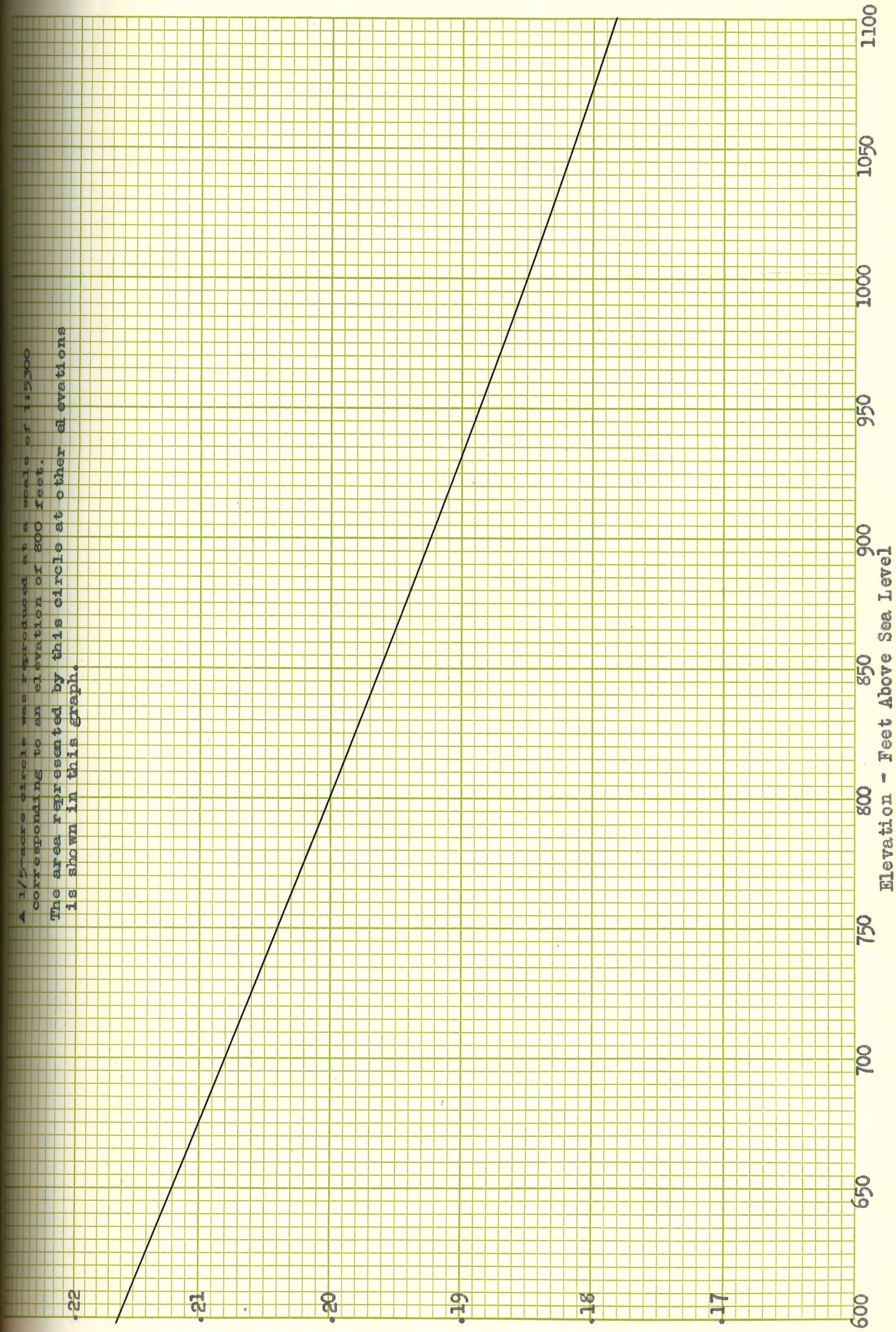
Aerial Cruise No. 1.

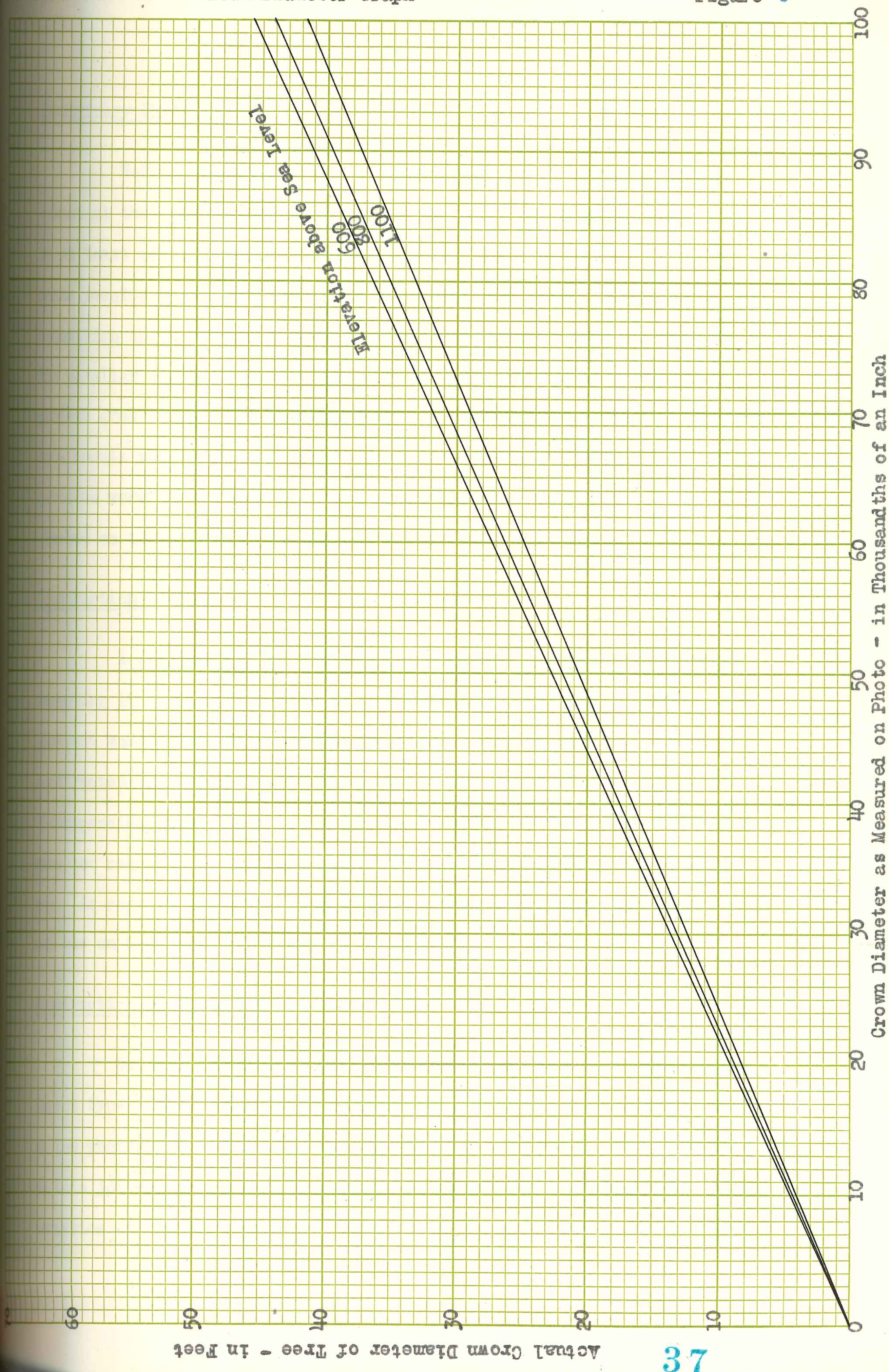
Shadow Factor Graph
Shadows Falling Downhill

Figure 7



 Area of 1/5-acre Circle Graph Figure 8




Crown Diameter as Measured on Photo - in Thousandths of an Inch
Actual Crown Diameter of Tree - in Feet
Elevation above Sea Level
600
800
1100
0
10
20
30
40
50
60
70
80
90
100

Preliminary Check Work

Before attempting photo-interpretation of any area it is essential that the interpreter gain a working knowledge of that area or at least of the general region in which the area lies. By this means results which are obviously erroneous can often be avoided. To accomplish this purpose a number of measurements of tree heights by the parallax and shadow methods were made in the vicinity of the project area and in the northernmost tip of the area. In addition, tree counts were made and species indentifications attempted. These portions were then visited in the field and the various photo estimates checked on the ground. No serious errors were discovered.

Construction of Base Map

A printed map of the project area was available but before accepting it a check was made against the photographs. A radial line plot was made using the transparent templet method and the map thus constructed was found to fit the printed map reasonably well. Chief discrepancies were found to be in the location of the river and these were not regarded as large enough to warrant discarding the printed map. As results from the 100% ground cruise later showed, the printed map has an area approximately 1.5% high.

Construction of Type Map

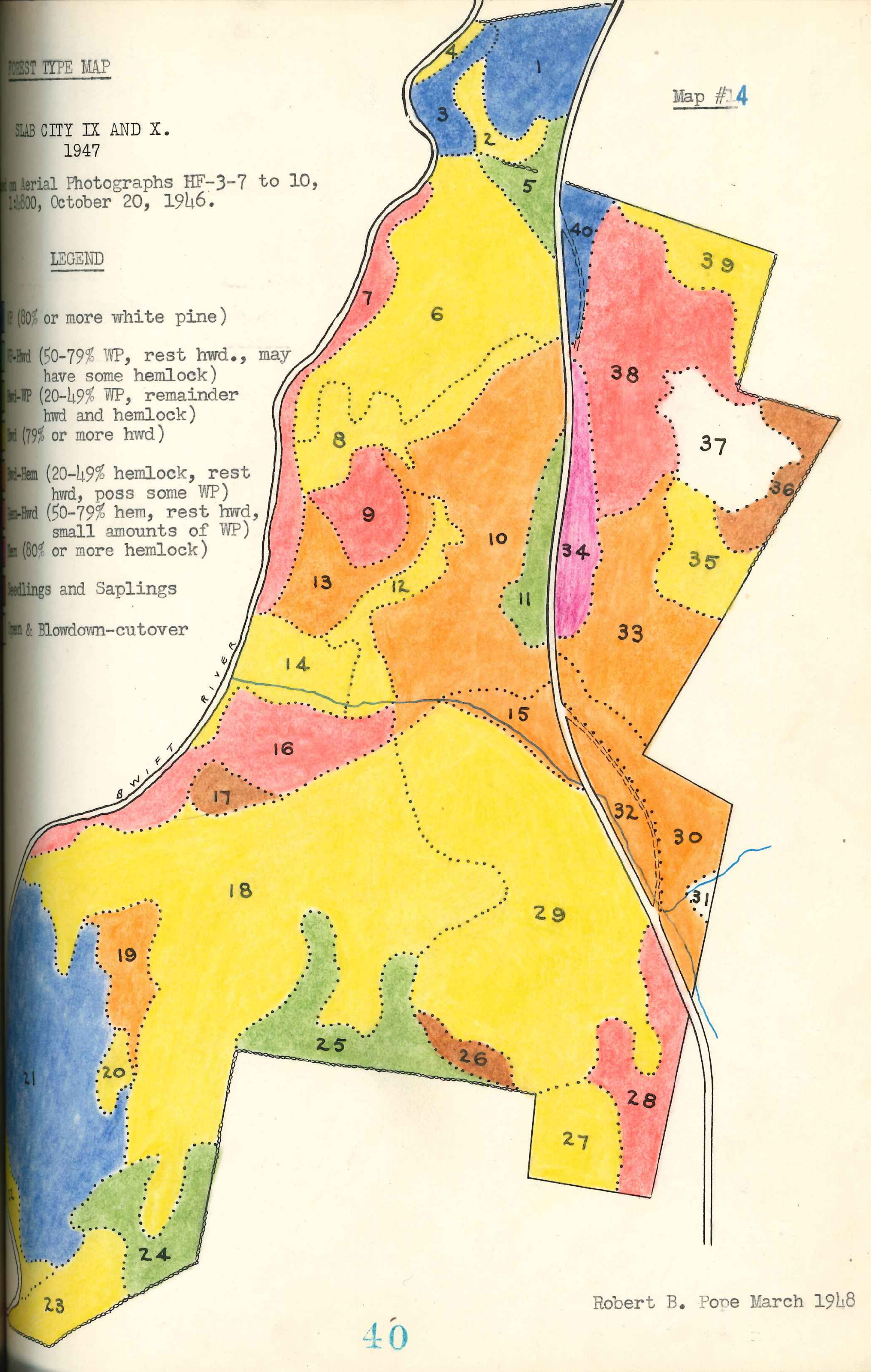
Using a magnifying pocket stereoscope, areas of homogeneous forest types based on species composition, height and density were marked on the photographs with a grease pencil. The length of time required to do this job was increased by certain difficulties imposed by the characteristics of the photographs. Because of the previously mentioned lack of tone differentiation, the various species could not readily be recognized. Only by careful study of individual crown shapes could white pine, hemlock and the hardwoods be separated. Because it was not possible to break down the hardwoods into species or species groups, all hardwoods are grouped together.

When delineation of the forest stands was completed on the photographs the type lines were transferred to the base map by means of the multiscope. The resulting stand and type map is shown in Map No. 4. Although the species composition, height and density of each numbered stand is different, for the purpose of constructing type map the stands were grouped into the species composition types shown in the map legend without regard to height or density.

Estimation of Volumes

Each stand was then carefully gone over and estimates made of the species percentages, total height or height range, average crown diameter, density, total number of trees per acre and merchantable number of trees per acre. These estimates are shown in columns 1 through 8 of Table No. 3. Species percentage estimates were based on the proportion of the area of each stand occupied by the various species. Difficulties were encountered in the measurement of tree heights. Because of the extreme length of the shadows it was not possible to use the shadow method except in rare instances, and due to the lack of detail in the shadows it was difficult to determine the level of the ground when employing the parallax method. In determining heights by the parallax method, the parallax wedge was used as well as a home-made device employing a floating circle.

Average crown diameters of each species component in a stand were measured with a wedge scale. Density, or percent of crown closure,


FOREST TYPE MAP
Map #14
SLAB CITY IX AND X.
1947
d on Aerial Photographs HF-3-7 to 10,
1:4800, October 20, 1946.
LEGEND
P (80% or more white pine)
P-Hwd (50-79% WP, rest hwd., may have some hemlock)
Hwd-WP (20-49% WP, remainder hwd and hemlock)
Hwd (79% or more hwd)
Hwd-Hem (20-49% hemlock, rest hwd, poss some WP)
Hem-Hwd (50-79% hem, rest hwd, small amounts of WP)
Hem (80% or more hemlock)
Seedlings and Saplings
Open & Blowdown-cutover
SWIFT RIVER
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
Robert B. Pope March 1948

RIAL CRUISE NO. 1

FOREST TYPE MAP

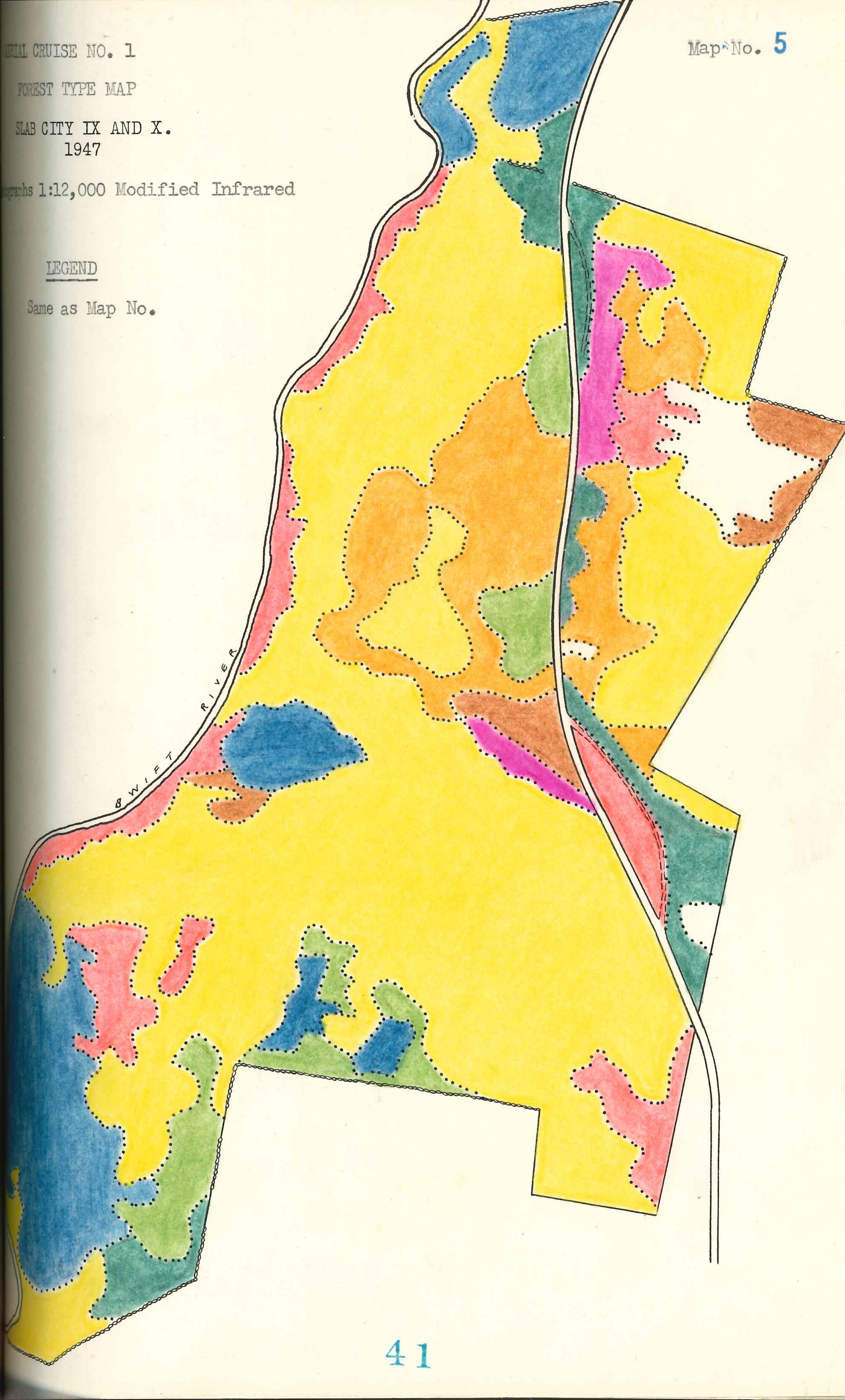
SLAB CITY IX AND X.
1947

graphs 1:12,000 Modified Infrared

LEGEND

Same as Map No.

Map No. 5



									1900	3.16	6005		
	WP	30	70-80	22	"	"	"		7200	"			22750
	Hem	20	65-75	18	"	"	"		3600	"		11375	
26	Seedlings and Saplings			--	30	--	--			.73			
27	Hwd	100	50-60	20	60	80	53		2000	1.80	3600		
28	Hwd	50	20-40	10	25	95	55	55		2.64	145		
	Hem	50	20-40	12	"	"	"	125		"		330	
29	Hwd	100	50-60	12	45	125	65	450		14.14	6365		
30	Hwd	45	60-70	17	70	105	60		1800	3.86	6950		
	Hem	40	65-75	15	"	"	"		4000	"		15440	
	WP	15	75	14	"	"	"		3000	"			11580
31	Open									.29			
32	Hwd	80	30-60	13	15	90	45	100		1.54	155		
	Hem	20	30-60	11	"	"	"	60		"		90	
33	Hwd	75	55-65	13	85	105	60		1900	4.96	9245		
	Hem	25	60-70	13	"	"	"		3500	"		17360	
34	Hem	80	75-85	16	90	80	60		21500	2.09		44935	
	Hwd	10	65-70	18	"	"	"		570	"	1190		
	WP	10	85-90	20	"	"	"		3500	"			7315
35	Hwd	100	50-60	18	55	60	40		2000	2.02	4040		
36	Seedlings and Saplings				35					1.51			
37	Blowdown-cutover									1.65			
38	Hem	60	60-75	13	85	120	70		10000	6.80		68000	
	Hwd	40	55-65	13	"	"	"		1600	"	10800		
39	Hwd	100	50-60	16	70	115	65		3800	1.76	6690		
	WP	--	80	24	--	4 trees			1023	1.76			1800
40	WP	80	80-90	24	60	35	30		16000	1.07			17120
	Hwd	20	65-70	20	"	"	"		840	"	900		
Road										1.47			
								Total acres		134.76			
								Total, cubic feet			8539	420	4100
								Totals, board feet			224595	286790	705795
								Error			+39.2%	-26.4%	+38.6%
								Totals, corrected for area			221001	282201	694502
								Error			+37.0%	-27.6%	+36.4%

Table No. 3

Measurements and Per-acre Volume Estimates

1	2	3	4	5	6	7	8	9	10	11	12	13	14	
Stand No.	Spec.	Percent Species	Total Height	Crown Diam.	Density	No. Trees Per Acre Total	Merch	Volume Per Acre Cu.Ft.	Bd.Ft.	Area Acres	Total Stand Vol. Bd.Ft. Hwd.	Hem.	W.P.	Cu.Ft.
1	WP	100	35	5	90	725	--	1800		2.28			4100	
2	Hwd	100	45	10	70	150	110	550		.84	460			
3	WP	90	70-90	14	70	145	100		21940	1.07			23500	
	WP	2 trees	110	20	--	--	--		1130	"			1220	
	Hem	10	75	9	"	"	"		1800	"		1900		
4	Hwd	100	50	20	40	40	30		1700	.33	560			
5	WP	35	90	25	50	7	trees		3571	1.12			4000	
	Hwd	65	65-75	20	"	15	trees		2411	"	2700			
6	Hwd	99	50-70	16	85	125	90		4500	8.08	36360			
	WP	--	105	20	--	3	trees		210	"			1700	
	WP	--	85	17	--	6	trees		235	"			1900	
7	Hwd	50	55-65	18	85	100	74		2500	2.75	6875			
	Hem	50	65-75	14	"	"	"		7500	"		20625		
8	Hwd	100	35-40	10	60	190	85	275		2.50	685			
9	Hwd	40	50-55	14	80	120	70		800	1.54	1230			
	Hem	50	55-60	9	"	"	"		2500	"		3850		
	WP	10	70	16	"	"	"		1450	"			2235	
10	Hwd	80	50-65	16	60	70	45		2300	8.63	19850			
	Hem	20	55-75	14	"	"	"		1600	"		13810		
11	Hwd	50	55-75	16	75	70	50		1900	1.32	2510			
	WP	25	80-90	24	"	"	"		7500	"			9900	
	Hem	25	60-80	14	"	"	"		3750	"		4950		
12	Hwd	100	35-40	10	60	190	85	275		2.09	575			
13	Hwd	80	50-60	16	75	95	60		2250	2.39	5375			
	Hem	20	55-65	16	"	"	"		1600	"		3825		
14	Hwd	100	60	15	60	85	55		2400	2.46	5905			
15	Hwd	55	50-55	13	40	75	55	220		.70	155			
	Hem	45	65	15	"	"	"		4000	"		2800		
16	Hem	68	65-75	14	85	110	90		10000	3.97		39700		
	Hwd	30	55-65	16	"	"	"		1200	"	4765			
	WP	2	75-80	17	--	10	trees		756	"			3000	
17	Seedlings and Saplings			--	40	--	--			1.14				
18	Hwd	100	60-70	14	80	145	80		3500	20.61	72135			
19	Hem	45	65-75	17	80	145	90		9000	1.51		13590		
	Hwd	55	55-65	14	"	"	"		1650	"	2490			
20	Hwd	100	60	14	60	75	60		2000	.48	960			
21	WP	95	80-100	22	90	100	70		47500	11.83			561925	
	Hem	5	80	18	"	"	"		1400	"		16560		
22	Hwd	100	55-60	22	40	40	30		2000	1.07	2140			
23	Hwd	100	55-70	14	80	110	60		3500	2.17	7595			
	Hem	--	70	15	--	5	trees		415	"		900		

was estimated with the aid of the Guide for Estimating the Degree of Stocking on Aerial Photos, produced by the Pacific Northwest Forest and Range Experiment Station. Column 7 of Table No. 3 represents an estimate of the total number of trees per acre regardless of size. Column 8 is an attempt to estimate the merchantable number of trees per acre using a minimum crown diameter of about fourteen feet for hardwoods and eight feet for softwoods. Data from this region indicate that these crown diameters approximately represent stem diameters of eleven and nine inches respectively. These stem diameters (d.b.h.) have been established as the minimum of merchantability for this project.

Using the estimations shown in the first eight columns, the per-acre volumes for each species component of each stand were obtained from aerial photo volume tables. In the determination of these volumes most of the applicable tables were used and their results roughly averaged. For hardwoods there were five tables available and for white pine, two. Since only one was available for hemlock the results of this table were supplemented by reference to the white pine tables. Columns 9 and 10 contain the per-acre volumes thus obtained. In the case of stands containing more than one species the per-acre volume for each species was first determined as if the entire acre were occupied by that species and then this figure was reduced by the percentage of the acre occupied by that species (the figure in column 3).

While working through the area stand by stand and making measurements, types lines were corrected and adjusted where necessary. The determination of stand areas was purposely left until this stage in order to permit these corrections to be made. Areas were first determined with a planimeter and the sum of the individual areas checked against the total area. As a matter of interest the total area was also determined with a dot grid and differed from the planimetered area by only 0.2 acre. Planimetered areas are shown in column 11.

Columns 12, 13 and 14 show the volumes by species for each stand obtained by multiplying the per-acre volumes by the stand acreages. Figures underlined in red indicate cubic feet.

Table No. 4 shows a summation of total board-foot and cubic-foot volumes for each stand and a percentage break down by species.

RESULTS AND ANALYSIS

Type Map

As a check on the species composition estimates of the first map another type map was made using 1:12,000 modified infrared photographs on which the species composition was more clearly distinguishable. This type map is shown as Map No. 5. At first glance there seem to be a large number of differences between these types and those determined from the 1:4800 photographs shown in Map No. 4. However, careful examination reveals that most of the discrepancies are due to minor differences in the percentages of the various species, such as a change from the hemlock-hardwood type to the hardwood-hemlock. The biggest mistake made on the 1:5300 type map occurred in stand No. 16 and was caused by mistaking an area of pure white pine for hemlock. A further check on the accuracy of species composition estimates is described in the following sub-section.

Volumes

Errors in estimation of volumes from aerial photographs may be due to errors in the estimation of species composition, in measurements such as height, density, crown diameter and tree count, and in the volume

Aerial Cruise No. 1 Table No. 4

Summation of Total Volume Estimates

[illegible]	Area	Per-acre Volume		Stand Volume		% Volume by Species		
	Acres	Cu.Ft.	Bd.Ft.	Cu.Ft.	Bd.Ft.	Hwd	Hem	WP
	2.28	1800		4100				100
	.84	550		460		100		
	1.07		24870		26620		7	93
	.33		1700		560	100		
	1.12		5982		6700	40		60
	8.08		4945		39960	91		9
	2.75		10000		27500	25		75
	2.50	275		685		100		
	1.54		4750		7315	17	53	30
	8.63		3900		33660	59	41	
	1.32		13150		17360	14	29	57
	2.09	275		575		100		
	2.39		3850		9200	58	42	
	2.46		2400		5905	100		
	.70	220	4000	155	2800	25	75	
	3.97		11956		47465	10	84	6
	1.14							
	20.61		3500		72135	100		
	1.51		10650		16080	15	85	
	.48		2000		960	100		
	11.83		48900		578485		3	97
	1.07		2000		2140	100		
	2.17		3915		8495	89	11	
	2.39		19450		46485	7	16	77
	3.16		12700		40130	15	28	57
	.73							
	1.80		2000		3600	100		
	2.64	180		475		31	69	
	14.14	450		6365		100		
	3.86		8800		33970	21	45	34
	.29							
	1.54	160		245		62	38	
	4.96		5400		26785	35	65	
	2.09		25570		53440	2	84	14
	2.02		2000		4040	100		
	1.51							
	1.65							
	6.80		11600		78880	14	86	
	1.76		4823		8490	79		21
	1.07		16840		18020	5		95
[illegible]	1.47							
Totals	134.76			13060	1217180			
			Error	-78.5%	+14.8%			
	Corrected for area			12851	1197705			
			Error	-78.9%	+13.0%			

tables used. In an effort to determine the major causes for the errors of volume estimation in this cruise, information has been assembled from the ground plots for ten of the forty stands that were mapped. The remaining thirty stands are small and do not contain sufficient plots to form a reliable average. Average per-acre volumes for hardwood, hemlock and white pine, as well as average height, density and number of merchantable trees per acre were computed for each of the ten stands from the ground plots that fell within that stand. These are shown in the first part of Table No. 5. Although some of the stands have only four or five plots and therefore the ground figures cannot be considered too accurate, nevertheless, the results should be helpful in indicating the major sources of error.

Following is a comparison of the errors in per-acre volume estimation for the ten selected stands with the errors in total volume estimation for the entire area.

	Hwd.	Hem.	W.P.	Total
Errors in Total Vol. Estimation, Entire Area	+37.0%	-27.6%	+36.4%	+13.0%
Errors in Per-acre Vol. Est., 10 Selected Stands	+52.9%	- 5.7%	+27.3%	+18.9%

It can be seen that the per-acre volume estimates for the ten selected stands follow the same trends of error as the total volume estimates for the entire area. An analysis of the volume errors for these ten stands, therefore, should reveal the major errors for the total volume estimates of the entire area. An analysis of these errors is made in the remaining portion of this section. In certain parts of this analysis only six of the ten stands are used but the same trends of error occur in these and so the comparison should be valid. (The estimate of total cubic-foot volume is 78% low when compared with that obtained from the ground cruise. However, since this ground cruise is only a 10.7% plot cruise, the result is considered only approximate and all further analysis of the aerial of Volumes, Heights, Densities and Number of Merchantable Trees Per Acre

Comparison of Per-acre Volumes for Ten Selected Stands

No. of Plots	Hardwood Volume		Hemlock Volume		White Pine Volume		Total Volume	
	Photo Est.	Plots	Photo Est.	Plots	Photo Est.	Plots	Photo Est.	Plots
5	--	--	--	--	5850*	1600	5850	1600
9	4500	860	--	2180	450	2060	4950	5100
8	2300	740	1600	6310	--	160	3900	7210
6	1200	880	10000	3080	750	4580	11950	8540
19	3500	1550	--	725	--	835	3500	3110
24	--	275	1400	305	47500	24320	48900	24900
5	1900	3115	3600	110	7200	9380	12700	12605
15	--	570	--	205	--	355	--	1130
4	1800	1855	4000	6110	3000	4675	8800	12640
8	1600	1140	10000	13425	--	2905	11600	17470
l	16800	10985	30600	32450	64750	50870	112150	94305
Diff.	+52.9%		-5.7%		+27.3%		+18.9%	

and was originally estimated in cubic feet but has here been converted to board feet by means of the original stand volume table so that it may be included in the comparison.

Comparison of Heights and Densities for Ten Selected Stands

No. of Plots	Height of Stand, Feet			Density of Stand, Percent		
	Photo Est.	Plots	Error	Photo Est.	Plots	Error
5	35	34	+1	90	86	+4
9	60	54	+6	85	64	+21
8	59	56	+3	60	65	-5
6	67	54	+13	85	75	+10
19	65	52	+13	80	65	+15
24	90	80	+10	90	64	+26
5	68	65	+3	75	65	+10
15	55	45	+10	45	43	+2
4	68	61	+7	70	58	+12
8	64	66	-2	85	79	+6
Total	631	567	68	765	664	111

Average Error, Feet 6.8
Average Error, Percent 12.0%
Aggregate Difference +11.1%

Average Error, Density % 11.1
Average Error, % of Av. Den. 16.7%
Aggregate Difference +15.2%

Comparison of Number of Merchantable Trees Per Acre For Ten Selected Stands

	Merch. Trees/A.		
	Photo Est.	Plots	Error
	90	42	+48
	45	61	-16
	90	102	-12
	80	32	+48
	70	99	-29
	65	82	-17
	0	16	-16
	60	88	-28
	70	112	-42
l	570	634	256

Average Error = 28 trees or 40%

Aggregate Difference = -10%

cruise will be confined to sawtimber volume).

Species Percentage Estimates--A completely reliable check on the accuracy of the species percentage estimates is difficult to obtain. In the original estimate a species percentage was expressed as the proportion of the area of that particular stand occupied by that species. No comparable ground data is available as a check and so a theoretical determination of species percentages was made as follows:

It was assumed that the area occupied by a species is proportional to the number of trees of that species times the square of the average crown diameter. (Average crown diameter as determined by mean squares.) The determination of species percentages by this method is shown in the first part of Table No. 6 for six stands. These six stands were selected because they contained the most ground plots; none less than eight. The visible crown diameter is that which was determined from the photographs since no such measurements were available from ground data. The crown diameters were again measured on the photographs to check the original estimates and revised in the case of the hardwoods in stands 29 and 38. The number of trees per acre, was obtained from the average of the plots within each stand. This number was multiplied by the square of the crown diameter and the result expressed as a percentage of the total figure for the stand.

A comparison of the original species percentage estimates with the theoretical percentages as thus determined is shown in the second part of Table No. 6. The results show that the estimation of hardwood percentages was correct (within3%) for only one of the six stands, and high for the other five. The average estimate for the six stands is twice the average as theoretically determined, a trend which tends to contribute to the overestimate of total hardwood volume.

rial Cruise No. 1. Table No. 6

parison of Species Percentages for Six Selected Stands

Determination of Species Percentages

Stand No.	Species	V.C.D.	No. of trees Per acre (n)	$nx(VCD)^2$	Spec. %
6	Hwd	16	14	3584	39
	Hem	12	19	2736	30
	WP	18	9	2916	31
	Total		42	9236	100
10	Hwd	16	11	2816	22
	Hem	14	49	9604	75
	WP	20	1	400	3
	Total		61	12820	100
18	Hwd	14	19	3724	61
	Hem	12	8	1152	18
	WP	16	5	1280	21
	Total		32	6156	100
21	Hwd	18	4	1296	3
	Hem	18	4	1296	3
	WP	22	91	44044	94
	Total		99	46636	100
29	Hwd	14	11	2156	72
	Hem	12	3	432	15
	WP	14	2	392	13
	Total		16	2980	100
38	Hwd	16	15	3840	19
	Hem	13	91	15379	74
	WP	16	6	1536	7
	Total		112	20755	100

Comparison of Estimated and Theoretically-Determined Species Percentages

Stand No.	Hwd. Percentage Est.	Hwd. Percentage Det.	Hem. Percentage Est.	Hem. Percentage Det.	W.P. Percentage Est.	W.P. Percentage Det.
6	99	39	0	30	1	31
10	80	22	20	75	0	3
18	100	61	0	18	0	21
21	0	3	5	3	95	94
29	100	66	0	18	0	16
38	40	13	60	79	0	8
Total	419	204	85	223	96	173
Average	70	34	14	37	16	29

Estimations of hemlock percentages were correct for one stand and low for the other five. The average of the estimates was only half thatof the theoretically determined average, a likely contribution to the over-all underestimate of hemlock volume.

White pine percentage estimates were correct for two of the stands and low for the other four. The average of the estimates was little more than half the theoretical average. This trend is contrary to the overestimation of total white pine volume and consequently, the error in white pine volume estimation must be elsewhere.

Height and Density Estimates--The average heights and densities were calculated from the ground plots for each of the ten stands having sufficient plots. These averages are compared with the estimated heights and densities in the second part of Table No. 5. The results of this comparison show that both heights and densities were overestimated for nearly every stand. The average error for heights is 6.8 feet, or 12% of the average height, while the aggregate difference is +11%. The average error for density estimates is 11% of crown closure, or 17% of the average density, while the aggregate difference is +15%. This trend of overestimation of heights and densities helps explain the overestimation of hardwood and white pine volumes but is contrary to the underestimation of hemlock volume.

Merchantable Trees Per-acre--In the third part of Table No. 5, the estimated number of merchantable trees per acre of all species is compared with the average determined from the ground plots for the ten selected stands. An overestimate occurred in two of the stands and an underestimate in the remaining eight. The average error was 28 trees per acre or 40%, while the aggregate difference was -10%. This general underestimation of trees per acre may be a factor in the underestimation of hemlock volume but is opposed to the overestimation of hardwood and white pine volumes. In all, it probably has little effect since most of the aerial volume tables used consisted of stand rather than individual tree tables.

Volume Table Checks--The final source of error to be considered is that inherent in the volume tables. Without accurate and detailed ground measurements of a number of trees it is difficult to obtain a precise check on aerial volume tables. However, by making some logical assumptions a comparison has been worked out that should at least indicate the trend of errors. Again the six stands having the greatest numbers of plots have been chosen for the comparisons. For these stands the following assumptions are made: Species percentages are those as previously determined on a theoretical basis. Heights, densities, and number of merchantable trees per acre for all species in a stand are those determined from the averages of the ground plots. Visible crown diameters are those determined from photo measurements.

In Table No. 7 the hardwood volumes for the six stands have been determined from five different aerial volume tables and compared with the volumes determined from the ground plots. The numbers of the volume tables correspond to those included and described in SECTION 1 -- INTRODUCTION of this report. It will be noted from the results of this comparison that only two of the five hardwood volume tables have an aggregate difference anywhere near zero and of these one has an extremely high average error. This leaves the other, Volume Table 2, as the best suited for hardwoods in this area. Since the volume estimations in Aerial Cruise No. 1 were made up of the averages of all available tables, it can be seen that errors due to volume tables would cause an underestimate of

Cruise No. 1

Table No. 7

Table Checks - Hardwood

Std #	Av. Ht.	Av. Den.	Merch Trees /A.	V.C.D.	Vol. Table No.	Per-acre Volume Table	Per-acre Volume Plots	Error	Agg. Diff.	Average Error
39	54	64	14	16	1	562	860	298		
					2	1000		140		
					3	693		167		
					4	622		238		
					5	770		90		
22	56	65	11	16	1	386	740	354		
					2	670		70		
					3	453		287		
					4	428		312		
					5	670		70		
61	52	65	19	14	1	733	1550	817		
					2	1095		455		
					3	747		803		
					4	753		797		
					5	665		885		
3	80	64	4	18	1	197	275	78		
					2	422		147		
					3	92		183		
					4	134		141		
					5	1230		955		
72	45	43	11	14	1	264	570	306		
					2	526		44		
					3	567		3		
					4	465		144		
					5	275		295		
19	66	79	15	16	1	782	1140	358		
					2	1367		227		
					3	475		665		
					4	623		714		
					5	1545		405		
		Total, Plot Volume					5135			
		Volume Table 1				2924		2211	-43.1%	43.1%
		Volume Table 2				5080		1083	- 1.1%	21.1%
		Volume Table 3				3027		2108	-41.1%	41.1%
		Volume Table 4				3025		2110	-41.1%	41.1%
		Volume Table 5				5155		2700	+ 0.6%	52.6%

1- Local stand volume table for all hardwoods based on total height alone.

2- Stand volume table for oak based on total height alone. U.S.F.S.

3- Stand volume table for hardwoods and mixedwoods based on crown diameter alone. U.S.F.S.

4- Stand volume alignment chart for hardwoods and spruce-fir, northern N.H., based on total height and crown diameter. U.S.F.S.

5- Individual tree, northern hwds, N.H., total height and crown diameter. U.S.F.S.

hardwood volume. Since the opposite is the case, other errors tending to cause an overestimate must have been more significant.

The first part of Table No. 8 shows the comparison of the two available white pine volume tables with the volumes determined from the ground plots. Although both tables give results that are high the indications are that the stand volume table (No. 6) is superior to the individual tree table (No. 7). An average of the two tables gives a result considerably high and is likely one of the factors contributing to the general overestimate of white pine volume.

Only one aerial volume table for use with hemlock was available and so the two white pine tables were also used. The second part of Table No. 8 shows the comparisons of these three tables with the hemlock volumes determined from the ground plots. Results indicate that the individual tree table for white pine gives slightly better results than the table for hemlock while the white pine stand table is considerably high. A confusing result is that when comparing the two white pine tables as used on white pine, the individual tree table is high, while a comparison of the same two tables as used on hemlock reveals that in this case the stand table is high. Because of this, and because two of the three tables used on hemlock are high and the third low, the effect of volume table errors on the hemlock volume estimate is considered inconclusive.

As a check to see how much improvement over the original volume estimates resulted from using the best known figures for species percentages, heights, densities, trees-per-acre, and crown diameters as applied to the best known volume tables, Table No. 9 was set up. In it the original volume estimates and the revised volume estimates using the best known figures and tables are compared with the volumes determined from the plots. Volume Table 2 was used for hardwood, Table 7 for hemlock and Table 6 for white pine. Results of this comparison show a

Cruise No. 1 | Table No. 8

Table Checks - White Pine and Hemlock

White Pine

WP %	Av. Ht.	Av. Den.	Merch Tr/A.	V.C.D.	Vol. Table	Per-acre Volume Table	Plots	Error	Agg. Diff.	Average Error
31	54	64	9	18	6	3445	2060	1385		
					7	1440		620		
3	56	65	1	20	6	360	160	200		
					7	192		32		
21	52	65	5	16	6	2230	835	1395		
					7	640		195		
94	80	64	91	22	6	24100	24320	220		
					7	36400		12080		
13	45	43	2	14	6	705	355	350		
					7	170		185		
7	66	79	6	16	6	1405	2905	1500		
					7	1140		1765		
		Total, Plot Volume					30635			
		Volume Table 6				32245		5050	+ 5.3%	16.5%
		Volume Table 7				39982		14877	+30.5%	48.6%

Hemlock

Hem %	Av. Ht.	Av. Den.	Merch Tr/A.	V.C.D.	Vol. Table	Per-acre Volume Table	Plots	Error	Agg. Diff.	Average Error
30	54	64	19	12	6	3335	2180	1155		
					7	1750		430		
					8	1520		660		
75	56	65	49	14	6	7640	6310	1330		
					7	6075		235		
					8	5590		720		
18	52	65	8	12	6	1910	725	1185		
					7	688		37		
					8	607		118		
3	80	64	4	18	6	768	305	463		
					7	1240		935		
					8	1295		990		
15	45	43	3	12	6	542	205	337		
					7	210		5		
					8	156		49		
74	66	79	91	13	6	14900	13425	1475		
					7	14900		1475		
					8	12000		1425		
		Total, Plot Volume					23150			
		Volume Table 6				29095		5945	+25.7%	25.7%
		Volume Table 7				24863		3117	+ 7.4%	13.5%
		Volume Table 8				21168		3962	- 8.6%	17.1%

6 - Local stand volume table for W.P. based on total height

7 - Local individual tree volume table for W.P. based on total height and crown dia.

8 - Individual tree table for spruce, fir and hemlock in N.H. based on total height and crown diameter.

al Cruise No. 1 Table No. 9

rison of Original and Revised Volume Estimates for Six Stands

Species	Plot Volume	Original Volume Estimate	Error	Vol. Table No.	Revised Volume Estimate	Error
Hwd	860	4500		2	1000	
Hem	2180	--		7	1750	
WP	2060	450		6	3445	
Total	5100	4950	150		6195	1095
Hwd	740	2300		2	670	
Hem	6310	1600		7	6075	
WP	160	--		6	360	
Total	7210	3900	3310		7105	105
Hwd	1550	3500		2	1095	
Hem	725	--		7	688	
WP	835	--		6	2230	
Total	3110	3500	390		4013	903
Hwd	275	--		2	422	
Hem	305	1400		7	1240	
WP	24320	47500		6	24100	
Total	24900	48900	24000		25762	862
Hwd	570	--		2	526	
Hem	205	--		7	210	
WP	355	--		6	705	
Total	1130	--	1130		1441	311
Hwd	1140	1600		2	1367	
Hem	13425	10000		7	14900	
WP	2905	--		6	1405	
Total	17470	11600	5870		17672	202
al	58920	72850	34850		62188	3478
gate Difference		+23.6%			+5.5%	
age Error			59.1%			5.9%

considerable improvement over the original estimate. The aggregate difference has been reduced from +23.6% to +5.5% while the average deviation has been reduced from 59% to 6%.

Summary of Error Trends--In order to see how the trends of the various types of errors compare with the errors of total volume estimation for the three species, the following table has been set up.

Error Trends for Factors Affecting Total Volume Estimate

Type of Error	Hardwood	Hemlock	White Pine
Species Percentage	High	Low	Low
Stand Heights	High	High	High
Stand Densities	High	High	High
Trees-per-acre	Low	Low	Low
Volume Tables	Low	?	High
Total Volume Estimate	High	Low	High

CONCLUSIONS

Errors Involved in This Cruise

Before considering the larger question of the value of an intensive use of large scale photographs, the particular error involved in this cruise will be considered.

The total hardwood volume estimate was 37% high. As can be seen from the preceding summary of error trends, the principal errors involved were an overestimate of species percentage, heights and densities, and an underestimate due to volume tables. (The underestimate of tree count is far less effective than the other factors, since it affects only one of five volume estimates.) Obviously, then, the three errors of overestimate more than counterbalanced the one of underestimate to produce a net overestimate. Apparently the greatest of the errors occurred in the estimation of species percentages. This seems logical since with the particular photographs involved, all trees appear at first glance to be hardwoods, and only with difficulty can the hemlocks and white pines be separated out. Furthermore, the habit of hemlock in growing as an understory causes an underestimate of hemlock percentage and a consequent further overestimate of hardwoods. Thus it seems natural that the overestimate in the percentage of hardwood should be one of the greatest errors. This is borne out by the fact that hardwood species percentage was overestimated by about 100%, densities by only 15% and heights by only 10%.

The total volume estimate for hemlock was about 28% low. Since the effect of the errors in heights and densities would tend to increase the volume, and since the effect of the volume tables is inconclusive, the principal error in the estimation of hemlock volume must have been that of species percentage. As the proportion of hemlock present was underestimated by more than 50%, this seems a reasonable explanation. Furthermore, it seems a natural one for reasons mentioned in the preceding paragraph--namely, the difficulty of distinguishing hemlock on these photos and the fact that much of it occurs as an understory and could not be seen in the aerial photographs.

White pine volume was overestimated by about 36%. Reference again to the summary of errors shows that this must be caused by a combination of overestimation of height and density with overrun of volume tables. The only important compensating error was an underestimate of species percentage and obviously this was insufficient to balance the overestimates. Somewhat more than half the pine volume of the entire area is included in one stand (No. 21) and since substantial overestimates of both height and density were made regarding this stand it is logically one of the chief contributing factors to the general overestimate of pine volume.

Value of Large Scale Photographs

It is unfortunate that the photos used in this cruise, while of an unusually large scale, were so deficient in other respects. A tremendous amount of time and effort was spent on the cruise of this small area and the cost, although not computed, would have been excessive. In spite of this, an error of 13% occurred in the total volume estimate while the errors for species components were more than double this figure. In view of these considerations it may be safely concluded that in this case such an intensive use of these particular large scale photographs without ground checking certainly did not pay.

However, after gaining experience with large scale photographs in this forest region, the writer feels that a much better job could now be done on extracting the correct information from the photographs. Furthermore, many improvements are possible in the photographs themselves and undoubtedly a better job could be done on photographs of the same scale taken earlier in the season, later in the day, and possibly on panchromatic film. The question then arises, "Given the best possible photographs of a large scale and an interpreter with experience in the region, could a satisfactory volume estimate be made from an intensive use of the photographs alone?" The answer requires some discussion.

First of all, what scale and type of photographs would be best suited to such an intensive cruise? At present there is insufficient experience in the use of aerial photographs in forestry to provide a conclusive answer to this question. Concerning scale, assuming that the larger the scale the more accurate the measurements of height and crown diameter, nevertheless, a point will be reached where such measurements will become more accurate than is warranted by the correlation between them and the actual volume of the trees. Furthermore, it is believed that the accuracy of density estimation will not continue to increase with extremely large scale photographs and may even fall off. Add to this the greatly increased cost of large scale photographs and the inconvenience of handling a large number of photographs for even a small area, and it becomes evident that simply to keep increasing the photo scale is no solution. It is the opinion of the writer that, all things considered, there would be little value in a photo scale larger than 1:5000.

As for the type of film, further experimentation is needed to answer the question. The modified infrared photographs used in this cruise were unsatisfactory chiefly because of the very long shadows and because being infrared, these shadows were completely opaque. It is possible that modified infrared photographs of a similar scale, taken when the shadows were shorter, would eliminate the objections and still produce the substantial tone differentiation between species inherent in infrared film. On the other hand, it is quite possible that even under these conditions the blackness of the shadows would be objectionable and that a sacrifice in species differentiation, typical of panchromatic film, would be preferable if some detail in the shadows could be produced.

Given, then, photographs of a scale of about 1:5000, say modified infrared, so taken that the shadows are not objectionable, how accurately could the necessary measurements be made? Assuming that the average trained interpreter can estimate parallax to the nearest .001-inch, his maximum error for the two readings necessary to measure a tree height would be .002-inch. At a scale of 1:5000, this would generally represent an error of about three feet and when this is applied to an average tree height of 60 feet it becomes about 5%. This may be considered the maximum error for an individual tree but an additional error is likely to be introduced when attempting to pick trees that represent the average of the stand, consequently, an average error of about 5% in height estimations may be considered likely.

Just how accurately the percent of crown closure may be estimated is a difficult question. The aggregate difference for this cruise was 15%. Certainly this figure can be improved upon but how much is unknown. It is the personal opinion of the writer that 5% would be considered excellent.

The results of volume table checks for this cruise show that the best of the hardwood tables was within 1%, the best of the white pine tables had an error of 5%, and for hemlock 8%. It seems reasonable that the best we can expect from aerial photo volume tables at the present time is about 5%.

There still remains the question of the determination of species percentages. How accurately this could be done on good photographs by an experienced interpreter cannot be stated, but it is certain that some error would result. Of course, the actual error in volume estimate would not be numerically the same as the error in species estimate because an error in the estimate of one species would necessarily be compensated by an opposite error in other species. Nevertheless, some error is bound to result.

It is possible, of course, that the various types of errors will compensate to produce a volume estimate nearly correct. But, on the other hand, assuming volume to be proportional to height and density, it is also possible to obtain errors of more than 15% with the assumptions of accuracy just made. It is the opinion of this writer that an intensive use of large scale photographs will generally result in volume errors of from 5% to 10%. This is partially confirmed by the results of Table No. 9, in which it was found that an error of about 6% occurred even when using the best known measurements and volume tables. In view of this, and of the extremely high costs involved, an intensive use of large scale photographs alone is not likely to be justified. It is felt that a less intensive use, probably of smaller scale photographs, coupled with some ground checking would produce a more accurate volume estimate for the same cost.

However, in view of the poor photographs used and the small size of the area treated, the results upon which these conclusions are based are by no means decisive and it is recommended that a further trial be given using a good set of large scale photographs.

SUMMARY

With the object of evaluating intensive use of large scale photographs for forest inventory and of determining the predominant errors involved, an aerial cruise was performed on an area of 133 acres. Photographs of a scale of 1:5300 were used as intensively as possible without regard to time or effort and a volume estimate made from the photographs alone. Later, the area was 100% cruised on the ground and the aerial volume estimate checked against this.

Chief errors of the aerial cruise were misestimation of the proportions of the various species in the stands, particularly an underestimation of the amount of hemlock, and overestimation of average heights and densities.

The total volume estimate for the area was 13% high, while that for hardwood alone was 37% high, hemlock 28% low and white pine

36% high. In view of the large amount of time and effort spent on this cruise such results are unsatisfactory, and it must be concluded that an intensive use of these photographs on this area was not practical. There are definite possibilities of improvement both in the quality of the photographs and in the accuracy of the interpretation but even if such improvements are assumed it is believed that an intensive use of large scale photos alone will not produce results as good as those of a less intensive cruise combined with some ground checking.

SECTION 4 -- AERIAL CRUISE NO. 2

A Moderately Intensive Use of Medium Scale Photographs to Construct a Type Map and Control the Collection of Ground Data

SECTION 4 — AERIAL CRUISE NO. 2

A Moderately Intensive Use of Medium Scale Photographs To Construct a Type Map and Control the Collection of Ground Data

INTRODUCTION

The purpose of this cruise is to provide data from a fairly intensive use of medium scale photographs for comparison with an extensive cruise using the same photographs, and with cruises using large scale photographs. The method adopted, while only moderately intensive when applied to a small unit such as the one treated in this report, may be considered quite intensive when applied to a large area. The method attempts to extract nearly the maximum amount of information from the given photographs while, at the same time, avoiding detail which would prove cumbersome when applied to a large area.

PHOTOGRAPHS

The photographs used were taken on September 13, 1945, or two and one-half years prior to their use in this cruise. The film was infrared with a minus blue filter, the scale about 1:18,700. An 8 1/4-inch lense was employed and the flying height was about 13,650 feet above sea level, or about 12,850 feet above the average elevation of the area. The photographs are of a good quality and detail stands out well. Hardwoods are easily separated from softwoods and it is possible to differentiate between hemlock and white pine in most cases. A stereogram from these photos is shown in Figure 1, page 6.

PROCEDURE

In brief, the process consists of dividing the area into a number of types based on composition, height, and density classes, using the photographs under the stereoscope. The photographs are then used to control the establishment of a series of ground plots from which the type volumes are computed. Two variations are employeed--in one the plots are distributed in proportion to area and in the other the plots are distributed in proportion to the timber values of the various types of estimated from the photographs.

Preliminary Work

After marking principal points and conjugate principal points on the photographs, a scale check was made. Distances were measured on the U.S.G.S. Topographic Quadrangle. The results were erratic and did not show the expected relationship of scale change with change of elevation due, it seems most likely, to tilt distortions in the photographs. An average scale, therefore, was determined at the average elevation of the points chosen for the check, and the scale at other elevations assumed from the relation between scale, focal length and flying height. In this project only three photographs are involved, but in a cruise involving a large number of photographs a scale check on a random selection of photographs should yield an average scale accurate enough to classify the forest stands into the types used in this cruise.

The parallax factor was determined for the highest and lowest elevations occurring on the area and for an elevation midway between these.

Base Map

A base map for this area was already available at a scale of

1:4800 and this map was used for all work. A check of the base map against the photographs in the multiscope shows some slight differences, particularly regarding the location of the river, but not enough to warrant remaking the base map.

Construction of Type Map

With careful study of the photographs it is possible to break down the forest area into a considerable number of types, based on species composition, height classes and density classes. For an area as small as the one treated here, however, such a breakdown would result in a large number of types each with only a small area. This would present a difficult sampling problem and so in designing this survey it was necessary to keep the number of forest types within reason even though in so doing the information on the photos was not utilized to the maximum.

For these reasons only three classes are recognized on the basis of composition: H - hardwood - 80% or more hardwoods; S - softwood - 80% or more softwoods; and M - Mixedwood - all other stands. Although it is possible to differentiate hemlock from white pine on these photographs, recognition of this breakdown would increase the number of possible types to the point of being cumbersome and so it was decided to combine the two species in the simple term "softwood".

Four height classes are recognized: (1) 0 to 30 feet; (2) 35 to 50 feet; (3) 55 to 70 feet; and (4) 75 feet or more. The actual limits of the height classes were estimated from the photographs so as to fall at the points believed least likely to occur.

Four crown density classes are recognized: A - 80% to 100%; B - 55% to 75%; C - 30% to 50%; and D - 0% to 25%. Crown closure appears somewhat difficult to estimate accurately on photographs at a scale of 1:18,000, and the recognition of more than four density classes would likely result in decreased accuracy as well as increased number of possible types. On the other hand, an initial trial with only three density classes resulted in practically all the stands in the area falling in one class and so the four classes were decided upon.

Type classes based on these criteria were delineated on the photographs. Due to the small size of the area treated it was necessary to drop the minimum size limit of the smallest type area to be recognized down to about one acre. On a larger area this limit could be increased somewhat without affecting the accuracy appreciably. Type lines were drawn in pencil on a sheet of frosted acetate laid over one photograph. Recognition of the simple types was easily and quite rapidly accomplished. Composition stood out plainly on the modified infrared photographs. The placing of the stands into one of the broad height classes was also easy for one acquainted with the general characteristics of the region—and photo-interpretation should not be attempted by anyone not at least partly familiar with the area. Many of the stands could be placed in a height class by estimation and only those on the border between classes required measurements. The parallax method was used to measure heights where this was felt necessary. Density classes were somewhat more difficult to distinguish. Most of the area was well stocked and on photographs of the scale used, appeared to be nearly 100% stocked at first glance. However, careful scrutiny and the use of a guide for estimating degree of stocking, such as is used by the Pacific Northwest Forest and Range Experiment Station, served to break the stands down into different density classes.

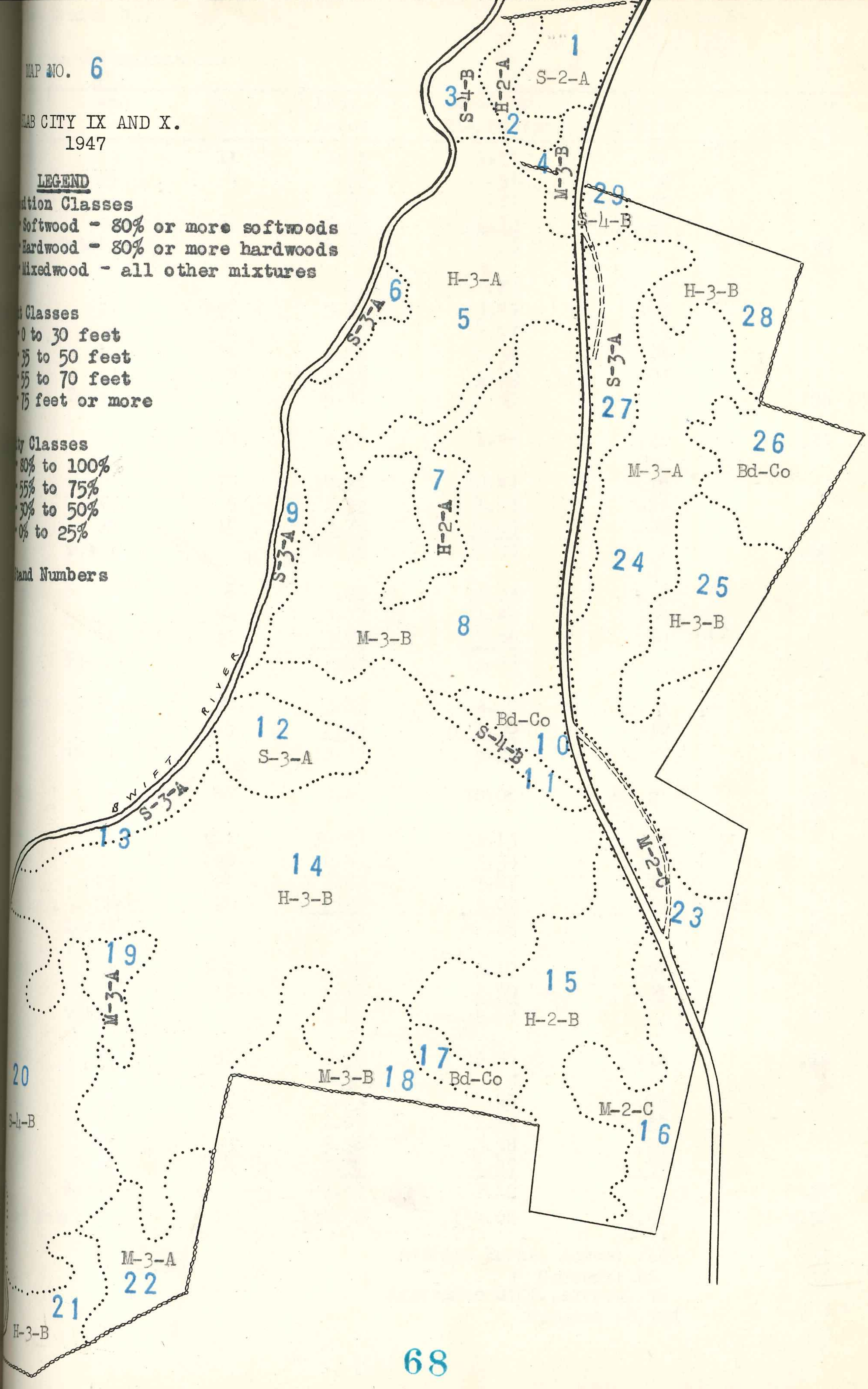
Type lines were transferred to the base map by means of an ordinary photographic enlarger, made possible by the fact that the types were drawn on acetate, and necessitated by the fact that the degree of enlargement required was more than six times--greater than that accomodated by any photogrammetric instruments available for this project. The type map thus made is shown in the accompanying Map No. 6 and is subject, of course, to all the distortions inherent in the one photograph over which the acetate was laid.

Estimation of Areas and Volumes

Areas of the types were estimated from the base map using a dot grid with 25 dots per square inch, each dot equaling .147 acres at the scale of the base map. As a matter of interest, the areas were also planimetered so that a comparison of time and accuracy could be made. The area computations by both methods are shown in Table No. 10.

For the purpose of computing average volumes per acre for the different types, a number of assumptions had to be made. Softwood stands were assumed to be composed on the average of 90% softwoods, 10% hardwoods; hardwood stands assumed to be 90% hardwoods and 10% softwoods; and the mixedwoods 50% of each. All trees in a type were assumed to be the height of the midpoint of that height class and the density of each type was assumed to be that of the midpoint of the density class. For example, the type M-3-B is assumed to be 50% softwoods, 50% hardwoods, 62.5% feet high and 65% stocked. The assumed heights and densities of each type are shown in the first part of Table No. 11.

Two empirical stand volume tables were used to determine the average per-acre volumes for the various types, one for softwoods and one for hardwoods. These were Volume Tables No. 1 and No. 6. Both


MAP NO. 6
LAB CITY IX AND X.
1947
LEGEND
ition Classes
Softwood - 80% or more softwoods
Hardwood - 80% or more hardwoods
Mixedwood - all other mixtures
Classes
0 to 30 feet
35 to 50 feet
55 to 70 feet
75 feet or more
ty Classes
80% to 100%
55% to 75%
30% to 50%
0% to 25%
Stand Numbers
SWIFT RIVER
1 S-2-A
2 H-2-A
3 S-4-B
4 M-3-B
29 S-4-B
5 H-3-A
6 S-3-A
28 H-3-B
27 S-3-A
26 Bd-Co
M-3-A
7 H-2-A
9 S-3-A
24
25 H-3-B
8 M-3-B
Bd-Co
10 S-4-B
11
12 S-3-A
13 S-3-A
14 H-3-B
M-2-C
23
19 M-3-A
15 H-2-B
17 Bd-Co
18 M-3-B
20 S-4-B
M-2-C 16
M-3-A 22
21 H-3-B

pe Area Determinations

pe	Stand No.	No. Dots	Area Acres	Area by Planimeter	Stand Error	Type Error
-B	3	11	1.62	1.21	.41	
	29	4	.59	.51	.08	
	11	7	1.03	.81	.22	
	20	82	12.00	11.72	.27	
	Total		15.24	14.25		.99
3-A	6	7	1.03	.88	.15	
	27	27	3.97	3.49	.48	
	9	6	.88	1.07	.19	
	12	16	2.35	2.31	.04	
	13	8	1.18	1.10	.08	
	Total		9.41	8.85		.56
2-A	1	14	2.06	1.95	.11	.11
3-A	24	70	10.28	10.47	.19	
	19	9	1.32	1.18	.14	
	22	19	2.79	2.83	.04	
	Total		14.39	14.48		.09
3-B	4	6	.88	1.03	.15	
	8	94	13.77	13.81	.04	
	18	21	3.09	3.09	.00	
	Total		17.74	17.93		.19
2-C	16	24	3.53	3.49	.04	
	23	15	2.20	2.50	.30	
	Total		5.73	5.99		.26
3-A	5	67	9.85	10.06	.21	.21
3-B	14	211	30.97	31.15	.18	
	21	20	2.94	3.34	.40	
	25	24	3.53	3.67	.14	
	28	20	2.94	3.09	.15	
	Total		40.38	41.25		.87
2-A	2	7	1.03	1.10	.07	
	7	19	2.79	2.50	.29	
	Total		3.82	3.60		.22
2-B	15	57	8.38	8.56	.18	.18
pen	17	7	1.03	.95	.08	
	10	7	1.03	1.32	.29	
	26	23	3.38	3.38	.00	
	Road	14	2.06	1.47	.59	
	Total		7.50	7.12		.38
and Total		915	134.50	134.04	5.51	4.06

Average Error, Acres: .18 .37
" " Percent: 4% 3%
Aggregate Diff.,Acres: +.46
Percent : 0.34%

liminary Volume Determinations

Volumes as Estimated from the Photographs

	Assumed Ht.	Assumed Den.	Per-acre Volumes Hwd	Per-acre Volumes Swd	Per-acre Volumes Total	Area	Tot. Type Volumes	Tot. Vol. %	(1)	(2)
-B	82.5	65	730	25400	26130	15.24	398221	33.1	19	19
-A	62.5	90	385	18500	18885	9.41	177707	14.8	9	8
-A	42.5	90	--	9100	9100	2.06	18746	1.5	5	5
-A	62.5	90	2500	13300	15800	14.39	227362	18.9	11	10
-B	62.5	65	1390	7400	8790	17.74	155935	13.0	8	10
-C	42.5	40	--	224	224	5.73	1284	0.1	5	5
-A	62.5	90	3360	2050	5410	9.85	53288	4.4	5	5
-B	62.5	65	2500	1480	3980	40.38	160712	13.4	8	8
-A	42.5	90	--	1000	1000	3.82	3820	0.3	5	5
-B	42.5	65	--	730	730	8.38	6117	0.5	5	5
						Total	1203192	100.0	80	80
						Error	+13.5%			
						Corr. for area	1186347			
						Error	+11.9%			

(1) Distribution of 80 plots based on volumes estimated from photos.
(2) Distribution of 80 plots vased on volumes from all ground plots.

Heights, Densities and Volumes of Types Based on All Available Plots

e	Gr. Est. Av. Ht.	Gr. Est. Av. Den.	No. of Gr. Plots	Av. Per-acre Tot. Vol.	Area by Planim.	Tot. Vol. by Types	Tot. Vol. %	(2)
-B	71	62	27	24448	14.25	348384	31.9	19
-A	61	75	13	17431	8.85	154264	14.1	8
-A	34	86	5	1600	1.95	3120	0.3	5
-A	61	72	15	12153	14.48	175975	16.1	10
-B	59	65	22	9764	17.93	175069	16.0	10
-C	46	30	5	3200	5.99	19168	1.8	5
-A	53	65	10	4860	10.06	48892	4.5	5
-B	52	65	41	3683	41.25	151924	13.8	8
-A	45	70	6	1367	3.60	4921	0.5	5
-B	44	38	13	1315	8.56	11256	1.0	5
al			157			1092973	100.0	80
					Error	+3.1%		
					Corr. for area	1081387		
					Error	+2.0%		

parison of Heights and Densities as Assumed from Photos and Estimated on Ground

e	Ht. Ass. from Photo	Av. Ht. Gd. Plots	Error	Den. Ass. from Photo	Av. Den. Gd. Plots	Error
-B	82.5	80	+ 2.5	65	62	+ 3
-A	62.5	61	+ 1.5	90	75	+ 15
-A	42.5	34	+ 8.5	90	86	+ 4
-A	62.5	61	+ 1.5	90	72	+ 18
-B	62.5	59	+ 3.5	65	65	0
-C	42.5	46	- 3.5	40	30	+ 10
-A	62.5	53	+ 9.5	90	65	+ 25
-B	62.5	52	+10.5	65	65	0
-A	42.5	45	- 2.5	90	70	+ 20
-B	42.5	44	- 1.5	65	38	+ 27
al	565.0	535	45.0	750	628	122
rage Error			4.5 ft.			12.2%
rage Error, %			8.4 %			19.4%
regate Difference, %			+5.6%			+19.4%

tables were derived from data pertaining to the area being treated and are based on total height alone. Computations for per-acre volume and total volume by types are also shown in Table No. 11. Board foot volumes only are shown since in making the ground check cruise it was possible to get a 100% tally of the sawtimber trees only. Sawtimber trees have been defined as those nine inches and up for softwoods and eleven inches and up for hardwoods. Data from this area show that hardwood trees below 60 feet in height average less than eleven inches d.b.h. and so no volumes are shown for hardwoods in height class 2.

Selection of Ground Plots

The number of ground plots established to determine the average volumes of the various types was arbitrarily selected as 80. This number was principally governed by the amount of time available for the taking of ground plots. The size of the ground plots is 1/10 acre. Although generally considered rather small for cruising purposes, it was necessitated by the limited time available and by the design of the ground cruise. These 80 tenth-acre plots constitute approximately 6% of the total area. Two methods were used to determine the distribution of these plots. In one case, the plots were distributed in proportion to the area of the various types. This is the kind of distribution which would presumably result from a straight mechanically-spaced plot cruise. In the second case, it was desired to spend more time on, and get a more accurate volume for, those types which were more valuable, and so the plots were distributed in proportion to the value of the various types. It so happens that in this area the sawtimber value of all species is very nearly the same. Consequently, value is proportional to volume and a distribution of plots by volume gives the desired result. Should value differences between species exist, as most generally would be the case, the plots would then be distributed in proportion to the value of the various types rather than the volume.

Since the 80 plots must be distributed among ten forest types, a proportional break down by either area or volume leaves some types with none or only a few plots. In order to obtain an average volume per acre for every type it was decided to establish a minimum of five plots in any one type. Consequently, all types rating less than five plots were given the minimum number of 5, and the remainder of the 80 plots were distributed in proportion to area, in the one case, or volume in the other. The differences in the two distributions of the 80 plots by the different methods are shown below:

ype	S-4-B	S-3-A	S-2-A	M-3-A	M-3-B	M-2-C	H-3-A	H-3-B	H-2-A	H-2-B	Tot.
ist. by Area	9	5	5	8	10	5	6	22	5	5	80
ist. by Vol.	19	9	5	11	8	5	5	8	5	5	80

Since the plots used in this cruise were taken in conjunction with the 100% ground survey, and were mechanically spaced, it remained only to select at random the desired number of plots from each type. In actually conducting a cruise of this kind the plots would likely be spaced along randomly selected cruise lines organized into units of work.

Computation of Volumes from Ground Plots

Per-acre volumes for each plot were determined for hemlock, white pine and for all hardwoods grouped together. Average per-acre volumes for each type were computed from the selected number of plots in that type. Table No. 12 shows the computations of these volumes and

Plots Distributed in Proportion to Volume

Type	No. Plots	Average Per-acre Volumes Hwd.	Hem.	W.P.	Tot.	Area Determined by Dot Count: Dot Count Area	Total Volumes by Type Hwd.	Hem.	W.P.	Tot.	Area Determined by Planimeter: Area by Planim.	Total Volumes by Type Hwd.	Hem.	W.P.	Tot.
S-4-B	19	540	292	21039	21871	15.24	8230	4450	320634	333314	14.25	7695	4161	299806	311662
S-3-A	9	1563	7888	6466	15917	9.41	14708	74226	60845	149779	8.85	13833	69809	57224	140866
S-2-A	5	--	--	1590	1590	2.06	--	--	3275	3275	1.95	--	--	3100	3100
M-3-A	11	1065	5857	4089	11011	14.39	15325	84282	58841	158448	14.48	15421	84809	59209	159439
M-3-B	8	1515	3549	6035	11099	17.74	26876	62959	107061	196896	17.93	27164	63634	108207	199005
M-2-C	5	1466	1554	300	3320	5.73	8400	8904	1719	19023	5.99	8781	9308	1797	19886
H-3-A	5	1762	1212	2840	5814	9.85	17356	11938	27974	57268	10.06	17726	12193	28570	58489
H-3-B	8	1015	2230	--	3245	40.38	40986	90047	--	131033	41.25	41869	91987	--	133856
H-2-A	5	92	2266	--	2358	3.82	351	8656	--	9007	3.60	331	8158	--	8489
H-2-B	5	682	72	994	1748	8.38	5715	603	8330	14648	8.56	5838	616	8509	14963
Open	0					7.50	--	--	--	--	7.12	--	--	--	--
Total	80					134.50	137947	346065	588679	1072691	134.04	138658	344675	566422	1049755
				Corrected for area		-	136019	341228	580450	1057697		137190	341025	560424	1038639
				Error, based on 100% cruise		-	-15.7%	-12.4%	+14.0%	-0.2%		-15.0%	-12.5%	+10.1%	-2.0%

Plots Distributed in Proportion to Area

Type	No. Plots	Average Per-acre Volumes Hwd.	Hem.	W.P.	Tot.	Area Determined by Dot Count: Dot Count Area	Total Volumes by Type Hwd.	Hem.	W.P.	Tot.	Area Determined by Planimeter: Area by Planim.	Total Volumes by Type Hwd.	Hem.	W.P.	Tot.
S-4-B	9	482	256	23470	24208	15.24	7346	3901	357683	368930	14.25	6868	3648	334448	344964
S-3-A	5	2508	4756	8498	15762	9.41	23600	44574	79966	148320	8.85	22196	42091	75207	139494
S-2-A	5	--	--	1590	1590	2.06	--	--	3275	3275	1.95	--	--	3100	3100
M-3-A	8	1023	7046	2836	10905	14.39	14721	101392	40810	156923	14.48	14813	102026	41065	157904
M-3-B	10	1301	5647	2383	9331	17.74	23080	100178	42274	165532	17.93	23327	101251	42727	167305
M-2-C	5	1466	1554	300	3320	5.73	8400	8904	1719	19023	5.99	8781	9308	1797	19886
H-3-A	6	872	567	1200	2639	9.85	8589	5585	11820	25994	10.06	8772	5704	12072	26548
H-3-B	22	1455	1243	1008	3706	40.38	58753	50192	40703	149648	41.25	60019	51274	41580	152873
H-2-A	5	92	2266	--	2358	3.82	351	8656	--	9007	3.60	331	8158	--	8489
H-2-B	5	682	72	994	1748	8.38	5715	603	8330	14648	8.56	5838	616	8509	14963
Open	0					7.50	--	--	--	--	7.12	--	--	--	--
	80					134.50	150555	324165	586580	1061300	134.04	150945	324076	560505	1035520
				Corrected for area		-	148447	319627	578368	1046442		149346	320644	554569	1024559
				Error, based on 100% cruise		-	-8.0%	-18.0%	+13.6%	-1.3%		-7.4%	-17.7%	+8.9%	-3.4%

of total volumes by type based on both the volume-distributed plots and the area-distributed plots. In each type of distribution the number of plots is the same (80), but the selection of the actual plots used was completely random for each method. It will be noted that the total volumes for each forest type have been computed twice; once using the type areas as determined from a dot count and once using type areas measured by planimeter.

In order to double-check results of the two methods of plot distribution the volumes were computed again, using a different set of ground plots. In this instance the selection of plots was arranged so that as many of the same plots were used for both types of cruise as possible. For example, Type S-4-A has 19 plots under the distribution-by-volume system and 9 plots under the distribution-by-area system. The 9 plots for the latter cruise were randomly selected from the 19 used in the former. The computations for this second trial are shown in Table No. 13.

RESULTS AND ANALYSIS

Construction of Type Map

The volume estimates made from the photographs alone were used solely to determine the distribution of the ground plots and for this purpose they were satisfactorily accurate, as will be shown later. Nevertheless, a number of errors were made in the type mapping and volume estimating from the photographs and it is of interest to examine these errors. It must be borne in mind that the errors discussed in the following paragraphs do not represent errors of the best work that could be done with the photographs. The species composition, height and density

Plots Distributed in Proportion to Volume

Type	No. Plots	Average Per-acre Volumes Hwd.	Hem.	W.P.	Tot.	Dot Count Area	Area Determined by Dot Count: Total Volumes by Type Hwd.	Hem.	W.P.	Tot.	Area by Planim.	Area Determined by Planimeter: Total Volumes by Type Hwd.	Hem.	W.P.	Tot.
S-4-B	19	217	983	24408	25608	15.24	3307	14981	371978	390266	14.25	3092	14008	347814	364914
S-3-A	9	1860	9443	5382	16685	9.41	17503	88859	50645	157007	8.85	16461	83571	47631	147663
S-2-A	5	—	—	1590	1590	2.06	—	—	3275	3275	1.95	—	—	3100	3100
M-3-A	11	932	6531	3695	11158	14.39	13411	93981	53171	160563	14.48	13495	94569	53504	161568
M-3-B	8	1084	6921	1569	9574	17.74	19230	122779	27834	169843	17.93	19436	124094	28132	171662
M-2-C	5	1394	1492	300	3186	5.73	7988	8549	1719	18256	5.99	8350	8937	1797	19084
H-3-A	5	782	1264	1376	3422	9.85	7703	12450	13554	33707	10.06	7867	12716	13843	34426
H-3-B	8	903	1630	802	3335	40.38	36463	65819	32385	134667	41.25	37249	67238	33082	137569
H-2-A	5	92	1482	—	1574	3.82	351	5661	—	6012	3.60	331	5335	—	5666
H-2-B	5	854	134	—	988	8.38	7157	1123	—	8280	8.56	7310	1147	—	8457
Open	0					7.50	—	—	—	—	7.12	—	—	—	—
Total	80					134.50	113113	414202	554561	1081876	134.04	113591	411615	528903	1054109
Corrected for area						-	111529	408403	546797	1066729		112388	407254	523300	1042942
Error, based on 100% cruise						-	-30.9%	+4.8%	+7.4%	+0.6%		-30.3%	+4.5%	+2.8%	-1.6%

75

Plots Distributed in Proportion to Area

Type	No. Plots	Average Per-acre Volumes Hwd.	Hem.	W.P.	Tot.	Dot Count Area	Area Determined by Dot Count: Total Volumes by Type Hwd.	Hem.	W.P.	Tot.	Area by Planim.	Area Determined by Planimeter: Total Volumes by Type Hwd.	Hem.	W.P.	Tot.
S-4-B	9	62	753	30658	31473	15.24	945	11476	467228	479649	14.25	884	10730	436876	448490
S-3-A	5	1856	11156	7624	20636	9.41	17465	104978	71742	194185	8.85	16426	98731	67472	182629
S-2-A	5	—	—	1590	1590	2.06	—	—	3275	3275	1.95	—	—	3100	3100
M-3-A	8	1023	7046	2836	10905	14.39	14721	101392	40810	156923	14.48	14813	102026	41065	157904
M-3-B	10	1646	5565	2727	9938	17.74	29200	98723	48377	176300	17.93	29513	99780	48895	178188
M-2-C	5	1394	1492	300	3186	5.73	7988	8549	1719	18256	5.99	8350	8937	1797	19084
H-3-A	6	1098	1100	1740	3938	9.85	10815	10835	17139	38789	10.06	11046	11066	17504	39616
H-3-B	22	1080	1164	775	3019	40.38	43610	47002	31295	121907	41.25	44550	48015	31969	124534
H-2-A	5	92	1482	—	1574	3.82	351	5661	—	6012	3.60	331	5335	—	5666
H-2-B	5	854	134	—	988	8.38	7157	1123	—	8280	8.56	7310	1147	—	8457
Open	0					7.50	—	—	—	—	7.12	—	—	—	—
Total	80					134.50	132252	389739	681585	1203576	134.04	133223	385767	648678	1167668
Corrected for area						-	130400	384283	672043	1186726		131811	381678	641802	1155291
Error, based on 100% cruise						-	-19.2%	-1.4%	+32.0%	+11.9%		-18.3%	-2.1%	+26.1%	+9.0%

of each stand was not actually estimated on the photographs but rather each stand was thrown into a type based on composition, height and density classes the limits of which hadalready been defined. Therefore, the resulting errors represent not only errors in photo-interpretation but also errors resulting from the fact, for example, that the average of all stands in a given height class is not likely to be the exact mid-point of that height class as was assumed in this cruise.

An examination of the data from the 100% ground cruise shows that 15% of the total volume is hardwood and 85% softwood, that is, hemlock and white pine. A similar check of the volumes as estimated from the photographs and shown in Table No. 11 indicates that of the total volume estimate of 1,203,192 board feet, 17% is hardwood, 83% softwood. For the area as a whole, therefore, the composition breakdown between hardwood and softwood is quite accurate.

A check of the hardwood-softwood volume breakdown of individual types as made from the photographs shows some large errors when compared with the average breakdown determined from all the ground plots falling in the same types. Following is a comparison of this breakdown by individual forest types.

	Est. fr. Phot.		Ave. of Plots	
Type	Hwd%	Swd%	Hwd%	Swd%
S-4-B	3	97	1	99
S-3-A	2	98	9	91
S-2-A	0	100	0	100
M-3-A	16	84	9	91
M-3-B	16	84	15	85
M-2-C	0	100	44	56
H-3-A	62	38	29	71
H-3-B	63	37	38	62
H-2-A	0	100	7	93
H-2-B	0	100	54	46
All	17	83	15	85

Five of the ten types are reasonably accurate but among the other five some serious errors occur. The worst being a complete reversal of the hardwood-softwood relationship in types H-3-A and H-3-B. However, other errors in individual types compensate so that for the area as a whole the hardwood-softwood relation is remarkably accurate.

Comparison of the assumed height for each type with the average height as estimated on the ground plots within that type show errors that are not too serious considering that the mid-points of the height classes were assumed and that the height of most stands was estimated rather than measured. At the bottom of Table No. 11 is a tabulation of these height comparisons showing errors ranging from 1.5 to 105 feet for individual types. The average error was 4.5 feet or 8.4% and the aggregate difference was +5.6% showing that, on the whole heights were over-estimated on the photos. None of the assumed heights for the individual types were far enough off to place that type in a different height class but two of the heights were about midway between the assumed height class and the next lower class.

A comparison of assumed type densities with the corresponding densities as estimated on the ground reveals errors of a greater magnitude, as is shown at the bottom of Table No. 11. Individual errors range from 0% to 27% while the average error is 12% of crown closure or 19.4% of the average crown closure. Since all density estimates from the photographs were high the aggregate difference is +19.4%. Five of the ten forest types should have been placed in the next lower density class. If this had been done the total volume estimated from the photographs would then have been about 0.3% low instead of 11.9% high as originally estimated.

The results of these checks indicate that the errors in setting up this group of forest types and classifying the stands of this area into these types were chiefly errors of density classification. The errors in type mapping can probably best be illustrated b y the following comparison of types as estimated on the photos and types as determined from the ground plots. The new classification of ground types is based on a study of ground estimated heights, densities, species compositions and volumes.

Photo Type	S-4-B	S-3-A	S-2-A	M-3-A	M-3-B	H-3-A	H-3-B	M-2-C	H-2-A	H-2-B
Ground Type	S-4-B	S-3-B	S-2-A	M-3-B		H-3-B		M-2-B		

Estimation of Type Areas

A comparison of the areas for each stand and for each type as between the dot count and planimeter methods is shown in Table No. 10. Assuming the planimetered areas to be correct the average error for the individual stands was .18 acres or 4% and the aggregate difference +.03%. For the individual types the average error was .37 acres or 3% and the aggregate difference, of course, the same as for the stands. An examination of the total volume estimates by both dot count areas and planimetered areas, as shown in Tables No. 12 and 13, reveals that in three cases out of four the volume estimates using dot-count areas were closer to the true volume than the estimates based on planimetered areas. The time required for the measurement of this small area was only slightly less for the dot grid method.

Estimation of Volumes from Photographs

The total volume estimate of 1,204,192 board feet is 13.5%

high, assuming the correct area of the tract to be unknown. However, after correction for area, as was done on the ground cruises, the error is only +11.9%. Since the exact volumes by types is not known, the estimated type volumes must be compared with the average volumes as determined from all the plots in each type. These average volumes are shown in the center section of Table No. 11. Since the computation of the total volume using these average type volumes is still 2% high after correction for area, each type volume has been reduced by 2% in order to get the best estimate of the actual per-acre volumes for each type. These figures are shown below and compared with the corresponding volumes as estimated from the photographs.

e	S-4-B	S-3-A	S-2-A	M-3-A	M-3-B	M-2-C	H-3-A	H-3-B	H-2-A	H-2-B
t Vol.	23960	17080	1570	11910	9570	3135	4760	3610	1340	1290
to Vol.	26130	18885	9100	15800	8790	224	5410	3980	1000	730
n, %	+9.1	+10.6	+480.0	+32.7	-8.2	-93.9	+13.7	+10.2	-25.4	-43.4

Although this comparison reveals some errors of extreme magnitude, the worst of the errors are in types of small total volume. The five types with the largest volumes, contain 92% of the total volume of the area and among these five types the average error is 13.6%. The greatest error, that in type S-2-A, is a result of two factors. This type is composed of only one stand with a height of 35 feet and it had to be placed in height class 2 with an assumed height of 42.5 feet. The greatest error in this type, however, seems to be caused by the empirical stand volume table used. Using a height of 34 feet and a density of 86%, the average of the ground plots, this table gives a value of 5210 board feet per acre, an error of 232% over the actual volume as determined from the ground plots. The remaining errors in other types appear to be a combination of errors in photo-interpretation, in volume tables, and in the grouping of stands into types with assumed average compositions, heights and densities.

In spite of the large errors in certain types, the over-all accuracy of the volumes as estimated from the photographs was sufficient to suit the purpose--namely to govern the distribution of a number of ground plots in proportion to volume. In table No. 11 is shown the various percentages of volume in each type as determined from the photos and as later determined from the ground plots. Based on these percentages of volume, 80 ground plots have been distributed among the various types, with a minimum of five in any one type. A comparison of the 80 plots as distributed in proportion to the photo-estimated volumes and 80 plots distributed in proportion to ground-determined volumes reveals the following: In seven of the ten types, no change in number of plots; in two types, a change of one plot; and in one type, a change of two plots.

Computation of Final Volume Estimates from Ground Plots

Volumes were computed using 80 plots distributed both by volume and by area and in each case the per-acre volumes were applied to areas determined both by dot count and by planimeter. These combinations provide four separate cruises and since each cruise was run through a second time using different plots a total of eight cruises resulted. A summary of the errors in total volume for the eight cruises follows.

	Areas by Dot Count		Areas by Planimeter	
	1st Cruise	2nd Cruise	1st Cruise	2nd Cruise
Plots distributed by Volume	-0.2%	+ 0.6%	-2.0%	-1.6%
Plots distributed by Area	-1.3%	+11.9%	-3.4%	+9.0%

It will be noted that in every case the cruises in which the plots were distributed by volume have a smaller error than those in which plots were distributed by area. Furthermore, in three cases out of four the volumes computed by the dot-cout areas were closer to the correct volume than those using planimetered areas.

Analyses of Variance

The actual errors of the various types of cruise have of course, a limited usefulness for the purposes of comparison, because of the strong effect of the element of chance present in only one trial. In order to overcome this deficiency and produce figures that could be more validly compared with the ground cruise results, several analyses of variance were made of the different types of cruise.

The first analysis made is shown in Table No. 14 and employs 164 plots which are all the plots available excepting four which fell partly in the open and partly in forest. The purpose of this analysis is to determine just how much reduction in variance was obtained by stratifying the plots from the photographs. All available plots were used rather than just 80 on the theory that the best estimate of the variance within each type is that based on the maximum number of plots in that type. The standard error of the mean for the 164 plots not stratified is 8.5%. When the plots are stratified into types by means of the photographs the standard error of the mean is reduced to 5.3%. These figures are based on the formula for an unlimited population and when that for a limited population is applied, the errors become 8.3% and 5.1% respectively.

A breakdown of the variance as between and within species composition classes, height classes and density classes reveals high l Cruise No. 2 Table No. 14

sis of Variance Based on 164 1/10-acre Ground Plots -- Variable-squared Method

Preliminary Computations

Volumes in Hundreds of Board Feet

	n	Sum	Sum-squares	C.T.	Corrected Sum-squares
	27	6601	1885259	1613822	271437
	13	2266	513618	394981	118637
	5	80	1462	1280	182
	15	1823	269679	221555	48124
	22	2148	282446	209723	72723
	5	160	9110	5120	3990
	10	486	48044	23620	24424
	41	1510	119598	55612	63986
	6	82	3274	1121	2153
	13	171	4379	2249	2130
	7	87	4637	1081	3556
	164	15414	3141506	1448728	1692778

$m = \frac{15414}{164} = 93.99$

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m 100 b.f.	SE_m %
Total	163	1692778	10385	101.91	7.96	8.5
Between Classes	10	1081436	108144			
Within Classes	153	611342	3996	63.21	4.94	5.3%

(based on limited population) Total - 8.3% Within Classes - 5.1%

Test of Statistical Significance Between Mean Type Volumes

	27	13	5	15	22	5	10	41	6	13
Type	S-4-B	S-3-A	S-2-A	M-3-A	M-3-B	M-2-C	H-3-A	H-3-B	H-2-A	H-2-B
S-3-A	h.s.									
	s.									
S-2-A	h.s.	h.s.	-							
	h.s.	h.s.	-							
M-3-A	h.s.	s.	h.s.	-						
	h.s.	0	h.s.	-						
M-3-B	h.s.	h.s.	s.	0	-					
	h.s.	s.	h.s.	0	-					
M-2-C	h.s.	h.s.	0	s.	s.	-				
	h.s.	h.s.	0	h.s.	h.s.	-				
H-3-A	h.s.	h.s.	0	h.s.	s.	0	-			
	h.s.	h.s.	0	h.s.	h.s.	0	-			
H-3-B	h.s.	h.s.	0	h.s.	h.s.	0	0	-		
	h.s.	h.s.	h.s.	h.s.	h.s.	0	0	-		
H-2-A	h.s.	h.s.	0	h.s.	h.s.	0	0	0	-	
	h.s.	h.s.	0	h.s.	h.s.	0	0	s.	-	
H-2-B	h.s.	h.s.	0	h.s.	h.s.	0	0	0	0	-
	h.s.	h.s.	0	h.s.	h.s.	0	s.	h.s.	0	-
Open	h.s.	h.s.	0	h.s.	h.s.	0	0	0	0	0
	h.s.	h.s.	0	h.s.	h.s.	0	0	s.	0	0

h.s. - highly significant s. - significant 0 - nonsignificant

Upper figures based on average variance for all plots of 3996.

Lower figures based on variances of indivi dual types.

significance for the composition and height classes, and nonsignificance in the case of density classes. This further bears out the previous findings that the greatest errors in photo-interpretation were made in the estimation of densities.

In order to determine whether the mean volume of each type differed significantly from the mean of every other type, the "t" test for statistical significance was employed. The second part of Table No. 14 shows the results of this test using both the over-all variance of all the plots and the individual variances of the types. In most cases there is agreement between the significances as computed by the two methods. It will be noted that the chief occurrence of nonsignificance is among the types with the lowest volumes and particularly between types differing only by density class, an additional confirmation of the poor quality of the density estimates.

Not all indications of nonsignificance are valid, of course, for certain of the comparisons have only a few degrees of freedom, and nonsignificance indicates only that significance has not been proved. Lack of sufficient plots may be the reason in some cases. Furthermore, lack of significance between the mean volumes of two types does not always mean that they should not be separated because difference is species composition alone may be sufficient reason. However, by comparing the actual heights, densities, mean volumes and species compositions of the types originally separated, it becomes apparent that certain of them are sufficiently alike to be combined. In the following table the types that appear to be sufficiently homogeneous to be combined are shown along with the new type designation.

Original Type Classifications	New Type
M-3-A, M-3-B	M-3-B
H-3-A, H-3-B	H-3-B
H-2-A, H-2-B, M-2-C	M-2-B

Analysis of Variance Based on 164 Plots Using Simplified Types

Type	n	Sum	Sum-squares	C.T.	Corrected Sum-squares	D.F.	Mean Square	σ	Mean	SE_m 100 b.f.	SE_m %
S-4-B	17	6601	1885259	1613822	271437	26	10440	102.18	244.48	19.66	8.0
S-3-A	13	2266	513618	394981	118637	12	9886	99.43	174.31	27.57	15.8
S-2-A	5	80	1462	1280	182	4	46	6.78	16.00	3.03	18.9
M-3-B	37	3971	552125	426185	125940	36	3498	59.14	107.32	9.73	9.1
M-2-B	24	413	16763	7107	23870	23	1038	32.22	17.21	6.58	38.2
H-3-B	51	1996	167642	78118	89524	50	1790	42.31	39.14	5.92	15.1
Open	7	87	4637	1081	3556	6	593	24.35	12.43	9.20	74.0
Total	164	15414	3141506	1448728	1692778	163	10385	101.91	93.99	7.96	8.5

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m 100 b.f.	SE_m %
Total	163	1692778	10385	101.91	7.96	8.5
Between Classes	6	1059632				
Within Classes	157	633146	4033	63.51	4.96	5.3

By combining these as shown above, the total number of types is reduced from eleven to seven. In order to determine what effect this change had on the standard error of the mean an analysis of variance was performed, based on the new types and is shown in Table No. 15. The SE_m for the total remains the same, of course, and that for the variance within classes also comes out exactly the same as the analysis based on the original types, that is, 5.3% for an unlimited population. The reduction in plot variance by stratification into the seven types is the same, therefore, as the reduction caused by stratification into the original eleven types and it is obvious that in the original cruise it was unnecessary to distinguish so many types.

In addition to the analyses based on 164 plots, another analysis was made based on the 80 plots selected in the second set of cruises in order to determine the standard errors of the means for the two different types of plot distribution, as applied to the original eleven types. The standard error for the plots as distributed by volume was 6.5% and for the plots distributed by area, 5.8%. It was felt that this result was not logical and probably due to the particular plots selected for the area-distributed cruise having less variation than those selected for the volume-distributed cruise. In order to check this the standard errors of the means of the individual types were determined for both cruise systems and are shown in Table No. 16. A glace at the table shows that in every case except where the plot numbers are equal, the standard deviations of the types in the volume-distributed cruise are higher than those of the corresponding types in the area-distributed cruise. This relation is not logical, for the standard deviation of any one type should remain approximately constant regardless of the number of plots. The difference, then, must be due to

Analysis of Variance Based on 80 Plots Used in 2nd Case (Volumes in hundred board feet).

Plots Distributed by Volume
(All volumes in hundreds of board feet)

Type	N	Sum	Sum-squares	C.T.	Corrected Sum-squares	D.F. (n-1)	Mean-Square	Mean	σ	SEm 100 b.f.	SEm %
S-4-B	19	4866	1408364	1246208	162156	18	9009	256.11	94.92	21.77	8.5%
S-3-A	9	1501	312501	250333	62168	8	7771	166.78	88.15	29.38	17.6%
S-2-A	5	80	1462	1280	182	4	46	16.00	6.78	3.03	18.9%
M-3-A	11	1227	177225	136866	40359	10	4036	111.55	63.53	19.14	17.2%
M-3-B	8	766	90032	73344	16688	7	2384	95.75	48.83	17.25	18.0%
M-2-C	5	160	9110	5120	3990	4	998	32.00	31.59	14.10	44.1%
H-3-A	5	171	10605	5848	4757	4	1189	34.20	34.48	15.39	45.0%
H-3-B	8	266	22108	8844	13264	7	1895	33.25	43.53	15.38	46.3%
H-2-A	5	79	3265	1248	2017	4	504	15.80	22.45	10.02	63.4%
H-2-B	5	50	668	500	168	4	42	10.00	6.48	2.89	28.9%
Total	80	9166	2035340	1050194	985146	79	12470	114.58	111.67	12.49	10.9%

Plots Distributed by Area

Type	N	Sum	Sum-squares	C.T.	Corrected Sum-squares	D.F. (n-1)	Mean-Square	Mean	σ	SEm 100 b.f.	SEm %
S-4-B	9	2834	923322	892395	30927	8	3866	314.89	62.18	20.73	6.6%
S-3-A	5	1032	253944	213004	40940	4	1024	206.40	32.00	14.29	6.9%
S-2-A	5	80	1462	1280	182	4	46	16.00	6.78	3.03	18.9%
M-3-A	8	872	118124	95048	23076	7	3297	109.00	57.42	20.29	18.6%
M-3-B	10	994	116672	98804	17868	9	1985	99.40	44.55	14.10	14.2%
M-2-C	5	160	9110	5120	3990	4	998	32.00	31.59	14.10	44.1%
H-3-A	6	236	14830	9283	5550	5	1110	39.33	33.32	13.60	34.6%
H-3-B	22	663	40807	19980	20827	21	992	30.14	31.50	6.72	22.3%
H-2-A	5	79	3265	1248	2017	4	504	15.80	22.45	10.02	63.4%
H-2-B	5	50	668	500	168	4	42	10.00	6.48	2.89	28.9%
Total	80	7000	1482204	612500	869704	79	11009	87.50	104.92	11.74	13.4%

the chance selection of plots with less variance in one case than in the other. That this is true is illustrated in the following example: For type S-4-B, the S.D. of the 19 plots selected in the volume-distributed cruise is 94.92. In the area-distributed cruise the 9 plots for type S-4-B were selected from these same 19 and yet their S.D. is 62.18. When a different 9 plots are selected from the original 19, the S.D. becomes 94.60, showing that the original group of 9 plots had a variance lower than average.

In order to avoid this sort of discrepancy caused by chance selection of plots, the standard deviation for each type was determined from all the plots falling in that type. This S.D. was then usedto calculate the corrected sum-squares for the two types of 80-plot distributions and the standard errors of the means were worked out as shown in Table No. 17. The SE_m for the volume-distributed cruise now becomes 6.9% and for the area-distributed cruise, 7.9% based on the theoretical means of these two cruises. These means were calculated from the 80-plot distributions using for the mean of each plot that which was determined from all the plots in each type. After correcting the SE_m for a limited population, they become 6.6% for the volume-distributed cruise and 7.7% for the area-distributed cruise.

In addition to the SE_m for each cruise as a whole, the SE_m for each type was recalculated based on the standard deviation as determined from all plots in that type. These, too, are shown in Table No. 17. In comparing the SE_m for each type as determined for the two cruise systems, it will be noted that four of the types have the same number of plots under each system, hence have the same SE_m. Of the remaining six types, for the three which have the highest volumes the SE_m is lower in the volume-distributed cruise; for the other three types,

Theoretical Analysis of Variance of the Two Distributions of 80 Plots Using Standard Deviations Determined from 157 Plots
(Volumes in hundred board feet)

Theoretical Values for Individual Types

	Data from 157 Plots				80 Plots Distributed by Volume					80 Plots Distributed by Area				
Type	n	Mean	Mean-square	σ	n	D.F.	SE_m 100 b.f.	SE_m %	Corrected Sum-squares	n	D.F.	SE_m 100 b.f.	SE_m %	Corrected Sum-squares
S-4-B	27	244.48	10440	102.18	19	18	23.44	9.6	187920	9	8	34.06	13.9	83520
S-3-A	13	174.31	9886	99.43	9	8	33.14	19.0	79088	5	4	44.39	44.6	39544
S-2-A	5	16.00	46	6.78	5	4	3.03	18.9	184	5	4	3.03	18.9	184
M-3-A	15	121.53	3437	58.63	11	10	17.66	14.5	34370	8	7	20.72	17.1	24059
M-3-B	22	97.64	3463	58.85	8	7	20.80	21.3	24241	10	9	18.62	19.1	31167
M-2-C	5	32.00	998	31.59	5	4	14.10	44.1	3992	5	4	14.10	44.1	3992
H-3-A	10	48.60	2714	52.10	5	4	23.26	47.9	10856	6	5	21.26	43.7	13570
H-3-B	41	36.83	1600	40.00	8	7	14.13	38.4	11200	22	21	8.53	23.2	33600
H-2-A	6	13.67	431	20.76	5	4	9.27	67.8	1724	5	4	9.27	67.8	1724
H-2-B	13	13.15	178	13.34	5	4	5.96	45.3	712	5	4	5.96	45.3	712
	157	97.62	10517	102.55	80	79	11.47	11.7	830843	80	79	11.47	11.7	830843

Theoretical Values of SE_m for the Two 80-plot Cruises

80 Plots Distributed by Volume

Theoretical mean = 115.30

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m
Total	79	830843	10517	102.55	9.9%
Between classes	9	476556			
Within classes	70	354287	5061	71.14	6.9%

SE_m (corrected for limited population) = 6.6%

80 Plots Distributed by Area

Theoretical mean = 81.21

Source	D.F.	Corrected Sum-Squares	Mean Square	σ	SE_m
Total	79	830843	10517	102.55	14.1%
Between classes	9	598771			
Within classes	70	232072	3315	57.58	7.9%

SE_m (corrected for limited population) = 7.7%

which have lower volumes, the SE_m is lower in the area-distributed cruise. To state it in another way, when comparing the SE_m of the six types that differ under the two systems of plot distribution, it will be found that the three which have lower errors under the volume-distributed system have 62.1% of the volume while the three types which have higher errors contain only 34.3% of the total volume.

COSTS

In estimating the costs of a cruise of this type a number of assumptions must be made, particularly regarding the cost of photographs. Again, as in the case of the ground cruises, it must be borne in mind that costs vary with a large number of factors and that costs as estimated here do not necessarily reflect costs of a similar cruise elsewhere under different conditions. Costs are estimated for the purpose of comparing different cruises under the same conditions and since similar assumptions are made for all cruises it is felt that such a comparison is valid.

The cost of obtaining aerial photographs is the most variable cost involved, particularly for such a small area as this. Even on large areas there is a wide variation in costs as estimated by different companies and by the same company at different times. Cost varies with such things as weather, distance from air base to the area and the amount of idle equipment available. The cost of photographing areas of only a few hundred acres as a separate job would be prohibitive and the only feasible plan would be that of having the area flown in conjunction with some larger area nearby or by some survey company that could catch it while passing from one job to another. Under these conditions, then, it is felt that a cost of about 10¢ an acre would be a reasonable assumption. Other assumptions regarding salary and mileage are the same as for the ground cruise. Following are the cost estimations for the two 80-plot cruises.

Plots Distributed in Proportion to Volume

Item	Man-hours @ $1.385	Cost	Cost per-acre	
1. Photographs			10.00	¢
2. Design and plan cruise	2	$ 2.77	2.09	
3. Preliminary photo work	3/4	1.04	.78	
4. Delineate types and transfer to base map	1¼	1.73	1.30	
5. Preliminary volume estimate	2½	3.46	2.61	
6. Plan field work	1	1.38	1.04	
7. Field work	32	44.32	33.42	
8. Computations	4	5.54	4.18	
9. Correct and complete type map	2	2.77	2.09	
10. Travel Time	1	1.39	2.05	
11. Mileage	24 miles @ .05	1.20	.90	
		Total	59.46	
		10% overhead	5.95	
		Total	65.41	¢

Plots Distributed in Proportion to Area

Items — 1, 2, 3, 4, 6, 7, 8, 9, 10 and 11 as above		56.85	
	10% overhead	5.68	
	Total	62.53	¢

The cost of these two cruises is very nearly the same while the accuracy of the one employing volume-distributed plots is somewhat better. The cost of the cruise employing 80 plots distributed in proportion to type volumes is slightly less, and the accuracy somewhat better, than that of the 20% strip cruise, which was the best of the ground cruises.

CRUISE OF A TOWNSHIP

The expansion of this cruise to the area of a township is shown in SECTION 7, where the required number of plots and estimated costs are compared with those of other cruises.

CONCLUSIONS

The results of this cruise have definitely shown the advantages accruing from the stratification of ground plots by the use of aerial photographs. Even though a number of errors were made in the original delineation of types on the photographs, still the SE_m of the unstratified plots was reduced from 8.3% to 5.1%. This results in a substantial reduction in the number of plots required for a given standard of accuracy. For example: If an accuracy of 5% two times out of three is desired the required number of plots when not stratified is 470, while the required number when stratified by the photos is only 181, or 38.5%.

The distribution of ground plots in proportion to volumes determined from the photos resulted in appreciably more accurate volume estimates than the distribution of ground plots in proportion to areas. Not only were the actual total volume estimates of the two trial cruises closer but the standard error of the mean was also lower. In addition, the lower standard errors occured in the highest volume types with the volume-distributed plots, while the reverse is true in the case of the area-distributed plots. Therefore, it may safely be concluded that a distribution of plots in proportion to estimated type volumes will produce a more accurate cruise than a distribution of plots in proportion to type areas. Such would also be true if the plots were distributed in proportion to actual value rather than volume. A further refinement in the distribution of ground plots would includethe estimation of expected standard deviations of each type and, as will be pointed out in Aerial Cruise No. 4, there seems to be definite promise that this can be estimated from the photographs with reasonable accuracy.

Certain conclusions regarding procedure and the most common errors may be inferred from the results of this study. Generalizations are difficult to make since the errors made here are in a large part perconal errors of the interpreter and may not necessarily occur with other interpreters. Nevertheless, it should be worth while to point them out so that they can be assembled with similar results from other tests and generalizations may then be drawn.

Chief errors made in the photo-interpretation were in the estimation of species composition and density. It seems likely that estimations of species composition will often be one of the most difficult problems of photo-interpretation. Certain species differentiations do not show up on the aerial photos, particularly in the case of stemwise mixtures. Furthermore, any species growing as an understory will necessarily be underestimated on any vertical photographs. For these reasons, accurate species composition information will nearly always have to be obtained from ground data. Fortunately, moderate errors in aerial estimation of species composition generally will not result in very large errors of total volume estimation.

Regarding the errors in estimation of crown closure or density from aerial photographs, it seems likely that this is also fairly common. It occurred in nearly all aerial cruises made in this study and similar results have been obtained by two other students at Harvard Forest experimenting with the use of aerial photographs in forestry. It is apparent that further work need be done on methods of estimating forest density from aerial photographs. Perhaps the use of a set of stereograms showing stands of known density would provide the best method.

In the execution of these cruises a tendency has been evidenced to break down the stands into more types than actually necessary. Whether this tendency is widespread among other interpreters is not known.

In spite of these errors and the rather rough methods of classifying types, it is evident from this study that total volume estimations from the photographs were sufficiently accurate to control the location of the ground plots. It may be concluded, therefore, that the photographs were used with sufficient intensity for the purpose and any further improvements in the accuracy of the photo-interpretation should serve to reduce the intensity with which the photographs need be used.

Results of this study indicate that the dot grid method of area estimation is just as satisfactory as the use of a planimeter, and over a large area should result in a substantial savings of time.

SUMMARY

For the purpose of evaluating a moderately intensive use of medium scale photographs an aerial timber cruise was made on a 133-acre area. The area was classified into rough types based on species composition, height and density classes by stereoscopic examination of 1:18,000 modified infrared photographs. Volumes for the types were estimated and 80 1/10-acre ground plots were distributed within the area in proportion to these estimated volumes. In another variation of this cruise 80 plots were distributed in proportion to the areas of the forest types. Final volume estimates were based on the data from these ground plots. The area was then 100% cruised and volume comparisons made.

Results indicate that the control of ground plots by aerial volume estimations produces more accurate results than the control of ground plots by type areas. Accurate volume estimates were obtained by this method, the error in total volume being less than 1% in one trial and less than 2% in a second trial. A substantial reduction in the standard error of the mean occurred as a result of stratifying the ground plots by means of the photographs, the figures for this being 8.3% when not stratified and 5.1% when stratified.

Certain errors in photo-interpretation were made, particularly in the estimation of species composition and stand density, but in spite of these the aerial volume estimations were sufficiently accurate to correctly distribute the ground plots in proportion to the actual volumes of the various types.

In spite of the high cost of aerial photographs for such a small area this cruise design resulted in a much better volume estimate at a slightly lower cost than the best of the ground cruises, the 20% strip.

SECTION 5 -- AERIAL CRUISE NO. 3

A Moderately Intensive Use of Large Scale Photographs to Construct a Type Map and Control the Collection of Ground Data

SECTION 5 — AERIAL CRUISE NO. 3

A Moderately Intensive Use of Large Scale Photographs to Construct a Type Map and Control the Collection of Ground Data

INTRODUCTION

A cruise has already been made involving a very intensive use of large scale photographs with no ground work (Aerial Cruise No. 1). The purpose of this cruise is to test a less intensive use of the same photographs for comparison with the more intensive cruise and with other cruises involving medium scale photographs. This cruise will not utilize all the information available on large scale photographs, as was done in Cruise No. 1.

PHOTOGRAPHS

The photographs used are the same 1:5300 modified infrared that were used in Aerial Cruise No. 1. A description of these photographs will be found in SECTION 3, and an example of them will be found in the stereogram of Figure 2, page 27.

PROCEDURE

The procedure is similar to that employed in Aerial Cruise No. 2, namely, stereoscopic examination of the photographs is used to divide the area into a number of stands based on fairly broad species composition, height, and density classes. Volumes are estimated for these types and then ground plots are distributed in proportion to these volumes. Final volume estimations are then based on the data from these ground plots.

Preliminary Work

Since only four photographs are involved and since most of the work done on them will be in the nature of estimates with only occasional check measurements, it was unnecessary to construct a series of graphs as was done in Aerial Cruise No1. The preliminary work, therefore, consisted merely of locating principle and conjugate principle points and computing scales and parallax factors for several elevations.

Base Map

The same base map at 1:4800 which has been used for previous cruises is used in this cruise.

Type Map

The limitations of the photographs regarding species differentiations have already been explained. In an effort to eliminate the shortcomings and produce the effect that might be expected from good quality large scale modified infrared photographs the following procedure was followed: Type lines based on species composition alone without regard to height or density were first drawn on a set of 1:12,000 modified infrared photographs upon which the species differentiations stood out more clearly. These type lines were then transferred directly to the 1:5300 photographs by means of the multiscope. The latter photos were then studied under the stereoscope and the composition types further broken down by height and density classes.

Three species composition classes were recognized: S - softwood - 80% or more softwoods; H - hardwood - 80% or more hardwoods; M - mixedwood - all other mixtures.

Four height classes were recognized: (1) 0 to 30 feet; (2) 35 to 50 feet; (3) 55 to 70 feet; and (4) 75 feet and more.

Four density classes were established: A - 80% to 100%; B - 55% to 75%; C - 30% to 50%; and D - 0 % to 25%. These composition, height and density classes are the same as were set up in Aerial Cruise No. 2.

The type lines were transferred from the 1:5300 photographs to the base map by means of the vertical sketchmaster and the resulting stand map is shown as Map No. 7.

Estimation of Areas and Volumes

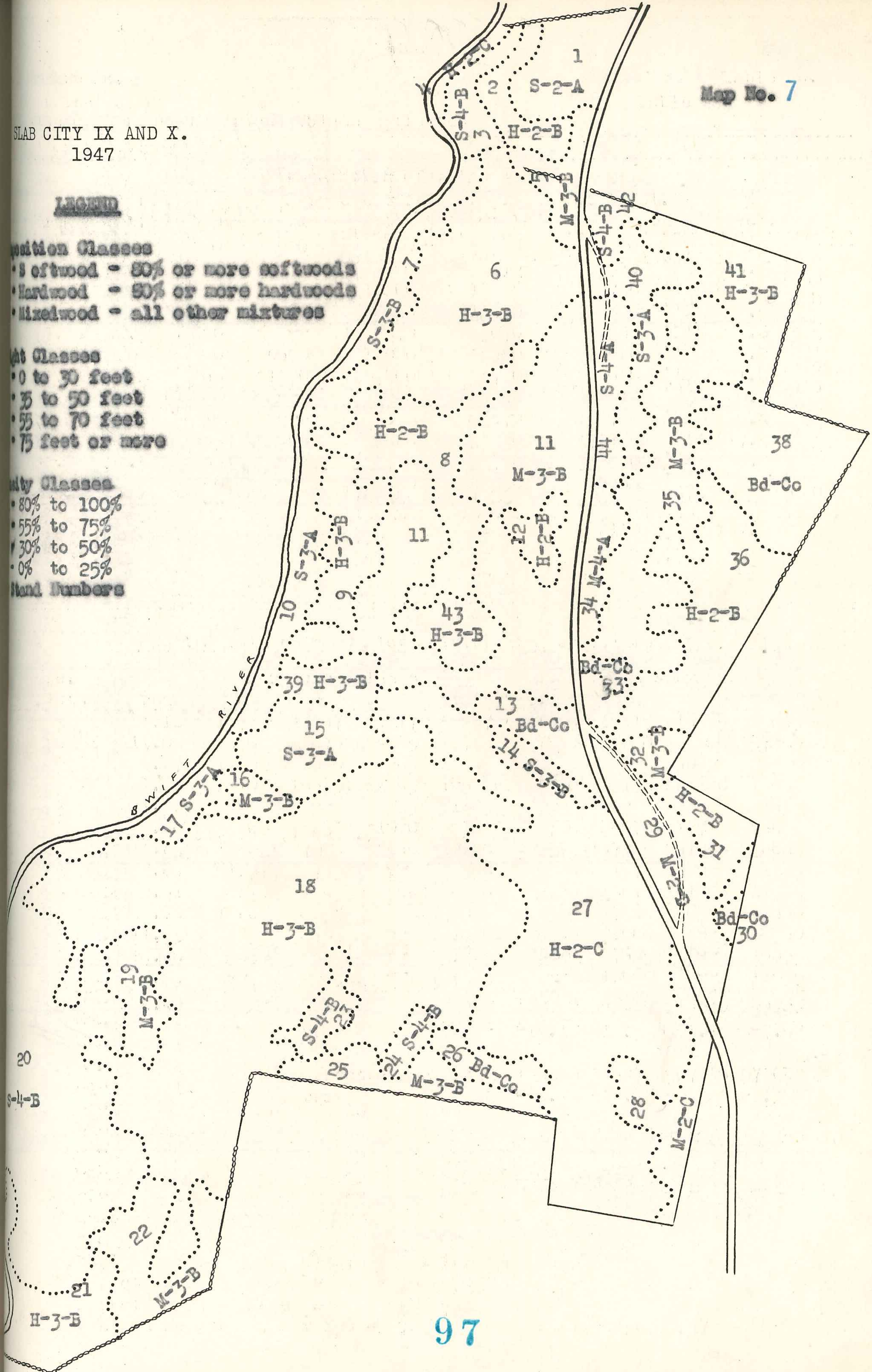
Areas of the various stands were measured by planimeter and totaled by types as shown in the first four columns of Table No. 18.

In estimating average per-acre volumes for each type the same assumptions are made as in Aerial Cruise No. 2--that softwood stands are composed on the average of 90% softwoods and 10% hardwoods; that hardwood stands are the same percentages reversed; and that mixed-wood stands are composed of 50% each. All trees in a given type are assumed to be the height of the height class midpoint and type densities are assumed to be those of the density class midpoints.

With these assumptions the per-acre volumes for the various types were determined from Aerial Volume Table No. 1 for hardwoods and No. 6 for softwoods. Computations for total volumes are shown in Table No. 18.

Selection of Ground Plots

A total of 90 ground plots was arbitrarily selected as being the maximum permissable in the time available. With 13 types and only


SLAB CITY IX AND X.
1947
LEGEND
sition Classes
S oftwood - 80% or more softwoods
Hardwood - 80% or more hardwoods
Mixedwood - all other mixtures
ght Classes
0 to 30 feet
35 to 50 feet
55 to 70 feet
75 feet or more
sity Classes
80% to 100%
55% to 75%
30% to 50%
0% to 25%
Stand Numbers
SWIFT RIVER
1 S-2-A
2 H-2-B
3 S-4-B
6 H-3-B
7 S-3-B
8 H-2-B
9 H-3-B
10 S-3-A
11 M-3-B
12 H-2-B
13 Bd-Co
14 S-3-B
15 S-3-A
16 M-3-B
17 S-3-A
18 H-3-B
19 M-3-B
20 S-4-B
21 H-3-B
22 M-3-B
23 S-4-B
24 S-4-B
25 M-3-B
26 Bd-Co
27 H-2-C
28 M-2-C
29 S-2-M
30 Bd-Co
31 H-2-B
32 M-3-B
33 Bd-Co
34 M-4-A
35 M-3-B
36 H-2-B
38 Bd-Co
40 S-3-A
41 H-3-B
42 S-4-B
43 H-3-B
44 S-4-A

al Cruise No. 3 Table No. 18

ation of Type Areas and Volumes

	Stand No.	Stand Area	Type Area	Assumed Ht.	Assumed Den.	Per-acre Vols. bd.ft. Hwd.	Per-acre Vols. bd.ft. Swd.	Per-acre Vols. bd.ft. Total	Total Type Volume	% Vol.	Dist. 90 Plots
A	44	1.18	1.18	80	90	920	32400	33320	39320	3.9	3
	3	.95									
	20	12.20									
B	23	.77									
	24	.51									
	42	.59	15.02	80	65	670	23400	24070	361530	36.2	26
	10	1.51									
A	15	2.17									
	17	1.14									
	40	2.05	6.87	62.5	90	385	18500	18885	129740	13.0	9
B	7	1.21									
	14	.59	1.80	62.5	65	280	13350	13630	24530	2.5	3
A	1	1.98	1.98	42.5	90	--	9070	9070	17960	1.8	3
A	34	.84	.84	80	90	4600	18000	22600	18980	1.9	3
	11	10.73									
	19	1.40									
	22	2.53									
B	25	1.47									
	32	.59									
	35	5.40									
	5	1.03									
	16	.70	23.85	62.5	65	1390	7400	8790	209642	21.0	15
C	28	2.06	2.06	42.5	40	--	2240	2240	4610	0.5	3
D	29	2.61	2.61	42.5	12	--	670	670	1750	0.2	3
	6	7.53									
	9	1.87									
	18	25.57									
B	21	3.34									
	39	1.36									
	41	3.12									
	43	1.21	44.00	62.5	65	2500	1480	3980	175120	17.5	13
	2	1.14									
	8	3.64									
B	31	1.21									
	36	4.66									
	12	.70	11.35	42.5	65	--	730	730	8290	0.8	3
C	4	.25									
	27	14.55	14.80	42.5	40	--	450	450	6660	0.7	3
	13	1.29									
	26	.88									
	30	.18									
	33	.22									
	37	1.10									
	38	2.64									
	Road	1.75	8.06	--	--	--	--	--	--	0.00	3
l		134.42	134.42						998132	100.0	90

Error -5.8%

Corrected for Area 984757
Error -7.1%

90 plots the problem of getting a proper sample of each was difficult. It was desired to distribute the plots in proportion to the estimated type volumes and yet provide each type with at least a few plots to form a volume average. It was decided to have a minimum of 3 plots in any one type. Since 3 is 3-1/3% of 90, all types having 3-1/3% or less of the total volume recieved the minimum of 3 plots. These totaled 24 and the remaining 66 were distributed among the rest of the types in proportion to their volumes as shown in Table No. 18. Admittedly, this constitutes a rather poor sample for many of the types.

Computation of Volumes from Ground Plots

Table No. 19 shows the computations for the final volumes determined from the 90 plots distributed in proportion to the estimated volumes. The determined number of plots for each type were randomly selected and the average per-acre volumes for hardwood, hemlock and white pine determined from them.

RESULTS AND ANALYSIS

Construction of Type Map

Since many of the types have only a few plots an analysis of the species composition estimates has not been attempted. Comparisons of photo-estimated heights and densities with those made from the ground, however, have been made as shown in the second part of Table No. 20. It will be noted that the average error in height estimation is 9.5%, while the aggregate difference is +3.2%. The average error in density estimation is 13% while the aggregate difference is only -0.1%. One type was placed in the wrong height class and two in the wrong density class, sted Volumes -- 90 Plots Distributed by Volume

	No. Plots	Area	Per-acre Volumes Hwd	Hem	WP	Tot.	Total Volumes by Type Hwd	Hem	WP	Tot.
-A	3	1.18	1573	16367	14317	32257	1855	19315	16895	38065
-B	26	15.02	490	470	22825	23785	7360	7060	342830	357250
-A	9	6.87	1330	8030	3505	12865	9135	55165	24080	88380
-B	3	1.80	1510	5535	3545	10590	2720	9965	6380	19065
-A	3	1.98	--	--	1845	1845	--	--	3655	3655
-A	3	.84	3220	4853	21090	29163	2705	4075	17715	24495
-B	15	23.85	1240	7020	2560	10820	29575	167425	61055	258055
-C	3	2.06	185	765	--	950	380	1575	--	1955
-D	3	2.61	2383	1943	500	4826	6220	5070	1305	12595
-B	13	44.00	1280	850	930	3060	56320	37400	40920	134640
-B	3	11.35	525	705	--	1230	5960	8000	--	13960
-C	3	14.80	565	520	--	1085	8360	7605	--	16055
n	3	8.06	--	2245	--	2245	--	18095	--	18095
l	90	134.42					130590	340840	514835	986265
			Error				-19.1%	-12.5%	+1.1%	-7.0%
			Corrected for area				128840	336273	507936	973049
			Error				-20.1%	-13.7%	-0.2%	-8.2%

arisons of Aerial and Ground Volumes, Heights and Densities

Ground Volumes Determired From All Available Plots

e	No. Plots	Area	Total Per-acre Volume	Total Vol. by Types	% Vol.	Dist. of 90 Plots	Aerial Dist. of 90 Plots
-A	3	1.18	32257	38065	3.6	3	3
-B	28	15.02	24520	368290	35.1	26	26
-A	10	6.87	12865	88380	8.4	6	9
-B	3	1.80	10590	19065	1.8	3	3
-A	5	1.98	1590	3150	0.3	3	3
-A	3	.84	29163	24495	2.3	3	3
-B	30	23.85	11475	273680	26.1	19	15
-C	3	2.06	950	1955	0.2	3	3
-D	4	2.61	7820	20410	2.0	3	3
-B	42	44.00	3635	159940	15.3	12	13
-B	11	11.35	1725	19580	1.9	3	3
-C	14	14.80	900	13320	1.3	3	3
n	8	8.06	2160	17410	1.7	3	3
al	164	134.42		1047740	100.0	90	90
	Error			-1.2%			

Comparison of Heights and Densities

Type	No. Plots	Height: Plots	Height: Photo	Height: Error	Density: Plots	Density: Photo	Density: Error
S-4-A	3	75	80	5	80	90	10
S-4-B	27	80	80	0	75	65	10
S-3-A	9	57	62.5	5.5	77	90	13
S-3-B	3	55	62.5	7.5	67	65	2
S-2-A	5	34	42.5	8.5	86	90	4
M-4-A	2	78	80	2	80	90	10
M-3-B	27	61	62.5	1.5	68	65	3
M-2-C	3	38	42.5	4.5	30	40	10
M-2-D	4	58	42.5	15.5	40	12	28
H-3-B	41	53	62.5	9.5	63	65	2
H-2-B	9	48	42.5	5.5	71	65	6
H-2-C	14	44	42.5	1.5	41	40	1
Total	147	681	702.5	64.5	778	777	99

Average Error,	Feet	5.4'	% Crown Closure 8.2%
Average Error,	%	9.5%	% of Average Cr.Cl. 13%
Aggregate Difference		+ 3.2%	-0.1%

according to the height and density checks made on the ground.

Volume Estimations

As shown in Table No. 18 the aerial total volume estimate was 7.1% low when corrected for area, somewhat better than the estimate made by similar methods from the 1:18,000 photographs. Volume estimations for the individual types, however, were not quite as good. The first part of Table No. 20 shows the distribution of 90 plots among the types in proportion to their volume as determined from the ground plots. Compared with this is the distribution of the 90 plots as made from the aerially estimated volumes. Nine of the thirteen types are so small as to have only three plots under both distributions, and hence there is no comparison. Of the remaining four types only one has the correct number of plots and the others have errors of one, three and four plots.

The final volume estimates as determined from the 90 ground plots are shown in Table No. 19. After correction for area the total volume estimate is 8.2% low while that for hardwood is 20.1% low, hemlock 13.7% low and white pine only 0.2% low. It is interesting to note that the total volume estimate based on the 90 ground plots has a larger error than that based on the photos alone.

Analysis of Variance

The first part of Table No. 21 shows an analysis of variance based on 164 plots thus making it comparable with a similar analysis made in Aerial Cruise No. 2. The SE_m based on 164 plots not stratified is 8.5%, the same as in Aerial Cruise No. 2 while the SE_m for the plots when stratified by the photographs is 4.7%. This is slightly better rial Cruise No. 3 Table No. 21

alysis of Variance

Based on All Available (164) Plots

Type	No. Plots	Sum	Sum-squares	C.T.	Corrected Sum-squares	Mean Square
S-4-A	3	968	345624	312341	33283	16641
S-4-B	28	6867	1936455	1684132	252323	9345
S-3-A	10	1286	225258	165380	59878	6653
S-3-B	3	317	47345	33496	13849	6924
S-2-A	5	80	1462	1280	182	46
M-4-A	3	875	272425	255208	17217	8608
M-3-B	30	3440	476446	394453	81993	2827
M-2-C	3	29	445	280	165	82
M-2-D	4	313	37085	24492	12593	4198
H-3-B	42	1526	106706	55445	51261	1250
H-2-B	11	190	8116	3282	4834	483
H-2-C	14	127	1741	1152	589	45
Open	8	173	9297	3741	5556	794
Total	164	16191	3468405	1598466	1869939	11472
Mean		98.72				

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m 100 b.f.	SE_m %
Total	163	1869939	11472	107.11	8.36	8.5
Between Classes	12					
Within Classes	151	533723	3535	59.46	4.64	4.7

SE_m (corrected for limited population = 4.3%

Theoretical Analysis of 90 Plots Based on Variances of All Plots

	Data from 164 Plots				90 Plots Distributed by Volume				
Type	n	Mean	Mean-square	σ	n	D.F.	SE_m 100 B.F.	SE_m %	Corrected Sum-square
S-4-A	3	323	16641	129.00	3	2	74.56	23.1	33283
S-4-B	28	245	9345	96.67	26	25	19.00	7.8	233625
S-3-A	10	129	6653	81.57	9	8	27.19	21.1	53224
S-3-B	3	106	6924	83.21	3	2	48.09	45.4	13849
S-2-A	5	16	46	6.78	3	2	3.92	24.5	92
M-4-A	3	292	8608	92.78	3	2	53.63	18.4	17217
M-3-B	30	115	2827	53.17	15	14	13.74	11.9	39578
M-2-C	3	10	82	9.06	3	2	5.24	52.4	165
M-2-D	4	78	4198	64.79	3	2	37.45	48.0	8396
H-3-B	42	36	1250	35.36	13	12	9.81	27.2	15000
H-2-B	11	17	483	21.98	3	2	12.71	74.8	966
H-2-C	14	9	45	6.71	3	2	3.88	43.1	90
Open	8	22	794	28.18	3	2	16.29	74.0	1588
Total	164	98.72	11472	107.11	90	89	11.29	8.2	1021008

Theoretical Mean of 90 Plots = 137.14

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m 100 b.f.	SE_m %
Total	89	1021008	11472	107.11	11.29	8.2
Between Classes	12					
Within Classes	77	417073	5416	73.59	7.75	5.7

SE_m (corrected for limited population) = 5.5%

than the 5.3% obtained from the stratification of the plots by the 1:18,000 photographs in Aerial Cruise No. 2.

A theoretical analysis of the 90 plots used in this cruise, based on standard deviations determined from the 164 plots, shows a SE_m of 5.5% based on the formula for a limited population. This is to be compared with a SE_m of 6.6% obtained from the 80 plots in Aerial Cruise No. 2.

Examination of composition, heights, densities, and volumes of the 13 types originally established indicates that possibly, as was the case in Aerial Cruise No. 2, too many types have been separated in this cruise, particularly since several are less than two acres in area. In order to determine what effect would result from combining certain of the types an analysis of variance was made on the following seven new types.

Original types	New type
S-4-A, S-4-B	S-4-B
S-3-A, S-3-B	S-3-B
S-2-A	S-2-A
M-4-A, M-3-B, M-2-D	M-3-B
H-3-B	H-3-B
H-2-B, H-2-C, M-2-C	H-2-C
Open	Open

The analysis is shown in Table No. 22. The SE_m for the plots not stratified is, of course, the same as before, 8.5%. When stratified into the new simplified types the SE_m becomes 5.1%, which is slightly higher than the 4.7% resulting from the stratification of the plots into the original types.

COSTS

Again it is advisable to point out that costs as estimated here are solely for the purpose of comparing the various cruises and ial Cruise No. 3 Table No. 22

lysis of Variance for Simplified Types

Type	n	Sum	Sum-squares	C.T.	Corrected Sum-squares	Mean Square
S-4-B	31	7835	2282079	1980233	301846	10062
S-3-B	13	1603	272603	197662	74941	6245
S-2-A	5	80	1462	1280	182	46
M-3-B	37	4628	785956	578875	207081	5752
H-3-B	42	1526	106706	55445	51261	1250
H-2-C	28	346	10302	4276	6026	223
Open	8	173	9297	3741	5556	794
Total	164	16191	3468405	1598466	1869939	11472
Mean		98.72				

Source	D.F.	Corrected Sum-squares	Mean Square	σ	SE_m 100 b.f.	SE_m %
Total	163	1869939	11472	107.11	8.36	8.5
Between Classes	6					
Within Classes	157	646893	4120	64.19	5.01	5.1

do not necessarily represent the exact costs that might be incurred in conducting a cruise of this type. Nevertheless, an effort has been made to be realistic and costs as estimated here may be regarded as approximate.

In making cost estimates of this sort a number of assumptions must necessarily be made, as pointed out in discussing the costs of Aerial Cruise No. 2, page 88. Probably the most variable cost is that of the aerial photographs. A cost of 10¢ an acre was assumed as reasonable for the 1:18,000 photographs. In keeping with this, 25¢ an acre should come somewhere near the probable cost for the 1:5300 photos. Other assumptions regarding costs are the same as were made in Aerial Cruise No. 2.

Item	Man-hours @ 1.385	Cost	Cost per-acre
Photographs			25.00 ¢
Design and plan cruise	2	$ 2.77	2.09
Preliminary photo work	1	1.38	1.04
Delineate types and transfer to base map	2½	3.46	2.61
Preliminary volume estimate	4	5.54	4.18
Plan field work	1	1.39	1.05
Field work	40	55.40	41.77
Computations	6	8.31	6.27
Correct and complete type map	2½	3.46	2.61
Travel time	1½	2.08	1.57
Mileage	24 miles @ .05	Total	89.09
		10% overhead	8.91
		Total	98.00 ¢

CRUISE OF A TOWNSHIP

The expansion of this cruise to the area of a township is shown in SECTION 7 where the required number of plots and estimated costs are compared with those of other cruises.

CONCLUSIONS

The conclusions regarding the stratification of ground plots by the use of aerial photos to be derived from an analysis of this cruise are similar to those of Aerial Cruise No. 2. In this case an even greater reduction of the SE_m of the ground plots was effected. This was to be expected, of course, since the photographs are of a scale more than three times larger. The reduction, based on a limited population, was from 8.3% to 4.3%. Translated into the required number of plots for a 5% accuracy two times out of three, the reduction would be from 470 plots to 145, a substantial saving in field work.

Since the design of this cruise and that of Aerial Cruise No. 2 are similar, it is of particular interest to compare the accuracies and costs of the two. The number of plots required for a 5% accuracy, based on the 80 plots of Aerial Cruise No. 2, is 140, while for this cruise the number is 115. Computing the costs of these two cruises using the same assumptions made previously, Aerial Cruise No. 2 would cost about 92¢ an acre and this cruise about 99¢. It may be concluded, therefore, that the use of the large scale photographs did not pay in this case.

The results of this cruise tend to confirm those of the previous cruise in that there is a tendency to break down the area into more types than necessary. In the case of this cruise the simplification of the original thirteen types into seven caused a slight increase in the standard error of the mean but it seems likely that this would be more than offset by the greater ease in adequately sampling seven rather than thirteen types.

As should be expected, the aerial volume estimate from the photos alone was better for the 1:5300 than the 1:18,000 photographs but it is doubtful that the increase in accuracy would offset the increase in cost. Estimations of stand heights were better than those of Aerial Cruise No. 2, the aggregate differences being +3.2% and +5.6%

respectively. Estimations of stand densities are also better with the large scale photos, the aggregate differences being -0.1% and +19.4%, respectively.

However, in spite of the better estimations of height and density and the better total volume estimate from the 1:5300 photographs, still the distribution of the 90 plots in this cruise incurred more error than the distribution of the 80 plots in Aerial Cruise No. 2. It is not possible to explain this fully but it would seem likely that with our present knowledge of the use of aerial photographs, there is insufficient correlationbetween photo measurements and tree volumes to warrant the use of such large scale photos.

SUMMARY

For the purpose of evaluating a moderately intensive use of large scale photographs the 133-acre study area was cruised using 1:5300 photographs. The design of the Cruise is similar to that used in Aerial Cruise No. 2, employing 1:18,000 photographs, in order that comparison might be readily made. The area was classified into rough types based on species composition, height and density classes, and volumes for these types estimated. Ninety 1/10-acre ground plots were distributed within the area in proportion to these estimated volumes and the final volume estimate based on data from these plots. The area was later 100% cruised and volume comparisons made.

Results again indicate a substantial reduction in error due to the stratification of the ground plots by the photographs. A slightly smaller SE_m was obtained using the 1:5300 photographs than when using the 1:18,000 but the increased cost was even more than the reduction of error.

The results of this cruise, then, further confirm those of Aerial Cruise No. 1 in that large scale photographs of a poor quality do not pay and it is felt by the writer that even if the photos were of a good quality it would still not pay to use such a large scale.

SECTION 6 -- AERIAL CRUISE NO. 4

An Extensive Use of Medium Scale Photographs

Employing Aerial Photo Plots

SECTION 6 — AERIAL CRUISE NO. 4

An Extensive Use of Medium Scale Photographs

Employing Aerial Photo Plots

INTRODUCTION

In order to test an extensive use of medium scale photographs this cruise was designed employing a series of plots which are located on the photographs and then classified into relatively simple types based on species composition, height and density. Average per-acre volumes are assumed for each type class based on aerial volume tables and then certain of the plots are visited in the field and ground data collected. The ground plots are established in proportion to the estimated volumes of the type classes and the aerial estimates are then adjusted by means of the ground data. For several reasons, this cruise was not completed and only the preliminary aerial volume estimate was made. However, it is thought that the results are sufficiently interesting to describe.

PHOTOGRAPHS

The photographs are 1:18,700 modified infrared—the same as used in Aerial Cruise No. 2, to which reference may be made for further information. A stereogram from these photos is shown in Figure 1, page 6.

PROCEDURE

Preliminary Work

Little time was required for the preliminary work since there were only three photographs on which to locate the principal and conjugate principal points, and since a scale check had already been made on a previous cruise using the same photos. Parallax factors were computed for each hundred-foot elevation as follows: 700' - 3.21'; 800' - 3.16; 900' - 3.11; and 1000' - 3.06. A base map at a scale of 1:4800 was already available.

Establishment of Aerial Plots

If this type of cruise were designed for a large area so that only a few plots fell on each photo it would be possible to establish these plots on the photos by means of some system which would eliminate error due to topographic relief. However, since in this case the entire area is covered by one photograph and since a reasonable number of plots must be established in order to sample the various forest types, a problem of plot location on the photographs develops. It was felt that about 150 plots were needed to adequately sample the area and no satisfactory method is known of establishing such a number on one photograph in a manner so as to eliminate error caused by relief. Consequently, the plots were mechanically spaced on the photograph and corrections for elevation made when estimating the areas of the various types. No particular size was assignedto the plots since it was merely desired to classify into certain foresttypes the point where the center of each plot fell.

In order to establish approximately 150 plots on the 133-acres a rectangular spacing of .125-inch was adopted. At a scale of 1:18,700 which holds for an elevation of 800', this spacing equals 194.8 feet on the ground. The acreage represented by each plot, then, equals 194.3^2 = 37,943 sq. ft. = .8713 acres at an elevation of 800' which is the base level assumed in this cruise. This rectangular spacing of .125-inch when randomly laid down on the photograph resulted in 157 plots falling within the area.

Classification of Plots

The plots having been established on the photos and marked with pin pricks, each was then examined with a pocket stereoscope and assigned to one of a series of types based upon species composition, height and density.

Three classes of species composition were recognized: H - hardwoods - 80% or more hardwoods; S - softwood - 80% or more softwoods; and M - mixedwood - all other mixtures.

Four height classes were established: (1) 0 to 29 feet, (2) 30 to 49 feet, (3) 50 to 69 feet, and (4) 70 feet or more.

Only three density classes were recognized: A - 70% to 100%, B - 40% to 69%, and C - 0% to 39%.

Thus, by recognition of these limits, the possibility of 36 forest types was set up. Each plot marked on the photographs was examined and assigned to one of these classes. In addition, the elevation of each plot was recorded to the nearest 100 feet. This was facilitated by transposing from the U.S.G.S. topographic sheet to the photographs certain contour lines to establish the boundaries of each 100-foot class.

The tabulation of the 157 plots by these type classes and by 100-foot elevation classes is shown in the first three columns of Table No. 23.

Estimation of Areas

Since no type map has been constructed and therefore no type areas can be measured, the area of each type class must be assumed to be rial Cruise No. 4 Table No. 23

mary of Types and Areas

Type	Elevation	No. Plots	Acreage Factor	Acres
S-4-A	700	13	.8846	11.500
	800	3	.8713	2.614
	Total	16		14.114
S-3-A	700	5	.8846	4.423
	800	2	.8713	1.743
	Total	7		6.166
S-3-B	900	1	.8575	.858
	1000	1	.8442	.844
	Total	2		1.702
S-2-A	800	1	.8713	.871
M-4-B	800	2	.8713	1.743
M-3-A	700	7	.8846	6.192
	800	17	.8713	14.812
	900	2	.8575	1.715
	Total	26		22.719
M-3-B	700	7	.8846	6.192
	800	9	.8713	7.842
	900	3	.8575	2.572
	Total	19		16.606
M-3-C	800	1	.8713	.871
M-2-a	800	1	.8713	.871
M-2-B	900	3	.8575	2.572
	1000	1	.8442	.844
	Total	4		3.416
M-1-B	900	1	.8575	.858
H-3-A	700	13	.8846	11.500
	800	16	.8713	13.941
	900	4	.8575	3.430
	T otal	33		28.871
H-3-B	700	4	.8846	3.538
	800	6	.8713	5.228
	900	6	.8575	5.145
	1000	2	.8442	1.688
	Total	18		15.599
H-2-A	700	4	.8846	3.538
	1000	1	.8442	.844
	Total	5		4.382
H-2-B	700	3	.8846	2.654
	900	2	.8575	1.715
	1000	4	.8442	3.377
	Total	9		7.746
H-1-B	1000	1	.8442	.844
Bd-Co	800	1	.8713	.871
	900	4	.8575	3.430
	Total	5		4.301
Road	800	6	.8713	5.228
Total		157		136.91

proportional to the number of plots falling in that class. However, because the plots were mechanically spaced on the photograph, corrections must be applied to avoid errors due to topographic relief. The acreage represented by a plot at an elevation of 800' has already been calculated as .8713. The acreage represented by a plot at other elevations has been calculated as follows: 700' - .8846, 900' - .8575, 1000' - .8442.

The calculations for areas are shown in the last two columns of Table No. 23. Total acreage is 136.91, which is 3.2% high compared with the acreage measured in the 100% ground cruise.

Estimation of Volumes

Per-acre volumes were estimated by making the rough assumptions of species percentage, height and density shown in the first four columns of Table No. 24. The height and density assumed for each type are the midpoints of the height and density classes for that type. The Tables used for determining the per-acre volumes are Volume Table No. 1 for hardwoods and Volume Table No. 6 for softwoods. Total volumes for each type are obtained by multiplying the per-acre volumes by the area previously determined.

Completion of Cruise

In order to complete the cruise the design called for the location on the ground of certain of the aerial photo plots. These were to be selected from the various types in proportion to the estimated volumes of the types. However, at this point it became evident that it was impossible to properly sample the types set up and that this sort of extensive cruise simply cannot be applied to a small area. There are seventeen types to be sampled, five of which have only one plot and others

Computation of Volumes

	Percent of:		Assumed		Per-acre Volumes				
ype	Swd	Hwd	Ht.	Den.	Softwood	Hardwood	Total	Area	Total Volume
-4-A	90	10	80	85	30600	1040	31640	14.11	446440
-3-A	90	10	60	85	16100	310	16410	6.17	101250
-3-B	90	10	60	55	10400	200	10600	1.70	18020
-2-A	90	10	40	85	7500	--	7500	.87	6525
-4-B	50	50	80	55	11000	2820	13820	1.74	24047
-3-A	50	50	60	85	8900	1550	10450	22.72	237424
-3-B	50	50	60	55	5780	1000	6780	16.61	112616
-3-C	50	50	60	20	2100	365	2465	.87	2145
-2-A	50	50	40	85	4160	--	4160	.87	3619
-2-B	50	50	40	55	2690	--	2690	3.42	9200
-1-B	50	50	13	55	--	--	--	.86	--
-3-A	10	90	60	85	1785	2790	4575	28.87	132080
-3-B	10	90	60	55	1155	1800	2955	15.60	46098
-2-A	10	90	40	85	735	--	735	4.38	3219
-2-B	10	90	40	55	540	--	540	7.75	4185
-1-B	10	90	13	55	--	--	--	.84	--
d-Co	--	--	--	--	--	--	--	4.30	--
oad	--	--	--	--	--	--	--	5.23	--
otal								136.91	1146868
					Error				+8.2%
					Corrected for Area				1110931
					Error				+4.8%

Calculation of Coefficient of Variation

Type	No.Plots (n)	Vol.(100b.f.) (x)	nx	nx^2
S-4-A	16	316	5056	1597696
S-3-A	7	164	1148	188272
S-3-B	2	104	208	21632
S-2-A	1	75	75	5625
M-4-B	2	138	276	38088
M-3-A	26	104	2704	281216
M-3-B	19	68	1292	87856
M-3-C	1	25	25	625
M-2-A	1	42	42	1764
M-2-B	4	27	108	2916
M-1-B	1	--	--	--
H-3-A	33	46	1518	69828
H-3-B	18	30	540	16200
H-2-A	5	7	35	245
H-2-B	9	5	45	225
H-1-B	1	--	--	--
Bd-Co	5	--	--	--
Road	6	--	--	--
Total	157		13072	2312188
Correction Term			=	- 1088390
Corrected Sum-squares			=	1223798
Mean Square = 1223798 ÷ 156 =				7845

$$CT = \frac{(\Sigma nx)^2}{n} = \frac{(13072)^2}{157} = 1088390$$

$$\text{Mean} = \frac{13072}{157} = 83.26$$

$$\sigma = \sqrt{7845} = 88.57$$

$$C_v\text{, aerial cruise} = \frac{88.57}{83.26} = 106.4\%$$

$$C_v\text{, ground plots} = \frac{84.26}{75.75} = 111.2\%$$

which have only a few plots. Obviously this condition does not lend itself to proper sampling and so this cruise was terminated at this point.

RESULTS AND ANALYSIS

The total volume estimate resulting from the foregoing procedure was 8.2% high. But this is based on an area estimate of 136.91 acres and when the total volume estimate is adjusted for correct area the error becomes only +4.8%. The error in hardwood volume estimate is 13.1% high uncorrected and 9.6% high when corrected for area. When the softwood volume estimate is compared with the actual volumes of hemlock and white pine combined it is found to be 7.3% high without area correction and only 3.9% high after being corrected for area. These are the best results obtained by any of the aerial cruises from the use of the photographs alone.

As a matter of interest the total volumes were also calculated without any adjustment for elevation. The acreage represented by each plot was assumed to be that for 800' elevation, or .8713. The results obtained by this method are slightly better than those obtained when corrections for elevation were made. The total volume estimate was 4.2% high, that for hardwood 9.4% high and for softwood 3.3% high. This does not mean, of course, that better answers can always be obtained by neglecting elevation adjustments, but simply that in thiscase the errors resulting from lack of elevation corrections partially compensated for other errors.

In order to compare the variation of the plots used in this cruise with the variation of the 142 ground plots referred to in SECTION 2 the coefficients of variation for both cruises were determined as shown in the second part of Table No. 24. The results show that the coefficient of variation for the 157 aerial plots is 106% while that of the 142 ground plots is 111%, close enough for all practical purposes.

CONCLUSIONS

Although this cruise was not carried through to completion because of the impossibility of obtaining an adequate sample from such a small area, nevertheless, it is felt that enough has been learned to indicate the merit of the system. That the volume estimate from the photographs alone was better than any other of the cruises does not prove, of course, that it is the best of the systems tested here. However, it does indicate that the system shows promise and is worthy of further testing on larger areas.

Although costs were not computed for this cruise, since it was not completed, it seems likely that it would prove one of the cheapest. The cost of the work done on the photographs is definitely less than any system employing the construction of a type map. However, since the ground plots are likely to be scattered in a random manner, and since an effort must be made to locate these plots in the exact spot indicated on the photographs, the cost per plot would undoubtedly be higher than that of the other systems. It seems likely, though, that fewer plots would be required under this system for any given standard of accuracy, because the variation within types should be less. When ground plots are scattered at random throughout a forest type which has been delineated from aerial photographs, these plots are likely to sample small holes or other irregularities within the type. This tends to cause a large variance. But when the ground plots are located in the same spots as the photo-plots, these irregularities may be accounted for and the variance should be less.

Just what would be the cost of a cruise such as this can only be determined, then, by further trial. Less photo work and fewer plots tend to decrease the cost, while a higher per-plot cost would tend to increase it. It seems reasonable that the cost of this cruise would be no more than that of the type such as Aerial Cruise No. 2, and probably would be less. The larger the area treated, the lower should be the relative cost of this aerial plot cruise.

An attempt was made to determine how much improvement resulted from correcting the area calculations for errors caused by elevation changes. This attempt failed, for the results were more accurate when not corrected than when corrected. This, of course, is not logical and is undoubtedly due to the fact that this area is too small and does not have sufficient elevational change to cause changes in types.

In designing any cruise employing sampling by ground plots, it is extremely useful to know the expected variance of these plots so that the approximate number needed for a given statistical accuracy can be calculated. Without this knowledge the variance must be estimated and later adjusted from the information obtained by the first group of plots established. This, however, necessitates a change in design in the middle of the cruise which results in inefficiency. The more accurately the plot variance can be estimated prior to the ground work the less the design of the cruise need be changed.

The results of this cruise indicate that there is a good possibility of obtaining an accurate estimation of the ground-plot variance by means of aerial photos. In this example, the standard deviation of the 157 aerial plots was 88.57 and the mean, 83.26. The number of plots required for a standard error of the mean of 10% and a probability of 22 to 1 may be calculated as follows: 10% of the mean is 8.326 and since a 22 to 1 probability is required the desired error is half this, or 4.16. Using the formula for an unlimited population, $n = \frac{\sigma^2}{SE_m^2} = \frac{88.57^2}{4.16^2} = 453$ plots. The number of plots required for a similar standard of accuracy has already been calculated from the data obtained from the 142 ground plots and is 494 plots. Thus the aerial photo estimate of the required number of plots is only 8.3% lower than the estimate based on the actual ground plots.

In connection with this problem it is of interest to note the results obtained by another student, R. C. Cameron, at the Harvard Forest. He attempted to locate the exact position of the 142 1/10-acre ground plots on the 1:5300 photographs and then estimated the volume on each plot using the individual tree method. The coefficient of variation for these aerial photo plots was 116.9%, and based on this data the number of plots required for the standards of accuracy stated above is 547, or 10.7% higher than the estimate based on the actual ground plots.

Therefore, the indications of these results show that there is promise of being able to estimate the expected variance of ground plots within 10% and this should be of considerable value when attempting to design a cruise involving ground plots on an area where no other information regarding this variance is available.

SUMMARY

This aerial cruise was designed for the purpose of testing an extensive use of medium scale photographs. 157 plots were mechanically spaced within the 133-acre area on 1:18,700 modified infrared photographs. These aerial plots were then classified into rough types based on simple species composition, height and density classes. Average per-acre volumes were assumed for the plots in each type and the areas of the types determined from the number of plots falling within each. Corrections in areas were made for changes in elevation.

The results of the aerial volume estimates thus made are the best of any of the aerial cruises. The total volume estimate was 4.8% high while that for hardwood was 9.6% high and for softwood 3.9% high. This, of course, does not necessarily prove this type of cruise to be best, but it neverhheless indicates that is has good possibilities and it is highly recommended that further experimentation be directed along this line.

As an interesting side note it was determined from this cruise, and from the aerial photo plots of a cruise done by another student, that the expected variance of ground plots on a given area can be determined from aerial photos with sufficient accuracy to aid in the designing of a cruise employing ground plots. It was found that the required number of plots for a given statistical accuracy could be determined from aerial photographs within about 10% of the actual number as determined from ground plot data.

SECTION 7 -- CRUISE OF A TOWNSHIP

Application of the Various Cruises to a Hypothetical Township of 23,040 Acres

SECTION 7 -- CRUISE OF A TOWNSHIP

Application of the Various Cruises to a Hypothetical Township of 23,040 Acres

INTRODUCTION

In order to better visualize the comparisons of the various cruises it is of interest to expand them and see how they would apply to a larger area. The size of the area chosen for this expansion is the six-mile-square township of 23,040 acres. This area was selected because it is one of the most frequently used survey units.

In making such an expansion a number of assumptions must be made, a few of which may not be strictly valid, but the purpose is to compare the different cruises under similar conditions rather than to compute actual numbers of plots and costs. So long as these assumptions hold for all the cruises compared they should serve to allow valid comparisons.

The hypothetical township is assumed to be composed of the same proportions of the same types as the 133-acre study area and the variance of these types is assumed to be the same as for the small area. This, of course, would seldom be strictly true, for the larger area would likely introduce more separate types than the smaller and probably include a wider variation of sites which would increase the variances within types. Assumptions regarding salaries, area accessibility, travel time, etc., are similar to those made when estimating costs for the cruises of the small area and are held the same for all cruises. These costs are highly theoretical and it must be emphasized again that they are for comparative purposes only.

In order to compare the various cruises certain standards of statistical accuracy must be set up and adhered to for all cruises. The desired accuracy of total volume estimate is assumed to be 10%. It is reasonable to allow about half of this for errors in field measurements, volume tables and area estimations. The required accuracy of sampling (standard error of the mean) then is 5%. The other question is that of what odds or probabilities to establish. Since the required accuracy of the volume estimate is only 10%, it is desirable that this accuracy be attained with reasonable certainty which means odds of at least 22 to 1 or twice the standard deviation. Empirical experience has shown that a $1\frac{1}{4}$% plot cruise is about the lowest that is generally acceptable for large areas of about township size. A computation reveals that for the mechanically spaced ground plot cruise odds of about 80 to 1, or $2\frac{1}{2}$ times the standard deviation, results in a cruise of 1-1/3%. Since this qualifies as acceptable, the sampling error set up for the following cruises is 5% with a probability of 80 to 1. In other words, 80 times out of 81 the error of the mean due to sampling should be less than 5%. Assuming an additional 5% error for other factors, the mean volume determined by the cruise should be within 10% of the true mean volume in 80 cases out of 81.

For the purpose of determining the number of plots required for a given standard of accuracy two formulas are available, one based on a limited population and one on an unlimited population. To determine whether or not the hypothetical township qualifies as an unlimited population when sampled by 1/10-acre plots, both formulas were tried on the 10.7% ground plot cruise. The number of plots required was 3093, based on an unlimited population, and 3049 based on a limited population. Since this difference is so slight the simpler formula for unlimited population will be used for all cruises.

Since Aerial Cruise No. 1 was extremely expensive it is not considered here and since the ground work for Aerial Cruise No. 4 was not completed it, too, cannot be expanded to a township size.

MECHANICALLY SPACED GROUND PLOT CRUISE

Since for the ground strip cruises there is no sampling unit, these cruises cannot be expanded to the township area. Expansion of the ground cruises, therefore, is limited to the one 10.7% plot cruise. The formula for determining the required number of plots is $n = \left(\frac{\sigma}{SE_m}\right)^2$. The appropriate data derived from the 10.7% ground plot cruise are: mean = 75.75, standard deviation = 84.26. An error of the mean of 5% is desired. 5% of 75.75 is 3.7875 and, since for odds of 80 to 1 $2\frac{1}{2}$ times the error must not exceed this, the required SE_m is 3.7875 divided by 2.5 or 1.515. Substituting in the formula:

$$n = \left(\frac{84.26}{1.515}\right)^2 = 3093 \text{ plots, a } 1.34\% \text{ cruise.}$$

Following are the estimated costs for a cruise of a township employing 3093 1/10-acre plots spaced about the same in both directions. It is assumed that available section lines will be used for base lines but that the spacing of the cruise lines will have to be marked off on the base lines.

Item		Man-hours @ $1.385	Cost	Cost Per-acre
Plan cruise		16	$ 22.16	.10 ¢
Mark base lines		112	155.12	.67
Establish 3093 plots		1488	2060.88	8.94
Computations		310	429.35	1.86
Travel time		50	62.95	.30
Mileage	1200 miles @ 5¢		60.00	.26
			Total	12.13 ¢
			10% Overhead	1.21
			Total	13.34 ¢

By spacing the plots closer together on lines farther apart a reduction in the cost of the cruise could be made. Some increase in error would likely occur, though to what extent it is impossible to predict. The estimated cost of the cruise by this method is 10.40¢ per acre.

AERIAL CRUISE NO. 2

In this cruise it was determinedthat distribution of plots in proportion to volume resulted in a smaller error than distribution of plots by areas. Consequently, only the former design is expanded and applied to a township.

In order to compute the required number of plots, the appropriate data derived from Aerial Cruise No. 2 are: mean = 115.30, standard deviation = 71.14. The required SE_m is 5% of 115.30 divided by 2.5, or 2.306.

$$n = \left(\frac{\sigma}{SE_m}\right)^2 = \left(\frac{71.14}{2.306}\right)^2 = 952 \text{ plots, a } 0.4\% \text{ cruise.}$$

In estimating costs for this cruise it will be assumed that the photographs will be used to lay out the ground work and no base lines will be necessary.

Item		Man-hours @ $1.385	Cost	Cost Per-acre
Photographs				.67 ¢
Plan cruise		24	$ 33.24	.14
Map Types and transfer to base map		9	12.46	.05
Preliminary volume estimate		6	8.31	.04
Plan field work		20	27.70	.12
Establish 952 plots		384	531.84	2.37
Computations		95	131.58	.57
Correct and complete type map		32	44.32	.19
Travel time		12	16.62	.07
Mileage	288 miles at 5¢		14.40	.06
			Total	4.22 ¢
			10% overhead	.42
			Total	4.64 ¢

AERIAL CRUISE NO. 3

The data required to compute the number of plots for this cruise are: mean = 137.14, standard deviation = 73.59. The required SE_m is 5% of 137.14 divided by 2.5, or 2.7428.

$$n = \left(\frac{\sigma}{Se_m}\right)^2 = \left(\frac{73.59}{2.7428}\right)^2 = 720 \text{ plots, a 0.3\% cruise.}$$

The same cost assumptions are made for this cruise that were made for the previous one.

Item		Man-hours @ $1.385	Cost	Cost per-acre
Photographs				2.50 ¢
Plan Cruise		24	$ 33.24	.14
Map Types and Transfer to Base Map		48	66.48	.29
Preliminary Volume Estimate		6	8.31	.04
Plan Field Work		24	33.24	.14
Establish 720 Plots		288	398.88	1.73
Computations		72	99.72	.43
Correct and complete Type Map		40	55.40	.24
Travel Time		9	12.46	.05
Mileage	216 miles @ 5¢		10.80	.05
			Total	5.61 ¢
			10% overhead	.56
			Total	6.17 ¢

SECTION 8 -- CONCLUSIONS

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CRUISE COMPARISONS

Following is a summary of comparisons for the various cruises. For the 133-acre area are shown the actual errors of the photo-estimated volumes and of the volumes as computed from the ground plots. Also shown is the standard error of the mean based on the ground plots, and the cost per acre. For the hypothetical township is shown the per-acre cost of the various cruises for a sampling accuracy of 5% and odds of about 80 to 1.

Cruise	Prelim, Photo Est. Error	133-acre Area Final Cruises Error	SE_m	Cost	Township Cost
Ground Plot					
Rectangular Spacing	--	-5.7%	8.8%	76.6¢	13.3¢
Close Plots on Wide Lines	--	--	--	--	10.4¢
Aerial Cruise No. 1 (1:5300)	+13%	--	--	--	--
Aerial Cruise No. 2 (1:18,000)	+11.9%	1.1%*	6.6%	65.4¢	4.6¢
Aerial Cruise No. 3 (1:5300)	- 7.1%	-8.2%	5.5%	98.0¢	6.2¢
Aerial Cruise No. 4 (1:18,000)	+ 4.8%	--	--	--	--

*This figure represent the average of four errors obtained from the two different selections of ground plots each employing both the dot-count areas and planimetered areas, as shown on page 80.

It will be noted that the best cruise for which complete comparisons are available is Aerial Cruise No. 2, using 1:18,000 photographs, and that there is a definite trend to indicate that the use of large scale photographs did not pay. A disadvantage of the straight ground cruises and Aerial Cruise No. 4 is that no type map is produced as the cruises are set up in this study, and additional costs would be incurred in the production of one.

It is unfortunate that Aerial Cruise No. 4 could not be completed but it simply is not applicable to a small area. The actual error of the preliminary volume estimate from the photographs alone was the best of any of the cruises. It may be assumed, therefore, that it would be sufficiently accurate to properly control the establishment of ground plots. The cost should be no more, and probably even less, than that of a design similar to Aerial Cruise No. 2.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study have established some concrete comparisons between several types of aerial and ground cruises and have indicated certain trends which, when combined with the results of additional study, may enable further conclusions to be drawn.

Regarding the estimation of timber volumes from photographs alone, it seems probable that errors of less than 15% can be consistently obtained by reasonably experienced interpreters, even on relatively small areas. (The actual errors of total volume estimation from the photographs alone for the four cruises were: 13%, 12%, 7% and 5%). Some decrease in the magnitude of the expected errors would be logical for larger areas. While such accuracy may not be regarded precise enough for the execution of a timber sale at least it is satisfactory for reconnaissance and planning purposes. Therefore, the use of aerial photographs without ground data may be of considerable value, particularly where the country is inaccessible. Although, in the particular cruises carried out here, the best volume estimate was obtained from the smaller scale photographs, this result is not logical and is undoubtedly due to chance. In general there should be a progressive increase in the accuracy of volume estimates with an increase in the scale of the photographs until a point is reached where the accuracy of the measurements on the photographs is greater than the correlation between these measurements and the tree volumes. Just where this point will be reached depends on a variety of factors but it is the writer's opinion that there would seldom be a need for photographs of a scale larger than 1:5000. This is not to say that 1:5000 would be the best scale to use, for when costs are considered it seems quite evident that the larger scale photographs do not pay. With costs taken into account, it seems likely that the largest scales practicable would be 1:12,000 or 1:15,000.

Results of this study further indicate that when aerial photographs are used in conjunction with the collection of ground data, large scale photographs do not pay their way. Likewise, the indications are that an intensive use of photographs is not practical. In conducting a detailed and accurate cruise there is too much information which is not obtainable from the photographs and must be gotten from the ground. The most efficient use of the photographs, then, consists of obtaining area estimates and controlling the collection of the ground data. For this purpose medium scale photographs appear to be more efficient in relation to their cost than do large scale photographs. It is evident that the photographs can be used to obtain the areas of various timber types more quickly and more accurately than such information can be obtained from the ground. Results of this study have shown that the volumes of the various types can be estimated from the photographs with sufficient accuracy to enable the ground work to be distributed in proportion to volumes or values, and that this will result in a more efficient cruise. Moreover, evidence obtained in this study indicates that the expected variation of the ground plots can be estimated from the photographs with reasonable accuracy, and thus aid in determining the proper number of ground plots for any desired standard accuracy. The reduction in the required number of plots for a given accuracy, caused by the stratification of the plots by the photographs, may be expected to be in the neighborhood of 60 or 70 percent.

Several other incidental conclusions may be drawn from the results of this study. The chief errors in photo-interpretation seemed rather consistently to be those of density estimation and of species composition percentages. The latter is not such a serious factor in the total volume estimate but the former is, and further study on methods of density determination seems indicated.

The best tests that could be made of the available volume tables indicate that errors of about 5% to 10% may be expected from this source. In general, better results were obtained from the stand volume tables than from the individual tree tables. This is probably due to the fact that the counting of trees from aerial photographs is generally subject to large errors.

Based on the results of this study, certain recommendations regarding further experimentation along this line may be made. It is realized that, because of the small size of the area involved, the results of this study are not decisive but only indicative. The first recommendation, then, is that a similar check of various types of cruise be carried out on a larger area if possible.

It is recommended that the direction of this further study trend towards testing extensive uses of medium scale photographs in controlling the collection of ground data. Particular emphasis should be placed on testing some sort of photo-plot cruise. Although an intensive use of good large scale photographs was not adequately tested in this study, indications are that the expense will outweigh the value. There is a possible use of this system for small valuable areas and for this reason it may be worth while to test a good set of large scale photographs on a small area. But it seems fairly certain that the large expense involved will preclude their use on any but such areas.

SUMMARY

The purpose of this study was to provide some concrete checks of several types of aerial volume cruise against known volumes in order to better understand the use of aerial photographs in forest mensuration, and to indicate directions for further experimentation. To accomplish this purpose four aerial volume cruises were made of a 133-acre forest tract in central Massachusetts. A 100% ground cruise was also made to provide a check for the aerial cruises and along with this an 11% ground plot cruise was also made to provide information for incorporation into the aerial cruises. Results of the aerial cruise volume estimations were compared with the ground cruises and with each other. An effort was made to determine the chief errors involved.

Results indicate that aerial volume estimates of small areas can be made with errors consistently less than 15% and often less than 10%. The use of aerial photographs to control the collection of ground data results in a 60 to 70 percent reduction in the amount of ground work required for the same accuracy by a straight ground plot cruise. For this purpose the indications are that a fairly extensive use of medium scale photographs is cheaper for a given accuracy than an intensive use of large scale photographs. It has been determined that volume estimations from an extensive use of medium scale photographs are sufficiently accurate to enable ground plots to be distributed in proportion to type volumes, and, furthermore, that such a distribution definitely produces more accurate results than a distribution of plots in proportion to type areas. In addition, there is promise of being

able to estimate with reasonable accuracy the expected variance of ground plots by checks on the aerial photographs.

It is recommended that additional work of a similar nature be carried out on a larger area and that the emphasis be placed upon extensive uses of medium scale photographs.