PREPARATION OF AERIAL TREE VOLUME TABLES FOR OLD-GROWTH PONDEROSA PINE

by

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FOR

OLD-GROWTH PONDEROSA PINE

INTRODUCTION

According to the Timber Resource Review (T.R.R.), the estimated timber consumption for the year 2000, will be between 18 and 22 billion cubic feet, as compared to the 1952 consumption of 12.2 billion cubic feet (43, p. 123). The T.R.R. (43,p. 128) also states that, "these potential demands pose a tremendous challenge to American forestry."

To meet this challenge, our forests will have to be more intensively managed in the future than they have been in the past. One of the first steps in developing a sound timber management plan is to make an inventory of the resource which is to be put under management. Timber inventories are expensive and should be kept up to date by making re-inventories at short intervals.

During the past few years, foresters have made increasing use of the vertical aerial photograph as a tool to aid them in their work of managing forest resources. One of the major forestry uses has been in forest inventory work. Bradshaw (4, p. 29), in a report to the International Society of Photogrammetry, said, "Probably more persons are directly and indirectly doing aerial photo-interpretation in connection with forest inventories than in any other field of resource inventory."

Dr. J. R. Dilworth (5); Head of the Forest Management Department, Oregon State College, has this to say about aerial photo cruising:

> "There are two main approaches to the problem of aerial cruising. The first is to use the photos for type mapping and in the preparation of the planimetric map. The type map is then used to stratify the timber so that a satisfactory sampling plan can be developed for ground estimation. The second method is the estimation of timber volume directly from the photos through the use of aerial photo volume tables or stereograms."

The proper use of aerial photo timber cruising techniques, in conjunction with some ground work, greatly reduces the time and cost of timber inventorying without sacrificing accuracy. Allison (2) reports that in 1953, aerial photo stand volume tables were used in forest inventory work in central British Columbia. Two years later the same area was cruised by conventional ground methods and there was no significant difference between the two cruises. The aerial photo cruise was accomplished in only 7½ percent of the time and at 12 percent of the cost of the ground cruise.

It should be kept in mind that at the present time, aerial photo cruising is not intended to completely replace ground cruising methods. The best results are obtained by the judicious combination of aerial and ground cruising techniques.

The use of aerial photos in forestry in the Northwest is relatively new. Wood (50, p. 477) states that:

"As late as 1946 photogrammetry and photographic interpretation, as applied to timber problems, was considered by practically all Northwest timber people to be only an interesting experiment. Today (1953) there are very few if any timber owners in the West who do not utilize aerial photography in some phase of their work."

Ponderosa pine (Pinus ponderosa Laws.) is the most popular and versatile softwood lumber in the United States (45). It accounts for 34.8 percent of the western pine region's sawtimber supply (44). The states of Oregon and Washington have 38 percent of the ponderosa pine in the United States (17, p. 2).

Due to the fact that ponderosa pine will play an important part in our future timber economy and that more intensive management will be necessary in the future, it seems that some research is justified in exploring the possibility of developing aerial photo volume tables for ponderosa pine. This is especially true in view of the success of similar studies in the Northwest by Pope (32), 1950 and Dilworth (6), 1956 with second-growth Douglas-fir (Pseudotsuga menziesii Mirb.) and with other species in other parts of the country, as shown by the relatively great number of references pertaining to volume estimation from aerial photos (2, 4, 8, 10, 12, 16, 23, 26, 28, 32, 40, 41, 53).

Aerial photos can be used to a great advantage in determining volume per acre and total area of a stand of timber. Even though area determination is an important aspect of timber cruising, it is outside the scope of this paper and will not be discussed further.

The intensity and method of sampling has a great effect on the accuracy of a cruise regardless of whether the cruise is conducted on the ground or from aerial photos. However, this is a problem in itself and will be mentioned only briefly.

Objectives and Scope of This Study

This study had three main objectives. The first objective was to determine if a good correlation exists between the attributes of a timber stand which can be measured directly from aerial photographs and D.B.H. The direct measurements considered were: Total tree height, crown diameter, and stand density. The second objective was to develop board foot aerial photo tree volume tables for mature and over-mature pure ponderosa pine stands on site IV land for the Deschutes Basin. Meyer (17, p. 10) reports that 75 percent of the ponderosa pine stands in Oregon and Washington are on site IV land. The third and final objective was to test the accuracy and practicability of these tables once they are developed.

Definition of Terms Used

Photogrammetry: Photogrammetry is the science of obtaining reliable measurements from photographs (3, p. 830).

Stand Aerial Photo-volume Table: A stand aerial photo-volume table is a table that shows the per acre (or other unit of area) volume of a stand and is based on one or more stand attributes measurable on aerial photographs. These attributes may include one or more of the following: Average total height, stand density, and crown diameter (6, p. 4).

Tree Aerial Photo-volume Table: A tree aerial photo volume table gives the volume of trees of a given species based on one or more attributes measureable on aerial photos. These attributes are usually crown diameter and tree height (6, p. 4).

REVIEW OF LITERATURE

Historical

The idea of photogrammetry dates back to 1839, when Arago (27, p. 89), a Frenchman, predicted the use of terrestial photography for map making.

In 1845, Aimé Laussedat (27, p. 89), a French Army officer, suggested the application of aerial photographs to mapping and conducted extensive experiments to design a practical method. In 1858, Laussedat (46, p. 23) experimented with a wet plate type aerial camera, first supporting it from a string of kites and later attaching it to a captive balloon. His results were not too successful because of the slow shutter speed of his camera and his inability to keep the camera in a stable position. This resulted in blurred photographs. In 1884, cameras were mounted in free balloons which were propelled by electric motors. This method was not widely used because the oscillation of the free balloon was too great (46, p.24). It was not until 1914 that the Germans solved the problem of rapidly moving the aerial camera by mounting it in an airplane.

In the early 1890's several important developments occurred. In 1890, Deville, a Canadian, constructed the first practical plotting instrument. In 1892, Stolze, a German, discovered the principle of the floating mark and soon thereafter his compatriot Pulfrich developed a practical method of measuring height with floating marks. In 1893, Adams developed the radial line plotting method with its corollary, the slotted templet method (46, p. 24-25).

One of the first attempts to use photogrammetry in forestry was in 1887, when a German forester experimented with the construction of a forest type map using photographs taken from a fixed hot air balloon (42, p. 551). His experiment was in the fall when the foliage of certain hardwood species was turning color. His experiment was only partially successful. Even though species could be identified, area calculations could not be made because the height of the balloon above the ground was not known and the photo scale was highly erratic due to rough topography.

Despite this early start, forest photogrammetry progress was slow. It was not until after World War I that foresters became interested in photogrammetry for forest mapping (42, p. 552). In 1919, Ellwood Wilson (42, p. 552) pioneered aerial mapping in Canada. High obliques were used at first and it was not until 1929 that vertical aerial photos were used in Canada.

Also in 1929, H. E. Seely, another Canadian, used tree heights, estimated from shadows on aerial photographs, and "crude aerial stand volume tables" to approximate timber volumes in forest survey work (42, p. 552).

Meanwhile in Germany the principles of photographic measurements for timber volume estimation were being worked out. As early as 1923, experiments in Germany were conducted in which forest stands were measured photogrammetrically. However, little practical application was found because of the extremely large scales used and the photographic equipment was expensive. The important point is that they laid the basis of many present day techniques such as: (1) the efficiency of parallax measurements of tree height, (2) direct measurement of crown diameter, and (3) the feasibility of preparing volume tables based on these measurements (42, p. 552). Hugershoff was primarily responsible for these accomplishments.

The first American volume tables were constructed in 1946 by Stephen H. Spurr (41, p. 168). Additional studies have been made by Pope, 1950 (32); Moessner, Brunsen and Jensen, 1951 (23); Ferree, 1953 (8); Dilworth, 1956 (6); Worley and Meyer, 1957 (53); Moessner, 1957 (26), and others.

<u>Literature Pertinent to Aerial Photo Volume Tables</u>

Measurements obtained from aerial photographs may be separated into two categories. The first category is direct measurement and includes information which can be measured directly from photographs. The second category is indirect measurement. This category includes information obtained by correlating one or more direct measurements with an indirect measurement. (Obtained from ground observations) In the review of literature these measurements pertinent to aerial volume tables will be discussed individually.

Direct Measurement: Some of the attributes that can be measured directly are as follows:

1. Total height
2. Visible crown diameter
3. Density of stocking
    (a) Individual crown count
    (b) Percent crown closure

Total Height: There are three basic methods for obtaining height measurements from aerial photographs: (1) direct measurement of displacement on single photographs of trees viewed on the oblique, (2) measurements of shadow length, and (3) measurement of parallax differences on stereoscopic pairs of photographs (41, p. 19).

The first method has only limited practical application. Since the displacement is small, the method is limited to either vertical photographs taken with a wide-angle lens at a low altitude or on oblique photographs (41, p. 21). However, under favorable conditions good results can be obtained by this method. Nash, (30) reported some success with this method.

Seely (37) pioneered the shadow method in Canada where it has been used for several years. However, it too has its limitations. Errors are frequently caused by the slope of the ground upon which the shadow falls and only trees next to clearings can be measured

(42, p. 21). Also, the exact time of exposure of the photograph must be known so that the angle of the sun can be calculated (42, p.21). Under favorable conditions this method can yield accurate results. Nash (30) using the shadow method on large scale photographs obtained standard errors of the estimate ranging from 2.2 to 2.5 feet for trees averaging 35 feet in height.

The measurement of parallax differences is the most widely used method and, once it is mastered, yields the most accurate results (42, p. 21). Several different instruments have been designed to measure parallax differences.

More important than the measuring device is the scale of the photograph and the focal length of the camera used to take the photograph (25). Moessner (25, p. 2) studied the effects of the different scales and different focal lengths on the accuracy of height measurements in the Rocky Mountains. His results are shown in Table I.

TABLE I

EFFECT OF PHOTO SCALE AND CAMERA FOCAL LENGTH
ON ACCURACY OF HEIGHT MEASUREMENTS

Scale	Focal Length	Standard Error
1:20,000	8¼ "	10.7 '
1:28,000	5¼ "	5.1 '
1:31,000	6 "	10.8 '

It can be seen that the most accurate results were obtained with shorter focal lengths and larger scales.

Worley and Landis (51, p. 823) studied the accuracy of height measurements with parallax instruments in upland oak forests using scales of 1:12,000 and found the standard error of estimate to be between 8 and 10 feet.

Sammi (36, p. 618-619) using a scale of 1:9,600 and a 12-inch focal length in mixed hardwoods and softwoods measured individual tree heights with an accuracy of only ± 24 percent (at the 5 percent significance level) using differential parallax methods.

Worley and Meyer (52, p. 372) using 1:12,000 scale photographs in upland oaks had a standard error of estimate of 5 to 10 feet on individual height measurements.

Losee (16, p. 752), using the parallax bar on 1:7,200 photos, had an average error of + 0.6 feet, and a standard error of 2.1 feet. On 1:1,200 photos he had an average error of + 2.1 feet and a standard error of 0.5 feet when measuring tree heights. It should be pointed out that Losee's results show a smaller average error with the smaller of the two scales tested, which is not what one would expect. On the other hand, more consistent results were obtained when the larger scale was used. Perhaps these results can be explained by Rodgers (35) who also experimented with height measurements on large scale photos. He pointed out that if the scale of a photo at the ground level is 1 inch equals 100 feet, (1:1,200) then the scale at the top of a 50-foot tree is 1 inch equals 89 feet and the scale at the top of a 100-foot tree is 1 inch equals only 76 feet.

The results of these different studies are not uniform and therefore difficult to evaluate. In view of this, Dilworth (6, p. 10) prepared the following table which gives the expected degree of accuracy for height measurements on good quality photographs provided the base of the tree or stand is visible and the scale of the point of measurement is known.

TABLE II

EXPECTED PRECISION OF TREE HEIGHT MEASUREMENTS

Scale	Average Error
1:10,000 or larger	5'
1:12,000	8'
1:15,840	10'
1:20,000	13'

Spurr and Brown (39) list seven factors that influence the accuracy of height measurement as follows:

1. Film emulsion
2. Scale of photography: The accuracy of tree height measurements is proportional to the scale of the photograph provided that the focal length of the camera and the overlap is not changed.

3. Focal length: The shorter the focal length the more accurate the height measurement is when using any of the parallax difference measuring devices.

4. Time of day: When using the shadow method, the best results are obtained when the shadow is one to two times the height of the tree.

5. Method of measurement: The best all around height measuring device is a parallax measuring instrument in the hands of a skilled operator.

6. Skill of observer: More skill is necessary to master the parallax method. A skilled photogrammetrist will be much more accurate than an unskilled operator.

7. Shape of tree: Trees with small or tapering crowns will be underestimated by all methods because the tip of the crowns will not be resolved on the photograph. Objects with a diameter less than three feet will not resolve on good photos of 1:20,000 scale.

8. Character of forest: More accurate results are obtained when the ground directly below the tree is visible on the photo and does not slope.

To compensate for lack of resolution on different scale photos and various types of crowns, Spurr and Brown (39, p. 720) have worked out the following table of correction factors.

TABLE III

CORRECTIONS FOR TREE HEIGHTS (FEET)
TO BE ADDED FOR LACK OF RESOLUTION

Scale	Tapering Crowns	Normal Crowns	Broad Crowns
1:10,000	2	1	0
1:16,000	$3\frac{1}{2}$	2	$\frac{1}{2}$
1:20,000	5	3	1

<u>Visible Crown Diameter</u>: Crown diameter measurements taken from aerial photographs are not directly comparable with similar measurements taken on the ground. Only that portion of the crown which is visible from directly above can be measured on the photograph. Branches cloaked by, or intermingled with branches from adjacent trees, can not be distinguished. Also, thin and narrow branches will not be resolved on the photograph (41, p. 24). For these reasons crown diameter measurements obtained from photos will be generally less than measurements taken from the ground (41, p.24). However, if ground measurements are taken with this in mind, the ground observer can make allowance for lack of resolution and clocking by other trees and come up with ground measurements comparable to photo measurements. These crown diameter measurements

are referred to as visible crown diameters (V.C.D.) (6, p. 4). There are two devices in common use which are used to make V.C.D. measurements on aerial photos. One is the micrometer wedge (also called shadow wedge) (49, p. 42). The wedge consists of two fine diverging lines marked on transparent material. The most widely used wedges are read in thousandths of an inch. The second device used to measure V.C.D. from the photographs is the dot wedge, which consists of a series of dots on transparent material. Each dot differs in diameter by a constant amount (49). Its use consists of simply matching up one of the dots with the tree crown in question (49). When using either of these wedges it is a simple matter to convert from the wedge reading in thousandths of an inch to V.C.D. in feet. It should be kept in mind that both ground and photo measurements of V.C.D. are only an estimate, although ground estimates are likely to be more accurate (6, p. 12).

Two instruments were mentioned in the literature for measuring crown diameters from the ground. The Nash Scale (29) measures crown diameter directly in feet. However, in order to use it, the operator must be a known distance from the tree and corrections must be made for slope, which requires an abney reading.

Dilworth (6, p. 40) mentioned another instrument. It was a hand level designed to measure right angles and was used to locate points on the ground directly below the edges of the visible crown. Dilworth located four of these points per tree, located in such a manner so that the maximum and minimum visible crown diameters could be measured. An average of the two measurements was used.

Losee (15, p. 752) measured crown diameters on 1:7,200 photos with an average error of - 1.3 percent, ± 9.9 percent. On 1:1,200 photos he had an average error of - 0.3 percent, ± 5.5 percent using the 5 percent significance level. Moessner and Jensen (24, p. 9) classified crown diameters in 4-foot classes on 1:20,000 photos. Spurr (41, p. 25) claims that crown diameters can be consistently classified into 2-foot classes at a scale of 1:12,000, 3-foot classes at 1:15,840, and 5-foot classes at 1:20,000.

Density of Stocking: Density of stocking is usually measured in terms of basal area, which is impossible to measure directly from aerial photographs. To substitute for this measure of density, either crown closure is estimated or crown counts are made. Each method has its advantages and disadvantages.

Crown closure, as defined by Spurr (41, p. 25), is the proportion of the area of the stand covered by the crown of trees. In most cases only the crown closure of the overstory is necessary. However, occasionally the closure of the understory is also considered. One method of estimating crown closure is with the dot grid. This device consists of a series of equally spaced dots printed on transparent material. This grid is placed over the photo and the proportion of dots which fall on tree crowns is an estimate of the crown closure (41, p. 26).

A more satisfactory device appears to be the crown density scale developed by Moessner (20). In use, the scale is placed on the photograph next to the area that is to be estimated for crown closure. The scale is simply slid up and down until the density on the scale corresponds to the density on the photograph. Moessner lists the advantages of this scale as follows:

1. The method is fast.
2. Estimates are more consistent than area computations and dot counts.
3. Little training is required and good estimates are possible by inexperienced men.
4. It is more accurate than ocular estimates made on the ground.

Spurr (41, p. 26-27) says that the following facts must be kept in mind to keep from overestimating crown closure when using the density scale.

1. Image quality: On fuzzy, poor quality photographs crown closure will generally be overestimated.
2. Shadows: Shadows tend to cloak small openings and cause the stand to look more dense than it is.

3. Scale of the photograph: Small openings on small scale photographs will not be resolved on the photo.

The primary disadvantage of using crown closure percent is that it is not free from personal bias.

On the other hand, crown closure will usually be ocularly underestimated on the ground (41, p. 27). The ground observer is apt to give too much emphasis to small spaces between crowns which are normal in fully stocked stands (41, p. 27). It must be remembered that the degree of crown closure is not always the same as normal stocking. For example, ponderosa pine growing on suboptimum sites will not have 100 percent crown closure, even when fully stocked (41, p. 28).

The only instrument mentioned in the literature to measure crown closure on the ground was the "Moosehorn" (33) which was developed in Canada. It was given its name because of its peculiar appearance.

The value of crown closure estimates lies in the fact that crown closure shows a good correlation with stand volume. As a result, stand volume tables can be constructed using crown closure and volume alone, or other variables may be added such as crown diameter and stand height (6, p. 15).

Moessner (26), Spurr (41, p. 28) and Worley and Meyer (52, p. 372) all found that crown closure estimates can be consistently made within 10 percent when using the density scale. The crown closure method of estimating stand density is used in the preparation and use of stand aerial volume tables.

When using or preparing tree aerial volume tables, crown counts are made as a measure of density. Crown counts can also be used as a measure of stand density (6, p. 12). Crown counts are made by simply counting the visible crowns on a given area of the photograph.

The main advantage of the crown count method is that a simple numerical value may be obtained that is relatively free from personal judgement (41, p. 28).

The main disadvantage lies in the difficulty of obtaining an accurate count (41, p. 28). Crown counts can be made with considerable accuracy in open grown stands. In dense stands many trees are not visible because they are overtopped by other trees (6, p. 13).

The two most important factors affecting the accuracy of crown counts are photo scale and density of stocking. Young (54) made a study of this relationship using one-fifth acre plots in mixed pine and hemlock stands. He analyzed his data by using a multiple linear regression formula which he found to be: Percent crowns counted = $30.57 + 114.63\ X_3 + 106,794.83\ X_2$, in which X_3 is the reciprocal of the number of trees[1] per one-fourth acre plot and X_2 is the reciprocal

[1] To a 4 inch D.B. H.

of the scale. The formula yields the following table:

TABLE IV

RELATIONSHIP BETWEEN TREE COUNT,
PHOTO SCALE, AND STAND DENSITY

No. Trees Per Acre	PHOTO SCALE 1:4,000	1:10,000	1:12,000	1:16,000
	PHOTO TREE COUNT			
5	80	64	62	60
10	69	53	51	49
20	63	47	45	43
100	58	42	40	48

It can be seen that the accuracy of the tree count decreases as the density increases and the scale decreases. The highest percentage counted was only 80 percent. This is a relatively low percent, considering the low density and large photo scale. This is undoubtedly due to the low D.B.H. limit and it is logical to conclude that a great majority of the trees not counted were in the small D.B.H. classes which would account for only a small portion of the total volume.

Other factors that influence the accuracy of crown counts are: (1) quality of the print, (2) size and shape of the individual crowns, (3) type of film used, (4) species composition and character of stand, and (5) skill of the interpreter (6, p. 13).

Crown count tests on the Harvard Forest showed the errors were cumulative and counts from photos were always low. The average error was approximately -20 percent on good quality, large scale photos and as high as -50 percent on smaller scale photos (41, p. 29).

Since crown count errors are cumulative and usually negative, it is possible and usually necessary to apply correction factors to compensate for crowns not counted.

<u>Indirect Measurement</u>: Some of the forest stand attributes that are obtained through indirect measurement are as follows:

1. Stem diameter at breast height (D.B.H.)
2. Merchantable tree height
3. Form class
   - (a) Age
   - (b) Site quality
4. Trees not visible

In order to accurately determine the volume of a given tree, the first three of these attributes must be known. The volume of trees not visible is important when volume per acre is wanted. Site quality and age are mentioned because they are factors closely associated with form class.

<u>Stem Diameter at Breast Height</u>: Since D.B.H. can not be measured directly it must be obtained by correlating one or more direct measurement with D.B.H. Several forest photogrammetrists have studied these correlations. The most commonly used independent variables are total height, crown diameter, stand density or all

three.

Spurr (41, p. 169) states that the regression of D.B.H. over V.C.D. is sigmoid (S- shaped). Spurr further states that the standard errors of estimate range from 2 to 4 inches when crown diameter alone is used and that the addition of total height as a second independent variable reduces the standard error from one quarter to one half.

Pope (32) and Dilworth (6, p. 116) agree with Spurr that the addition of total height as a second independent variable along with V.C.D. increases the accuracy with which D.B.H. may be estimated. However, Pope (32), Dilworth (6, p. 116), Ferree (8, p. 18), and Miner (19, p. 491) disagree with Spurr in that they found the regression of D.B.H. over V.C.D. to be linear instead of segmoid.

Miner (19) using crown diameter alone to predict D.B.H. had a standard error of estimate of 1.6 inches and a correlation coefficient of + 0.873 based on 2,491 loblolly pines (_Pinus_ _taeda_ L.).

Dilworth (6, p. 46) using V.C.D. to predict D.B.H. had a standard error of estimate of 1.17 inches with a correlation coefficient of + 0.995 in second-growth Douglas-fir. When using both V.C.D. and total height (T.H.) to predict D.B.H., the standard error of estimate was reduced to 0.824 inches (6, p. 67).

Merchantable Tree Height: It is usually necessary to know merchantable tree heights when standard volume tables are used in conjunction with aerial photo measurements (6, p. 23). Bruce and Girard (10, p. 42) have developed a formula to convert total height to merchantable height, which is: $N = 0.0406H + 0.34$, when N is the merchantable height in 16-foot logs and H is the total height. When using this formula the merchantable height is defined as: Merchantable height equals 50 percent of the scaling diameter of the first 16-foot log, or 8 inches, whichever is greater.

Form Class: Form class must be known when aerial photo volume tables are derived from standard volume tables based on form class. In the Pacific Northwest, the Girard form class is most commonly used. It is defined as the ratio of the scaling diameter of the first standard log in the tree, over D.B.H. (7, p. 107).

Very little has been done to correlate form class with attributes measurable on aerial photos (6, p. 20). Dilworth (6, p. 25) attempted to correlate form class with total height, but the correlation coefficient was only + 0.1005. Dilworth (7, p. 220) shows the relationship between merchantable height in 16-foot logs and average form class for ponderosa pine in the Deschutes Basin. This relationship is based on Mason, Bruce and Girard form class tables.

Because of the difficulty of obtaining form class from aerial photos, most forest photogrammetrists have not considered form class in the construction of aerial photo volume tables.

Site quality and age are both closely related to form class. Site quality classes (18, p. 10) are based on total stand height at a given age. Total height can be measured from aerial photographs, but stand age can not. However, several authors have found that it is possible to correlate such factors as topography, soil, climate, and vegetative cover with site quality (15) (49).

However, site quality of mature and over-mature stands can be measured from aerial photographs because after maturity, stands grow very little in height and the site index curve of height over age flattens out to an almost horizontal line (18, p. 10).

Spurr (40, p. 91) found that trees growing on poorer sites are older than trees of the same height and species growing on better sites and, therefore have a higher form class.

<u>Trees Not Visible</u>: Trees not visible pose a problem only when they account for a substantial part of the volume. This would depend on the situation. In making board foot estimates of saw-timber size stands, the volume included in trees not visible may be very small (6, p. 23). In making cubic foot estimates, trees not visible may account for a larger percent of the volume, since a lower D.B.H. limit is usually used. Correction factors should be applied for trees not visible. Ferree (8, p. 22) found that the volume per acre of trees not visible increased as the stand density increased. He devised a correction factor based on a regression of total volume of trees not visible over total gross volume per plot.

Photo Volume Tables: The first tree aerial photo volume table in the United States was produced in 1946 by Spurr (41, p. 168). It was for white pine (Pinus strobus L.) and the independent variables used were visible crown diameter and total height. The multiple correlation coefficient was + 0.83 (40, p. 302). Spurr (40, p. 303) also produced a stand volume table for white pine. Height was the only independent variable used and the correlation coefficient was 0.937. A test of the table showed an average error of + 8.6 percent on a total of ten stands.

Since 1946, several other photogrammetrists have published reports dealing with aerial photo volume tables. Some of the more prominent authors are; Pope (32), Moessner, Brunsen and Jensen (23), Ferree (8), Gingrich and Meyer (9), Dilworth (6), and Worley and Meyer (53). The results of the work of these authors will be discussed individually.

Pope (32) was the first to develop aerial photo volume tables for second-growth Douglas-fir in the Pacific Northwest. He used data collected on 18 one-fifth acre plots and 1:23,000 scale photos. The independent variables considered were: Total height, crown diameter, crown density, and tree counts. Experimentation with different combinations of independent variables showed that the most reliable results were obtained when total height, crown diameter, and crown density were used to predict volume. When these variables were used, the accuracy when tested against field volumes was within 3 percent when the tests were made on the same site and same degree of stocking. Other tests using poorer sites and lower stocking classes showed that the photo estimates were from 25 to 40 percent low. Pope's conclusion was that the variables used in constructing the tables can be estimated with sufficient accuracy to provide a reliable estimate, provided the table fits the timber. Pope's study would indicate that density of stocking and site index should be considered in the construction of aerial photo volume tables.

Moessmer, Brunsen, and Jensen (24) published a set of aerial photo volume tables in 1951 for hardwood stands in Kentucky. The independent variables used were: Total height, visible crown diameter, and crown cover percent. A photo scale of 1:20,000 was used. As a result of testing the variation among the photo measurements of several interpreters, they decided to group heights into 10 foot height classes, crown density into 20 percent cover classes, and crown diameter into 5 foot classes. The results of a test of these tables, in which 70 photo plots were measured and compared with actual ground volumes are shown in table V.

TABLE V

RESULTS OF VOLUME ESTIMATE TESTS

	Total Volume (Board Feet)	Mean Volume (Per Acre)	Agg. Error
Interpreter A	310,200	4,431±388	+0.05
Interpreter B	295,700	4,224±368	-4.60
Field Estimate	310,000	4,429±548	

In 1953 Ferree (8) develop tree aerial photo volume tables. He used visible crown diameter to predict D.B.H. and then converted these diameters to volumes by using appropriate site class volume tables. Accuracy tests showed that experienced interpreters could obtain an accuracy of ± 30 percent when measuring an individual plot and the accuracy was within 10 percent when several plots were measured.

In 1955 Gingrich and Meyer (9) published their findings on aerial photo stand volume tables in upland oak. They used 93 one-fifth acre plots and 1:12,000 photos. The multiple regression method of analysis was used. Seven independent variables were used. They were: Total height, visible crown diameter, crown cover percent, and various interaction combinations. All terms containing crown diameter proved to be not significant and they finally ended up with only two significant independent variables. They were total height and crown cover percent. This gave a multiple correlation coefficient of + 0.85. The simple correlations found in this study are shown in table VI.

TABLE VI

SIMPLE CORRELATION COEFFICIENTS BETWEEN PLOT VOLUME AND STAND CHARACTERISTICS[2]

		Y	X_1	X_2	X_3
Volume	Y	1.000			
Total Height	X1	0.841	1.000		
Crown Diameter	X_2	0.422	0.519	1.000	
Crown Cover	X_3	0.299	0.186	0.224	1.00

It can be seen that the best correlation exists between height and volume. The addition of crown cover as a second independent variable raised the correlation from 0.84 to 0.85.

Tree counts on photographs showed a very poor correlation with tree counts on the ground. This was attributed to the interlocking character of the hardwood crowns and multiple stemmed trees.

One of the more recent studies in aerial photo cruising was by Dilworth (6) in 1956. His study, like Pope's, was in second-growth Douglas-fir. However, he used the tree volume approach instead of the stand volume approach. He used data collected on 90 one-fifth acre plots on the Oregon State College school forest, plus 350 trees from Pope's study. Some of the significant findings of his study

[2] To a 5 inch D.B.H. limit.

are as follows:

1. Visible crown diameter increased for a given D.B.H. as site quality decreased.
2. Visible crown diameter increased as the density decreased for stands less than 70 percent stocked. In stands with a stocking of 70 percent or more, density had little effect on the V.C.D. - D.B.H. relationship.
3. Geographical location had only a limited effect on the V.C.D. - D.B.H. relationship.
4. A test of the standard aerial photo volume table gave an aggregate difference of - 2.8 percent and a standard error of estimate of 13.4 percent.
5. The average deviation between photo and ground stem counts was + 1.0 and the standard error of estimate was 2.02 trees.
6. The average deviation between photo and ground V.C.D. measurements was - 0.5 and the standard error of estimate was 1.84 feet.
7. The multiple regression method gave more accurate results than the harmonized curve method.
8. The final conclusion was that aerial photo cruising of second-growth Douglas-fir is possible at normal standards of accuracy.

An article on photo stand volume tables by Worely and Meyer (53) was published in 1957. Their study was in upland oak on 1:12,000 photographs of high quality. Total height and crown closure was used to predict volume. A test of accuracy showed a standard error of from 104 to 108 cubic feet per one-fifth acre plot. They concluded that systematic errors were the most serious, and amounted to four times the accidental errors. Because of this, ground control is necessary when making a photo cruise. They further concluded that in their study it would take three to four times as many photo plots to obtain the same accuracy as would be derived from ground plots. It was estimated that 10 photo plots could be measured in the time required to measure one ground plot. Their final conclusion was that aerial photo cruising is both practical and economical.

TABLE VII

SUMMARY OF VARIOUS VOLUME TABLE STUDIES

REPORTER	PHOTO SCALE	NO. PLOTS	INDEPENDENT VARIABLES	AGGREGATE DIFFERENCE	SE[3]
Spurr	1:12,000	10	V.C.D. - T.H.	+ 8.6%	
Pope	1:23,000	18	V.C.D. - T.H.	Within 3.0%	
Moessner	1:20,000	70	V.C.D. - T.H. Crown Closure	- 4.6%	8.3%
Moessner	1:20,000	70	V.C.D. - T.H. Crown Closure	- 0.05%	7.6%
Ferree			V.C.D.	Within 10.0%	30.0%
Gindrich & Meyer	1:12,000	93	V.C.D. Crown Closure		
Dilworth	1:10,000	90	V.C.D. - T.H. Crown Closure	- 2.8%	13.4%
Worley	1:12,000		T.H. - Crown Density		104 cu. ft.

[3] Standard error of the difference.

DATA COLLECTION FOR THIS STUDY

The objectives of this study, as stated earlier,[4] are three fold. The first objective is to determine the correlations between measurable stand attributes and volume. The second and third objectives are to prepare volume tables for ponderosa pine and finally to test their accuracy.

Obviously, the first step is the collection of data. The data for this study are of two types and may be classified into field and office data.

Field Data

All field data were collected on site IV land on the Pringle Falls Experimental Forest, which is located approximately 30 miles south of Bend, Oregon. The information collected consisted of the measurements of individual trees[5] on 50 one-fifth acre circular plots. A total of 363 trees were measured. Of this total it was decided (while in the field) that 292 could be seen from above and consequently would show up on vertical aerial photographs. All plots were taken in stands which had not been cut. The stands were predominatly mature[6] ponderosa pine with some lodgepole pine

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4 See page 3

5 Only trees of sawtimber size were measured (11.0 inch D.B.H. and over)

6 Two-hundred and fifty years and older (17, p. 9)

(Pinus contorta Dougl.) scattered throughout. The majority of the lodgepole pine was in the pole class[7] and does not involve board feet.

Each plot center was accurately pin pricked on the aerial photograph while being viewed through a pocket stereoscope. The plots were not necessarily picked at random. In some cases they were taken at 3-chain intervals on a particular bearing. Other plots were picked because of the ease of identification on the photograph and their degree of stocking. However, for all practical purposes, each individual tree can be considered as being selected at random. An attempt was made to obtain an approximate equal number of plots in each stocking class. The stocking classes are well, medium, and poor as defined by Meyer (18, p. 26) in Technical Bulletin 630.

Following is a list of the data collected on each individual plot:

1. Prism count to determine basal area per acre
2. Information collected for each individual tree
    (a) Total tree height to the nearest one foot (T.H.)
    (b) Diameter breast height to the nearest one-tenth of an inch (D.B.H.)
    (c) Visible crown diameter to the nearest one foot (V.C.D.)
    (d) Tree species

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[7] Between 5.00 inches and 19.99 inches D.B.H.

Plot Measurement Methods: Prism counts were made in the conventional manner (7, p. 192-228) with a four diopter prism as recommended for the type of timber involved (7, p. 199). Plot boundaries were measured with a 100-foot steel tape. Individual tree heights were measured with the conventional percent abney, the distance from the tree being measured. Diameter at breast height was measured with a D.B.H. tape. Dilworth's approach (6, p. 40) to V.C.D. measurement was used. Briefly a hand level designed to measure at right angles was used to locate points on the ground directly below the edge of the tree crown. Measurements between these points to obtain maximum and minimum crown measurements were taken. An average of the two diameters was recorded. Only that portion of the tree which, in the opinion of the observer, would resolve on the photograph was measured.

Vertical panchromatic aerial photographs printed on semi-matte double weight paper were used in the field. All photographs were taken in 1954 with a camera which had a 12 inch focal length lens. The scale of each photo was accurately determined in the field by measuring a base line on the ground and accurately pinpricking the ends of the line on the photo. The photo scales ranged from 1:9,050 to 1:9570.

Office Data

In the office, plot locations were accurately transferred from the photos used in the field to duplicate photos which were printed on glossy single weight paper. A glossy print yields more detail and makes photo measurements more accurate than if semi-matte prints were used. Glossy prints, however, are not practical for field use because they do not stand up under field conditions.

Office data may be separated into two categories. The first category is that information which is measured directly from aerial photographs, by means of standard measuring techniques, and includes the following:

1. Total tree height of the four tallest trees on each plot
2. Visible crown diameter of each tree
3. Number of visible crowns on each plot

The second category is data computed from either field measurements, office measurements, or both and includes:

1. Basal area per acre and therefore density class of each plot
2. Merchantable tree height
3. Site index of each plot
4. Form class of each tree
5. D.B.H. of each tree
6. Board-foot volumes for each tree and plot

Office Measurements: Standard procedures were used in obtaining all photogrammetric measurements. Total tree heights were determined with the aid of an Abrams height finder. Visible crown diameters were measured with a dot wedge (41, p. 24) calibrated in 0.005 of an inch. Knowing the photo scale, it is a simple matter to convert to V.C.D. in feet. A photo tree count is nothing more than the sum of the visible crowns as counted from the photo. The tree counts were made stereoscopically. Photo plot boundaries were determined by placing a piece of transparent material with a circle drawn on it, which represented one-fifth of an acre on the ground, over the plot.

Computed Data: Basal area per acre was computed directly from the prism count. Percent of stocking was determined by comparing the basal area per acre, as determined from the prism count, with the basal area per acre of a fully stocked normal stand as shown in Technical Bulletin 630 (18, p. 13). Percent stocking of each plot is shown in table XXIV of the appendix. The standard categories of density classification were used which are; nonstocked, under 10 percent; poorly stocked, 10 to 39 percent; medium stocked 40 to 69 percent; and well stocked, 70 percent and over (18, p. 24). The distribution of stocking classes in this study turned out to be: Poorly stocked, 15 plots; medium stocked, 21 plots; and well stocked, 14 plots.

Total tree height was converted to merchantable tree height by a formula developed by Bruce and Girard (10, p. 42)[8].

Site index was determined with the aid of table 2 of Bulletin 630 (18, p. 10). Form class was determined from table XX of Dilworth's Log Scaling and Timber Cruising handbook (7, p. 220).

Diameter breast height was obtained from a multiple regression solution using V.C.D. and total height as independent variables and keeping the three stocking classes separate.

Aerial photo tree board foot volume tables were constructed by substituting volume for D.B.H. for a given total height and form class. Mason, Bruce and Girard form class tables were used (10).

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[8] See page 23

DETAILS OF AERIAL PHOTO TREE VOLUME TABLE CONSTRUCTION

It was decided that the tree aerial photo volume table approach would be used. The review of literature revealed that the main objection to the tree approach is that crown counts in most species are not very accurate.[9] The main reasons why the individual tree volume approach was used in preference to the stand volume approach are as follows:

1. Density classification by percent crown cover (stand approach) is not free from personal bias[10].
2. Ponderosa pine characteristically grows in open grown stands, especially mature and overmature timber. More accurate crown counts may be made in open grown stands than in dense stands.
3. Only board foot volumes are considered in this study. Since the lower D.B.H. limit considered is 11.00 inches, it is reasonable to predict that very few sawtimber size trees will not be counted in a crown count.
4. A normal fully stocked ponderosa pine stand often does not have a 100 percent crown closure. This makes visual estimates of crown closure, based on percent

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[9] See page 19

[10] See page 18

closure at a normal stand, more difficult.

5. In ponderosa pine stands there is a great variation in D.B.H., T.H., and V.C.D.

Estimation of D.B.H.

The three things which must be known about a given tree to accurately estimate its volume are merchantable height, D.B.H., and form class. Total height can be measured directly and may be converted to merchantable height if necessary. Estimation of form class has been discussed previously. The real problem is that of estimating D.B.H. This must be done indirectly by correlating one or more measurable attributes with D.B.H. The review of literature revealed that the degree of stocking and site quality have an influence on D.B.H. As previously stated, this study is limited to site IV land. To test the effect of density of stocking the data was separated into three stocking classes. Then simple correlations between V.C.D. and D.B.H., total height and D.B.H., and finally V.C.D. and total height were computed. These correlations are shown in table VIII.

It can be seen from table VIII that the best correlation is between V.C.D. and D.B.H. for each stocking class. The next best correlation is between T.H. and D.B.H. It was interesting to note that the correlation between T.H. and V.C.D. was quite low. These

TABLE VIII

SIMPLE CORRELATION COEFFICIENTS BETWEEN Y AND TREE CHARACTERISTICS X_1, AND X_2

		Well Stocked			Medium Stocked			Poorly Stocked		
		X_1	X_2	Y	X_1	X_2	Y	X_1	X_2	Y
T.H.	X_1	1.00			1.00			1.00		
V.C.D.	X_2	0.41	1.00		0.35	1.00		0.18	1.00	
D.B.H.	Y	0.66	0.75	1.00	0.65	0.73	1.00	0.50	0.73	1.00

correlation coefficients would lead one to believe that if both T.H. and V.C.D. were used to predict D.B.H., the multiple correlation coefficient would be still higher. If the correlation between T.H. and V.C.D. were perfect, nothing would be gained by using two independent variables. However, the correlation was low and it appeared that a multiple regression analysis was in order.

It was interesting to note the relationship of the correlations among the different stocking classes. The correlations between V.C.D. and D.B.H. were about the same for each stocking class. The correlations between both T.H. and D.B.H., and T.H. and V.C.D. decreased as the degree of stocking decreased.

Figure 1 shows the relationship among the three different stocking classes. For each class it shows the regression line of

Y on X_2. Well and medium stocked plots have similar lines of regression while the poorly stocked plots have a somewhat different line of regression. This shows the possibility of combining the data of medium and well stocked plots.

Figure 2 illustrates two things. First, it shows a definite difference between poor stocking and the two other stocking classes, when Y is plotted against X_1. This further indicates that the poorly stocked plots should be kept separate from the other stocking classes. Secondly, Figure 2 shows a slight tendency toward curvilinearity when Y is plotted against X_1. However, the curves were fitted by eye and the evidence of curvilinearity is not conclusive. A test of curvilinearity with X_1 will be discussed in a later section.

Figures 3 and 4 again show the regression line of Y on X_2. They also show the means of D.B.H.'s plotted against V.C.D. classes. These figures showed a smaller indication of curvilinearity than Y on X_1. Therefore, to simplify the multiple regression equation, X_2 was not tested for curvilinearity.

The next step was to decide on a multiple regression equation. In view of the simple correlation coefficients already calculated and the relationships shown on Figures 1 and 4, the following regression equation was decided upon:

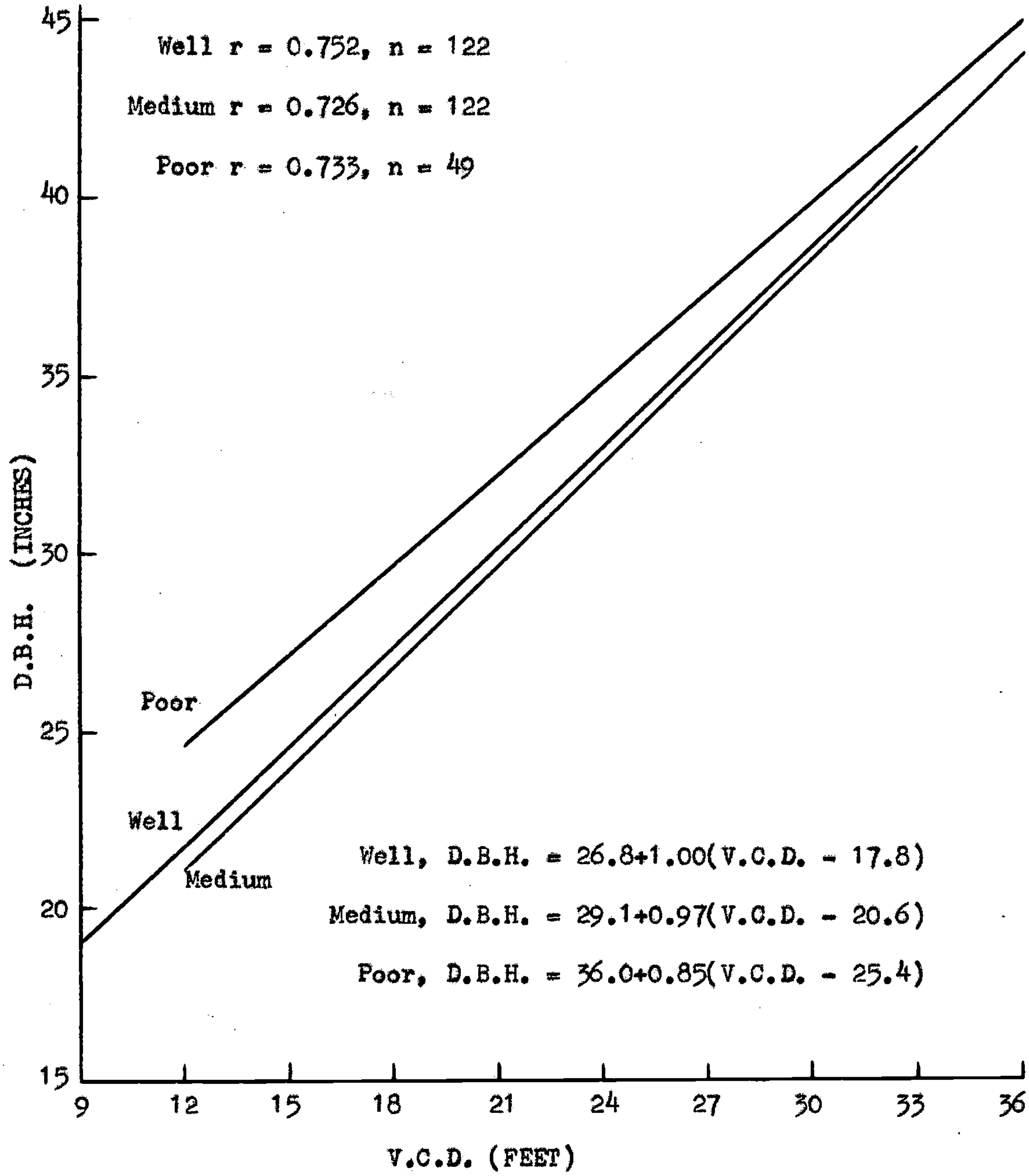

Figure 1. Regression of D.B.H. on V.C.D. for Different Stocked Stands

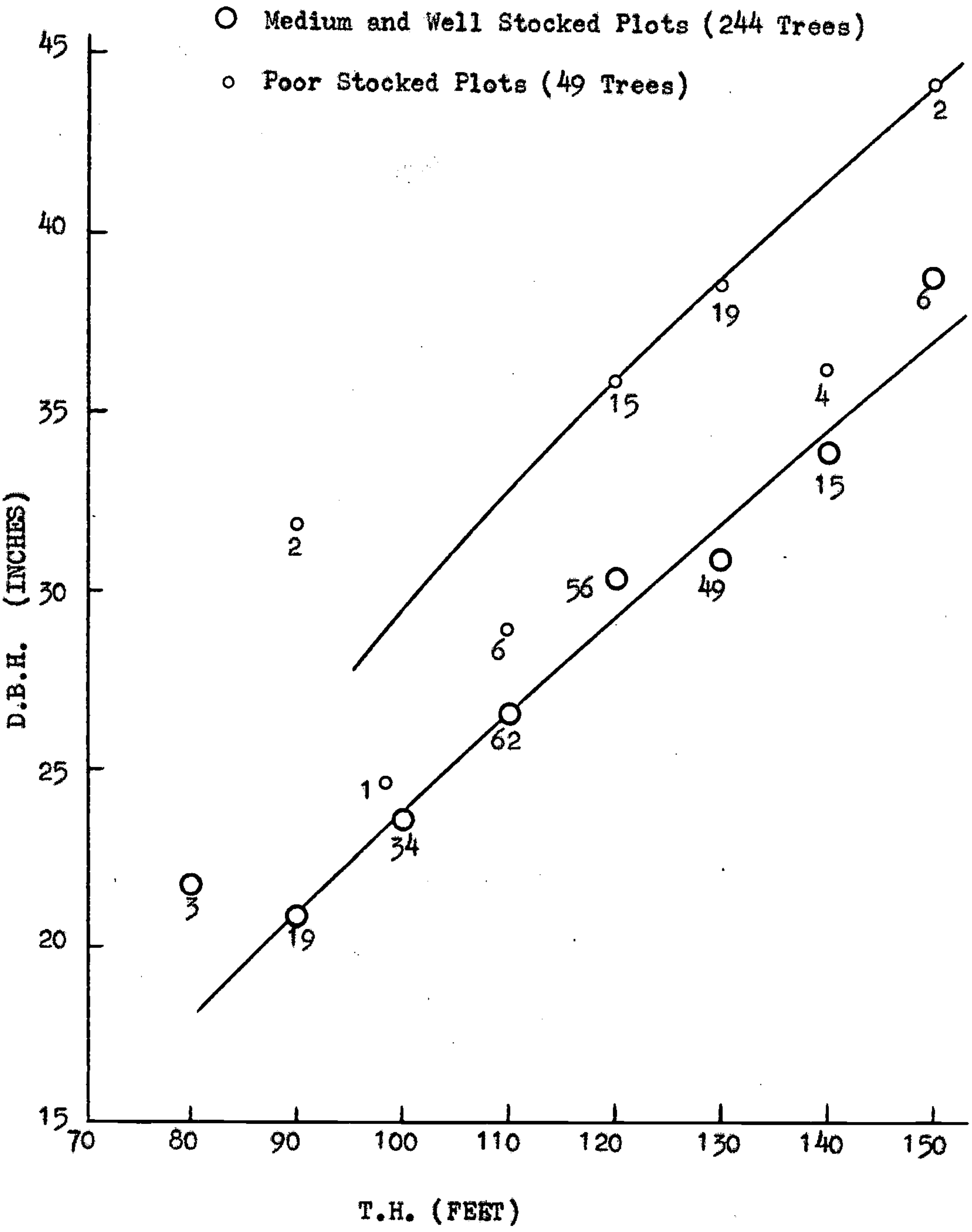

Figure 2. Relationship of D.B.H. Against T.H. for Poorly and Medium and Well (combined) Stocked Stands

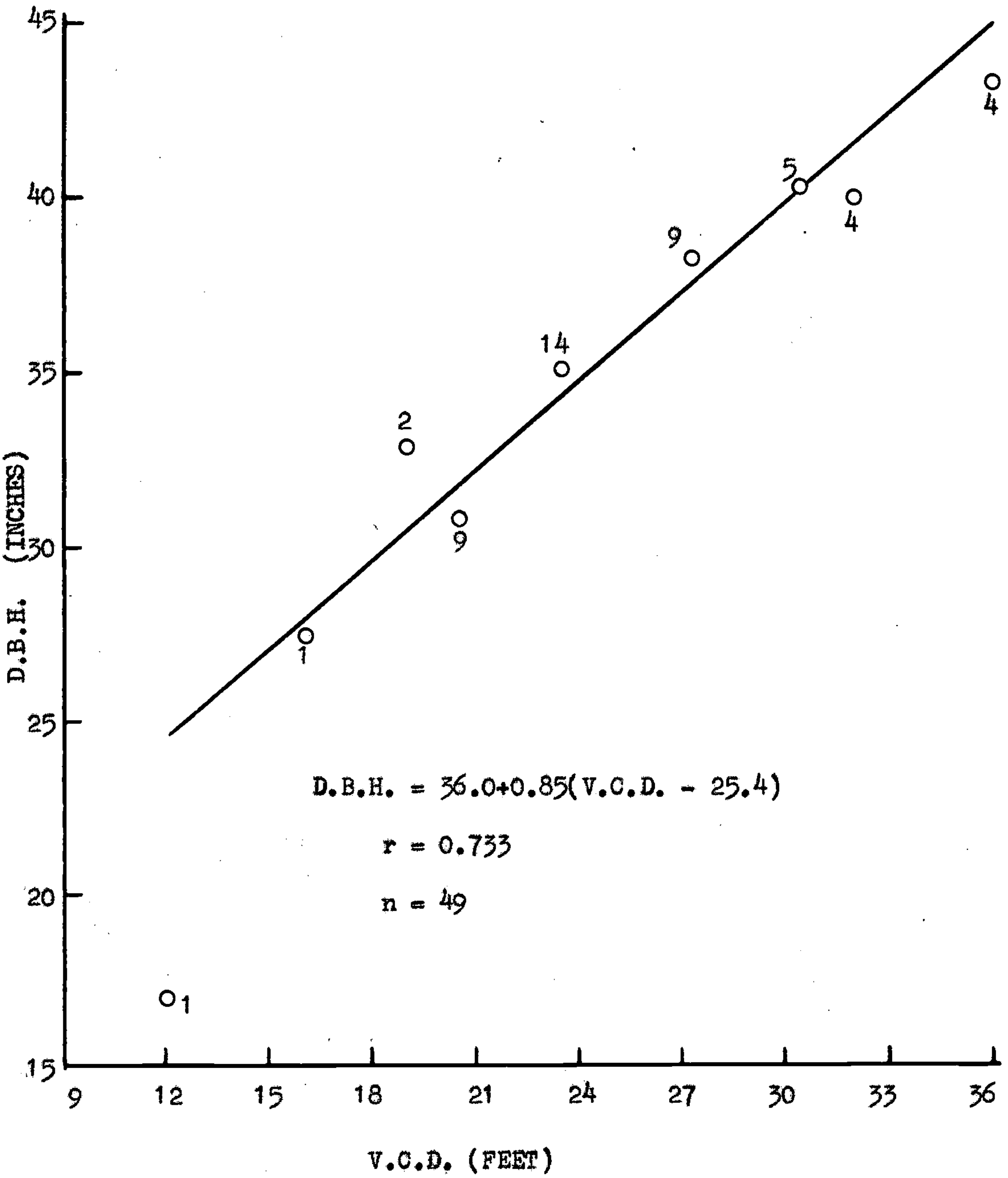

Figure 3. Regression of D.B.H. on V.C.D. for Poorly Stocked Stands

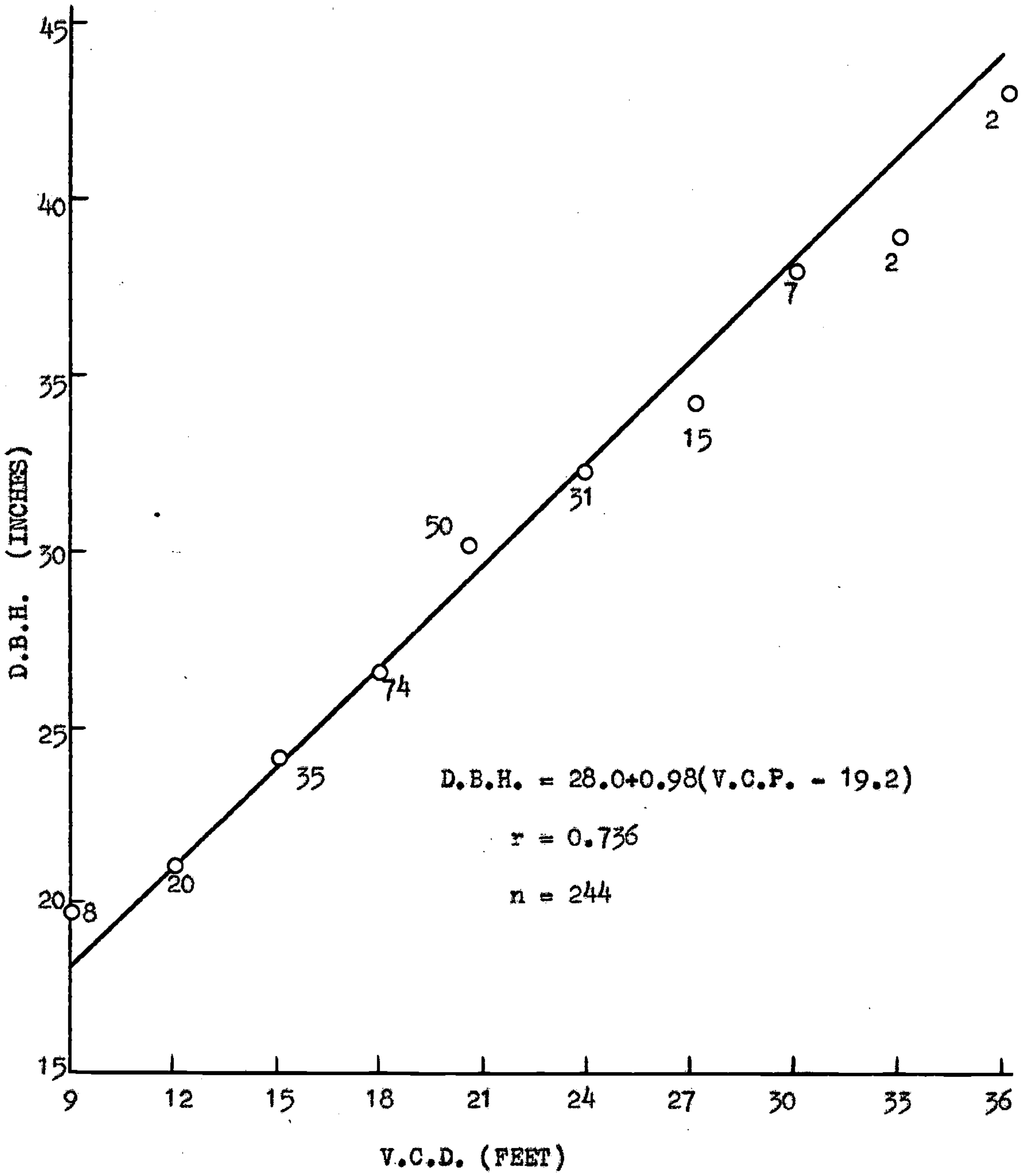

Figure 4. Regression of D.B.H. on V.C.D. for Medium and Well (combined) Stocked Stands

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_2 + b_4X_1^2$$

When: Y = D.B.H.

X_1 = T.H.

X_2 = V.C.D.

b_0 = Intercept

b_1, b_2, b_3, b_4 = Regression Coefficients

After the regression coefficients were determined by the least squares method, they were tested for significance by an F test as shown in table IX. With one exception, the F test showed that all of the regression coefficients were non-significant at the 5-percent significance level. In this case they were not significant because of the high correlation among the independent variables.

Dropping the interaction term caused b_2 to become significant in all stocking classes. However, b_1 and b_5 remained non-significant.

Dropping the b_5 term resulted in b_1 and b_2 becoming significant in all cases. The results are shown in table X. The conclusion is that the line of regression of Y on X_1 and X_2 is linear for each stocking class.

The solutions of the regression equations of Y on X_1 and X_2 for medium and well stocking are shown in tables XXIV and XXV in the appendix. The solution for poorly stocked stands is shown in table XI.

TABLE IX

CONSTANTS IN THE MULTIPLE REGRESSION OF D.B.H. ON T.H. AND V.C.D. FOR THE EQUATION

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_1X_2 + b_4X_1^2$$

WELL STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	-15.895	0.79NS
b_1 (Linear effect of T.H.)	0.2914	0.85NS
b_2 (Linear effect of V.C.D.)	0.9249	2.29NS
b_3 (Interaction)	- 0.001253	0.06NS
b_4 (Curvilinearity effect of T.H.)	- 0.000342	0.05NS

MEDIUM STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	1.627	0.10NS
b_1 (Linear effect of T.H.)	0.0360	0.02NS
b_2 (Linear effect of V.C.D.)	0.6956	1.38NS
b_3 (Interaction)	0.000638	0.02NS
b_4 (Curvilinearity effect of T.H.)	0.000555	0.22NS

POORLY STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	3.358	0.01NS
b_1 (Linear effect of T.H.)	- 0.2888	0.02NS
b_2 (Linear effect of V.C.D.)	0.9091	9.35**
b_3 (Interaction)	- 0.00109	0.23NS
b_4 (Curvilinearity effect of T.H.)	0.00107	0.22NS

** Significant at the 1% level
NS Non-significant at the 5% level

TABLE X

CONSTANTS IN THE MULTIPLE REGRESSION OF D.B.H. ON T.H. AND V.C.D. FOR THE EQUATION

$$Y = b_0 + b_1X_1 + b_2X_2$$

WELL STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	-8.752	10.62**
b_1 (Linear effect of T.H.)	0.1902	56.33**
b_2 (Linear effect of V.C.D.)	0.7735	108.58**

MEDIUM STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	-6.934	7.31**
b_1 (Linear effect of T.H.)	0.1765	58.59**
b_2 (Linear effect of V.C.D.)	0.7647	141.64**

POORLY STOCKED

COEFFICIENT	CONSTANT	F VALUE
b_0 (Intercept)	-8.765	2.39NS
b_1 (Linear effect of T.H.)	0.2039	19.20**
b_2 (Linear effect of V.C.D.)	0.7704	61.92**

** Significant at the 1% level
NS Non-significant at the 5% level

Figure number 5 shows the relationship between D.B.H. and V.C.D. among the three different stocking classes for the 90, 120, and 150-foot height classes. The slope of each stocking class is about the same. It can be seen that the regression lines for medium and well stocked stands are similar, while the regression line for poorly stocked stands is consistently above the other two. For this reason the data for medium and well stocked stands was combined and a new regression equation was calculated. The regression solution for the combined medium and well stocked stands is shown in table XII. It can also be observed from Figure 6 that any error made by combining the two stocking classes are negligible for the 120-foot height class (mean height). The regression lines are identical. Errors in other height classes are in different directions. For heights above the 120-foot height class, the regression equation for well stocked stands yields a higher value than for medium stocked stands. Just the reverse is true for heights below the 120-foot height class.

Preparation of Standard Aerial Tree Volume Tables:

It is a simple matter to convert tables XI and XII to volume tables by simply substituting volume for D.B.H. for the appropriate height class. These tables are number XIII and XIV respectively, and expressed graphically in Figures 6 and 7. In this study standard volume tables developed by Bruce and Girard (10) based on total height

TABLE XI

REGRESSION SOLUTION OF D.B.H. ON V.C.D. AND T.H.
FOR PONDEROSA PINE TREES IN POORLY STOCKED STANDS
ON SITE IV LAND

V.C.D.	TOTAL HEIGHT (FEET)							
FEET	80	90	100	110	120	130	140	150
	D.B.H. IN INCHES							
9	14.5	16.5	18.6	20.6				
12	16.8	18.8	20.9	22.9	24.9	27.0	29.0	
15	19.1	21.1	23.2	25.2	27.3	29.3	31.3	
18	21.4	23.5	25.5	27.5	29.6	31.6	33.6	35.7
21	23.7	25.8	27.8	29.8	31.9	33.9	36.0	38.0
24	26.0	28.1	30.1	32.2	34.2	36.2	38.3	40.3
27	28.3	30.4	32.4	34.5	36.5	38.5	40.6	42.6
30	30.6	32.7	34.7	36.8	38.8	40.9	42.9	44.9
33			37.0	39.1	41.1	43.2	45.2	47.2
36			39.3	41.4	43.4	45.5	47.5	49.6
39				43.7	45.7	47.8	49.8	51.9
42					48.0	50.1	52.1	54.2

Based on 49 trees

Figures not enclosed are extrapolated values

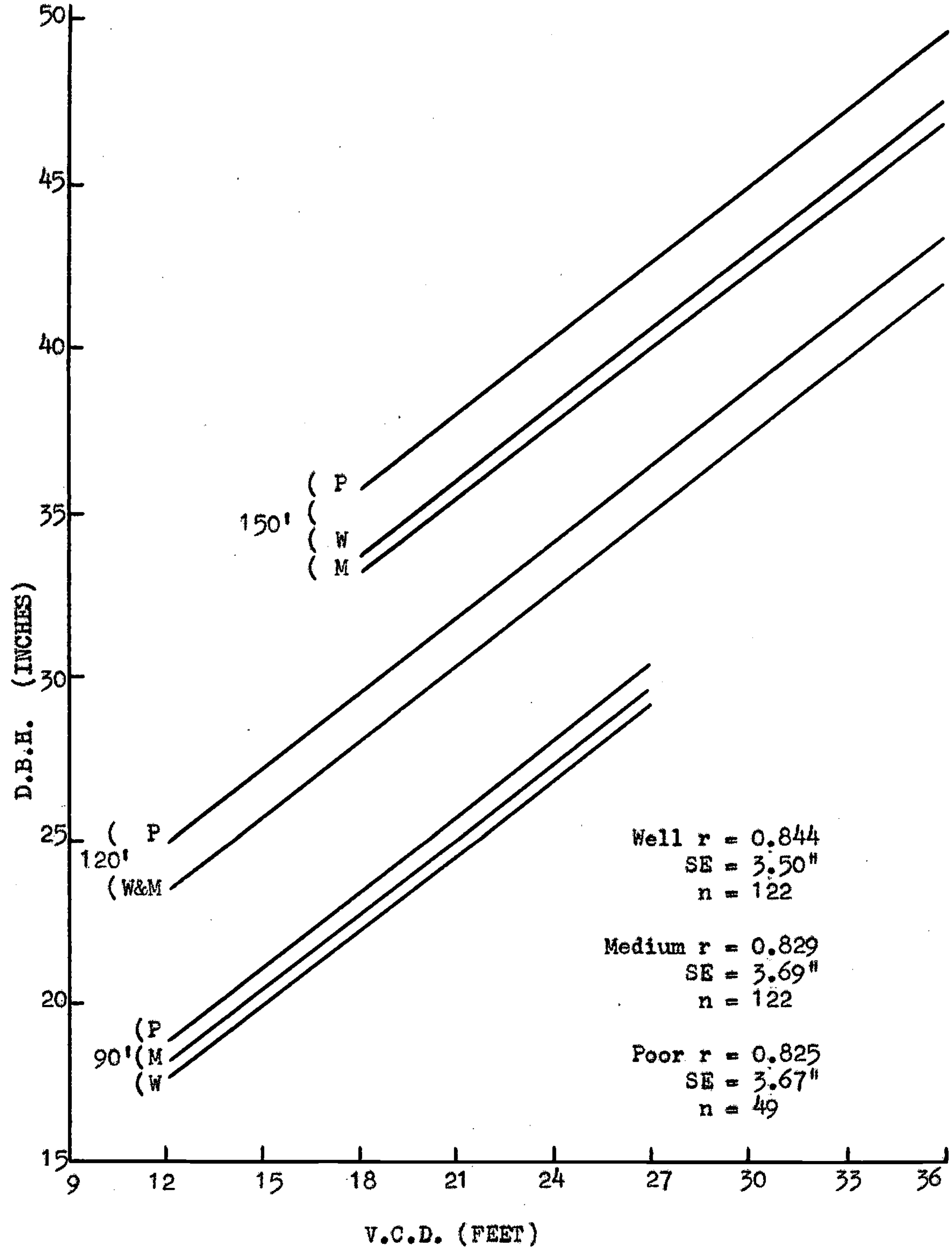

Figure 5. Regression of D.B.H. on V.C.D. to Show the Relationship Among Stocking Classes for 90, 120, and 150 Foot T.H. Classes

TABLE XII

REGRESSION SOLUTION OF D.B.H. ON V.C.D. AND T.H.
FOR PONDEROSA PINE TREES IN MEDIUM AND WELL STOCKED STANDS
ON SITE IV LAND

V.C.D. FEET	TOTAL HEIGHT IN FEET 70	80	90	100	110	120	130	140	150
	D.B.H. IN INCHES								
6		11.4	13.3	15.1	16.9	18.7	20.5	22.4	
9	11.9	13.7	15.6	17.4	19.2	21.0	22.9	24.7	26.5
12	14.2	16.1	17.9	19.7	21.5	23.3	25.2	27.0	28.8
15	16.6	18.4	20.2	22.0	23.8	25.7	27.5	29.3	31.1
18	18.9	20.7	22.5	24.3	26.2	28.0	29.8	31.6	33.4
21	21.2	23.0	24.8	26.7	28.5	30.3	32.1	33.9	35.8
24	23.5	25.3	27.2	29.0	30.8	32.6	34.4	36.3	38.1
27	25.8	27.6	29.5	31.3	33.1	34.9	36.8	38.6	40.4
30			31.8	33.6	35.4	37.2	39.1	40.9	42.7
33			34.1	35.9	37.7	39.6	41.4	43.2	45.0
36				38.2	40.1	41.9	43.7	45.5	47.3
39					42.5	44.2	46.0	47.8	49.7
42					44.7	46.5	48.3	50.2	52.0

Based on 244 trees

Figures not enclosed are extrapolated values

TABLE XIII

STANDARD TREE PHOTO VOLUME TABLE
FOR MATURE PONDEROSA PINE IN POORLY STOCKED STANDS
ON SITE IV LAND

V.C.D.	TOTAL HEIGHT IN FEET							
FEET	80	90	100	110	120	130	140	150
	BOARD FEET TREE VOLUMES (SCRIBNER)							
9			388	538	742			
12			510	685	922	1220	1570	
15	308	459	647	850	1130	1460	1850	
18	403	587	799	1030	1350	1720	2160	2630
21	508	724	967	1230	1590	2000	2500	3000
24	625	874	1150	1450	1840	2310	2860	3400
27	755	1040	1350	1690	2120	2630	3230	3820
30	897	1230	1570	1940	2420	2990	3630	4270
33			1800	2200	2730	3350	4050	4740
36			2040	2490	3060	3740	4500	5260
39				2790	3410	4150	4970	5780
42					3780	4580	5450	6330

Developed from Table XI and standard volume tables (10)

Volume is in board feet (Scribner) from a one foot stump to a merchantable top limit of 50 percent of the scaling diameter of the first 16-foot log or eight inches, whichever is greater. Values not enclosed are extrapolated

TABLE XIV

STANDARD TREE PHOTO VOLUME TABLE
FOR MATURE PONDEROSA PINE
IN MEDIUM AND WELL STOCKED STANDS

V.C.D. FEET	TOTAL HEIGHT IN FEET — BOARD FEET TREE VOLUMES (SCRIBNER)								
	70	80	90	100	110	120	130	140	150
6		65	138	226	332	469	656	888	
9	69	128	218	328	457	627	847	1100	1380
12	123	201	311	444	590	795	1050	1340	1650
15	188	281	416	573	748	986	1270	1610	1960
18	258	373	532	717	927	1190	1520	1890	2280
21	339	474	662	884	1120	1420	1780	2210	2640
24	429	589	813	1060	1320	1670	2060	2550	3020
27	530	714	979	1250	1550	1930	2390	2910	3410
30			1140	1460	1790	2210	2720	3280	3840
33			1340	1680	2040	2539	3070	3690	4290
36				1920	2320	2850	3430	4110	4760
39					2640	3180	3830	4560	5280
42					2930	3540	4240	5040	5800

Developed from Table XII and standard volume tables (10)

Volume is in board feet (Scribner) from a one foot stump to a merchantable top limit of 50 percent of the scaling diameter of the first 16-foot log or eight inches, whichever is greater. Values not enclosed are extrapolated and form class were used. Table XIV shows the form class used for each total height class. This table was developed with the aid of Table XX of Dilworth's Log Scaling and Timber Cruising handbook (7, p. 220) and a formula for converting the total height to merchantable which was developed by Bruce and Girard (10, p. 42).[11]

TABLE XV

RELATIONSHIP BETWEEN
FORM CLASS AND TOTAL HEIGHT

Total Height	70'	80'	90'	100'	110'	120'	130'	140'	150'
Form Class	78	79	81	82	83	83	84	85	85

The particular set of tables used is not as important as the method involved. Since the D.B.H. can be predicted, other types of volume tables could be converted to aerial photo volume tables; for example, volume tables based on site, local volume tables, or even cubic foot tables. However, in this study, only trees of sawtimber size were considered and cubic foot tables usually go below the 11.00 inch D.B.H. limit.

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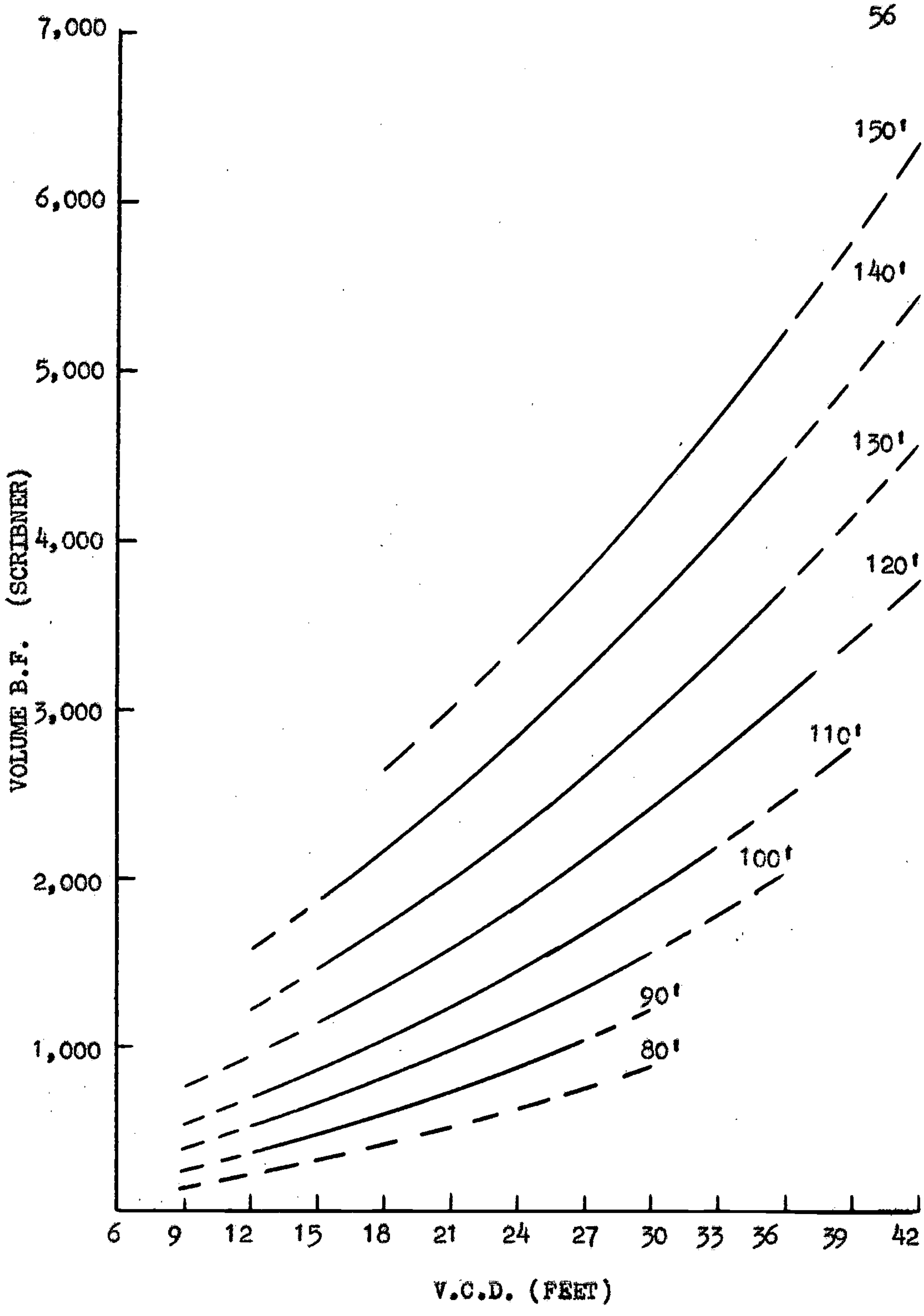

Figure 6. Volume Against V.C.D. for Different T.H. Classes for Poorly Stocked Mature Ponderosa Pine Stands on Site Four Land

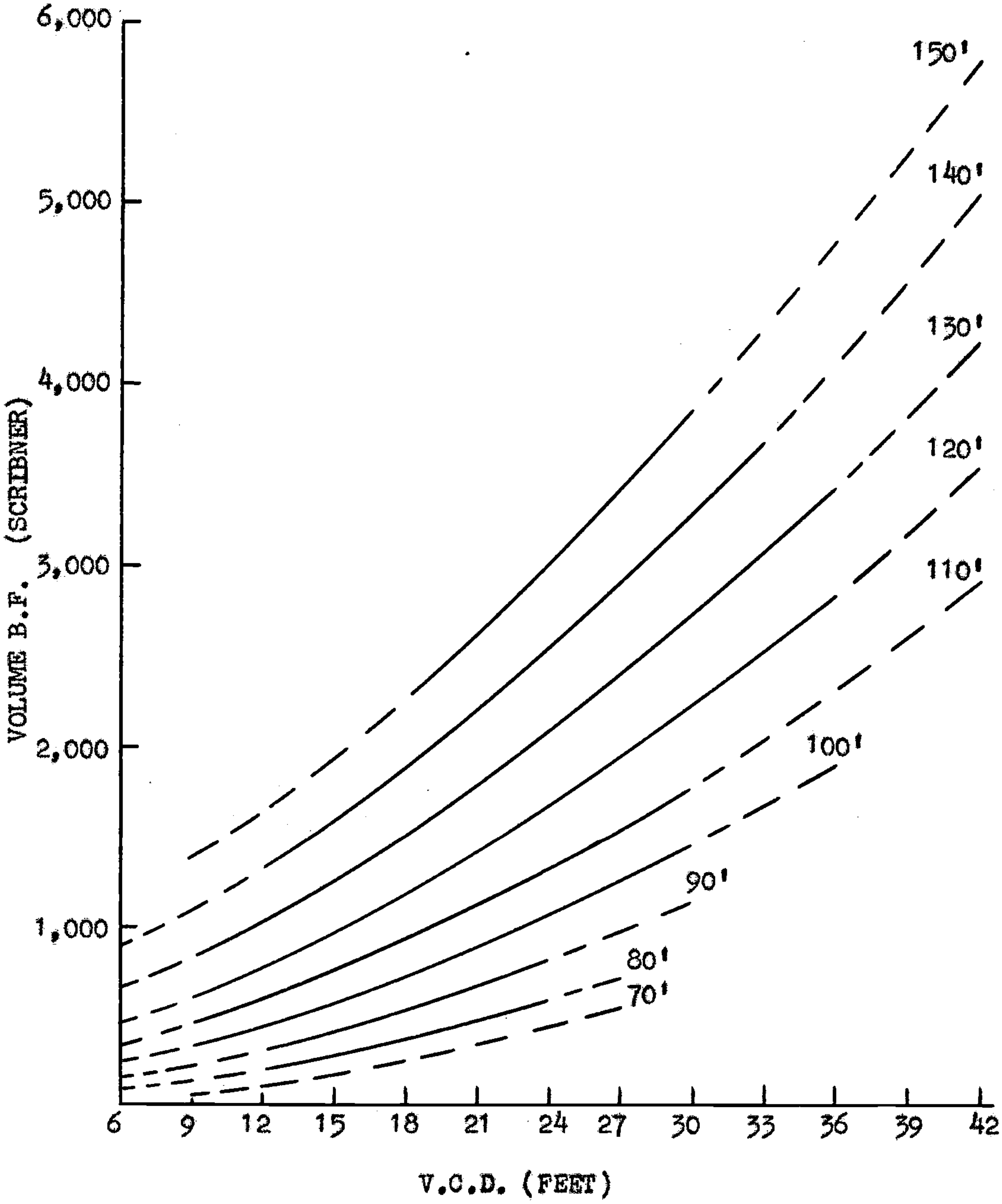

Figure 7. Volume Against V.C.D. for Different T.H. Classes for Medium and Well Stocked Mature Ponderosa Pine Stands on Site Four Land

ACCURACY OF PHOTO MEASUREMENTS

The accuracy of photo measurements which can be expected for various scales of photography is covered in the review of literature. The accuracy varies with each different set of conditions and each interpreter. In this study a test of the author's accuracy of measurements was made by comparing photo measurements with field measurements.

Visible Crown Diameter Measurements

Table XVI shows the results of comparing 240 photo V.C.D. measurements with corresponding field V.C.D. measurements. It should be kept in mind that errors in field measurements are quite possible, however it is felt that field measurements are more accurate than the photo measurements.

TABLE XVI

ACCURACY OF PHOTO V.C.D. MEASUREMENTS

STOCKING CLASS	NO OF TREES	MEASUREMENTS FIELD	MEASUREMENTS PHOTO	MEAN DIFFERENCE	STANDARD ERROR OF DIFFERENCE
		FEET		FEET	
Well	88	17.75	17.44	- 0.31	1.75
Medium	106	20.62	20.30	- 0.32	1.99
Poorly	46	25.41	25.13	- 0.28	1.87
All	240	20.07	19.76	- 0.31	1.88

Spurr (41, p. 25) states that at the scale of photography used in this study, V.C.D. measurements may be accurately classified into 2-foot height classes. Three-foot height classes were used in this study. Table XVI shows that at one standard deviation, the accuracy of photo V.C.D. measurements are well within these limits.

Total Height Measurements:

Table XVII shows the results of comparing photo measured heights with field measured heights. This table is based on a comparison of the heights of the four tallest trees on 36 of the original 50 plots.

TABLE XVII

ACCURACY OF TOTAL HEIGHT MEASUREMENTS

STOCKING CLASS	NO OF TREES	MEASUREMENTS FIELD	MEASUREMENTS PHOTO	MEAN DIFFERENCE	STANDARD ERROR OF DIFFERENCE
		FEET		FEET	
Well	48	122.65	123.58	0.93	7.58
Medium	46	120.00	120.37	0.37	7.86
Poorly	38	123.24	121.77	1.47	7.95
All	132	121.89	121.94	0.05	7.78

The aggregate difference is quite low. This is because a correction factor has been made for the author's systematic error of approximately - 10 feet. Each interpreter has a different systematic error. It is felt that very little of this negative error is due to lack of crown resolution on the photo. Table III[12] shows a zero correction factor for 1:10,000 photos with broad crowns. The important part of Table XVII is the column showing the standard error of estimate. In each case the standard error of estimate is less than the 10-foot height classes used in this study. A more experienced interpreter would probably have even a smaller standard error of estimate. Spurr (41, p. 23) states that a skilled interpreter should have a standard error of estimate of not more than 5 feet on 1:15,840 photos.

Crown Counts:

In this study only those crowns were counted which, in the opinion of the field observer, would be interpreted by the photogrammetrist, as belonging to trees of sawtimber size. The best indication an interpreter has in separating sawtimber from pole timber is total height and, to some extent, crown size. As a consequence several short trees, just barely in the sawtimber class, were not included in the photo count because they were thought to be of pole timber size. This caused a much lower crown count than expected. If all visible crowns, regardless of size or tree height, had been counted from the photos, a large positive error in crown count would have been made. This would have caused a large positive error in volume estimation. The alternative is to count only those

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trees which appear to the interpreter as sawtimber. Even though a relatively large negative error was made on the photo count, it accounted for only a small percentage of the total volume. This is because the trees not counted were quite small, containing little volume. Table XVIII shows the results of the crown count tests.

TABLE XVIII

ACCURACY OF CROWN COUNTS[13]

STOCKING CLASSES	TOTAL CROWNS OF SAWTIMBER SIZE	PHOTO CROWN COUNT ERRORS		
		NO OF TREES	PERCENT	
			TREES	VOLUME
Well	149	-27	-18.1	-3.45
Medium	146	-24	-16.4	-1.74
Poorly	68	-19	-28.0	-1.87
All	363	-70	-19.3	-2.35
Medium & Well	295	-51	-17.3	-2.52

It can be observed from Table XVIII that this approach does not involve a large percentage error in volume. There is a second category of trees not counted. This category consists of sawtimber trees whose crowns are visible but not counted because they could not be separated from crowns of other trees growing in clumps. This is another negative crown count error in addition to those errors shown in Table XVIII. These errors are shown in Table XIX.

13 Crowns not counted because they were either not visible or thought to be of pole size.

TABLE XIX

ACCURACY OF CROWN COUNTS[14]

STOCKING CLASSES	TOTAL CROWNS OF SAWTIMBER SIZE	PHOTO CROWN COUNT ERRORS		
		NO OF TREES	PERCENT	
			TREES	VOLUME
Well	149	-11	-7.4	-5.64
Medium	146	- 5	-3.4	-3.38
Poorly	68	- 2	-2.9	-1.24
All	363	-18	-5.0	-3.48
Medium & Well	295	-16	-5.4	-4.48

This category of crown count errors is smaller in percentage of crown counts than those errors shown in Table XVII. However, the error in volume is greater because in this case the trees not counted are larger. The volume errors in Table XIX are partially compensated for. This is because when two trees are counted as one, the V.C.D. measurement is that of one large crown instead of two small crowns. This has a partial compensating effect. For example, consider two trees with 18-foot crowns, 120 feet tall in a medium stocked stand. If they are counted as two trees, the volume from Table XV, is 1838 board feet. The combined area of the crowns of these same two trees is approximately 510 square feet. If the combined area of the crowns of these same two trees were counted as one, the resulting V.C.D.

14 Crowns not counted because two or more crowns were counted as one.

would be 26 feet. The volume of a 120 foot tree with a 27 foot crown is 1550 board feet. The loss is 16 percent and not 50 percent. This makes it quite difficult to determine exactly what percent of volume is lost due to tree crowns not counted. Because of this and other variables, one correction factor will be made that takes all errors into consideration. This correction factor is discussed later.

ACCURACY OF VOLUME TABLES

Spurr (41, p. 75) states that there are three parameters which indicate the precision of volume tables. They are: (1) aggregate differences, (2) standard error of estimate, and (3) correlation coefficients. Aggregate difference should not exceed one percent in standard volume tables (41, p. 75). The standard error of estimate should not exceed 12.5 percent for standard volume tables (6, p. 85). With this in mind, Dilworth (6, p. 86) set standards of precision for photo volume tables. These standards are summarized in Table XX.

TABLE XX

STANDARDS OF PRECISION FOR VOLUME TABLES

TYPE OF TABLE	AGGREGATE DIFFERENCE	STANDARD ERROR OF ESTIMATE (%)
Standard	1.0	12.5
Standard Photo	2.0	15.0
Local Photo	3.0	30.0

According to these standards, the tables developed in this study should have an aggregate difference of not more than 2 percent and a standard error of estimate of not more than 15 percent.

Test No. 1.

In order to test the accuracy of the tables without introducing errors of photo measurement, field measurements of V.C.D. and T.H. were used to predict volume. The data from all 50 plots were used. The results of the test are shown in Table XXI.

TABLE XXI

FIRST TEST OF VOLUME TABLES

TABLE	FIELD VOLUME BOARD FEET	TABLE VOLUME BOARD FEET	AGGREGATE DIFFERENCE(%)	STANDARD ERROR OF ESTIMATE(%)
XVI	111,290	109,386	-1.71	13.95
XV	310,313	304,657	-1.88	15.94

Both Table XIV and Table XV are within the acceptable limits for aggregate differences. The standard error of estimate for Table XIV is also with the acceptable limits and Table XV is only 0.94 percent greater than the limits as set by Dilworth (6, p. 86).

<u>Test No. 2.</u>

In test number two, field measurements were again used. The difference being that an average total height and an average crown diameter was calculated for each plot. From this, the average tree volume was determined from the table and multiplied by the number of trees per plot. The results of this test are shown in Table XXII.

TABLE XXII

SECOND TEST OF VOLUME TABLES

TABLE	FIELD VOLUME BOARD FEET	TABLE VOLUME BOARD FEET	AGGREGATE DIFFERENCE(%)	STANDARD ERROR OF ESTIMATE(%)
XIV	111,290	106,616	-4.2	16.16
XV	310,313	293,557	-5.4	16.88

When this method is used, both the aggregate difference and the standard error of estimate are increased. This increased error is due to the method used, not the volume tables. Even though the first method yields more accurate results, it has its disadvantages. It is much slower because when photo measurements are taken, it is quite difficult to measure each tree separately. It is much easier to take three or four height measurements per plot to establish an average stand height, than it is to measure all tree heights and try and keep the proper height with the proper crown measurement. This method of averaging total heights gives an un-biased estimate only when the regression of D.B.H. on T.H. in linear. The same statement applies to the averaging of crowns. The estimate is un-biased only when the regression of D.B.H. on V.C.D. is linear. In this study both of these relationships are linear.

It may be more economical to settle for a slightly higher standard error of estimate per plot and take more plots. As the number of plots taken per cruise increases, the standard error of estimate decreases. Correction factors may be applied to the aggregate difference once its magnitude is established.

There are two reasons why the aggregate differences are not equal to zero. The first is that even though field measurements were used, the volume tables were constructed to be read by 3-foot V.C.D. classes and 10-foot height classes. These errors, however, are compensating and not too important. The main reason for these negative errors is in the method of constructing the tables. When comparing D.B.H. values from Tables XI and XII with actual D.B.H.'s there will be positive and negative differences, but their sum total is very close to zero. This is not true of the volume tables. An example will serve to illustrate. Consider two trees, both 120 feet tall. The first tree has a 20-inch D.B.H. and the second tree a 30-inch D.B.H. If the D.B.H. of the first tree is overestimated by 4 inches, the overestimation in volume is 288 board feet. If the D.B.H. of the second tree is under estimated by 4 inches, the under estimation in volume is 380 board feet. Even though the D.B.H. errors cancel out, the volume errors do not.

One way to eliminate this is to solve directly for volume in the regression analysis. Going through D.B.H. to establish volume also has an advantage. If D.B.H. is known it is a very simple matter to convert any type of volume table to a photo volume table.

If volume is solved directly from the regression equation, only one type of volume table is produced. To make another type of photo volume table would require another regression analysis. A regression equation which would predict volume would be more complicated because it is known that volume tables are curvilinear.

Test No. 3.

A comparison of heights of the four trees on each plot was made with the average height of all the trees on the plot. The correlation coefficient was 0.94 and the average of the four tallest trees was six feet taller than the average of all trees on the plot. This does not pertain to the poorly stocked plots because if a plot has more than four sawtimber sized trees, it is in the medium or well stocking class.

Since the medium and well stocked plots have been combined into one volume table, there is no need to separate these two stocking classes. If a poorly stocked one-fifth acre plot is considered to have four or less sawtimber sized trees, a test shows that only one plot out of the 50 in this study falls in the wrong category.

In test number three, photo measurements were used. The V.C.D.'s were averaged on the basis of their squares, because volume is directly proportional to the square of the diameter (either D.B.H.

or V.C.D.) (41, p. 175). An average height of the four tallest trees minus six feet was calculated. Then the volume of the average tree was determined from the appropriate table. This volume was multiplied by the photo crown count. The results of this test are shown in Table XXIII. Thirty-six of the 50 plots were used in this test, of which 13 were in poorly stocked stands and 23 were in medium and well stocked stands.

TABLE XXIII

THIRD TEST OF VOLUME TABLES

TABLE	FIELD VOLUME BOARD FEET	TABLE VOLUME BOARD FEET	AGGREGATE DIFFERENCE(%)	STANDARD ERROR OF ESTIMATE PER PLOT(%)
XIV	97,880	93,117	-4.87	17.12
XV	223,338	212,905	-4.64	21.67

The errors in Table XXIII are the combined errors of photo measurement, trees not visible and errors in the aerial volume tables.

CORRECTION FACTORS

Worley and Meyer[15] state that, because of systematic errors, some ground control is necessary so that the magnitude of these errors may be determined and corrections applied to the photo cruise. Spurr (41, p. 416-417) suggests the following method for adjusting photo volumes:

> "The photographic volume estimates are adjusted by the technique of double sampling or regression sampling. The adjustment is based on the plots that have been estimated both on the photographs and on the ground. For these plots, the ground plot volume estimates are plotted over the photographic volume (independent variable) on ground plot volume (the dependent variable) is obtained either graphically or by the least square analysis. The average volume for the stand class obtained from the photographic estimate is adjusted by the use of this regression."

This method of correcting photo plot volumes was tried. The regression coefficients were tested for significance. In each case the hypothesis was that the regression coefficient is equal to zero. The F value for the medium and well stocked regression line of field volume on photo volume was 41.81, indicating a positive slope at the one percent significance level. The F value for the poorly stocked regression line of field volume on photo volume was 4.71, indicating a positive slope at the six percent significance level. More plots

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[15] See page 30

should be taken in poorly stocked stands to better establish the significance of the regression coefficient.

Dr. Lyle D. Calvin, statistician for the Oregon Agricultural Experiment Station, suggested that a different form of correction factor might be more realistic. Dr. Calvin suggested that a restriction be placed on the least squares estimate of the regression of field volume on photo volume. The restriction is that the line of regression is forced through the origin; that is, the zero point for both field and photo volume.

Both of these lines of regression are shown in Figure 8 for the poorly stocked plots and in Figure 9 for the medium and well stocked plots. The advantage of the restricted model can be seen from either Figure 8 or 9. First, the correction factor is always positive and becomes greater as the photo volume becomes greater; whereas the unrestricted model causes the correction factor to positive at lower volumes and negative at higher volumes. It is reasonable to expect that the correction factor should be positive and greater for larger volumes, because as the stand becomes more dense, there is a better chance that more trees will be over topped and, therefore, not seen on the photo. The second point in favor of the restricted model is that there is no correction for a zero photo volume. The unrestricted model shows a positive correction factor of approximately 2,000 board feet for medium and well stocked stands and 4,400 board feet for the

Unrestricted Field Vol. = 7,600 + 0.435(Photo Vol.-7,100)
Restricted Field Vol. = 1.05115(Photo Vol.)

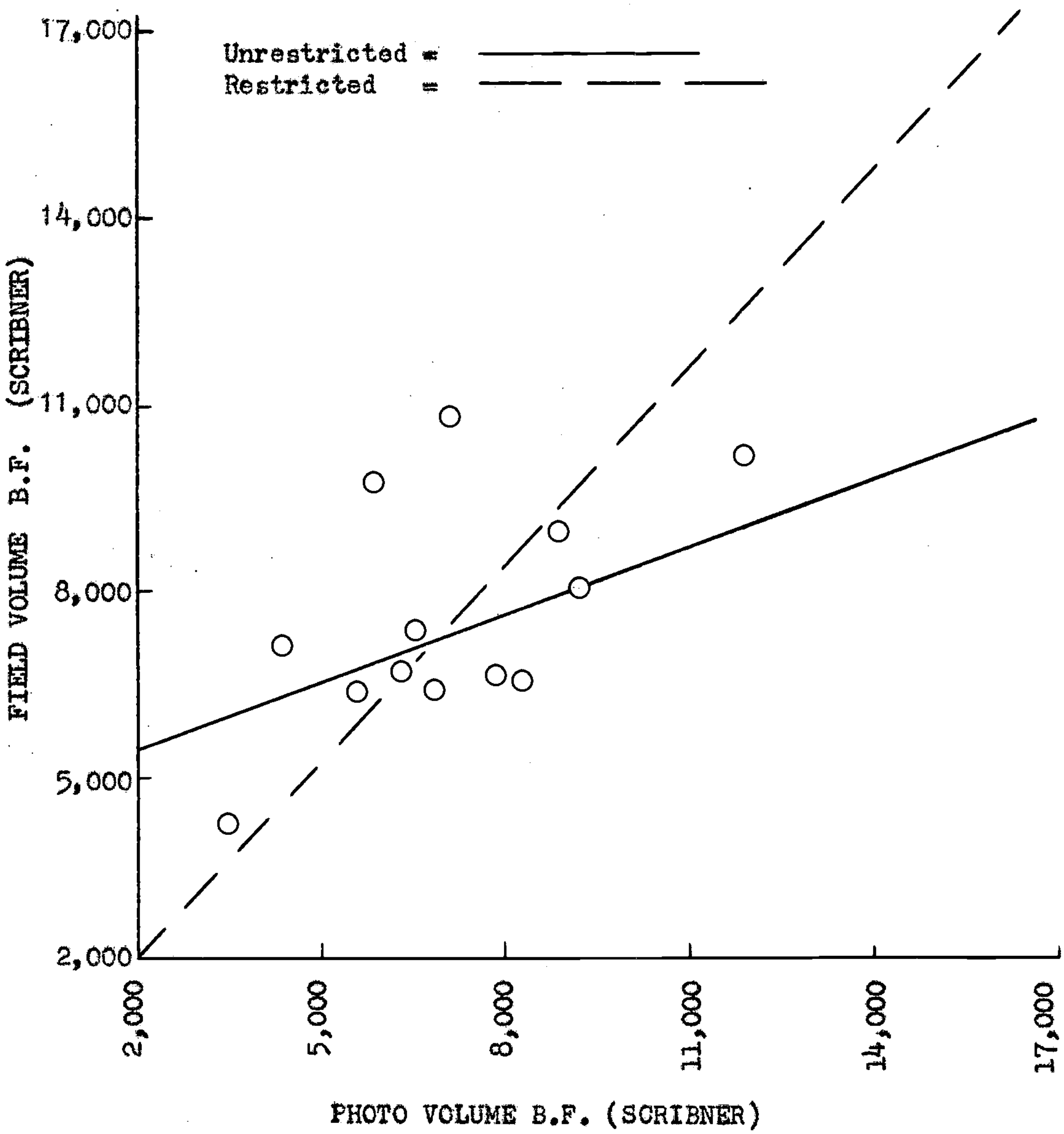

Figure 8. Graphical Representation of Restricted and Unrestricted Models of Regression Correction Factors for Poor Stocked Stands

Unrestricted   Field Vol. = 9,700 + 0.787(Photo Vol.-9,300)
Restricted   Field Vol. = 1.04900(Photo Vol.)

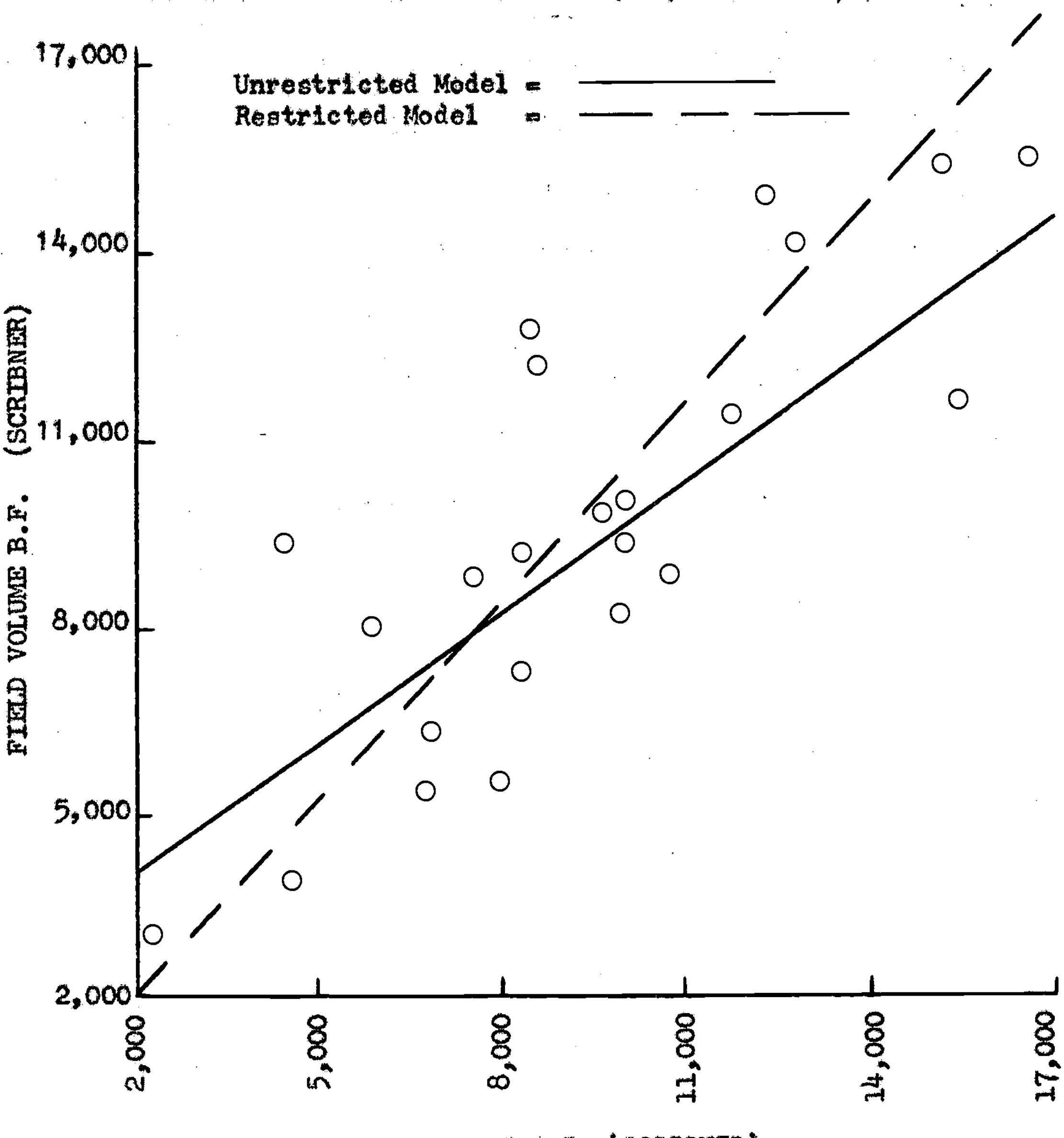

Figure 9. Graphical Representation of Restricted and Unrestricted Models of Regression Correction Factors for Medium and Well Stocked Stands

poorly stocked stands. This seems almost ridiculous. The application of either of the two types of correction factors reduced the aggregate difference in Table XIII to zero. Therefore, it became necessary to make at least one more test, using a new set of data.

ACCURACY OF VOLUME ESTIMATION

Test number four was also conducted on site IV land in the Pringle Falls Experimental Forest. In this test a 100 percent photo cruise was compared with a 100 percent ground cruise of the same 7½ acres. Since a 100 percent cruise was made in both cases, no sampling error is involved.

The results of the test were quite encouraging. The area had 172 trees of sawtimber size of which 129 were counted on the photos. The remaining 43 trees were not counted for one of the following reasons: (1) They were not visible, (2) they were visible, but interpreted as poles, and (3) two or more trees were counted as one. Further results are shown in Table XXVI. It can be seen from this table that the restricted model for estimating correction factors proved to be much more accurate than the unrestricted model and indicates that the restricted model of regression correction factor is the proper model.

TABLE XXIV

RESULTS OF TEST USING NEW DATA[16]

	TOTAL VOLUME B.F. (SCRIBNER)	VOLUME ERROR B.F. (SCRIBNER)	VOLUME ERROR PERCENT
Photo Volume			
Un-corrected	169,566	- 7,479	- 4.21
Corrected[17]	212,219	+35,174	+19.87
Corrected[18]	178,045	+ 976	+ 0.55
Field Volume	177,045	---	

16 A comparison of a 100 percent photo cruise with a 100 percent ground cruise of 7½ acres

17 Corrected by unrestricted model

18 Corrected by restricted model

SUMMARY AND CONCLUSIONS

For several years the vertical aerial photograph has been used in forest inventory work. Its principal use has been in the preparation of timber type maps and the stratification timber stands so that an acceptable sampling scheme may be worked out for selecting sample plots to be taken on the ground.

A more recent development has been the use of vertical aerial photographs to estimate timber volume directly. At the present time, this phase of forest photogrammetry is still in the experimental stage in most parts of the country. The studies to date indicate that this approach to volume cruising is within the limits of accuracy desired and can be accomplished at great savings of both time and money.

The objective of this study was to explore the possibility of cruising mature ponderosa pine directly from vertical aerial photographs.

The basic data were collected on 50 one-fifth acre plots on the Pringle Falls Experimental Forest. All plots were taken in mature or over-mature, uncut, pure stands of ponderosa pine on site IV land. Simple correlations between attributes measurable on aerial photographs and D.B.H. were calculated. These correlations appeared to be high enough to warrant the development of a regression equation to predict D.B.H. A suitable equation was found to be: D.B.H. = b_0 + b_1 (T.H.) + b_2 (V.C.D.). Three such equations were calculated, one for each stocking class (well, medium, and poor). These equations were solved for various values of T.H. and V.C.D. to produce a D.B.H. table. Three foot V.C.D. classes and ten-foot height classes were used.

It was then a simple matter to convert these D.B.H.'s to individual tree volumes by using standard volume tables based on total height and form class. Total height and visible crown diameter can be measured directly from the photos. The choice of form class was based on a study which correlated form class with total height.

The volume tables for medium and well stocked plots were so similar that the original data for these two stocking classes were combined to make one photo volume table for medium and well stocked plots. This eliminated the problem of distinguishing between medium and well stocked plots. A simple photo crown count distinguishes between poorly stocked plots and medium and well stocked plots. If a one-fifth acre plot contains four or less sawtimber trees, the table for poorly stocked plots is used. If the plot contains five or more sawtimber trees, the table for medium and well stocked plots is used.

Plot volumes are determined as follows: For poorly stocked plots the total height and visible crown diameter of each tree are measured from the photo. Then the corresponding volume of each tree is obtained from the photo volume table. The plot photo volume is the sum of the tree volumes.

A little different procedure was used for medium and well stocked plots. All V.C.D.'s were averaged by their squares, since volume is proportional to $(D.B.H.)^2$. The four tallest trees of each plot were averaged, and six feet subtracted from this average to obtain an average stand height. The volume of the average tree was then obtained from the photo volume table and multiplied by the crown count to arrive at a photo plot volume.

A test of accuracy of the photo volume tables using the same data that were used in their development, showed that they contain a negative systematic error of between one and two percent. This error could be partially eliminated by developing regression equations that could be solved directly for volume without going through D.B.H. However, the approach used in this study allows the development of any type volume table from the D.B.H. tables.

Another test of accuracy was made in which photo measurements instead of field measurements of the original data were used. The errors were again negative, but less than five percent.

Two types of correction factors were developed to correct for the combined errors of photo measurements, crowns not visible, and aerial photo volume table errors. The first correction factor was in the form of a regression equation of field volume on photo volume developed by the least squares method. The second type of correction factor was also a least squares estimate of field volume on photo volume with one restriction. The restriction was that the regression line must pass through the origin.

A final test of the photo volume tables was the comparison of a 100 percent photo cruise with a 100 percent ground cruise of 7½ acre plot on the Pringle Falls Experimental Forest. The photo cruise was 4.21 percent low before any correction factor was applied. When the first correction factor was used (unrestricted model) the photo cruise was 19.87 percent high. However, the application of the second type of correction factor (restricted model) resulted in an overestimation by only 0.55 percent and indicates that restricted model is the proper one to use.

Other significant findings of this study are:

1. The degree of stocking has little effect on the V.C.D. - T.H. - D.B.H. relationship for plots 40 percent or better stocked by basal area.
2. The D.B.H. for a given T.H. and V.C.D. for plots 39 percent or less stocked is 2 to 4 inches greater than for trees in 40 percent or better stocked plots.

3. The multiple regression of D.B.H. on T.H. and V.C.D. is linear for the range of trees studied.
4. Visible crown diameters were measured from 1:9,600 scale photos with a standard error of 1.88 feet.
5. Total tree heights were measured with a standard error of 7.78 feet.

The final conclusion is that mature ponderosa pine can be cruised from vertical aerial photos within the standard limits of accuracy. More research is needed to determine the effects of different site qualities, different geographical locations, different maturity classes, and different degrees of cutting.

APPENDIX

TABLE XXV

REGRESSION SOLUTION OF D.B.H. ON V.C.D. AND T.H.
FOR PONDEROSA PINE TREES IN MEDIUM STOCKED STANDS
ON SITE IV LAND

V.C.D.	TOTAL HEIGHT IN FEET							
FEET	80	90	100	110	120	130	140	150
	D.B.H. IN INCHES							
9			17.6	19.4	21.1	29.9		
12	16.4	18.1	19.9	21.7	23.4	25.2	26.9	
15	18.7	20.4	22.2	23.9	25.7	27.5	29.2	
18	20.9	22.7	24.5	26.2	28.0	29.8	31.5	33.3
21	23.2	25.0	26.8	28.5	30.3	32.1	33.8	35.6
24	25.5	27.3	29.1	30.8	32.6	34.4	36.1	37.9
27			31.4	33.1	34.9	36.6	38.4	
30			33.6	35.4	37.2	38.9	40.7	
33					39.5	41.2	43.0	
36					41.8	43.5		

Based on 122 trees

TABLE XXVI

REGRESSION SOLUTION OF D.B.H. ON V.C.D. AND T.H.
FOR PONDEROSA PINE TREES IN WELL STOCKED STANDS
ON SITE IV LAND

V.C.D. FEET	TOTAL HEIGHT IN FEET							
	80	90	100	110	120	130	140	150
	D.B.H. IN INCHES							
9			17.2	19.1	21.0	22.9		
12	15.7	17.6	19.5	21.5	23.4	25.3	27.2	
15	18.1	20.0	21.9	23.8	25.7	27.6	29.5	
18	20.4	22.3	24.2	26.1	28.0	29.9	31.8	33.7
21	22.7	24.6	26.5	28.4	30.3	32.2	34.1	36.0
24	25.0	26.9	28.8	30.7	32.6	34.5	36.4	38.3
27			31.1	33.1	35.0	36.9	38.8	
30			33.5	35.4	37.3	39.2	41.1	
33					39.6	41.5	43.4	
36					41.9	43.8		

Based on 122 trees

TABLE XXVII

STANDARD TREE PHOTO VOLUME TABLE
FOR MATURE PONDEROSA PINE
IN MEDIUM STOCKED STANDS

V.C.D.	TOTAL HEIGHT IN FEET							
FEET	80	90	100	110	120	130	140	150
	VOLUME - BOARD FEET (SCRIBNER)							
9			348	468	634	847		
12	211	319	455	607	803	1050	1330	
15	293	425	585	755	986	1270	1590	
18	381	542	731	927	1190	1520	1880	2270
21	484	674	891	1120	1420	1780	2190	2610
24	599	820	1070	1380	1660	2060	2520	2980
27			1280	1540	1930	2360	2870	
30			1460	1790	2210	2690	3250	
33					2510	3040		
36					2830	3400		

Developed from Table XXV and Mason, Bruce, and Girard from class tables (10).

TABLE XXVIII

STANDARD TREE PHOTO VOLUME TABLE
FOR MATURE PONDEROSA PINE
IN WELL STOCKED STANDS

V.C.D. FEET	TOTAL HEIGHT IN FEET							
	80	90	100	110	120	130	140	150
	VOLUME - BOARD FEET (SCRIBNER)							
9			319	452	627	847		
12	188	298	434	595	803	1060	1360	
15	270	406	567	748	986	1280	1630	
18	356	522	710	919	1190	1530	1940	2330
21	461	650	870	1110	1420	1790	2230	2670
24	573	794	1040	1310	1670	2080	2560	3050
27			1230	1550	1940	2410	2940	3470
30			1440	1790	2220	2730	3320	3900
33					2530	3080	3720	
36					2850	3450		

Developed from Table XXV and Mason, Bruce, and Girard from class tables (10).

TABLE XXIX

SUMS OF SQUARES AND PRODUCTS
USED TO DEVELOP D.B.H. TABLES

SUMS OF:	TABLE NO. XXIII	TABLE NO. XXVII
n	49.	122.
X_1	6,039.	14,044.
X_1^2	751,227.	1,646,082.
X_2	1,245.0	2,515.5
X_2^2	33,084.00	54,788.60
X_1X_2	153,996.5	292,882.5
$X_1^2X_2$	19,216,470.5	34,678,578.5
$X_1X_2^2$	4,104,449.75	6,440,269.85
$X_1^2X_2^2$	515,975,904.75	768,958,258.25
Y	1,760.9	3,555.4
Y^2	65,225.23	108,752.12
YX_1	218,867.9	416,999.1
YX_2	45,972.5	76,124.8
YX_1X_2	5,727,372.7	9,012,840.6
YX_1^2	27,440,288.3	49,731,821.7
X_1^3	94,259,433.	196,236,586.
X_1^4	11,923,236,135.	23,769,031,590.
$X_1^3X_2$	2,417,572,647.5	4,171,105,282.5

TABLE XXIX (CONTINUED)

SUMS OF SQUARES AND PRODUCTS
USED TO DEVELOP D.B.H. TABLES

SUMS OF:	TABLE NO. XXVIII	TABLE NO. XIV
n	122.0	244.0
X_1	14,015.0	28,590.0
X_1^2	1,632,917.0	3,278,999.0
X_2	2,166.0	4,681.5
X_2^2	41,125.5	95,914.1
X_1X_2	251,994.5	544,877.0
$X_1^2X_2$	29,739,606.5	
$X_1X_2^2$	4,848,201.2	
$X_1^2X_2^2$	579,799,630.2	
Y	3,327.2	3,828.6
Y^2	92,542.0	201,249.1
YX_1	382,828.6	799,827.7
YX_2	60,781.2	136,906.0
YX_1X_2	7,199,878.0	
YX_1^2	45,390,887.8	
X_1^3	192,867,437.0	
X_1^4	23,080,328,993.0	
$X_1^3X_2$	3,558,220,434.5	

TABLE XXX

ORIGINAL FIELD DATA SUMMARIZED BY PLOTS

PLOT NO.	NO. TREES	DENSITY PERCENT	SITE INDEX	T.H. AVE.	V.C.D. AVE.	VOLUME B.F. VISIBLE	TOTAL
1	4 - 4	43	79	122	21	6,130	6,201
2	6 - 6	43	71	108	18	9,313	9,375
3	5 - 2	43	66	97	18	2,576	2,920
4	7 - 7	60	74	114	18	9,135	9,135
5	9 - 12	78	70	104	18	7,582	7,809
6	4 - 4	34	78	121	24	7,255	7,371
7	6 - 10	52	68	100	18	3,309	3,756
8	7 - 7	60	71	107	24	7,249	7,249
9	8 - 10	86	69	103	18	5,341	5,505
10	7 - 9	69	80	124	24	11,491	11,659
11	10 - 11	121	71	107	21	8,600	8,798
12	6 - 10	52	78	121	21	6,531	6,869
13	4 - 4	34	78	120	27	6,648	6,648
14	9 - 12	104	82	129	18	14,514	15,176
15	9 - 11	86	79	123	18	11,746	12,533
16	4 - 4	52	82	129	18	7,107	7,413
17	3 - 3	34	87	138	24	7,640	7,707
18	8 - 8	60	79	122	21	10,219	10,219
19	13 - 13	121	74	114	18	13,729	13,729
20	10 - 12	95	76	117	18	11,307	11,635
21	4 - 8	34	80	123	21	7,650	8,001
22	3 - 3	26	83	132	24	10,570	10,765
23	9 - 9	95	79	123	21	16,223	16,223
24	3 - 3	26	82	130	24	6,630	6,630
25	6 - 6	52	78	120	24	10,595	10,595
26	3 - 4	26	82	128	27	9,200	9,594
27	4 - 4	34	79	123	30	10,140	10,140
28	4 - 4	34	72	111	27	6,260	6,314
29	7 - 7	69	79	122	24	14,860	14,860
30	7 - 7	60	80	124	27	15,508	15,508

TABLE XXX (CONTINUED)

PLOT NO.	NO. TREES	DENSITY PERCENT	SITE INDEX	T.H. AVE.	V.C.D. AVE.	VOLUME B.F. VISIBLE	TOTAL
31	6 - 6	52	81	127	24	8,194	8,194
32	6 - 6	52	80	125	24	10,450	10,450
33	5 - 5	43	79	122	24	10,290	10,290
34	6 - 7	52	71	107	18	5,377	5,439
35	7 - 10	78	75	115	21	9,102	9,379
36	4 - 6	34	78	120	21	6,690	6,690
37	8 - 12	78	70	105	18	6,769	7,213
38	8 - 9	78	75	115	18	8,118	8,419
39	7 - 9	95	80	126	18	8,375	9,175
40	4 - 4	43	71	108	18	4,020	4,141
41	5 - 5	52	69	103	21	4,517	4,885
42	7 - 8	60	67	99	21	5,476	5,594
43	8 - 11	78	70	104	18	6,955	7,145
44	5 - 5	60	75	115	18	5,905	6,629
45	7 - 7	78	80	125	21	13,700	13,700
46	3 - 3	26	78	121	27	6,600	6,600
47	3 - 10	17	78	119	24	6,417	7,127
48	2 - 2	17	79	123	36	6,760	6,760
49	3 - 3	26	79	123	33	8,910	8,910
50	2 - 2	17	80	124	27	4,220	4,220

The first number is the number of visible trees when viewed from above. The second number is the total number of sawtimber size trees on the plot.

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