AN ABSTRACT OF THE THESIS OF

Joseph Nelson Graham for the degree of Master of Science

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Title: THE USE OF A THREE STAGE SAMPLE TO ESTIMATE THE EFFECT OF COMMERCIAL THINNING ON THE GROWTH OF TWO STANDS OF DOUGLAS-FIR

Abstract approved: Signature redacted for privacy.

John F. Bell

A three stage sample was taken of two high-site, second growth Douglas-fir (Pseudtsuga menziesii) stands located in the extreme northwestern portion of the Oregon Coast Range. Permanent plots were established during the first stage variable-plot cruise. A Hartley-List sample, taken from the first stage Douglas-fir trees, selected second stage sample trees in proportion to their estimated total height. A subsequent equal probability systematic sample was taken to choose the third stage sample trees.

First stage variable-plot cruise data provided a conventional estimate of stand volume per acre and the basis for expansion of estimates from subsequent sample stages.

Second stage sample trees were measured for form and volume with a Barr and Stroud Type FP15 dendrometer. These measurements were converted to tree volume estimates and expanded to volume per acre estimates for the stand.

Third stage sample trees were felled. Cross-sectional disks were cut at measured intervals along the bole. Radial increment measurements

from these disks provided the basis for estimating growth of individual trees and stand parameters.

Findings indicate that the average tarif number, for use with the DNR (Department of Natural Resources, State of Washington) tarif volume tables, computed from stem analysis data for the present Douglas-fir component of these stands is significantly different from that estimated by conventional methods using tree height and diameter. This suggests that the growth habit and stem form of Douglas-fir may be altered as a result of commercial thinning. It also implies that volume tables constructed for natural stands may underestimate volume in thinned stands.

Evaluation of King's site index revealed a decreasing trend in apparent site index of about one site class from 15 to 30 years breast height age. This downward trend appears to subside about the time of the initial thinning operations and remain relatively constant thereafter. Examination of stem analysis data from an unthinned stand about 25 miles east of the project area revealed a similar trend in site index.

Present volume per acre for an unthinned stand was predicted using past stand parameters and the DNR yield tables for the Douglas-fir zone. Results indicate that volume in the surviving stand plus that removed by commercial thinnings exceeds the predicted stand yield. This amounted to about 5 percent in one stand and about 16 percent in the higher density, more heavily thinned stand. This comparison implies that total yield in Douglas-fir stands 50 to 55 years of age may be slightly increased by repeated commercial thinnings.

The Use of a Three-Stage Sample to Estimate the Effect of Commercial Thinning on the Growth of Two Stands of Douglas-fir

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INTRODUCTION

Big Creek is a tributary of the Columbia River, entering it about 15 miles east of Astoria, Oregon. Within this drainage, Boise Cascade Corporation owns approximately 27,000 acres of high site timberland, stocked primarily with second-growth Douglas-fir. Of this acreage, about 12,000 acres are stocked with trees 30 to 60 years of age. In these older stands, nearly 9000 acres have been commercially thinned.

Thinning operations began in 1961 and have continued to present. Some of the older stands have been thinned more than once. Those selected for this study have been entered three or four times within about a 15 year period.

The trees of this drainage are intended primarily for production of high value specialty products, such as poles, pilings, structural timbers, and veneer. Some of these products have requirements concerning the size and number of knots, and the number of annual rings per inch. Aside from obtaining some insight as to how thinning practices have affected the number of rings per inch and tree form, Boise Cascade Corporation was interested in volume and growth information. This study will help determine the applicability of the DNR (Department of Natural Resources, State of Washington) "Empirical

Yield Tables for the Douglas-fir Zone" (Chambers et al., 1972) to the thinned stands in the Big Creek drainage. The results also provide the basic data necessary for an economic analysis of the thinning operations in this drainage.

In general, the purpose of this study was to quantify the growth response of two Douglas-fir stands which had been commercially thinned.

LITERATURE REVIEW

Thinning in Douglas-Fir

Thinning is the major silvicultural practice that characterizes intensive forestry. It is a cultural practice undertaken in established stands, primarily for an economic gain.

Prior to 1945, thinning in Douglas-fir was not a common practice in the Pacific Northwest. But with the increased demand for housing in the post-war years and the diminishing acreage of readily accessible old-growth Douglas-fir, the possibility of commercially thinning young stands began to surface.

Commercial thinning as used here denotes an operation "that produces merchantable products that have a value at least equal to their cost of extraction" (Worthington et al., 1961). The theory and practice of thinning for economic gain is based on two major assumptions: 1) that the growth potential of a stand can be redistributed to approach the optimum utility of growth limiting resources (water, light, and nutrients) and 2) that maximum utilization of merchantable material produced by the stand during a rotation will be possible (Worthington et al., 1961). Studies suggest that the benefits from commercial thinning result primarily from an earlier harvest of products and not from any substantial increases in the volume of usable wood produced (Reukema, 1972, 1973).

A survey of past results in commercial thinning of Douglas-fir indicates that some generalities can be stated with regards to this species: 1) the ability of trees to respond to release decreases with age, 2) the response tends to be better on higher sites, and 3) the response of a tree is dependent on its crown size and position (Reukema, 1961, 1972; Worthington et al., 1961). In other words, the gain from redistribution of growth potential in a particular stand appears to be primarily a function of the age at which the stand is entered and the selection of trees removed. Reukema (1972) confirmed this and inferred that removal of some of the larger, more vigorous trees in the stand, which may be more efficient in capturing the growth potential (than some of those in the residual stand) is necessary to obtain adequate release. He pointed out that if the better dominants and codominants are to be left, the removal of neighboring intermediate trees would result in little or no release, concluding that adequate release of these larger trees can be obtained only by cutting other dominants and codominants.

Crown development after thinning plays a major role in determining a tree's response to release. The rapid height growth characteristic of Douglas-fir is important in thinning, since height growth largely controls the rate of crown development (Worthington et al., 1961). Although height growth has classically been considered independent of stocking (Worthington et al., 1961), recent studies by Groman (1972) and Reukema (1970) suggest that Douglas-fir may grow taller when released by thinning than in a natural stand.

Also affected by height growth is the site index of the stand.

With Groman's (1972) findings that dominants in a thinned stand increased 4.9 feet more over a 15-year period than in a similar unthinned stand, it is no surprise that there was a corresponding increase in site index. To date, such results have not been conclusive and the effects of thinning on apparent site index is not clearly understood.

Site index is commonly used as a predictor variable in estimating stand growth and yield of both thinned and unthinned stands. This study may help determine the accuracy of using this stand parameter as a measure of productivity for thinned stands.

Use and Accuracy of the Dendrometer

The optical dendrometer is described by the manufacturer (Barr and Stroud, undated) as:

> ...a small specialized rangefinder incorporating an inclinometer. It is designed to measure the diameters of tree trunks at selected heights, for the purpose of assessing the volume, growth and value in standing trees.

The instrument is manufactured by Barr and Stroud Limited of Glasgow, Scotland. The FP15 dendrometer is an eight-inch base coincident type rangefinder with a 5.5X magnification. The original version of which was developed from a rangefinder used for tank gunnery.

The FP15, the most recent and the last model produced, incorporates the refinements to the previous model, the FP12, that were recommended by Hartman (1967) and Mesavage (1967). These include a translucent lens barrel for easier dendrometer scale-reading, a sight to aid aiming through foliage or in dense stands, limits of 60 degrees for both elevation and depression angles, and an inclinometer graduated in terms of (1 + sin) to prevent confusion between negative and positive readings near zero elevation. These modifications make the FP15 more flexible, primarily by increasing the number of potential instrument set-up points.

The basic principles and techniques of operating an optical dendrometer can be mastered in a short time. A pamphlet provided by the manufacturer discusses the basic technical data and provides instructions for operating, cleaning, and adjusting the dendrometer (Barr and Stroud, undated).

The instrument can be used to measure trees 1.5 to 200 inches (3.8 to 508 cm) in diameter at ranges from 12 to 200 yards (11 to 183 m). Trees up to 30 inches (76 cm) in diameter can be measured from any point within this range. Ranges can be measured between 12 and 675 yards (11 to 617 m).

Literature on the accuracy of measurements made with the dendrometer indicates diverse findings. Bell and Groman (1968, 1971) indicated that the level of accuracy obtained with the dendrometer was very satisfactory for most mensurational projects. They found that the dendrometer overestimated smaller diameters by 0.06 inch and larger diameters by 0.04 inch.

This tendency to overestimate diameters has been reported by others. Brickell (1976) found a bias in diameter measurements that increased with size. He stated that the source of this bias was not readily apparent, but that it might be caused by some characteristic of human vision. In conclusion, he indicated that this diameter measurement bias could be expected to give an average volume overestimate of about 2.4 percent.

Error in height measurements are stated by the manufacturer to be 1.5 percent under average conditions. Bell and Groman (1968, 1971) found the accuracy of height measurements to decrease rapidly from the horizontal to the maximum vertical angle. Brickell (1976) found no difference in the error of height measurements made on short or tall trees. He also indicated that height measurements with the dendrometer are unbiased.

STUDY AREAS

Location

The study areas are located on industrially owned land on the west side of the Coast Range in Clatsop County, Oregon. The two stands in the Big Creek drainage were selected by the owner, Boise Cascade Corporation, as representative of well-executed commercial thinning operations.

Clatsop County lies in the extreme northwestern corner of Oregon, bordered on the north by the Columbia River and on the west by the Pacific Ocean. The stands at Big Creek are about 20 miles (32 km) from the coast and 3 miles (5 km) south of the river, near the town of Knappa, Oregon (see Figure 1). The elevation of the areas ranges from about 500 to 750 feet (152 to 229 m). The larger unit, 13-Loop, is a southwest-facing stand of about 220 acres (89 hectares). While the smaller unit, Pigpen, has an east to northeast aspect and a size of about 50 acres (20 hectares).

For the most part, the two stands can be described legally as Township 7 North, Range 7 West, Sections 2 and 3, Willamette Meridian.

Climate

Clatsop County has a temperate and equable climate west of the Coast Range because of the marine influence. The climate is

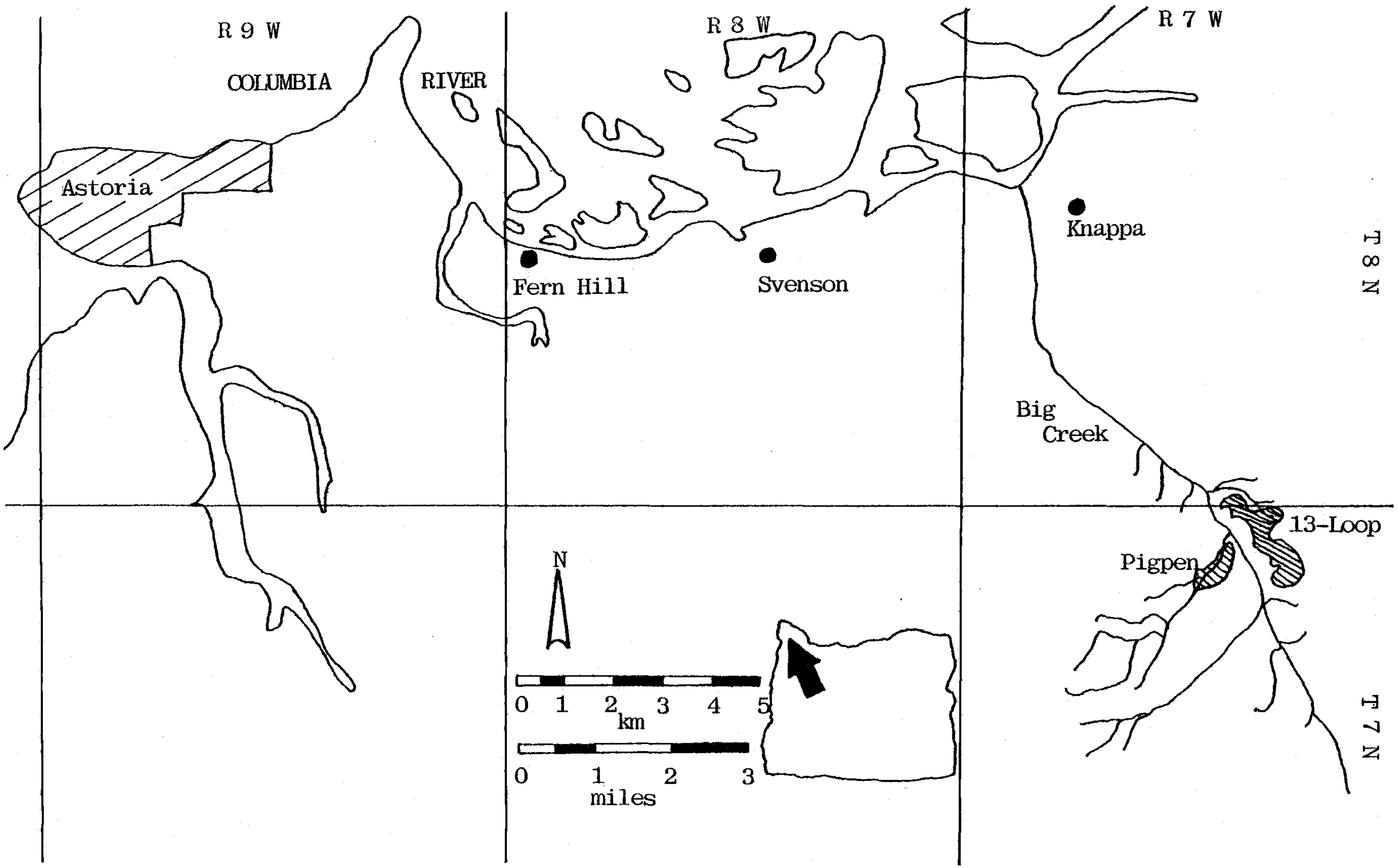

Figure 1. Map showing study sites in northwestern Oregon.

characterized by mild, wet winters and cool, relatively dry summers. At Astoria, 15 miles from the study area, the mean annual temperature is about 51°F (11°C), with a mean winter temperature of about 42°F (6°C). There is little freezing weather in the western part of the county. As a result, the length of the frost-free growing season at Astoria averages 272 days.

The Coast Range has a great influence on the climate and rainfall of this area. Eastward from the coast, rainfall increases rapidly with altitude on the west slopes, reaching more than 100 inches (254 cm) a year near the crest. In the northern part of the county, the rainfall decreases eastward up the Columbia River. The climate of this area is similar to that of the coast region.

The mean annual rainfall at Astoria is 76.57 inches (194.49 cm). The average precipitation for the study areas is probably between 80 and 100 inches (203 to 254 cm). Most of the precipitation occurs as rainfall during fall and winter, with the wet season beginning in October and extending through April (Appendix 1). There is moderate rainfall during the summer in the western part of the county.

Snowfall differs considerably in various parts of the county. At Astoria, elevation 50 feet (15 m), the average annual snowfall is 4.2 inches (10.7 cm), and it seldom remains on the ground for more than a few hours. At the Big Creek study areas, elevation 500 to 750 feet (152 to 229 m), snow may be somewhat heavier and probably remains on the slopes longer because of the usually colder winter temperatures associated with increased elevation and distance from the coast (Torgenson, 1949).

Soils and Topography

The soils of Clatsop County have developed under the influence of a marine climate with mild temperatures and an abundant moisture supply that has produced dense stands of coniferous forest growth.

The Astoria series soils, like those found in Big Creek, are residual in character, having developed from the weathering of the sandstone and shale uplands (Torgenson, 1949). The surface soils are rarely more than three feet deep, but the parent material may be permeable to depths of 10 to 25 feet. The heavy rainfall and warm winter temperatures have produced rounded topography and well-leached soils. The clay soils, leached of lime and other soluble constituents, are distinctly acid and belong to the soil order, Alfisols (Loy, 1975).

The Undifferentiated Astoria soils, like those associated with Big Creek, occur commonly on forested, hilly to rough topography of the area. The last and only soil survey of this county was done in 1937 - 1938. For economic reasons, the survey was limited to the better developed lands bordering the Pacific Ocean and the major river valleys and tributaries (Torgenson, 1949). Detailed mapping of the forest soils was not considered expedient, and thus the "Undifferentiated" classification.

Topography of the stands ranges from flat to steep. Both sites are dissected by numerous permanent and intermittent streams, and have isolated marshy areas.

Vegetation

The Big Creek study area lies on the border of the *Picea sitchensis* and *Tsuga heterophylla* Zones of Franklin and Dyrness (1973). In the climax stage, the *Picea sitchensis* zone is characterized by dense stands of Sitka spruce, western hemlock, western red cedar, Douglas-fir and grand fir. The *Tsuga heterophylla* zone is the most extensive vegetation zone in Washington and Oregon, and most important in terms of timber production. Characteristic of this region is the Douglas-fir subclimax and the climax western hemlock - western red cedar formations; although in second-growth stands, Douglas-fir is usually the dominant species.

The present stand in both study areas appears to have been established after the 1923 Big Creek fire. The oldest trees in the stand are about 54 years old, total age. The overstory of both study areas is predominantly Douglas-fir (*Pseudotsuga menziesii*). Other coniferous species found sharing the overstory or in the understory include western hemlock (*Tsuga heterophylla*), Sitka spruce (*Picea sitchensis*), and western red cedar (*Thuja plicata*). (See Table 1.) Prominant understory tree and shrub species include vine maple (*Acer cirinatum*), salal (*Gaultheria shallon*), bracken fern (*Pteridium aquilinum*), Oregon grape (*Berberis nervosa*), and red huckleberry (Vaccinium paraifolium). Red alder (Alnus rubra) and salmonberry (Rubus spectabilis) are abundant on disturbed, wet sites in and around the stands; while wild blackberry (Rubus vitifolius) and evergreen blackberry (Rubus laciniatus) seem to prefer the skid-roads created by thinning operations.

Table 1. STAND COMPOSITION BY BASAL AREA AND PERCENT.

Units	Study Area	Douglas-fir	Western Hemlock	Sitka Spruce	Western Red Cedar	Total
Basal Area (sq ft/ acre)	13-Loop	116.3	22.9	1.2	---	140.4
	Pigpen	99.4	20.6	2.4	2.9	125.3
Percent	13-Loop	82.8	16.3	0.9	---	100.0
	Pigpen	79.3	16.4	1.9	2.4	100.0

History

The forest industry has been the most important factor in the economic life of Clatsop County. The forest lands are primarily adapted to this use because of their inaccessibility for other uses, and because the climate and soil conditions favor the growth of forest trees.

Lumbering as an industry in Clatsop County started in the middle 1800's. Logging and milling methods were primitive. Trees were felled by hand and skidded with ox teams. By the turn of the century, all the timber close to the mill or stream had been cut, and the hauling distances became too great for oxen. Logging in Clatsop County belonged to the steam donkey and high line. By this time, the steam locomotives were popular, and hundreds of miles of track covered the hills and valleys of the county. Over these tracks rolled many billions of board-feet of logs, old-growth Douglas-fir and Sitka spruce.

The Big Creek Company had a railroad that ran from Knappa up Big Creek, with spurs leading out to the logging operations on the slopes of Big Creek basin. The Big Creek Logging Camp, which was associated with the Wauna mill, employed 200 men and had 12 steam donkeys, averaging 276,000 board-feet per eight-hour-day. During this period, the spring freshets of Big Creek were sometimes utilized to move the logs to the creek and then to the river for rafting. In 1923 a fire spread to Big Creek lands and caused one of their biggest fires. (The two stands examined in this study, noted on company records as established in 1924, were very likely a result of this fire.)

In 1929 the logging truck trailer, perhaps the first, was developed in Clatsop County. During the next twelve years a significant change took place in the local logging industry. The use of railroads and high-lead methods gave way to the use of trucks and tractors. In 1941 the last railroad logging operation was removed from the county.

In 1942, Big Creek was closed, and the remaining land and timber were sold to St. Helen's Pulp and Paper Company. St. Helen's was merged with Crown Zellerbach Corporation in 1953, adding 50,000 acres to Crown's holdings in Clatsop County. About half of this acreage was in the Big Creek drainage. Crown Zellerbach had enlarged its holdings in the county to 184,000 acres. The same year, the Federal Trade Commission filed an anti-trust suit against the corporation.

In 1964, after ten years of litigation, the St. Helen's mill and lands were sold to Boise Cascade Corporation. The sale agreement included a five-year transition period which gave Crown Zellerbach cutting/thinning rights in Big Creek (St. Helen's, 1964).

The stands in this study were thinned once by Crown Zellerbach in 1961. All subsequent thinning were done under the guidance of Boise Cascade.

Treatments

Thinning operations were begun in both study areas by Crown Zellerbach in 1961. At that time, the average breast height age for Douglas-fir was about 29 years in Pigpen, and 33 years in 13-Loop (based on stem analysis of third-stage sample trees). Complete records of these initial entries are not available. For purposes of analysis, it is assumed that the removal in 13-Loop and the lower third of Pigpen amounted to about 7500 board-feet per acre (personal communication with Russ McKinley, Boise Cascade Corporation). This estimate, according to Alan Berg, seems reasonable in light of Crown Zellerbach's commercial thinning philosophy at that time (personal communication with Alan Berg, Forest Research Laboratory, Oregon State University). He indicated that their thinnings tended to be "heavy" selection type cuts, removing many dominants and codominants to afford release of the residual stands.

All subsequent thinning operations were performed under the auspices of Boise Cascade Corporation. These operations might be termed "free" thinnings, removing trees from all parts of the canopy to afford the release of the better crop trees. (See Table 2 for a summary of estimated removals.)

Table 2 (A & B). ESTIMATED THINNING REMOVALS*

A. Pigpen

Year	MBF** Per Acre Removed by Species				MBF Per Acre Removal for Year
	Douglas-fir	W. Hemlock	Sitka Spruce	W. Red Cedar	
1961***	2.50	----	----	----	2.50
1969	7.24	4.14	----	0.07	11.45
1974	2.84	1.24	0.02	----	4.10
Total	12.58	5.38	0.02	0.07	18.05

Estimated Douglas-fir removal = 70% of total.

B. 13-Loop

Year	MBF** Per Acre Removed by Species				MBF Per Acre Removal for Year
	Douglas-fir	W. Hemlock	Sitka Spruce	W. Red Cedar	
1961	7.50	----	----	----	7.50
1969	2.95	2.33	----	----	5.28
1971	0.85	0.37	----	----	1.22
1974	6.63	4.41	0.01	----	11.05
Total	17.93	7.11	0.01	0.00	25.05

Estimated Douglas-fir removal = 72% of total

* Based on Boise Cascade Corp. depletion and operation records.

** MBF: Thousand Board-Feet Scribner, net scale.

*** A removal of 7.5 MBF per acre assumed on one-third of the study area.

METHODS AND PROCEDURES

General Field Procedure

The two stands were sampled to determine volume per acre, growth, and change in stem form. The data were collected in a three-stage sampling scheme. Each stand was considered a separate population for purposes of sampling.

The first-stage sample was obtained using a variable plot cruise of the individual stands. This cruise provided stand parameter estimates, distribution of data collection points, and the population from which subsequent samples were taken. These data were used to estimate the tarif number, volume per acre, diameter and species distribution, and other stand related parameters.

A Hartley-List sampling technique was used to select the second-stage sample from the "in" trees tallied in the variable plot cruise of the first-stage. This selection was made after all the first-stage data had been collected for the stand. Second stage sample trees were subsequently measured for form and volume, using an optical dendrometer.

The third-stage sample selection was from an unweighted list of trees measured in the second-stage. These trees were felled, bucked, and measured for stem analysis.

First-Stage Sampling and Field Procedure

Information gathered in this stage permitted the calculation of stand parameters in subsequent stages. It also provided parameter estimates which could be compared with estimates made from the second- and third-stage samples.

A variable plot cruise was used to select the first-stage sample trees. A square sampling pattern was employed as a plot grid to provide the most complete coverage of stand variation. Data from a recent company cruise were utilized in determining the number of sample points needed within a stand in order to obtain the desired standard error of 5.0%. (See Appendix II for sample calculations.) Area estimates of the stands were obtained by using a planimeter in conjunction with aerial photographs and ground measurements. The area and plot calculation data were used in computing the plot grid distance between lines and plots, which would result in the desired number of sample points. (See Appendix III for sample computations.)

The variable plot cruise began in a similar manner for each stand. A tree near the base camp was chosen at random, and from it the researcher paced three chains due north, then three chains due east, and at this point established the first plot.

Preliminary sampling indicated that a Basal Area Factor (BAF) of 20 should give a tree count of about eight trees per plot, close to the optimum of seven, recommended by Beers (Beers et al., 1964). By taking tree counts at breast height (BH) for trees seven inches and larger at DBH, the DNR empirical yield tables could be utilized to estimate stand parameters (Chambers et al., 1972).

All plots were permanent plots, 34 in Pigpen and 49 in 13-Loop, and the set-up procedures were similar for all. The plot center was established and marked with a cedar stake. The distance between plots was paced at about 4 chains in Pigpen and 7 chains in 13-Loop. Tree counts were taken at each point in a systematic manner. Trees were sighted at BH with a relaskop using a BAF of 20. The first "in" tree to the right of due east became number "one" for the plot. All subsequent "in" trees were counted and numbered by continuing in a clockwise sweep around the plot. Plots were full-plots as opposed to half-plots which are commonly used in this region.

At least one "in" tree on each plot was measured for total height to the nearest foot. This was determined with a relaskop, usually at a horizontal distance of 100 feet. These measured trees were chosen somewhat at random, under the criteria that they should be spread across the range of diameters in the stand. These measured trees were used to provide an estimate of the stand's tarif number. In the field, these measured trees were used as a gauge to help estimate the heights of the remaining "in" trees on that plot. The measured or estimated height, which was recorded for each "in" tree, was later used to weight the second-stage sample selection. Trees measured for height were marked with an asterisk on the cruise card for later reference.

Each "in" tree had its tree number spray-painted on it somewhere above breast height, so as to be visible from the plot center. One or two trees on each plot were also painted with the plot number, which preceeded and was separated from the tree number with a dash. For example, tree 3 on plot 18 would be labeled "18-3".

Ribbon was strung between plots on each line to aid plot relocation at subsequent stages. At the beginning and end of each line of plots, when a road was encountered, trees or old logs along the road were spray-painted with the line number, the number of the adjacent plot, and the approximate distance and direction to the plot. This roadside reference system made plot finding for subsequent operations much easier.

The equipment used in the first-stage data collection included:

- Speigal relaskop
- compass
- steel diameter tape
- 75-foot reel tape
- tatum
- plastic flagging
- spray paint
- hatchet
- cedar stakes
- knapsack

Second-Stage Sampling and Field Procedure

The data collected at this stage provided a second estimate of volume per acre for the stand, and some inference to individual tree form and volume.

The selection of second-stage sample trees was subsequent to completion of the first-stage variable plot cruise. These trees were selected using a Hartley-List sampling technique in which all first-stage Douglas-fir trees were ordered and weighted by their estimated height. The probability of selection with this procedure was proportional to a tree's estimated height. (See Appendix VIII.)

These sample trees were chosen in proportion to basal area in the first-stage, and to estimated total height in the second-stage. Therefore, tree selection at this stage was proportional to tree volume. In this way, the sampling procedure favored selection of the larger, more valuable trees in the stand. This logic was consistent with a thinning study of stands, 40 to 60 years of age, by Groman (1972), in which he indicated that the larger trees at this stage of development are the important stand components for growth and volume investigations.

Measurements were taken with the optical dendrometer, following the methodology suggested by Groman (1969):

1) Diameter outside bark (DOB) at about 16.5 feet, along the surveyor's pole.

2) At least two DOBs and heights at equally spaced points along the bole between 16.5 feet and the lower live crown.

3) Stem DOB and height at lower live crown.

4) Stem DOB and height at upper live crown (on trees with branches missing on one side of the stem).

5) Additional DOB and height measurements within the crown and lower live crown where possible.

6) Total tree height.

7) DOB and height at lower and upper limits of defect, on trees with defect that reduces volume.

Supplemental data recorded on each tree included diameter outside bark at breast height (4.5 feet) and stump (usually 1.0 feet).

Field measurements were recorded on a form designed by Robert Gourley, of the Forest Science Laboratory, Oregon State University.

The following is a description of the actual field procedure: The dendrometer was placed in the storage box and carried along with other gear in a knapsack between plots. This afforded maximum protection to the instrument. The tripod was carried in one hand and the collapsed surveyor's pole in the other. With this load and both hands encumbered, maneuvering in the woods was frequently awkward.

Upon arrival at a plot, all the equipment was deposited at a central location, usually uphill from the plot. Sample trees were subsequently identified and the area was surveyed for arrangement of crowns to determine potential instrument set-up points, which would be examined more closely. If there was more than one tree to be measured on a particular plot, a set-up point from which all the trees could be observed was sought. This saved much time which would have been spent in additional instrument set-ups and allowed concentration of time and effort on the more critical tree measurements.

If a location looked satisfactory, it was marked with plastic flagging on some nearby vegetation for easy relocation. If necessary, other possible set-up points were subsequently investigated.

It was desireable that set-up points for the dendrometer be located uphill from the subject tree(s). Reasons for this include: (1) it allows measurements to be made more easily from a single point;

(2) it should increase the accuracy of measurements, by being closer to the tree; (3) it lessens optical errors which are compounded by making measurements at greater angles (e.g. below the elevation of the subject trees); and (4) it allows the surveyor's pole to be placed and viewed on the uphill side of the tree, which is consistent with other forest measurements.

Next, the subject tree was prepared. The telescoping surveyor's pole was placed in an appropriate location on the uphill side of the stem and extended. Any brush or debris which might obscure measurements was cleared away. Using the surveyor's pole as a guide, diameter measurements were taken along the bole at 1.0 and 4.5 feet (.30 and 1.37 m) with a steel diameter tape. An increment boring was also taken at breast height (4.5 ft/1.37 m) to estimate radial growth for the past five years.

The instrument set-up was usually made next, choosing the location which appeared to give the best view of the subject tree(s). Prior to making any observation along the bole, the top of the tree(s) was sighted to insure that all observations could be made from that set-up point.

Dendrometer measurements began on each tree at about the 16.5-foot level along the surveyor's pole. To assist in discerning this point, through the sometimes unavoidable vegetation, a short length of plastic flagging was affixed to the pole at the 16.5-foot mark.

Subsequent dendrometer measurements were made proceeding up the tree. Measurements along the bole were made between internodes, avoiding the swollen part of the stem associated with them. Sometimes sighting on lichen patches helped to contrast the subject tree from its background.

After measuring the first few trees, it became apparent that the concept of an upper and lower live crown requires a good deal of subjective judgement in the field. For example, the lower live crown was apt to be discontinuous where previous thinning operations had damaged or removed limbs, or perhaps caused some adventitious branching. Whereas the upper live crown might be obscured in the crowns of the surrounding trees, or difficult to distinguish without spending an inordinate amount of time doing so.

Another problem was encountered in observing total tree height. Sometimes individual tree tops were difficult to discern, let alone locate, with the dendrometer. Also, the range-finder system of the dendrometer requires a perceptible width to be measured, in order to compute range and height. This problem was overcome as much as possible by locating the tree's terminal and making observations as near to the tip as possible. Later, it was realized that all this additional effort was for naught. As Grosenbaugh's (1974, 1971, 1967) computer program, which was used to manipulate these data, did not require a top measurement, but computed the top height with an algorithm based on the stem taper associated with the lower measurements. These top measurements could be used to compute total height, but their reliability may be shadowed by the manufacturer's minimum diameter limit of 1.5 inches.

Low underbrush was not a serious problem with dendrometer measurements, as the stump and DBH measurements were taken with a diameter tape in conjunction with a surveyor's pole. Tall underbrush, the trunks and branches of other trees, and branches of the subject tree at times limited measurements in the upper portion of the stem.

Since the third-stage sample trees had been selected prior to any second-stage field procedures, they were identified and given special treatment. These trees were marked by spray-painting a ring around the tree at BH as indicated by the 4.5-foot point on the surveyor's pole. These trees were also painted with the word "CUT" in a prominent place to afford easy relocation and identification by the contracted faller.

The equipment needed for the second-stage field measurements included:

- Barr and Stroud FP15 dendrometer and case
- tripod
- 25-foot telescoping surveyor's pole
- diameter tape
- increment borer
- binoculars
- tatum
- hand ax
- knapsack

Field measurements made on the second-stage sample trees were later transferred to ADP (Automatic Data Processing) forms, designed by Space (1973). These forms were specifically designed for use with Grosenbaugh's (1974) STX 3-3-73 computer program which had been modified by Space (1973).

Third-Stage Sampling and Field Procedure

Trees selected for this part of the study were felled, bucked, and measured for stem analysis. This provided not only very accurate individual tree volume estimates, but inference into growth and volume change over time. This stage of the experiment also yielded empirical data on the response of these stands to commercial thinnings, by providing estimates of volume per-acre over time for the surviving members of the stand.

Sample trees for this stage of the study were chosen from the dendrometered trees of the second-stage. A systematic sample with a random start was selected from an unweighted list of dendrometered trees which had been ordered by DBH, thus producing a sample across the range of diameters. This sample was selected subsequently to the completion of the first-stage variable plot cruise and selection of the second-stage sample trees. (See Appendix VIII.)

Felling and Bucking Procedure

Felling and bucking of these sample trees were done by a professional faller to keep breakage at a minimum, reduce hazard, and to insure the future utility of these valuable trees.

All trees were limbed and bucked at the time of felling. The merchantable parts of these trees were bucked primarily into lengths of 17.5 feet to a four-inch top diameter. This allowed removal of a stem cross-section from each log, permitted utility of the logs in peeler lengths, and still provided reliable stem analysis data. Necessary variations in bucking lengths were left to the faller's discretion, as he was told to buck for scale where breakage and defect were concerned. Stump height was also left to the faller's determination by instructing him to cut them as he would on a normal show.

It was assumed that, with these additional instructions, the felled trees would provide reliable data for computation of a "net" or logable volume. With this, an estimated recovery-ratio was calculated for the stands. (See Appendix IX.)

Because of the high cost of the contracted faller, it was necessary to fell the trees in the shortest possible time. Therefore, at the time of felling, no cross-sections, except for the large stump sections, were cut; and no tree measurements were taken.

Data Collection in the Field

After all the third stage sample trees in a stand had been felled, stem analysis data collection was begun.

Upon relocating a sample tree, the basic field procedure consisted of:

1) Reconstruction and measuring the stem by sections.

2) Cutting and measuring stem cross-sections.

Field measurements were recorded on a form which was a modified version of that used by Herman (et al., 1975). The exception to this was towards the end of the project, when the first fall rains made it impossible to record data with a pencil and paper. By this time, the measurements had become routine, and the data could be recorded using a portable cassette deck. The cassette recorder was carried in a knapsack and connected to a remote control microphone placed in a convenient pocket. The recorded measurements were transferred to the standard forms at the end of the day.

Stem length measurements were first. They began at the base of each tree by determining the average distance from the stump end of the first log to the BH line which had been painted on the tree in the second-stage. With this, stump height could be computed in relation to the BH point on the uphill side of the tree.

The stem sections were numbered consecutively up the tree, and each was measured to the nearest tenth-inch. Where broken or missing sections were encountered, the surrounding area was searched, and the tree reconstructed.

It should be noted here, that this reconstruction in some instances could become quite time consuming. As more often than not, when the top of a felled tree struck the ground, it was like the crack of a whip. Finding the last few or several feet of stem among the brush, or distinguishing it from the slash, was at times an unreasonable expenditure of effort. A point was made to reconstruct all trees to at least a four-inch top diameter. With this, total tree height was later predicted using a regression equation

(See Appendix IV.)

After all the stem sections had been measured for length, the cutting and measuring of cross-sectional disks began. As a general rule, disks of 2 to 3 inches in thickness were cut from the bottom of each stem section which had a diameter of about 20 inches or larger. Disks of 1 to 2 inches were taken from the smaller diameter sections. Cross-sectional disks above the merchantable top were taken at shorter intervals, 6 to 10 feet, near the internodes. A chain saw was used in cutting all disks except for the smallest, for which a hand saw was utilized. Seven to ten disks were cut from each tree.

Each disk was measured for diameter outside bark and bark thickness (usually six measurements per disk). Disks were numbered consecutively up the tree, and tallied according to the corresponding stem section from which they were cut and the location within that section. Therefore, each disk had an above-the-stump height associated with it. Each disk was labeled with a permanent ink marking-pencil. This label was written across the face of the larger disks and on the smooth bark of the smaller cross-sections. It included: plot number, tree number, section number, and indicated the upper or lower face of the disk.

In summary, the measurements taken on a felled tree included:

1) stump height, using the BH reference line.

2) cumulative stem height above the stump.

3) height to the first live limb.

4) height to the live crown.

5) number and location of transverse sections.

6) outside bark diameter of each transverse section.

7) bark thickness measurements on each transverse section.

8) age at the stump.

The smaller diameter sections were usually collected at the time of measurement and carried out in a knapsack. The larger slabs had to be collected at a later time, by strapping one to four disks to a packframe and transporting them to the nearest road. This was a time and energy consuming task, especially where an unfavorable grade was involved.

Trees were measured and packed-out in groups of seven to ten, and transported to Corvallis for storage and later increment measurements.

The equipment used during the third-stage field procedures included:

- chain saw and accessories
- 75-foot reel tape
- steel diameter tape
- 6-inch ruler with .05-inch graduations
- small hand saw
- tatum
- packframe and strappings
- knapsack

Data Collection Indoors

The storage of cross-sectional disks and its effect on shrinkage were early concerns, as it became apparent that some disks would not be measured for up to two months after their removal from the woods. This matter was discussed with Don DeMars, of the U. S. Forest Service, Pacific Northwest Range and Experiment Station. He indicated that as a part of the stem analysis study with Herman (et al., 1975), Herman had studied the effect of shrinkage on measurements. With this added insight, it was concluded that the storage of disks in a cool, dark place for up to two months should have no effect on the accuracy of measurements.

The data collection procedure and format used in this portion of the project were based on the work done by Herman (et al., 1975). It is here that the field measurements were combined with the indoor measurements for subsequent data processing.

The procedure for ring counts and sequential radial growth measurements was somewhat unique to this project. Single ring counts were relatively uncomplicated; however, due to the age of the trees, the time involved and the purpose of the study, single ring measurements were made only for the last 22 years, i.e. 1956 to present. Radial growth measurements prior to this period were made at 5-year intervals.

This procedure provided growth data by year, beginning five years prior to the first thinning operation. It was assumed that this would give sufficient insight into the growth response of these stands. In 1956, the average breast height (BH) age in Pigpen and 13-Loop were 23 and 27 years respectively (based on third-stage stem analysis trees).

The measurement procedure on a disk began by making a ring count from the circumference toward the pith. A representative radius was chosen and the ring measurement intervals were marked along it. Cumulative radial increment measurements were made from the pith outward, and recorded on a standard ADP (Automatic Data Processing) coding form adapted to this prupose.

Because of limited time, selection of a "representative" radius was expedient. This was derived by halving the DIB estimated from field measurements, and ocularly selecting an aberration-free radius on the disk which approximated this average DIB.

Unless a tree was extremely out-of-round, or the pith excessively off center, as is sometimes the case in trees on very steep slopes, only one selected radius was taken for sections where the longest radius differed from the shortest by ten percent or less. Otherwise, at least two radii, the longest and one about 180° from it, were selected. On stump sections, three radii were taken, the longest and two about 120° to either side of it.

When more than one radius was measured on a disk, sequential increment measurements of each radius were reproportioned, and a simple arithmetic average of each reproportioned radial increment was calculated. (See Table 3.) These reproportioned data were then coded on the ADP form. Reproportioning was done by the equation (Herman et al., 1975):

$$RRIM = ((DIB/2) / TAR) * RIM$$

Where: RRIM = Reproportioned radial increment measurement.

DIB = Diameter inside bark of the section, determined from field measurements.

TAR = Total length of measured representative radius.

RIM = Radial increment measurement from the representative radius.

Table 3. REPROPORTIONED RADIAL INCREMENT COMPUTATIONS.

Tree 1 Plot 13

Section: Stump DIB: 25.2 inches

Measured radial data			Reproportioned radial data			Average reproportioned radial data
Radius 1	Radius 2	Radius 3	Radius 1	Radius 2	Radius 3	
0.44	0.38	0.41	0.41	0.40	0.51	0.44
2.14	1.70	1.65	1.98	1.78	2.07	1.94
4.30	3.66	3.47	3.98	3.82	4.35	4.05
5.91	5.35	4.86	5.47	5.59	6.09	5.72
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
12.74	11.31	9.58	11.79	11.82	12.00	11.87
13.11	11.57	9.77	12.13	12.09	12.24	12.15
13.44	11.86	9.96	12.43	12.39	12.47	12.43
13.62	12.06	10.06	12.60	12.60	12.60	12.60

Multiple radii were reproportioned and averaged with a hand calculator.

Reproportionment of sequential radial growth measurements for disks with a single radius was done automatically by a computer program.

Therefore, these sections were coded and keypunched as measured.

Radial increment measurements along a selected radius were made with a 24-inch rule graduated to the nearest .02 inch and a hand-held magnifying glass. Measurements were estimated to the nearest .01 inch.

For easier ring counts and measurements along representative radii, the surface of the disk was smoothed. After trying numerous implements, it was found that a Stanley Surform plane gives the best results with the least effort.

To make annual rings more distinct, water was found to provide sufficient enhancement.

Method of Analysis

First Stage

Data analysis involved two commonly used procedures. An average tarif number for the stand was determined using both British Columbia Coastal Immature Douglas-fir and Weyerhaeuser Douglas-fir Cubic Volume Tarif Access Tables. Volume per acre and cruise statistics were computed by methods described by Dilworth (1973) and Bell (1975). A stand table of the "surviving" (current) stand was also derived from the cruise data. The data collected in this stage were also used in the subsequent stages to obtain the necessary expansion coefficients.

Second Stage

Data analysis employed the use of Grosenbaugh's STX program (1974). which had been modified by Space (1973). This produced an array of information including tree volumes and heights to a 6-inch top, a 4-inch top and 0.1-inch top. (A default system within the program prohibited computations to the projected total tree height.) Volume per acre estimates for each stand and the Douglas-fir component of the stands were computed.

Third Stage

Analysis of data in this stage was by far the most intensive. To begin with, the radial increment measurements made on the cross-sectional disks were reproportioned as described by Herman (1975). Utilizing a regression equation derived from DNR stem analysis data (Appendix VI), an estimate of total tree height was computed for 30 of the 42 third stage trees which lacked this field measurement.

A computer program was written to compute the tree's height at consecutive years above breast height. These data were used to determine King's site index for the stands from 1944 to present.

Since no cross-sections were taken at DBH, its change over time had to be estimated. This was done by employing an equation that Curtis and Arney (1977) had derived for estimating DBH from stump diameters and heights in second-growth Douglas-fir. This equation allowed for stump diameters to be measured at variable heights.

$$DBH = 0.8522 * (H^{.1063}) * DOB$$

Where: DBH = Diameter outside bark at breast height.

H = Stump height.

DOB = Diameter outside bark at the stump.

To give estimates of DBH over time, DOB at the stump was varied using the reproportioned radial increment measurements of the stump section to estimate the DIB (diameter inside bark). An estimate of the double bark thickness was added to the DIB to give the DOB. Bark thickness was assumed to change at a constant rate over time.

After computing an estimate of the current DBH, it became quite apparent that the estimates needed to be reproportioned in a manner similar to that used with radial increment measurements.

$$RDBH = (MPDBH/EPDBH)\ EDBH$$

Where: RDBH = Reproportioned DBH estimate.

MPDBH = Measured present DBH (second-stage DBH measurement).

EPDBH = Estimated present DBH (estimated by Curtis equation).

EDBH = Estimated DBH (estimated from stump section measurements and Curtis equation).

In addition, it had to be assumed that radial growth at the stump was proportional to that at DBH, and that reproportionment of that growth by the measured versus estimated DBH ratio maintained the radial growth relationship.

The effect of DBH on stand tarif number and volume estimates was investigated with the aid of the computer and a measurement error simulation (Appendix V).

Using the expansion coefficients developed by Smouse (Appendix VII), stand parameters were estimated from the second and third-stage data.

The difference in stand tarif number between estimation methods (access tables versus stem analysis cubic volume) was further investigated by using a t-test. (See Results: Tarif Number Trends and Applicability.)

RESULTS AND DISCUSSION

First Stage Sample

The first-stage variable plot cruise of the study area provided estimates by species of the volume, basal area, and number of trees per acre. These data and other parameter estimates are summarized in Tables 4-7 and Figures 2-3.

The average volume per acre (Scribner board-feet to a 6-inch top diameter) estimate obtained from the first stage sample was 35350 BF/a for 13-Loop and 28755 BF/a for Pigpen. The sample size for each area was computed by using data from a recent company cruise and assuming an allowable error of 5.0 percent (Appendix II). The resultant standard errors for the first stage volume estimates were 3.9 and 6.4 percent for 13-Loop and Pigpen respectively.

Table 4. AVERAGE DIAMETER AT BREAST HEIGHT.

Unit	Douglas-fir		Minor Species	
	Inches	Centimeters	Inches	Centimeters
Pigpen	23.5	59.7	16.8	42.7
13-Loop	22.0	55.9	17.4	44.2

Table 5. FIRST STAGE AND COMPANY VARIABLE PLOT CRUISE ESTIMATES OF VOLUME PER ACRE.

Unit	Cruise Type	Volume Per Acre (Scribner board-feet)[1]			Standard Error in Percent	Average Tarif Number	
		Douglas-fir	Minor Species	Total		Douglas-fir	Minor Species
Pigpen	Company	18770	2728	21498	9.2%	----	----
	Study (BC)[2]	22777	5453	28230	6.4%	35.9	40.0
	Study (W)[3]	23302	5453	28755	6.4%	36.5	40.0
13-Loop	Company	29364	3533	32897	4.9%	----	----
	Study (BC)	27966	6672	34638	3.9%	39.0	40.0
	Study (W)	28678	6672	35350	3.9%	39.8	40.0

[1]Scribner formula volume to a 6-inch top diameter.

[2]BC: British Columbia volume equations used in tarif computations.

[3]W: Weyerhaeuser Douglas-fir cubic volume equation used in tarif computation.

Table 6. STAND STRUCTURE OF PIGPEN UNIT.

DBH class (inches)	Average Number of Stems				Basal Area			
	Douglas-fir		Minor Species*		Douglas-fir		Minor Species	
	/acre	/hectare	/acre	/hectare	ft^2/acre	m^2/hectare	ft^2/acre	m^2/hectare
8	1.69	4.17	3.38	8.35	0.59	0.14	1.18	0.27
10	----	----	4.32	10.67	----	----	2.35	0.54
12	0.75	1.85	5.25	12.97	0.59	0.14	4.12	0.95
14	0.55	1.36	2.75	6.80	0.59	0.14	2.94	0.67
16	0.84	2.08	1.68	4.15	1.17	0.27	2.35	0.54
18	3.00	7.41	1.66	4.10	5.30	1.22	2.93	0.67
20	4.31	10.65	1.89	4.67	9.40	2.16	4.12	0.95
22	4.90	12.11	0.45	1.11	12.94	2.97	1.19	0.27
24	4.31	10.65	0.75	1.85	13.54	3.11	2.36	0.54
26	4.47	11.05	0.32	0.79	16.48	3.78	1.18	0.27
28	4.40	10.87	0.28	0.69	18.81	4.32	1.20	0.28
30	2.52	6.23	----	----	12.37	2.84	----	----
32	1.05	2.59	----	----	5.86	1.35	----	----
34	0.09	0.22	----	----	0.57	0.13	----	----
36	0.17	0.42	----	----	1.20	0.28	----	----
Totals	33.05	81.66	22.73	56.17	99.42	22.82	25.92	5.95

*Minor species include: western hemlock, Sitka spruce, and western red cedar.

Table 7. STAND STRUCTURE OF 13-LOOP UNIT.

DBH class (inches)	Average Number of Stems				Basal Area			
	Douglas-fir		Minor Species*		Douglas-fir		Minor Species	
	/acre	/hectare	/acre	/hectare	ft^2/acre	m^2/hectare	ft^2/acre	m^2/hectare
8	1.17	2.89	----	----	0.41	0.09	----	----
10	----	----	----	----	----	----	----	----
12	0.52	1.28	1.56	3.85	0.41	0.09	1.22	0.28
14	0.38	0.94	3.05	7.54	0.41	0.09	3.26	0.75
16	3.22	7.96	4.67	11.54	4.49	1.03	6.52	1.50
18	5.78	14.28	3.69	9.12	10.20	2.34	6.52	1.50
20	6.74	16.65	2.06	5.09	14.69	3.37	4.49	1.03
22	8.50	21.00	1.70	4.20	22.45	5.15	4.49	1.03
24	7.53	18.61	0.26	0.64	23.67	5.43	0.82	0.19
26	4.32	10.67	0.11	0.27	15.92	3.65	0.41	0.09
28	2.77	6.84	0.19	0.47	11.84	2.72	0.81	0.19
30	0.91	2.25	----	----	4.49	1.03	----	----
32	0.37	0.91	----	----	2.04	0.47	----	----
34	0.13	0.32	----	----	0.82	0.19	----	----
36	----	----	----	----	----	----	----	----
Totals	42.33	104.62	17.29	42.72	111.84	25.67	28.54	6.55

*Minor species include: western hemlock and Sitka spruce.

Species	Trees/acre
Douglas-fir	33.05
w. hemlock	16.88
Sitka spruce	1.58
w. red cedar	4.27
Total	55.78

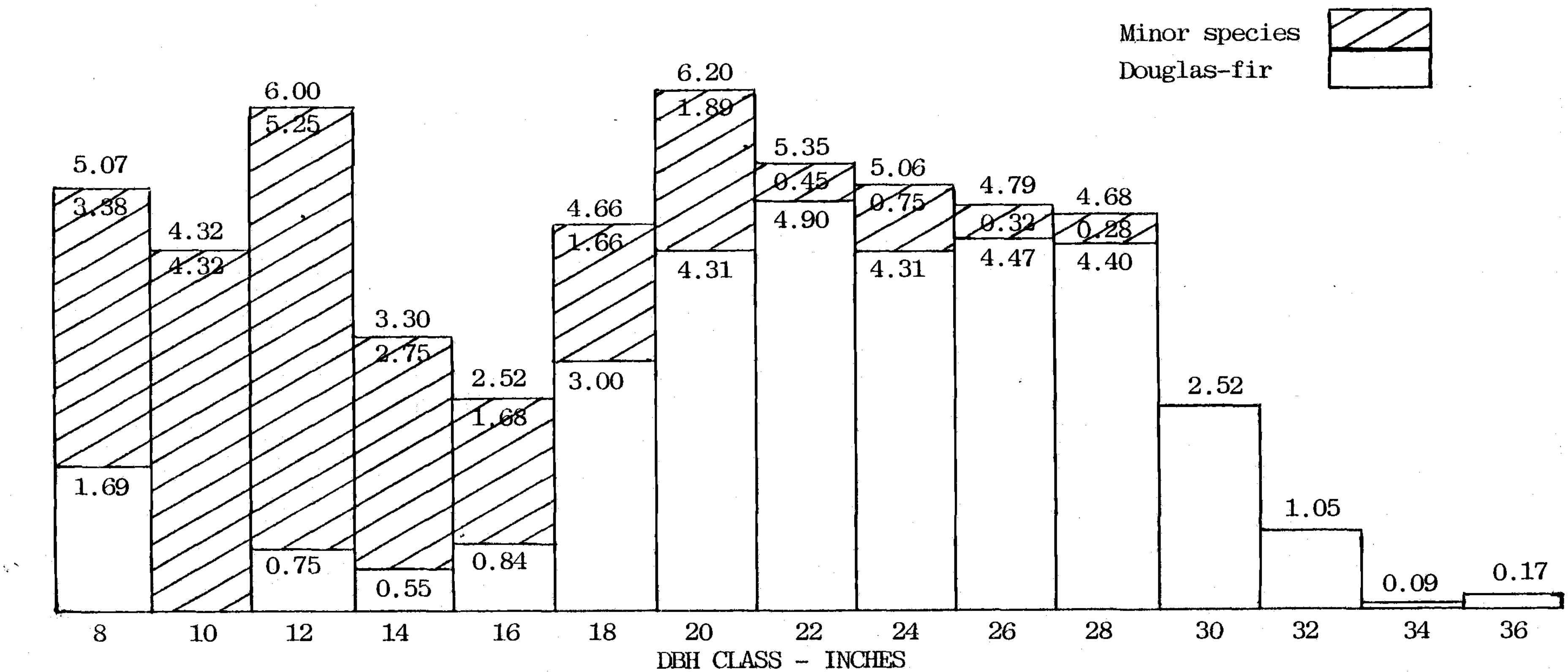

Figure 2. PIGPEN - STAND STRUCTURE BY TWO-INCH DIAMETER CLASSES.

Species	Trees/acre
Douglas-fir	42.34
w. hemlock	16.22
Sitka spruce	1.07
Total	59.63

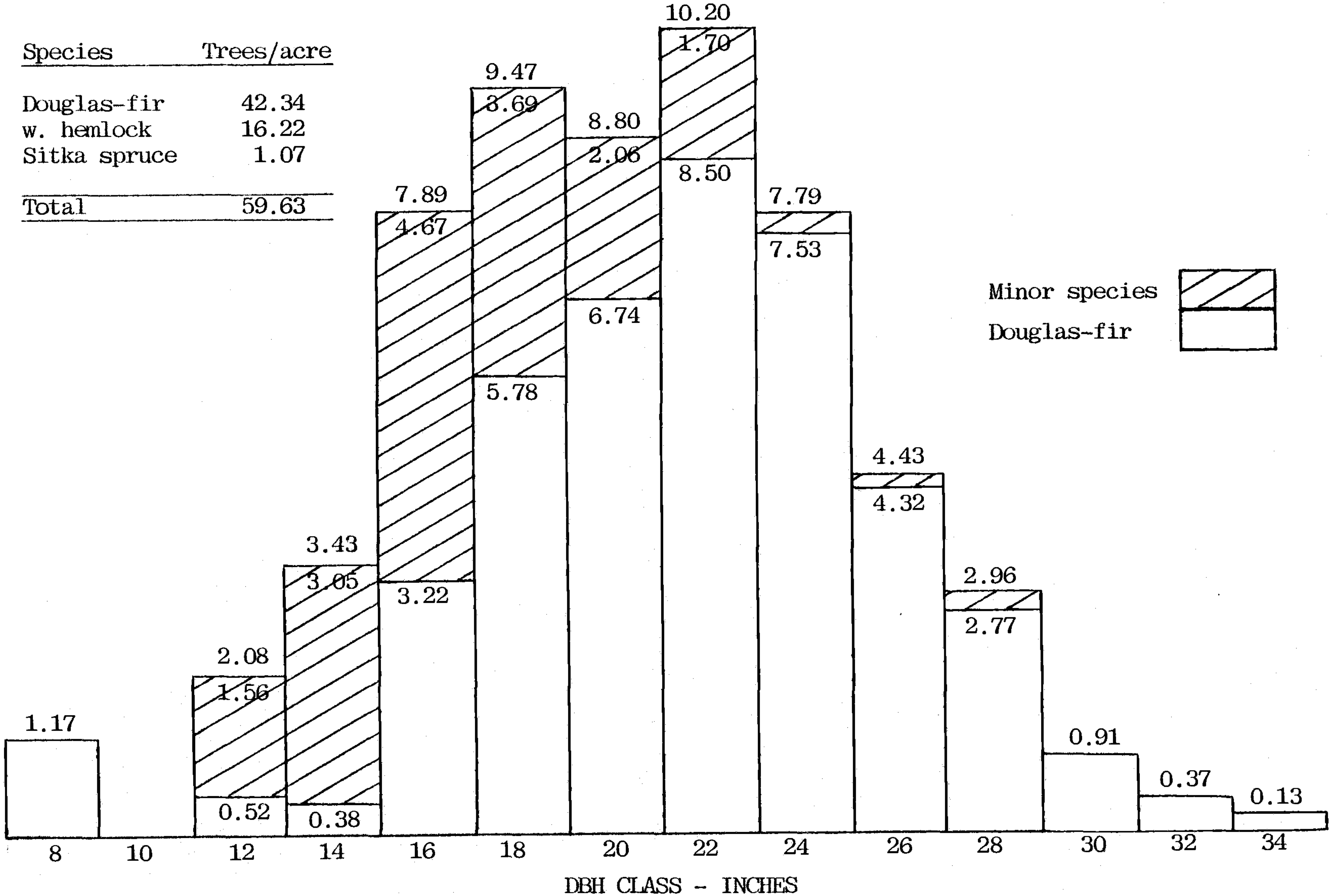

Figure 3. 13-LOOP - STAND STRUCTURE BY TWO-INCH DIAMETER CLASSES.

Second Stage

The volume estimates obtained at this sampling stage were derived from optical dendrometer measurements of the sample trees. Individual tree volumes were computed by using Grosenbaugh's (1974) 3-3-73 STX program which had been modified by Space (1973). Per acre volume estimates were calculated with the expansion equations formulated by Evan Spouse of the Survey Research Center, Oregon State University. (See Appendix VIII.) Sample variance for these estimates was computed by employing the Horvitz-Thompson variance estimator for samples with unequal probability (Appendix VIII). The resultant sample statistics are summarized in Table 9.

Using the equations outlined by Brackett (1973), two tarif numbers were computed for each sample tree to allow comparison of methods. One tarif number was derived from the dendrometer estimate of CV4 (cubic-foor volume to a 4-inch top). The other was computed by using the second stage measurements of DBH and total tree height in Weyerhaeuser's Douglas-fir cubic volume equation. (See Appendix X.) Table 8 allows comparison of these results on a stand basis.

Table 8. SECOND STAGE ESTIMATES OF AVERAGE TARIF NUMBER.

Method	Average Tarif Number by Stand			
	13-Loop (n=59)	Pigpen (n=50)	Pigpen Upper (n=23)	Pigpen Lower (n=27)
CV4*	43.7	41.2	39.0	43.0
W**	42.6	39.8	37.8	41.6

* Computed from second stage dendrometer estimate of cubic-foot volume to a 4-inch top.

** Computed from Weyerhaeuser's Douglas-fir cubic volume equation using second stage estimates of DBH and total tree height.

Table 9. SECOND STAGE VOLUME PER ACRE ESTIMATES AND STATISTICS.

Unit	Sample Size (Trees)	Entire Stand		Douglas-fir Only		Second Stage SE%	Combined*** SE%
		CV4*	SV6**	CV4	SV6		
Pigpen	50	5117	29986	4380	25672	1.9	6.7
13-Loop	59	6295	38009	5194	31362	1.6	4.2

* Cubic-foot volume per acre to a 4-inch top diameter.

** Scribner board-foot volume per acre to a 6-inch top diameter.

*** Combined standard error in percent for the first and second stages.

Third Stage

Stem analysis of sample trees provided the basis for individual tree and stand parameter estimates. These data, used in conjunction with numerous computer programs written by the author, allowed investigation of several contemporary stand parameters and their behavior over the past twenty years.

Individual tree volumes above the stump to a four and six-inch top diameter, were calculated by using Smalian's formula for a paraboloid frustum.

$$V = (H/2) * (A_b + A_u)$$

Where: V = Volume in cubic units.

H = Height or length of section.

A_b = Cross-sectional area at base of section.

A_u = Cross-sectional area at top of section.

Per acre estimates of volume and other individual tree parameters were obtained by utilizing the expansion equations derived by Smouse (Appendix VIII). Variance for the volume per acre estimates were computed by using the Horvitz-Thompson variance estimator for samples with unequal probability. (See Appendix VIII.)

Using the tarif equations from Brackett (1973) (Appendix X), estimates of the current average tarif number were made for Douglas-fir. (See Table 10.) The resultant stand tarif numbers and their corresponding volume per acre estimates are presented in Table 11 for comparison with stem analysis estimates.

Table 10. THIRD STAGE ESTIMATES OF AVERAGE TARIF NUMBER.

Method	Average Tarif Number by Stand for Douglas-fir			
	13-Loop (n=24)	Pigpen (n=18)	Pigpen Upper (n=9)	Pigpen Lower (n=9)
CV4*	46.8	40.7	37.5	43.9
W**	41.5	38.7	36.0	41.4
BC***	40.7	38.0	35.3	40.9

* Computed from third stage stem analysis estimates of tree volume.

** Computed from Weyerhaeuser's Douglas-fir cubic volume equation and third stage data.

*** Computed from British Columbia cubic volume equation and third stage data.

An in depth discussion of the trends and predictions drawn from the third stage sample is covered in the following sections; but it is interesting to note here the difference between tarif estimates (Table 10) and the corresponding volume per acre estimates for the present Douglas-fir component of these stands. (See Table 12.) The Weyerhaeuser estimates are characteristically greater than the British Columbia tarifs. This indicates a difference in form and volume of a tree for a given DBH and height. Stem analysis data suggest that thinned trees in both stands tend to have a greater volume than would be predicted by either the British Columbia or Weyerhaeuser volume equation for this species.

Table 11. VOLUME PER ACRE ESTIMATES OF THE PRESENT STANDS BASED ON THIRD-STAGE DATA ANALYSIS.

Unit	Sample Size (Trees)	Entire Stand		Douglas-fir Only		Third Stage SE%	Combined*** SE%
		CV4*	SV6**	CV4	SV6		
Pigpen	18	5103	29911	4319	25315	5.5	8.6
13-Loop	24	6601	39857	5446	32884	4.1	5.8

* Cubic-foot volume per acre to a 4-inch top diameter.

** Scribner board-foot volume per acre to a 6-inch top diameter.

*** Combined standard error in percent for all three stages.

Table 12. COMPARISON OF VOLUME PER ACRE BY TARIF ESTIMATION METHODS FOR THE DOUGLAS-FIR COMPONENT OF THE STUDY AREAS.

Unit	Tarif Estimation Method		
	CV4[1]	W[2]	BC[3]
	Cubic-Foot[4] Volume Per Acre		
Pigpen	4301	4090	4016
13-Loop	5546	4918	4823
	Scribner[5] Volume Per Acre		
Pigpen	26788	25170	24585
13-Loop	34299	30146	29463

[1] Computed from stem analysis volumes.

[2] Computed from Weyerhaeuser's Douglas-fir cubic volume equation.

[3] Computed from British Columbia cubic volume equation.

[4] Cubic-foot volume to a 4-inch top.

[5] Scribner formula volume to a 6-inch top.

Site Index Trends

Total height and breast height age data were compiled for each third stage sample tree for the past 34 years. Utilizing these data in conjunction with King's (1966) site index tables, the site index of each tree was determined at two-year intervals from 1944 to the present.

King's (1966) diameter guide equations for selection of site trees were used to determine which third stage trees were consistent with the site curve construction. The equations for the guide are:

Maximum DBH of site trees = 3.16 + 1.416 ADBH

Minimum DBH of site trees = 0.73 + 1.135 ADBH

Where: ADBH = Average DBH of the Douglas-fir component of the stand.

Using the estimate of average DBH for Douglas-fir from the first stage variable-plot cruise and the estimate of DBH growth by year from the third stage trees, the DBH limits for site trees were computed for the period from 1956 to 1977. It was assumed that any third stage tree which met the DBH restrictions for this period would also have qualified from 1944 to 1955.

After applying these limitations, only seven trees in each stand remained. This sample size, in stands 30 years and older breast height age, should, according to King (1966), provide a standard error of the estimated mean site index of two to three feet. The site index trends for the individual stands are plotted by year in Figures 4 and 5, and by breast height age in Figures 6 and 7. These data are also summarized

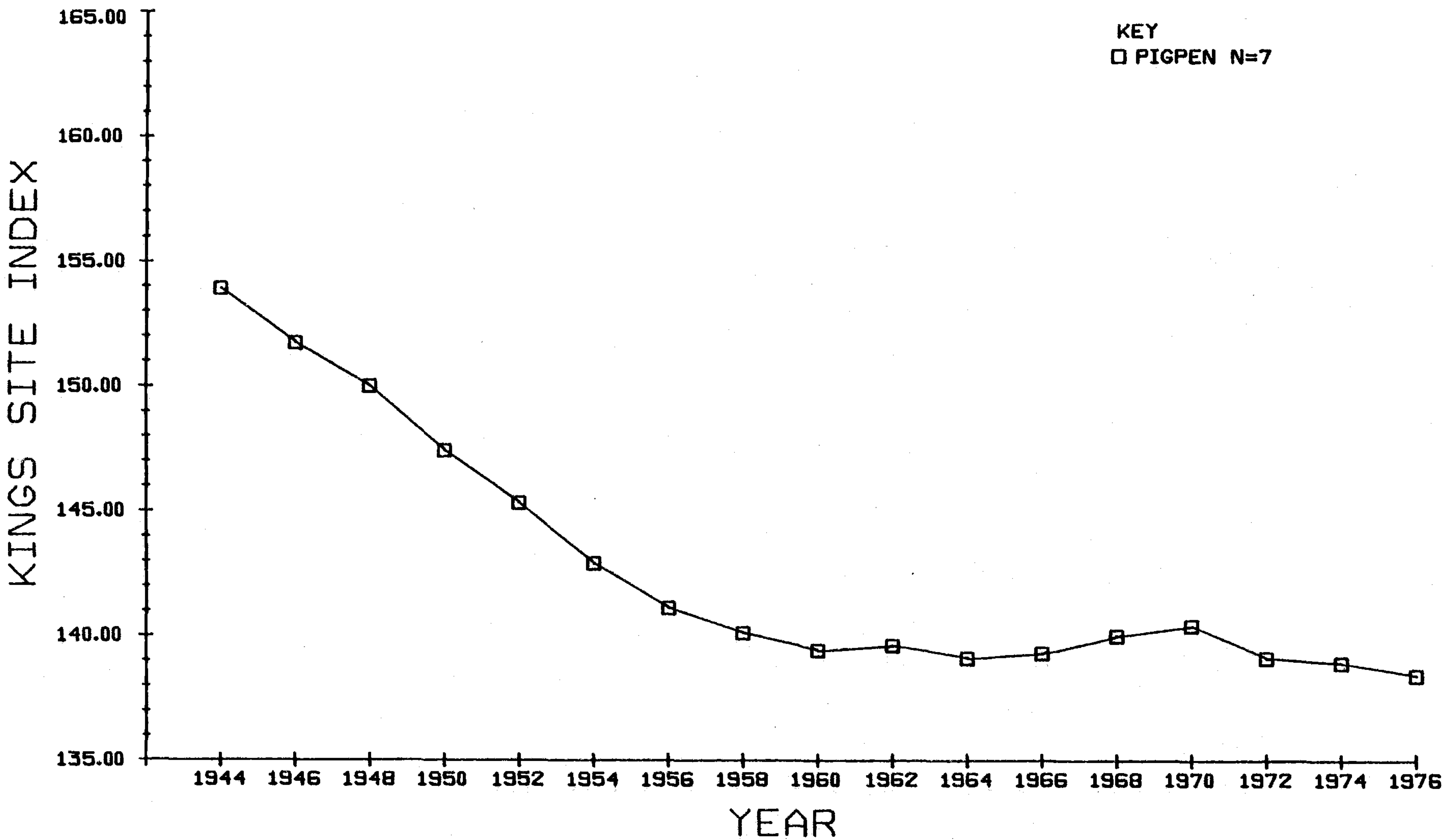

Figure 4. KING'S SITE INDEX TREND IN PIGPEN FROM 1944 TO 1976.

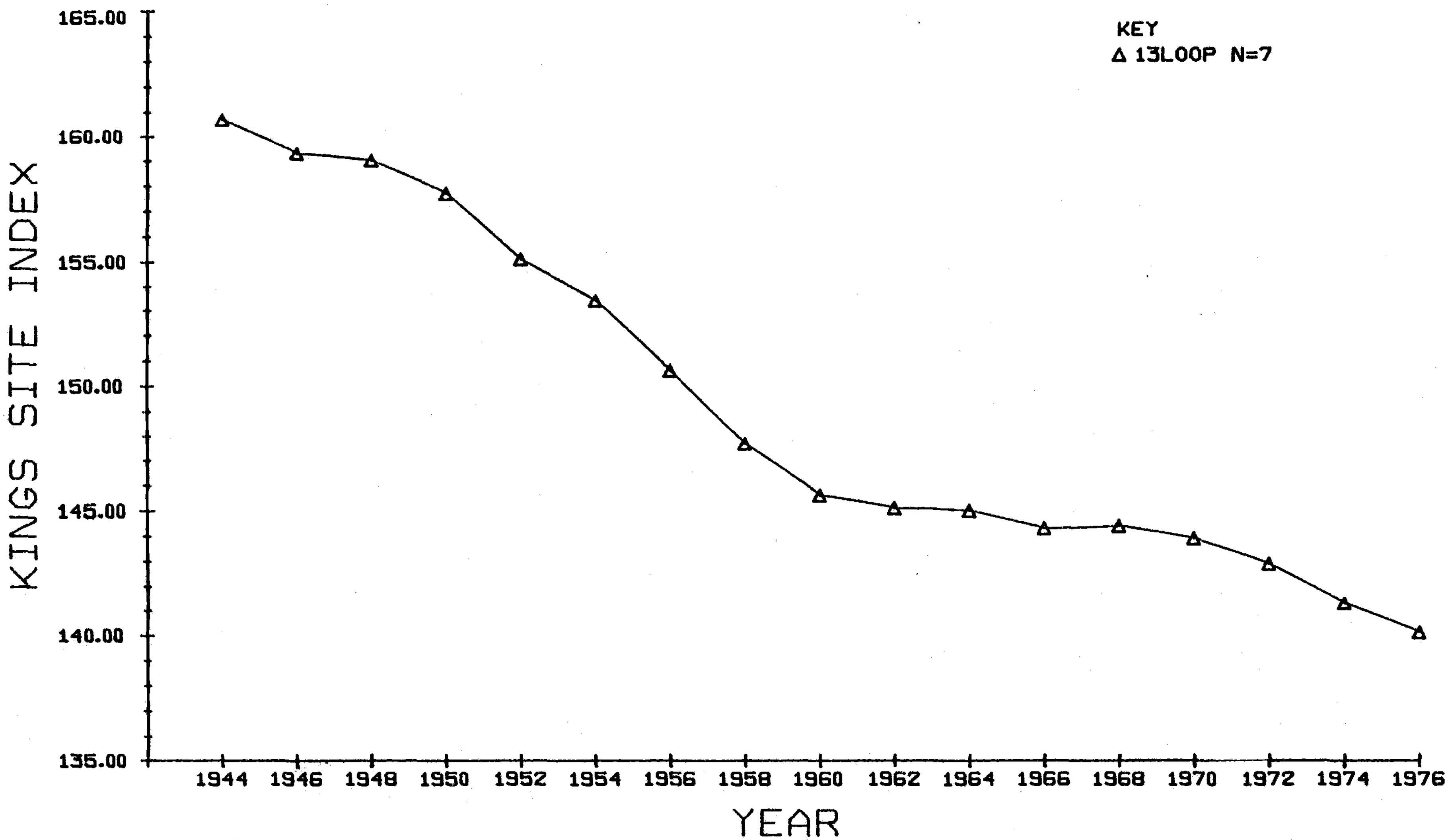

Figure 5. KING'S SITE INDEX TREND IN 13-LOOP FROM 1944 TO 1976.

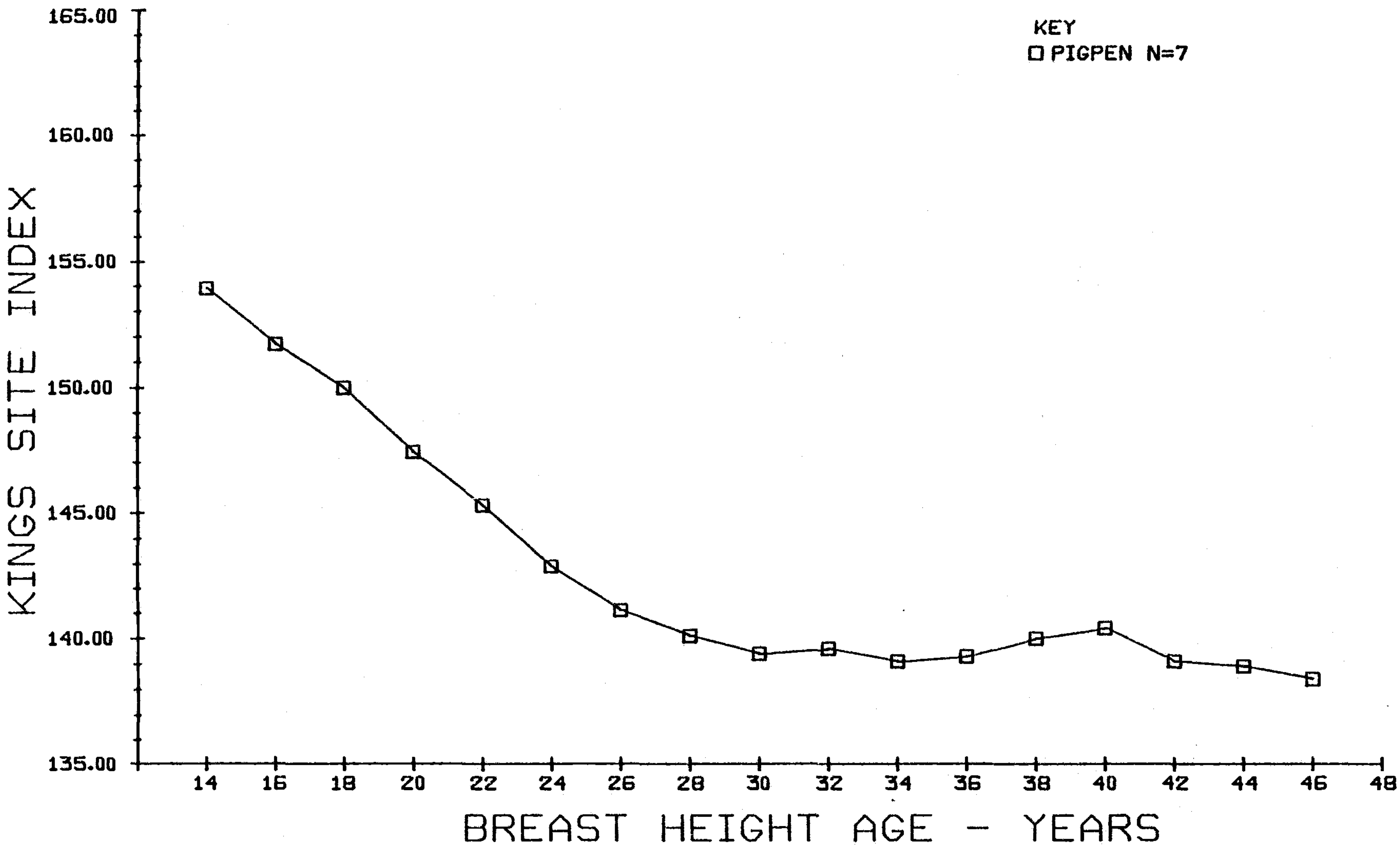

Figure 6. KING'S SITE INDEX TREND IN PIGPEN BY AVERAGE BREAST HEIGHT AGE.

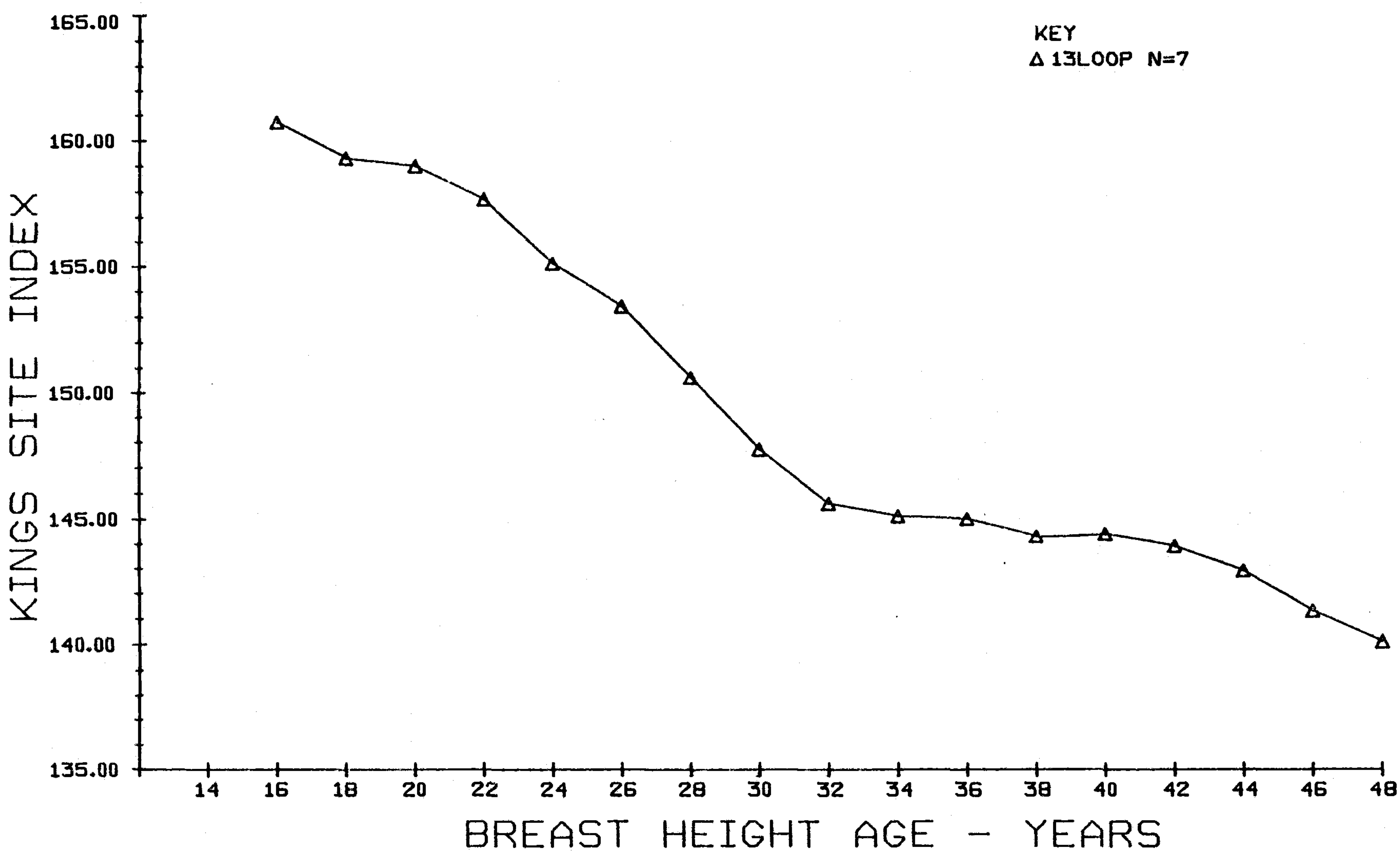

Figure 7. KING'S SITE INDEX IN 13-LOOP BY AVERAGE BREAST HEIGHT AGE.

in Table 13. A comparison of these two stands, plotted in Figure 8, shows the site index trends and reflects the similarity in response to both environmental factors and thinning operations.

It should be noted here that theoretically, the site index of a stand should remain relatively constant over time. Although these plots reveal something quite different from the expected, the downward trend in site index in both stands appears to diminish about the time that thinning operations began in these stands, 1961. (See Figure 8.) This curtailment may not have been a result of thinning operations, although thinning has probably affected the more recent site index trends.

The site index estimates on some trees in the early portion of the examination period are conservative. Several trees exhibited age-height relationships which were beyond the site index tables' limit of 160. Extrapolated values based on the height to site index trend at a particular age, were reduced by 20 percent of their value above 160.

In stands studied by Groman (1972), thinned stands grew more in height than unthinned stands, over a fifteen year period. This resulted in a corresponding increase in the apparent site index. The stands in this study had been thinned from below, removing the suppressed and intermediate trees. This probably increased the amount of water and nutrients available to the remaining trees, but afforded them little or no release. Thus, height competition remained critical to the trees in the upper canopy.

The situation at Big Creek was apparently quite different, with early thinnings probably coming from above. This, it is assumed,

Table 13. AVERAGE KING'S SITE INDEX BASED ON THIRD STAGE STEM ANALYSIS DATA.

	13-Loop				Pigpen		
Year	BH Age n=24	SI[1] n=24	SI[2] n=11	SI[3] n=7	BH Age n=17	SI[1] n=17	SI[3] n=7
1976	48	135.3	136.4	140.1	46	138.7	138.4
1974	46	136.2	137.6	141.3	44	138.8	138.9
1972	44	137.2	139.3	142.9	42	140.2	139.1
1970	42	138.1	140.4	143.9	40	141.4	140.4
1968	40	138.6	140.7	144.4	38	140.9	140.0
1966	38	138.9	140.7	144.3	36	140.8	139.3
1964	36	139.3	141.0	145.0	34	140.9	139.1
1962	34	139.8	141.4	145.1	32	141.5	139.6
1960	32	140.8	141.8	145.6	30	141.3	139.4
1958	30	142.3	143.9	147.7	28	141.5	140.1
1956	28	144.4	146.5	150.6	26	142.4	141.1
1954	26	146.6	149.3	153.4	24	143.7	142.9
1952	24	148.6	151.7	155.1	22	146.4	145.3
1950	22	150.3	154.3	157.7	20	148.8	147.4
1948	20	152.2	156.1	159.0	18	151.8	150.0
1946	18	154.0	157.4	159.3	16	154.0	151.7
1944	16	156.4	159.8	160.7	14	156.0	153.9

[1]Includes all third stage trees for which site index could be determined throughout the period 1944 to 1976.

[2]Includes all trees which met the DBH requirement for 75% or more of the entire period.

[3]Includes only trees which met the DBH restriction for the entire period.

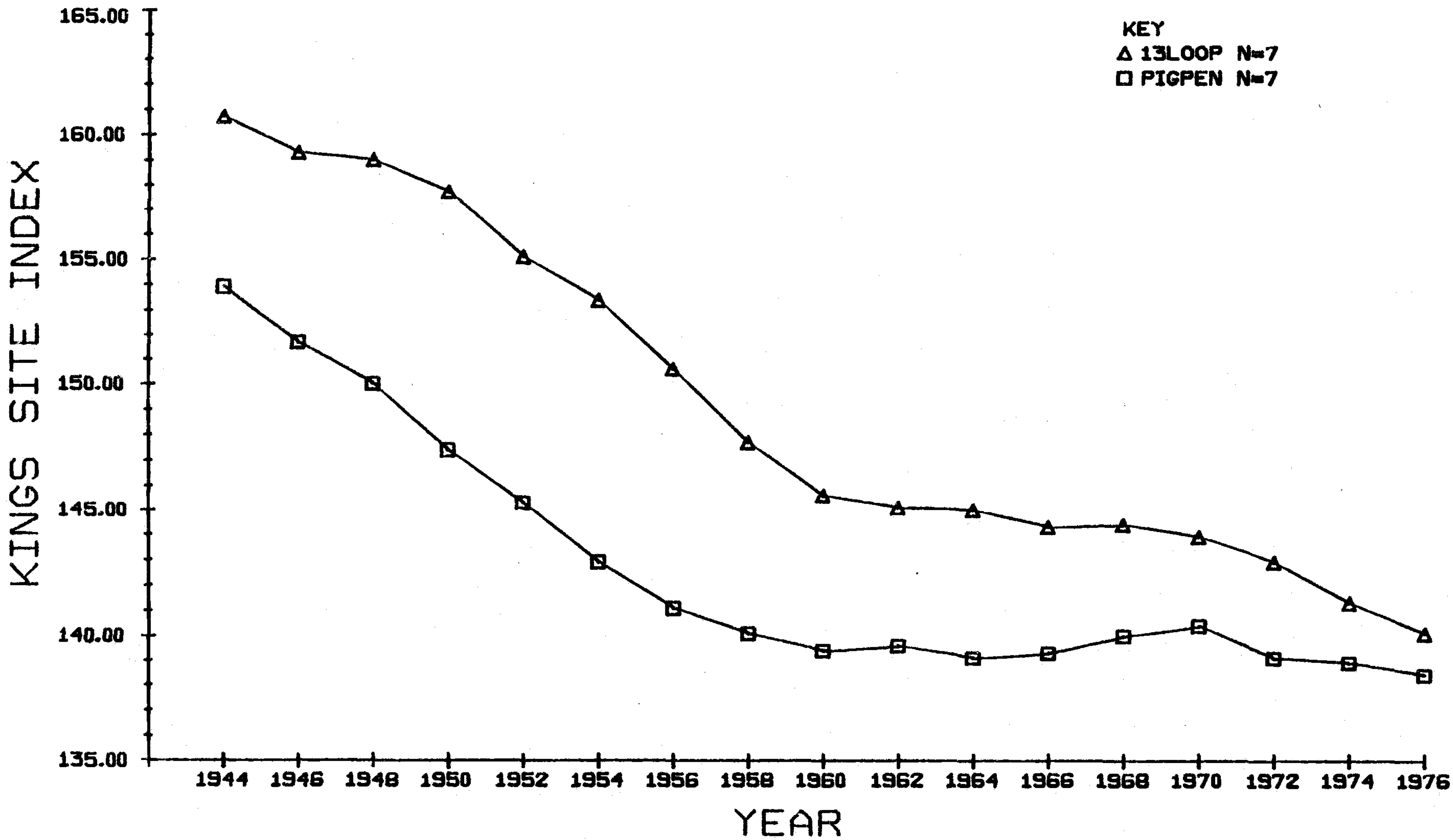

Figure 8. COMPARISON OF SITE INDEX TRENDS IN PIGPEN AND 13-LOOP.

provided not only a shift in the growth potential of the stand, but some release to the side of the remaining trees of the upper canopy. This difference in thinning regimes could well be a major factor contributing to the difference in height response observed in Big Creek. It appears that the early thinning from above resulted in crown expansion with stem growth favoring increases in girth instead of height. This perception is further supported and discussed in the following section on tarif number and trends.

The reason for the apparent drop in site index from about 15 to 30 years breast height age cannot be easily explained. Since no control stand was available for study in Big Creek, stem analysis data from an unthinned stand of Douglas-fir near Apiary, Oregon was examined for comparison. (Data provided by Dr. Walter Thies of the U.S. Forest Service, Pacific Northwest Range and Experiment Station, Corvallis, Oregon.) This stand is about 25 miles east of Big Creek, about 15 years younger, and one site class lower. A summary of this stand's parameters can be found in Appendix VI. In general, a similar downward trend in apparent site index was exhibited by the young stand. (See Figure 9.) This suggests that these stands may not follow the general growth curve used to develop Kings site index curves.

Assuming that the site estimates in the older stands are correct, these stands apparently have a tendency to grow more in height while young than the "normal" Douglas-fir stand. This height growth pattern of rapid growth in the young stand which drops off markedly with age could, according to James King, occur on sites with shallow soils

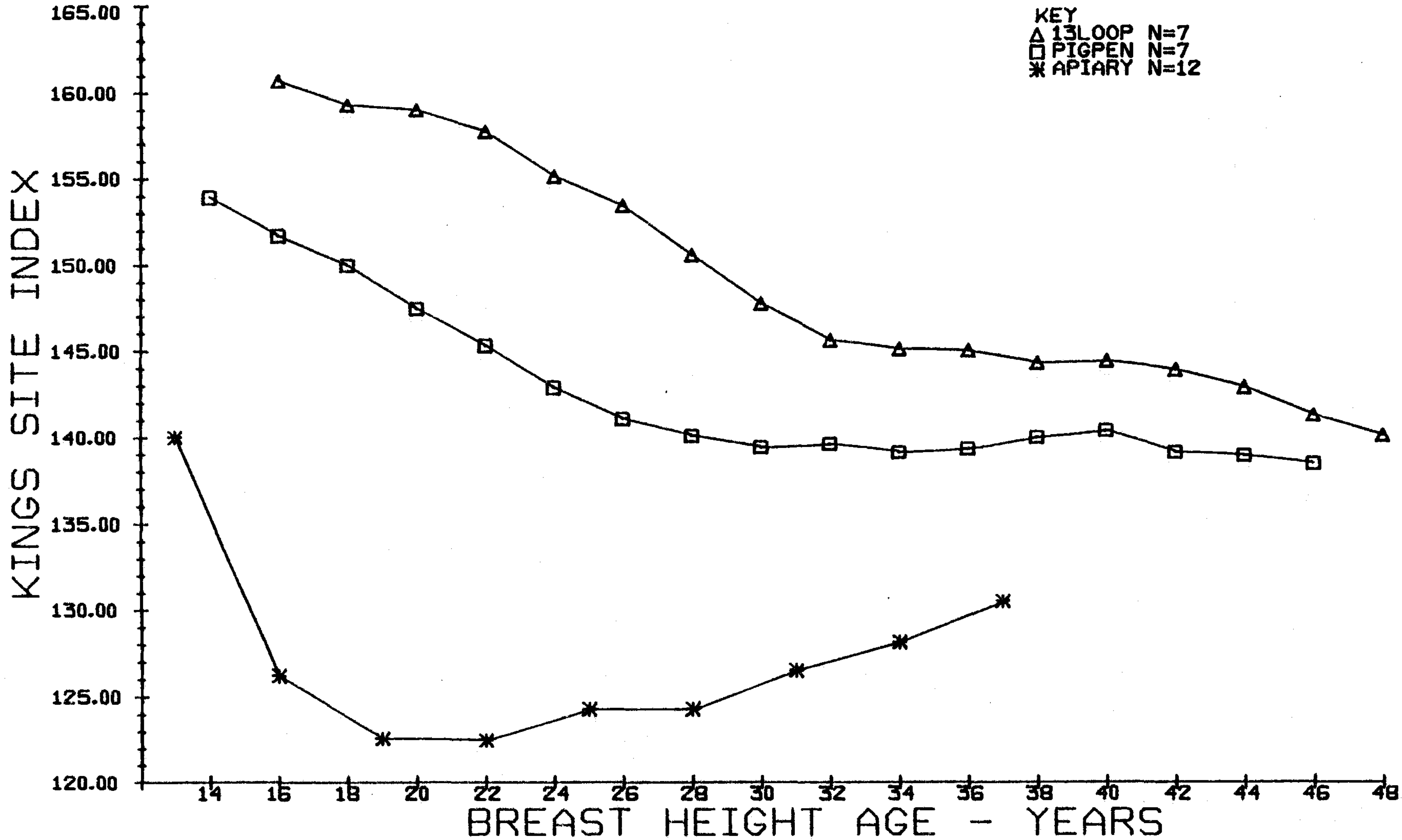

Figure 9. COMPARISON OF THE SITE INDEX TREND IN AN UNTHINNED STAND WITH THOSE OF THE STUDY STANDS.

(personal communication with Dr. J.F. Bell). Although shallow is only a relative term, perhaps herein lies a partial explanation of the extraordinary height growth exhibited by these stands in their early development. The surface soils of this area are generally noted as rarely being more than three feet deep; although the sandstone and shale parent material is often permeable to depths of 10 to 25 feet. Whatever the explanation of this anomaly may be, it is apparent that the use of site index, measured in a young Douglas-fir stand within this drainage and perhaps within this general area, may result in an erroneous prediction regarding the productive capacity of a site and its associated yields.

Additional plots of site index trends were made to further examine this apparent anomaly. Figures 10 and 11 exhibit the trend in each stand of all third stage sample trees versus those meeting King's DBH criteria. It is interesting to note that in Pigpen (Figure 10), the selected site trees portray a similar, but slightly lower trend than the overall sample; while in the other stand, 13-Loop, the selected site trees exhibit a marked difference from the overall trend of about plus five tarif units.

Taking a closer look at the situation in Pigpen, it becomes obvious that the upper and lower portions of the stand are quite different. This becomes more apparent upon examination of the depletion records for the stand. The upper, wider spaced portion was initially entered in 1967, while the lower and more dense portion of the stand was first thinned in 1961. Figure 12 reveals the difference in site

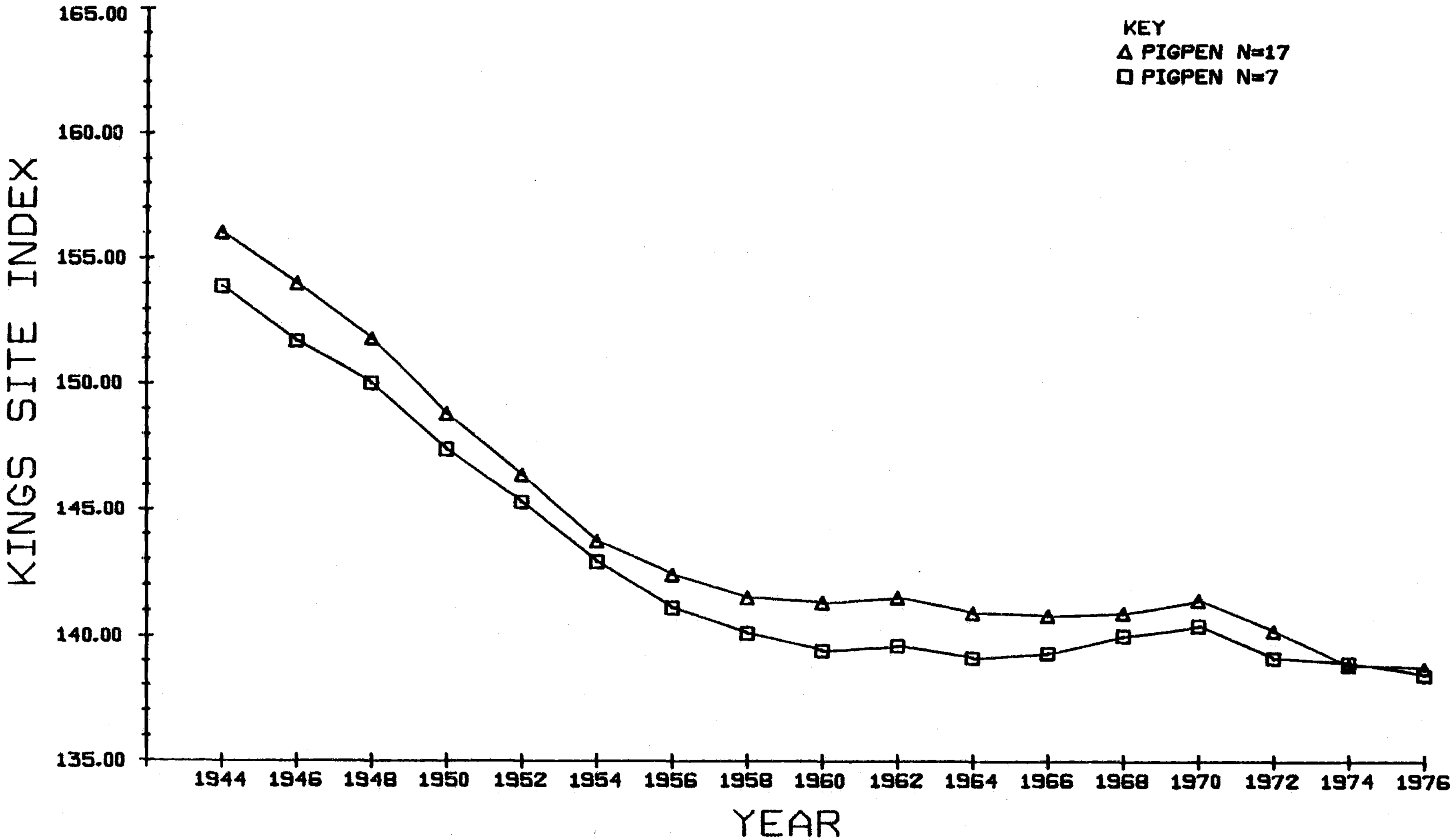

Figure 10. COMPARISON OF SITE INDEX TRENDS IN PIGPEN FOR SITE TREES SELECTED BY DIAMETER AND ALL THIRD STAGE SAMPLE TREES.

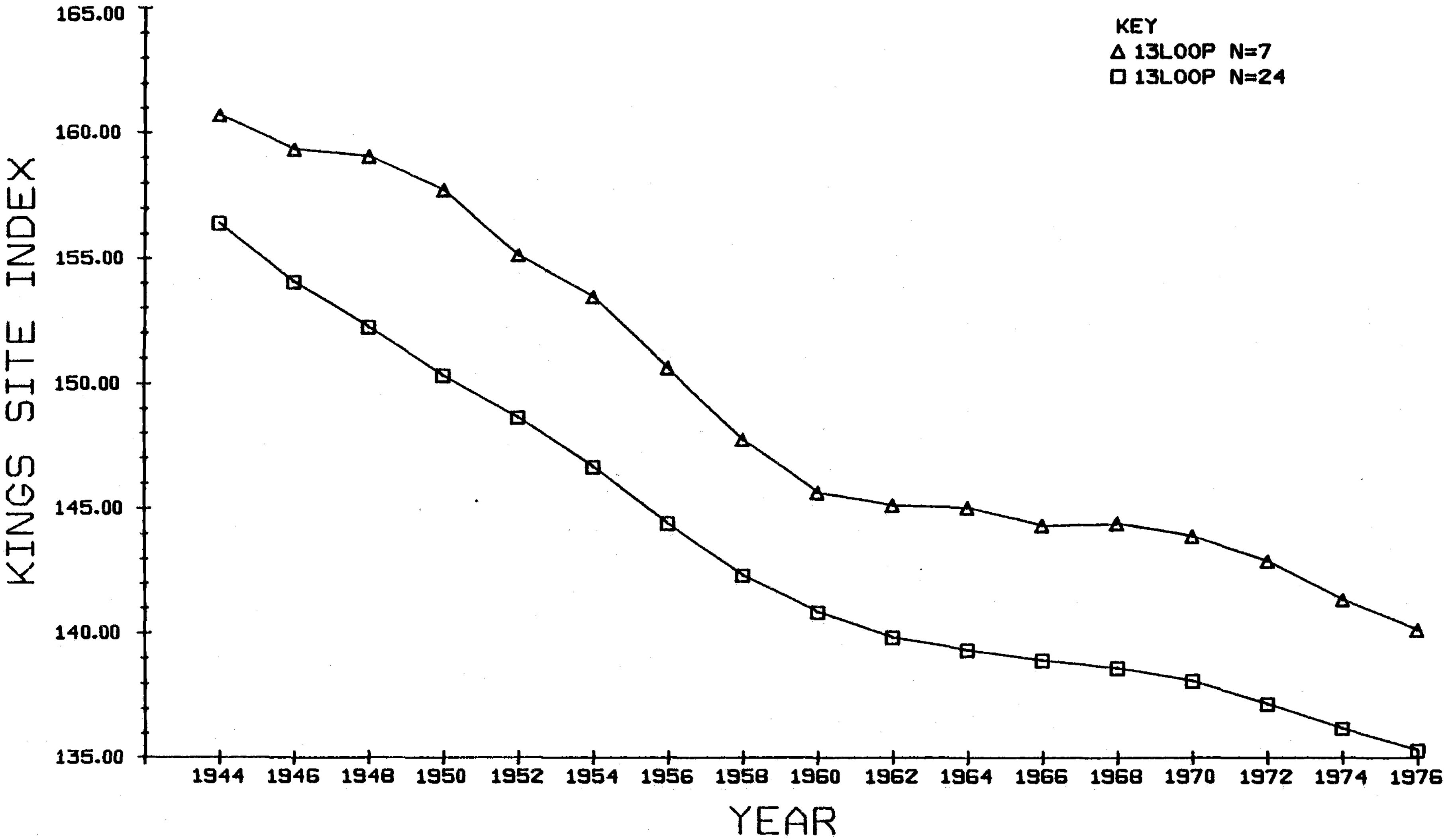

Figure 11. SITE INDEX TRENDS IN 13-LOOP FOR SITE TREES SELECTED BY DIAMETER AND ALL THIRD STAGE SAMPLE TREES.

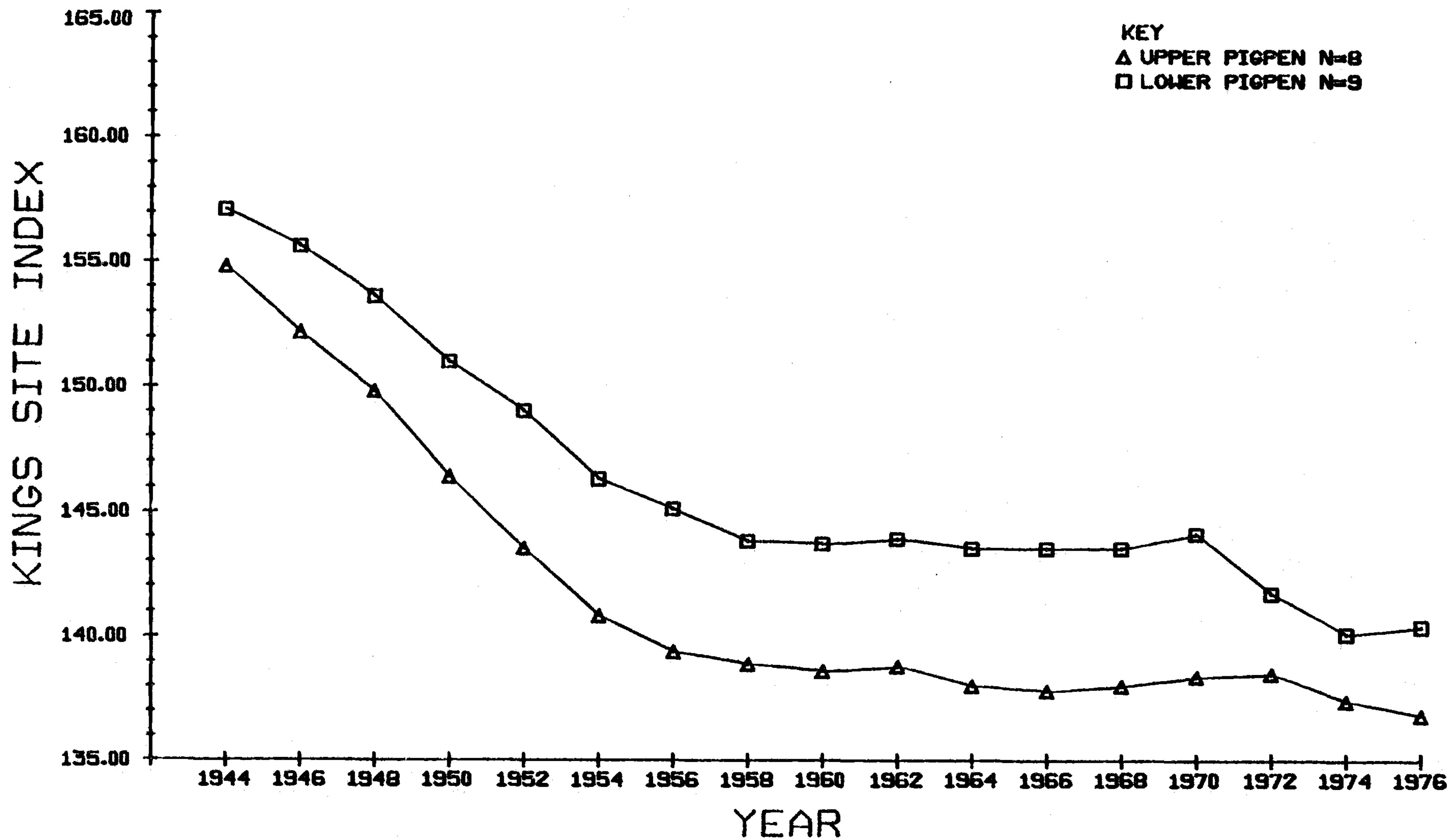

Figure 12. SITE INDEX TRENDS IN THE UPPER AND LOWER PORTIONS OF PIGPEN.

index trends within the stand. It should be noted here, that the trees in the upper, initially wider spaced portion of the stand, tend to be of a larger DBH class and thus five of the seven trees in the stand which met King's diameter restrictions and were used to express the site index trend for the whole stand came from this portion.

It is also interesting to examine the apparent similarity in site index trends between the lower portion of Pigpen and that of 13-Loop, expecially after the initial thinning operations began in 1961. (See Figure 13.) Perhaps some of the difference in site index, and therefore height growth, of these young stands could be attributed to their aspect; Pigpen having a slightly northeast aspect, while 13-Loop is generally of a southwest orientation.

Additional site index data for other stands in Big Creek were obtained from John Olson of the University of Washington, Seattle. These data are from plots which are a part of a Regional Fertilizer and Nutrition Research Program (RFNRP). On five plots, the apparent King's site index for 1975 ranges from about 133 to 146, with an average of 138.5. The average breast height age for these trees is about 46 years. These data are quite comparable with those of the thinned stands in this study. (See Table 13.)

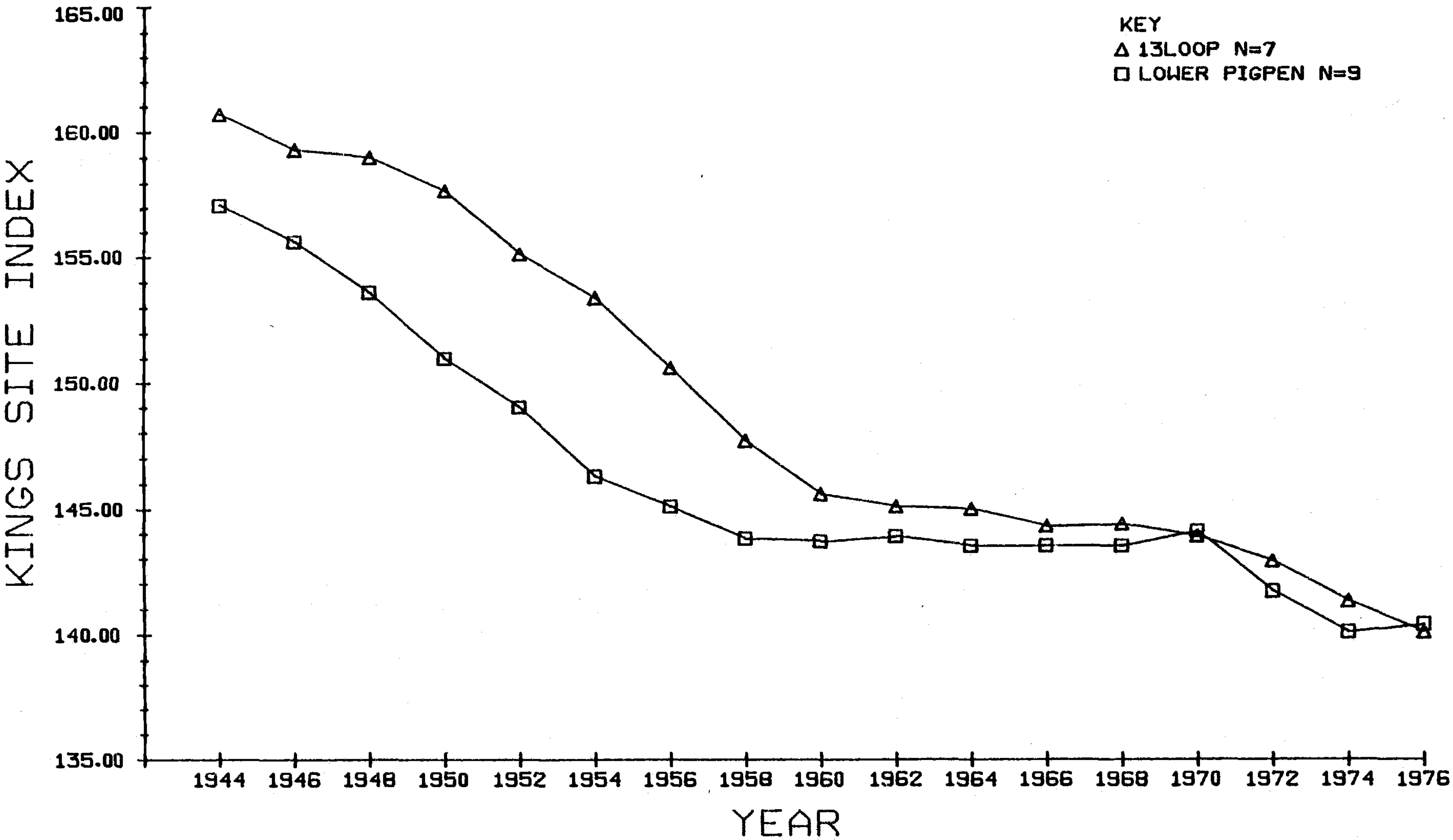

Figure 13. COMPARISON OF SITE INDEX TRENDS IN 13-LOOP AND THE LOWER PART OF PIGPEN.

Tarif Number Trends and Applicability

The tarif system, as developed by the DNR (Turnbull et al., 1963), defines tarif number as the cubic-foot volume to a four-inch top for a tree of one-square-foot of basal area. Therefore, as tarif number increases, the volume to basal area ratio increases and the form of the tree changes. Access to the tarif volume tables can be obtained by using two standard tree parameters, DBH and total height, in conjunction with converted standard volume tables or volume equations for a species. Tarif can also be computed from DBH and actual stem volume measurements. A tarif number, or form, can be determined for an individual tree; and by sampling numerous trees within a stand, the average form can be estimated. This system is noted to have sufficient accuracy for volume and growth determination in research (Bell, 1975). But the crux of the system, whether for research, inventory or cruising applications, appears to be in the reliability of the access method.

The stem analysis of third stage sample trees permitted computation of a tree's tarif number from its cubic-foot volume estimate. Tarif numbers for these trees were also computed by conventional methods, Weyerhaeuser and British Columbia cubic volume equations, which use DBH and total tree height as independent variables. (See Appendix X for equations)

Using estimates of DBH, total height, and cubic-volume to a four-inch top (CV4), tarifs of third stage sample trees were computed for the period 1956 to 1977. These trends, expressed as stand averages, appear in Figures 14 and 15 for the three aforementioned methods of tarif determination.

Since DBH was estimated from stump measurements and a regression equation (see Methods of Analysis), the effect of an error in DBH on tarif was investigated (Appendix V). Findings indicate that varying DBH estimates had very little effect on the stand tarif number, when utilizing the Weyerhaeuser and British Columbia cubic volume equations. In these two methods, a change in DBH affected the estimated tree volume in the same direction. Thus, a reduction in DBH reduced the estimated volume and, since height remained constant, the form of the tree "improved", i.e. the tarif number increased. The reverse held true for an increase in estimated DBH. In brief, for the Weyerhaeuser and British Columbia estimates, a fluctuation of DBH on all sample trees by .2 inch resulted in the average tarif number shifting about .1 tarif unit in the opposite direction. For the stem analysis tarif estimates, the effect was much more pronounced, because tree volume estimates remained constant. The same .2 inch variation in DBH resulted in a change of about .8 tarif unit for the stand.

Therefore, it is assumed that the effect of errors in estimating past DBHs on the average stand tarif number is minimal, if not self-compensating.

Examination of the tarif trends in Figures 14 and 15 reveals an obvious difference in relationship of the tarif estimation methods between the two stands. To help understand this difference, Pigpen third stage sample trees were once again segregated by their location in the stand,

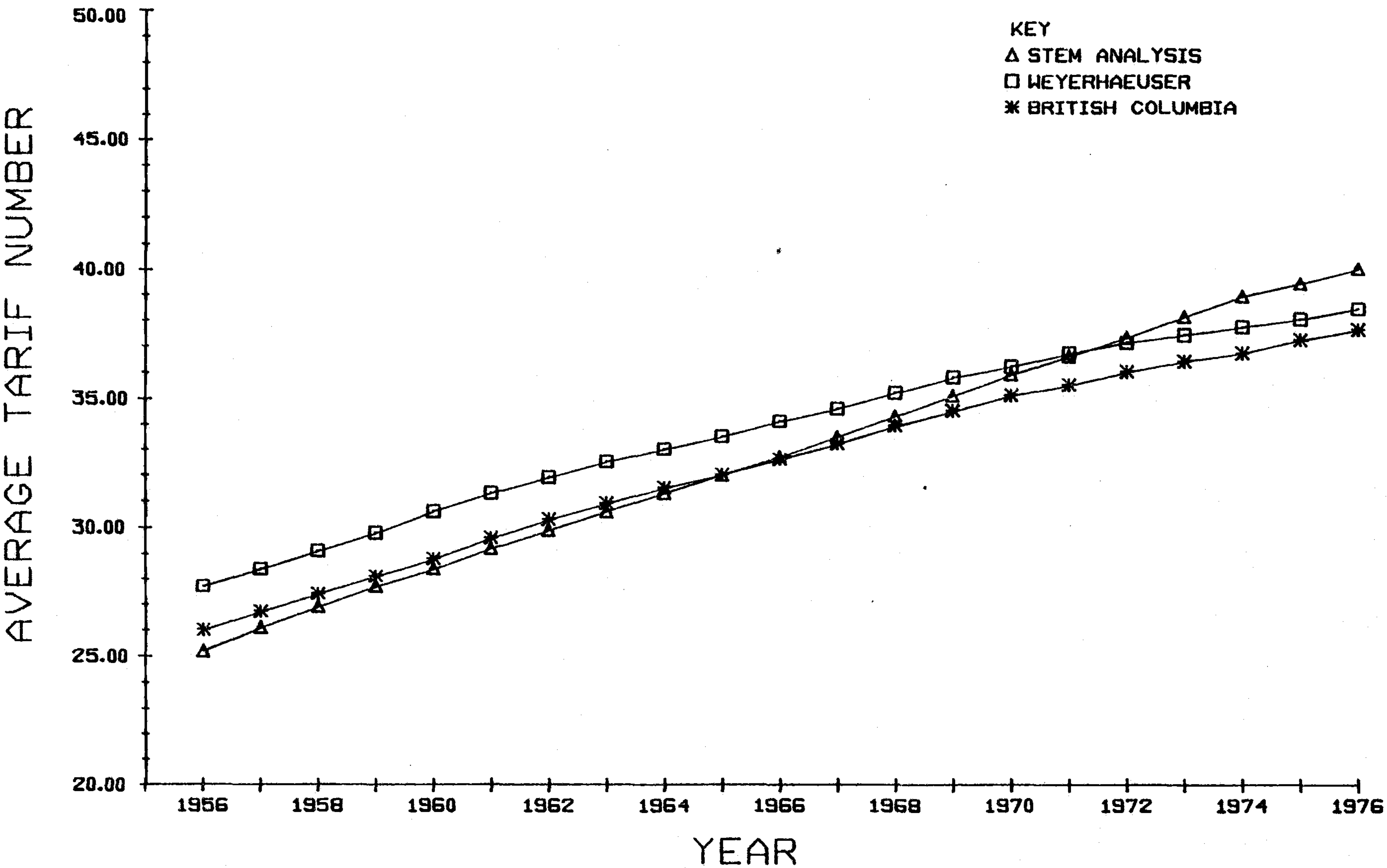

Figure 14. TARIF TRENDS IN PIGPEN BY TARIF ESTIMATION METHOD.

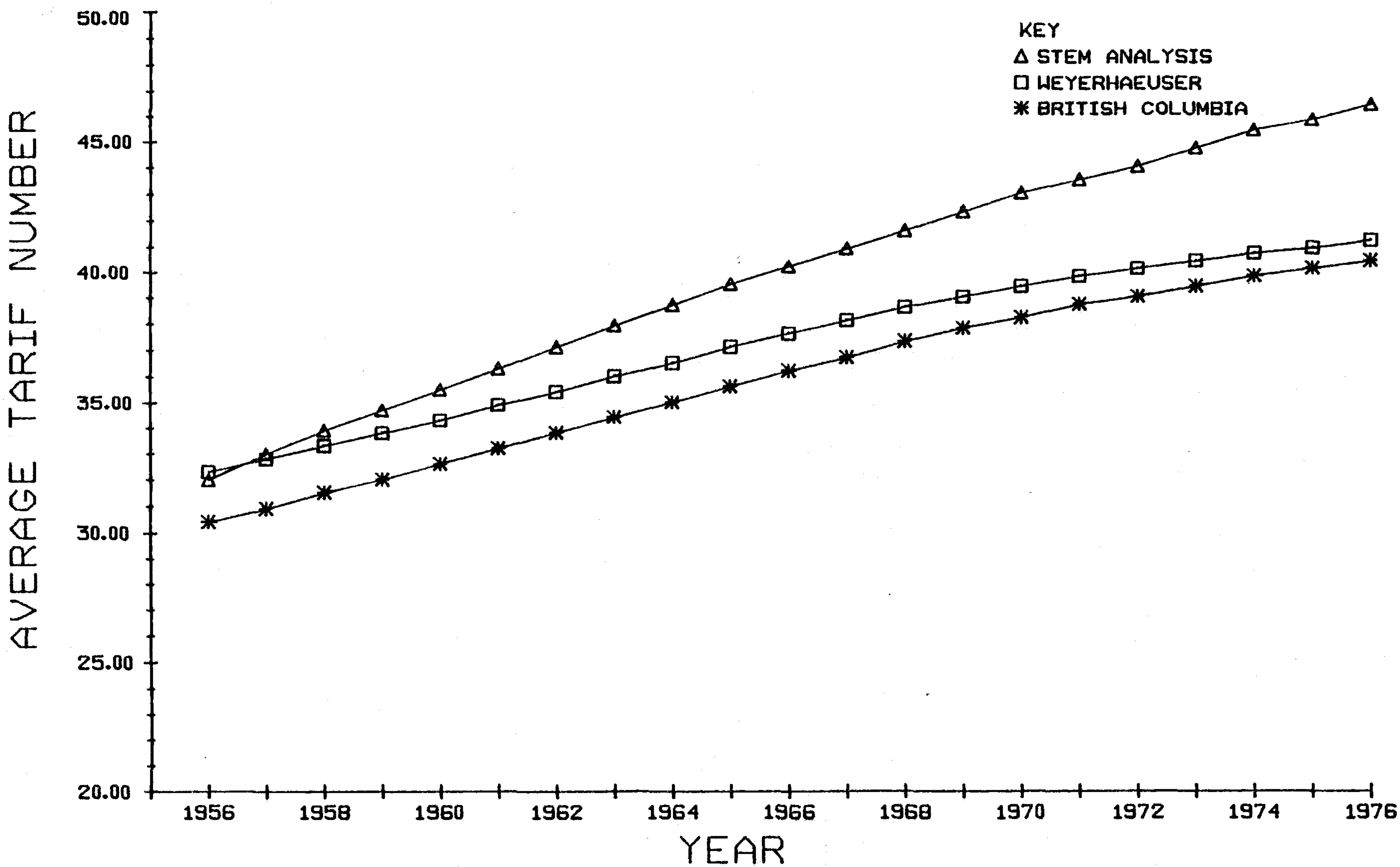

Figure 15. TARIF TRENDS IN 13-LOOP BY TARIF ESTIMATION METHOD.

upper or lower half. Figure 16 shows the results of this segregation in relation to the average tarif trend. The hypothesis that the average tarif of the upper and lower portions of the stand are equal was tested with an unpaired t-test at three points in time, and was easily rejected at each.

Table 14. RESULTS OF UNPAIRED T-TEST ON AVERAGE TARIF NUMBER FOR UPPER AND LOWER PIGPEN.

H_o: $\overline{TARIF}_U = \overline{TARIF}_L$

Year	Average Tarif Upper	Average Tarif Lower	Degrees of Freedom	T-Value	Probability Level (two-tailed)
1956	20.8	29.6	16	-3.593	.0012*
1966	28.7	36.7	16	-4.037	.0005**
1977	36.7	43.3	16	-3.389	.0019*

The tarif trends by estimation method were plotted for each portion of Pigpen, Figures 17 and 18, to better perceive the situation and growth within this stand.

An examination of Figures 14, 15, 17, and 18 reveals that Weyerhaeuser and British Columbia tarif trends nearly parallel one another for the observation period. The higher Weyerhaeuser estimates suggest that the trees they are based on, Douglas-fir in the state of Washington, exhibit a "better" form for a particular DBH and height. Using the Weyerhaeuser cubic volume equation to estimate tarifs in

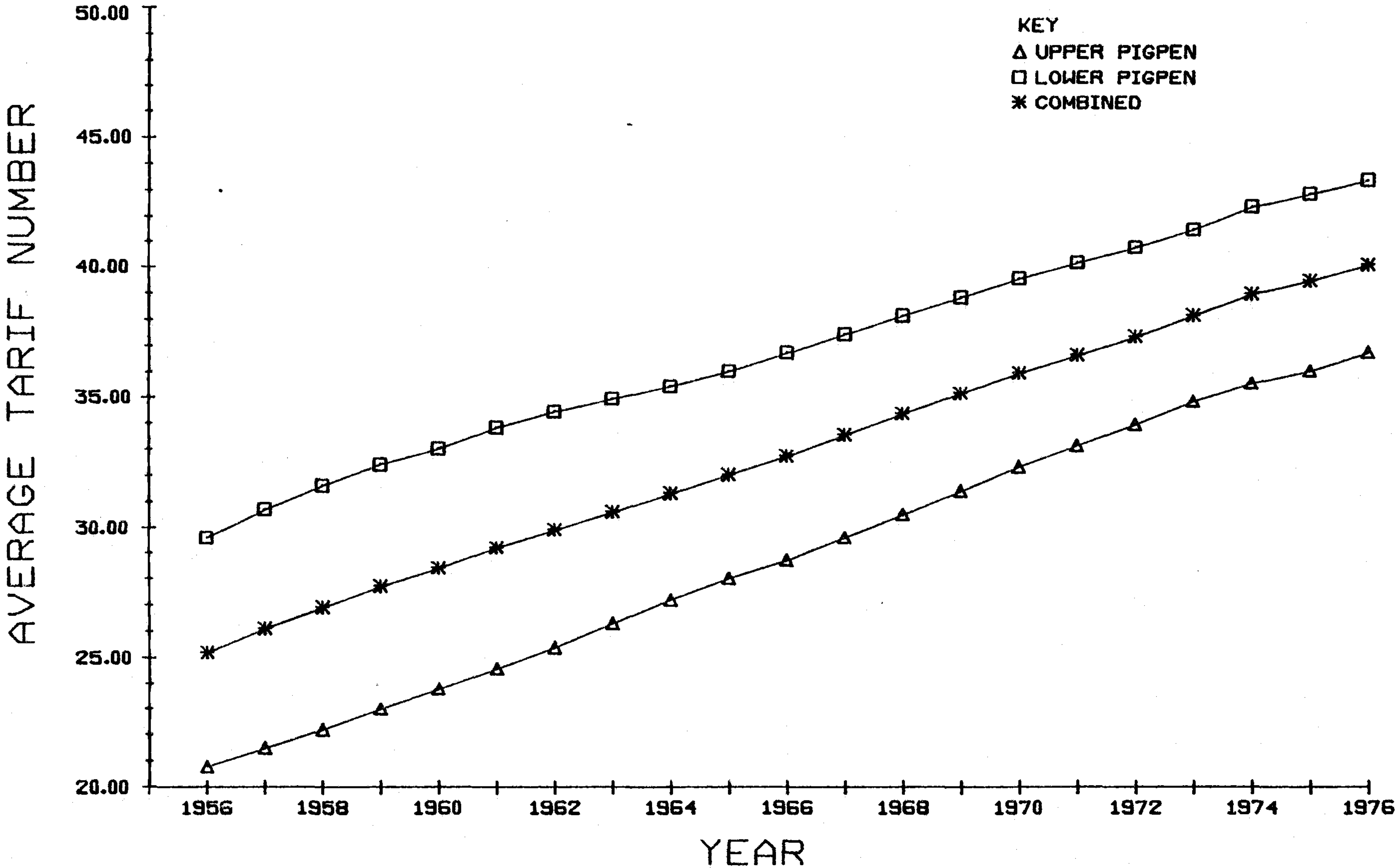

Figure 16. COMPARISON OF TARIF TRENDS IN THE UPPER AND LOWER PORTIONS OF PIGPEN AND THE COMBINED AVERAGE.

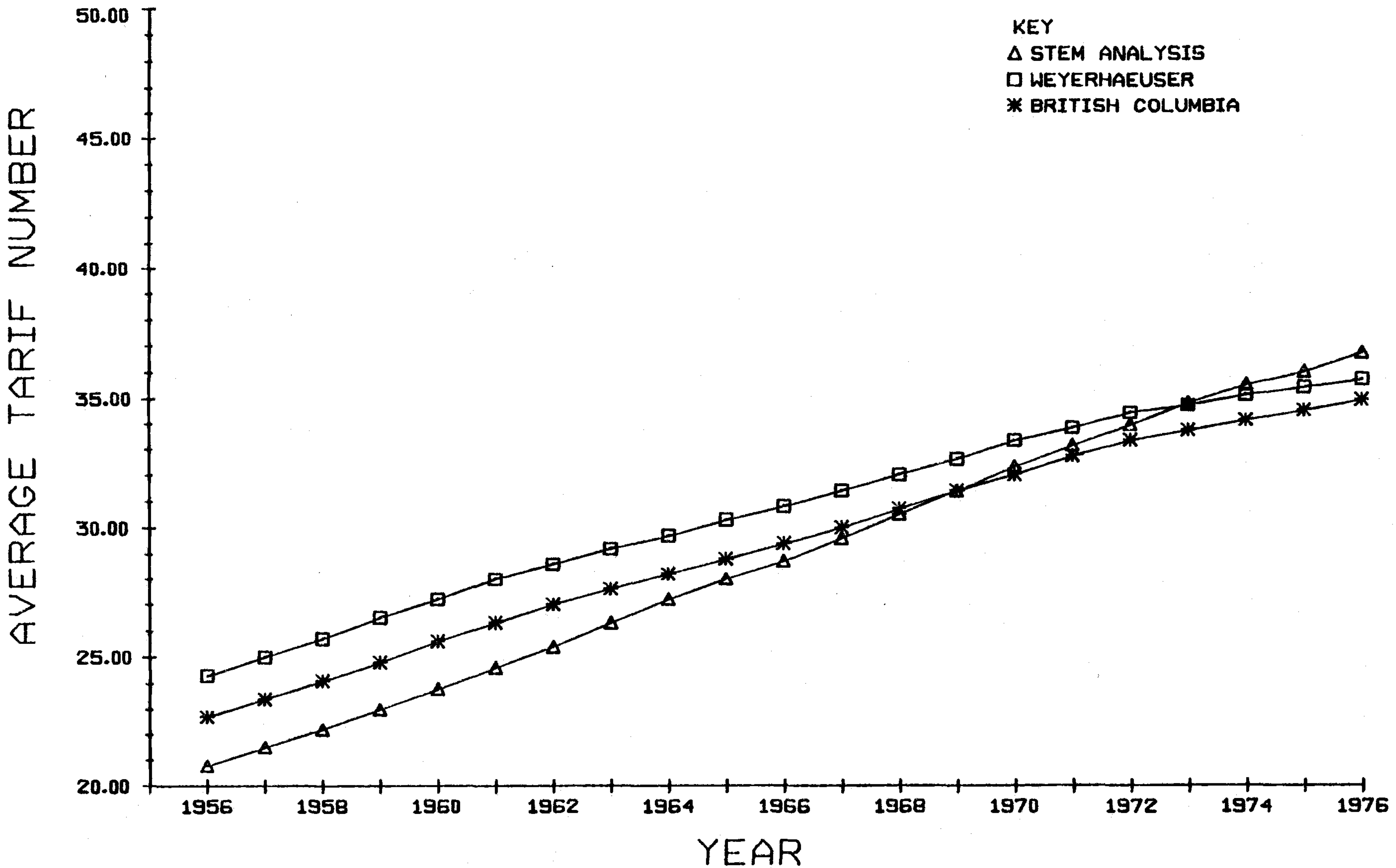

Figure 17. TARIF TRENDS IN UPPER PIGPEN BY TARIF ESTIMATION METHOD.

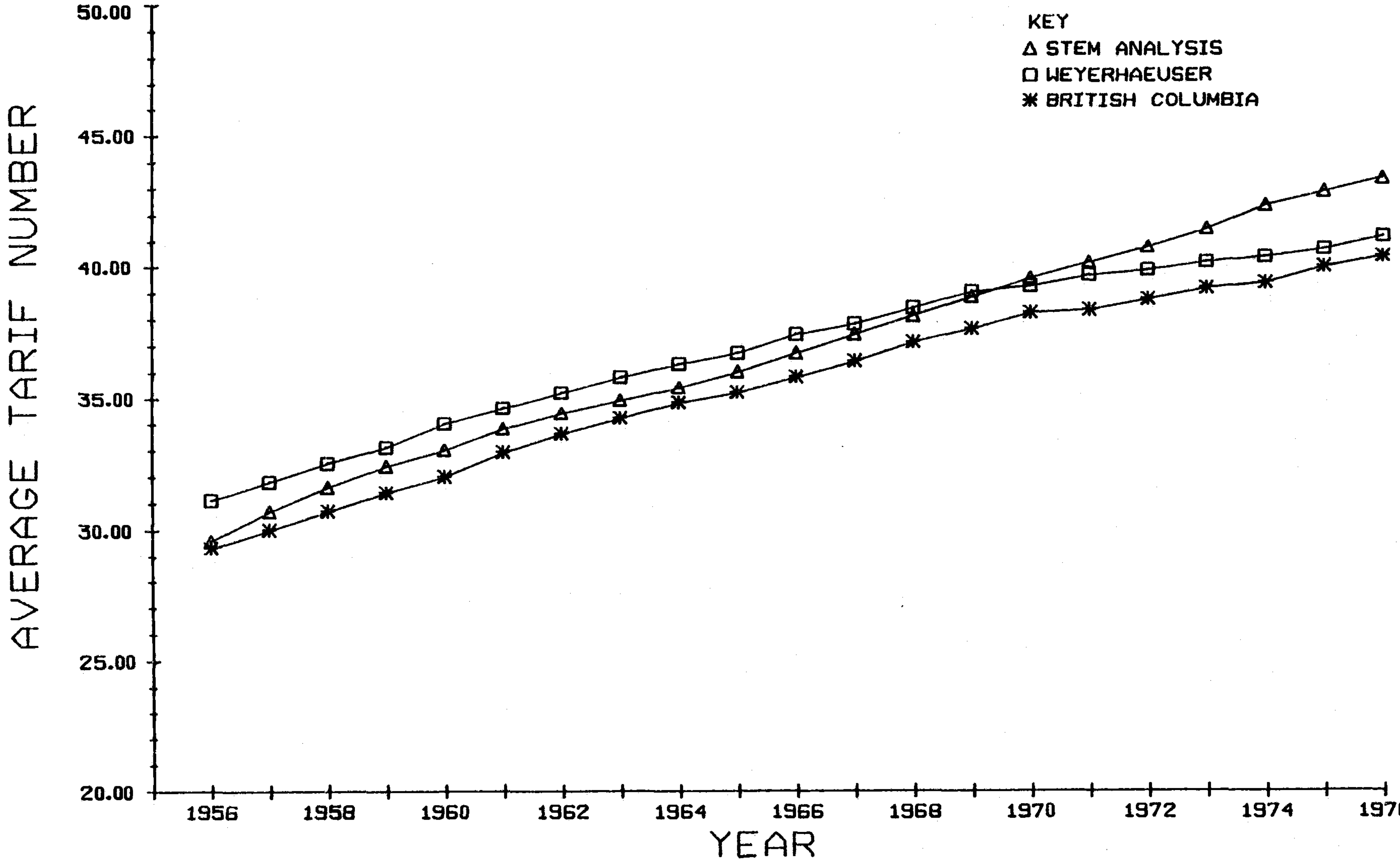

Figure 18. TARIF TRENDS IN LOWER PIGPEN BY TARIF ESTIMATION METHOD.

Big Creek was recommended by Chuck Chambers of the DNR (personal communication).

Testing among tarif estimation methods was limited to Weyerhaeuser and stem analysis estimates. A paired t-test was performed on these data to test the hypothesis that the average tarif from stem analysis equaled that from Weyerhaeuser estimates. The results of these tests by unit are summarized in Table 15.

Interpretation of the results varies slightly between stands, but in general, it appears that these trees might be of a poorer form, i.e. lower volume and tarif, when young. But in the present stand, after repeated commercial thinning, the form of these trees appears to have "improved" to where the average tarif is significantly greater in both stands than would be predicted by the Weyerhaeuser cubic volume equation for Douglas-fir.

The annual tarif increment was examined for each stand. Although the average annual increment from stem analysis data (Table 16) is considerably greater than the .3 tarif unit per year reported by Reukema (1972), a closer look at the data somewhat supports his findings. Reukema's 21-year study involved a high site Douglas-fir stand from age 57 to 76; whereas the stem analysis data in this study covered stand growth from about 20 to 55 years of age. The change in tarif by year (Tables 21 and 22) was plotted (Figure 19) to help examine any trends. The increment fluctuation is somewhat similar for both stands, with the overall trend being generally downward. From this, it is conceivable that over the next twenty years the annual increment could be reduced to

Table 15. SUMMARY OF PAIRED T-TESTS ON METHOD OF TARIF ESTIMATION.

H_0: $\overline{TARIF}_{cv4} = \overline{TARIF}_{w}$

Unit	Year	Average Tarif CV4[1]	Average Tarif W[2]	df	t-value	Probability Level (two-tailed)
13-Loop	1956	32.0	32.3	23	-0.377	.3548
	1966	40.2	37.6	23	3.245	.0018*
	1976	46.4	41.2	23	5.711	.0000***
Pigpen	1956	25.2	27.7	17	-4.762	.0001***
	1966	32.7	34.1	17	-2.276	.0180
	1976	40.0	38.4	17	2.442	.0129
Pigpen (Upper)	1956	20.8	24.3	8	-7.350	.0000***
	1966	28.7	30.8	8	-4.451	.0011*
	1976	36.7	35.7	8	1.303	.1145
Pigpen (Lower)	1956	29.6	31.1	8	-1.805	.0544
	1966	36.7	37.4	8	-0.530	.3052
	1976	43.3	41.1	8	2.163	.0312

[1] Computed from stem analysis volume estimates.

[2] Computed from Weyerhaeuser Douglas-fir cubic volume equation.

the level Reukema observed.

Table 16. COMPARISON OF AVERAGE ANNUAL TARIF INCREMENT BY ESTIMATION METHOD AND OBSERVATION PERIOD.

Unit	Observation Period: 1956-1977			Observation Period: 1968-1977		
	Average Annual Increment (tarif units/year)					
	Estimation Method					
	CV4	W	BC	CV4	W	BC
13-Loop	.70	.44	.49	.52	.29	.34
Pigpen	.74	.52	.58	.64	.32	.42
Combined	.72	.48	.54	.58	.31	.38
Pigpen (Upper)	.80	.56	.60	.70	.40	.46
(Lower)	.68	.49	.55	.58	.30	.38

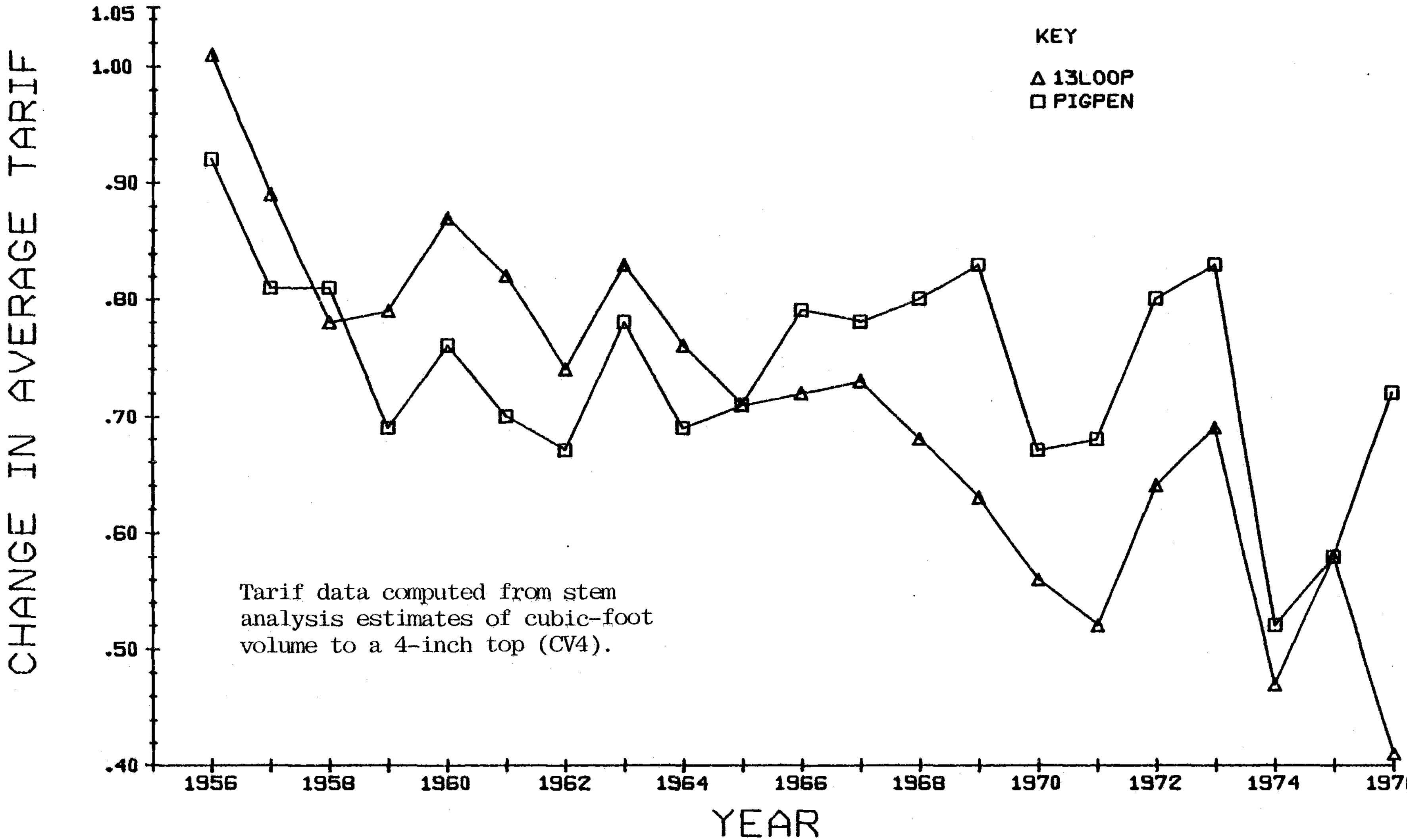

Figure 19. ANNUAL CHANGE IN TARIF NUMBER FOR DOUGLAS-FIR.

Estimation of Past Stand Parameters

Stem analysis of the third stage sample trees provided the data base from which past volume and growth parameters could be estimated. These estimates were computed by year for the period 1956 to 1977 and expanded to estimate per acre trends for both the surviving stand and its Douglas-fir component (Tables 17-20).

These per acre stand estimates along with sample tree parameter estimates (Tables 21 and 22) and stand depletion records were used to reconstruct the stand in the past and allow a comparison of its total yield with that of the DNR empirical yield tables for the Douglas-fir zone (Chambers et al., 1972).

Incorporating thinning removals into past stand volume and growth estimates required making some data manipulations and assumptions. Depletion records in net Scribner log scale volumes were converted to estimates of gross Scribner formula volume by utilizing a scale to formula conversion factor (Appendix XII) and a recovery ratio (Appendix IX). Both of these correction factors were derived from sample data collected in this study. It was assumed that the thinned trees had grown at the same rate as that projected for the entire stand. To help keep this estimate conservative, annual growth percent for the stand was computed using Pressler's growth percent formula (Husch et al., 1972).

$$P = ((S_n - S_o)/(S_n + S_o)) * (200./N)$$

Where: S_n = Size of parameter at beginning of growth period.

S_o = Size of parameter at end of growth period.

Table 17. THIRD STAGE EXPANDED ANNUAL ESTIMATES AND INCREMENTS FOR VOLUME AND BASAL AREA OF THE SURVIVING STAND IN PIGPEN.

	PER ACRE TOTALS				CHANGE PER ACRE PER YEAR			
YEAR	CVTS	CV4	SV6	BA	CVTS	CV4	SV6	BA
1956	1411.89	1356.46	6010.93	50.64	0	0	0	0
1957	1544.62	1485.06	6763.55	53.62	132.73	128.60	752.63	2.98
1958	1679.95	1616.26	7531.42	56.72	135.33	131.20	767.87	3.10
1959	1812.37	1744.53	8289.20	59.60	132.43	128.27	757.77	2.88
1960	1945.14	1873.23	9064.88	62.47	132.76	128.70	775.68	2.87
1961	2076.57	2000.57	9864.57	65.00	131.43	127.34	799.69	2.53
1962	2232.10	2151.37	10783.79	68.26	155.53	150.80	919.22	3.26
1963	2409.36	2323.26	11816.67	72.07	177.27	171.90	1032.87	3.81
1964	2590.17	2498.43	12882.67	75.56	180.81	175.16	1066.01	3.49
1965	2769.33	2672.04	13941.08	79.01	179.17	173.61	1058.41	3.45
1966	2933.86	2831.33	14931.30	81.88	164.53	159.30	990.22	2.87
1967	3121.68	3013.14	16085.47	85.02	187.82	181.80	1154.17	3.13
1968	3305.74	3191.35	17235.94	87.94	184.06	178.21	1150.47	2.92
1969	3480.64	3360.59	18339.72	90.45	174.89	169.24	1103.78	2.51
1970	3681.21	3554.74	19631.72	93.39	200.57	194.14	1292.00	2.94
1971	3875.05	3742.45	20863.90	96.42	193.85	187.72	1232.18	3.03
1972	4066.92	3928.20	22099.35	99.31	191.87	185.74	1235.46	2.89
1973	4282.77	4137.09	23494.35	102.33	215.85	208.90	1395.00	3.02
1974	4519.89	4366.59	25049.54	105.61	237.12	229.50	1555.19	3.28
1975	4759.46	4598.54	26557.30	109.64	239.58	231.94	1507.76	4.04
1976	5018.65	4849.46	28198.76	113.78	259.19	250.92	1641.46	4.14
1977	5280.40	5102.80	29911.17	117.51	261.75	253.34	1712.41	3.73

Table 18. THIRD STAGE EXPANDED ANNUAL ESTIMATES AND INCREMENTS FOR VOLUME AND BASAL AREA OF THE SURVIVING DOUGLAS-FIR COMPONENT IN PIGPEN.

	PER ACRE TOTALS				CHANGE PER ACRE PER YEAR			
YEAR	CVTS	CV4	SV6	BA	CVTS	CV4	SV6	BA
1956	1194.94	1148.03	5087.31	42.86	0	0	0	0
1957	1307.28	1256.87	5724.29	45.38	112.34	108.84	636.98	2.52
1958	1421.81	1367.91	6374.17	48.00	114.54	111.04	649.88	2.62
1959	1533.89	1476.47	7015.51	50.44	112.08	108.56	641.34	2.44
1960	1646.25	1585.40	7672.00	52.87	112.36	108.92	656.49	2.43
1961	1757.49	1693.17	8348.81	55.01	111.24	107.77	676.81	2.14
1962	1889.12	1820.80	9126.79	57.77	131.63	127.62	777.98	2.76
1963	2039.15	1966.28	10000.95	61.00	150.03	145.48	874.16	3.22
1964	2192.17	2114.53	10903.16	63.95	153.02	148.25	902.21	2.96
1965	2343.81	2261.46	11798.94	66.87	151.64	146.93	895.77	2.92
1966	2483.05	2396.28	12637.00	69.30	139.25	134.82	838.07	2.43
1967	2642.01	2550.15	13613.83	71.95	158.96	153.87	976.82	2.65
1968	2797.79	2700.98	14587.51	74.42	155.78	150.83	973.69	2.47
1969	2945.81	2844.22	15521.69	76.55	148.02	143.24	934.18	2.13
1970	3115.56	3008.53	16615.17	79.04	169.75	164.31	1093.48	2.49
1971	3279.62	3167.40	17658.01	81.60	164.06	158.87	1042.84	2.56
1972	3442.01	3324.60	18703.63	84.05	162.39	157.20	1045.62	2.45
1973	3624.69	3501.40	19884.28	86.60	182.68	176.80	1180.65	2.56
1974	3825.37	3695.64	21200.50	89.38	200.68	194.24	1316.22	2.77
1975	4028.14	3891.94	22476.59	92.80	202.77	196.30	1276.08	3.42
1976	4247.50	4104.31	23865.82	96.30	219.36	212.37	1389.24	3.50
1977	4469.03	4318.72	25315.11	99.46	221.53	214.41	1449.29	3.16

Table 19. THIRD STAGE EXPANDED ANNUAL ESTIMATES AND INCREMENTS FOR VOLUME AND BASAL AREA OF THE SURVIVING STAND IN 13-LOOP.

	PER ACRE TOTALS				CHANGE PER ACRE PER YEAR			
YEAR	CVTS	CV4	SV6	BA	CVTS	CV4	SV6	BA
1956	2596.35	2501.88	12352.70	75.18	0	0	0	0
1957	2772.77	2672.59	13450.64	77.74	176.42	170.70	1097.94	2.57
1958	2944.88	2839.14	14518.01	80.29	172.11	166.56	1067.36	2.55
1959	3103.46	2992.61	15508.84	82.65	158.58	153.47	990.83	2.36
1960	3262.91	3146.90	16510.57	84.89	159.45	154.29	1001.73	2.24
1961	3416.97	3295.93	17500.63	86.72	154.06	149.02	990.06	1.82
1962	3596.65	3469.80	18628.62	89.21	179.68	173.88	1128.00	2.49
1963	3781.74	3648.95	19800.13	91.89	185.09	179.15	1171.50	2.69
1964	3995.90	3856.23	21163.04	94.88	214.16	207.28	1362.92	2.99
1965	4197.07	4050.93	22449.26	97.57	201.17	194.70	1286.22	2.70
1966	4397.26	4244.67	23726.95	100.28	200.19	193.74	1277.69	2.71
1967	4606.54	4447.21	25072.77	103.06	209.28	202.54	1345.82	2.78
1968	4814.27	4648.24	26434.08	105.69	207.73	201.02	1361.32	2.63
1969	5016.39	4843.84	27749.06	108.22	202.12	195.60	1314.97	2.53
1970	5235.62	5056.02	29171.31	111.16	219.23	212.18	1422.26	2.94
1971	5448.66	5262.23	30564.32	114.09	213.04	206.21	1393.01	2.93
1972	5646.82	5454.01	31858.22	116.74	198.16	191.78	1293.90	2.65
1973	5869.40	5669.40	33336.75	119.49	222.58	215.40	1478.53	2.76
1974	6095.53	5888.20	34870.02	122.13	226.12	218.80	1533.27	2.64
1975	6344.07	6128.78	36518.58	125.68	248.54	240.58	1648.56	3.55
1976	6614.39	6390.41	38361.46	129.27	270.32	261.63	1842.88	3.60
1977	6832.20	6601.23	39856.85	132.25	217.81	210.82	1495.38	2.97

Table 20. THIRD STAGE EXPANDED ANNUAL ESTIMATES AND INCREMENTS FOR VOLUME AND BASAL AREA OF THE SURVIVING DOUGLAS-FIR COMPONENT IN 13-LOOP.

	PER ACRE TOTALS				CHANGE PER ACRE PER YEAR			
YEAR	CVTS	CV4	SV6	BA	CVTS	CV4	SV6	BA
1956	2142.10	2064.16	10191.50	62.02	0	0	0	0
1957	2287.65	2205.00	11097.35	64.14	145.56	140.84	905.85	2.12
1958	2429.65	2342.41	11977.97	66.25	142.00	137.42	880.62	2.10
1959	2560.49	2469.03	12795.45	68.19	130.83	126.62	817.48	1.94
1960	2692.04	2596.33	13621.91	70.04	131.55	127.30	826.47	1.85
1961	2819.15	2719.28	14438.75	71.54	127.11	122.95	816.84	1.50
1962	2967.39	2862.73	15369.40	73.60	148.24	143.46	930.65	2.05
1963	3120.10	3010.54	16335.94	75.82	152.71	147.81	966.54	2.22
1964	3296.79	3181.55	17460.40	78.28	176.69	171.01	1124.46	2.46
1965	3462.76	3342.19	18521.58	80.50	165.97	160.64	1061.18	2.22
1966	3627.93	3502.03	19575.73	82.73	165.16	159.84	1054.15	2.23
1967	3800.59	3669.14	20686.09	85.03	172.66	167.11	1110.36	2.29
1968	3971.98	3834.99	21809.23	87.20	171.39	165.85	1123.14	2.17
1969	4138.74	3996.37	22894.14	89.29	166.76	161.38	1084.91	2.09
1970	4319.61	4171.43	24067.56	91.71	180.87	175.06	1173.42	2.42
1971	4495.37	4341.56	25216.85	94.13	175.77	170.13	1149.29	2.42
1972	4658.86	4499.79	26284.37	96.31	163.49	158.23	1067.52	2.18
1973	4842.50	4677.50	27504.22	98.59	183.64	177.71	1219.85	2.27
1974	5029.07	4858.02	28769.23	100.76	186.56	180.52	1265.02	2.18
1975	5234.12	5056.50	30129.36	103.69	205.06	198.49	1360.13	2.93
1976	5457.15	5272.36	31649.82	106.66	223.03	215.86	1520.45	2.97
1977	5636.86	5446.29	32883.57	109.11	179.70	173.93	1233.76	2.45

Table 21. ANNUAL ESTIMATES AND INCREMENTS FOR THIRD STAGE SAMPLE TREES IN PIGPEN.

YEAR	BH AGE	DBH	DBH INCREMENT	TARIF	TARIF INCREMENT	TOTAL HEIGHT	HEIGHT INCREMENT
1956	23	18.0	0	25.2	0	80.6	0
1957	24	18.5	.53	26.1	.92	83.3	2.70
1958	25	10.0	.54	26.9	.81	86.0	2.74
1959	26	19.5	.48	27.7	.81	88.8	2.74
1960	27	19.9	.46	28.4	.69	91.5	2.72
1961	28	20.3	.40	29.2	.76	94.2	2.73
1962	29	20.8	.49	29.9	.70	96.8	2.61
1963	30	21.3	.55	30.6	.67	99.3	2.48
1964	31	21.8	.49	31.3	.78	101.7	2.37
1965	32	22.3	.47	32.0	.69	104.0	2.30
1966	33	22.7	.39	32.7	.71	106.3	2.31
1967	34	23.1	.41	33.5	.79	108.6	2.32
1968	35	23.4	.37	34.3	.78	111.0	2.40
1969	36	23.7	.32	35.1	.80	113.4	2.40
1970	37	24.1	.36	35.9	.83	115.5	2.05
1971	38	24.4	.36	36.6	.67	117.4	1.95
1972	39	24.8	.34	37.3	.68	119.4	1.94
1973	40	25.1	.35	38.1	.80	120.9	1.52
1974	41	25.5	.38	38.9	.83	122.5	1.56
1975	42	25.9	.46	39.4	.52	124.3	1.88
1976	43	26.4	.45	40.0	.58	126.2	1.88
1977	44	26.8	.40	40.7	.72	128.1	1.88

Table 22. ANNUAL ESTIMATES AND INCREMENTS FOR THIRD STAGE SAMPLE TREES IN 13-LOOP.

YEAR	BH AGE	DBH	DBH INCREMENT	TARIF	TARIF INCREMENT	TOTAL HEIGHT	HEIGHT INCREMENT
1956	28	18.7	0	32.0	0	94.8	0
1957	29	19.0	.32	33.0	1.01	96.8	2.00
1958	30	19.3	.31	33.9	.89	98.8	1.95
1959	31	19.6	.28	34.7	.78	100.7	1.91
1960	32	19.9	.26	35.5	.79	102.7	1.96
1961	33	20.1	.21	36.3	.87	104.7	2.07
1962	34	20.4	.28	37.1	.82	106.8	2.09
1963	35	20.7	.30	37.9	.74	109.0	2.17
1964	36	21.0	.33	38.7	.83	111.2	2.18
1965	37	21.3	.29	39.5	.76	113.3	2.16
1966	38	21.6	.29	40.2	.71	115.5	2.14
1967	39	21.9	.29	40.9	.72	117.4	1.98
1968	40	22.1	.27	41.6	.73	119.5	2.02
1969	41	22.4	.26	42.3	.68	121.4	1.89
1970	42	22.7	.30	43.0	.63	123.1	1.74
1971	43	23.0	.29	43.5	.56	124.8	1.70
1972	44	23.2	.26	44.0	.52	126.3	1.46
1973	45	23.5	.27	44.7	.64	127.7	1.47
1974	46	23.8	.26	45.4	.69	129.2	1.42
1975	47	24.1	.34	45.8	.47	130.6	1.42
1976	48	24.4	.33	46.4	.58	132.0	1.42
1977	49	24.7	.27	46.8	.41	133.4	1.42

N = Number of time units in growth period.

This formula computes growth rate on the average value for the period instead of the initial value. The effect is a reduction in the growth rate. The results of applying this growth rate to the estimated removals and computing their per acre volume and growth contributions are summarized in Tables 23 and 24, and plotted in Figures 20 and 21.

Although board-foot estimates are not as accurate as cubic-foot estimates in measuring volume growth, because of fundamental limitations (Husch et al., 1972); they were used in this portion of the study, not only for ease of computation, but because of the relative accuracy of depletion records.

Four additional figures (Figures 22-25) have been included to further illustrate growth trends in these stands. These figures present some of the data from Tables 18 to 20 in an alternate form to facilitate perception. These figures represent the Douglas-fir component of these stands, based on third stage stem analysis data. Examination of these figures reveals strong similarities in growth trends, both stands having been partially thinned in 1961, 1969, and 1974. The effect of climatic factors appears obvious in these figures, but examination of these factors was not an objective of this study.

It should be noted that in Figure 25 height data from about 1974 on is somewhat normalized. This is due to two factors: the total heights for 30 of the 42 third stage sample trees were estimated from a regression equation; and for the last few years, height growth between the last stem cross-section and the apex was averaged for all trees.

Table 23. PROJECTED PAST VOLUME, GROWTH, AND REMOVALS IN PIGPEN.

YEAR	SURVIVING STAND			THINNED	THINNED TREES		COMBINED	
	(A) VOLUME (BF/a)[1]	(B) GROWTH (BF/a)[1]	GROWTH[4] PERCENT	VOLUME (BF/a)[2]	(C) VOLUME (BF/a)[1]	(D) GROWTH (BF/a)[1]	(A+C) VOLUME (BF/a)[1]	(B+D) GROWTH (BF/a)[1]
1977	29911						29911	
1976	28199	1712	6.13				28199	1712
1975	26557	1642	6.21				26557	1642
1974*	25050	1508	6.06	3698	3698		28748	1508
1973	23494	1555	6.67		3467	231	26961	1786
1972	22099	1395	6.36		3260	207	25359	1602
1971	20864	1235	5.97		3070	184	23934	1419
1970	19632	1232	6.35		2892	184	22524	1416
1969*	18340	1292	7.13	9408	12108	192	30448	1484
1968	17236	1104	6.48		11371	737	28607	1841
1967	16085	1150	7.25		10602	769	26687	1919
1966	14931	1154	7.79		9836	766	24767	1920
1965	13941	990	7.17		9178	658	23119	1648
1964	12883	1058	8.30		8475	703	21358	1761
1963	11817	1066	9.15		7765	710	19582	1776
1962	10784	1033	9.72		7077	688	17861	1721
1961*	9865	919	9.47	3244[3]	9709	612	19574	1645
1960	9065	800	8.99		8908	801	17973	1601
1959	8289	776	9.49		8136	772	16425	1548
1958	7531	758	10.26		7379	757	14910	1515
1957	6764	768	11.48		6619	760	13383	1528
1956	6011	753	12.68		5874	745	11985	1498

* Thinning operation

1 Scribner Formula Volume, 16-foot logs, 6-inch top

2 Adjusted thinning removals

3 Estimated removal of 7500 BF/a

4 Pressler's growth percent

Table 24. PROJECTED PAST VOLUME, GROWTH, AND REMOVALS IN 13-LOOP.

YEAR	SURVIVING STAND			THINNED	THINNED TREES		COMBINED	
	(A) VOLUME (BF/a)[1]	(B) GROWTH (BF/a)[1]	GROWTH[4] PERCENT	VOLUME (BF/a)[2]	(C) VOLUME (BF/a)[1]	(D) GROWTH (BF/a)[1]	(A+C) VOLUME (BF/a)[1]	(B+D) GROWTH (BF/a)[1]
1977	39857						39857	
1976	38361	1496	3.90[4]				38361	1496
1975	36519	1342	5.05				36519	1842
1974*	34870	1649	4.73	14339	14339		49209	1649
1973	33337	1533	4.60		13708	631	47045	2164
1972	31858	1479	4.65		13099	609	44957	2088
1971*	30564	1294	4.24	1557	14123	533	44687	1827
1970	29171	1393	4.78		13479	644	42650	2037
1969*	27749	1422	5.13	6877	19698	658	47447	2080
1968	16434	1315	4.97		18765	933	45199	2248
1967	25073	1361	5.43		17799	966	42872	2327
1966	23727	1346	5.70		16839	960	40566	2306
1965	22449	1278	5.69		15932	907	38381	2185
1964	21163	1286	6.09		15017	915	36180	2201
1963	19800	1363	6.90		14048	969	33848	2332
1962	18629	1171	6.31		13214	834	31843	2005
1961*	17501	1128	6.47	9732[3]	22143	803	39644	1931
1960	16511	990	5.99		20892	1251	37403	2241
1959	15509	1002	6.45		19626	1266	35135	2268
1958	14518	991	6.83		18371	1255	32889	2246
1957	13451	1067	7.96		17016	1355	30467	2422
1956	12353	1098	8.93		15621	1395	27974	2493

* Thinning operation
1 Scribner Formula Volume, 16-foot logs, 6-inch top
2 Adjusted thinning removals
3 Estimated removal of 7500 BF/a
4 Pressler's growth percent

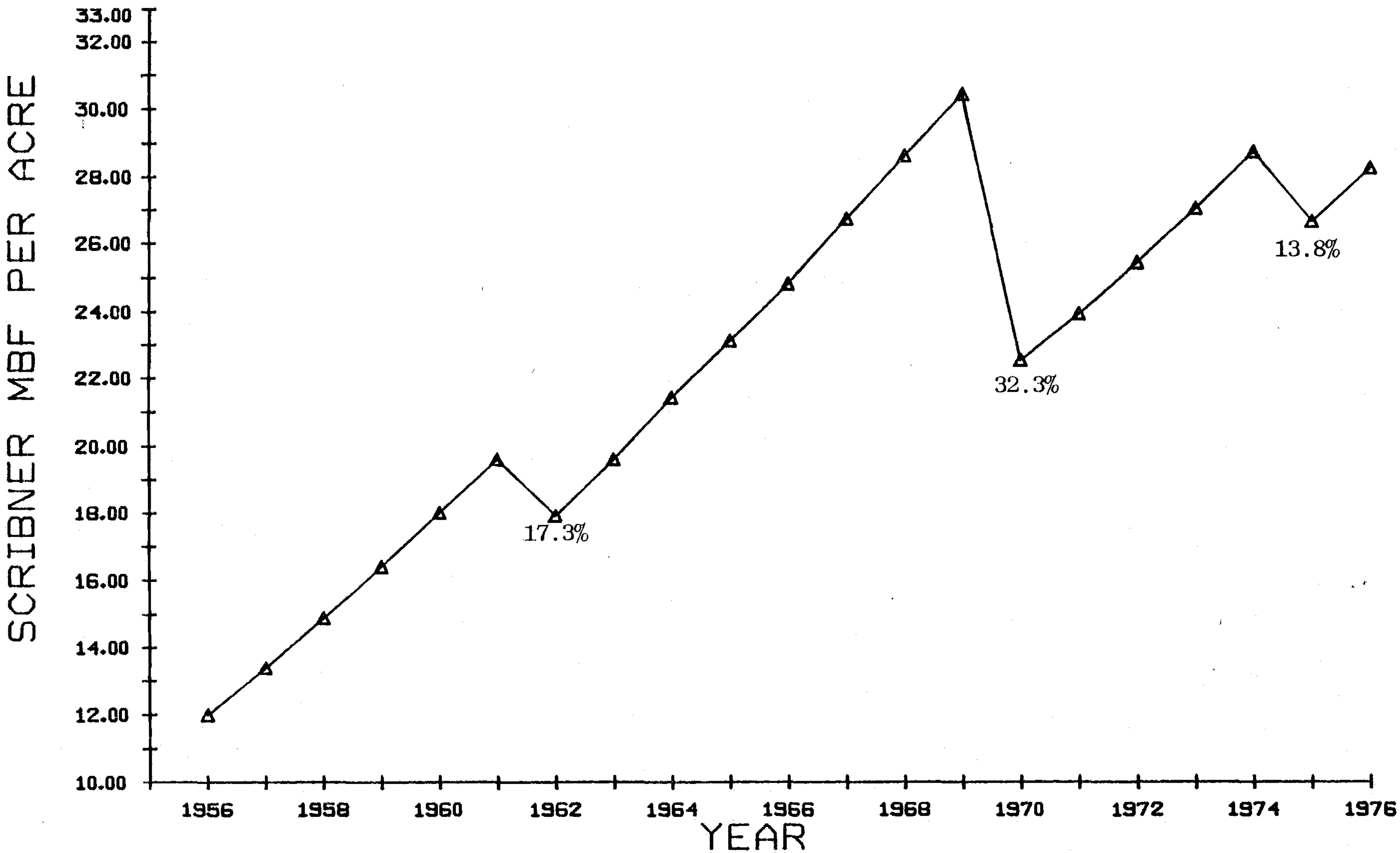

Figure 20. PROJECTED PAST TREND OF VOLUME, GROWTH, AND REMOVALS FOR PIGPEN.

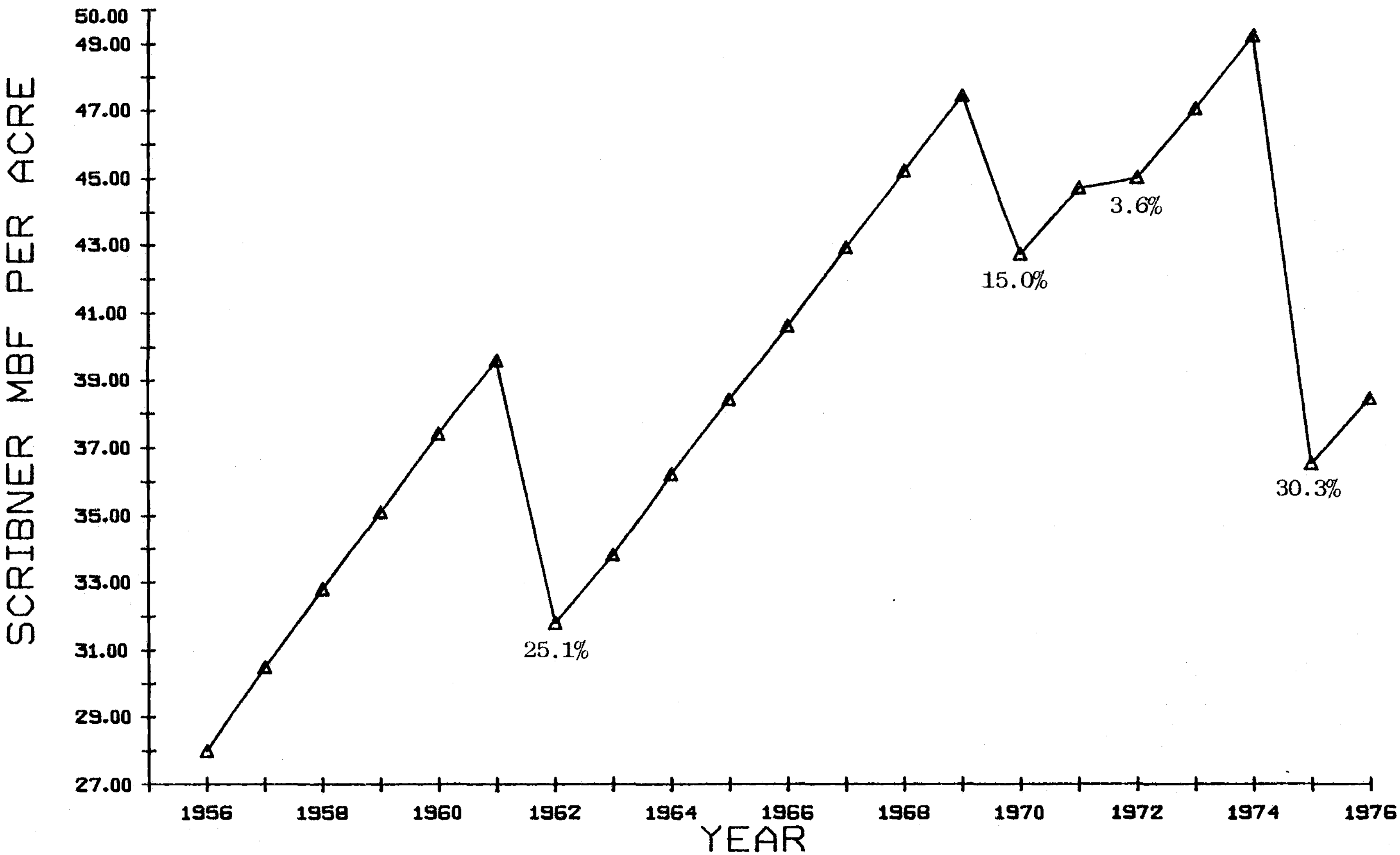

Figure 21. PROJECTED PAST TRENDS OF VOLUME, GROWTH, AND REMOVALS FOR 13-LOOP.

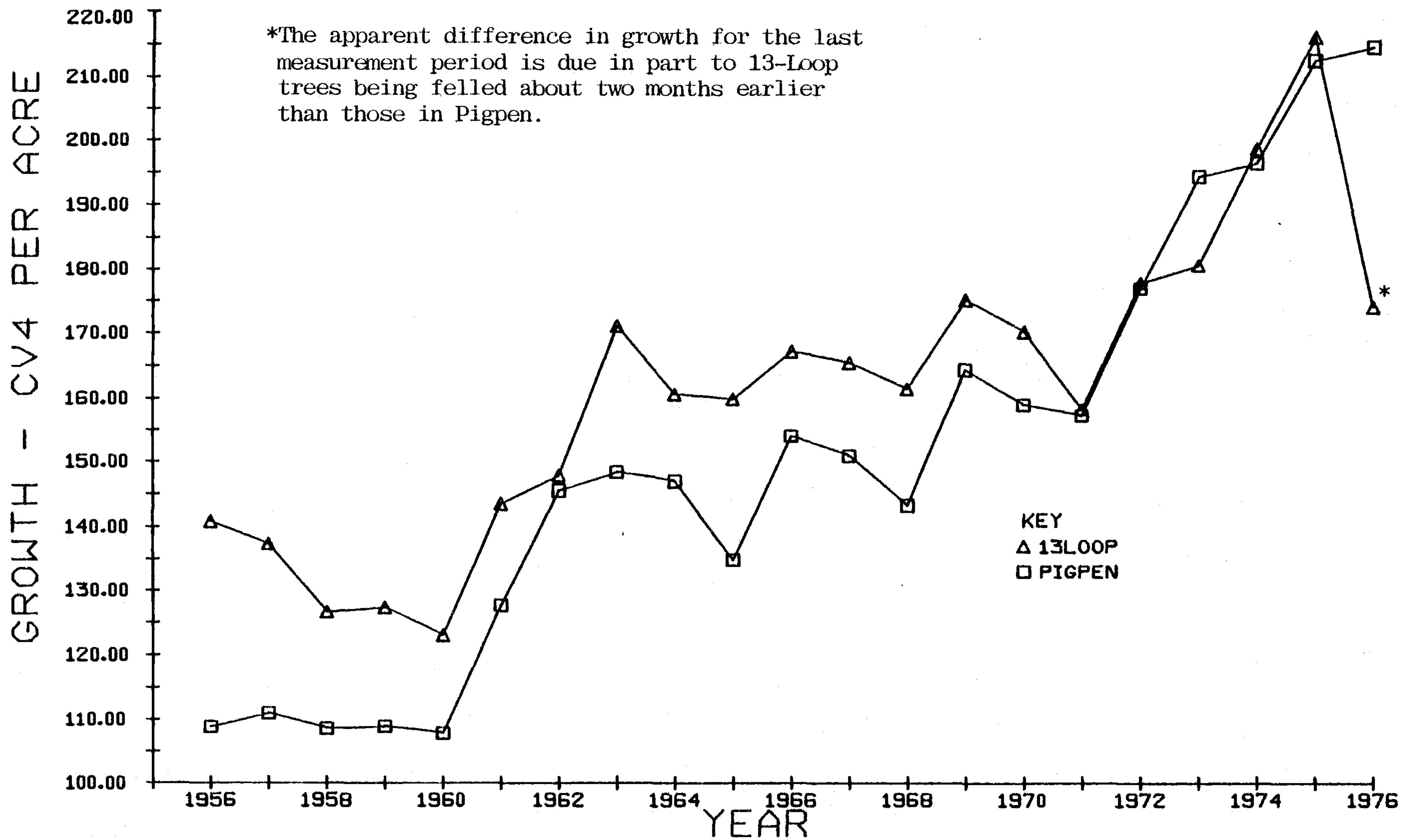

Figure 22. VOLUME GROWTH TRENDS FOR THE SURVIVING DOUGLAS-FIR COMPONENT OF THE STUDY AREAS.

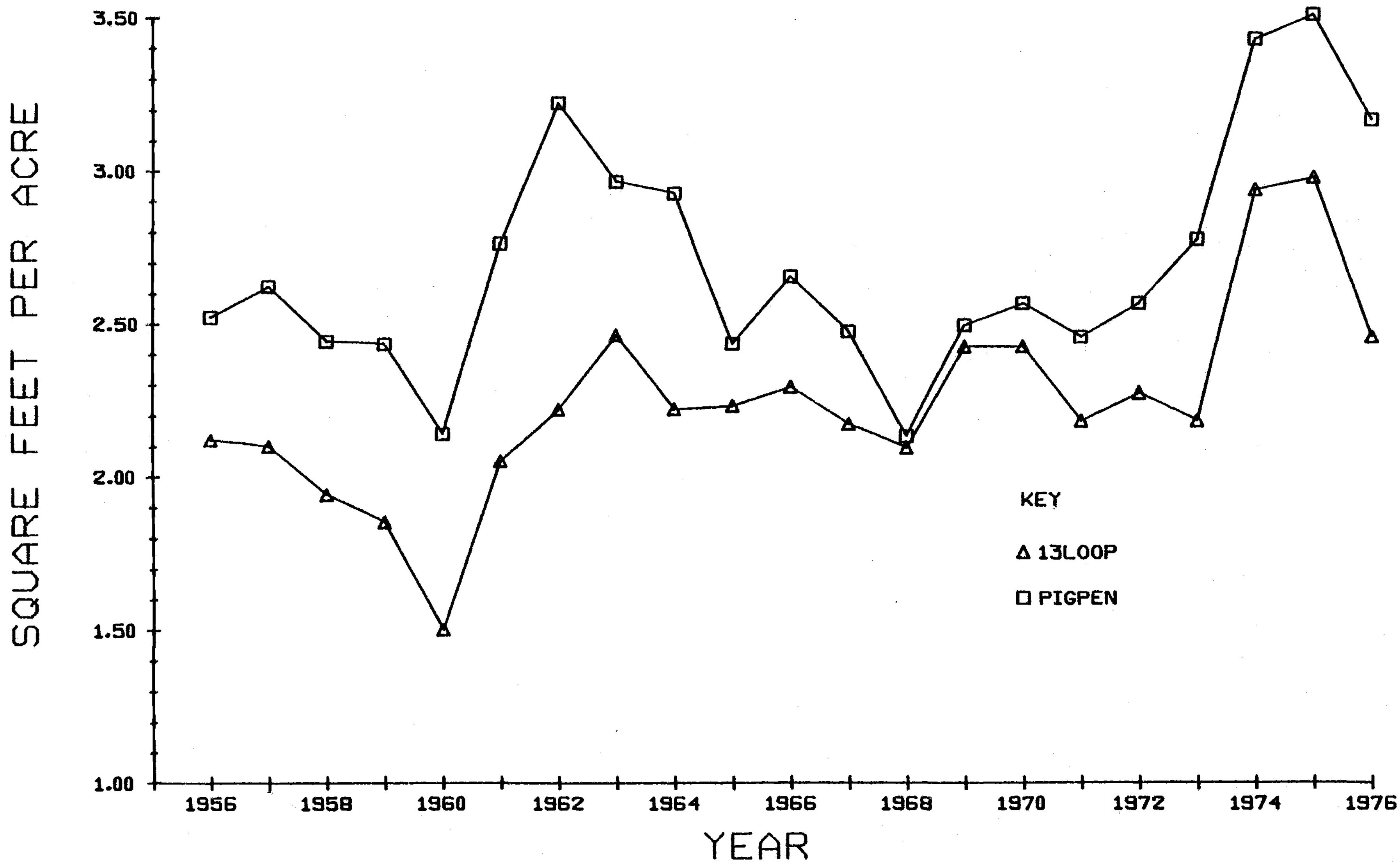

Figure 23. BASAL AREA GROWTH TRENDS FOR THE SURVIVING DOUGLAS-FIR COMPONENT OF THE STUDY AREAS.

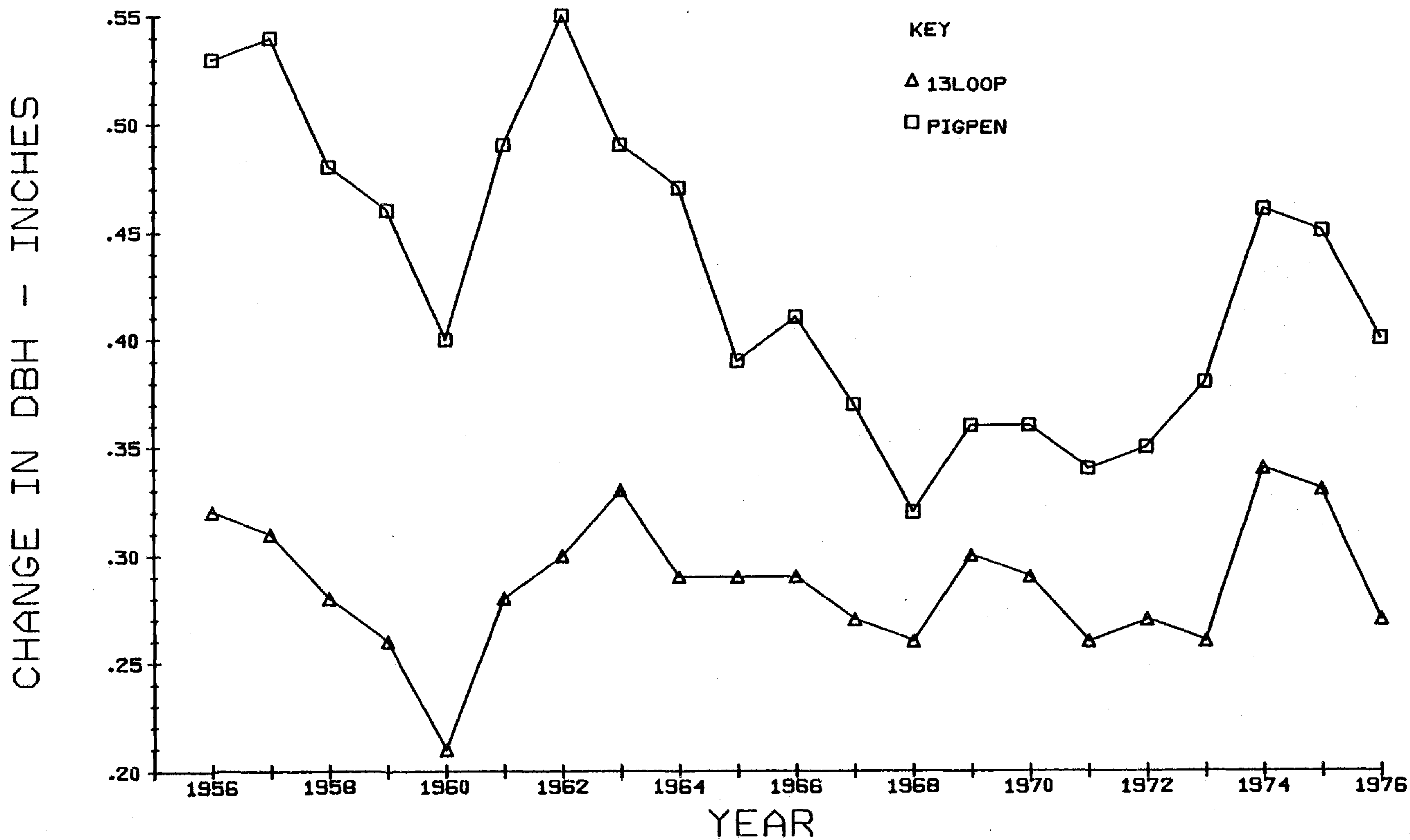

Figure 24. DIAMETER GROWTH TRENDS FOR THE THIRD STAGE SAMPLE TREES BY STUDY AREA.

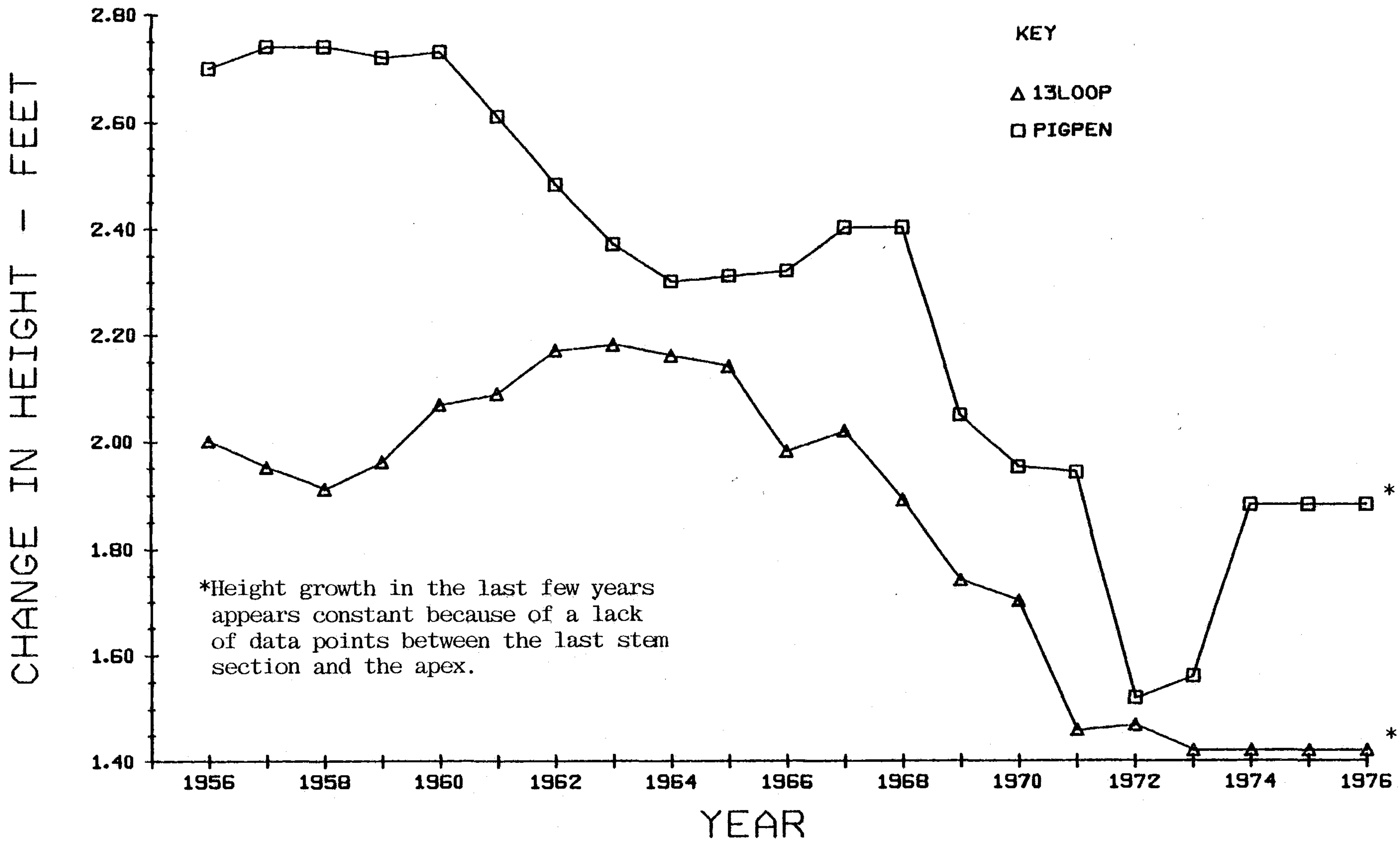

Figure 25. HEIGHT GROWTH TRENDS FOR THE THIRD STAGE SAMPLE TREES BY STUDY AREA.

Comparison with the DNR Empirical Yield Tables

Since no control area was available for this study, the effect of commercial thinning on the yield of these stands is difficult to discern. For this reason, the DNR empirical yield tables for the Douglas-fir zone (Chambers et al., 1972) were used to predict what the total yield of these stands might have been without thinning.

In discussing the application of these yield tables, Chambers (et al., 1972) states:

> These tables should be used to estimate volume for a given age, site index and density. Because stands change in density over time, any attempt to predict future volumes requires additional information or assumptions on the expected change in density.

This problem of predicting what the current, 1976, stand density would have been without thinning was resolved by making several basic assumptions and applying them to the past stand parameter estimates. (See Tables 23-25.)

It was assumed that the average DBH of the surviving Douglas-fir component of the stand, prior to any thinning operations, was equal to that of the trees which were later removed. The average tarif for the stand, prior to thinning, was assumed equal to that estimated by the stem analysis data.

These two assumptions enabled the stand's basal area per acre for the removed trees to be estimated from their estimated volume per acre. Combining the estimated basal area of the surviving and removed components of the stand allowed the percent normal basal area (PNBA)

Table 25. SUMMARY OF BASIC DATA AND RESULTS OF DNR YIELD TABLE PREDICTIONS.

Parameter	Pigpen		13-Loop	
Year	1956	1961	1956	1961
Average DBH (inches)	14.7	17.0	16.5	17.9
Average tarif	25.2	28.4	32.0	36.3
Average breast height age (years)	23	28	28	33
King's site index	141.1	139.5	150.6	145.3
Stem analysis and depletion record Volume estimate (Scribner BF/a)	11985	19574	27974	39644
Basal area of surviving stand (sq ft/a)	50.6	65.0	75.2	86.7
Basal area of removals (sq ft/a)	55.4	69.4	93.5	106.6
Total basal area (sq fr/a)	106.4	134.4	168.7	193.3
PNBA (initial)	70.5%	77.1%	91.5%	96.1%
PNBA 1976	89.3%		99.6%	
DNR predicted 1976 yield (Scribner BF/a)	42724	41853	62769	59033
Stem analysis 1976 yield plus past removals (Scribner BF/a)	44549		70866	
Percent volume/acre difference	4.3%	6.4%	12.9%	20.0%
Average	5.4%		16.5%	

to be computed as described by Chambers (et al., 1972). These data were computed for two points in time for the past stand: 1961, the year these stands were initially entered; and 1956, five years prior to the first thinning.

These two data points, in conjunction with a third assumption, were used to predict stand density in 1976. To do this, it was assumed that the stand's ability to approach the basal area of the "normal" stand remained at a constant rate, as indexed by the pre-thinning period 1956 to 1961. "Normal" here is denoted to be the normal basal area (NBA) as defined by the DNR yield tables (Chambers et al., 1972).

These data and the resulting predictions have been summarized in Table 25. These results indicate that the yield of the surviving stand plus commercial thinning removals exceeds the predicted stand yield, by about 5 percent in Pigpen and about 16 percent in the higher density, more heavily thinned 13-Loop.

Comparison of Parameter Estimates Among Sampling Stages

Three stand parameters; basal area, tarif, and volume, were examined to permit a comparison among sampling stages. These data are summarized in Tables 26 through 29.

A comparison of tarif estimates for Douglas-fir (Table 27) shows a consistent difference between estimation methods. Average tarif estimates derived from second and third stage stem measurements exceed those derived from the Weyerhaeuser cubic volume equation for Douglas-fir in all categories. It might be argued that the sample trees at the second and third stages were probably larger than the first stage sample trees and therefore have a higher tarif. But an examination of, or some experience with the tarif system indicates that within even-aged stands, such as those in this study, trees of the smaller diameter classes tend to have higher tarifs.

The effect of tarif estimation method on volume per acre estimate was explored. Volume estimates for the first stage variable plot cruise were generated for each tarif estimate. (See Table 29.) Between first stage Weyerhaeuser estimates and third stage stem analysis estimates the volume per acre difference was about 3500 board-feet per acre (BF/a) in Pigpen and about 5600 BF/a in 13-Loop.

It is interesting to compare the second and third stage Douglas-fir volume estimates in Tables 28 and 29. The expansion estimates of Table 28 are all lower than the variable-plot cruise/tarif estimates based on the same trees. Theoretically, if all the first stage estimated total tree heights were consistent, these volume estimates should be about equal. Perhaps the difference between these values reflects the extent of error in height estimation.

A comparison of height estimates was made for third stage sample trees. The average difference between first stage and third stage height estimates showed that first stage estimates were low in both stands. This amounted to about 8 percent in Pigpen and 6 percent in 13-Loop.

A comparison of sample tree distribution by sampling stage and DBH class can be found in Appendix XIII.

Table 26. COMPARISON OF BASAL AREA ESTIMATES AMONG SAMPLING STAGES.

Unit	Basal Area Per Acre (sq ft/a)					
	Entire Stand			Douglas-fir Component		
	Stage 1	Stage 2	Stage 3	Stage 1	Stage 2	Stage 3
Pigpen	125.3	----	117.5	99.4	98.6	99.5
13-Loop	140.4	----	132.3	111.8	111.4	109.1

Table 27. COMPARISON OF AVERAGE TARIF ESTIMATES FOR DOUGLAS-FIR AMONG SAMPLING STAGES.

Unit	Average Tarif Number				
	Weyerhaeuser[1]			Stem Measurement[2]	
	Stage 1	Stage 2	Stage 3	Stage 2	Stage 3
13-Loop	39.8	42.3	41.5	43.7	46.8
Pigpen	36.5	39.8	38.7	41.2	40.7
Pigpen (Upper)	----	37.8	36.0	39.0	37.5
Pigpen (Lower)	----	41.6	41.4	43.0	43.9

[1] Weyerhaeuser cubic volume equation for Douglas-fir
[2] Stage 2: dendrometer volume
Stage 3: stem analysis volume

Table 28. COMPARISON OF VOLUME ESTIMATES AMONG SAMPING STAGES.

Unit	Cubic-Foot Volume to a 4-inch top			Scribner Board-Foot Volume to a 6-inch top		
	Stage 1*	Stage 2	Stage 3	Stage 1*	Stage 2	Stage 3
ENTIRE STAND						
Pigpen	4885	5117	5103	28755	29986	29911
13-Loop	5903	6295	6601	35350	38009	39857
DOUGLAS-FIR						
Pigpen	3858	4331	4319	23302	25672	25315
13-Loop	4716	5194	5446	28679	31362	32884
SAMPLING ERROR OF THE MEAN IN PERCENT				Combined		
	Stage 1	Stage 2	Stage 3	1 & 2		1, 2 & 3
Pigpen	6.4	2.0	5.6	6.7		8.6
13-Loop	3.9	1.7	4.2	4.2		5.8

* Weyerhaeuser tarif

Table 29. THE EFFECT OF TARIF ESTIMATION METHOD ON VARIABLE-PLOT CRUISE VOLUME ESTIMATES FOR THE DOUGLAS FIR STAND COMPONENT.

Unit	Douglas-fir Volume Per Acre							
	First Stage		Second Stage			Third Stage		
	BC	W	BC	W	CV4	BC	W	CV4
	Average Tarif Number for Douglas-fir							
Pigpen	35.9	36.5	39.1	39.8	41.2	38.0	38.7	40.7
13-Loop	39.0	39.8	41.5	42.3	43.7	40.7	41.5	46.8
	Cubic-Foot Volume to a 4-Inch Top							
Pigpen	3794	3858	4132	4206	4354	4016	4090	4301
13-Loop	4622	4716	4918	5013	5179	4823	4918	5546
	Scribner Board-Foot Volume to a 6-Inch Top							
Pigpen	22777	23302	25481	26041	27118	24585	25170	26788
13-Loop	27967	28679	30146	30782	31857	29463	30146	34299

BC = British Columbia cubic volume equation for immature coastal Douglas-fir.
W = Weyerhaeuser cubic volume equation for Douglas-fir.
CV4= Cubic volume estimates: Second stage/dendrometer, Third stage/stem analysis.

CONCLUSIONS

Site Index

Evaluation of King's site index revealed a decreasing trend in apparent site index of approximately one site class from about 15 to 30 years breast height age. Theoretically, if the growth trends developed by King (1966) are the same for all geographical zones, the site index trend of a stand should remain relatively constant with time.

The downward trend in site index, exhibited by both stands in this study, appears to normalize about the time thinning operations were initiated. This may just have been a coincidence; as this pattern of rapid height growth in a young stand has been suggested, by King, to occur on sites with shallow soils.

An investigation of this trend was made in the upper portion of Pigpen, which was first entered eight years after the initial thinning operations; and also in a natural stand near Apiary, Oregon. It showed that both of these stands exhibited a similar decreasing trend in their apparent site index as a young stand.

After the initial period of rapid height growth, it appears that these stands do tend to follow the age-height relationship developed by King and incorporated into his site index curves for Douglas-fir.

Perhaps over the eons, Douglas-fir of this coastal region has evolved a more rapid than normal juvenile height growth pattern to compete successfully with fast-growing competitors.

Whatever the explanation of this growth pattern may be, it is apparent that the use of site index, measured in a young Douglas-fir stand within this drainage or perhaps within this cover type, may result in an overestimation of the productive capacity of a site.

The difference in site index trends between the upper and lower portions of Pigpen suggests that the use of King's diameter guide for site tree selection, in a situation like this study, may bias the estimate. In a heterogeneous stand, where distinct populations can be easily identified by density, age, or perhaps by aspect, slope or species composition, stratification may be desirable. This should provide a more representative sample and a more accurate prediction of the stand's productive capacity.

The effect of commercial thinning on apparent site index may be a function of the type and extent of thinning. Findings in this study suggest that the effect of commercial thinning on site index (height growth) may be negligible.

Tarif

Findings indicate that the average tarif number, computed from stem analysis data for the present Douglas-fir component of these stands, is significantly greater than estimates made by using conventional access methods, Weyerhaeuser and British Columbia cubic volume equations for

Douglas-fir. These higher tarifs suggest that the growth habit and stem form of Douglas-fir may be altered as a result of commercial thinning.

Interpretation of tarif trends may vary slightly between the two stands examined in this study; but generally, in the young stands it appears that trees might be of a "poorer" form, lower volume, than would be predicted by the Weyerhaeuser cubic volume equation for Douglas-fir. In other words, for a given DBH and height, it appears that these trees tend to have less volume than would be predicted. Perhaps this growth habit or stem form of apparently thinner upper stem trees is responsible for the apparent drop of King's site index in the young stand.

In the present stand, after repeated commercial thinnings, the form of these trees seems to have "improved". Their average tarif is significantly greater in both stands than would be predicted by the Weyerhaeuser equation.

This implies that volume tables constructed for natural or unthinned stands of Douglas-fir may underestimate the volume in commercially thinned stands. Use of these volume tables to determine the response of a stand to thinning could cause erroneous conclusions to be drawn.

The effect of tarif estimation method on volume per acre estimate in these stands was investigated. Comparison of volume estimates between the first stage conventional tarif estimates and the third stage stem analysis tarif estimates showed a difference of about 3500 board-feet per acre in Pigpen and about 5600 board-feet per acre in 13-Loop.

Use of a Three Stage Sample

The three stage sample used in this study provided a convenient comparison of individual tree and stand estimates. An examination of the combined sampling errors for the second stage reveals an increase of only .3% in both stands; while the addition of a third stage increased the combined sampling error in Pigpen from 6.7% to 8.6%, and in 13-Loop from 4.2% to 5.8%. The loss in accuracy from inclusion of a third stage amounted to less than 2% in each stand.

The relatively large increase in sampling error from the second to third stage was investigated. This appears to be due primarily to the size of the third stage sample in relation to that of the second stage, the sampling interval. The probability of selection at the third stage and its effect on the variance equation suggest that sampling of a relatively larger portion of the second stage sample at the third stage would reduce the error at this stage.

Thinning

From the yields predicted from the DNR yield tables, it appears that no substantial gain in yield was obtained in Pigpen, but the thinning did provide early returns from this stand. The originally denser, and subsequently more heavily thinned stand, 13-Loop, appears to have obtained a greater total yield than that predicted for a natural stand by the DNR yield tables. Perhaps the apparent increase in yield was in part a result of forestalling mortality.

Initial reaction to these results seems to suggest that there is no loss in total yield with commercial thinning as has been carried out in these stands. It also appears that there might be a significant gain in yield, from performing these operations in high-site Douglas-fir stands, particularly those of high density stocking, which most nearly utilize the site to its full capacity.

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APPENDICES

APPENDIX I

CLIMATIC DATA FOR ASTORIA, OREGON

Elevation 50 Feet

Month	Mean Temperature		Average Precipitation			
			Rain		Snow	
	°F	°C	Inches	Centimeters	Inches	Centimeters
January	40.5	4.7	12.09	30.71	1.8	4.6
February	42.7	5.9	9.43	23.95	1.2	3.0
March	45.7	7.6	8.04	20.42	0.4	1.0
April	49.4	9.7	5.00	12.70	0.0	0.0
May	53.6	12.0	3.66	9.30	0.0	0.0
June	57.7	14.3	2.86	7.26	0.0	0.0
July	61.0	16.1	1.11	2.82	0.0	0.0
August	61.6	16.4	1.19	3.02	0.0	0.0
September	59.0	15.0	3.33	8.46	0.0	0.0
October	54.1	12.3	6.27	15.93	0.0	0.0
November	47.3	8.5	11.31	28.73	0.1	0.3
December	42.5	5.8	12.28	31.19	0.7	1.8
Yearly Average	51.3	10.7	76.57	194.49	4.2	10.7

APPENDIX II

PLOT CALCULATIONS: PIGPEN

1) Basic Inventory Data (dated 4/28/77).

		VBAR	Tree Count
BAF = 40	n	27.00	23.00
	Σx	8816.00	127.00
	Σx^2	3082298.00	791.00
	SD	88.52	2.02
	SE	17.03	.42
	SE%	5.21	7.62
	$\overline{x}$	326.62	5.52
	Combined SE%	9.23	

2) Coefficient of Variation (C).

$C = SD/\overline{x} * 100$

VBAR: $C = \frac{88.52}{326.52} \cdot 100 = 27.11\ \%$

TC: $C = \frac{2.02}{5.52} \cdot 100 = 36.59\%$

3) Combined Coefficient of Variation.

$C = ((C_{VBAR})^2 + (C_{TC})^2)^{\frac{1}{2}}$

$= ((27.11)^2 + (36.59)^2)^{\frac{1}{2}}$

$= 45.54$

4) Correction for Coefficient of Variation from BAF 40 to BAF 20.

$C^2_{20} = C^2_{40} * (P_{40}/P_{20})^{\frac{1}{2}}$ Where: P = average plot size.

Assume average dbh = 26 inches

Plot average = $R^2/43560$ Where: $R_{20} = 50.5$
$R_{40} = 35.7$

$A_{20} = .1838$ acre
$A_{40} = .0918$ acre

(from Table II, p. 16, Dilworth and Bell.)

$C^2_{20} = (45.54)^2 \quad .0918/.1838$
$= 1465.59$
$C_{20} = 38.28$

5) Calculation of Desired Sample Size.

Assume: Allowable error = 5%
Average plot size (20 BAF) ≑ .2 acre
Total stand area = 57.55a ≑ 58a

N = number of possible plots
= 58a · 5 plots/a ≑ 290

$$n = \frac{N\ C^2}{NA^2+C^2} = \frac{290\ (38.28)^2}{290\ (5.0)^2+(38.28)^2}$$
= 48.76 plots

If:	A = 3%	n = 105.27
	A = 4%	n = 69.60
	A = 6%	n = 35.86

Note: Computations for sample size were made at one standard error, i.e. .67 probability.

APPENDIX III

PLOT GRID CALCULATIONS: PIGPEN

Assume: 49 plots desired
56 acres total area
square plot grid

$$\text{Area} = 56\text{a} * 10\ \text{chains}^2/\text{a} = 560\ \text{chains}^2$$

$$\text{Area/plot} = 560\ \text{chains}^2/49\ \text{plots} = 11.43\ \text{chains}^2/\text{plot}$$

$$\text{Distance between plots} = \sqrt{\text{Area/plot}} = \sqrt{11.43\ \text{chains}^2} = 3.38\ \text{chains}$$

If: 40 plots
D = 3.7 chains

35 plots
D = 4 chains

APPENDIX IV

TOTAL HEIGHT REGRESSION EQUATION

A stepwise multiple regression was performed to develop an equation which could be used to predict total height for stem analysis trees in this study lacking this measurement. The data set consisted of 255 Douglas-fir trees ranging in DBH from 7 to 24 inches. These trees had been used to develop the original DNR tarif tables. Total tree height (THT) regressed against DBH, DBH^2, and height to a six-inch top diameter (HT6), provided a simple prediction equation with an R^2 value of .952.

THT = 66.884 + (1.1018*HT6) - (4.3697*DBH) + (.087771*DBH**2.)

Additional equations were derived to estimate the merchantable height of trees 11 inches and larger from a known total height:

Height to a 4-inch top:

$$HT4 = -17.978 + .99795 * THT$$

$$(R^2 = .976)$$

Height to a 6-inch top:

$$HT6 = -28.297 + 1.0052 * THT$$

$$(R^2 = .956)$$

A "rule of thumb" might be drawn from these equations for merchantable height in feet:

$$HT4 \doteq THT-18$$

$$HT6 \doteq THT-28$$

Total tree heights estimated with this regression equation were compared against the twelve third stage stem analysis trees from which a field estimate of this parameter was obtained. On the average, the absolute difference in height was about 3.4 feet, ranging from .3 to 8.3 feet. The overall average shows estimated heights to be 2.0 feet low.

To reduce the amount of variation in total height estimates, the data set should have been reduced to include only trees greater than 19 inches DBH, and included the 12 sample trees with field measurements.

APPENDIX V

THE EFFECT OF DBH ON TARIF NUMBER

The effect on the average tarif number of an error in estimating past DBHs was investigated. This was simulated by varying the DBH of all third stage sample trees a constant amount and computing the average tarif by the different estimation methods. DBHs were varied from plus or minus .2 to 1 inch.

There was little variation in results across the range of tarifs. An excerpt reveals the general trend:

DBH Deviation (inch)	Average Tarif Number Estimation Method		
	CV4	W	BC
+1.0	37.7	38.2	37.6
+0.6	38.9	38.4	37.8
+0.2	40.1	38.6	38.0
0.0	40.7	38.7	38.1
-0.2	41.2	38.8	38.2
-0.6	42.7	39.1	38.3
-1.0	44.2	39.3	38.5

CV4: Stem analysis volume
W: Weyerhaeuser Douglas-fir cubic volume
BC: British Columbia coastal immature Douglas-fir cubic volume

Variation in DBH had very little effect on tarif estimates made with the Weyerhaeuser and British Columbia cubic volume equations. This is because a change in DBH changed the estimated volume of a tree.

The effect of an error in DBH was much more drastic when tarif was computed from a constant tree volume estimate, as in the stem analysis method. It must be noted that all sample trees were varied a set amount in a single direction. Therefore, it is assumed that the effect of errors in estimating past DBHs on the average stand tarif number is minimal, if not self-conpensating.

APPENDIX VI

SITE INDEX TREND IN AN UNTHINNED STAND

This natural stand is located about 30 miles east of the Big Creek study areas, near Apiary, Oregon. A more complete stand description can be found in Appendix XI.

The stem analysis data were used to determine the trend in King's site index for the stand. Using stand data from a variable-plot cruise of the area (Appendix XI) the diameter guides for site tree selection were computed for the current stand (King, 1966). With this, twelve defect-free trees were selected from about 170 trees which were felled and measured for stem analysis. It was assumed these trees would provide data representative of the site index trend of the stand from 1952 to 1976.

Year	Average BH Age (years)	Average Site Index (n=12)
1952	13	140.0
1955	16	126.2
1958	19	122.6
1961	22	122.5
1964	25	124.3
1967	28	124.3
1970	31	126.5
1973	34	128.1
1976	37	130.5

These data are plotted in Figure 9, page 61 of the text.

APPENDIX VII

SECOND AND THIRD STAGE SAMPLING CALCULATIONS

Second Stage - Hartley-List Sample

Pigpen Unit

Sum of Heights = 20024

Desired Number of Sample Trees = 50

Sampling Interval = Ht/# sample trees

= 20024/50

= 400.48 $\doteq$ 400

Random starting point between 0 and 400 for the list sample was obtained from the random number table on page 209 in Dilworth:

195

Third Stage - Unweighted List Sample

N = 50 second stage/dendrometer trees

n = 18 stem analysis trees

Interval = N/n = 50/18 = 2.78

Random starting point between 0 and 2.78 derived from Dilworth and Bell (1973), page 209:

1.22

Sample Tree List

Pigpen Unit

Tree No.	Height	Cumulative Height	Cumulative Sample No.		Sample Tree No.	
			Stage		Stage	
	(feet)	(feet)	2	3	2	3
202	50	50				
1402	80	130				
* 205	85	215	195		1	
1401	90	305				
1902	90	395				
1903	90	485				
2204	90	575				
* 1203	95	670	595	1.22	2	1
502	100	770				
1603	100	870				
2003	100	970				
* 2706	100	1070	995		3	
204	104	1174				
1804	104	1278				
2004	105	1383				
* 2904	105	1488	1395	4.00	4	2
2905	105	1593				
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
3002	135	19338				
* 3008	135	19473	19395	48.48	49	18
3209	135	19608				
3305	136	19744				
* 2903	140	19884	19795		50	
2908	140	20024				

APPENDIX VIII

VOLUME AND VARIANCE ESTIMATORS

The first stage estimates of volume per acre and variance were computed, using the equations found in Dilworth and Bell (1973). These equations apply to any variable plot cruise in which all plots are measured for volume.

$$VOL_1 = \sum_{i=1}^{N} \sum_{j=1}^{n_i} (BAF/N) * ((4.*144.)/(\pi*DBH_{ij}**2.)) * VOL_{ij}$$

Where: VOL_1 = First stage estimate of volume per acre.

BAF = Basal area factor.

N = Number of first stage sample points.

DBH_{ij} = DBH of the j^{th} tree on the i^{th} plot.

n_i = Number of sample trees on the i^{th} plot.

VOL_{ij} = Volume for the ji^{th} tree.

$$VBAR_{ij} = ((4.*144.)/(\pi*DBH_{ij}**2.)) * VOL_{ij}$$

$$VOM_1 = (BAF**2./N) * (\sum_{i=1}^{N}((VBAR_{i.}-\overline{VBAR})**2.)/(N-1))$$

Where: $VBAR_{ij}$ = Volume Basal Area Ratio for the ji^{th} tree.

VOM_1 = Variance of the mean for the first stage sample.

$\overline{VBAR}$ = Average VBAR per plot.

The expansion equations for estimating volume per acre from the second and third stage samples were derived by Evan Smouse, of the Survey Research Center at Oregon State University. Essentially they are an extension of the first stage equation, incorporating the probability of selection at each stage.

$$VOL_2 = \sum_{i=1}^{N} \sum_{k=1}^{M_i} (BAF/N) * ((4.*144.)/(\pi*DBH_{ik}**2.)) * VOL_{ik} * (SI2/HT_{ik})$$

$$VOL_3 = \sum_{i=1}^{N} \sum_{l=1}^{r_i} (BAF/N) * ((4.*144.)/(\pi*DBH_{il}**2.)) * VOL_{il} * (SI2/HT_{il}) * SI3$$

Where: VOL_{ik} = Volume of the k^{th} second stage sample tree on the i^{th} plot.

M_i = Number of second stage sample trees on the i^{th} plot.

SI2 = Sampling interval at the second stage.
= Inverse of the probability of selection at the second stage.
= Sum of estimated heights of all first stage trees divided by the number of second stage sample trees.

HT_{ik} = First stage estimate of total height of the ik^{th} second stage sample tree.

VOL_{il} = Volume of the l^{th} third stage sample tree on the i^{th} plot.

r_i = Number of third stage sample trees on the i^{th} plot.

HT_{il} = First stage estimate of total height of the il^{th} third stage sample tree.

SI3 = Sampling interval at the third stage.
= Inverse of the probability of selection at the third stage.
= Number of second stage sample trees divided by the number of third stage sample trees.

At the suggestion of Evan Smouse, the Horvitz-Thompson variance estimator for samples with unequal probabilities was utilized to compute the second and third stage sample variances. The general equation used was:

$$VOM = (V_i**2.) * (1.-P_i)/(P_i**2.)$$

Where: V_i = Volume of the i^{th} sample tree.

P_i = Probability of selection of the i^{th} sample tree.

The probability of selection (P_i) of a sample tree at:

First stage P_i = (N/(BAF*AREA)) * (π*DBH**2./4.*144.)

Second stage P_i = (N/(BAF*AREA)) * (π*DBH**2./4.*144.) * (HT/SI2)

Third stage P_i = (N/(BAF*AREA))* (π*DBH**2./4.*144.) * (HT/SI2)/SI3

Where: AREA = Area of the stand.

APPENDIX IX

RECOVERY RATIO ESTIMATION

These volume estimates are based on SV6[1] of felled, third stage, stem analysis trees.

Individual Tree Volumes

13-Loop (n = 24) Gross SV6	Net[2] SV6	Pigpen (n = 18) Gross SV6	Net SV6
1267.7	840.9	913.4	913.4
1355.8	893.5	896.2	895.9
937.2	675.4	1446.8	1278.3
879.9	605.0	1165.7	803.7
691.8	690.5	1181.2	778.1
845.0	572.7	1061.0	1043.6
901.2	897.7	1092.3	670.7
846.6	582.3	419.3	181.5
963.6	942.1	914.7	441.8
1380.9	1369.9	712.3	711.4
1458.4	1450.5	464.4	455.2
1584.6	1549.2	967.4	690.7
1035.3	695.3	1114.7	763.9
951.3	921.2	1049.0	701.3
958.8	946.4	1570.1	1195.4
952.5	945.3	937.4	932.2
885.1	627.4	1200.7	1132.4
787.1	783.9	857.5	599.9
794.4	779.8		
1145.7	1140.6	17964.1	14189.4
1066.4	1061.7		
1004.3	988.8		
560.6	380.1		
771.7	769.6		
24025.9	21109.8		

$RR_{pp} = 14189.4/17964.1 = 0.79$

$RR_{13Loop} = 21109.8/14025.9 = .88$

$$RR_{combined} = \frac{21109.8 + 14189.4}{24025.9 + 17964.1} = \frac{35299.2}{41990.0} = 0.84066$$

[1]SV6: Scribner formula volume, board-feet, to a 6-inch top.

[2]Net: 16.5-foot minimum log length.

APPENDIX X

TARIF COMPUTATIONS

The following equations were used in this project to estimate tarif access numbers for individual trees. These equations can be found in Brackett (1973), pages 5-7.

1) Tarif number from cubic-foot volume to a four-inch top. (CV4)

```
TARIF = (CV4 * .912733)/(BA - .087266)

Where:  BA = basal area at DBH

           = .005454154 * DBH**2.
```

2) Tarif number from Weyerhaeuser's Douglas-fir cubic foot volume equation.

```
TARIF = CVTS * TATS

Where:  CVTS = Cubic Volume Top and Stump
             = 10.**(-3.21809)
               *HT**(LOG(DBH)*.04948)
               *DBH**(LOG(DBH)*(-.15664))
               *DBH**2.02132
               *HT**1.63408
               *HT**(LOG(HT)*(-.16185))

        TATS = .912733/
               ((1.0330*(1.+1.382937*EXP(-4.015292*(DBH/10))))
               *(BA+.087266)-.174533)
```

3) Tarif number from British Columbia's cubic volume equations.

```
TARIF = CVTS * TATS

Where:  CVTS = 10.**A*DBH**B*HT**C

        TATS = .912733/
               ((1.0330*(1.+1.382937*EXP(-4.015292*(DBH/10))))
               *(BA+.087266)-.174533)
```

British Columbia Immature Coastal Douglas-fir

Species	Volume Equation Coefficients		
	A	B	C
Douglas-fir	-2.658025	1.739925	1.133187
Western hemlock	-2.702992	1.842680	1.123661

APPENDIX XI

COMPARISON OF TARIF NUMBERS BY ESTIMATION METHODS IN AN UNTHINNED STAND

This stand is located near Apiary, Oregon, about 30 miles east of the study areas in Big Creek. A variable plot cruise of the area was completed by Dr. Walt Thies (USFS, PNW Range and Expr. Sta., Corvallis, OR) and the author. Stem analysis data from a two-acre study site in the middle of the stand were used to compute tarif numbers.

Stand Data:

Species	Scribner Volume (BF/a)	Basal Area (sq ft/a)	Trees per acre	Standard Error
Douglas-fir	18908	114.6	83.4	2.7%
W. Hemlock	209	1.7	2.2	
Total	19117	116.3	85.6	

Average Tarif Estimates:

Data base of 31 stem analysis trees with an average breast height age of 37 years.

Estimation Method	Average Tarif
Stem analysis	34.4
Weyerhaeuser	34.1
British Columbia	33.6

It appears that in an unthinned natural Douglas-fir stand of this age and site quality, the form and volume of trees can be readily estimated by use of the Weyerhaeuser cubic volume equation for Douglas-fir.

APPENDIX XII

CORRECTION FACTOR FOR CONVERSIONS OF SCRIBNER LOG SCALE TO SCRIBNER FORMULA VOLUME

These correction factors are based on first stage estimates of volume per acre for 13-Loop and Pigpen units.

<u>Scale to Formula Ratio (SFR)</u>

13-Loop: (Formula/Scale)	Pigpen:
SFR = 23141.7/21294.9	SFR = 18847.6/17330.5
= 1.08672	= 1.08754

Combined SFR = 1.09

This ratio was used to convert past removal estimates based on scale records to estimates of formula volume for past stand reconstruction. (See Results: Estimation of Past Stand Parameters.)

APPENDIX XIII

SAMPLE TREE DISTRIBUTION BY SAMPLING STAGE AND DBH CLASS

	DBH Class (Inches)															
Unit	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	TOTAL
Pigpen																
First Stage																(213)
DF_1	1		1	1	2	9	16	22	23	28	32	21	10	1	2	169
WH	1	3	5	4	3	4	7	2	4	2						35
SS			1	1							2					4
RC	1	1	1		1	1										5
Second Stage																
DF_2			1		1		5	8	4	9	11	8	2		1	50
Third Stage																
DF_3							2	1	2	3	5	4	1			18
13-Loop																
First Stage																(344)
DF_1	1		1	1	11	25	36	55	58	39	29	11	5	2		274
WH			3	8	14	15	11	10	2		2					65
SS					2	1		1		1						5
Second Stage																
DF_2					2	2	8	9	13	16	6	2	1			59
Third Stage																
DF_3							2	4	4	12	1		1			24

DF: Douglas-fir
WH: Western hemlock
SS: Sitka spruce
RC: Western red cedar

APPENDIX XIV

MEAN AND PERIODIC ANNUAL VOLUME GROWTH

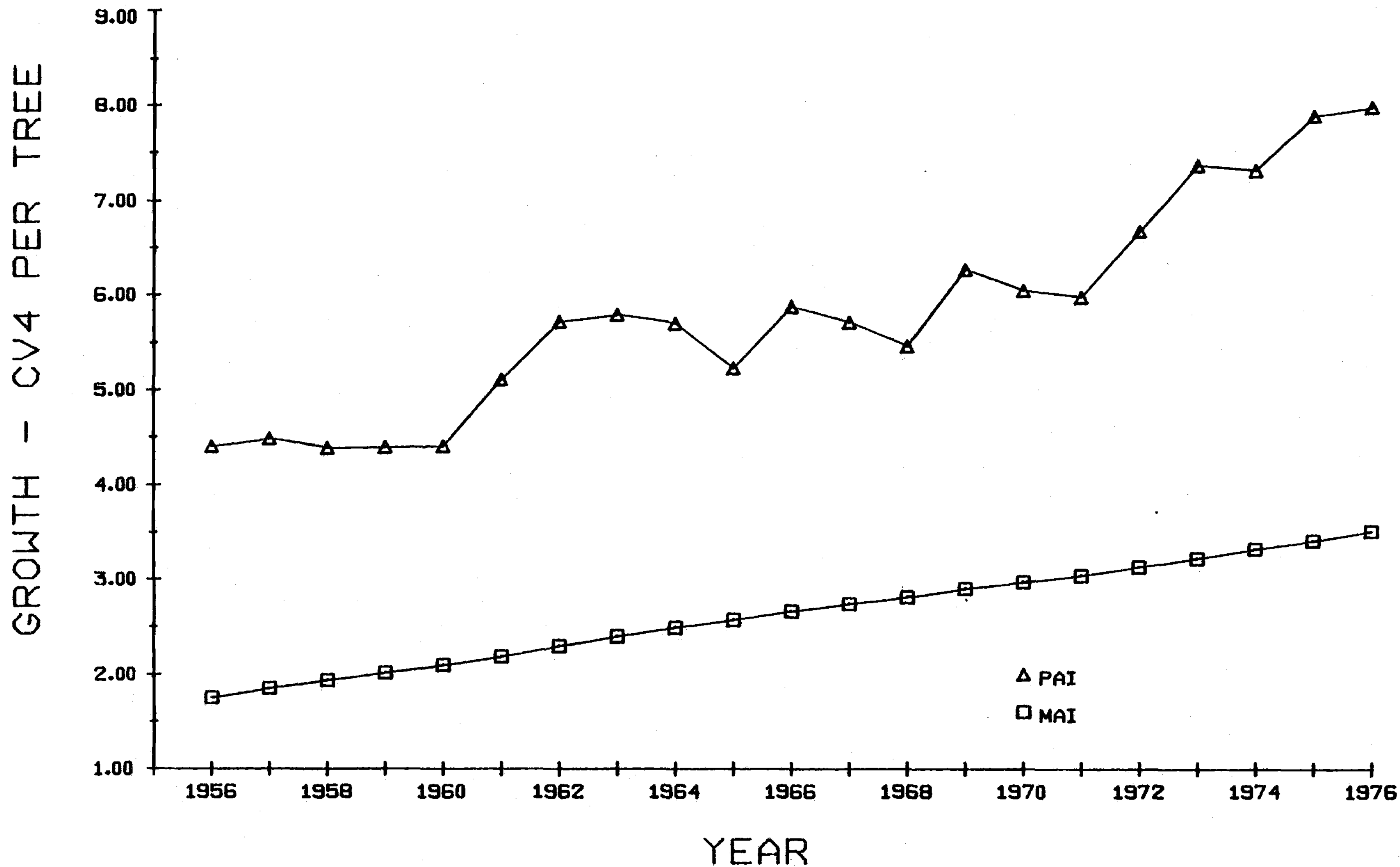
Graphs of mean and periodic annual volume growth from 1956 to 1976 indicate that the mean annual increment has not yet culminated. The effect of thinning on culmination can not be isolated in this study. But, noting that both stands were thinned in 1961, 1969 and 1974, the effect of thinning on the periodic annual increment can be eximined in the following figures.

MEAN AND PERIODIC ANNUAL INCREMENTS FOR PIGPEN.

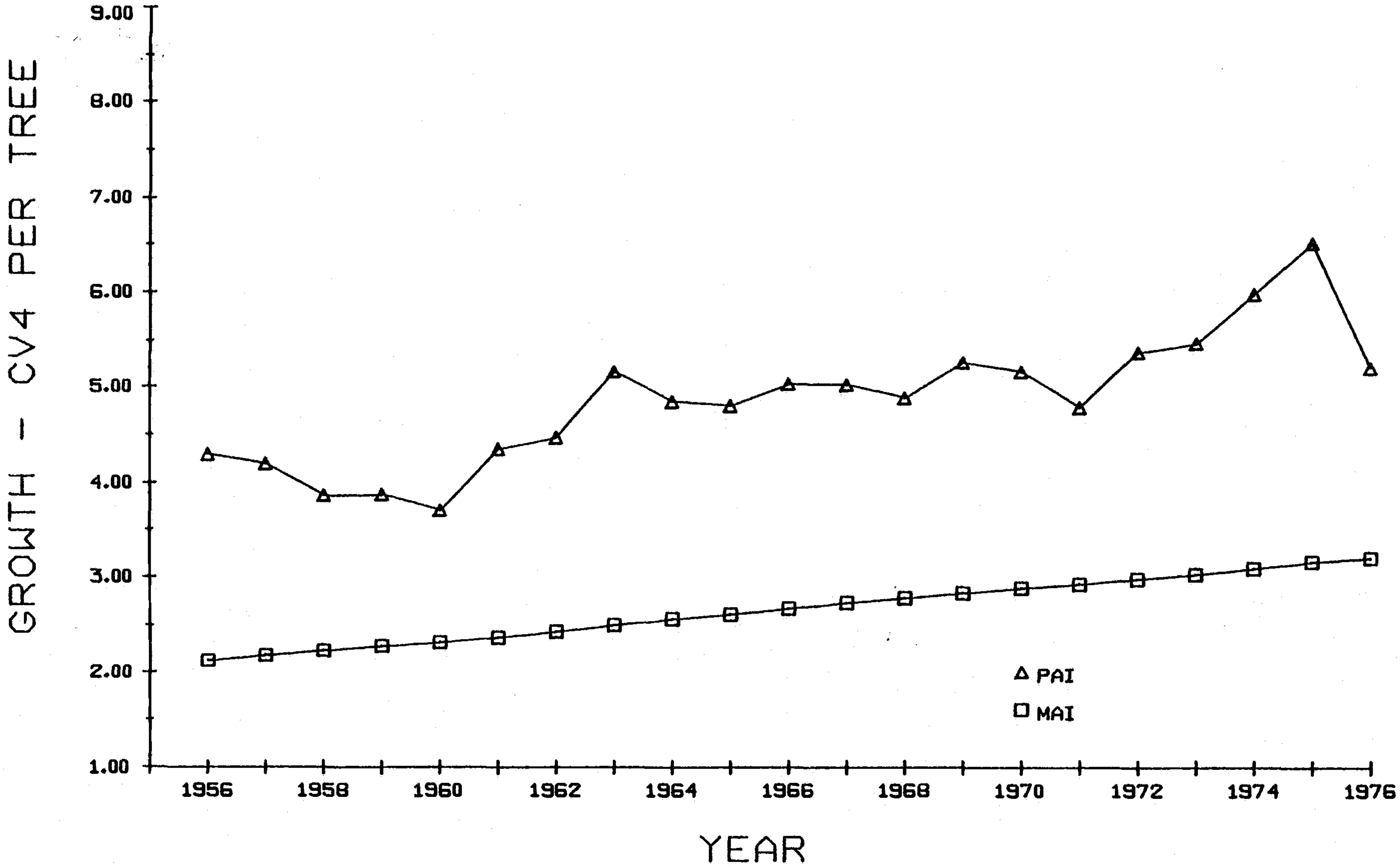
YEAR	TOTAL AGE	DBH	DBH GROWTH	PAI (CV4)	PAI (SV6)	MAI (CV4)	MAI (SV6)
1956	24	18.5	.53	4.40	26.10	1.75	7.94
1957	25	19.0	.54	4.48	26.65	1.85	8.59
1958	26	19.5	.48	4.38	26.42	1.94	9.20
1959	27	19.9	.46	4.39	27.14	2.02	9.78
1960	28	20.3	.40	4.40	27.99	2.10	10.36
1961	29	20.8	.49	5.11	31.87	2.19	11.02
1962	30	21.3	.55	5.72	35.31	2.30	11.75
1963	31	21.8	.49	5.79	36.11	2.40	12.46
1964	32	22.3	.47	5.70	35.71	2.49	13.11
1965	33	22.7	.39	5.23	33.20	2.57	13.66
1966	34	23.1	.41	5.87	37.69	2.66	14.31
1967	35	23.4	.37	5.71	37.40	2.74	14.92
1968	36	23.7	.32	5.46	36.04	2.81	15.46
1969	37	24.1	.36	6.26	42.18	2.90	16.13
1970	38	24.4	.36	6.04	40.47	2.97	16.72
1971	39	24.8	.34	5.97	40.43	3.04	17.29
1972	40	25.1	.35	6.67	45.06	3.13	17.93
1973	41	25.5	.38	7.36	50.41	3.22	18.66
1974	42	25.9	.46	7.31	47.91	3.32	19.31
1975	43	26.4	.45	7.88	52.46	3.41	20.03
1976	44	26.8	.40	7.97	54.86	3.51	20.77

MEAN AND PERIODIC ANNUAL INCREMENTS FOR 13LOOP.

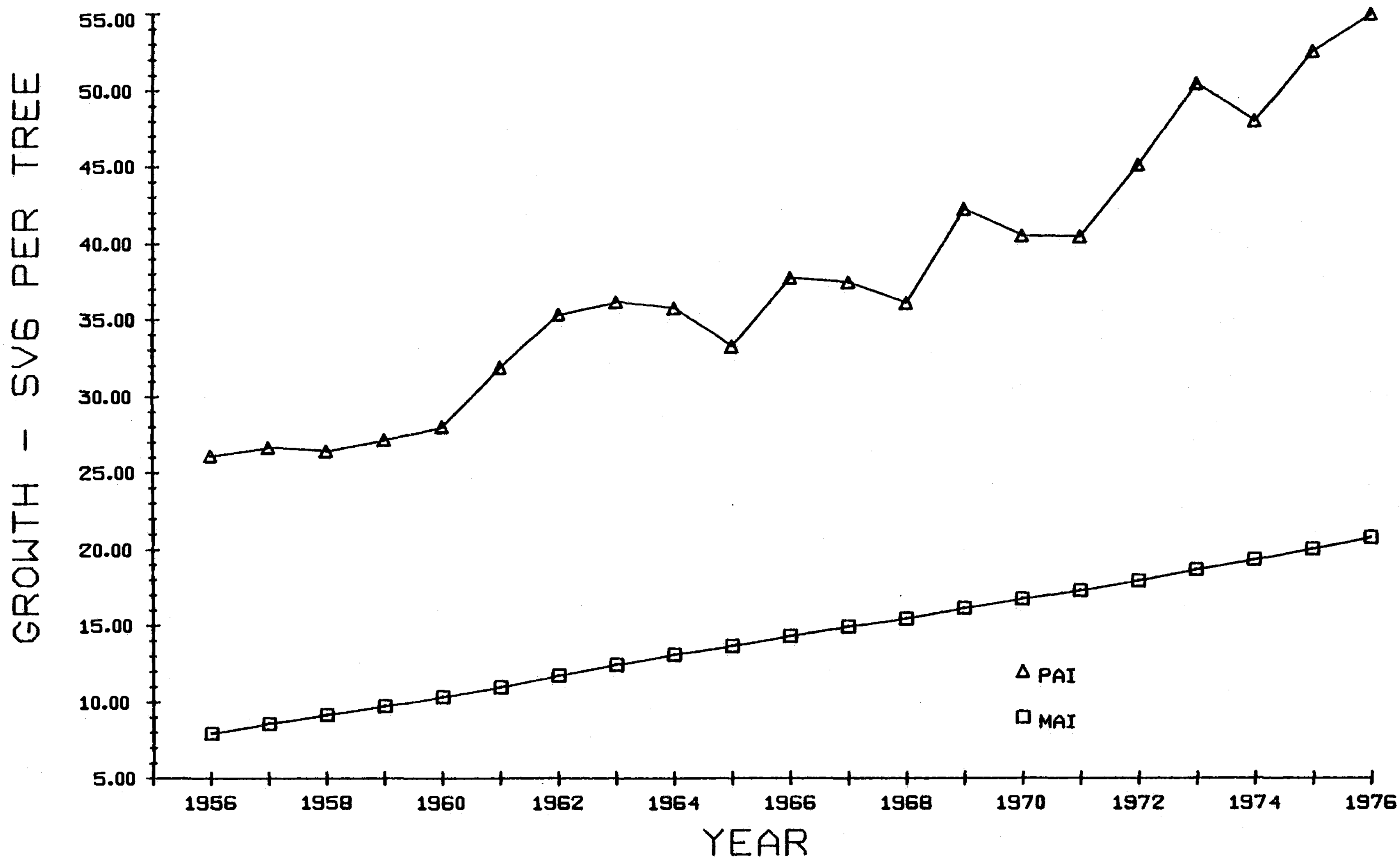
YEAR	TOTAL AGE	DBH	DBH GROWTH	PAI (CV4)	PAI (SV6)	MAI (CV4)	MAI (SV6)
1956	29	19.0	.32	4.29	27.73	2.12	10.68
1957	30	19.3	.31	4.19	27.03	2.18	11.18
1958	31	19.6	.28	3.86	25.08	2.23	11.60
1959	32	19.9	.26	3.87	25.32	2.28	11.99
1960	33	20.1	.21	3.78	24.72	2.32	12.35
1961	34	20.4	.28	4.34	28.23	2.37	12.78
1962	35	20.7	.30	4.46	29.23	2.43	13.22
1963	36	21.0	.33	5.15	34.01	2.50	13.76
1964	37	21.3	.29	4.83	32.06	2.56	14.22
1965	38	21.6	.29	4.79	31.73	2.61	14.65
1966	39	21.9	.29	5.02	33.56	2.67	15.10
1967	40	22.1	.27	5.01	34.09	2.73	15.55
1968	41	22.4	.26	4.87	32.92	2.78	15.94
1969	42	22.7	.30	5.25	35.33	2.83	16.38
1970	43	23.0	.29	5.15	34.87	2.88	16.78
1971	44	23.2	.26	4.77	32.27	2.92	17.11
1972	45	23.5	.27	5.36	37.00	2.97	17.53
1973	46	23.8	.26	5.46	38.36	3.02	17.96
1974	47	24.1	.34	5.97	41.07	3.08	18.42
1975	48	24.4	.33	6.50	45.98	3.15	18.97
1976	49	24.7	.27	5.19	36.86	3.19	19.31



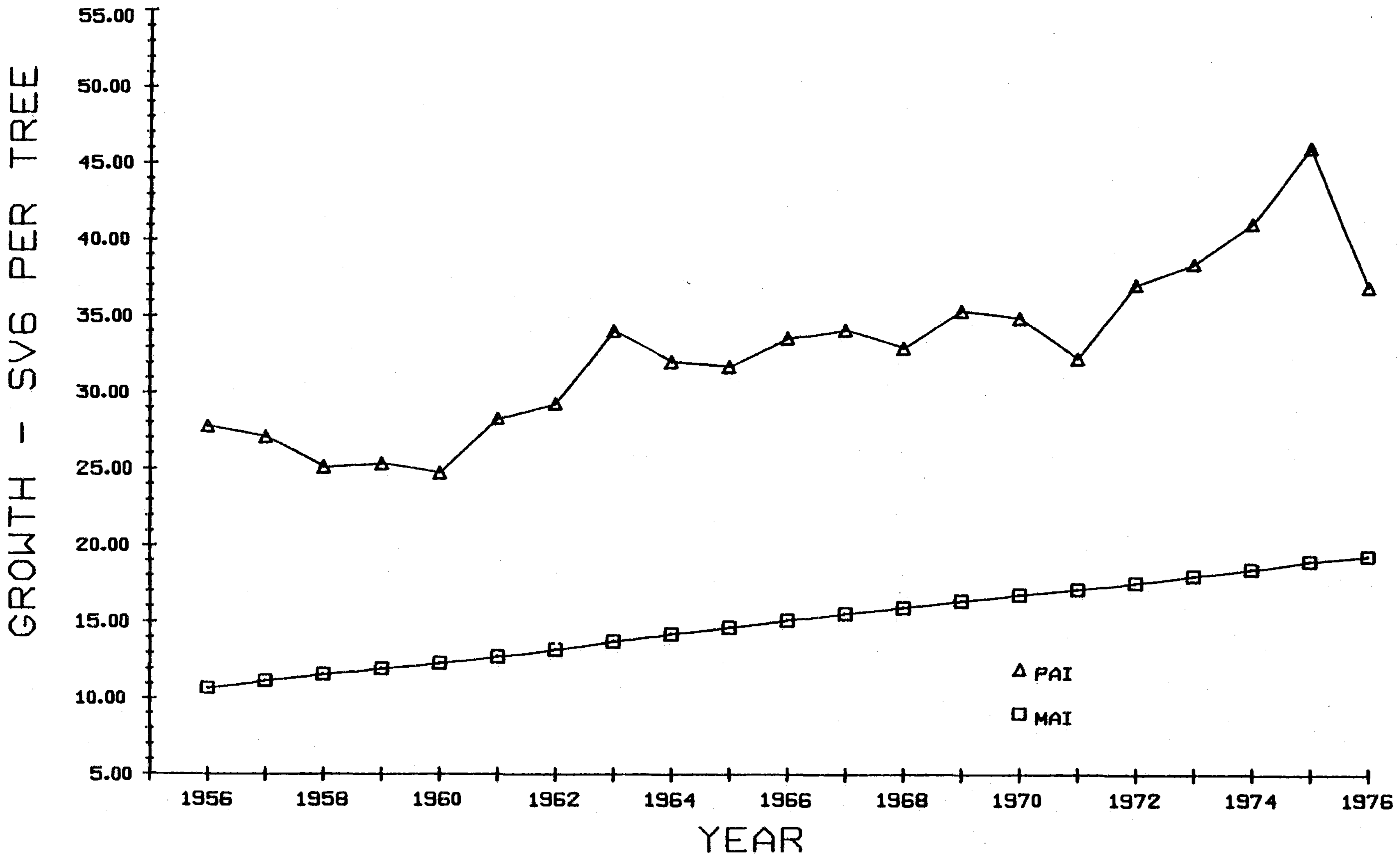
CUBIC VOLUME MEAN AND PERIODIC ANNUAL INCREMENT FOR PIGPEN.



CUBIC VOLUME MEAN AND PERIODIC ANNUAL INCREMENT FOR 13-LOOP.



SCRIBNER VOLUME MEAN AND PERIODIC ANNUAL INCREMENT FOR PIGPEN.



SCRIBNER VOLUME MEAN AND PERIODIC ANNUAL INCREMENT FOR 13-LOOP.