AN ECONOMIC EVALUATION OF COMMERCIAL THINNING DOUGLAS-FIR IN THE COASTAL REGION OF BRITISH COLUMBIA

by
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British Columbia Ministry of Forests

WP-6-002

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EXECUTIVE SUMMARY

Introduction

The purpose of this study was to conduct an economic evaluation of commercial thinning Douglas-fir in the coastal region of British Columbia, which included the estimation of the economic impacts of the thinning on the final harvest. This was done by simulating the growth and yield impacts of a commercial thinning, estimating the potential costs and revenues derived from the thinning and the final harvest, and determining the net present value of the full impacts of commercial thinning. The analysis was limited to the consideration of only one commercial thinning per rotation of an even-aged stand but included simulations in which the stand had previously been pre-commercially thinned.

The reader should keep in mind that the results presented are based on simulations of tree growth and not on actual field experiments. Wherever possible a comparison of the simulated results to actual field results was attempted. Nevertheless the major results of this study were based on the growing and harvesting of electronic trees within a computer.

The major methods and techniques used in the study were:

- The evaluation of commercial thinning was performed by assessing the economic efficiency of various thinning options, as compared to the unthinned option, using the techniques of benefit-cost analysis. The basic method used was to estimate the expected flow of benefits and cost which could be derived from the alternative growing regimes and to discount each flow back to a present value in order to determine the net present value (NPV) of each alternative. The management alternative which yielded the highest net present value was considered to be the best alternative and if the net present value was positive it was considered to be an economically efficient choice.

- The simulations of stand growth and yield used were produced by the Tree and Stand Simulator (TASS) developed by the Research Branch of the British Columbia Forest Service. The TASS model simulates the growth of trees and stands in three dimensions and was designed to be used to assess the effects of silviculture treatments and environmental factors on stand growth and yield. In selecting growing regimes it was decided to control for four factors: site index, stand density prior to the commercial thinning, thinning age, and post-commercial thinning stand density. Simulations were run for site index 36, 30 and 24. Simulations started with an initial planting density of 2,500 SPH (stems per hectare) and density prior to commercial thinning was then varied by running simulations which had no pre-commercial thinning and running other simulations which included a pre-commercial thinning down to 1,100 SPH, 800 SPH or 500 SPH. At each site index a simulation was run without a thinning and three simulations were run with a commercial thinning occurring at different ages. For each commercial thinning regime up to five thinning intensities were simulated, thinning from below to 200, 300, 400, 600, and 800 leave trees per hectare. A total of 115 simulations were run.

- The revenue from the thinnings and the final harvests were estimated using a bucking simulator which optimised the value of the logs which could be bucked from the bole of the trees harvested. The value of the logs was determined using prices from the Vancouver Log Market. The average price for each log grade was calculated as the weighted average price over the period 1990-1992 using the volume of logs sold in each year as the weights. Log prices were first converted from nominal to real prices using the Industrial Producer Price Index (Statistics Canada, 1992).

- The costs of conventionally skidder logging the commercial thinnings and the final harvest of the thinned and unthinned stands were estimated using the coast and interior appraisal manuals produced by the B.C. Forest Service.

Conclusions

The conclusions of the study are discussed below under five major headings.

1. Feasible Commercial Thinning Regimes

The biological foundations for density management were reviewed and it was shown that thinnings may be used as a means of reducing stand density in order to: 1) salvage tree volume which otherwise would be lost to mortality; 2) increase the portion of total stand volume which reaches a given merchantable limit; and 3) concentrate the growth potential of the site on fewer trees which may increase the value of the stand's final harvest. Depending on the species there may be a potential range of stand densities which can be maintained without sacrificing volume production. The ability of the trees left after a thinning to respond to the increased light, nutrients and water will depend on the vigour of the leave trees which is in turn determined by the size of the tree's live crown, the age of the stand, the species, and the quality of the site. The impact of each thinning method and thinning intensity on both the existing and desired stand structure must also be carefully considered when determining the appropriate thinning regime for a particular stand.

Based on the discussion of thinning methods it was suggested that low thinnings would be the most appropriate thinning method for Douglas-fir stands on good and medium sites. The timing of the thinning should be just before the onset of serious tree mortality but delayed enough that sufficient merchantable volume is available in order for the thinning to be economically viable.

2. Effects of Thinning on Cumulative Merchantable Volume

The simulations of the impacts of commercial thinning Douglas-fir leads to the conclusion that commercial thinning will likely provide only a marginal increase in the cumulative merchantable volume available from a stand over a rotation. Thus, if commercial thinning is to be justified as a viable forest management option it will have to be based on either the potential of the thinning to increase the value of the stand, by concentrating the stand's growth potential on a smaller number of trees, or on the earlier financial return obtained from thinning the stand.

3. Economic Evaluation

Thinning in the range of 200 to 400 leave trees per hectare was shown by the simulations to be economically superior to the corresponding unthinned regime for almost all site index 36 simulations run and for most of the site index 30 simulations run. The optimum thinning regimes may potentially increase the NPV of the simulated stands by 10-20% at site index 36 and by 3-30% at site index 30, depending on the thinning age and initial stand density. At site index 24 only a few of the pre-commercially thinned simulations showed commercial thinning to be viable with the best results achieved in stands which were pre-commercially thinned to 500 SPH. While these increases are not trivial they are by no means massive either. Thus, the economic gain from commercial thinning will, by themselves, be modest but still potentially well worth pursuing. The poor results achieved at site index 24 indicates that this is probably the lower limit for viable commercial thinning operations, at least under current log prices and harvest costs.

The higher NPV provided by some of the commercial thinning regimes can be attributed to two factors. First, the thinnings concentrated the growth on the larger dominant trees which produced a higher value per m^3 of wood grown. Second, the thinnings produced interim revenues

through the harvesting of trees who's timber values would have grown at a rate lower than the social discount rate. Typically the NPV of the thinned regimes drops off quickly as the thinning intensity was reduced. This highlights the economic advantage obtained from an early financial return from the stand. Using an investment analogy, if the stand is viewed as an investment portfolio and each tree as a separate stock than the commercial thinning may be viewed as the liquidation of those stocks producing the poorest investment yields. In addition, the thinning has the added advantage of increasing the returns on the remainder of the investment portfolio - the leave trees.

The foregoing comparison of NPVs was based on the comparison of the maximum NPV obtainable from the unthinned stand to the maximum NPV obtainable from a thinned stand which would occur at each stand's economic rotation age. The economic rotation ages for the unthinned stands were quite short ranging from 60-65 years of age at site index 36 and ranging from 60-70 years of age at site index 30 and 24. However, current forest management practices in British Columbia would see a stand harvested at the age which cumulates, or maximizes, the stand's mean annual (volume) increment, or MAI. In the unthinned stands cumulation of MAI occurred at ages ranging from 75-100 years. Cumulation of MAI is know as the physical rotation age as it is the age which maximizes volume growth. If the NPVs of the various regimes are compared at the physical rotation age then the viability of commercial thinning is even further enhanced particularly with the lower site index simulations. Thus, when rotation ages longer than the economic rotation age are planned commercial thinning becomes an even more attractive forest management option.

4. Sensitivity Analysis

The purpose of sensitivity analysis is to investigate how responsive the basic results were to changes in the key parameters used in the analysis. This was done to see if the ranking of the regimes would change in response to changes in any of the key parameters. For this study the major parameters tested were the discount rate, thinning costs, final harvest costs, road development costs, and basic silviculture costs. Overall the sensitivity of the base case results to changes in the key parameters increased as the site index declined and as initial stand density increased. This was not unexpected as the ability of a stand to respond to release will decline with a lower site index and with a higher stand density. The results show that a lower discount rate, higher thinning costs, or a lower final harvest cost will change some of the rankings. Tests of the potential economic consequences of any stand damage, which could occur during thinning, showed the results to be sensitive to potential stand damage highlighting the need to take measures to reduce any stand damage if commercial thinning is to remain economically viable.

Recommendations for Further Research

The simulation of the impacts of thinning on stand development and the assessment of the economic viability of commercial thinning provides numerous suggestions for areas of further research including:

- the assessment of commercially thinning the province's other major commercial tree species, such as Western Hemlock and Lodgepole Pine;
- the sensitivity of the results to any stand damage indicates a need to quantify the effects of various levels of stand damage;
- an assessment of commercial thinning when used in conjunction with other silvicultural treatments, particularly fertilization;
- the compilation of data on actual commercial thinning revenues and costs; and
- the development of optimal thinning schedules where more than one commercial thinning per rotation is planned.

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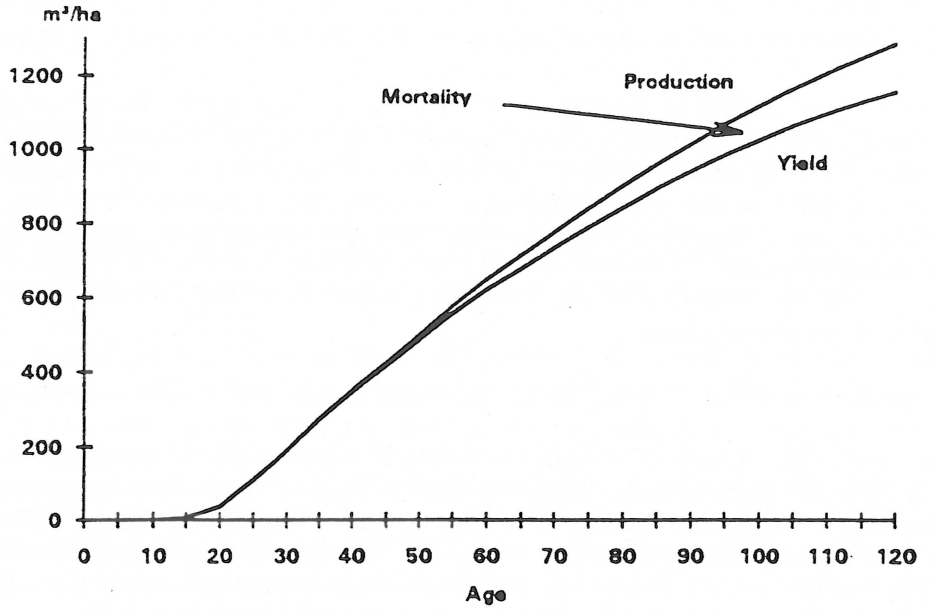


FIGURE 2-2. TOTAL PRODUCTION AND YIELD
Gross Production and Net Yield for a Douglas-fir Stand Naturally Regenerated at Site Index 30. Data from Mitchell et al., (1992).

2.3 Production and Yield

The total, or cumulative production of a site is the volume of all stem wood produced in a given period and is measured from tree top to ground level in m^3 per hectare. Total production includes all tree volume produced on a site including the volume of stem wood grown on trees which have died between the time of regeneration and the time of measurement. Net production, or yield, is that portion of total, or cumulative, production which is available for harvest at any given time and excludes the volumes lost due to tree mortality. The relationship between production and yield is shown in Figure 2-2. The volume lost to mortality is represented by the distance between the cumulative production curve and the yield curve.

Of course not all of a tree's wood is capable of being utilised. Merchantable volume is that portion of the stems of a stand which meets some minimum dimension requirement usually specified as some minimum diameter at breast height over bark (DBH) or small end diameter.[1] For this study merchantable yield was defined as the volume of trees with a minimum DBH of 12.5 cm and for that portion of the stem from a stump height of 0.3 m to a minimum top diameter inside bark of 10 cm.

The relationship between total yield and merchantable volume is shown in Figure 2-3, which shows that merchantable volume begins at a later date because trees take some time to reach a merchantable size. As the stand ages the merchantable volume slowly converges with total yield because more and more of the surviving trees reach a merchantable size leaving only the tops and stumps of the trees with unmerchantable volume. However, the definition of merchantable volume used will have a significant impact on the quantity of merchantable timber available at any given time. Figure 2-3 shows the merchantable volume curves for three different merchantable volume

[1] Breast height is the height above the germination point of the tree which is defined arbitrarily as 1.30 m.

definitions. The smaller the DBH limit for merchantable volume the greater will be the volume available and the greater will be the portion of total volume which is deemed utilizable. The differences in the curves converge as stand age is increased due to the smaller portion of trees falling in the lower diameter classes. The choice of which merchantable definition to use will ultimately be determined by the ability of industry to utilise small diameter wood profitably.

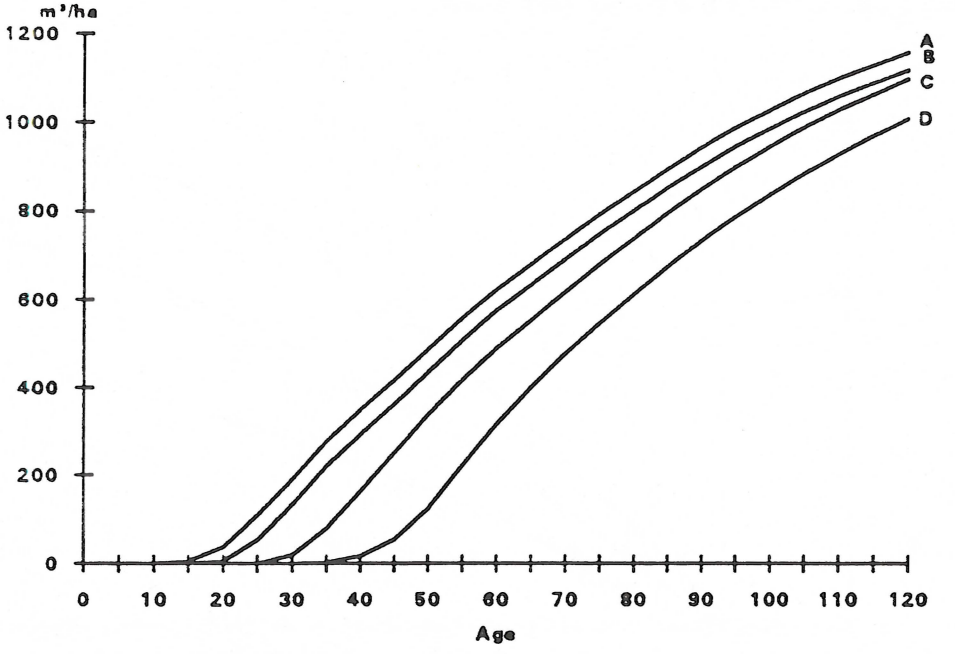


FIGURE 2-3. TOTAL YIELD AND MERCHANTABLE VOLUME
Naturally Regenerated Douglas-fir at Site Index 30, A - Total Yield, B - Merchantable Volume 12.5+ cm DBH, C - Merchantable Volume 22.5+ cm DBH, D - Merchantable Volume 32.5+ cm DBH. Data from Mitchell et al., (1992).

2.4 Site Quality and Stand Density

For any given tree species the factors which determine the amount and quality of the merchantable timber which a site can produce are site quality and stand density (Davis and Johnson, 1987). Site quality refers to the productivity of the forest land measured by the maximum amount of timber which can be grown in a given time. A site's quality is a function of its environmental conditions such as soil (type, depth, mineral composition etc.), micro-climate (rainfall and sunlight received, temperature, etc.), aspect, slope and other factors.

Site quality is, for a number of reasons, not measured directly as the maximum volume produced during a given period, but is instead measured indirectly using the site index method.[2] The site index for a given site is the height growth of the dominant trees on the site measured at some reference age. In British Columbia, site index is measured as the average height of the 100 largest diameter trees per hectare measured at a reference age of 50 years breast-height age (Mitchell and Cameron, 1985). Figure 2-4 shows the effect of changes in the site index on total volume.

[2] Direct measurement of site quality is difficult because standing volume will be affected if the stand is understocked, has mixed species, been attacked by disease or insects, had previous cuttings, etc.

While site quality determines the maximum potential production on a site, actual yield, for a given site quality, will also be determined by the amount, type and distribution of the trees on the site. Stand density is a quantitative measure of the amount of tree vegetation on a given area and is commonly measured using number of trees per hectare, volume per hectare, total basal area per hectare, and several stand density indexes (see Davis and Johnson [1987] for a review). Stand density can describe not only the level to which a site is being utilised but also the degree of competition taking place between the trees on the site.

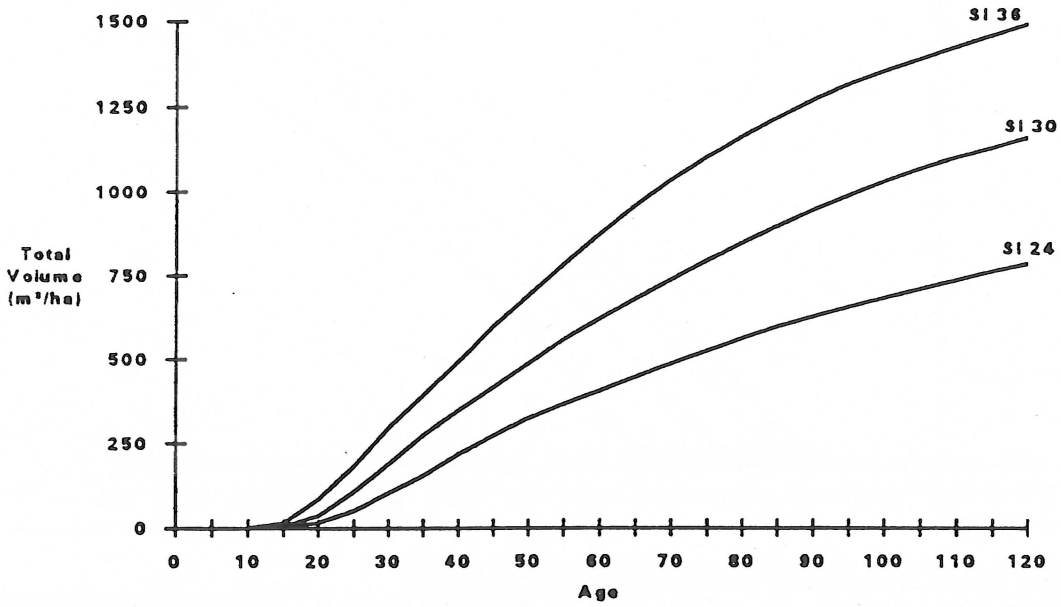


FIGURE 2-4. SITE QUALITY
Total Volume for Douglas-fir Naturally Regenerated at Three Site Indexes. Data from Mitchell et al., (1992).

A concept closely related to stand density is stocking. While stand density is a measurable attribute of a stand, i.e. a fact, stocking is a ratio comparison of the subject stand to some comparable "ideal" or reference stand (Davis and Johnson, 1987). An under stocked stand is not fully utilising the productive potential of the site and is characterised by trees which are excessive in taper, have coarse branches and a high live-crown ratio (Bickford et al., 1957). At the other extreme an overstocked stand produces trees with little taper, few slender branches and a low live-crown ratio. A fully stocked stand is one which is using the full growth potential of the site, however, many studies have shown that a stand can be considered fully stocked over a range of stand densities rather than only at a single point (for example, see Mar:Möller, 1947). The size of this range depends upon the species and narrows with poorer quality sites (Bickford et al., 1957).

In practice the only operationally feasible means of changing site quality is by fertilization.[3] This leaves stand density as the major factor which can be used to control stand development. Adjusting stand density gives the forest manager some control over diameter growth rates, wood quality, and the amount of merchantable timber available at any given age. This is achieved by reducing the number of trees occupying a site which concentrates the growth potential of the site on fewer trees allowing for greater tree diameter increment while forestalling mortality losses by reducing competition. In addition, if the trees removed are those that would not have survived until final rotation, and if these trees have reached a merchantable size, then the reduction in stand

[3] Other more costly site improvement techniques includes drainage and soil rehabilitation.

density will allow the salvage of merchantable volume that would otherwise be lost to natural mortality. However, care must be taken in selecting the appropriate reduction in stand density in order that large gaps or holes in the canopy are not created which could not be quickly filled by the expanding canopies of the remaining trees. Otherwise the site would not be fully stocked and part of the site's growth potential would be lost.

Thus, the potential benefits which may be derived from the adjustment of stand density through spacing, pre-commercial or commercial thinning include:

- increased merchantable volume - the portion of total volume which reaches a utilizable size in a given time may be increased which would be particularly important if a high minimum merchantability DBH were used;
- increased stand value - for a given volume, stands of larger average diameter trees have a higher value[4]; and
- salvage of mortality (except for thinning waste) - increased merchantable volume from trees which would have been lost to mortality

2.5 Density Management

Of the various indices available to measure and compare stand density the relative density index (RDI) of Drew and Flewelling (1979), and its associated density management diagram, are particularly useful in illustrating the potential impacts of density management on stand growth.[5] In developing this index the authors observed a consistent relationship in natural Dougals-fir even-aged stands between the maximum average tree volume on a site and the maximum stand density, expressed as the number of trees per hectare.[6] They developed the following equation for even-aged Douglas-fir stands to quantify this maximum size-density relationship:

(2-1) $\ln V = 10.437 - 1.5 \ln S$

where V = average tree volume in m^3, and
S = maximum stand density (number of trees per hectare).

Rearranging terms yields:

(2-2) $\ln S = (10.437 - \ln V)/1.5$

Drew and Flewelling's density index is based on the premise that for a given average tree size the density of a particular stand can be below the maximum density attainable. Their index is the ratio of the actual stand density to the maximum stand density attainable in a stand with the same average tree volume or:

$$RDI = \frac{\text{actual stand density in trees per hectare}}{\text{maximum density attainable in a stand with the same average tree volume}}$$

---

[4] A necessary caveat to this claim is that there would not be a corresponding decline in wood quality which could in some circumstances offset the increased value due to diameter increment.

[5] The forest literature abounds with numerous measures of stand density, most of which are based on the sums of tree diameters. For example, Curtis (1982) bases his index on the ratio of basal area per acre over the quadratic mean stand diameter. West (1982) provides a comparison of the mathematical properties of many of the alternative stand density indexes.

[6] Readers should note that the theoretical basis for the RDI, the -3/2 power law of self-thinning, has recently been severely criticised by Zeide (1987) and Weller (1987). In addition, Cameron (1988) found that the density management diagram for coastal Douglas-fir performed poorly as a reliable predictor of stand yield when predicted yields were compared to remeasured plot data from British Columbia. The RDI and density management diagram are used here only for illustrative purposes and are not recommended for use in place of growth and yield models such as TASS or TIPSY.

the thinning. Thus, as Bickford et al. (1957) noted in their review of density management "it becomes clear that we must recognise not one ideal forest, but a series of alternatives whose relative desirability depends on a combination of silviculture, management and economics."

2.6 Tree Classifications

While stand density indexes, such as the RDI, assist in predicting future growth patterns they do not provide a complete picture. Oliver and Murray (1983) stressed that variations in stand structure, which may not be reflected in a density index, would also effect the resulting growth pattern for the stand. Stand structure refers to the diameter class distribution of the trees in the stand and the relative position of the trees both horizontally on the site and vertically in the canopy. Thus, planned adjustments to stand density by thinnings should also detail the desired stand structure to be achieved.

To understand the impact thinnings would have on stand structure and the various types of thinning methods requires an understanding of tree classifications. Trees are typically classified according to the position of their crown in the surrounding forest canopy as shown in Figure 2-6. The four most common classifications are (Braathe, 1957):

- *Dominant Trees* - trees with crowns that rise somewhat above the canopy and receive full light from above and some from the sides.
- *Codominant Trees* - trees that are somewhat shorter than the dominants but form part of the crown canopy. They receive light from above but little from the sides and may be hemmed in laterally by dominants.
- *Intermediate Trees* - trees with about two-third the height of dominants which receive some light through holes in the canopy and are subject to lateral competition from the crowns of upper class trees.
- *Suppressed Trees* - trees that have been overtopped by surrounding tree crowns. These trees receive little direct light and exist by virtue of the light that filters through the canopy.

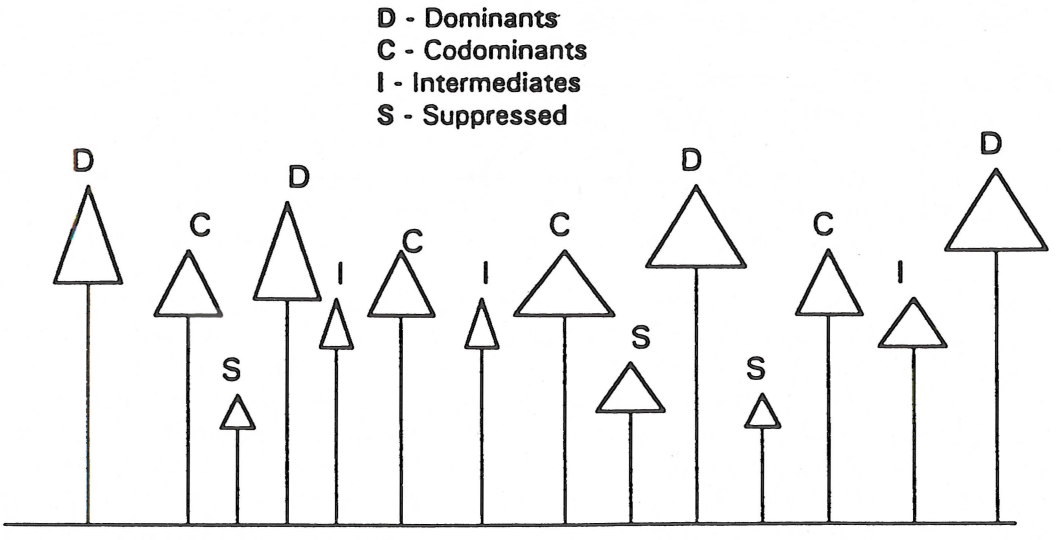


FIGURE 2-6. TREE CROWN CLASSIFICATION

2.7 Types of Thinnings

Thinnings have typically been classified according to that portion of the forest canopy from which trees are removed. The four types of thinnings most commonly recognised are (Braathe, 1957)[7]:

- *Low Thinning* - release of the dominant and codominant trees by the removal of the lower class trees. This type of thinning is based on the assumption that the lower classes are significant users of the site's nutrients and water which is detrimental to the growth of upper class trees. With low thinnings four or five grades of thinning intensity have usually been recognised and are classed from grade A, the lowest intensity, to grade E, the highest intensity (Hummel, 1954). Uniform definitions for these grades has not been reached but a conservative approach would see the poorest suppressed trees removed with a grade A thinning, all suppressed and the poorest intermediates at grade B, all suppressed and intermediates at grade C, all suppressed and intermediates plus many codominants at grade D, and the three lowest tree classes plus some dominants at grade E (Smith, 1986). E grade thinnings, while freeing the selected dominants on all sides for rapid growth, may result in gaps in the forest canopy which may not close resulting in the incomplete utilisation of the site. Total volumes removed during low thinnings may be as low as 5% of total stand volume before thinning for A grade thinnings, 20-35% for C grade, 40% or more for D grade and even higher for E grade. However, Smith (1986) notes that only stands of tolerant trees could have A and B grade thinnings as a stand of intolerant trees would have few surviving suppressed and intermediate trees. Figure 2-7 gives an illustrative example of a low thinning.

- *High or Crown Thinning* - release of the dominant crop trees and good codominant trees by removing competing codominants and, if appropriate tree spacing requires it, dominants. The only lower class trees taken are those of merchantable size which would not survive to the next thinning or to final harvest if no other thinnings are planned. Under this scheme it is assumed that the lower class trees are not significant competitors for the site's nutrients and water, rather the real competition is amongst the dominants and codominants. Figure 2-7 gives an example of a high thinning.

- *Selection Thinning* - releases the codominants and intermediate class, which become the crop trees, by the removal of the dominant trees.. Thinning in this manner can be justified in two ways (Hawley and Smith, 1954). First, the thinning may improve the quality of the final crop trees by removing dominants of poor form in favour of better formed lower class trees. Second, the thinning may be justified if the stand's end product goal is to produce smaller dimension products, such as pulp logs.

- *Free Thinning* - removal of trees from all classes in order to ensure a high utilisation of the site. Free thinning assumes that stands are not sufficiently uniform in stocking to produce a good future stand of crop trees.

One means proposed for measuring the thinning method is the thinning ratio (Eide and Langsaeter, 1941) which is defined as

$$\text{thinning ratio} = d/D$$

where d = mean diameter of the stems removed, and
D = mean diameter of the residual stems.

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[7] A fifth type of thinning is mechanical or geometric thinnings where the trees are taken in a geometric pattern such as row or strip thinning. This method seems more appropriate to juvenile spacing than commercial thinning and is not discussed further.

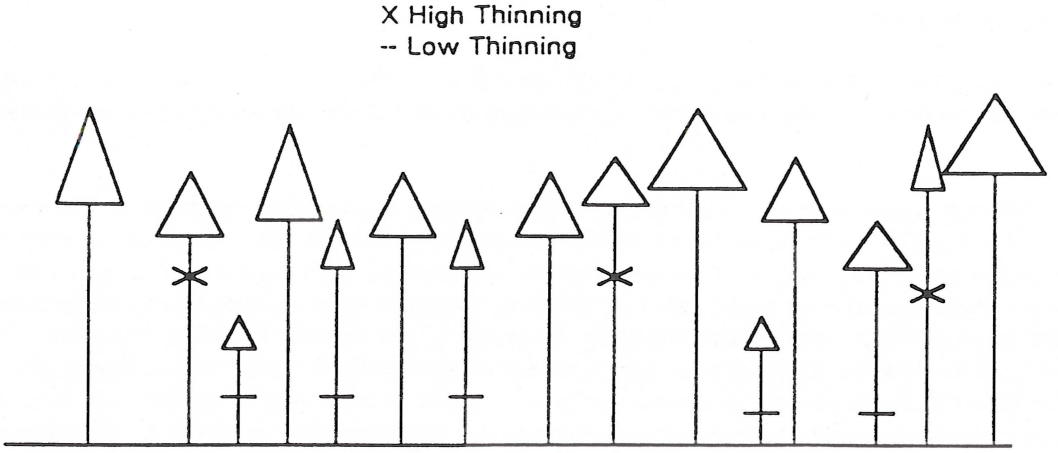


FIGURE 2-7. LOW AND HIGH THINNINGS

Using this ratio a thinning can be classified according to type as follows:

- $d/D \leq 0.70$ low thinning;
- $0.70 < d/D \leq 0.85$ intermediate between low and high thinning;
- $0.85 < d/D \leq 1.00$ high thinning; and
- $d/D \geq 1.0$ selection thinning.

Thinnings with a ratio at or below 0.85 are also known as "thinning from below" because the trees removed are the primarily the stand's smaller dimension trees which would of course come from the stand's lower tree classes. Thinnings with ratios above 1.00 are also known as "thinning from above" as the stand's largest trees are being taken which come from the upper tree classes. Free thinnings typically have ratios of less than 1.00.

Many authors, for example Joergensen (1957) and Smith (1986), have defined the thinning ratio using D equal to the average diameter *before* thinning. This thinning ratio will be denoted as d/D^* in the remainder of this report in order to avoid any confusion when using thinning ratios. Using the d/D^* ratio, thinnings may be classified as (Joergensen, 1957):

- $d/D^* \leq 0.65$ improvement cutting or cleaning;
- $0.65 < d/D^* \leq 0.75$ low thinning;
- $0.75 < d/D^* \leq 0.90$ severe low thinning or light high thinning;
- $0.90 < d/D^* \leq 1.0$ severe high thinning; and
- $d/D^* \geq 1.0$ selection thinning.

2.8 Response to Thinnings

The ability of a tree to respond to the additional sunlight, growing space, nutrients and water made available by a thinning will be determined by the tree's vigour, which is in turn determined by crown condition, age, species, site quality, and stand density. Crown condition, particularly the length of the live crown, is an important indicator of potential response. Trees with longer live crowns will be better able to utilise the additional sunlight, water, nutrients made available and can more easily expand to fill the additional growing space. Age is also significant because as trees grow older their height growth declines and becomes negligible for mature trees. This means that for mature trees the crown response may be limited to lateral growth or to increased photosynthate efficiency.

The species growing on a site affects the response to thinning not only through the species' inherent growth rate but also through its relative tolerance. Tolerance refers to the relative capacity of a tree to compete under conditions of low light and high root competition (Daniel, et al., 1987). The lower branches of intolerant trees die off relatively quickly when shaded from sunlight due to competition from surrounding trees. This moves the base of the live crown further up the tree resulting in a shorter live crown. Tolerant trees on the other hand retain their lower branches longer as their leaves remain functional at lower light levels. Thus, for a given site, tolerant species are more likely to have longer live crowns than intolerant species which in turn means they are more likely to respond to the thinning release. In addition, tolerant species will typically have thicker foliage and more branches than intolerant species. This also suggests that lower class intolerant trees may be unable to quickly respond to release.

A lack of response to release is caused by the trees inability to use the increased growing space, sunlight, water and nutrients. This may be a result of the tree already occupying a dominant position or to a poor root system or poor live crown ratio. In some cases following thinning the leave tress may experience "thinning shock" which is a reduction in height and/or diameter growth, chlorotic foliage, and damage or mortality resulting from increased exposure following release. See Harrington and Reukema (1983) for a further discussion of thinning intensity and thinning shock.

2.9 Stand Volume Increment Following Thinning

In thinning from below the first trees to be removed would be on the verge of death and their removal would likely have a negligible effect on the stand's volume growth. However, as the intensity of the thinning increases and more and more trees are removed a point would be reached where the stand is no longer fully occupying the site and the volume growth of the stand would drop below that of an unthinned stand, at least in the short term (Bradley, 1963). If the thinning is too intense then it is possible that the stand might never fully re-occupy the site and thus there would be a permanent drop in the stand's volume growth. Between these extremes one would likely see, for most thinnings, an initial drop in annual volume increment from the stand as the residual trees could not immediately fully utilise the extra light, water and nutrients available, but as the trees started to respond to release volume growth would increase and surpass the volume growth of the unthinned stand. The increased annual volume growth following re-occupation would be a result of the residual trees being able to more efficiently utilise the site. However, as the thinned stand ages, competition between the residual trees would increase and annual volume growth would likely return to that achieved by the unthinned stand.

This latter scenario is illustrated in Figure 2-8 below which shows the annual volume growth for two hypothetical thinnings measured as a percentage of an unthinned stand's annual volume growth. Whether a thinning would increase total volume growth would depend on how much volume growth was lost during the re-occupation of the site and how much volume was gained after the site was re-occupied but before competition reduced volume growth to the level of the unthinned stand. The heavier the thinning the longer it would likely take to make up for the lost volume. This is an important point to remember when setting rotation ages for stands which are to be commercial thinned. The intensity of the thinning in these cases should be set to ensure that the full volume response is achieved prior to the intended final harvest date or else volume growth available from the thinning response would be lost.

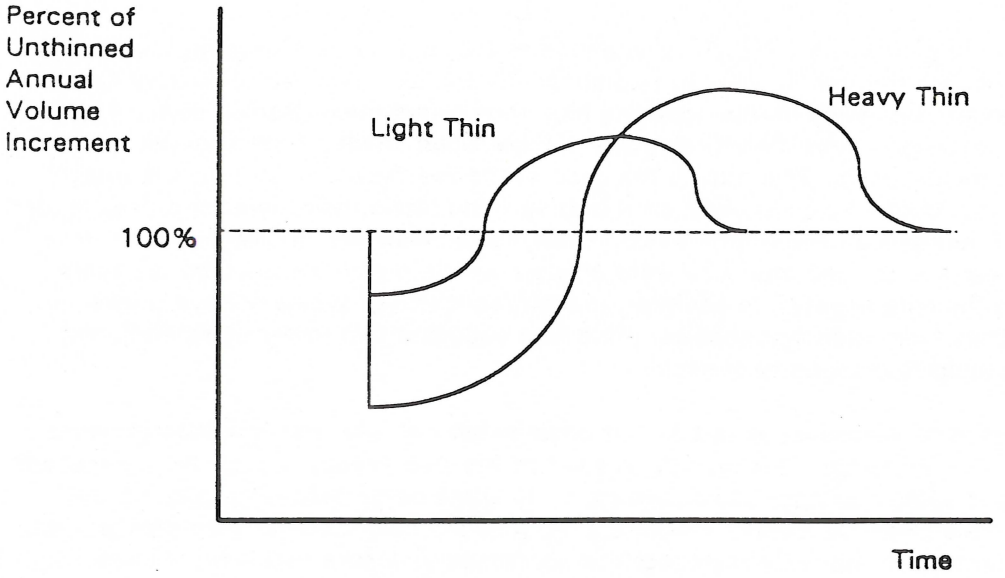


Figure 2-8 Stand Growth Following Thinning

2.10 Discussion of Thinning Methods

A major advantage given for low thinnings is its close relationship to the natural succession of stand development (Smith, 1986). Its major drawback is that the taking of smaller trees may be less profitable than other thinning methods. Low thinnings will most likely be useful in stands of intolerant trees where lower class trees have achieved a merchantable size but would likely be lost if left or have such a small crown as to be unable to respond if they were released (Smith, 1986). This condition would likely occur in the later half of a stands rotation. Thus, the timing of a low thinning, when only one thinning per rotation is planned, would be when the suppression of trees of a merchantable size is imminent.

Crown thinnings, by harvesting trees mainly from the codominant class, should have a decided economic advantage over low thinnings because of the relatively larger and more valuable trees taken. Crown thinnings by focusing the thinning on the release of a selected number of crop trees should allow these trees to reach a given size earlier or achieve a larger size within a given time (Smith, 1986). However, in intolerant stands crown thinnings may not salvage or prevent the loss of lower class trees, one of the major advantages typically attributed to commercial thinnings, as the remaining dominants and codominants expand to fill the canopy. This would, of course, be less of a concern in stands of tolerant species. A crown thinning of a stand of intolerant trees is still possible if the stand is still young enough that the crowns of the lower class trees are able to respond to the release provided by the thinning, however the quantity of merchantable volume available from such a thinning may be small.

In practice any thinning would likely combine elements of more than one thinning type. For example, a low thinning may also take some dominant trees of poor form and some poorly spaced codominants while in a mixed stand some of the lower class tolerant trees may be left. Crown thinnings of intolerant stands would likely include the harvest of lower class trees as they would be unlikely to survive to a subsequent thinning or to the final harvest age. Free thinnings, which would likely take place in stands of a fairly heterogeneous structure, would combine elements of both low and high thinnings.

2.11 Thinning Guides and Schedules

A number of rule-of-thumb spacing guides have been proposed to assist in determining the appropriate spacing between trees to be left after spacing. These guides are based on the arithmetic relationship which exists between tree spacing, tree diameter, tree heights, number of trees, basal area and volume (Davis, 1966). The rules-of-thumb include:

- *Diameter Based Rules* - Two commonly cited rules are the Dx rule (diameter times rule) and the D + x rule (diameter plus rule). The Dx rule states that distance between trees should be a multiple of the stand's average DBH times a constant. This method is applicable in circumstances where the thinning is designed to maintain a constant basal area. The constant x is determined by the basal area it is desired to maintain.[8] The D + x rule states that the distance between trees should be equal to the average DBH of the stand plus some constant. This type of rule will ensure an increasing basal area over time.[9]

- *Height Based Rules* - A number of authors have suggested using top height as the basis for determining the extent and timings of thinnings. For example, Wilson (1946, 1951 and 1955) recommended that the spacing in stands of tolerant species be maintained at one-sixth of top height while stands of intolerant trees should have a spacing equivalent to one-quarter of top height. Hummel (1954) suggested that spacing equivalent to 20% of top height following thinning should be the standard used.

- *Height/Diameter Ratio Rules* - Smith (1986) suggested that the ratio of top height to average DBH, both measured in centimetres, provides a useful indicator of when and how intense to thin a stand. He suggests that this guide is particularly useful because it focuses attention on the stand's diameter growth rate.

When more than one thinning is planned during a rotation a thinning schedule, i.e. the timing between thinnings, must be determined. Thinning schedules based on height growth have an intuitive appeal in that they take into account the fact that young stands have higher height growth and can quickly expand to fill gaps left by the removal of small trees while older trees, with lower height growth, require more time to occupy the larger holes left in the canopy by the thinnings. Thus, the use of a constant height increment to schedule thinnings means that the interval between thinnings lengthens as the stand ages.. A commonly used height increment between thinnings is 10 feet (see for example the Forestry Commission, 1946).

While these rule-of-thumb provide a handy reference for field application they tend to be based on experience with specific species under specific growing conditions which may make their general application suspect. These rules do not for instance take into account variations in stand structure which may not be reflected in the variables used in the rules, or give guidance to which thinning method to employ. Thus, these rules do not relieve the forester from performing a careful analysis of the current conditions of a stand being considered for thinning and the desired stand structure to be achieved after the thinning. In addition, the judicious use of modern computer simulation models of stand growth and yield may provide better guidance in determining the appropriate timing and intensity for the thinning of a particular stand than can be achieved by these simple rules-of-thumb.

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[8] The constant x is calculated in metric units as 177.25 divided by the square root of the basal area to be left, measured in m^2/ha. See Davis (1966) for its derivation in english units.

[9] See Davis (1966) for a useful review and comparison of the Dx and D + X rules.

- Timber values were measured using log prices taken from the Vancouver Log Market. The underlying assumption is that the log market accurately reflects the values of the coastal timber resources as determined by a fully competitive atomistic market.[1]

- All revenues and costs were measured in constant 1992 dollars. By concentrating on constant prices and costs (also known as real prices and costs) the effects of inflation on current prices and costs can be ignored.

- No real price increases in timber values or harvest costs were used. Many forestry studies have frequently included a real price increase of 1-3% per year for timber prices when assessing the economics of various silviculture investments However, this study has rejected the use of simple price inflators as being too simplistic as they ignore the potential effects of product substitution in the market place which would act against real price increases by lowering the demand for products made from wood. An example might be an increase in the use of steel studs in house construction if the price of wood studs increased dramatically.

- The age at which the commercial thinning took place was used as year zero, or the base year, in the discounting of costs and revenues. This must be kept in mind when comparing alternate growing regimes which have different commercial thinning ages.

- Merchantable volume was defined as trees with a minimum DBH of 12.5 cm and for that portion of the stem from a stump height of 0.3 m to a minimum top diameter inside bark of 10 cm. A low diameter utilisation limit was used because future mills will likely be able to use smaller diameter trees and areas currently facing timber supply constraints will also likely be looking to adopt more stringent utilisation standards.

- Basic silviculture regeneration costs were assumed to include the cost of planting only which was assumed to cost $600/ha. For comparison the average costs for planting in the Vancouver Forest Region during 1991/92 was $552/ha exclusive of the cost of seedlings (Ministry of Forests [1993]).

- The cost of pre-commercial thinnings (PCT) were estimated using the cost equations developed by Stone (1992). The estimated average cost per hectare was $868, $878 and $888 for thinnings to 1,100 SPH, 800 SPH and 500 SPH respectively.[2]

- Road development costs for access to the site were assumed to occur only once per rotation and would occur at the time of the thinning for thinning regimes and at the time of final harvest for the unthinned regimes. Thus, an access road put in at the time of thinning would be available for the final harvest from the thinned stands.

The specific assumptions and methods used to estimate the costs and revenues from the thinnings and final clear-cut harvests are presented in detail in Section 5.

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[1] The basic assumptions of perfect competition are: (a) both consumers and producers are price takers; (b) the product of all producers are identical (homogeneous products); (c) all resources are free to move in and out of the market; and (d) both producers and consumers have perfect knowledge of market prices and costs. See Ferguson and Gould (1975), or any other microeconomic theory text, for a more complete discussion of the concept of a perfectly competitive market.

[2] The estimates were calculated using the linear average cost equation (2-2) of Stone (1992). The average values for the Vancouver Forest Region contained in the report were used as the values for all independent variables except for the number of trees removed.

3.3 Determination of Net Present Values

A project's net present value (NPV) will be the sum of the discounted benefits yielded by a project minus the sum of the discounted costs of the project. This can be written mathematically as:

$$(3\text{-}1) \quad NPV = \sum_{i=0}^{A} R_i (1+r)^{-i} - \sum_{i=0}^{A} C_i (1+r)^{-i}$$

where R_i = revenue, or benefit, received in year i,
C_i = cost incurred at year i,
r = social discount rate, and
A = terminal year of the project.

For the growing regimes involving the unthinned stands the net present value would be calculated as:

$$(3\text{-}2) \quad NPV_u = (R_u - C_u - C_d + SV_u) / (1 + r)^{A-a}$$

where

NPV_u = net present value at age 'a' of the unthinned stand harvested at age A,
R_u = revenue derived from the harvest of the unthinned stand at age A
C_u = cost of harvesting the unthinned stand at age A,
C_d = road development cost,
SV_u = site value, defined below, of an infinite series of unthinned stands harvested at rotation age A,
A = final harvest age, and
a = base year from which the present value is being evaluated (the age at which the commercial thinning will take place in the corresponding thinned stands).

For the growing regimes involving thinned stands the net present value would be calculated as:

$$(3\text{-}3) \quad NPV_t = R_c - C_c - C_d + (R_t - C_t + SV_t) / (1 + r)^{A-a}$$

where

NPV_t = the net present value at age 'a' of the thinned stand harvested at age A,
R_c = the revenue derived from the thinning at age a,
C_c = the cost of the thinning at age a,
R_t = the revenue derived from the harvest of the thinned stand at age A
C_t = the cost of harvesting the thinned stand at age A,
C_d = the road development cost,
SV_t = the site value of an infinite series of rotations of thinned stands harvested at rotation age A,
A = the final harvest age, and
a = the base year from which the present value is being evaluated (the thinning age).

Note that the regeneration cost of establishing the current rotation are not included in equations (3-2) and (3-3). This is because we are examining the feasibility of commercially thinning an established stand, which means that past regeneration costs can be considered to be sunk costs (or historical costs) and this analysis was only concerned with current and future costs and revenues. Thus, past costs are irrelevant to our analysis on whether or not to commercially thin an established stand. If on the other hand one was examining alternative management regimes starting from bare land then the regeneration costs would be considered and the most efficient option would be found by comparing site values as described below.

The site value (SV) represents the maximum amount that someone would be willing to pay for bare land if the land was devoted to producing an infinite series of rotations of identical growing regimes.[3] It is the capitalised value of the periodic net income derived from producing timber under a specified growing regime. The general formula for determining the SV is (Gregory, 1972):

$$(3\text{-}4) \quad SV = \frac{\sum_{i=o}^{A} R_i (1+r)^{A-i} - \sum_{i=0}^{A} C_i (1+r)^{A-i}}{(1+r)^A - 1}$$

The general formula can be simplified for the unthinned growing regimes to:

$$(3\text{-}5) \quad SV_u = \frac{R_u - C_u - C_d - S(1+r)^A}{(1+r)^A - 1}$$

where S equals the basic silviculture regeneration costs.[4] For the thinned growing regimes the general formula can be simplified to:

$$(3\text{-}6) \quad SV_t = \frac{R_t - C_t + (R_c - C_c - C_d)(1+r)^{A-a} - S(1+r)^A}{(1+r)^A - 1}$$

For stands which have been pre-commercially thinned the cost of the pre-commercial thinning must be accounted for in both equations 3-5 and 3-6. To do this the following term must be subtracted from the numerator in each equation

$$C_s(1+r)^{A-b}$$

where C_s = the cost of the pre-commercial thinning, and
b = the age at which the pre-commercial thinning would take place.

Once estimates of the revenues and costs associated with each growing regime have been made equations (3-2) and (3-5) can be used to estimate the NPV of each unthinned regime and equations (3-3) and (3-6) can be used to estimate the NPV of the thinned regimes. Section 6 presents the results of these calculations.

The values for NPV_t and NPV_u will vary with changes in A, the final harvest age. The harvest age at which the highest net present value is achieved for each regime, denoted as NPV_t^* and NPV_u^* for the thinned and unthinned regimes respectively, would be considered to be the optimum economic rotation age for each regime and will be denoted as A_t and A_u. Note that the final harvest ages need not be the same for the thinned and unthinned regimes. For the thinning

[3] Site value is also referred to in the literature as soil rent, bare land value, and soil expectation value.
[4] Regeneration costs are assumed to take place in the same year as the final harvest.

regime to economically viable the optimum net present value must be greater than the optimum net present value of the unthinned regime or,

(3-7) $$NPV_t^{\circ} \geq NPV_u^{\circ}$$

3.4 Minimum Net Revenue Requirements

Another way of looking at the problem of determining the feasibility of commercial thinning would be to determine the minimum net revenue required from the commercial thinning in order to make up any difference in the net present value of the final harvests and future rotations of the thinned and unthinned stands. This can be found by substituting equations (3-2) and (3-3) into equation (3-7) rearranging terms and dividing each side by the commercial thinning volume (Vol_C) to yield:

(3-8) $$\frac{R_C - C_C - C_d}{Vol_C} \geq \frac{[(R_u - C_u - C_d + SV_u)/(1 + r)^{Au-a}] - [(R_t - C_t + SV_t) / (1 + r)^{At-a}]}{Vol_C}$$

The left hand side of equation (3-8) represents the average value of the net revenue extracted from the thinning. The right hand side represents the difference between the net present values of the final harvests and future rotations of the unthinned and thinned regimes which is the minimum net revenue required from the thinning in order for the thinning to be economically efficient. The minimum net revenue requirements for each thinning regime simulated are presented in Section 6.

SECTION FOUR
GROWTH AND YIELD SIMULATIONS

4.1 The TASS Model

The simulations of stand growth and yield used in this study were produced by the Tree and Stand Simulator (TASS) developed by the Research Branch of the British Columbia Forest Service. The TASS model simulates the growth of trees and stands in three dimensions and was designed to be used to assess the effects of silviculture treatments and environmental factors on stand growth and yield. The model can provide numerous descriptive statistics of stand growth at each age including estimates of the number of live trees, total standing volume, merchantable volume, basal area, and the average and quadratic mean DBH of the stand. See Mitchell (1975), and Mitchell and Cameron (1985) for further details on the model and its development.

The TASS model, which is calibrated using data from research plots, predicts yields which are greater than those that may be achieved operationally. Mitchell and Cameron (1985) attribute this operational "falldown" to microsite conditions, irregular spacing, environmental conditions and other factors which are not as carefully controlled in operational conditions as they are in research installations. They estimate the yield losses to be in the range of 5-25% at rotation age. The operational loss would be greatest for naturally regenerated stands, with their irregular spacing, and would be smallest for planted sites.

In this study no adjustments were made to the simulation results produced by the model to account for any potential operational falldown for two reasons. First, the effect of actual falldown on the subsequent log grade distribution cannot be assessed. The relative log grade distribution was an important consideration in this study as the distribution will account for any changes in wood values resulting from the thinning. Second, and more importantly, this analysis focused on the differences between the harvests on a site with and without commercial thinnings rather than on the actual totals themselves. In addition, because the simulations used in the study were for planted sites, the potential for operational falldown should be at the lower end of the yield losses suggested by Mitchell and Cameron. Nevertheless, the potential effect of operational falldown was tested as part of the sensitivity analysis described in Section 7.

A second factor which was not accounted for in the simulations used in this study was the potential effect on yield resulting from tree damage which might occur during the thinning, or to any area taken out of production for skid trails or landings. The amount of stand damage which occurs can be reduced by proper planning, use of appropriate harvesting methods and by proper crew training and supervision. Still, the potential impacts of stand damage on the final harvest following thinning is an important consideration and therefore the potential impacts of various levels of stand damage was tested in Section 7 by reducing the final harvest by various amounts.

4.2 Growing Regimes Simulated

In selecting growing regimes to simulate it was decided to control for four factors: site index, stand density prior to the commercial thinning, age of thinning and post-thinning stand density. The Silviculture Manual of the Ministry of Forests recommends that commercial thinning be restricted to good and medium sites.[1] Thus, to cover the range of potential second growth Douglas-fir commercial thinning sites, three site indexes were chosen for analysis; site index 36, 30 and 24.

Each site was assumed to be planted at the initial density of 2,500 SPH. To allow for variation in stand density prior to the commercial thinning different simulations were run for stands

[1] See Section 9.43 of the Silviculture Manual.

which had and had not been pre-commercially thinned (PCT). Simulations which included PCT were run which left 1100, 800 and 500 SPH following the PCT. The PCTs were designed to leave the largest well spaced trees and occurred at age 14, 16, and 19, for the site index 36, 30 and 24 simulations respectively.

For each site index and stand density a simulation was run without a commercial thinning in order to provide a control simulation. Simulations were then run which had a commercial thinning taking place at one of the three commercial thinning ages for each site index as shown in Table 4-1. As noted in Section 2, the timing of the thinning will depend on site index, initial spacing and market considerations. From a biological viewpoint the thinning should take place before the onset of serious inter-tree competition if the goal is maximization of merchantable yields. However, this biological need for an early entry has to be balanced against the need for the stand to have grown enough to provide sufficient merchantable products in order to finance the cost of extraction. This was one reason why as the site index declined the range of ages at which the simulated commercial thinning took place was increased so that sufficient merchantable volume would be available for the commercial thinning harvest.

TABLE 4-1
GROWING REGIMES SIMULATED

Pre-Commercial Thin Stand Density	Age of Thinning SI 36	SI 30	SI 24	Post Commercial Thin Stand Densities
(SPH)		(years)		(SPH)
No PCT	-	-	-	Unthinned
No PCT	30	40	50	200, 300, 400, 600
No PCT	40	50	60	200, 300, 400, 600, 800
No PCT	50	60	70	200, 300, 400, 600, 800
PCT 1,100	-	-	-	Unthinned
PCT 1,100	30	40	50	200, 300, 400
PCT 1,100	40	50	60	200, 300, 400, 600
PCT 1,100	50	60	70	200, 300, 400, 600
PCT 800	-	-	-	Unthinned
PCT 800	30	40	50	200, 300, 400
PCT 800	40	50	60	200, 300, 400
PCT 800	50	60	70	200, 300, 400
PCT 500	-	-	-	Unthinned
PCT 500	30	40	50	200
PCT 500	40	50	60	200
PCT 500	50	60	70	200

For each growing regime up to five thinning intensities were simulated. They were thinning from "below" to densities of 200, 300, 400, 600 and 800 leave trees per hectare as shown in Table 4-1. From the earlier review of thinning methods this means that the largest trees, the dominants and larger codominants, were left to form the final crop trees and the smaller ones, the suppressed, intermediate and smaller codominants, were harvested. For each growing regime the stand growth was simulated up to the relevant thinning age and the appropriate number of stems removed from the stand. The simulations were then continued to asses the effects of the commercial thinning on the final clear-cut harvest. Table 4-1 shows that a total of 115 simulations

were run which should provide broad coverage of the potential commercial thinning options for coastal Douglas-fir stands.[2]

4.3 Simulation Results

Tables 4-2 to 4-4 show the simulated effect, per hectare, of a commercial thinning on the number of trees, total volume, merchantable volume and basal area. Obviously as the number of residual trees left after the commercial thinning is reduced the percentage impact on total volume, merchantable volume and basal area increases. However, as the age at which the thinning takes place is increased, for a given thinning intensity (i.e. the number of leave trees per hectare), the percentage change in total volume, merchantable volume and basal area resulting from the thinning is reduced. This is because as the stand ages a greater percentage of stand volume and basal area is concentrated on the dominant trees, thus, as we are thinning from below, the removal of the smaller trees has less of an impact on the stand as the stand grows older. Similarly as the stand density prior to commercial thinning is reduced, by the simulation of a pre-commercial thinning, the percentage impact of the commercial thinning at a given age on volume and basal area is also reduced. Again this is because a larger portion of stand volume and basal area has been concentrated on the dominant trees - this time as a result of the PCT.

The intensity of the inter-tree competition taking place in the unthinned stand can be seen by examining the mortality which would have taken place in the unthinned stand between the earliest and latest commercial thinning ages. For example, for site index 36 simulations between age 30 and 50, a total of 743 SPH would die in the No PCT stand while only 132 SPH, 49 SPH and three SPH would die during this time period in the stands which had been PCT to 1100 SPH, 800 SPH and 500 SPH respectively.

Tables 4-5 to 4-7 provide the thinning ratios for each growing regime and thinning intensity. Based on the d/D ratio all thinnings would be classified as low thinnings or in a few cases as intermediate thinnings. However, there was surprisingly little variation in the ratios. This lack of variation for thinning from below occurs because while d increases as you take out larger trees so does D because the largest diameter trees are always left. Because of the interrelationship between d and D the second thinning ratio d/D^* may serve as a better measure of the thinning type. Using this second ratio the heaviest thinnings can be classified as severe low thinnings while the lightest thinnings would be classified as improvement cuttings or low thinnings. In most simulations, thinning to 200 SPH at the earliest thinning age resulted in a d/D^* ratio classified as a high thin. Both the d/D and d/D^* ratios dropped as the age at which the thinning took place was increased for a given initial density.

Tables 4-5 to 4-7 also report the live crown ratios for the residual trees, which indicates the potential of the final crop trees to respond, and the percentage crown cover left after thinning, which indicates the level of site utilisation. The live crown length for the leave trees is quite high for most thinning intensities except for the lightest thinning suggesting that the additional trees left on the site from the light thinnings would be unlikely to respond to the thinning. However, for the most intense thinnings the crown cover has been reduced to such a low level that full utilisation of the site has been sacrificed for many years - indeed full crown closure may not occur before the final harvest takes place. On the other hand, the crown cover for the lightest thinnings is hardly altered at all, suggesting that the thinnings will have little impact on diameter increment. The impact of a given thinning intensity on crown cover declines as the thinning age and initial density increases. Again, because we are thinning from below, the largest dominant trees are being left which increases their share of the canopy area as competing trees are removed, either through PCT or by the competition induced mortality of the smaller trees.

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[2] Originally only 6 simualtions were planned thus the large number of simulations actually run once again shows that simulations are to researchers what narcotics are to drug addicts.

TABLE 4-2
COMMERCIAL THINNING SUMMARY STATISTICS
SITE INDEX 36

Stems			Total Volume			Merchantable Volume			Basal Area		
Before	After	%Δ	Before	After	%Δ	Before	After	%Δ	Before	After	%Δ
(trees/ha.)			(m^3/ha.)			(m^3/ha.)			(m^2/ha.)		
No PCT, Thin at Age 30											
2000	200	90.0	307	83	73.0	254	77	69.7	42.2	10.4	75.4
2000	300	85.0	307	115	62.5	254	106	58.3	42.2	14.4	65.9
2000	400	80.0	307	144	53.1	254	132	48.0	42.2	18.0	57.3
2000	600	70.0	307	192	37.5	254	174	31.5	42.2	24.3	42.4
No PCT, Thin at Age 40											
1574	200	87.3	508	185	63.6	458	176	61.6	57.7	18.8	67.4
1574	300	80.9	508	251	50.6	458	237	48.3	57.7	25.7	55.5
1574	400	74.6	508	305	40.0	458	288	37.1	57.7	31.5	45.4
1574	600	61.9	508	386	24.0	458	362	21.0	57.7	40.5	29.8
1574	800	49.2	508	436	14.2	458	408	10.9	57.7	46.6	19.2
No PCT, Thin at Age 50											
1257	200	84.1	704	319	54.7	659	306	53.6	69.6	28.3	59.3
1257	300	76.1	704	424	39.8	659	406	38.4	69.6	38.0	45.4
1257	400	68.2	704	502	28.7	659	481	27.0	69.6	45.5	34.6
1257	600	52.3	704	601	14.6	659	573	13.1	69.6	55.9	19.7
1257	800	36.4	704	653	7.2	659	620	5.9	69.6	62.2	10.6
PCT to 1,100 SPH, Thin at Age 30											
1052	200	81.0	271	92	66.1	241	85	64.7	36.5	11.7	67.9
1052	300	71.5	271	128	52.8	241	118	51.0	36.5	16.4	55.1
1052	400	62.0	271	160	41.0	241	147	39.0	36.5	20.6	43.6
PCT to 1,100 SPH, Thin at Age 40											
1002	200	80.0	486	197	59.5	450	187	58.4	54.2	20.5	62.2
1002	300	70.1	486	269	44.7	450	255	43.3	54.2	28.2	48.0
1002	400	60.1	486	329	32.3	450	310	31.1	54.2	34.7	36.0
1002	600	40.1	486	414	14.8	450	389	13.6	54.2	44.5	17.9
PCT to 1,100 SPH, Thin at Age 50											
920	200	78.3	697	334	52.1	659	320	51.4	68.7	30.2	56.0
920	300	67.4	697	445	36.2	659	426	35.4	68.7	40.6	40.9
920	400	56.5	697	529	24.1	659	505	23.4	68.7	48.9	28.8
920	600	34.8	697	631	9.5	659	601	8.8	68.7	60.0	12.7
PCT to 800 SPH, Thin at Age 30											
767	200	73.9	244	97	60.2	220	90	59.1	33.0	12.7	61.5
767	300	60.9	244	136	44.3	220	125	43.2	33.0	17.8	46.1
767	400	47.8	244	170	30.3	220	156	29.1	33.0	22.4	32.1
PCT to 800 SPH, Thin at Age 40											
757	200	73.6	458	208	54.6	428	196	54.2	51.1	21.9	57.1
757	300	60.4	458	284	38.0	428	269	37.1	51.1	30.3	40.7
757	400	47.2	458	347	24.2	428	327	23.6	51.1	37.4	26.8
PCT to 800 SPH, Thin at Age 50											
718	200	72.1	675	344	49.0	641	330	48.5	66.3	31.7	52.2
718	300	58.2	675	462	31.6	641	443	30.9	66.3	43.0	35.1
718	400	44.3	675	502	25.6	641	481	25.0	66.3	45.5	31.4
PCT to 500 SPH, Thin at Age 30											
480	200	58.3	200	107	46.5	182	99	45.6	27.7	14.6	47.3
PCT to 500 SPH, Thin at Age 40											
479	200	58.2	404	229	43.3	380	216	43.2	45.5	25.2	44.6
PCT to 500 SPH, Thin at Age 50											
477	200	58.1	626	377	39.8	596	361	39.4	61.5	35.8	41.8

TABLE 4-3
COMMERCIAL THINNING SUMMARY STATISTICS
SITE INDEX 30

Stems			Total Volume			Merchantable Volume			Basal Area		
Before	After	%Δ	Before	After	%Δ	Before	After	%Δ	Before	After	%Δ
(trees/ha.)			(m^3/ha.)			(m^3/ha.)			(m^2/ha.)		
No PCT, Thin at Age 40											
1898	200	89.5	370	109	70.5	316	101	68.0	48.3	12.6	73.9
1898	300	84.2	370	149	59.7	316	138	56.3	48.3	17.4	64.0
1898	400	78.9	370	185	50.0	316	171	45.9	48.3	21.7	55.1
1898	600	68.4	370	243	34.3	316	224	29.1	48.3	29.0	40.0
No PCT, Thin at Age 50											
1635	200	87.8	509	182	64.2	458	172	62.4	58.5	18.6	68.2
1635	300	81.7	509	247	51.5	458	233	49.1	58.5	25.3	56.8
1635	400	75.5	509	301	40.9	458	284	38.0	58.5	31.1	46.8
1635	600	63.3	509	381	25.1	458	357	22.1	58.5	40.2	31.3
1635	800	51.1	509	433	14.9	458	405	11.6	58.5	46.6	20.3
No PCT, Thin at Age 60											
1343	200	85.1	635	266	58.1	589	255	56.7	65.9	24.7	62.5
1343	300	77.7	635	356	43.9	589	340	42.3	65.9	33.3	49.5
1343	400	70.2	635	427	32.8	589	407	30.9	65.9	40.3	38.8
1343	600	55.3	635	520	18.1	589	494	16.1	65.9	50.4	23.5
1343	800	40.4	635	575	9.4	589	543	7.8	65.9	56.9	13.7
PCT to 1,100 SPH, Thin at Age 40											
1044	200	80.8	335	118	64.8	303	109	64.0	42.7	14.2	66.7
1044	300	71.3	335	163	51.3	303	152	49.8	42.7	19.7	53.9
1044	400	61.7	335	203	39.4	303	189	37.6	42.7	24.7	42.2
PCT to 1,100 SPH, Thin at Age 50											
1002	200	80.0	479	192	59.9	444	181	59.2	54.3	20.1	63.0
1002	300	70.1	479	262	45.3	444	247	44.4	54.3	27.7	49.0
1002	400	60.1	479	320	33.2	444	302	32.0	54.3	34.2	37.0
1002	600	40.1	479	406	15.2	444	381	14.2	54.3	44.1	18.8
PCT to 1,100 SPH, Thin at Age 60											
955	200	79.1	610	273	55.2	572	261	54.4	63.5	26.1	58.9
955	300	68.6	610	368	39.7	572	350	38.8	63.5	35.4	44.3
955	400	58.1	610	442	27.5	572	420	26.6	63.5	43.0	32.3
955	600	37.2	610	538	11.8	572	510	10.8	63.5	53.8	15.3
PCT to 800 SPH, Thin at Age 40											
766	200	73.9	307	126	59.0	281	117	58.4	39.2	16.4	60.7
766	300	60.8	307	175	43.0	281	162	42.3	39.2	21.6	44.9
766	400	47.8	307	216	29.6	281	201	28.5	39.2	26.9	31.4
PCT to 800 SPH, Thin at Age 50											
759	200	73.6	455	203	55.4	425	192	54.8	51.3	21.8	57.5
759	300	60.5	455	279	38.7	425	263	38.1	51.3	30.1	41.3
759	400	47.3	455	341	25.1	425	321	24.5	51.3	37.1	27.7
PCT to 800 SPH, Thin at Age 60											
742	200	73.0	590	287	51.4	558	274	50.9	61.1	27.8	54.5
742	300	59.6	590	387	34.4	558	369	33.9	61.1	38.0	37.8
742	400	46.1	590	466	21.0	558	443	20.6	61.1	46.2	24.4
PCT to 500 SPH, Thin at Age 40											
479	200	58.2	256	139	45.7	237	129	45.6	33.4	17.7	47.0
PCT to 500 SPH, Thin at Age 50											
479	200	58.2	400	225	43.8	376	212	43.6	45.6	25.0	45.2
PCT to 500 SPH, Thin at Age 60											
478	200	58.2	539	316	41.4	511	301	41.1	55.9	31.7	43.3

TABLE 4-4
COMMERCIAL THINNING SUMMARY STATISTICS
SITE INDEX 24

Stems			Total Volume			Merchantable Volume			Basal Area		
Before	After	%Δ	Before	After	%Δ	Before	After	%Δ	Before	After	%Δ
(trees/ha.)			(m^3/ha.)			(m^3/ha.)			(m^2/ha.)		
No PCT, Thin at Age 50											
1974	200	89.9	344	95	72.4	291	88	69.8	47.4	11.6	75.5
1974	300	84.8	344	131	61.9	291	122	58.1	47.4	16.1	66.0
1974	400	79.7	344	163	52.6	291	151	48.1	47.4	20.1	57.6
1974	600	69.6	344	217	36.9	291	198	32.0	47.4	27.0	43.0
No PCT, Thin at Age 60											
1803	200	88.9	427	135	68.4	374	127	66.0	54.0	15.0	72.2
1803	300	83.4	427	185	56.7	374	172	54.0	54.0	20.6	61.9
1803	400	77.8	427	227	46.8	374	212	43.3	54.0	25.5	52.8
1803	600	66.7	427	294	31.1	374	274	26.7	54.0	33.7	37.6
1803	800	55.6	427	343	19.7	374	316	15.5	54.0	39.9	26.1
No PCT, Thin at Age 70											
1646	200	87.8	501	178	64.5	451	168	62.7	59.1	18.3	69.0
1646	300	81.8	501	241	51.9	451	228	49.4	59.1	25.1	57.5
1646	400	75.7	501	294	41.3	451	277	38.6	59.1	30.8	47.9
1646	600	63.5	501	371	25.9	451	349	22.6	59.1	39.8	32.7
1646	800	51.4	501	422	15.8	451	394	12.6	59.1	46.3	21.7
PCT to 1,100 SPH, Thin at Age 50											
1048	200	80.9	307	106	65.5	276	98	64.5	41.0	13.3	67.6
1048	300	71.4	307	147	52.1	276	137	50.4	41.0	18.6	54.6
1048	400	61.8	307	184	40.1	276	170	38.4	41.0	23.3	43.2
PCT to 1,100 SPH, Thin at Age 60											
1025	200	80.5	395	147	62.8	361	138	61.8	48.5	16.8	65.4
1025	300	70.7	395	204	48.4	361	190	47.4	48.5	23.4	51.8
1025	400	61.0	395	252	36.2	361	234	35.2	48.5	29.1	40.0
1025	600	41.5	395	326	17.5	361	303	16.1	48.5	38.3	21.0
PCT to 1,100 SPH, Thin at Age 70											
1004	200	80.1	475	192	59.6	440	181	58.9	54.8	20.3	63.0
1004	300	70.1	475	262	44.8	440	247	43.9	54.8	28.0	48.9
1004	400	60.2	475	320	32.6	440	301	31.6	54.8	34.5	37.0
1004	600	40.2	475	404	14.9	440	379	13.9	54.8	44.6	18.6
PCT to 800 SPH, Thin at Age 50											
769	200	74.0	281	112	60.1	255	104	59.2	37.5	14.4	61.6
769	300	61.0	281	156	44.5	255	145	43.1	37.5	20.1	46.4
769	400	48.0	281	194	31.0	255	180	29.4	37.5	25.2	32.8
PCT to 800 SPH, Thin at Age 60											
767	200	73.9	369	156	57.7	340	146	57.1	45.1	18.1	59.9
767	300	60.9	369	215	41.7	340	201	40.9	45.1	25.2	44.1
767	400	47.8	369	265	28.2	340	247	27.4	45.1	31.4	30.4
PCT to 800 SPH, Thin at Age 70											
762	200	73.8	450	200	55.6	420	190	54.8	51.6	21.7	57.9
762	300	60.6	450	275	38.9	420	259	38.3	51.6	30.0	41.9
762	400	47.5	450	336	25.3	420	317	24.5	51.6	37.0	28.3
PCT to 500 SPH, Thin at Age 40											
481	200	58.4	231	124	46.3	212	115	45.8	31.4	16.5	47.5
PCT to 500 SPH, Thin at Age 50											
480	200	58.3	314	173	44.9	292	162	44.5	38.9	20.9	46.3
PCT to 500 SPH, Thin at Age 60											
479	200	58.2	393	222	43.5	369	210	43.1	45.4	24.9	45.2

TABLE 4-5
THINNING RATIOS, CROWN COVER, CROWN LENGTHS
AND DENSITY AND SPACING INDEXES - SITE INDEX 36

Thinning Intensity (leave trees)	Thinning Ratio (d/D)	Thinning Ratio (d/D^2)	Crown Cover (%)	Live Crown Percentage (%)	RDI	Average Spacing (m)	Relative Spacing (%)	H/DBH
No PCT, Thinned at Age 30								
2000	n.a.	n.a.	100	23	0.54	2.24	11	121.95
200	0.58	0.92	36	53	0.11	7.07	35	77.82
300	0.58	0.88	50	52	0.15	5.77	29	81.30
400	0.58	0.85	61	50	0.19	5.00	25	83.68
600	0.56	0.78	79	48	0.27	4.08	20	88.11
No PCT, Thinned at Age 40								
1574	n.a.	n.a.	100	16	0.70	2.52	9	124.54
200	0.55	0.88	50	45	0.18	7.07	26	77.97
300	0.54	0.83	67	43	0.25	5.77	21	81.52
400	0.53	0.78	80	41	0.32	5.00	19	85.13
600	0.51	0.69	95	36	0.42	4.08	15	91.81
800	0.50	0.63	100	30	0.51	3.54	13	98.90
No PCT, Thinned at Age 50								
1257	n.a.	n.a.	100	14	0.81	2.82	9	121.80
200	0.53	0.84	60	41	0.26	7.07	22	76.24
300	0.51	0.77	78	38	0.36	5.77	18	80.80
400	0.50	0.71	91	35	0.44	5.00	15	85.04
600	0.47	0.61	99	28	0.57	4.08	13	94.19
800	0.46	0.54	100	21	0.67	3.54	11	102.86
PCT to 1,100 SPH, Thinned at Age 30								
1052	n.a.	n.a.	100	38	0.41	3.08	16	94.29
200	0.71	0.92	39	55	0.11	7.07	36	72.53
300	0.70	0.88	54	53	0.16	5.77	29	75.00
400	0.69	0.84	66	52	0.21	5.00	25	77.34
PCT to 1,100 SPH, Thinned at Age 40								
1002	n.a.	n.a.	100	24	0.58	3.16	12	102.29
200	0.64	0.88	51	45	0.19	7.07	26	74.24
300	0.63	0.83	68	43	0.27	5.77	22	77.46
400	0.61	0.77	82	41	0.33	5.00	19	80.72
600	0.57	0.67	96	36	0.45	4.08	15	87.30
PCT to 1,100 SPH, Thinned at Age 50								
920	n.a.	n.a.	100	18	0.73	3.30	10	105.52
200	0.60	0.85	60	41	0.27	7.07	22	74.20
300	0.58	0.78	79	38	0.37	5.77	18	78.31
400	0.56	0.71	92	35	0.46	5.00	15	82.28
600	0.52	0.60	99	27	0.59	4.08	13	91.04
PCT to 800 SPH, Thinned at Age 30								
767	n.a.	n.a.	100	46	0.34	3.61	18	84.19
200	0.75	0.91	43	58	0.12	7.07	36	69.37
300	0.74	0.87	60	57	0.17	5.77	29	71.64
400	0.72	0.82	74	55	0.21	5.00	25	73.78
PCT to 800 SPH, Thinned at Age 40								
757	n.a.	n.a.	100	29	0.52	3.63	14	91.13
200	0.69	0.88	52	46	0.20	7.07	26	71.39
300	0.67	0.82	71	44	0.28	5.77	22	74.37
400	0.64	0.75	85	42	0.35	5.00	19	77.39
PCT to 800 SPH, Thinned at Age 50								
718	n.a.	n.a.	100	23	0.66	3.73	11	94.75
200	0.65	0.85	60	41	0.27	7.07	22	72.38
300	0.62	0.78	80	38	0.38	5.77	18	76.11
400	0.59	0.70	93	35	0.47	5.00	15	79.85
PCT to 500 SPH, Thinned at Age 30								
480	n.a.	n.a.	100	60	0.26	4.56	23	72.69
200	0.80	0.90	54	65	0.13	7.07	36	64.59
PCT to 500 SPH, Thinned at Age 40								
479	n.a.	n.a.	100	41	0.41	4.57	17	76.72
200	0.76	0.88	59	49	0.21	7.07	26	66.75
PCT to 500 SPH, Thinned at Age 50								
477	n.a.	n.a.	100	32	0.54	4.58	14	80.00
200	0.72	0.85	65	42	0.29	7.07	22	67.92

TABLE 4-6
THINNING RATIOS, CROWN COVER, CROWN LENGTHS
AND DENSITY AND SPACING INDEXES - SITE INDEX 30

Thinning Intensity (leave trees)	Thinning Ratio (d/D)	Thinning Ratio (d/D^2)	Crown Cover (%)	Live Crown Percentage (%)	RDI	Average Spacing (m)	Relative Spacing (%)	H/DBH
No PCT, Thinned at Age 40								
1898	n.a.	n.a.	100	18	0.82	2.30	10	121.67
200	0.58	0.91	40	46	0.13	7.07	32	77.11
300	0.58	0.87	54	45	0.18	5.77	26	80.51
400	0.57	0.84	66	43	0.23	5.00	23	83.27
600	0.55	0.76	84	40	0.31	4.08	19	88.31
No PCT, Thinned at Age 50								
1635	n.a.	n.a.	100	14	0.71	2.47	9	124.88
200	0.55	0.88	49	42	0.18	7.07	27	77.33
300	0.54	0.83	66	40	0.25	5.77	22	81.10
400	0.53	0.78	79	38	0.31	5.00	19	84.44
600	0.51	0.70	95	33	0.42	4.08	15	91.10
800	0.49	0.63	99	28	0.50	3.54	13	97.79
No PCT, Thinned at Age 60								
1343	n.a.	n.a.	100	13	0.77	2.73	9	122.00
200	0.54	0.86	57	40	0.23	7.07	23	77.22
300	0.53	0.80	75	37	0.32	5.77	19	81.12
400	0.52	0.74	88	35	0.40	5.00	16	85.20
600	0.50	0.65	99	28	0.52	4.08	13	93.27
800	0.48	0.58	100	22	0.61	3.54	12	101.33
PCT to 1,100 SPH, Thinned at Age 40								
1044	n.a.	n.a.	100	29	0.46	3.09	14	94.74
200	0.69	0.91	41	47	0.13	7.07	33	72.00
300	0.69	0.87	57	46	0.19	5.77	27	74.74
400	0.67	0.83	70	44	0.24	5.00	23	77.14
PCT to 1,100 SPH, Thinned at Age 50								
1002	n.a.	n.a.	100	22	0.58	3.16	12	101.14
200	0.65	0.89	50	42	0.19	7.07	27	74.30
300	0.64	0.84	67	40	0.26	5.77	22	77.55
400	0.62	0.78	81	38	0.33	5.00	19	80.61
600	0.59	0.68	96	33	0.44	4.08	15	86.93
PCT to 1,100 SPH, Thinned at Age 60								
955	n.a.	n.a.	100	18	0.67	3.24	11	104.81
200	0.62	0.86	57	40	0.23	7.07	23	74.94
300	0.60	0.80	76	37	0.33	5.77	19	78.61
400	0.59	0.75	89	34	0.41	5.00	16	82.43
600	0.55	0.64	99	28	0.53	4.08	13	90.24
PCT to 800 SPH, Thinned at Age 40								
766	n.a.	n.a.	100	37	0.40	3.61	17	85.10
200	0.74	0.91	45	50	0.14	7.07	33	69.11
300	0.72	0.86	62	48	0.20	5.77	27	71.85
400	0.71	0.81	76	46	0.25	5.00	23	74.32
PCT to 800 SPH, Thinned at Age 50								
759	n.a.	n.a.	100	27	0.51	3.63	14	90.10
200	0.70	0.88	51	42	0.19	7.07	27	70.97
300	0.68	0.83	70	41	0.27	5.77	22	73.95
400	0.65	0.76	84	39	0.34	5.00	19	76.97
PCT to 800 SPH, Thinned at Age 60								
742	n.a.	n.a.	100	23	0.61	3.67	12	93.52
200	0.66	0.86	58	39	0.24	7.07	23	71.97
300	0.64	0.80	77	37	0.34	5.77	19	75.56
400	0.61	0.73	90	34	0.42	5.00	17	79.11
PCT to 500 SPH, Thinned at Age 40								
479	n.a.	n.a.	100	50	0.30	4.57	21	72.82
200	0.80	0.90	56	56	0.15	7.07	33	64.58
PCT to 500 SPH, Thinned at Age 50								
479	n.a.	n.a.	100	39	0.41	4.57	17	76.15
200	0.77	0.88	59	47	0.21	7.07	27	66.42
PCT to 500 SPH, Thinned at Age 60								
478	n.a.	n.a.	100	32	0.49	4.57	15	78.76
200	0.74	0.86	63	42	0.26	7.07	23	67.71

TABLE 4-7
THINNING RATIOS, CROWN COVER, CROWN LENGTHS
AND DENSITY AND SPACING INDEXES - SITE INDEX 24

Thinning Intensity (leave trees)	Thinning Ratio (d/D)	Thinning Ratio (d/D^2)	Crown Cover (%)	Live Crown Percentage (%)	RDI	Average Spacing (m)	Relative Spacing (%)	H/DBH
No PCT, Thinned at Age 50								
1974	n.a.	n.a.	100	17	0.58	2.25	11	118.86
200	0.59	0.92	38	43	0.12	7.07	34	76.47
300	0.59	0.88	51	42	0.17	5.77	28	79.69
400	0.59	0.85	63	40	0.21	5.00	24	82.21
600	0.57	0.79	81	38	0.29	4.08	20	86.67
No PCT, Thinned at Age 60								
1803	n.a.	n.a.	100	14	0.66	2.36	10	123.08
200	0.57	0.90	44	41	0.15	7.07	29	77.67
300	0.57	0.86	60	39	0.21	5.77	24	81.08
400	0.56	0.82	73	38	0.26	5.00	21	84.21
600	0.55	0.75	90	34	0.35	4.08	17	89.89
800	0.53	0.69	98	29	0.43	3.54	15	95.24
No PCT, Thinned at Age 70								
1646	n.a.	n.a.	100	13	0.70	2.46	9	123.83
200	0.56	0.89	50	39	0.18	7.07	27	77.49
300	0.55	0.84	67	38	0.25	5.77	22	81.29
400	0.54	0.80	81	36	0.31	5.00	19	84.66
600	0.53	0.72	95	31	0.41	4.08	15	91.07
800	0.51	0.65	99	25	0.50	3.54	13	97.79
PCT to 1,100 SPH, Thinned at Age 50								
1048	n.a.	n.a.	100	28	0.44	3.09	15	92.38
200	0.70	0.91	40	45	0.12	7.07	34	70.79
300	0.69	0.87	55	43	0.18	5.77	28	73.31
400	0.68	0.84	68	42	0.23	5.00	24	75.74
PCT to 1,100 SPH, Thinned at Age 60								
1025	n.a.	n.a.	100	23	0.52	3.12	13	96.73
200	0.68	0.90	46	42	0.16	7.07	30	72.48
300	0.67	0.86	62	40	0.22	5.77	24	75.24
400	0.65	0.81	76	38	0.28	5.00	21	77.96
600	0.61	0.71	93	34	0.38	4.08	17	83.16
PCT to 1,100 SPH, Thinned at Age 70								
1004	n.a.	n.a.	100	20	0.58	3.16	12	100.38
200	0.65	0.89	51	40	0.19	7.07	27	73.61
300	0.64	0.84	68	38	0.26	5.77	22	76.81
400	0.62	0.78	82	36	0.33	5.00	19	79.82
600	0.58	0.68	97	31	0.44	4.08	15	86.04
PCT to 800 SPH, Thinned at Age 50								
769	n.a.	n.a.	100	36	0.37	3.61	18	82.73
200	0.75	0.91	44	47	0.13	7.07	34	67.99
300	0.74	0.87	60	46	0.18	5.77	28	70.55
400	0.73	0.83	75	45	0.24	5.00	24	72.79
PCT to 800 SPH, Thinned at Age 60								
767	n.a.	n.a.	100	29	0.45	3.61	15	86.50
200	0.73	0.90	48	43	0.16	7.07	30	69.71
300	0.71	0.85	65	41	0.23	5.77	24	72.48
400	0.69	0.80	80	39	0.29	5.00	21	75.00
PCT to 800 SPH, Thinned at Age 70								
762	n.a.	n.a.	100	25	0.51	3.62	14	89.80
200	0.70	0.89	51	40	0.19	7.07	27	71.16
300	0.68	0.83	70	38	0.27	5.77	22	73.95
400	0.66	0.77	84	36	0.34	5.00	19	76.97
PCT to 500 SPH, Thinned at Age 50								
481	n.a.	n.a.	100	49	0.28	4.56	22	71.18
200	0.80	0.90	55	55	0.14	7.07	34	63.27
PCT to 500 SPH, Thinned at Age 60								
480	n.a.	n.a.	100	41	0.34	4.56	19	73.83
200	0.78	0.89	57	48	0.17	7.07	30	64.93
PCT to 500 SPH, Thinned at Age 70								
479	n.a.	n.a.	100	36	0.40	4.57	17	75.86
200	0.77	0.88	59	44	0.20	7.07	27	66.33

Drew and Flewelling's relative density index was calculated for each thinning regime and the results are also given in Tables 4-5 to 4-7. Examining just the site index 36 simulations by initial density reveals the following points:

No Pre-Commercial Thin

- At age 30 the stand would only just be entering the zone of imminent competition induced mortality. All of the thinnings simulated at this age would reduce the RDI below 0.41 which indicates that some future volume gain would be lost however tree size would be increased. Indeed thinning to 300 SPH would take the RDI down to the line "which approximates crown closure" and thinning to 200 SPH would take the stand below this line.
- At age 40 the RDI indicates that the stand would be well into the self-thinning zone. A total of 436 SPH would have been lost to mortality in the last ten years. Thinning to 600 or 800 SPH keeps the RDI in the volume maximization area while the heavier thinnings may result in some loss of growth potential - at least in the short run.
- By age 50 the stand has advanced well into the self-thinning zone and would lose another 317 SPH to mortality in the proceeding ten years. The light thinnings would not take the stand below the self-thinning line and thus would have little effect on average tree increment. Thinning to 400 SPH would keep the stand in the volume maximizing zone.

PCT to 1,100 SPH

- At age 30 the stand has only just entered the volume maximization area and thus, at this age and initial density, thinnings could only be justified if the maximization of tree size were a priority. Note that only 48 SPH have been lost to mortality since the time of the PCT.
- At age 40 the stand would have just crossed over the self-thinning line and thus thinnings could now be used to forestall mortality. While mortality has only been 50 SPH during the proceeding ten years the volume loss should now start to increase.
- By age 50 a further 80 SPH have been lost to mortality. The stand is now well into the self-thinning zone and would have to be thinned to 400 SPH in order to take the RDI below the self-thinning line.

PCT to 800 SPH

- At age 30 only 33 SPH have been lost to mortality since the PCT and the stand would not be in need of a thinning unless very large trees or a very short technical rotation age were desired.
- By age 40 only 10 more SPH would have been lost to mortality during the proceeding ten years and the stand would be just below the self-thinning line.
- At age 50 the stand has finally entered the self-thinning zone and mortality in the proceeding ten years would have increased to 39 SPH.

PCT to 500 SPH

- The stand does not reach the self-thinning line until age 50 and mortality between age 30 and 50 would only be 3 SPH.

A comparison of the estimated RDIs for the site index 30 and 24 simulations reveals a very similar story as did the site index 36 simulations described above. That is at the early thinning age (i.e. age 40 for site index 30 and age 50 for site index 24) a thinning may only be required for the densest stands and may safely be deferred until the middle thinning ages for the PCT to 1,100 simulations and to the late thinning age for the PCT to 800 simulations, while the PCT to 500 simulations would not require a commercial thinning at all to control stand density unless maximization of average tree size was an overriding consideration.

The average between tree spacing, based on square spacing, before and after each thinning and the relative spacing index, which shows the average spacing as a percentage of top height, are also presented in Tables 4-5 to 4-7. Before the thinnings the No PCT simulated stands for all site indexes were quite dense with a relative density index of 9-11%. For the PCT to 1,100 SPH

simulations the range was 10-16%, 11-18% for the PCT to 800 SPH simulations and 14-23% for the PCT to 500 SPH simulations. If Hummel's (1954) recommendation of 20% as an appropriate relative spacing is accepted then at the early commercial thinning age only the lightest thinnings would be required. However, the thinning intensity required to meet this goal quickly increased as the stands aged. Naturally the intensity of the thinning required to meet the 20% target would decline as the stand density prior to the commercial thinning was lowered. If, on the other hand, we take Wilson's (1944) recommendation of 25% as the appropriate relative spacing for intolerant conifers then the intensity of the would have to be increased or, in some cases, the age of the thinning reduced.

The ratio of top height to average DBH before and after each thinning are also presented in Tables 4-5 to 4-7. If we follow the recommendations of the Silviculture Manual to thin to a ratio of 75 then a heavy thinning would be required for the No PCT and PCT to 1,100 SPH simulations, while a light thin would be needed for the PCT to 800 SPH simulations and no thinnings would be required for the PCT to 500 SPH simulations.

Table 4-8 presents the merchantable volume per hectare harvested by the simulated commercial thinnings and the average volume per merchantable tree harvested. As discussed in Section 5, these two factors are important determinants of average harvesting costs. The simulations show:

- Thinning volume and average volume per merchantable tree increased with an increase in the thinning intensity. Naturally as more trees are cut the greater will be the volume harvested. In addition, because we are thinning from below, as thinning intensity increase we would be taking larger and larger trees which would increase the average size of the trees harvested.
- Thinning volume, for a given thinning intensity, increased the older the stand was at the time of the thinning. The exceptions to this rule were the lightest thinnings, i.e. thinning to 600 and 800 SPH. As the stand ages the mortality would occur in the smaller trees which because we are thinning from below would reduce the number of trees harvested by the lightest thinnings.
- Thinning volume declined the lower the initial stand density, in SPH, was prior to the commercial thinning. For stands which had been PCT a greater portion of the stand volume would be concentrated on the leave trees which results in a smaller volume being available for the thinning harvest.
- Average volume per merchantable tree harvested increased with stand age.

4.4 Changes in the Final Harvests

For each growing regime and thinning intensity the thinned and unthinned stands had their growth simulated to various final harvest ages and the merchantable volume at each final harvest age determined. Figures 4-1 to 4-36 and the tables in Appendix A present the total or cumulative volume received from the thinnings and from the final harvest at the different final harvest ages simulated for each growing regime.

The simulations suggest that the effect of the thinnings on cumulative volume depends greatly on the rotation age chosen. If one is prepared for long rotation ages (i.e. for 100 or more years) then the volume response is maximized for thinnings in the range of 300 to 400 leave trees per hectare. However, if shorter rotation ages are chosen then the lighter thinnings produce the greatest volume response. The reason for the lighter thinnings having the better short term volume response while the heavier thinnings have the better long term response is explained by the effect the thinnings have on growth as discussed below. As expected, the volume response declines for the lower site index simulations. The light thinnings also had little effect on other possible stand management goals such as increasing piece size, increasing wood values, or minimising final harvest

TABLE 4-8
COMMERCIAL THINNING HARVEST
MERCHANTABLE VOLUME PER HECTARE

Thinning Intensity	Volume				Volume/Merchantable Tree			
	No PCT	PCT to 1,100 SPH	PCT to 800 SPH	PCT to 500 SPH	No PCT	PCT to 1,100 SPH	PCT to 800 SPH	PCT to 500 SPH
(leave trees	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/ha)	(m^3/tree)	(m^3/tree)	(m^3/tree)	(m^3/tree)
			Site Index 36, Thinned at Age 30					
200	177	156	130	83	0.16	0.21	0.24	0.30
300	148	123	95	-	0.15	0.19	0.22	-
400	122	94	64	-	0.14	0.17	0.19	-
600	80	-	-	-	0.12	-	-	-
			Site Index 36, Thinned at Age 40					
200	282	263	232	164	0.26	0.35	0.43	0.59
300	221	195	159	-	0.22	0.30	0.36	-
400	170	140	101	-	0.19	0.26	0.30	-
600	96	61	-	-	0.14	0.18	-	-
800	50	-	-	-	0.10	-	-	-
			Site Index 36, Thinned at Age 50					
200	353	339	311	235	0.37	0.48	0.61	0.85
300	253	233	198	-	0.29	0.39	0.48	-
400	178	154	114	-	0.23	0.31	0.36	-
600	86	58	-	-	0.15	0.19	-	-
800	39	-	-	-	0.11	-	-	-
			Site Index 30, Thinned at Age 40					
200	215	194	164	108	0.20	0.26	0.30	0.39
300	178	151	119	-	0.18	0.23	0.27	-
400	145	114	80	-	0.16	0.21	0.23	-
600	92	-	-	-	0.13	-	-	-
			Site Index 30, Thinned at Age 50					
200	286	263	233	164	0.26	0.35	0.43	0.59
300	225	197	162	-	0.23	0.30	0.36	-
400	174	142	104	-	0.20	0.26	0.30	-
600	101	63	-	-	0.15	0.18	-	-
800	53	-	-	-	0.11	-	-	-
			Site Index 30, Thinned at Age 60					
200	334	311	284	210	0.33	0.43	0.53	0.76
300	249	222	189	-	0.27	0.35	0.43	-
400	182	152	115	-	0.23	0.29	0.34	-
600	95	62	-	-	0.16	0.19	-	-
800	46	-	-	-	0.11	-	-	-
			Site Index 24, Thinned at Age 50					
200	203	178	151	97	0.17	0.23	0.28	0.35
300	169	139	110	-	0.16	0.21	0.24	-
400	140	106	75	-	0.14	0.19	0.21	-
600	93	-	-	-	0.12	-	-	-
			Site Index 24, Thinned at Age 60					
200	247	223	194	130	0.21	0.29	0.35	0.47
300	202	171	139	-	0.18	0.26	0.31	-
400	162	127	93	-	0.16	0.23	0.27	-
600	100	58	-	-	0.13	0.16	-	-
800	58	-	-	-	0.10	-	-	-
			Site Index 24, Thinned at Age 70					
200	283	259	230	159	0.25	0.34	0.42	0.57
300	223	193	161	-	0.21	0.29	0.36	-
400	174	139	103	-	0.18	0.25	0.30	-
600	102	61	-	-	0.14	0.17	-	-

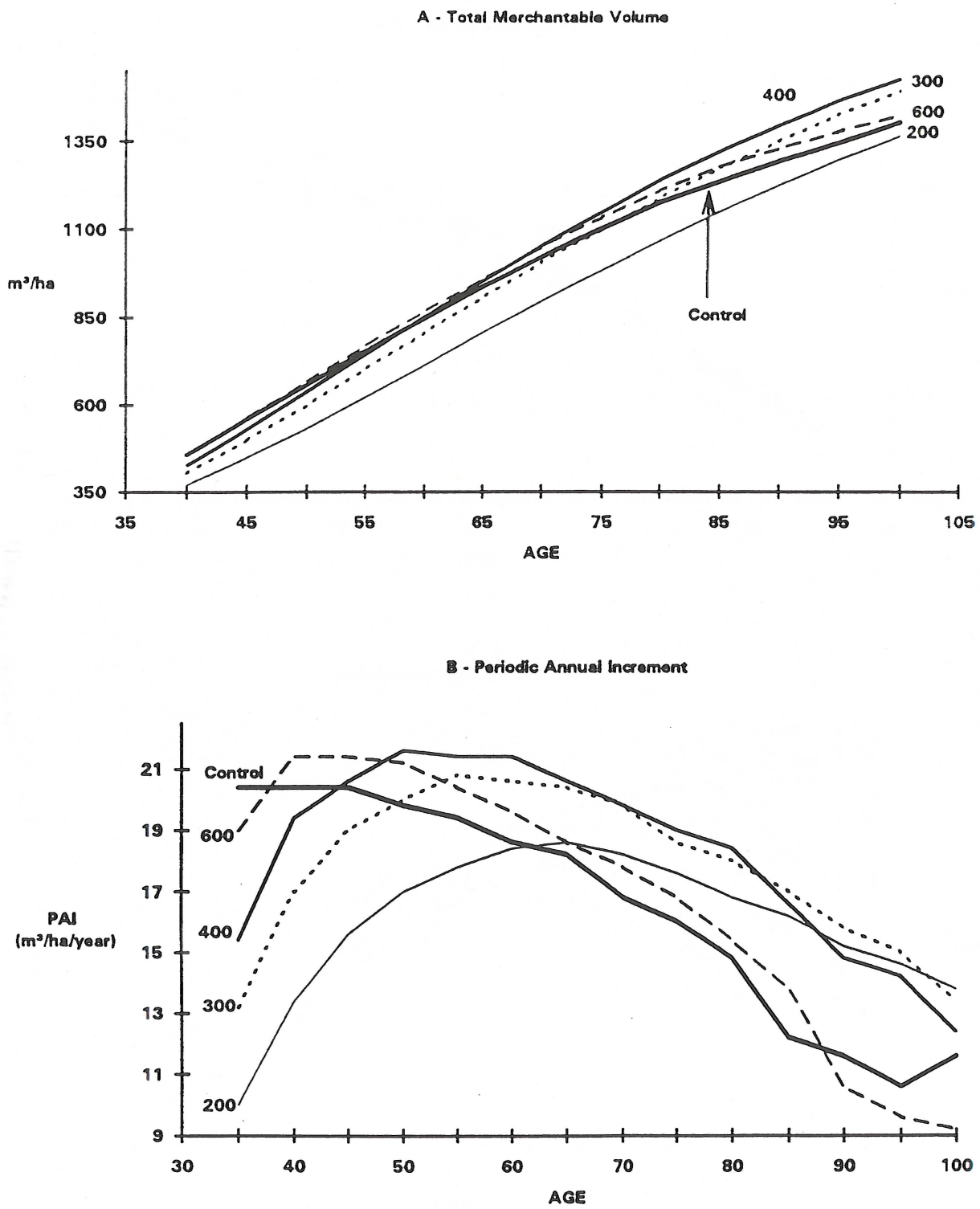


FIGURE 4-1 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 30

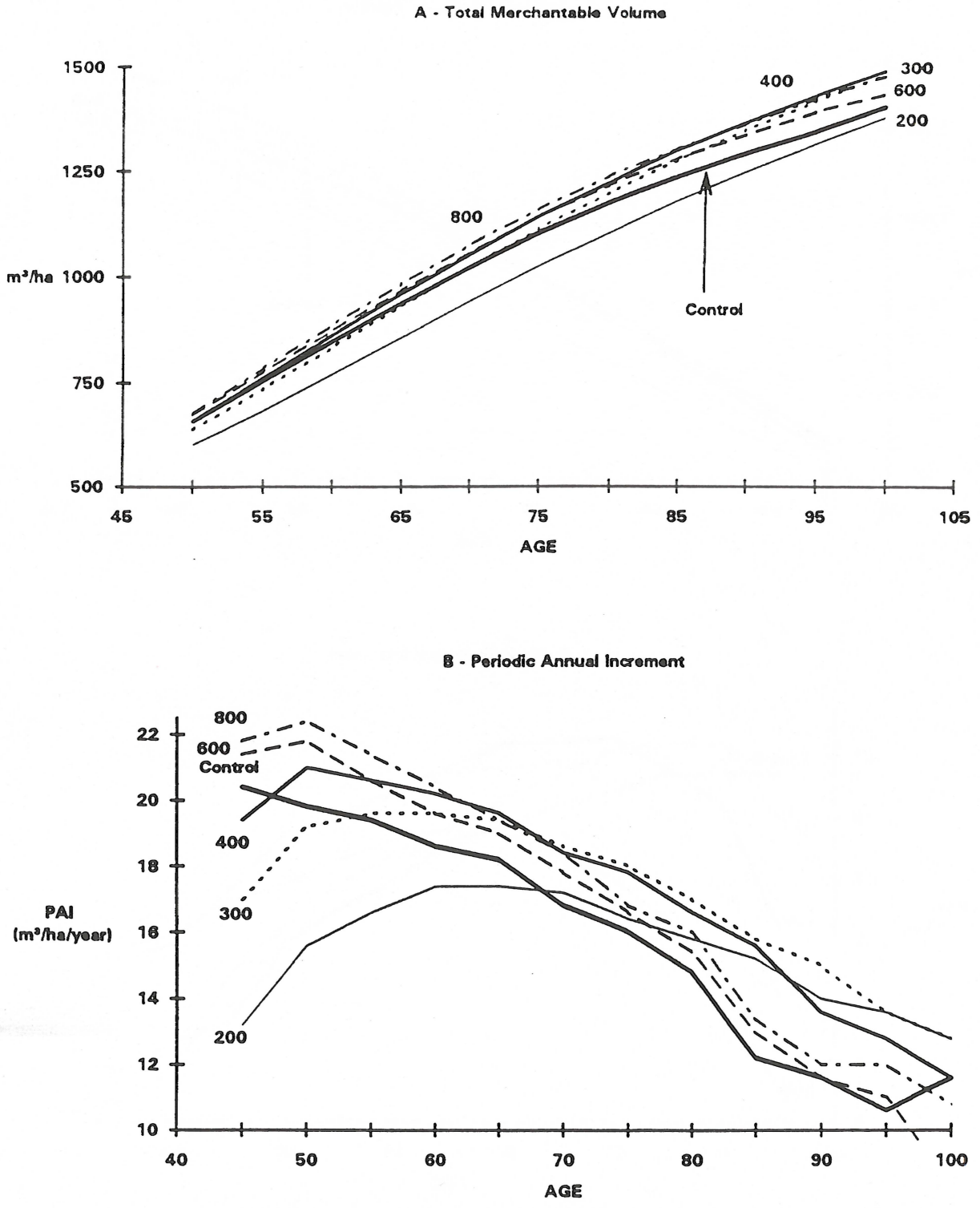


FIGURE 4-2 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 40

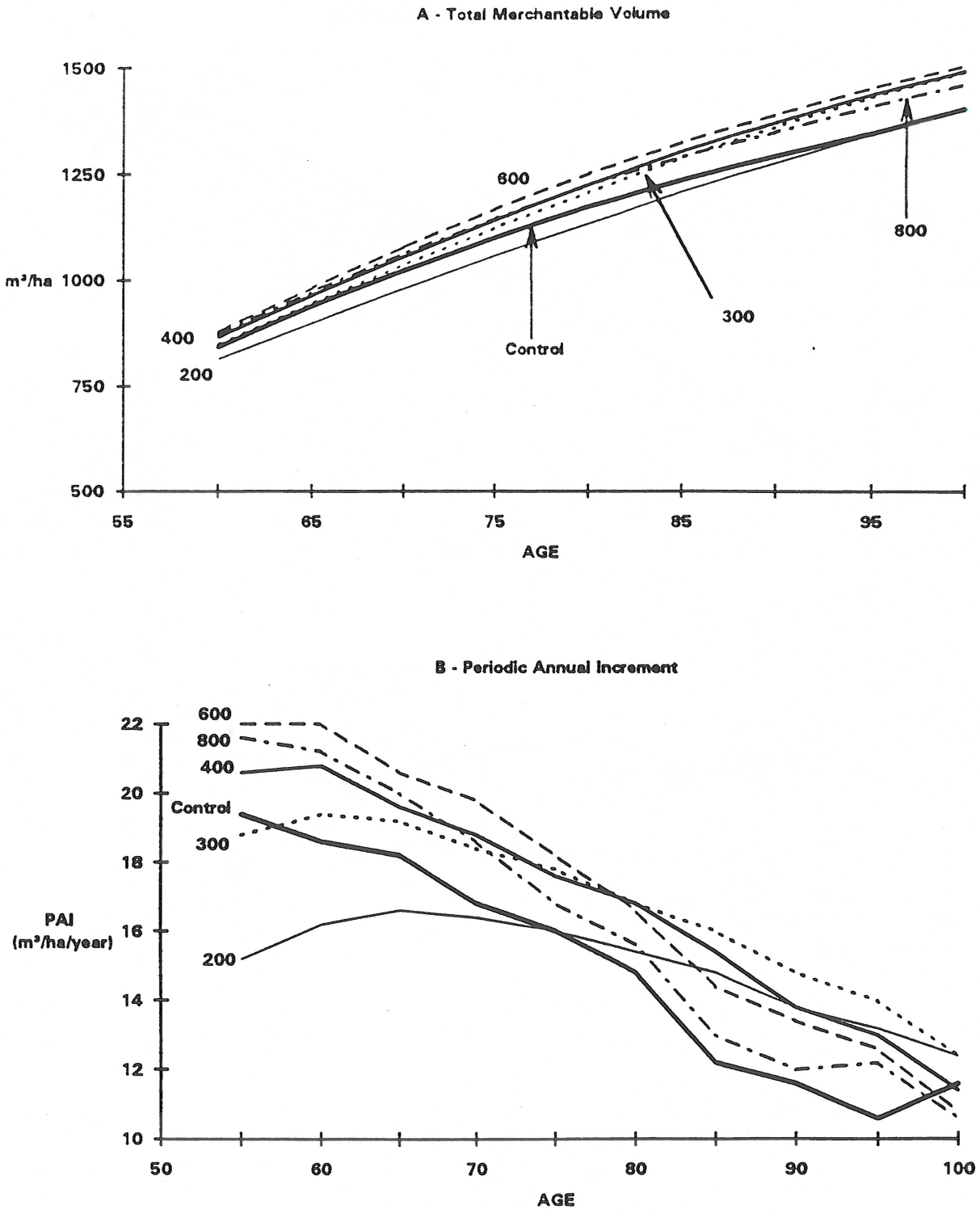


FIGURE 4-3 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 50

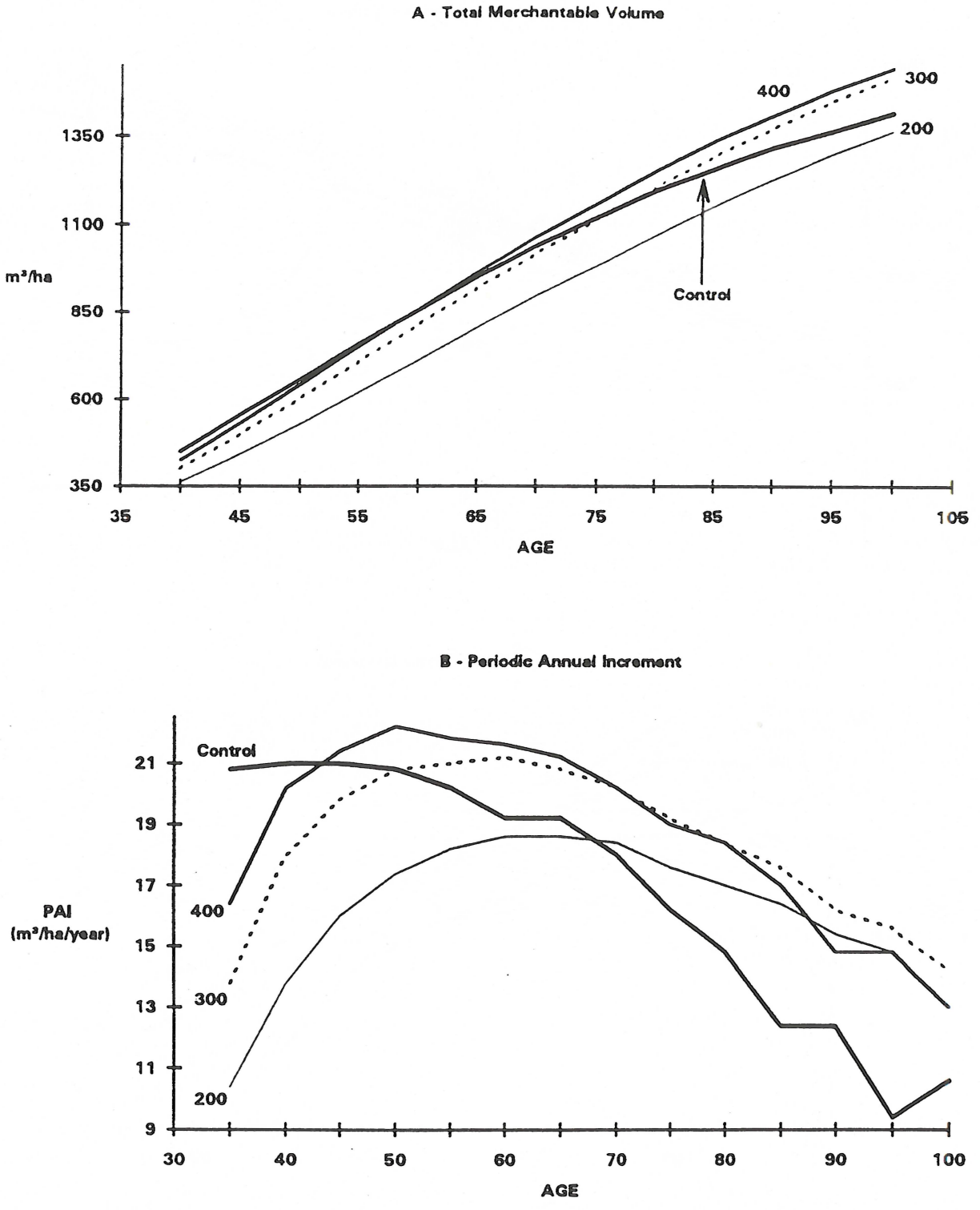
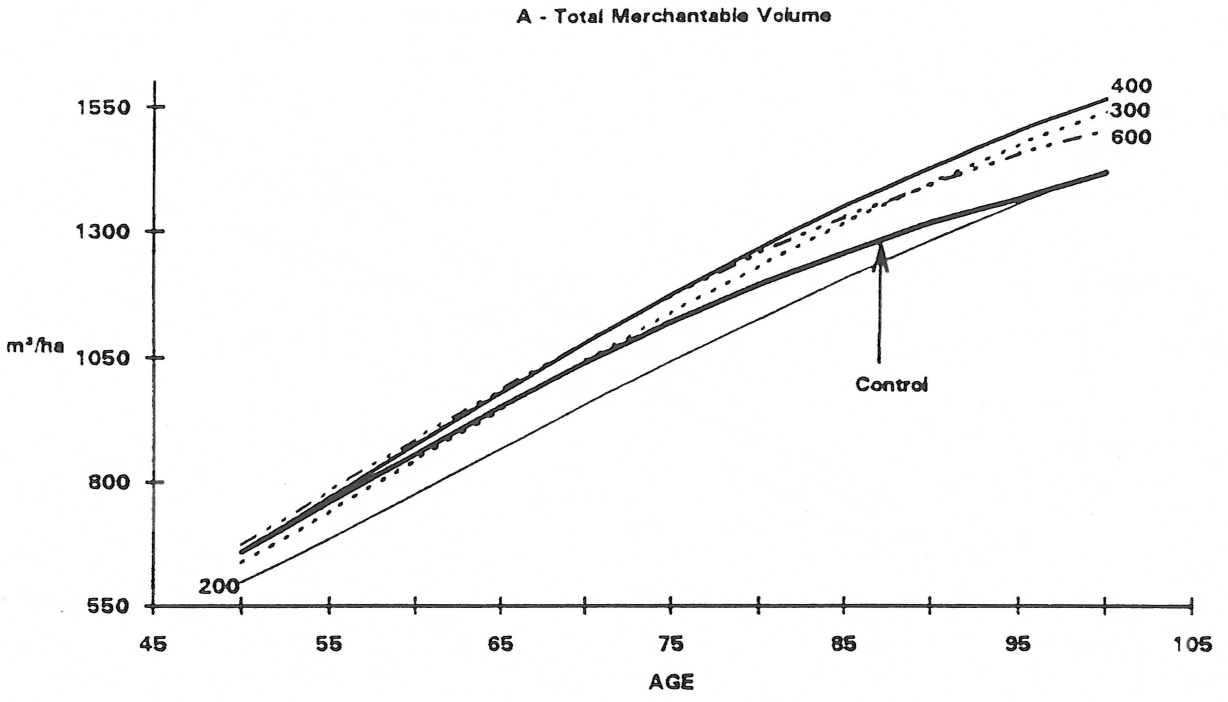


FIGURE 4-4 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 30



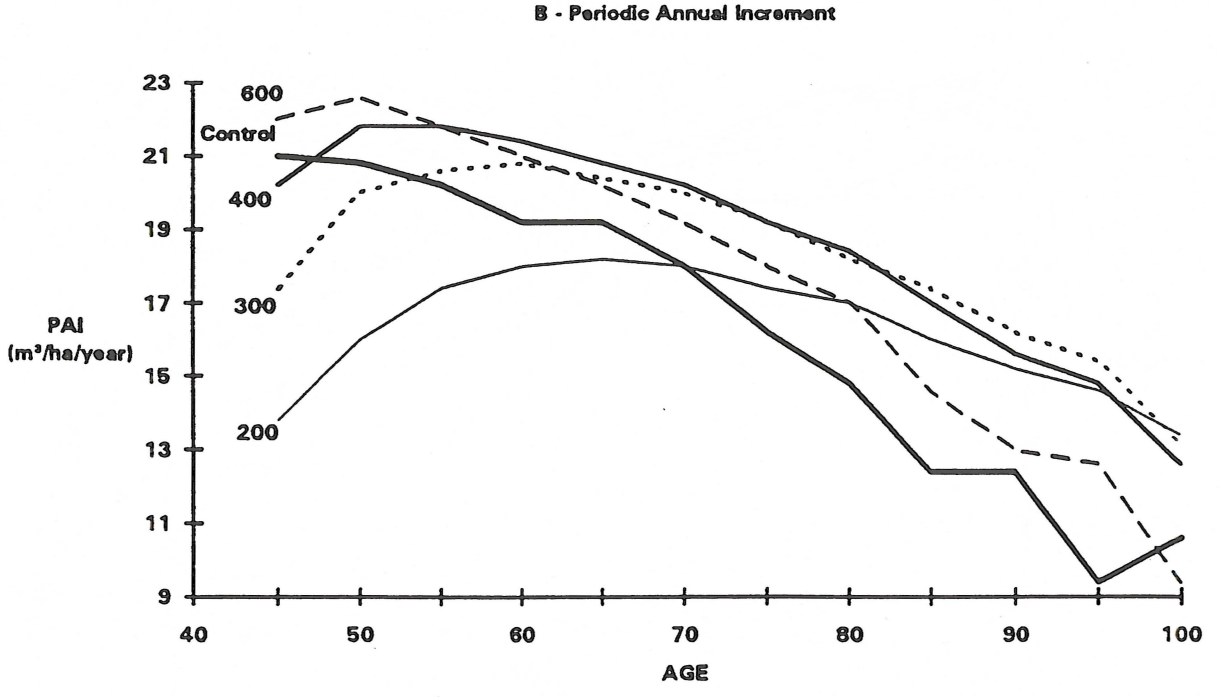


FIGURE 4-5 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 40

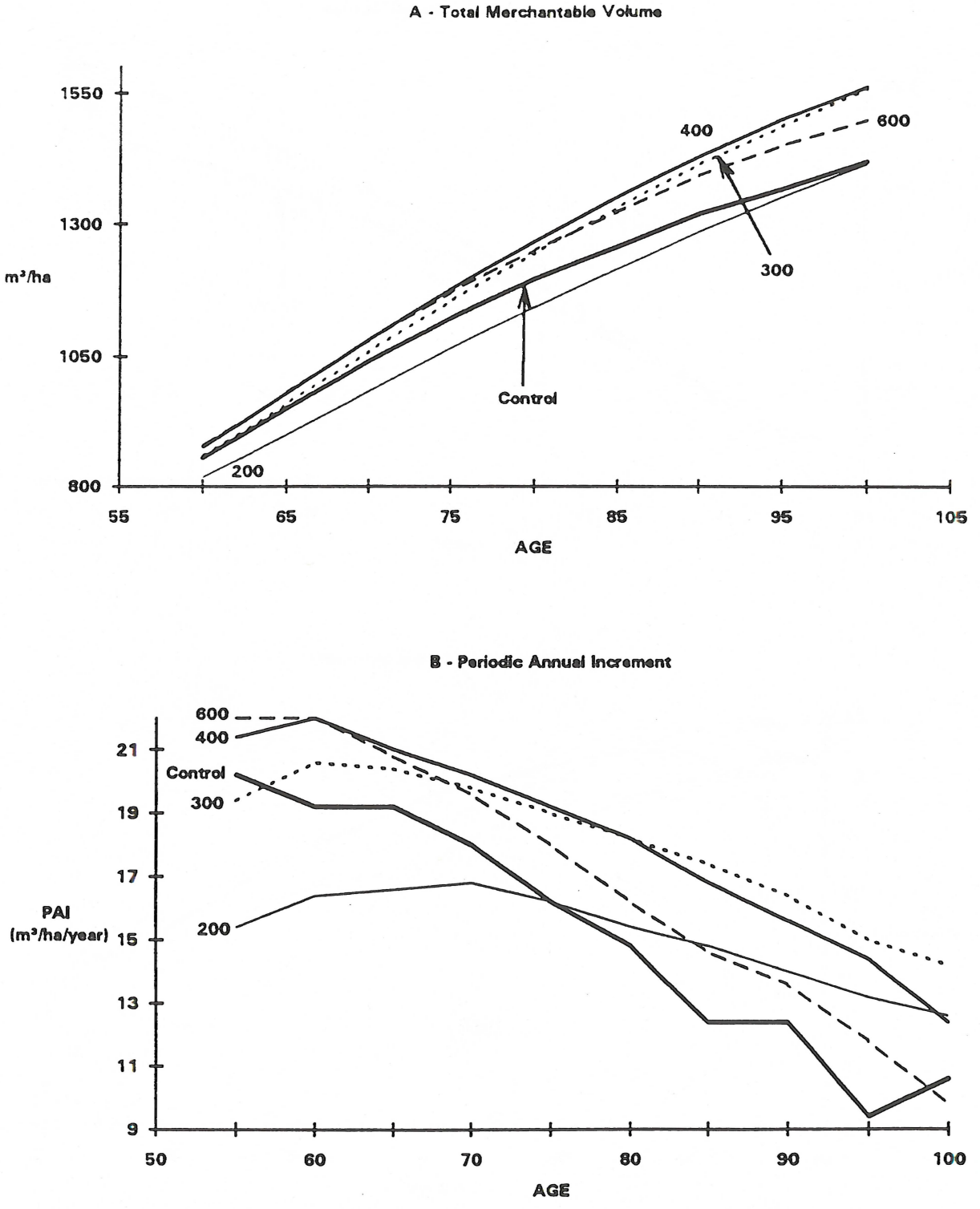


FIGURE 4-6 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 50

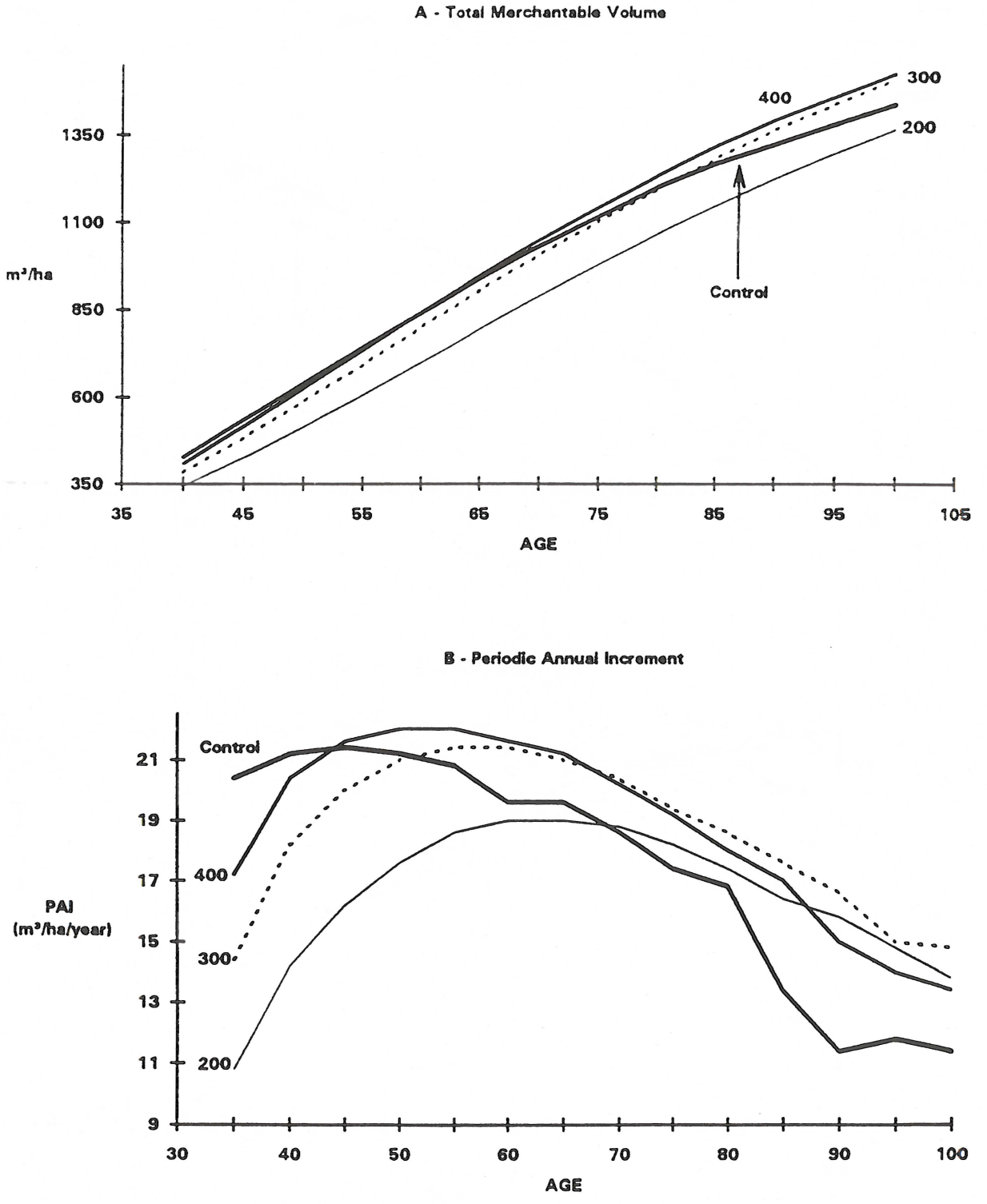
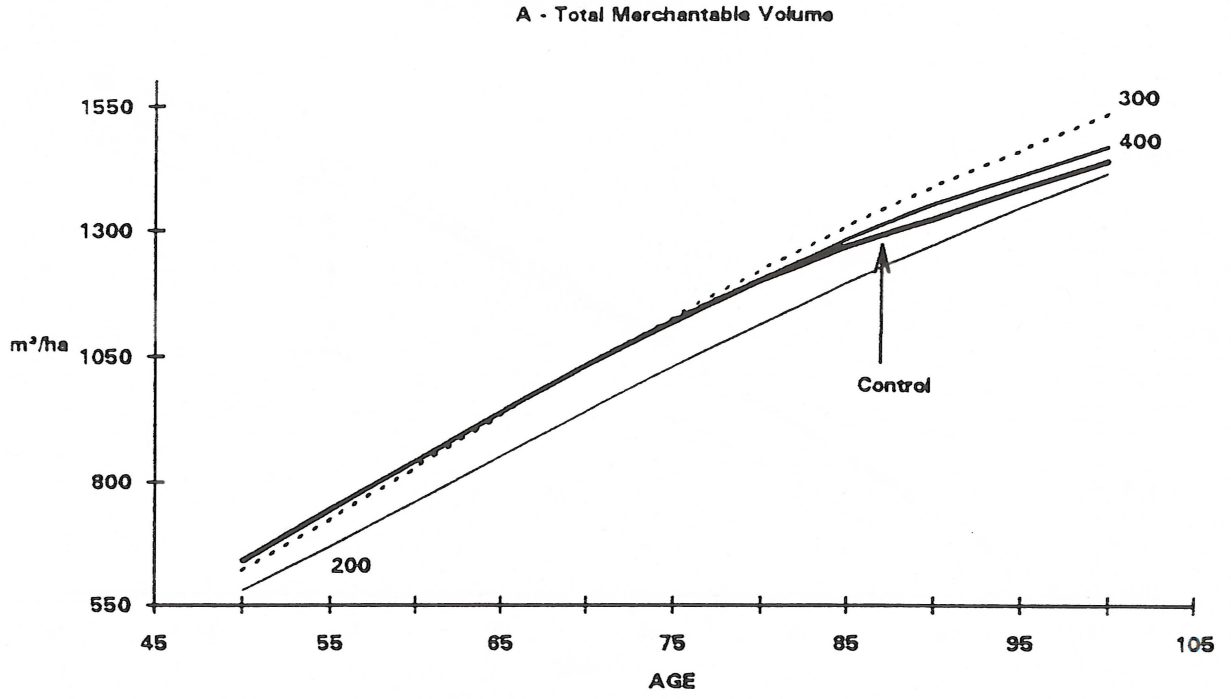


FIGURE 4-7 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 30



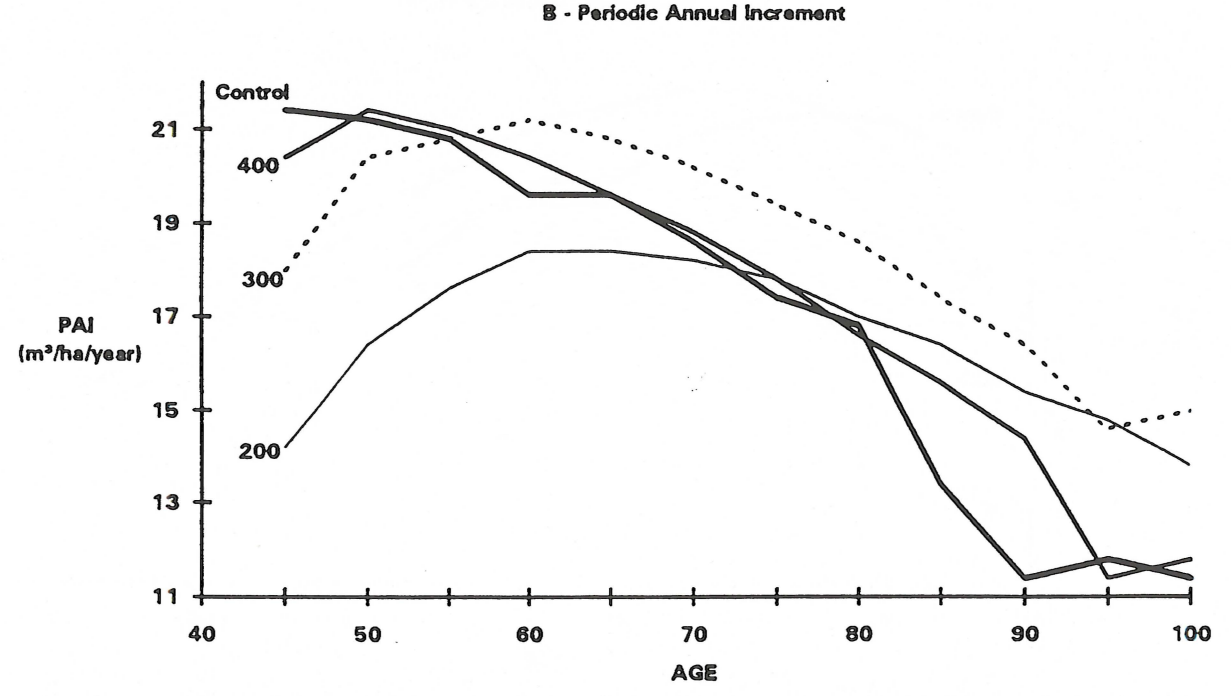


FIGURE 4-8 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 40

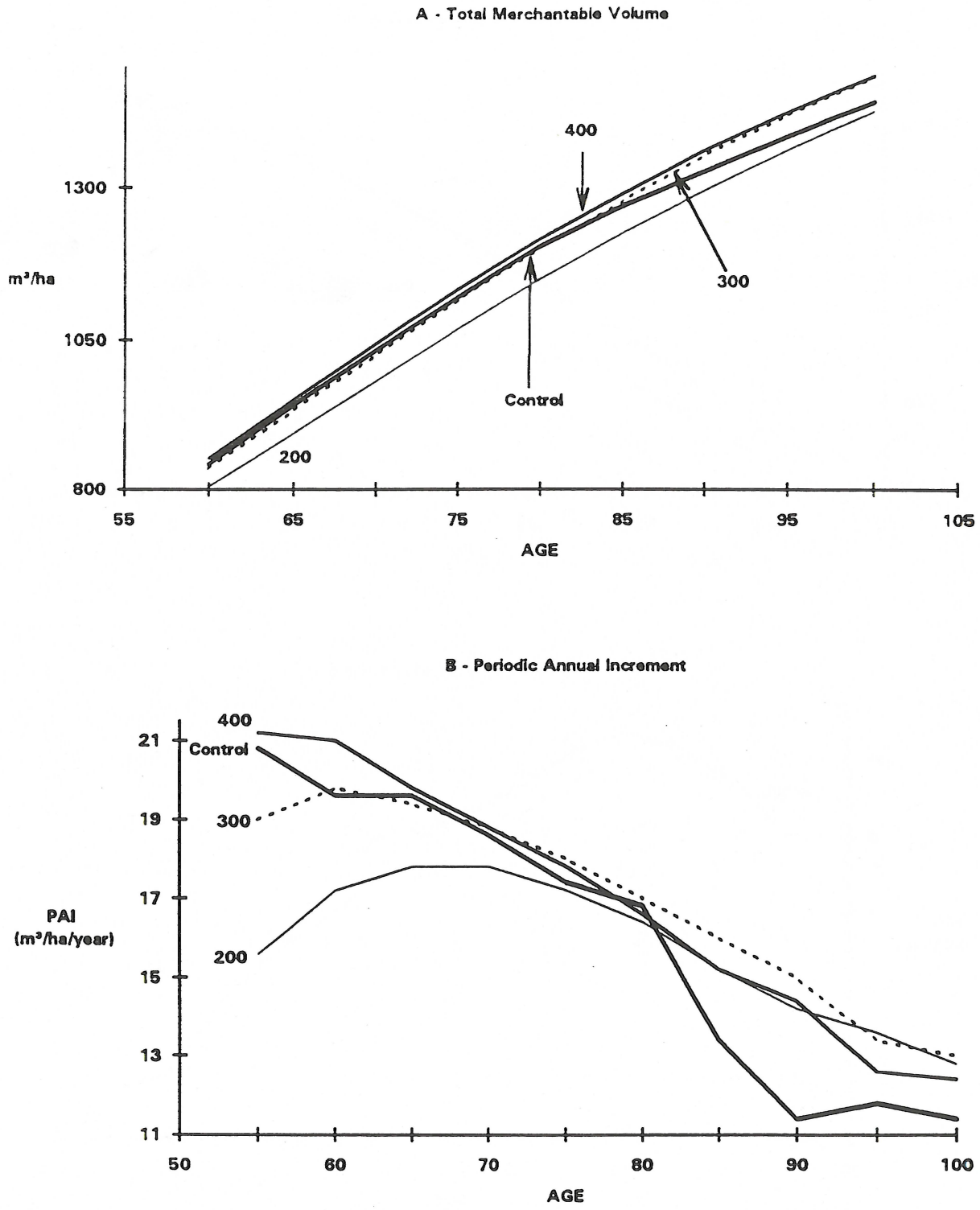


FIGURE 4-9 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 50

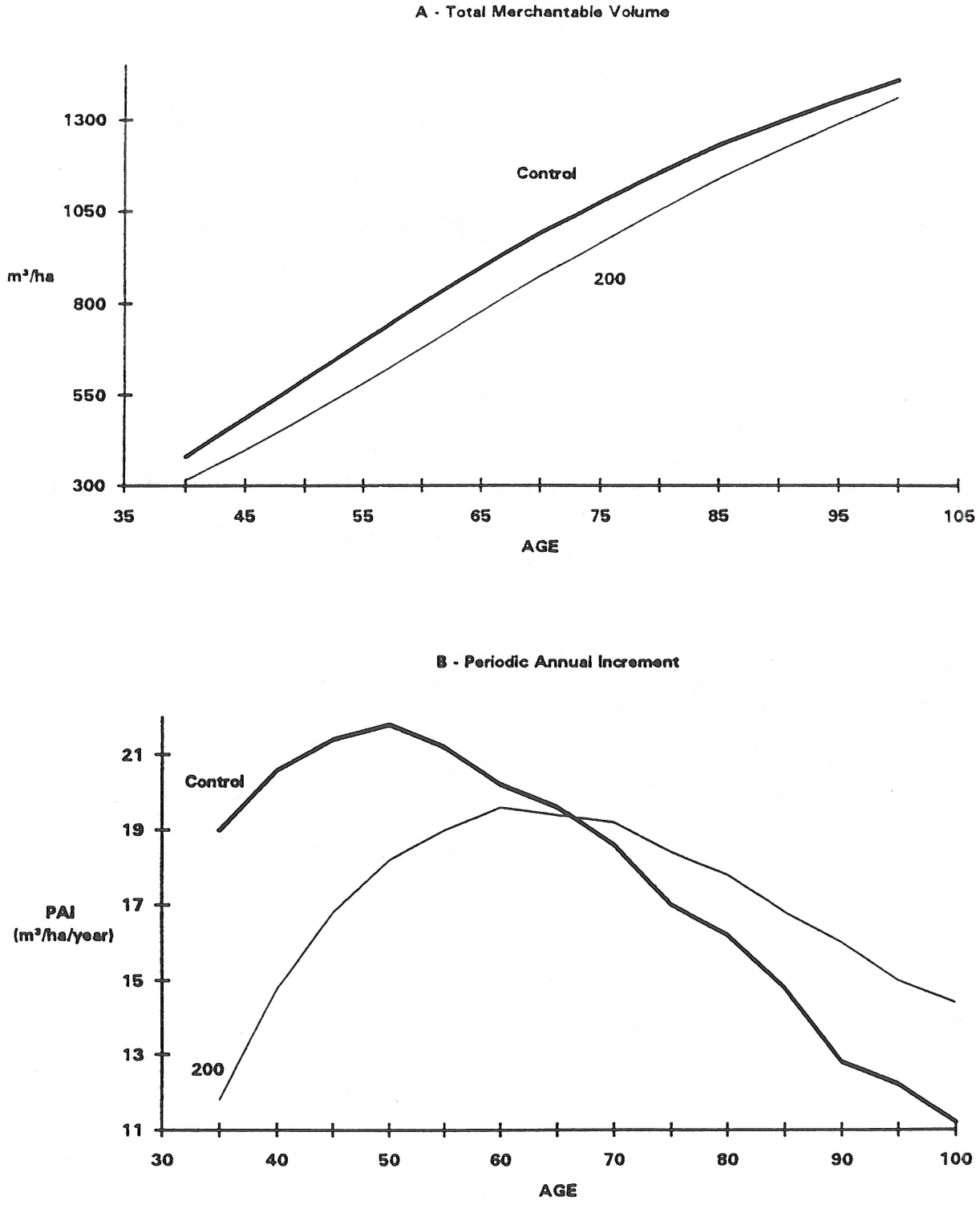


FIGURE 4-10 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 30

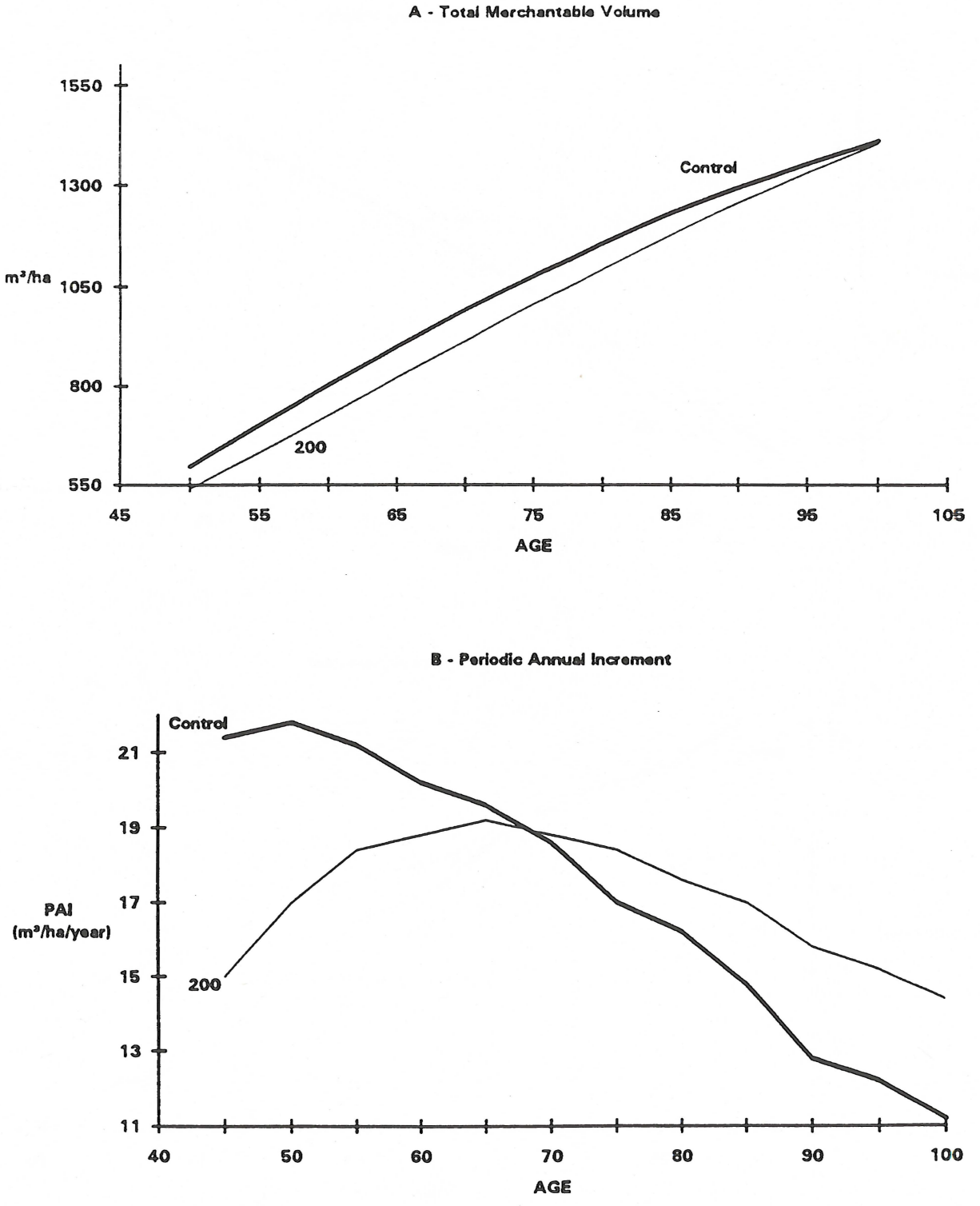
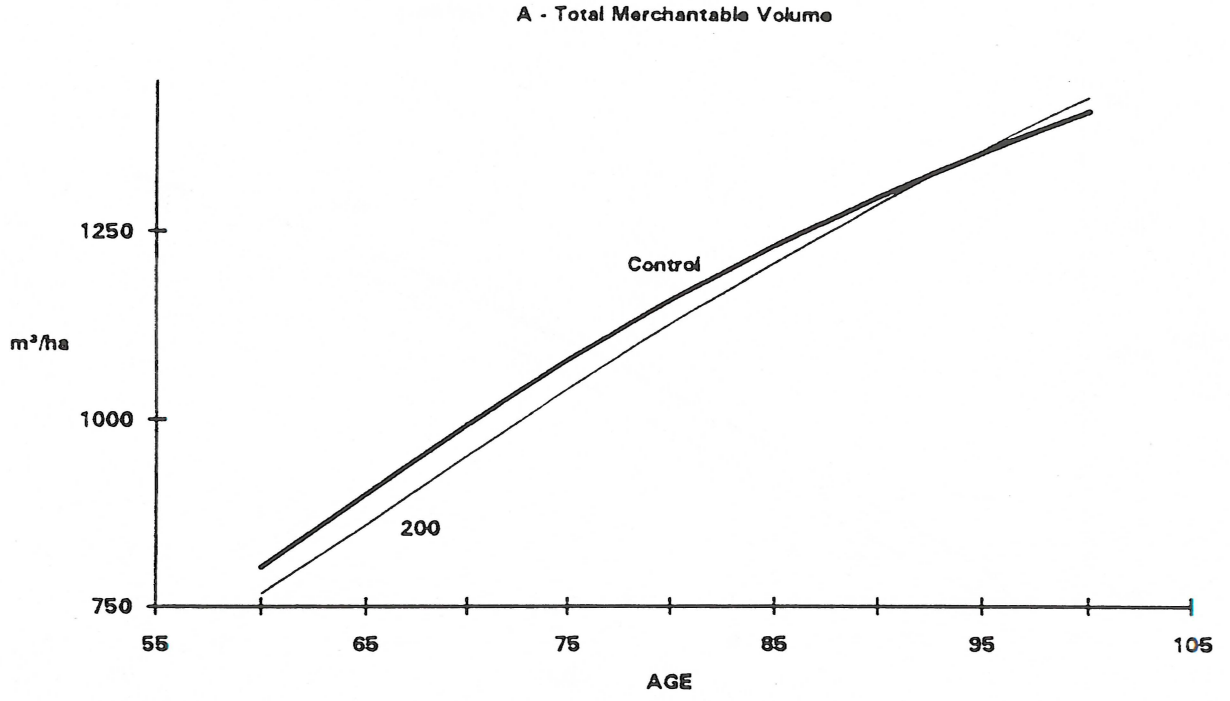


FIGURE 4-11 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 40



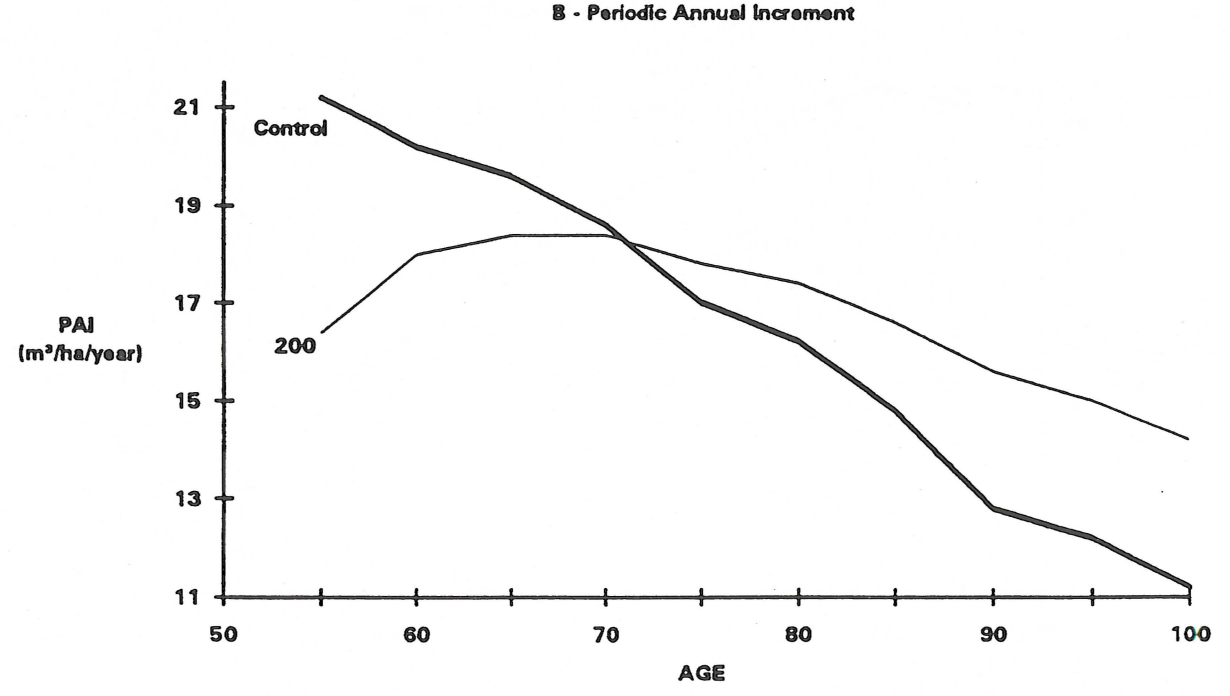


FIGURE 4-12 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 36, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 50

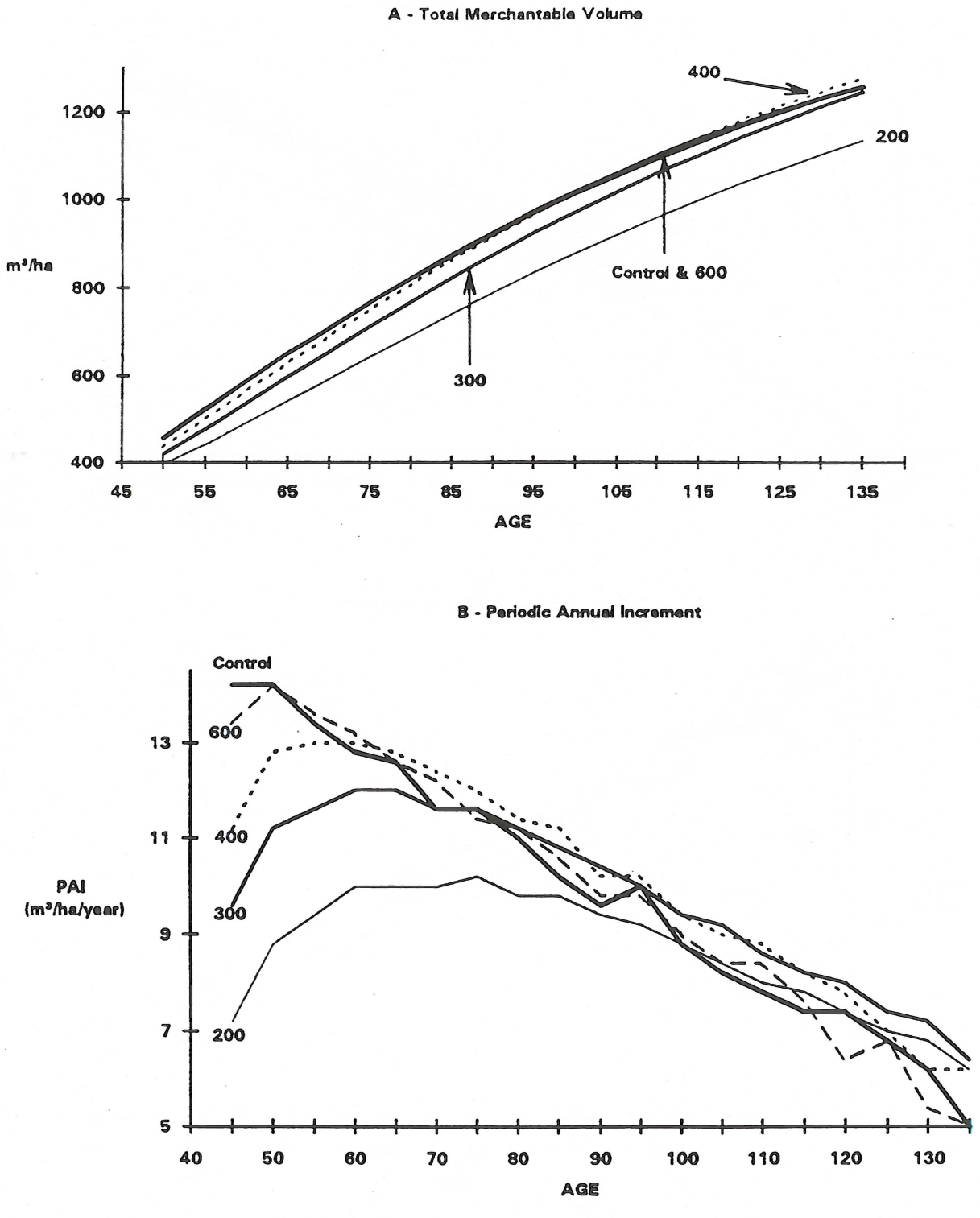


FIGURE 4-13 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 40

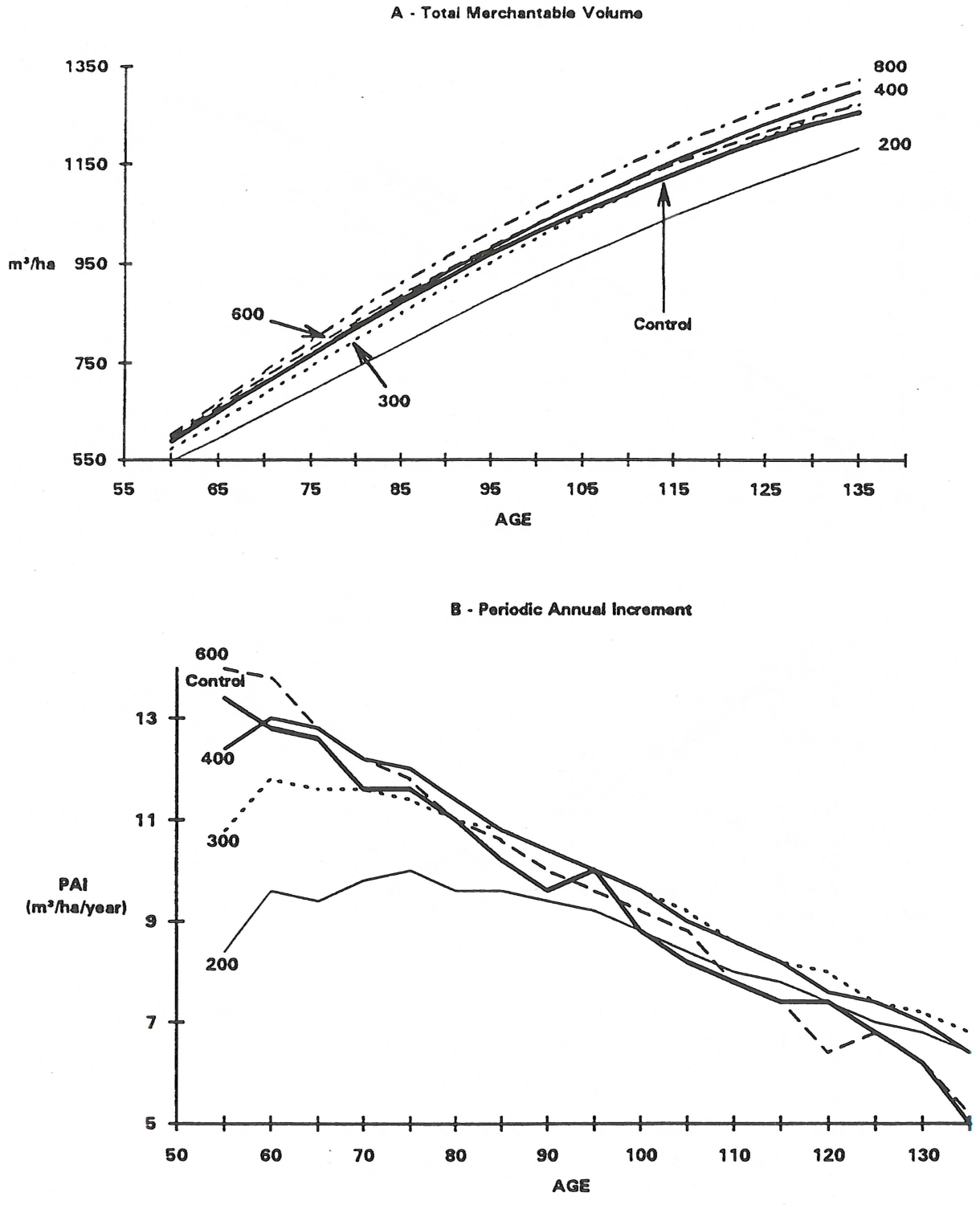


FIGURE 4-14 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 50

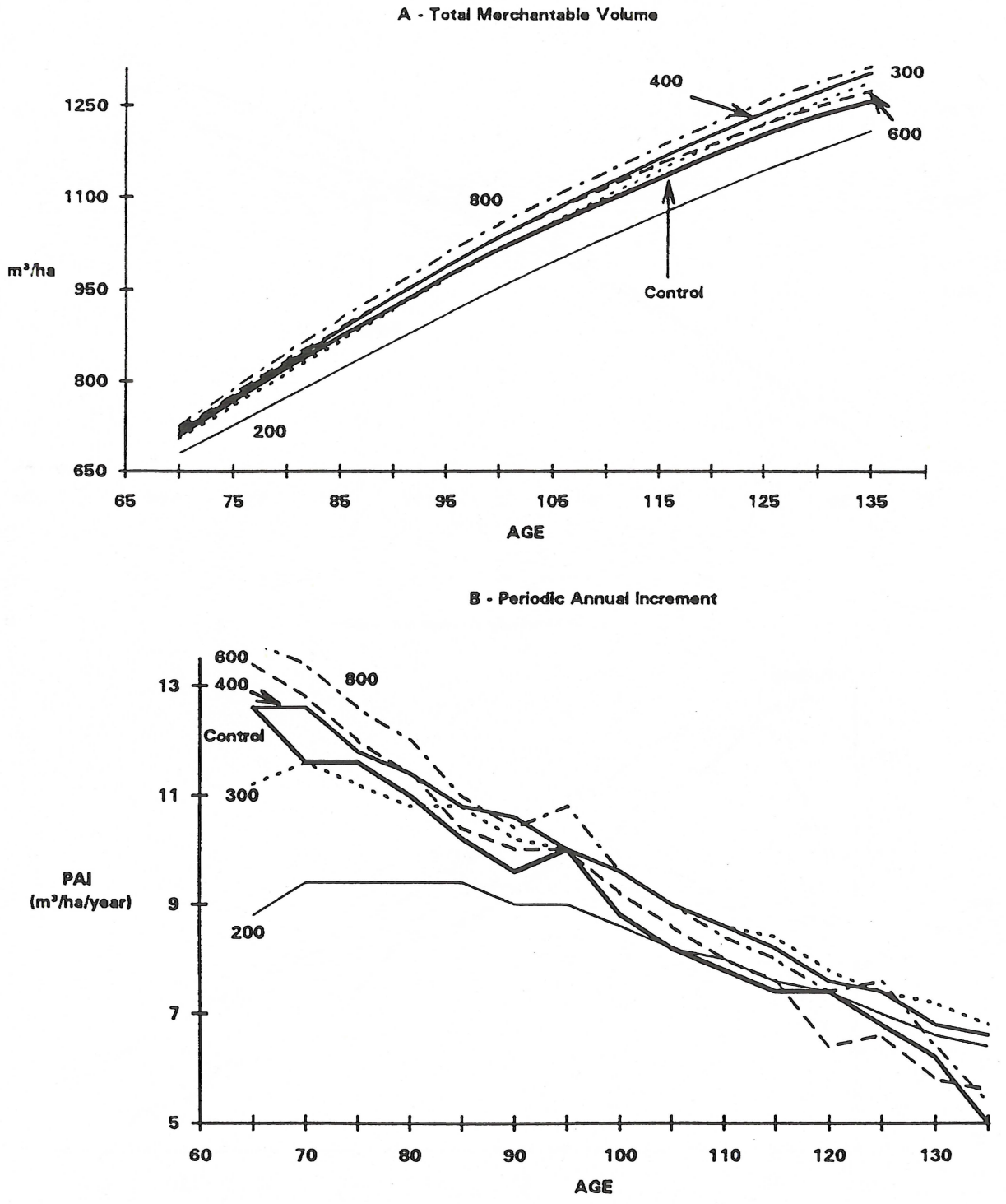


FIGURE 4-15 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 60

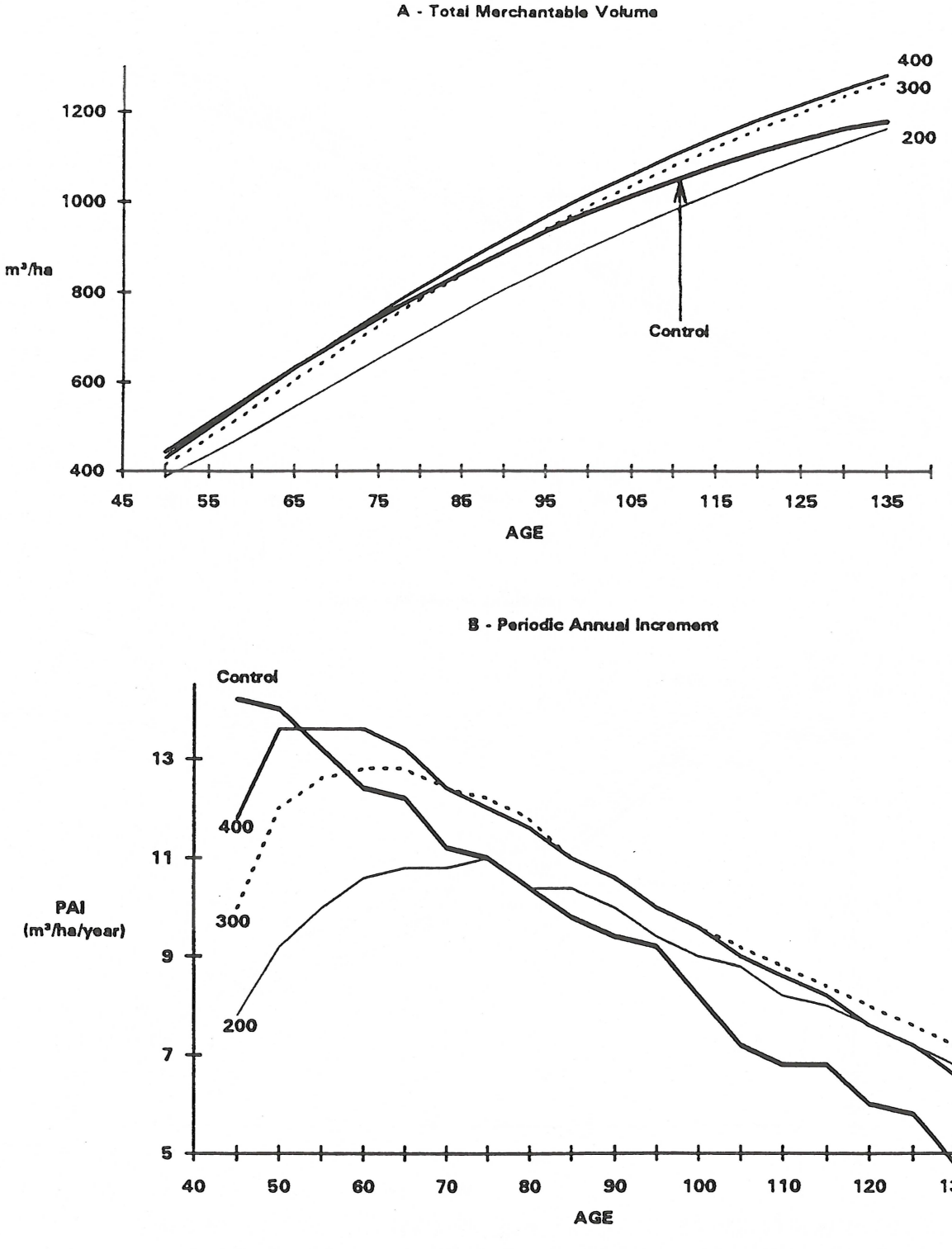
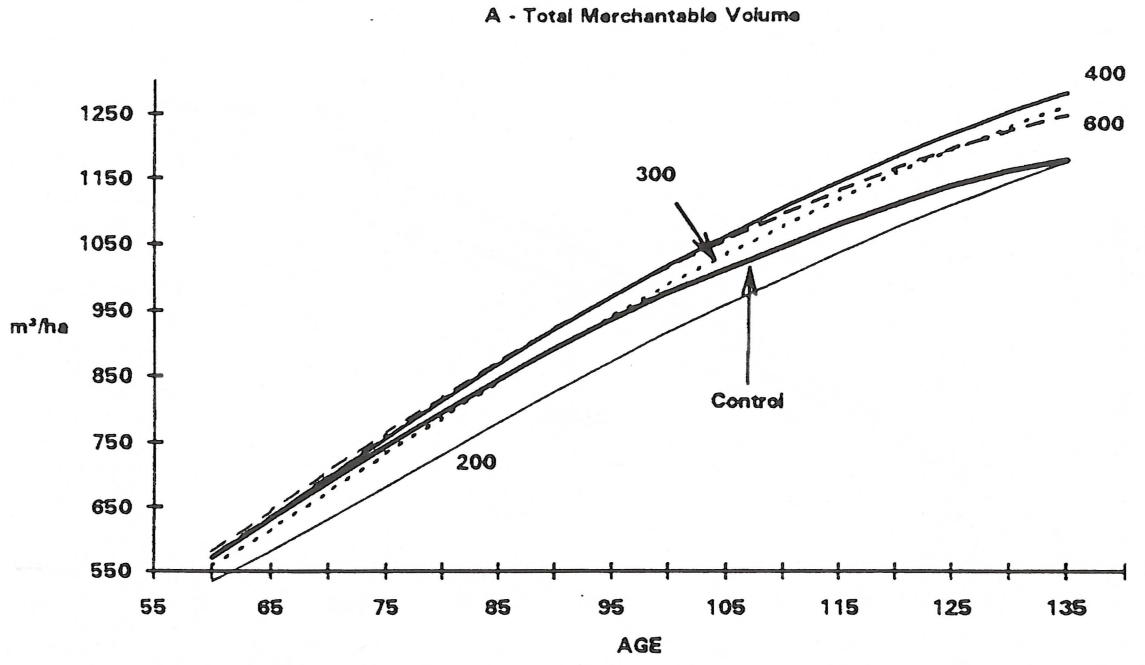


FIGURE 4-16 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 40



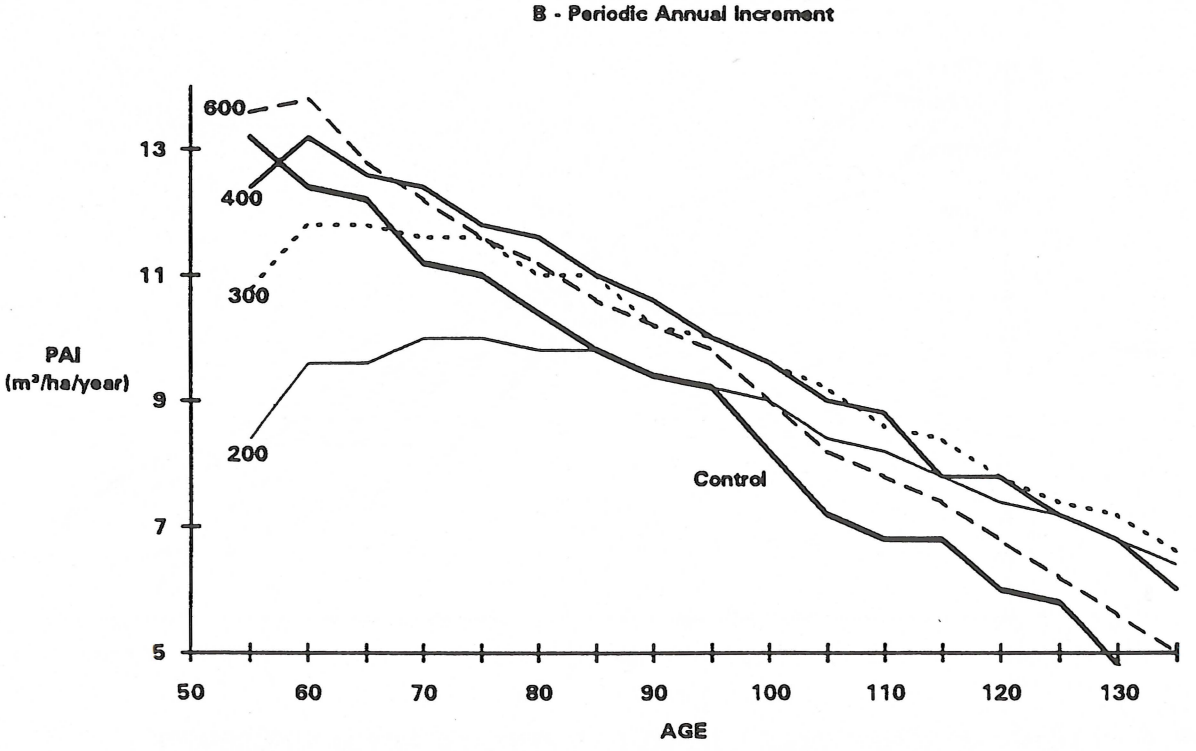


FIGURE 4-17 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 50

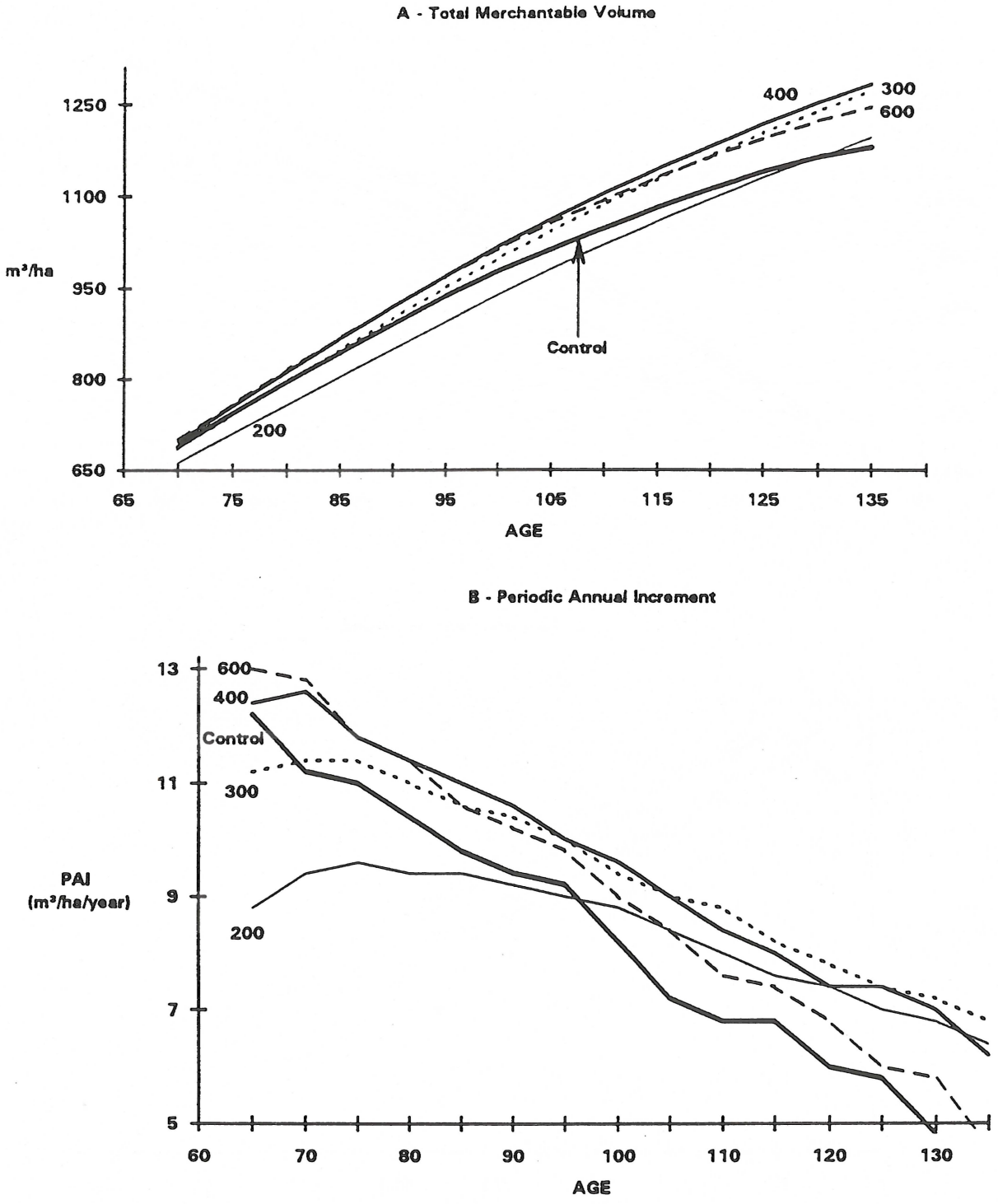
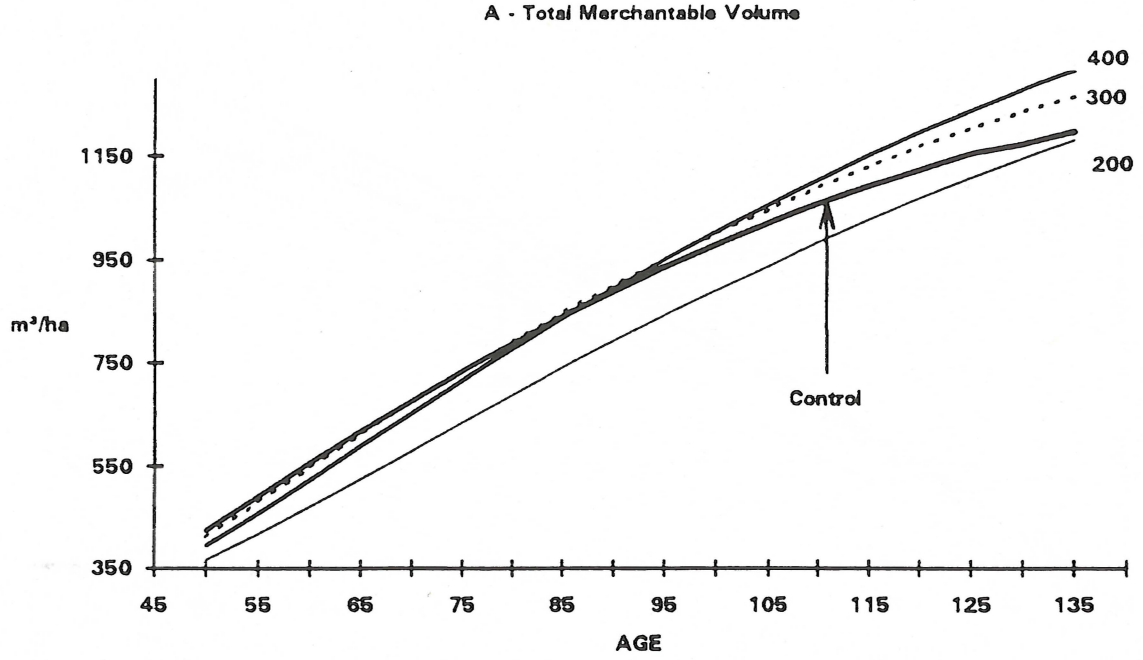


FIGURE 4-18 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 60



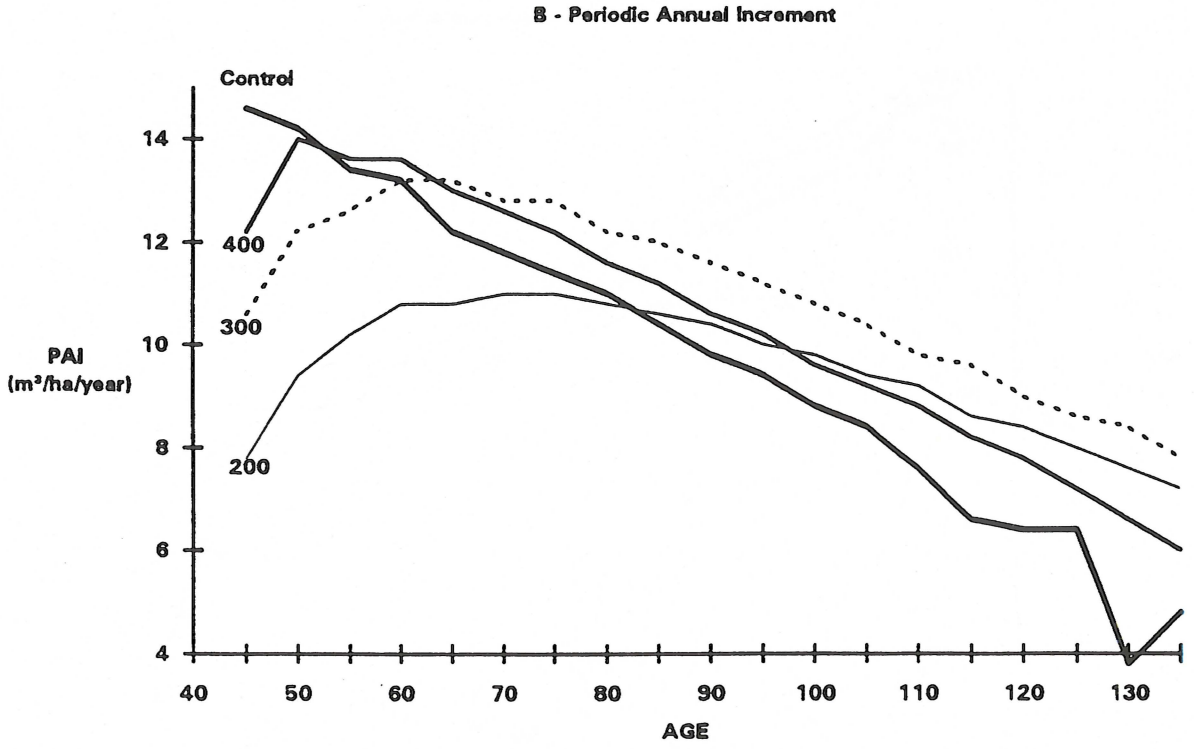


FIGURE 4-19 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 40

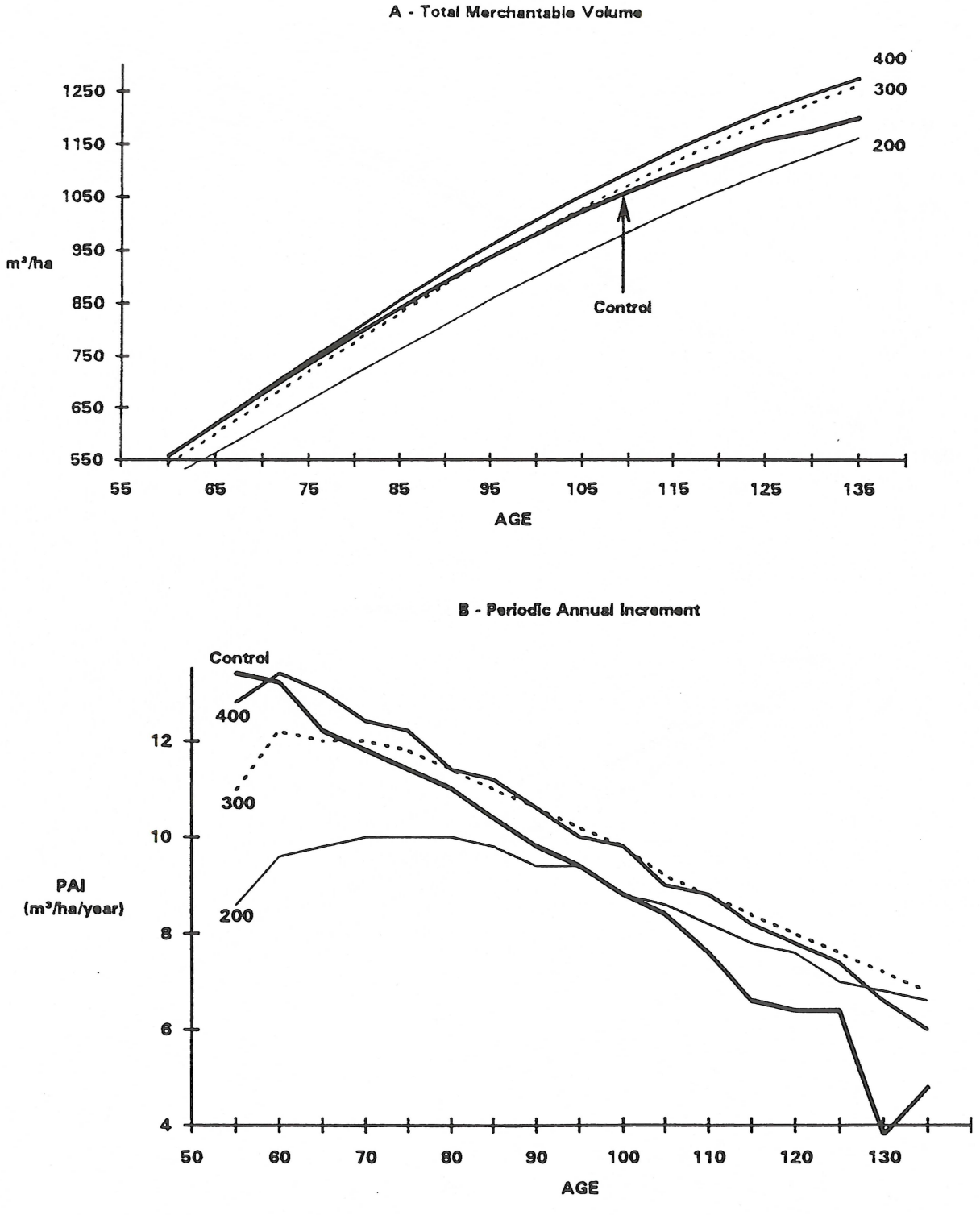


FIGURE 4-20 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 50

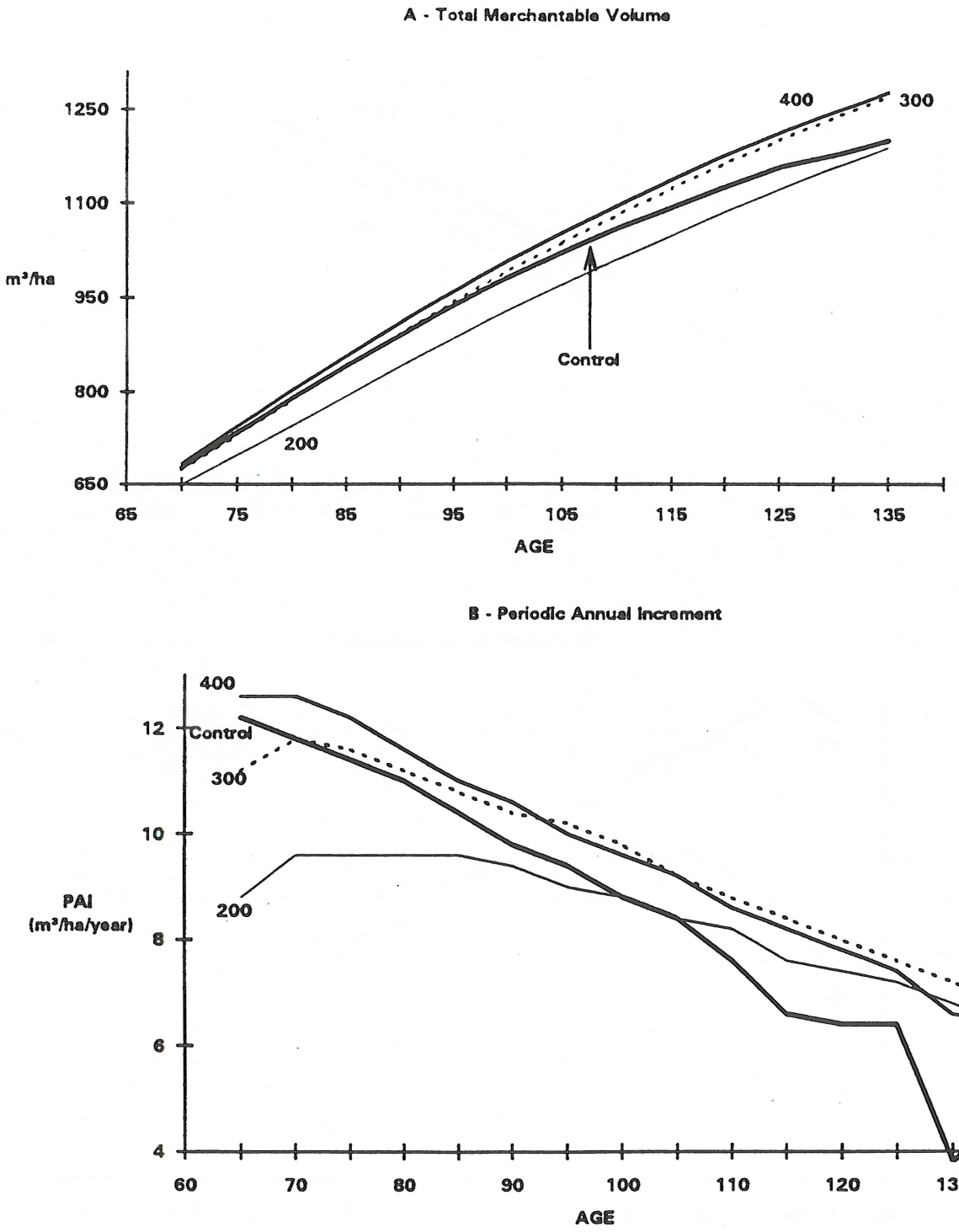
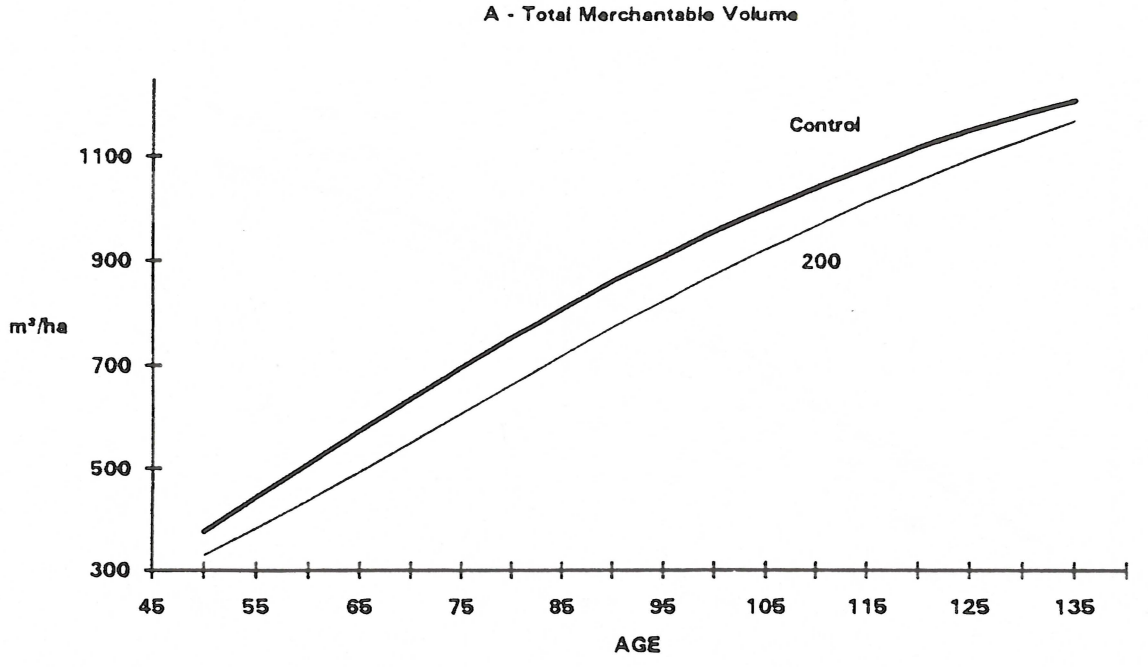


FIGURE 4-21 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 60



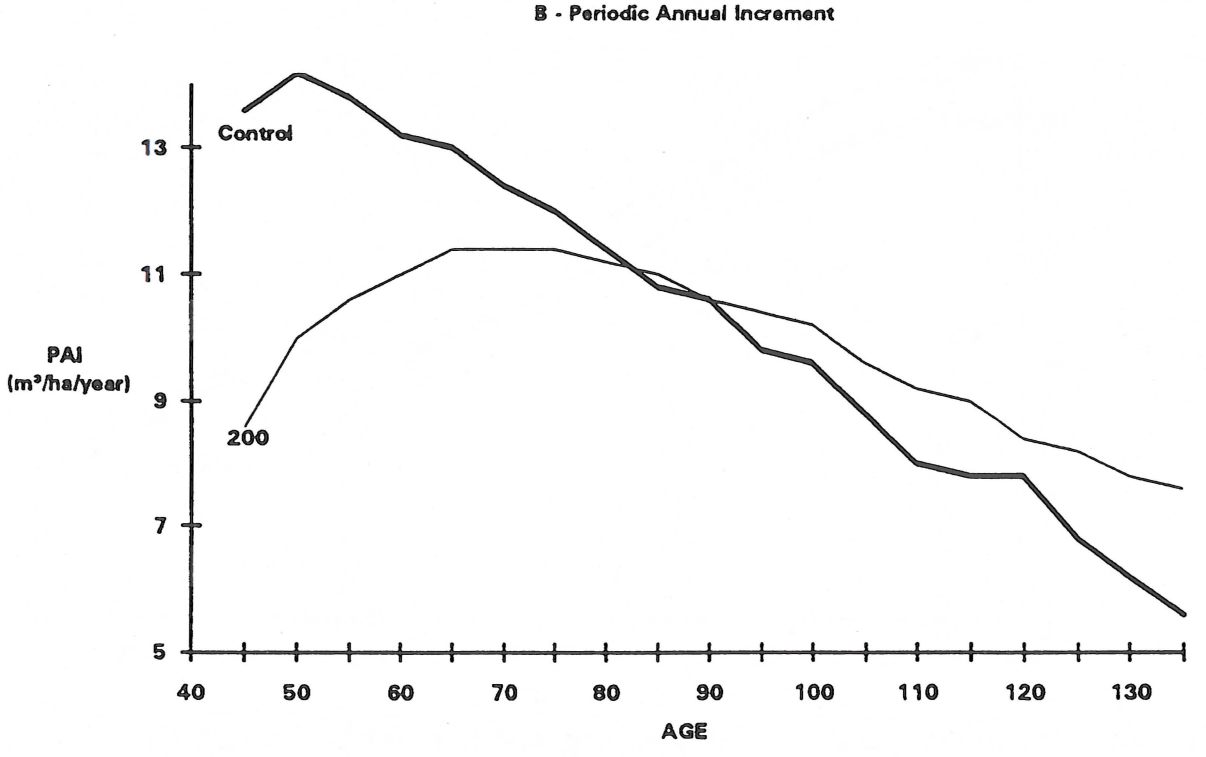


FIGURE 4-22 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 40

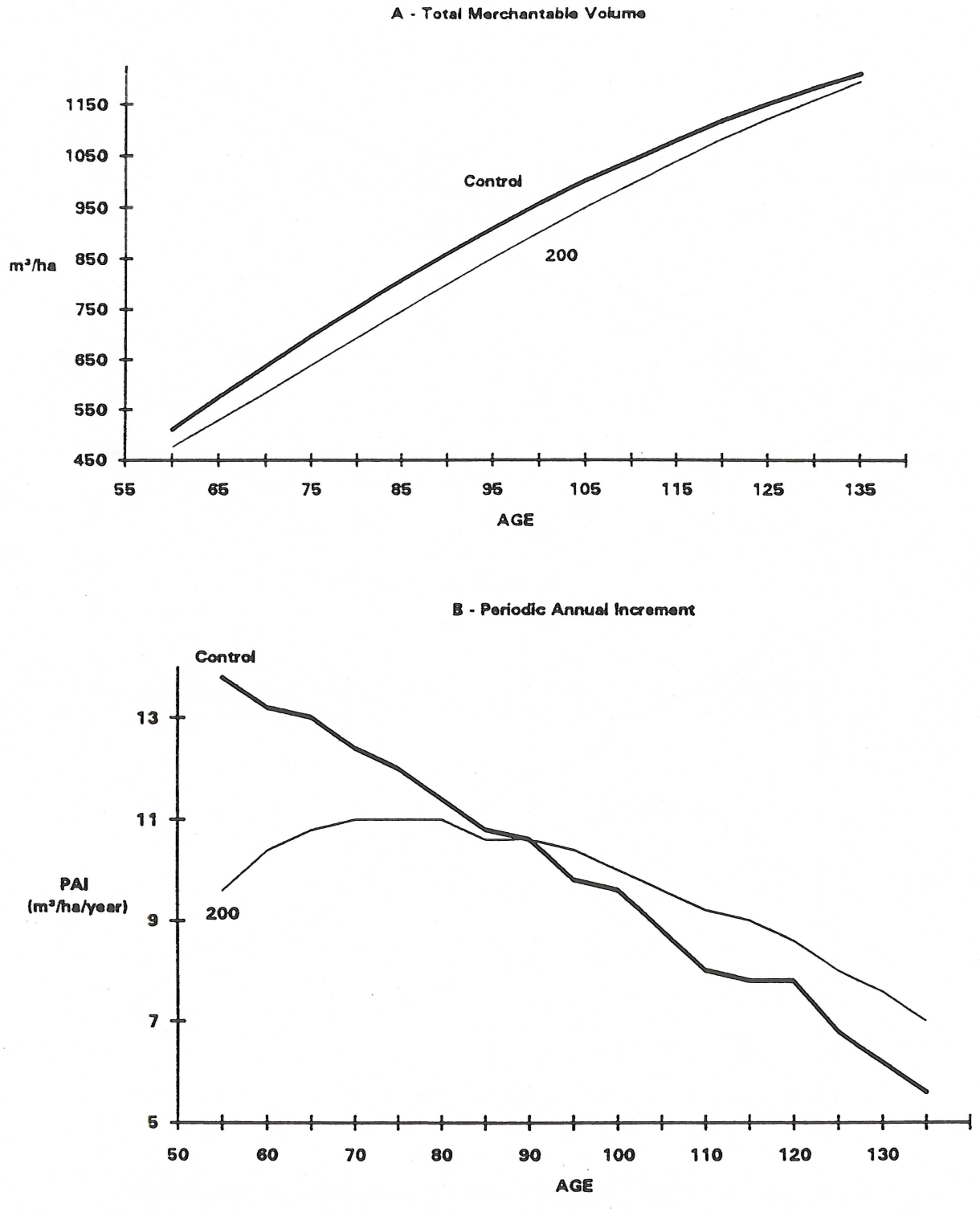


FIGURE 4-23 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 50

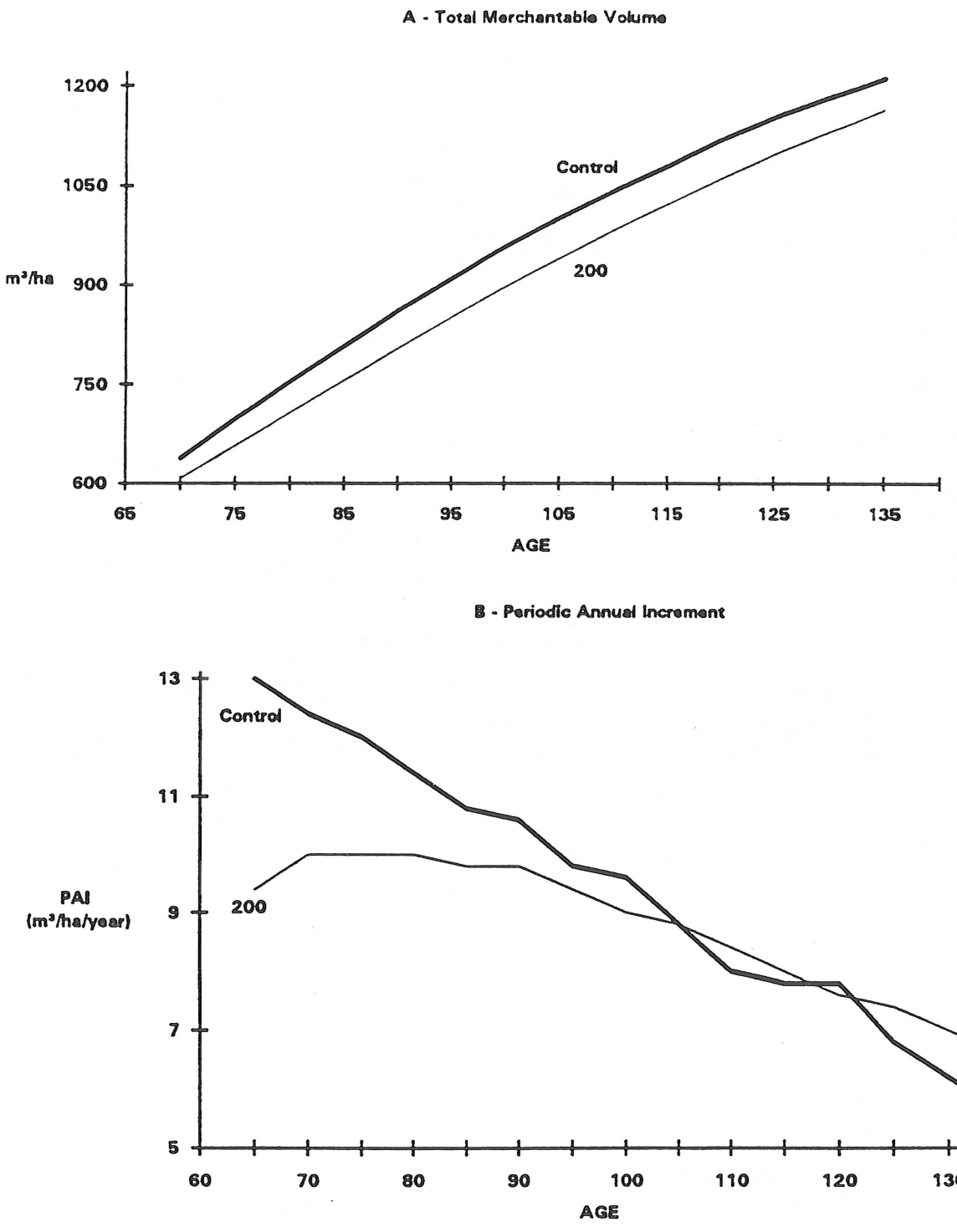


FIGURE 4-24 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 30, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 60

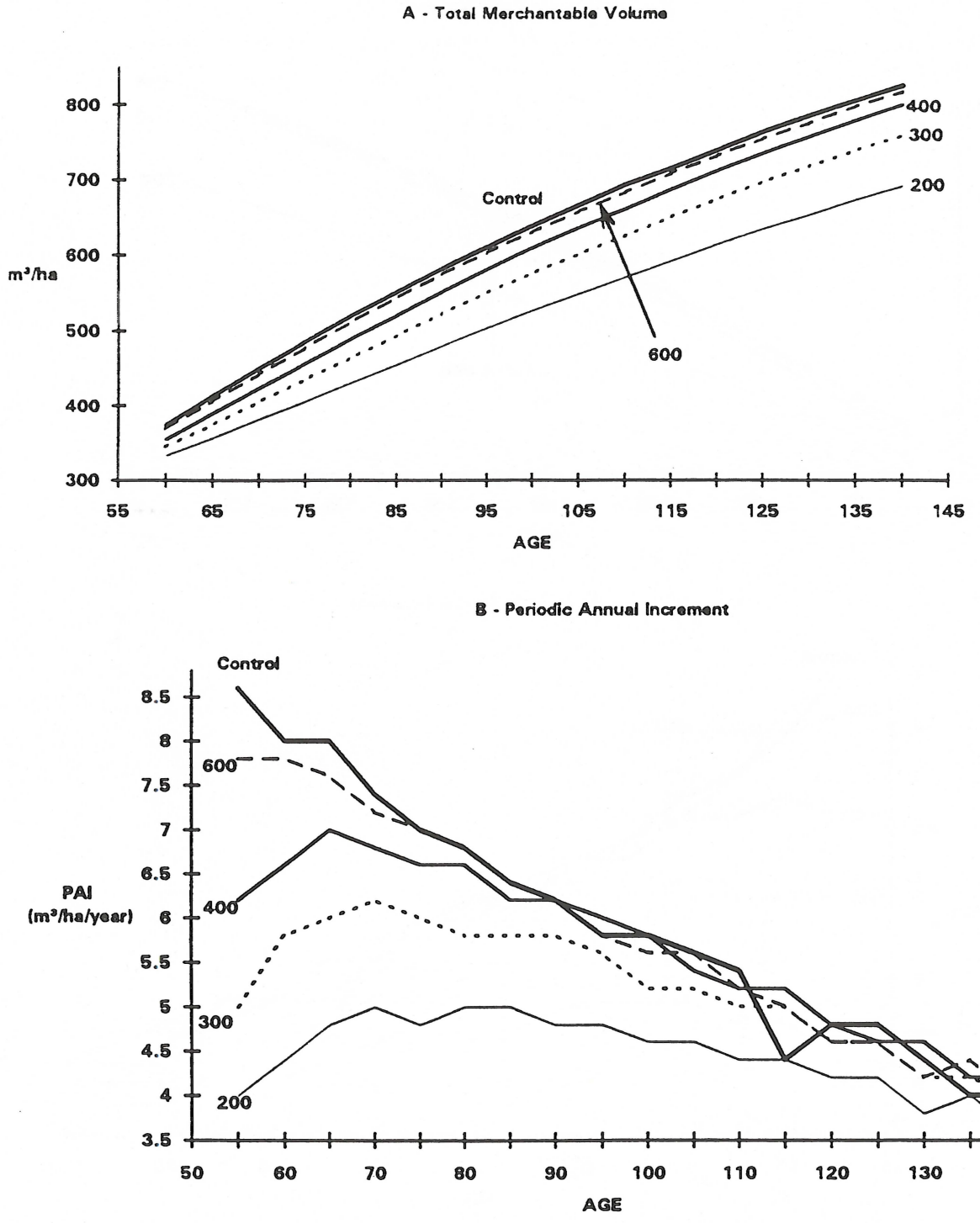
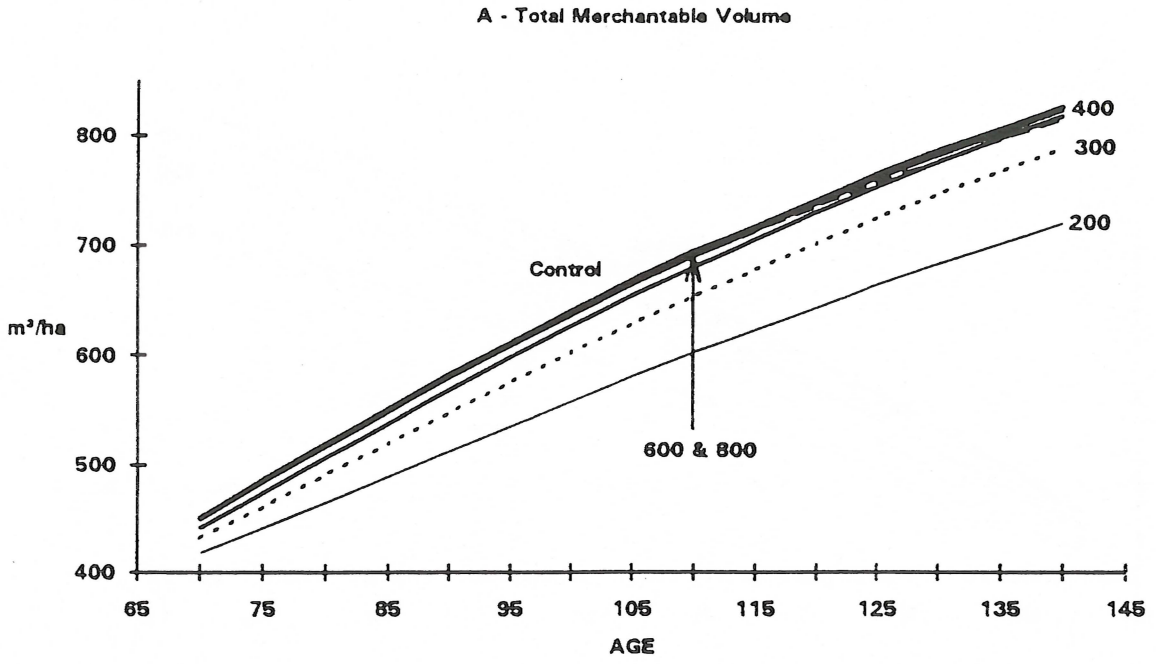


FIGURE 4-25 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 50



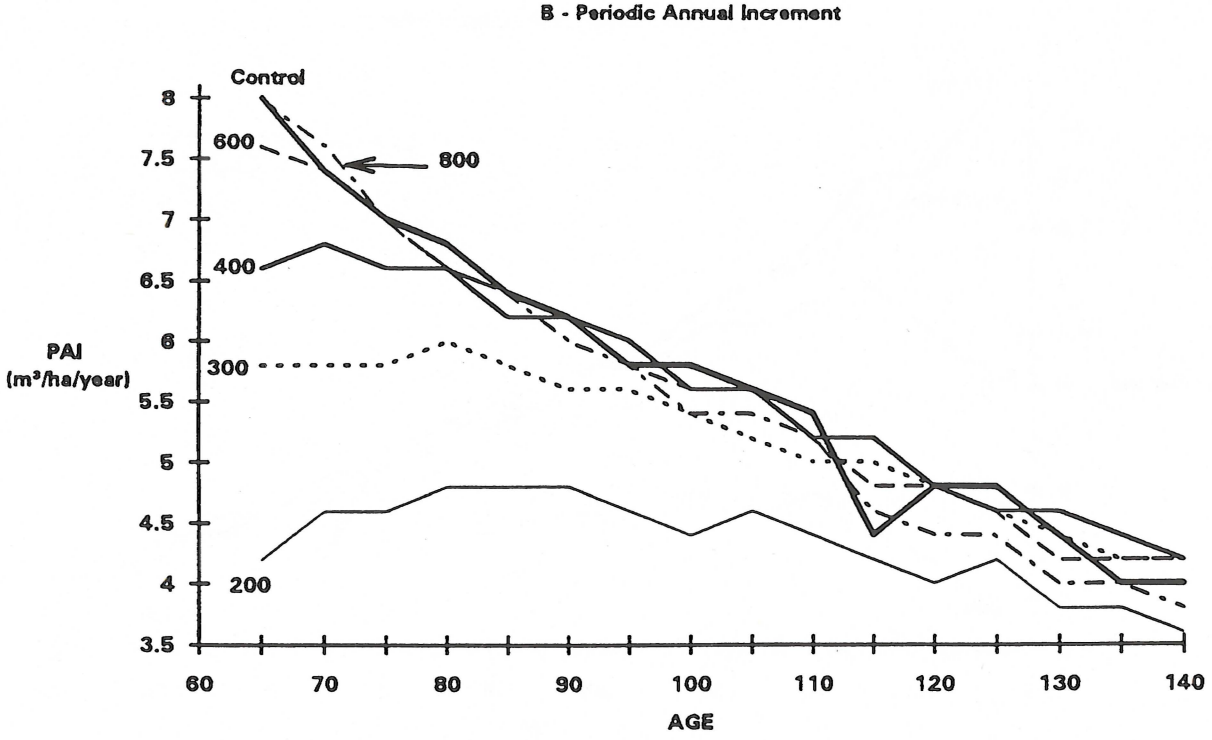


FIGURE 4-26 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 60

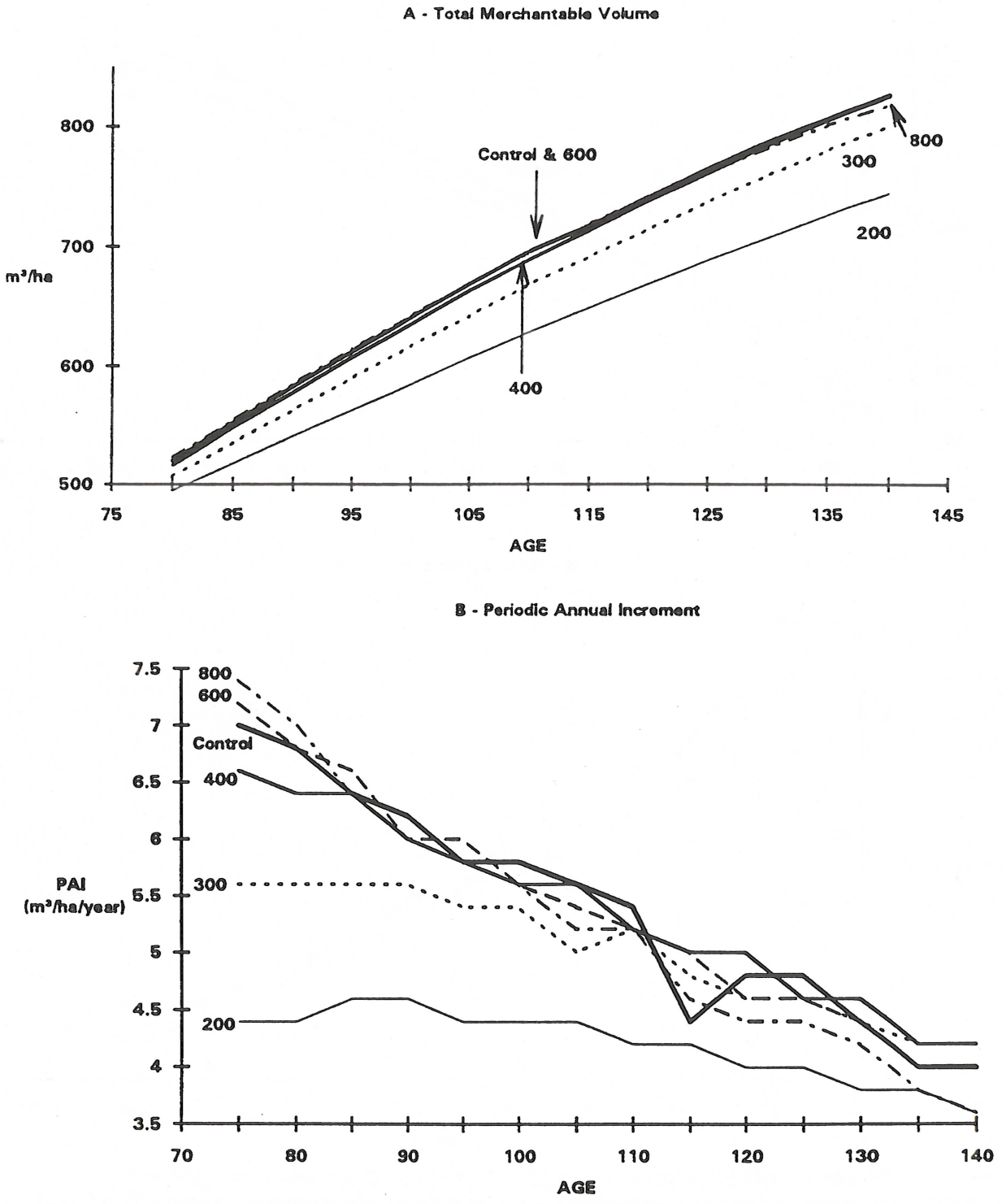


FIGURE 4-27 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, NO PRE-COMMERCIAL THIN, COMMERCIAL THINNED AT AGE 70

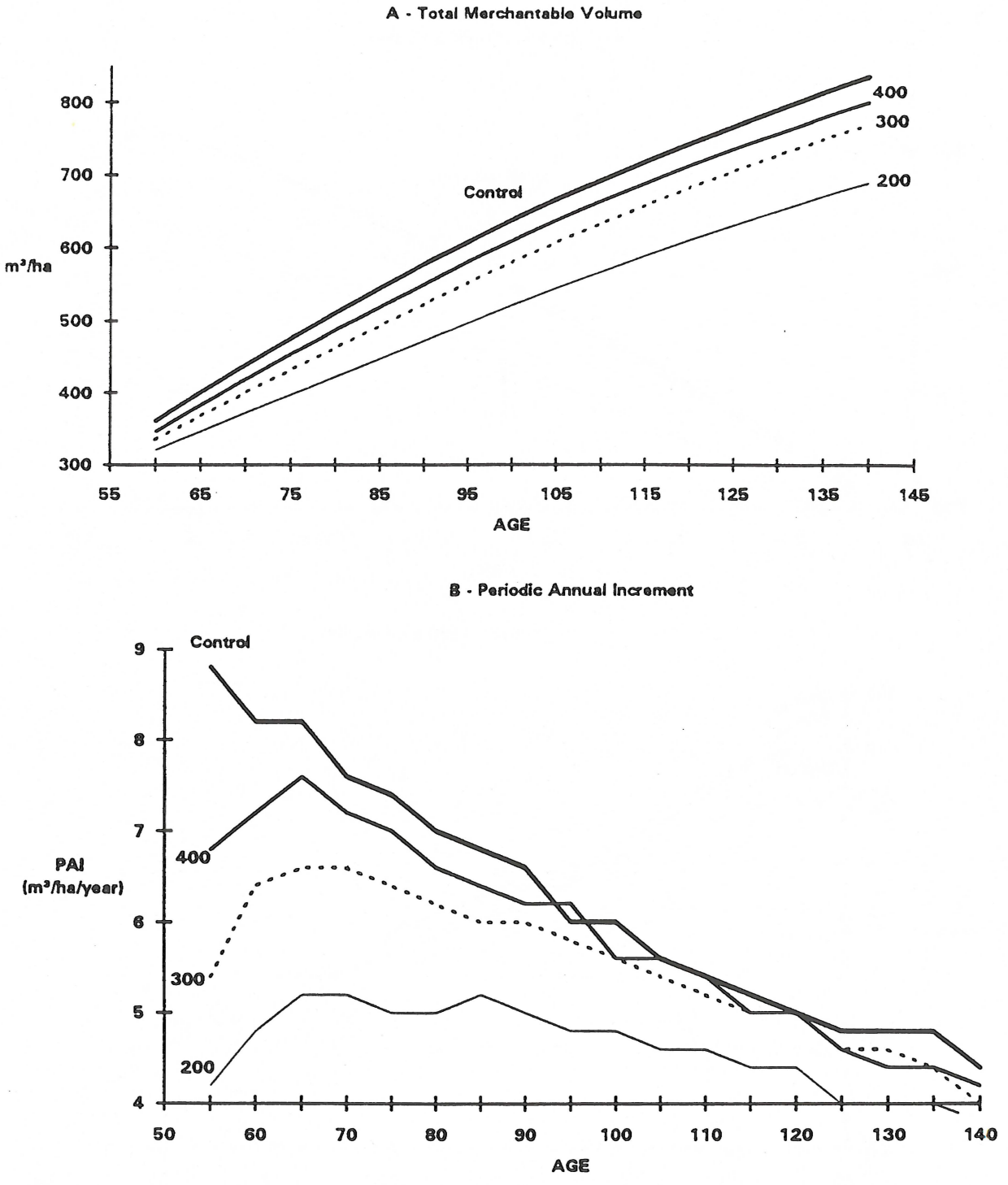


FIGURE 4-28 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 50

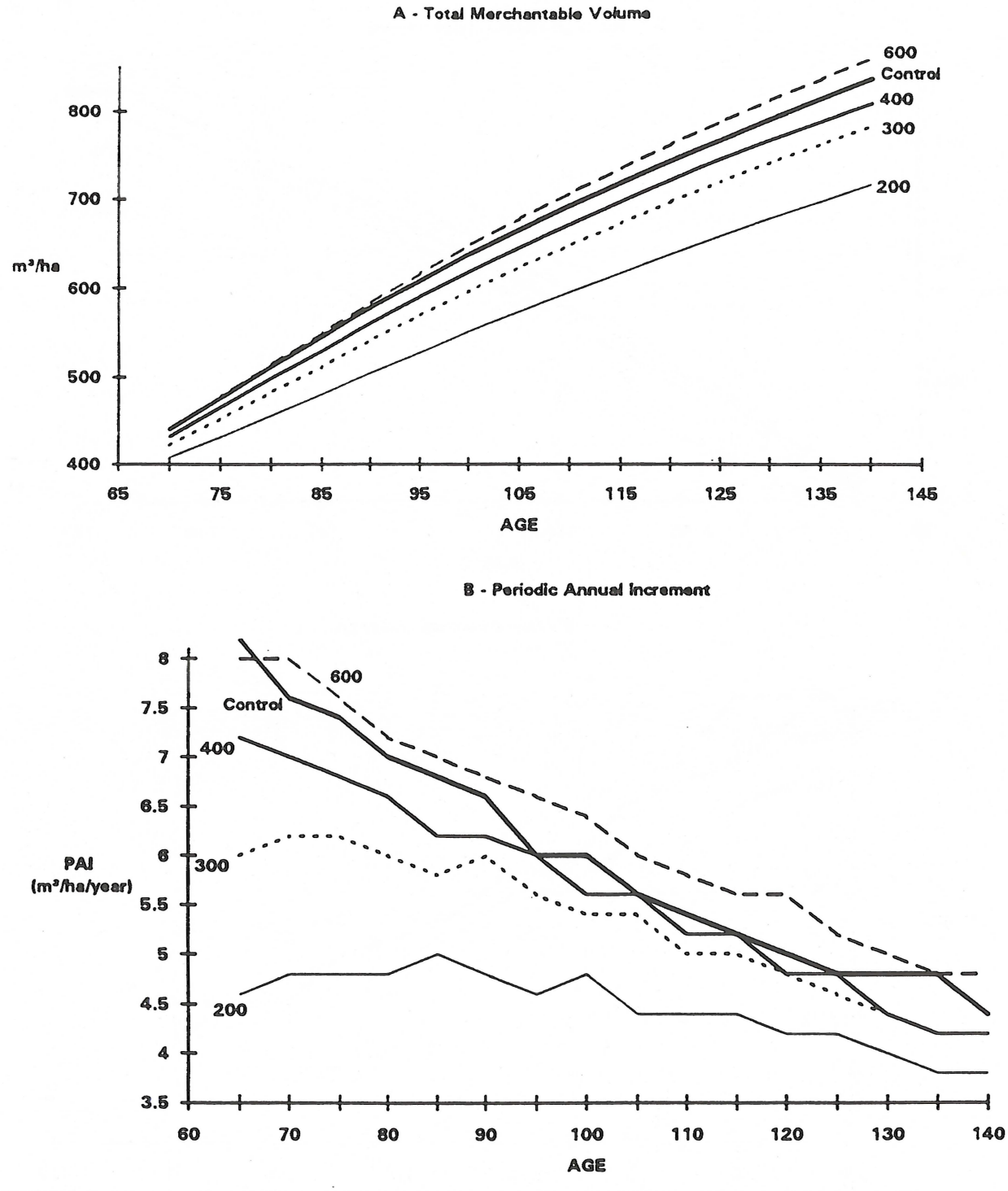


FIGURE 4-29 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 60

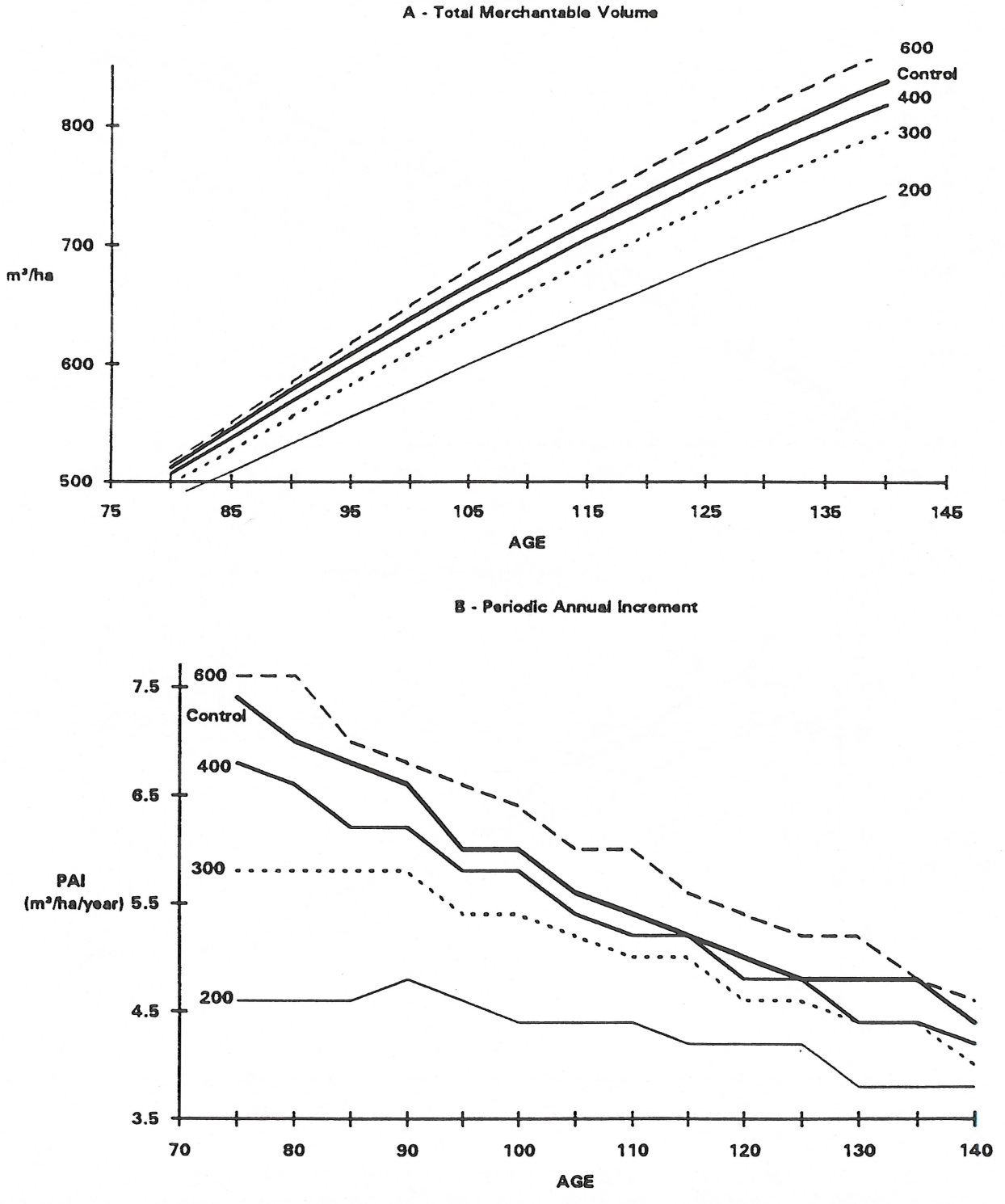
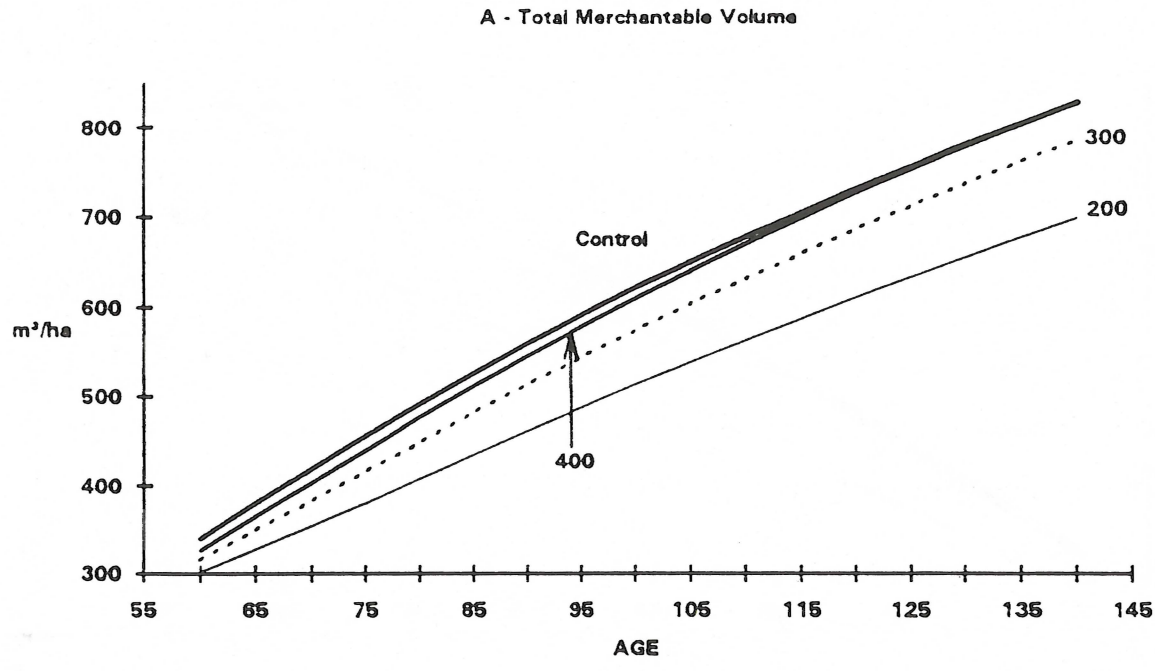


FIGURE 4-30 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 1,100 SPH, COMMERCIAL THINNED AT AGE 70



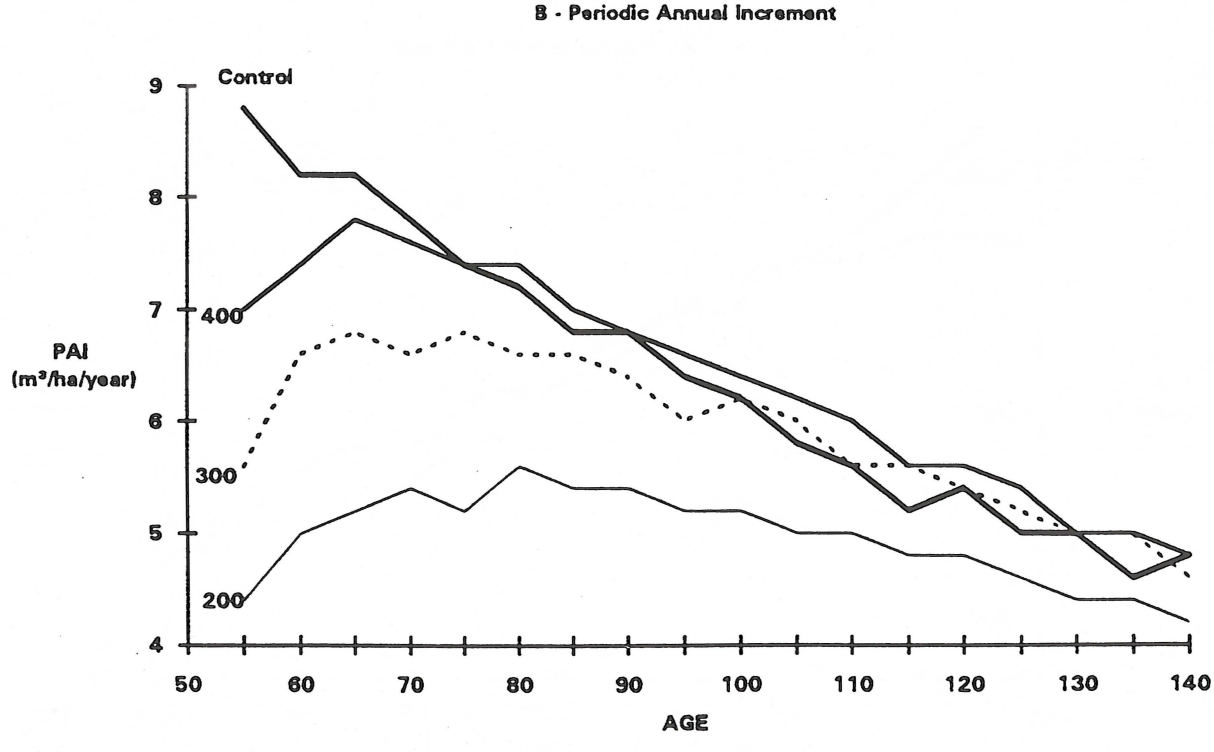


FIGURE 4-31 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 50

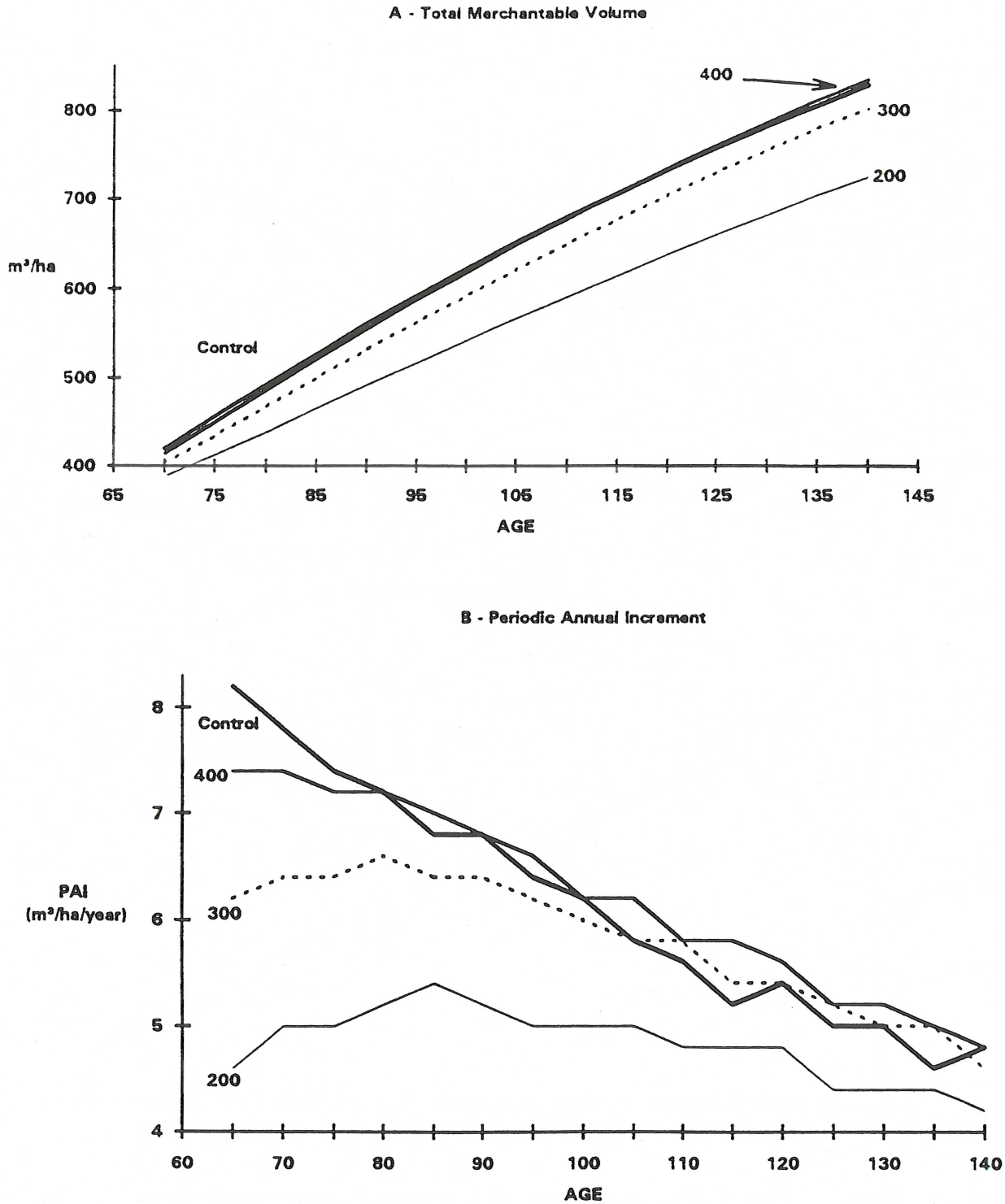
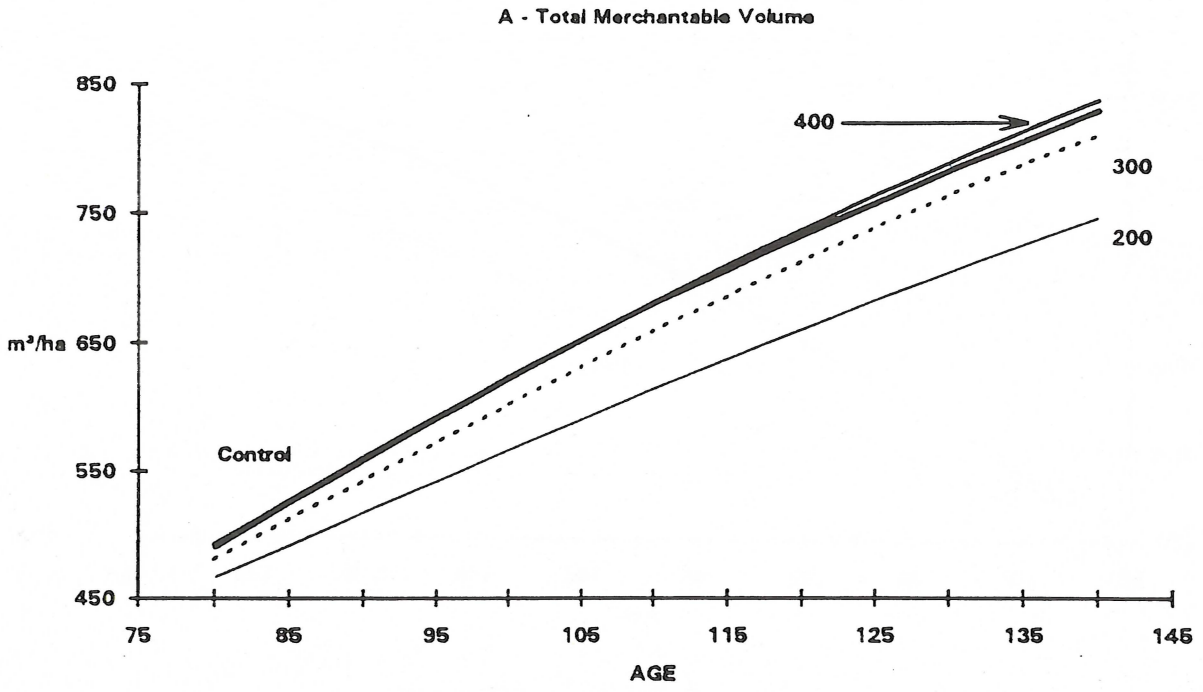


FIGURE 4-32 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 60



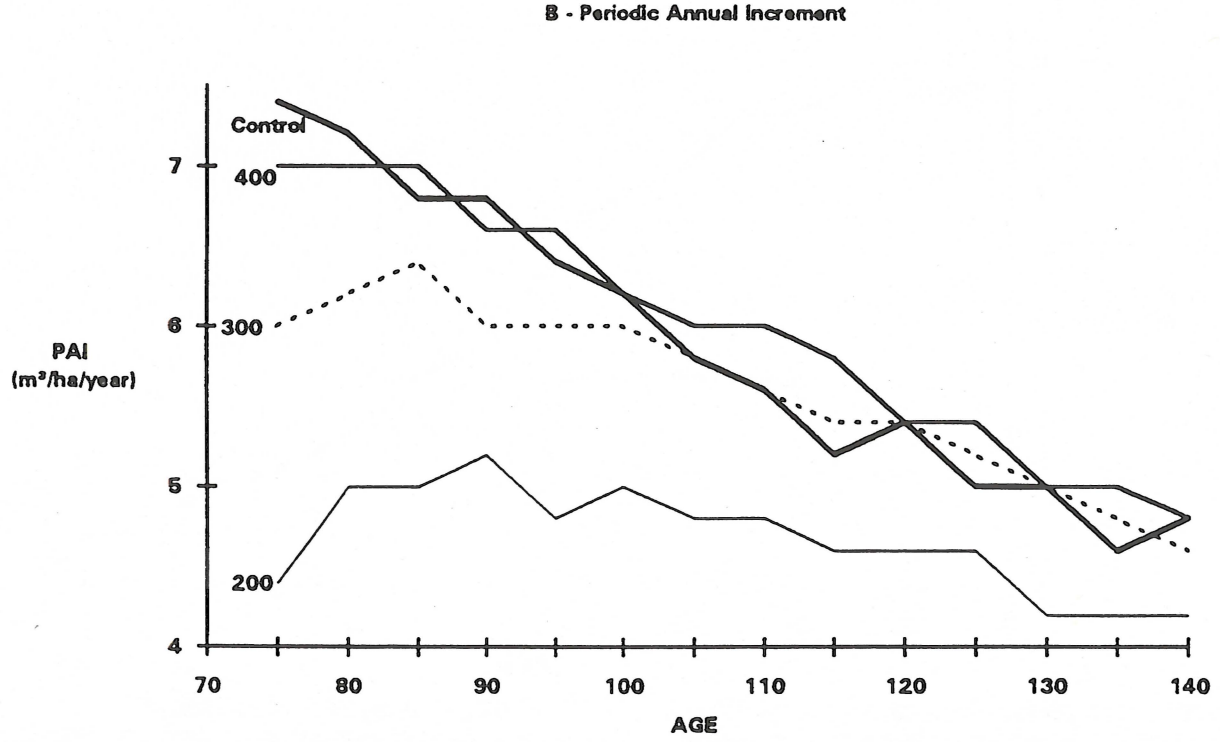


FIGURE 4-33 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 800 SPH, COMMERCIAL THINNED AT AGE 70

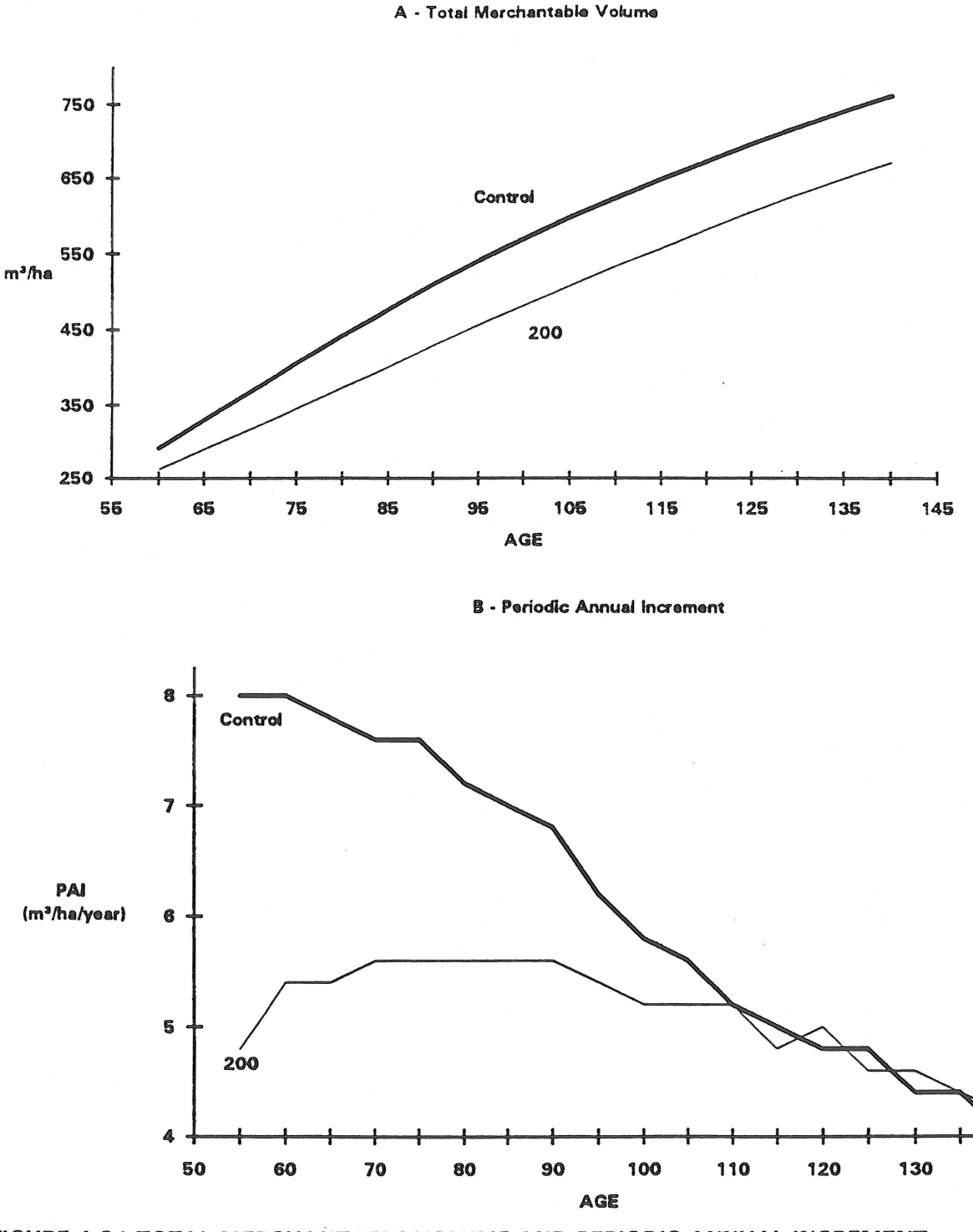
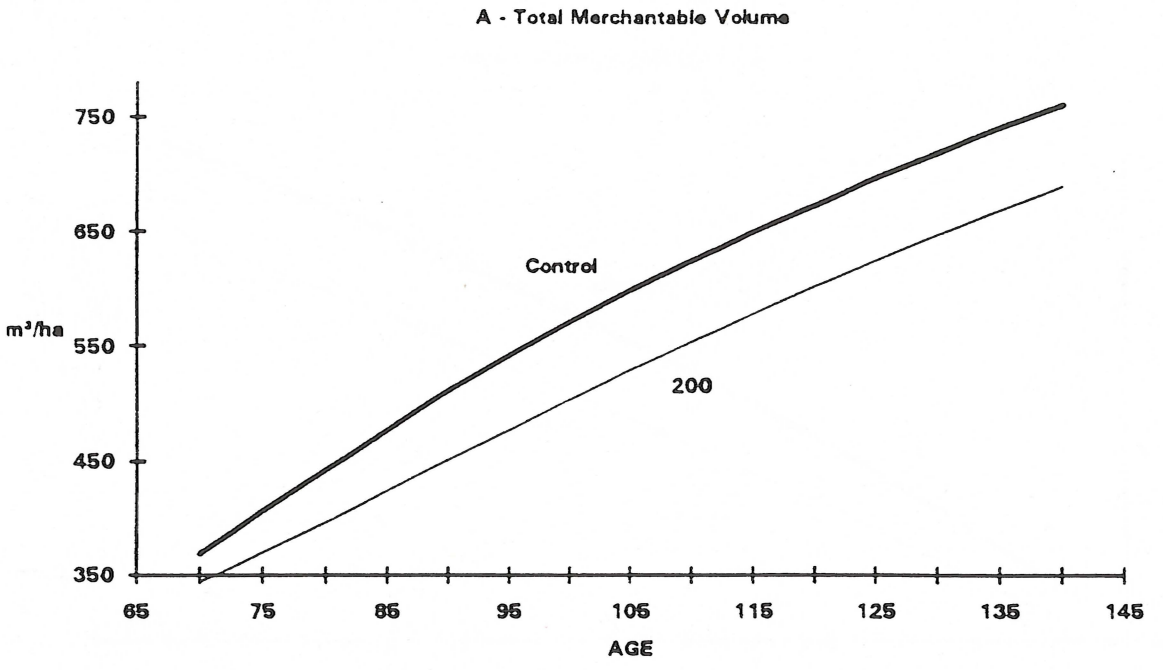


FIGURE 4-34 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 50



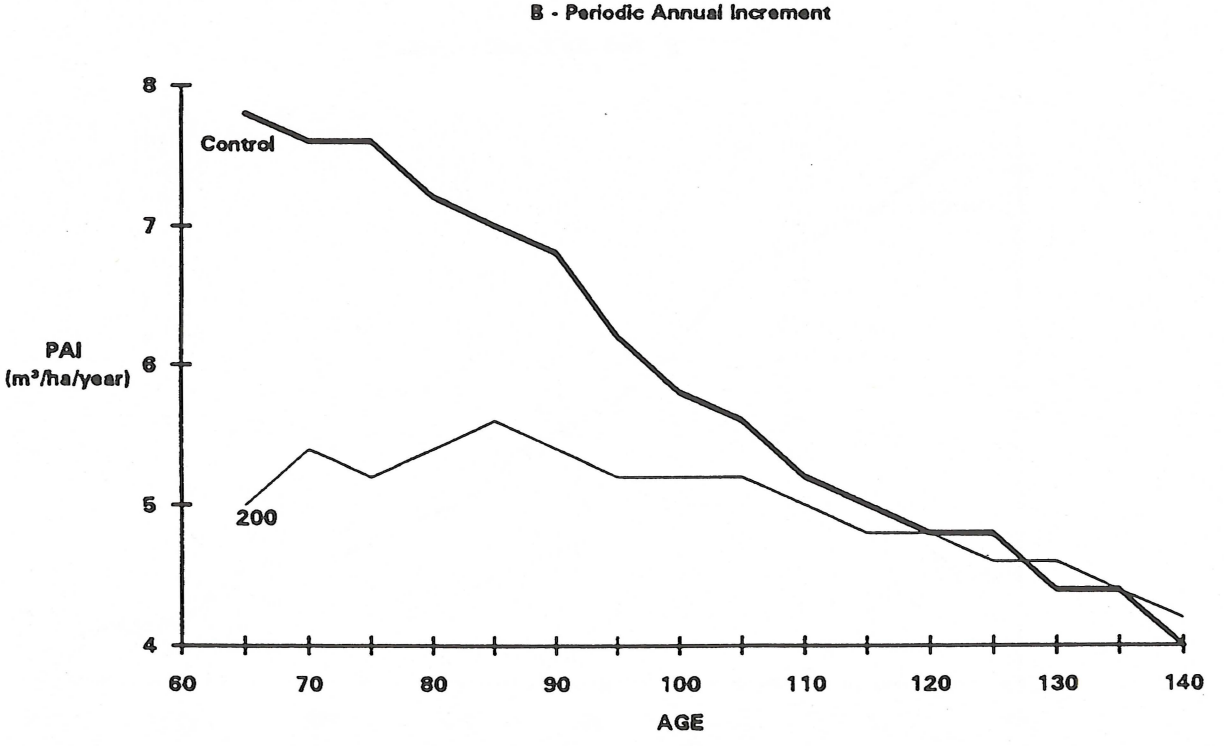


FIGURE 4-35 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 60

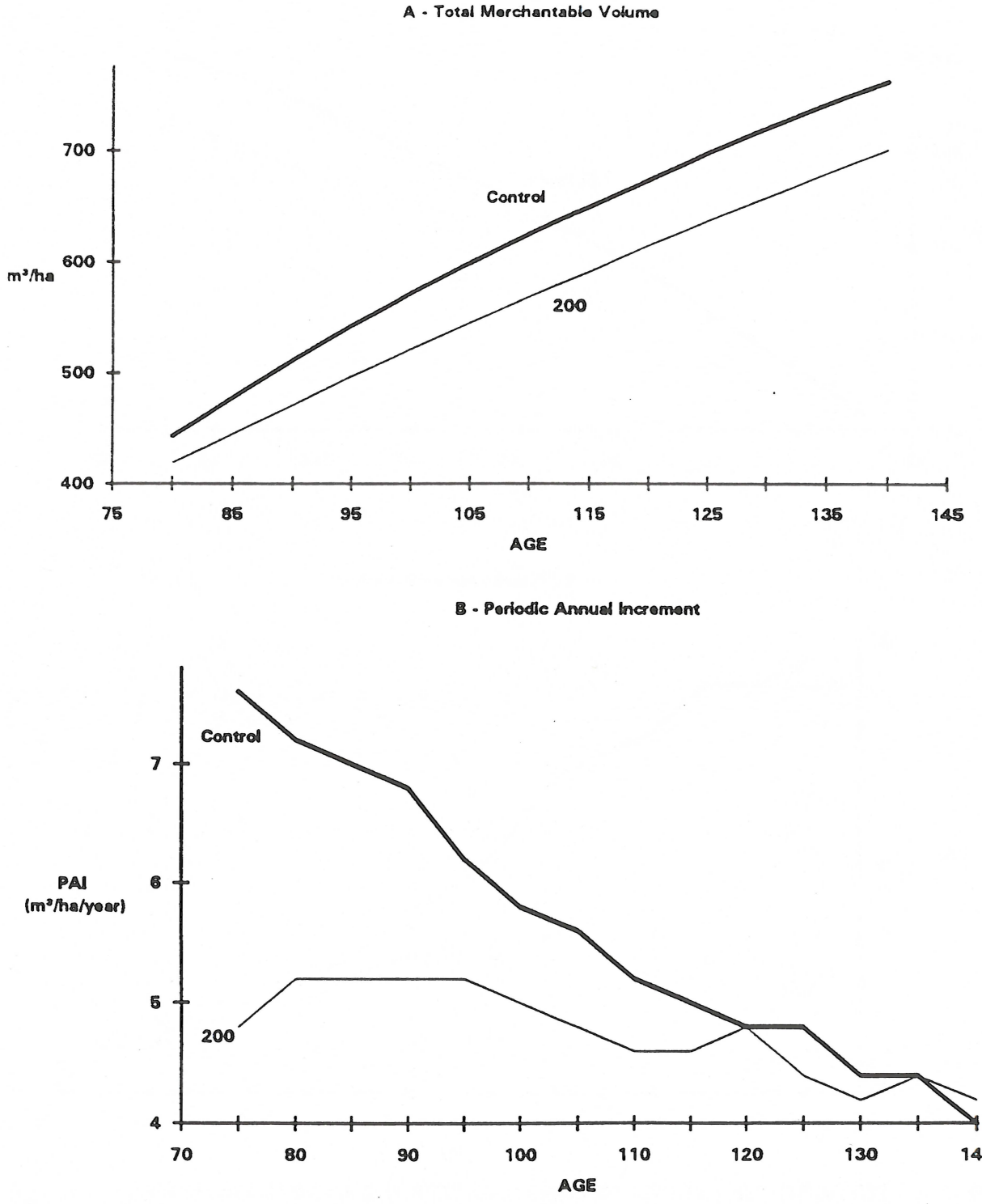


FIGURE 4-36 TOTAL MERCHANTABLE VOLUME AND PERIODIC ANNUAL INCREMENT, SITE INDEX 24, PRE-COMMERCIAL THINNED TO 500 SPH, COMMERCIAL THINNED AT AGE 70

costs. For all growing regimes simulated except one, thinning to 200 leave trees per hectare reduced the total volume produced by the stand over a rotation. Thus, if the forest manager's goal was the maximization of timber volumes then thinning to 200 leave trees per hectare would generally be considered to be too heavy a thinning.

Generally the effect of delaying the age at which the thinning takes place was to increase the cumulative volume produced. One reason was the higher merchantable volume taken at the commercial thinning at the later thinning ages as shown in Table 4-8. The table indicates that the merchantable volume of the commercial thinning typically increased as the thinning age was increased for all site indexes and initial densities which means that the volume growth on trees to be thinned if left for another ten years would be greater than the volume lost to mortality over that period. The exceptions to this rule were some of the early light thinnings. Thus, if the objective was to maximize merchantable volume then the stands should be thinned at the later thinning age. However, delaying the thinning age also means that the volume taken at the final harvest will be smaller for any given final harvest age. This is because the stand would have had less time to respond to the thinning. This means that the higher volume taken at the thinning as a result of delaying the thinning age will come at the expense of a lower final harvest volume.

Figures 4-1 to 4-36 also show the 5-year periodic annual increment (PAI) of the simulated stands following each thinning intensity. The PAIs can be viewed as the stand's marginal growth rates.[3] The heaviest thinnings, thinning to 200 leave trees per hectare, results in an immediate drop in PAI well below the PAI for the corresponding unthinned stand. At site index 36 it takes 20 to 35 years before the PAI of the 200 leave trees per hectare stand equals that of the unthinned stand but then remains above the PAI of the unthinned stand from there on. At lower site indexes it takes substantially longer for the PAI of the 200 leave trees per hectare stand to converge toward the PAI of the unthinned stand. For the 300 leave trees per hectare simulations the PAI initially drops after the thinning but quickly increases to surpass the PAI of the unthinned stands. For the 400 leave trees per hectare simulations there was an initial drop in the PAI at the two earliest thinning ages but at the later thinning age the PAI remains close to or above the PAI of the unthinned stand. Part of the reason for this initial drop in PAI is that the heavier thinnings create larger holes in the canopy which take longer to fill. This means that until crown closure occurs there would be a period when the site would not be fully utilised. For the heaviest thinning regimes the holes created take so long to close that some volume growth is sacrificed. Thus, in the short term the lightest thinning will achieve the highest growth rates while in the longer term the growth rates for the 300 to 400 leave trees per hectare regimes will rise above the other regimes and usually produce the greatest cumulative merchantable volume. The PAI of the 600 and 800 leave trees per hectare simulations are not usually significantly different from the unthinned stand simulations. As the age at which the thinning takes place is increased more of the canopy is occupied by the largest trees which means that smaller holes are created in the canopy by a given thinning intensity and thus the initial drop in PAI is smaller.

Tree mortality in the unthinned stands which had not been previously PCT would be substantial in comparison to that found after the thinnings in the thinned stands. Simulated mortality in the stand thinned the heaviest was insignificant or non-existent over the rotations simulated but increased as the intensity of the thinnings was lowered. For example, in the site index 36 thinned to 800 leave trees per hectare at age 40 simulations, by age 100 only 466 of the leave trees would have survived. Tree mortality was lower in the lower site index simulations for any given post-thinning density because of the lower growth rates of these sites which lessens the intensity of inter-tree competition.

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[3] It would be more correct to say that a PAI is the average marginal growth rate over a 5-year period.

Conclusion

The simulations of the impacts of commercially thinning Douglas-fir described above leads to the important conclusion that commercial thinning will provide only a marginal increase in the net merchantable volume available from a stand over a rotation. Thus, if commercial thinning is to be justified as a viable forest management option it will have to be based on either the potential of the thinning to increase the value of the stand, by concentrating the stand's growth potential on a smaller number of trees, or on the earlier financial return obtained from thinning the stand. These considerations are examined in detail in Sections 6 and 7.

4.5 Effect of Thinning on Rotation Age

Section 3 described the economic rotation age as that final harvest age which would maximize the net present value of an infinite series of identical growing regimes. However, net present value is not the only criteria upon which rotation ages are based, indeed it is a criterion which is seldom used in British Columbia. Rotation ages are instead usually determined based upon the physical rotation age or the technical rotation age. The physical rotation age is based upon the selection of a final harvest age which maximizes the annual production of timber obtainable from the stand. This occurs at the cumulation of the stand's mean annual increment, as discussed below. The technical rotation age is based upon meeting a specific stand characteristic. A common basis used for setting technical rotation ages in British Columbia is the attainment of a minimum average stand DBH of 45 cm.

Mean annual increment (MAI) is simply the average annual volume growth rate for a stand and is calculated as the total volume of a stand divided by its age. Current annual increment (CAI) is the stand's net volume growth in any given year. Figure 4-37 shows the MAI and CAI curves for a hypothetical stand. The CAI curve shows that a young stand's growth rate quickly increases until a maximum is reached at age A_1, from which point the growth rate for the stand starts to decline with age. However, the MAI curve continues to rise past A_1 and continues to rise as long as the CAI curve lies above the MAI curve. MAI is maximised, or cumulates, at the point where the CAI curve intersects the MAI curve from which point the MAI curve declines with the CAI curve. At the age at which MAI cumulates, denoted as A_2, the annual production of a site is maximised and if volume maximization is the forest manager's goal then the stand should be harvested at age A_2 and a new faster growing stand established.

The effect of thinnings on the cumulation of MAI is shown in Figure 4-38. The figure presents the PAI curve, used as an approximation of the CAI curve, and the MAI curve for the No PCT site index 36 growing regime. The PAI curve intersects the MAI curve at approximately age 80 which would thus be considered the appropriate physical rotation age for this regime. Also shown in the figure is the PAI curve for the 300 leave trees per hectare thinned at age 40 regime. The figure shows that the PAI curve for the thinned regime initially drops below the unthinned PAI curve, because the thinned regime no longer fully occupies the site. However, the crowns of the residual stand left after the thinning quickly expands to occupy the site which results in the thinned PAI curve quickly rising above the unthinned PAI curve. Two MAI curves are shown for the thinned regime in the figure. The first, labelled as MAI_r is the MAI for the residual stand and excludes the volume taken during the thinning which is the reason why the curve drops at age 40. The second MAI curve, labelled as MAI_C, is the cumulative MAI for the residual stand and includes the volume taken at the thinning. The age at which the MAI for the thinned stand cumulates depends upon which MAI curve is chosen. If you wish to maximize the volume from the residual stand then MAI_r would be used, however if the objective is to maximize cumulative volume then MAI_C should be used. The latter objective was used in this report. Note that the MAI_C cumulates prior to MAI_r.

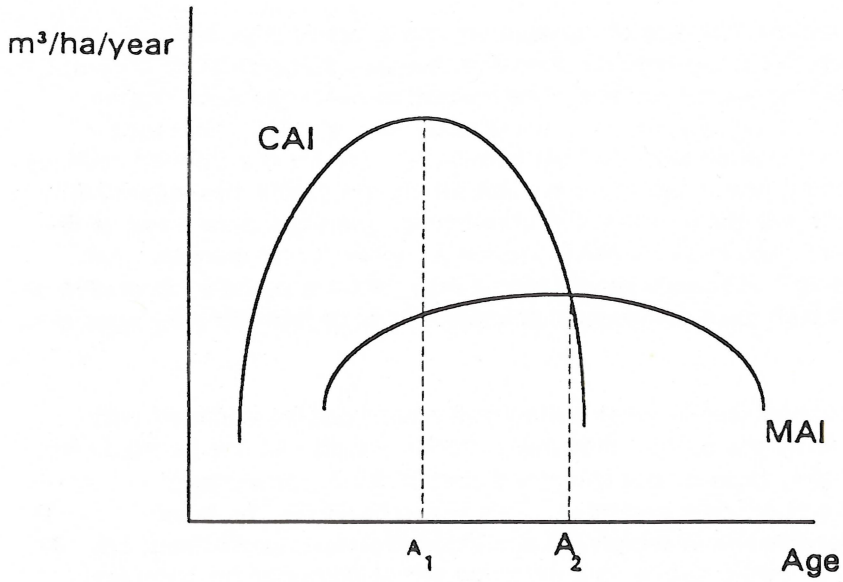


FIGURE 4-37 CUMULATION OF MEAN ANNUAL INCREMENT

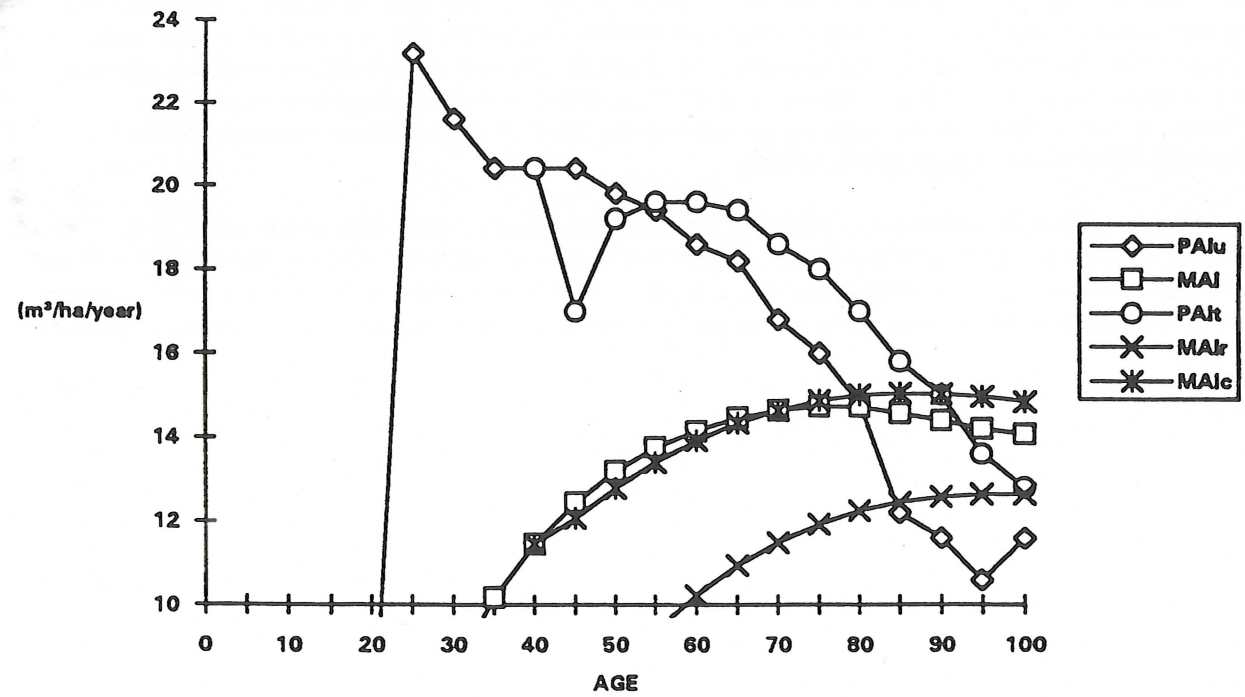


FIGURE 4-38 EFFECT OF THINNING ON CUMULATION OF MEAN ANNUAL INCREMENT

Whether the MAI of the thinned stand cumulates before or after the MAI of the unthinned stand will depend upon the shifts in the PAI and MAI curves resulting from the thinning. For the thinning shown in Figure 4-38 the thinned stand cumulates after the unthinned stand. However, as shown in the Tables 4-9 to 4-11 this was not the case for all thinning regimes. These tables list the

maximum MAI attained under each regime, the age of cumulation, the average DBH achieved by the stand at cumulation, the age at which the stand would achieve an average stand DBH of 45 cm, and the MAI corresponding to the technical rotation age. The maximum MAIs for each regime reinforces the earlier conclusion that commercial thinning will provide only a modest increase in timber yields. For the higher site index simulations the MAI cumulates later for the thinned regimes than was the case for the corresponding unthinned regime. The simulation of the site index 24 thinned at age 70 regimes are hopefully atypical in that the commercial thinnings take place at the same time as the unthinned simulation cumulates its MAI. However, other forest management planning constraints, such as "green-up" adjacency requirements may cause a stand's harvest to be delayed past cumulation of MAI, in which case commercial thinnings at such late thinning ages may be viable.[4]

The average DBH of the unthinned stands were quite small and of course declined with lower site index simulations. Some foresters believe that these stands would still not be ready for harvest at the cumulation of MAI as they believe that the stand should reach some stand characteristic in order to meet some end product objective. This is the basis for "technical" rotations. Tables 4-9 to 4-11 also list the age at which the simulated regimes would reach an average stand DBH of 45 cm which, as noted above, is a common target diameter for technical rotations in British Columbia. The lightest thinnings have little effect on technical rotation age, while the heavier thinnings substantially reduce the technical rotation age for the residual stand. However, the logic of using commercial thinnings to achieve an earlier technical rotation age is somewhat dubious for if the timber removed during the thinning, which would have an average DBH well below 45 cm, can be used in the marketplace then so could the timber from the final harvest of the unthinned stand. In addition, the increased average DBH of the thinned stand is only partially due to increased diameter growth and partially an artifice caused by the removal of below average DBH trees from the stand during the thinning. In addition, the use of a technical rotation age may cause a substantial loss in a site's growth potential resulting from delaying harvest past the cumulation of MAI. This can be seen by comparing the MAI of the technical rotation to the maximum MAI for each regime in the tables.

As the technical rotation age diverges from the physical rotation age there must be a sacrifice of volume in order to achieve the goal of the technical rotation. Unless the net present value of the stand under a technical rotation is greater than that achieved under a physical rotation there would appear to be no economic rationale for choosing the technical rotation over the physical rotation.

[4] Adjacency or green-up requirements refer to the requirement that a harvest block must have been reforested and have reached some minimum average tree height or age before any adjacent cut-blocks could be harvested. The impact of adjacency requirements is typically to extend the minimum harvest age past the cumulation of MAI.

TABLE 4-9
EFFECT OF THINNINGS ON ROTATION AGE AND STAND DBH - SITE INDEX 36

Thinning Intensity (leave trees)	Max MAI (m^3/ha/year)	Age of Max MAI (years)	DBH at Max MAI (cm)	DBH 250 at Max MAI (cm)	Age to 45 cm DHB (years)	MAI at 45 cm DBH (m^3/ha/year)
No PCT, Thinned at Age 30						
Unthinned	14.7	80	41.4	56.5	85	14.6
200	13.7	100	73.4	73.4	50	10.7
300	15.1	90	61.9	64.6	55	12.8
400	15.6	85	54.2	60.6	60	14.2
600	15.2	80	44.8	55.4	80	15.2
No PCT, Thinned at Age 40						
Unthinned	14.7	80	41.4	56.5	85	14.6
200	13.9	90	66.2	66.2	55	12.5
300	15.1	85	57.2	59.8	60	13.9
400	15.3	85	52.1	58.0	65	14.8
600	15.2	80	44.4	55.3	85	15.1
800	15.5	80	42.6	56.5	85	15.4
No PCT, Thinned at Age 50						
Unthinned	14.7	80	41.4	56.5	85	14.6
200	14.3	85	62.5	60.5	55	13.4
300	15.2	85	56.5	58.9	60	14.2
400	15.4	85	51.6	57.8	65	14.8
600	15.7	80	45.2	56.5	80	15.7
800	15.4	80	42.9	56.5	85	15.2
PCT to 1,100 SPH, Thinned at Age 30						
Unthinned	15.0	75	41.7	55.9	85	14.8
200	13.7	95	72.6	72.6	50	10.6
300	15.3	95	63.8	66.8	55	12.9
400	15.7	85	55.2	61.4	60	14.3
PCT to 1,100 SPH, Thinned at Age 40						
Unthinned	15.0	75	41.7	55.9	85	14.8
200	14.3	95	69.7	69.7	50	12.0
300	15.6	90	60.7	63.4	55	13.5
400	15.9	85	54.1	60.1	60	14.6
600	15.7	80	46.2	57.3	75	15.6
PCT to 1,100 SPH, Thinned at Age 50						
Unthinned	15.0	75	41.7	55.9	85	14.8
200	14.3	85	63.6	63.6	55	13.4
300	15.7	90	59.9	62.4	60	14.3
400	15.9	85	53.6	59.7	65	15.1
600	15.7	80	46.4	57.7	80	15.7
PCT to 800 SPH, Thinned at Age 30						
Unthinned	15.1	80	46.5	58.6	80	15.1
200	13.7	100	75.1	75.1	50	10.3
300	15.2	90	63.3	66.2	50	11.8
400	15.6	85	55.8	61.9	60	14.1
PCT to 800 SPH, Thinned at Age 40						
Unthinned	15.1	80	46.5	58.6	80	15.1
757	14.2	95	70.8	70.8	50	11.6
300	15.5	90	61.8	64.3	55	13.2
400	15.1	85	53.9	59.8	60	14.1
PCT to 800 SPH, Thinned at Age 50						
Unthinned	15.1	80	46.5	58.6	80	15.1
200	14.4	85	65.1	65.1	50	12.8
300	15.1	90	59.9	62.3	55	13.4
400	15.2	85	53.8	59.7	60	14.2
PCT to 500 SPH, Thinned at Age 30						
Unthinned	14.5	85	53.6	62.2	60	13.4
200	13.7	100	77.0	77.0	45	8.9
PCT to 500 SPH, Thinned at Age 40						
Unthinned	14.5	85	53.6	62.2	60	13.4
200	14.1	100	74.8	74.8	50	10.8
PCT to 500 SPH, Thinned at Age 50						
Unthinned	14.5	85	53.6	62.2	60	13.4
200	14.4	95	71.5	71.5	50	11.9

TABLE 4-10
EFFECT OF THINNINGS ON ROTATION AGE AND STAND DBH - SITE INDEX 30

Thinning Intensity (leave trees)	Max MAI (m^3/ha/year)	Age of Max MAI (years)	DBH at Max MAI (cm)	DBH 250 at Max MAI (cm)	Age to 45 cm DHB (years)	MAI at 45 cm DBH (m^3/ha/year)
No PCT, Thinned at Age 40						
Unthinned	10.3	80	30.7	46.4	135	9.3
200	8.8	100	58.2	58.2	70	8.5
300	9.8	95	51.0	53.3	75	9.5
400	10.2	95	46.5	51.6	90	10.2
600	10.3	85	38.6	47.2	125	9.7
No PCT, Thinned at Age 50						
Unthinned	10.3	80	30.7	46.4	135	9.3
200	9.3	90	53.5	53.5	70	9.2
300	10.1	90	48.7	50.6	80	10.0
400	10.4	90	45.0	49.4	90	10.4
600	10.5	85	38.6	47.2	125	9.8
800	10.7	85	35.8	47.7	130	10.0
No PCT, Thinned at Age 60						
Unthinned	10.3	80	30.7	46.4	135	9.3
200	9.7	75	44.5	44.5	75	9.7
300	10.2	90	48.2	49.9	80	10.2
400	10.4	90	44.8	49.2	95	10.4
600	10.5	85	38.7	47.5	135	9.5
800	10.6	85	35.8	48.0	135	9.8
PCT to 1,100 SPH, Thinned at Age 40						
Unthinned	10.0	80	34.1	47.0	130	9.0
200	9.0	100	60.4	60.4	65	8.4
300	9.9	95	52.8	54.8	70	9.5
400	10.2	90	46.9	51.6	85	10.2
PCT to 1,100 SPH, Thinned at Age 50						
Unthinned	10.0	80	34.1	47.0	130	9.0
200	9.2	95	56.2	56.2	70	9.0
300	9.9	95	51.0	53.0	75	9.8
400	10.2	90	46.1	50.5	85	10.2
600	10.3	90	40.4	49.7	120	9.7
PCT to 1,100 SPH, Thinned at Age 60						
Unthinned	10.0	80	34.1	47.0	130	9.0
200	9.5	80	49.7	49.7	70	9.5
300	10.0	95	50.4	52.2	80	10.0
400	10.2	95	46.7	51.5	90	10.2
600	10.2	85	39.5	48.5	120	9.7
PCT to 800 SPH, Thinned at Age 40						
Unthinned	9.9	85	38.6	49.8	120	9.4
200	9.0	110	64.3	64.3	60	7.9
300	10.1	105	56.6	58.9	70	9.3
400	10.1	95	48.8	53.6	80	9.9
PCT to 800 SPH, Thinned at Age 50						
Unthinned	9.9	85	38.6	49.8	120	9.4
200	9.0	95	57.3	57.3	65	8.7
300	9.9	100	53.5	55.5	75	9.6
400	10.1	95	48.2	53.0	80	10.0
PCT to 800 SPH, Thinned at Age 60						
Unthinned	9.9	85	38.6	49.8	120	9.4
200	9.3	90	54.4	54.4	70	9.3
300	9.9	95	51.7	53.4	75	9.8
400	10.1	95	47.9	52.7	85	10.1
PCT to 500 SPH, Thinned at Age 40						
Unthinned	9.6	100	47.7	56.2	85	9.5
200	8.8	130	71.0	71.0	60	7.3
PCT to 500 SPH, Thinned at Age 50						
Unthinned	9.6	100	47.7	56.2	85	9.5
200	9.1	115	66.2	66.2	60	7.9
PCT to 500 SPH, Thinned at Age 60						
Unthinned	9.6	100	47.7	56.2	85	9.5
200	9.0	100	60.2	60.2	60	8.5

TABLE 4-11
EFFECT OF THINNINGS ON ROTATION AGE AND STAND DBH - SITE INDEX 24

Thinning Intensity (leave trees)	Max MAI (m^3/ha/year)	Age of Max MAI (years)	DBH at Max MAI (cm)	DBH 250 at Max MAI (cm)	Age to 45 cm DHB (years)	MAI at 45 cm DBH (m^3/ha/year)
No PCT, Thinned at Age 50						
Unthinned	6.5	80	23.3	36.1	>150	<5.8
200	5.8	80	31.4	31.4	105	5.2
300	5.8	90	38.8	40.1	125	5.6
400	6.1	95	37.3	40.5	>150	<5.8
600	6.4	85	31.8	37.2	>150	<5.7
No PCT, Thinned at Age 60						
Unthinned	6.5	80	23.3	36.1	>150	<5.8
200	6.0	70	34.5	34.5	110	5.5
300	6.2	70	32.8	33.6	130	5.8
400	6.3	80	33.9	36.3	>150	<5.7
600	6.5	80	30.9	35.9	>150	<5.7
800	6.5	80	28.6	35.8	>150	<5.7
No PCT, Thinned at Age 70						
Unthinned	6.5	80	23.3	36.1	>150	<5.8
200	6.2	80	37.3	37.3	115	5.6
300	6.3	80	35.4	36.2	135	5.8
400	6.5	85	34.9	37.4	>150	<5.8
600	6.5	85	31.8	37.2	>150	<5.8
800	6.5	80	28.7	36.0	>150	<5.8
PCT to 1,100 SPH, Thinned at Age 50						
Unthinned	6.4	90	29.7	40.2	>150	<5.9
200	5.3	80	40.9	40.9	95	5.2
300	5.8	95	42.0	43.2	115	5.7
400	6.1	95	39.1	42.1	145	5.7
PCT to 1,100 SPH, Thinned at Age 60						
Unthinned	6.4	90	29.7	40.2	>150	<5.9
200	5.8	70	36.4	36.4	100	5.5
300	6.0	80	37.6	38.4	120	5.8
400	6.2	85	36.8	39.3	150	5.7
600	6.5	100	35.7	41.3	>150	<5.9
PCT to 1,100 SPH, Thinned at Age 70						
Unthinned	6.4	90	29.7	40.2	>150	<5.9
200	6.1	80	39.0	39.0	105	5.7
300	6.2	80	37.2	38.0	120	5.9
400	6.3	80	35.5	37.9	150	5.7
600	6.5	95	35.0	41.3	>150	<5.9
PCT to 800 SPH, Thinned at Age 50						
Unthinned	6.2	100	33.9	42.4	>150	<5.8
200	5.2	100	48.0	48.0	90	5.1
300	5.8	105	45.4	46.7	105	5.8
400	6.1	110	43.0	46.4	125	6.1
PCT to 800 SPH, Thinned at Age 60						
Unthinned	6.2	100	33.9	42.4	>150	<5.8
200	5.5	70	37.6	37.6	95	5.4
300	5.9	100	43.7	44.8	110	5.9
400	6.2	105	41.8	45.0	130	6.1
PCT to 800 SPH, Thinned at Age 70						
Unthinned	6.2	100	33.9	42.4	>150	<5.8
200	5.8	80	40.3	40.3	100	5.7
300	6.0	85	39.7	40.6	110	6.0
400	6.2	100	40.7	43.7	135	6.0
PCT to 500 SPH, Thinned at Age 50						
Unthinned	5.7	100	40.1	46.0	150	5.3
200	4.9	120	54.8	54.8	85	4.7
PCT to 500 SPH, Thinned at Age 60						
Unthinned	5.7	100	40.1	46.0	150	5.3
200	5.1	110	51.6	51.6	85	5.0
PCT to 500 SPH, Thinned at Age 70						
Unthinned	5.7	100	40.1	43.0	150	5.3
200	5.2	85	44.5	44.5	90	5.2

SECTION FIVE
ESTIMATION OF REVENUES AND COSTS

5.1 Introduction

The purpose of this section was to develop estimates of the revenues and costs which could be derived from the simulated commercial thinnings and the final harvests of both the thinned and unthinned stands. Using the estimated costs and revenues from the thinnings, an initial assessment of the viability of commercial thinnings was made based on whether or not sufficient revenues would be produced to cover the estimated cost of the thinning. The section ends with a comparison of the simulated costs and revenues to actual costs and revenues found in commercial thinning operations in the Sayward Forest on Vancouver Island.

5.2 Revenue Estimates

For each regime simulated the TASS model produced a tree data file for the trees harvested at each rotation age and a separate tree data file for the trees removed at the commercial thinning. This information was then passed to a bucking simulator which bucked the trees so as to maximise the value of the logs produced from each tree harvested (see Mitchell, et al. [1989] for further details on the tree files and the bucking simulator). The volume for each log grade can then be multiplied by the average price per m^3 for that grade to yield the gross revenue per log and the gross revenue per log summed to yield the total gross revenue for each harvest. In calculating the revenues in this manner it can be seen that the value of a tree is determined by the number and value of the logs which can be bucked from the bole of the tree. Tree growth contributes to value by moving logs from one grade to another and by producing new or longer logs as the top of the tree grows in height.

The average price per m^3 for each log grade was determined using prices from the Vancouver Log Market over the period 1990 to 1992. This period was chosen as the current log grading system was introduced in 1990. The price for each log grade were converted from nominal to real prices using the Industrial Producer Price Index (Statistics Canada, 1992). The average price for each log grade used in this study was calculated as the weighted average over the period 1990-1992 using the volume of logs sold in each year as the weights. Figure 5-1 presents the estimated average log values used to estimate harvest revenues. As one moves up through the log grades, the increasing value per m^3 of timber results from two major factors. First, the increasing diameter and length of the log means that larger dimension products, which typically have a price premium, can be cut from the log.[1] Second, larger diameter logs have higher lumber recovery factors which means that more lumber can be cut from a given volume of timber.[2]

In grading the logs produced from the bucking simulator the log grading rules listed in Table 5-1 were used. These rules are a simplification of the actual grading rules given in the Ministry of Forests' Scaling Manual.[3] Other important factors considered in log grading which could not be included in this analysis were form, defect, ring width, twist, etc. Note that the grades only go as high as grade H. Higher grades require that the log be able to produce a certain percentage of the clear (i.e. knot free) lumber or the ability to use the log as a veneer peeler. Unfortunately second-growth Douglas-fir timber is unlikely to produce any clear lumber, unless the trees have been pruned, because of the poor self-pruning characteristics of Douglas-fir. In addition, the information available from the tree files is insufficient to assess the logs usefulness as a peeler log. Thus, log

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[1] For example, on a board foot basis 2"x10"x14' dimension lumber will typically have a price premium of over 30% over 2"x4"x14' dimension lumber.

[2] The lumber recovery factor, which indicates the proportion of lumber which can be cut from a log of a given diameter, increases at a decreasing rate as the diameter of a log is increased.

[3] See Section 5A.461 of the Scaling Manual for Douglas-fir grading rules.

grades used in this study were restricted to grade H and lower which may slightly under-estimate the value of the logs produced.

TABLE 5-1
LOG GRADING RULES USED

Log Grade	Minimum Log Length (m)	Minimum Log Diameter (cm)	Maximum Knot Size (cm)
H	5.0	38	5
I	3.8	38	8
J	5.0	16	4
U	5.0	10	4
X	3.8	10-38	4
X	3.0	10	4
Y	all other logs with a minimum top diameter of 10 cm.		

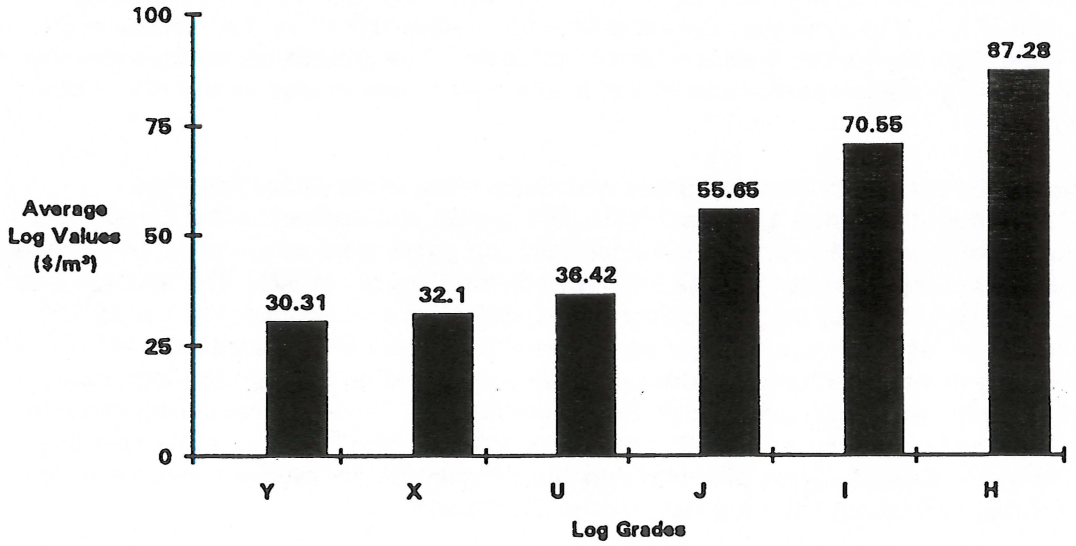


FIGURE 5-1
AVERAGE LOG VALUES BY GRADE

It should be noted that by using the existing log grade prices, we are implicitly assuming that these log grades adequately reflect changes in the value of the products which can be derived from a log in each grade. In addition, it must be kept in mind that the current log grading system has been developed primarily for the grading of old-growth timber and thus may not completely reflect the variation in new-growth values.[4] The log grades also produce a stepped value function

[4] It has been suggested that because new-growth timber will typically have less rot and decay it may, for a given log grade, be more valuable than old-growth timber. However, others have expressed concerns that new-growth timber may have other wood quality problems associated with faster growing trees.

with discrete jumps rather than a smooth continuous function which would more accurately reflect the value of the logs as they increase in diameter and length.[5]

The commercial thinnings cause the average value per m^3 of the final harvest from the thinned stands to be higher than the average value of the final harvest from the unthinned stands which is due to two factors. First, the thinning removed trees which, while capable of surviving until the final harvest, would have been smaller than the average tree from the thinned stand which results in a lower average value for the timber from the unthinned stands. Second, the thinnings concentrated the growth on the larger dominant trees which would produce wood of a higher value. However, while the unthinned stands had the lowest average value per m^3, these stands also had the highest simulated total gross revenue from the final harvest due to the larger volume available at final harvest from the unthinned stands.

5.3 Harvesting and Road Development Cost Estimates

The costs of conventionally logging the commercial thinnings and the final harvest of the thinned and unthinned stands were estimated using the coast and interior appraisal manuals of the B.C. Forest Service (Ministry of Forests, 1990 and 1992). The cost equations and assumptions used are detailed below for each logging phase.

Cost Bases and Trend Adjustments

The equations used in the coast and interior appraisal manuals are based on cost surveys conducted by the Ministry of Forest's Valuation Branch. As these surveys were conducted in different years the cost base for each manual is different. In order to convert the manuals' cost estimates to constant 1992 dollars the cost trend factors issued by the Valuation Branch were used. For costs estimated with the coast manual, a cost adjustment factor of 1.043 was applied to all cost estimates while a factor of 1.078 was used for any costs estimated with the interior manual.

Tree-to-Truck Costs

Tree-to-truck harvesting costs were estimated using equations from the interior manual rather than the coastal manual because the coastal manual's tree-to-truck cost equation includes only the site's average slope as an independent variable. As the major difference in costs between thinning regimes will come from variations in merchantable volume per hectare and the number of stems per hectare the coastal manual's equation was inadequate for the purposes of this study. However, the interior manual's tree-to-truck cost equations include these variables and so the equation for conventional skidder yarding in the dry-belt Douglas-fir zone of the Vancouver Forest Region was selected to estimate tree-to-truck costs. Costs included in the tree-to-truck phase would include the expenses incurred for landing construction, skid trail construction, felling, skidding, bucking, loading, crew transportation, and any contractor overhead and profit.[6] The cost equation used was:

$$\$/m^3 = 0.9709\ [12.39 + 1.11SPH/1{,}000 - 4.21VPH/1{,}000 + 0.0035DM + 0.0284S]$$

where
- SPH = average stems per hectare;
- VPH = average volume per hectare;
- DM = distance to marshalling point; and

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[5] For example, to go from the minimum diameter for log grade U to the minimum diameter for log grade J, the log must increase by 6 cm. in diameter. If a tree grows on average by 1.0 cm/year (2/5"/year) then it would take 6 years for the log to reach grade J.

[6] See Section 4.1.3 of the Interior Appraisal Manual.

S = average slope in percent.

For the purposes of this study DM, the one-way distance from the geographic centre of the cutting authority to the nearest marshalling point, was assumed to be 50 km and the average slope was held constant at 20%.

The interior manual also has a low volume per tree cost additive which applies only to sites with an average volume per tree (VPT) of less than 0.20 m^3. The low volume cost adjustment was calculated using the following formula:

$\$/m^3 = 3.92 - 19.58VPT.$

Haul Costs

Haul costs were estimated using the haul cost equation from the coastal manual which was:

$\$/m^3 = 3.4529 + 0.0575D$

where D is the weighted average one-way haul distance in kilometres.[7] Haul cost estimates used in this study were based on an assumed one-way haul distance of 50 km. These assumptions result in an estimated haul cost of $\$6.33/m^3$ which was used for all simulations.

Routine Maintenance Costs

Routine maintenance costs include the cost of grading, brush control, minor surfacing repairs, sanding, snowplowing, ditch maintenance and repair, replacement of culverts, slough removal, waterbar construction, seasonal erosion control and putting roads to bed.[8] In Zone 2 (South), which includes the Campbell River Forest District, these costs were estimated in the coastal manual to be $\$1.86/m^3$.

Overhead Costs

Overhead costs include "all aspects of executive and administrative support functions at the company Head Office, operating and support costs of logging and log supply departments, all right-of-way easements, foreshore and other land leases necessary for the logging function, and the consolidated corporate Forest Management Engineering functions."[9] The coastal manual estimated these costs to be $\$10.73/m^3$.

Road Development Costs

Road development costs have typically been a major component of harvesting old growth timber in the province. However, road development costs for commercial thinning in the Sayward Forest have been very modest, averaging approximately $\$1.50/m^3$ (McKerricher, pers. comm., 1992). Average thinning harvests have averaged approximately 200 m^3/ha resulting in an average road development cost of only $300/ha. Development costs have been this low due to the existing network of major haul roads and a system of old logging railroad grades which have been easily upgraded to provide access to the sites. As there are many other coastal areas which share these characteristics, a low development cost of $300/ha was used in the base case analysis. However, the sensitivity of the results to changes in development cost was tested, as discussed in Section 7 below.

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[7] See Section 4.5.1 of the Coast Appraisal Manual.
[8] See Section 4.5.3 of the Coast Appraisal Manual.
[9] See Section 4.6.1 of the Coast Appraisal Manual.

Total Costs

Using the harvesting and road development cost assumptions described above the total cost of harvesting the thinnings and the final clear-cuts were estimated. The estimated average total cost of commercial thinnings varied from a low of $33.59/m³ for the heaviest thinnings to a high of $44.40/m³ for the lightest thinnings. The higher thinning costs result from the low volume cost adjustment, particularily for light thinnings, and the averaging of the road development costs over a small thinning harvest volume.

For the thinned stands the average total cost of the final harvest varied from $25.28/m³ to $29.91/m³, while the cost for the unthinned stands varied from $27.48/m³ to $32.86/m³. The closeness of the harvesting cost between the thinned and unthinned stand may be surprising but results from two factors. First, the average cost for the unthinned stands included road development costs which were absent for the thinned stands as this cost was incurred at the time of the thinning. Second, while the unthinned stands had a higher volume per hectare, which lowered average cost, they also had a higher number of stems per hectare, which raised average cost as shown in the tree-to-truck cost equation.

5.4 Initial Assessment of the Viability of Commercial Thinning

The first test of the viability for commercial thinning would be whether the estimated total revenue from the thinning was sufficient to cover the total cost of the thinnings. Tables 5-2 to 5-4 show the estimated revenue, cost and profit (loss) per m³ harvested for each thinning intensity, each site index and each thinning age. The table show that average harvest costs dropped sharply as the thinning intensity increased. This is due, as noted above, to the ability to average the fixed development cost over a larger volume plus a drop in the tree-to-truck costs. Average revenues on the other hand increased rapidly with thinning intensity due to the harvesting of larger and more valuable trees.

Not surprisingly, in all cases the heaviest thinning, thinning to 200 leave trees per hectare, produced the greatest net revenue with net revenues dropping sharply as the thinning intensity declines. In simulations which included thinning to 600 or 800 stems per hectare the thinning resulted in a negative net return. In addition, except for the very lightest thinnings the profitability of the thinnings increased as the age at which the thinning took place was increased.

For each initial density the average net profit per m³ from the commercial thinning increased as the age at which the thinning took place was increased. This would be due to the combination of a higher thinning volume and to a higher average volume per tree harvested by the thinning as was shown in Table 4-8. The average value of the timber from the thinning also increased as the thinning age was increased.

Generally the thinnings from the PCT to 1,100 and 800 SPH stands provided the highest average net profit per m³. While these stands would produce a lower thinning harvest than the No PCT stands the average value per m³ of the timber from the thinnings of the PCT stands was higher which more than offset the lower total volume. However, for the PCT to 500 SPH stands the higher value of the timber from the thinnings could not offset the lower thinning volume.

While this initial assessment of the viability of commercial thinning will help eliminate thinning regimes which would generate a net loss from the thinning harvest we have not yet taken into account the effect of the thinning on the net returns from the final harvest. The selection of the thinning intensity and age will be a balancing of the expected effect of the thinning on the final harvest and the need to provide sufficient volume to make the commercial thinning financially feasible.

TABLE 5-2
COMMERCIAL THINNING REVENUES, COSTS AND PROFITS
SITE INDEX 36

Regime	Total Revenue ($/ha)	Total Cost ($/ha)	Total Profit ($/ha)	Average Revenue ($/m³)	Average Cost ($/m³)	Average Profit ($/m³)
No PCT Thinned at 30						
200	6519	6261	258	37.98	36.48	1.50
300	5155	5275	-120	36.29	37.13	-0.84
400	4031	4399	-368	34.68	37.85	-3.17
600	2534	2913	-379	34.63	39.80	-5.17
No PCT Thinned at 40						
200	11860	9499	2361	43.10	34.52	8.58
300	8751	7435	1316	41.20	35.00	6.20
400	6348	5792	556	39.36	35.91	3.45
600	3128	3381	-253	35.75	38.64	-2.89
800	1500	1866	-366	34.39	42.77	-8.38
No PCT Thinned at 50						
200	15663	11717	3946	45.24	33.84	11.40
300	10711	8490	2221	43.54	34.51	9.03
400	7065	6018	1047	41.41	35.27	6.14
600	2877	3068	-191	36.20	38.60	-2.40
800	1186	1530	-344	34.41	44.40	-9.99
PCT to 1,100 SPH Thinned at 30						
200	6190	5526	664	39.75	35.49	4.26
300	4732	4419	313	38.86	36.29	2.57
400	3416	3468	-52	36.89	37.45	-0.56
PCT to 1,100 SPH Thinned at 40						
200	11780	8901	2879	45.33	34.25	11.08
300	8395	6674	1721	43.83	34.85	8.98
400	5620	4826	794	41.49	35.63	5.86
600	2172	2254	-82	38.03	39.46	-1.43
PCT to 1,100 SPH Thinned at 50						
200	15576	11284	4292	46.40	33.61	12.79
300	10276	7852	2424	45.00	34.38	10.62
400	6475	5243	1232	43.62	35.32	8.30
600	2109	2145	-36	38.67	39.33	-0.66
PCT to 800 SPH Thinned at 30						
200	5194	4673	521	39.71	35.72	3.98
300	3694	3469	225	39.02	36.64	2.38
400	2372	2434	-62	37.51	38.49	-0.98
PCT to 800 SPH Thinned at 40						
200	10477	7887	2590	45.56	34.30	11.26
300	7130	5522	1608	45.32	35.10	10.22
400	4229	3569	660	43.14	36.40	6.74
PCT to 800 SPH Thinned at 50						
200	14469	10369	4100	46.87	33.59	13.28
300	9145	6760	2385	46.72	34.53	12.19
400	5056	3979	1077	45.71	35.97	9.74
PCT to 500 SPH Thinned at 30						
200	3427	3126	301	40.42	36.87	3.55
PCT to 500 SPH Thinned at 40						
200	7509	5718	1791	45.72	34.81	10.91
PCT to 500 SPH Thinned at 50						
200	11036	8021	3015	46.69	33.93	12.76

TABLE 5-3
COMMERCIAL THINNING REVENUES, COSTS AND PROFITS
SITE INDEX 30

Regime	Total Revenue ($/ha)	Total Cost ($/ha)	Total Profit ($/ha)	Average Revenue ($/m³)	Average Cost ($/m³)	Average Profit ($/m³)
No PCT Thinned at 40						
200	8007	7264	743	39.13	35.50	3.63
300	6449	6064	385	38.55	36.24	2.30
400	5064	4999	65	37.51	37.03	0.48
600	2859	3241	-382	34.44	39.03	-4.60
No PCT Thinned at 50						
200	11810	9429	2381	43.26	34.54	8.72
300	8757	7434	1323	41.23	35.00	6.23
400	6417	5826	591	39.54	35.90	3.64
600	3265	3482	-217	36.05	38.44	-2.39
800	1555	1929	-374	34.21	42.45	-8.24
No PCT Thinned at 60						
200	14275	11049	3226	43.98	34.04	9.94
300	10280	8268	2012	43.07	34.64	8.43
400	7011	6069	942	40.78	35.30	5.48
600	3202	3326	-124	36.84	38.27	-1.43
800	1381	1543	-162	34.24	38.27	-4.03
PCT to 1,100 SPH Thinned at 40						
200	7841	6625	1216	41.43	35.01	6.42
300	6033	5222	811	41.05	35.53	5.52
400	4489	4001	488	40.69	36.27	4.42
PCT to 1,100 SPH Thinned at 50						
200	11572	8824	2748	44.96	34.28	10.68
300	8306	6672	1634	43.40	34.86	8.54
400	5640	4861	779	41.31	35.61	5.70
600	2228	2309	-81	37.90	39.27	-1.37
PCT to 1,100 SPH Thinned at 60						
200	13917	10370	3547	45.44	33.86	11.58
300	9664	7472	2192	44.69	34.55	10.14
400	6297	5187	1110	42.98	35.40	7.58
600	2264	2289	-25	38.66	39.08	-0.42
PCT to 800 SPH Thinned at 40						
200	6842	5697	1145	42.22	35.15	7.07
300	4813	4196	617	41.23	35.95	5.28
400	3229	2919	310	41.22	37.26	3.96
PCT to 800 SPH Thinned at 50						
200	10420	7870	2550	45.42	34.31	11.11
300	7088	5573	1515	44.63	35.09	9.54
400	4240	3660	580	42.07	36.31	5.76
PCT to 800 SPH Thinned at 60						
200	13013	9463	3550	46.55	33.85	12.70
300	8510	6409	2101	46.07	34.70	11.37
400	4948	3989	959	44.64	35.99	8.65
PCT to 500 SPH Thinned at 40						
200	4571	3881	690	42.42	36.01	6.41
PCT to 500 SPH Thinned at 50						
200	7455	5680	1775	45.71	34.83	10.88
PCT to 500 SPH Thinned at 60						
200	9625	7181	2444	45.86	34.21	11.65

TABLE 5-4
COMMERCIAL THINNING REVENUES, COSTS AND PROFITS
SITE INDEX 24

Regime	Total Revenue ($/ha)	Total Cost ($/ha)	Total Profit ($/ha)	Average Revenue ($/m³)	Average Cost ($/m³)	Average Profit ($/m³)
No PCT Thinned at 50						
200	7474	6933	541	38.97	36.15	2.82
300	6001	5847	154	37.78	36.81	0.97
400	4711	4895	-184	36.09	37.50	-1.41
600	2875	3298	-423	34.23	39.26	-5.03
No PCT Thinned at 60						
200	9273	8199	1074	39.56	34.98	4.58
300	7348	6773	575	38.89	35.85	3.04
400	5767	5462	305	38.47	36.43	2.04
600	3184	3515	-331	35.24	38.91	-3.67
800	1678	2079	-401	34.15	42.30	-8.15
No PCT Thinned at 70						
200	11056	9326	1730	41.06	34.63	6.43
300	8322	7381	941	39.56	35.09	4.47
400	6214	5767	447	38.50	35.73	2.77
600	3251	3567	-316	35.26	38.69	-3.43
800	1655	2051	-396	34.15	42.32	-8.17
PCT to 1,100 SPH Thinned at 50						
200	6990	6104	886	40.35	35.23	5.11
300	5402	4839	563	39.93	35.77	4.16
400	3935	3766	169	38.51	36.86	1.65
PCT to 1,100 SPH Thinned at 60						
200	9179	7503	1676	42.45	34.70	7.75
300	6778	5792	986	41.24	35.24	6.00
400	4879	4341	538	40.44	35.98	4.46
600	1990	2182	-192	36.47	40.00	-3.53
PCT to 1,100 SPH Thinned at 70						
200	11254	8630	2624	44.79	34.35	10.44
300	8040	6494	1546	43.26	34.94	8.32
400	5464	4726	738	41.29	35.71	5.58
600	2121	2238	-117	37.63	39.70	-2.07
PCT to 800 SPH Thinned at 50						
200	6105	5255	850	41.10	35.38	5.72
300	4337	3929	408	39.94	36.18	3.75
400	2903	2768	135	39.36	37.53	1.83
PCT to 800 SPH Thinned at 60						
200	8353	6602	1751	43.98	34.76	9.22
300	5785	4810	975	42.72	35.52	7.20
400	3699	3274	425	41.53	36.76	4.77
PCT to 800 SPH Thinned at 70						
200	10122	7709	2413	45.11	34.36	10.75
300	6923	5479	1444	44.40	35.14	9.26
400	4189	3602	587	42.31	36.38	5.93
PCT to 500 SPH Thinned at 50						
200	4131	3389	742	43.18	35.42	7.76
PCT to 500 SPH Thinned at 60						
200	5711	4521	1190	44.85	35.50	9.35
PCT to 500 SPH Thinned at 70						
200	7107	5471	1636	45.37	34.93	10.44

5.5 Comparison of the Estimated Revenues and Costs to Actual Commercial Thinning Revenues and Costs

In order to validate the revenue and costs estimates developed above they were compared to actual harvesting results from commercial thinning operations in the Sayward Forest harvested under the Small Business Forest Enterprise Program (SBFEP). In the Sayward Forest commercial thinning in 45 to 60 year-old Douglas-fir stands thinned to between 250 and 350 leave trees per hectare have recently produced timber with an average value of approximately $\$45/m^3$ (McKerricher, pers. comm., 1992). Discussions with two commercial thinning operators working in the Sayward Forest in the fall of 1992, put their estimate of their average revenues at approximately $\$48/m^3$. Comparing these average values to the estimated revenues from the simulated thinnings shows the averages to be quite close. If anything, the estimated revenues from the simulations appears to have been somewhat conservative.

Using SBFEP estimates of the average revenue derived from commercial thinning harvests, the average costs of extracting the thinnings may be imputed by subtracting the average stumpage payments determined through the SBFEP's competitive bidding process. Typical stumpage payments under this program have been approximately $\$20/m^3$ for ground skidding, $\$15/m^3$ for cable yarding and $\$9/m^3$ for horse logging operations. Thus, the average total costs for commercial thinning in the Sayward Forest would be approximately $\$25/m^3$, $\$30/m^3$ and $\$36/m^3$ for skidder, cable and horse logging respectively. Note that this estimate would include all costs including tree-to-truck, haul and overhead, plus road development costs and include the operator's allowance for profit and risk. To these estimates must be added the SBFEP's administrative costs for layout, cruising, inspection and sale of the timber. These costs are estimated to be approximately $\$8/m^3$ (McKerricher, pers. comm., 1992). This places the total cost at approximately $\$33/m^3$, $\$38/m^3$ and $\$42/m^3$ for skidder, cable and horse logging respectively. The cost estimates developed above for the simulated commercial thinnings thus typically lies between the SBFEP estimate for skidder and cable logging. Nevertheless, a range of costs was used in Section 7 in calculating the net present values of each regime in order to test the sensitivity of the base case results to changes in harvest costs.

SECTION SIX
ECONOMIC EVALUATION OF THE SIMULATED REGIMES

6.1 Introduction

Using the methods and assumptions outlined in Section 3 and the estimated revenues and costs detailed in Section 5, the net present value (NPV) derived from each regime were determined and the results are presented below. For each simulated thinning the minimum stumpage requirement, that is the minimum net revenue from the thinnings needed to make up for any differences in the final harvest and future rotations of the thinned and unthinned stands, was also estimated. The section concludes with a discussion of the economic efficiency of commercial thinning when the forest management objective is something other than the maximization of the economic benefits of timber production and a discussion of commercial thinning's role in forest level planning.

6.2 Estimated Net Present Values

The estimated NPVs of each growing regime and thinning intensity are displayed in Figures 6-1 to 6-12, while Table 6-1 to 6-3 present the maximum NPV for each regime and the rotation age at which the maximum NPV occured. Note that the tables must be used in conjunction with the diagrams because, in some cases, the optimum NPV of the unthinned simulations occurred at a much earlier age than that of the thinned simulations and thus the maximum NPV of the unthinned simulations may not be shown in the range of ages used in the diagrams.

The site index 36 simulations reveal that commercial thinning in the range of 200 to 400 leave trees per hectare is economically superior to the unthinned simulations for all initial densities simulated. At site index 30, thinning in the range of 200 to 300 leave trees per hecatre was superior at the early and mid thinning ages for the No PCT simulations and thinning to 200 leave trees per hectare was superior at the late thinning age. For the site index 30 simulations which included a PCT, all commercial thinning simulations were superior to the unthinned simulations. For the No PCT simulations at site index 24, only one of the lighter commercial thinnings simulated provided a NPV which was just larger than the NPV of the unthinned simulation at both the early and mid thinning ages but all commercial thinnings had a lower NPV at the late thinning age. For site index 24 stands which had been PCT to 1,100 SPH or 800 SPH, the unthinned simulations were in all cases superior to the commercial thinned simulations. However, the thinned simulations dominated for the site index 24 thinned to 500 SPH simulations. Where commercial thinning proved to be the economically superior to the unthinned simulations the potential increase in the NPV of the simulated stands ranged from 2-20% at site index 36, from 3-30% at site index 30, and from 9-14% at site index 24. While these potential increases in the NPV of the stands are not trivial they are by no means massive either. Thus, the economic gain from commercial thinning will, by themselves, be modest but still potentially well worth pursuing.

The higher NPV provided by some of the commercial thinning regimes can be attributed to two factors. First, the thinnings concentrated the stand's growth on the larger dominant trees which produced a higher value per m^3 of wood grown. Second, the thinnings produced interim revenues through the harvesting of trees who's timber values would have grown at a rate lower than the social discount rate. Typically the NPV of the thinned regimes drops off quickly as the thinning intensity was reduced. This highlights the economic advantage obtained from an early financial return from the stand. Using an investment analogy, if the stand is viewed as an investment portfolio and each tree as a separate stock than the commercial thinning may be viewed as the liquidation of those stocks producing the poorest investment yields. In addition, the thinning has the added advantage of increasing the returns on the remainder of the investment portfolio - the leave trees.

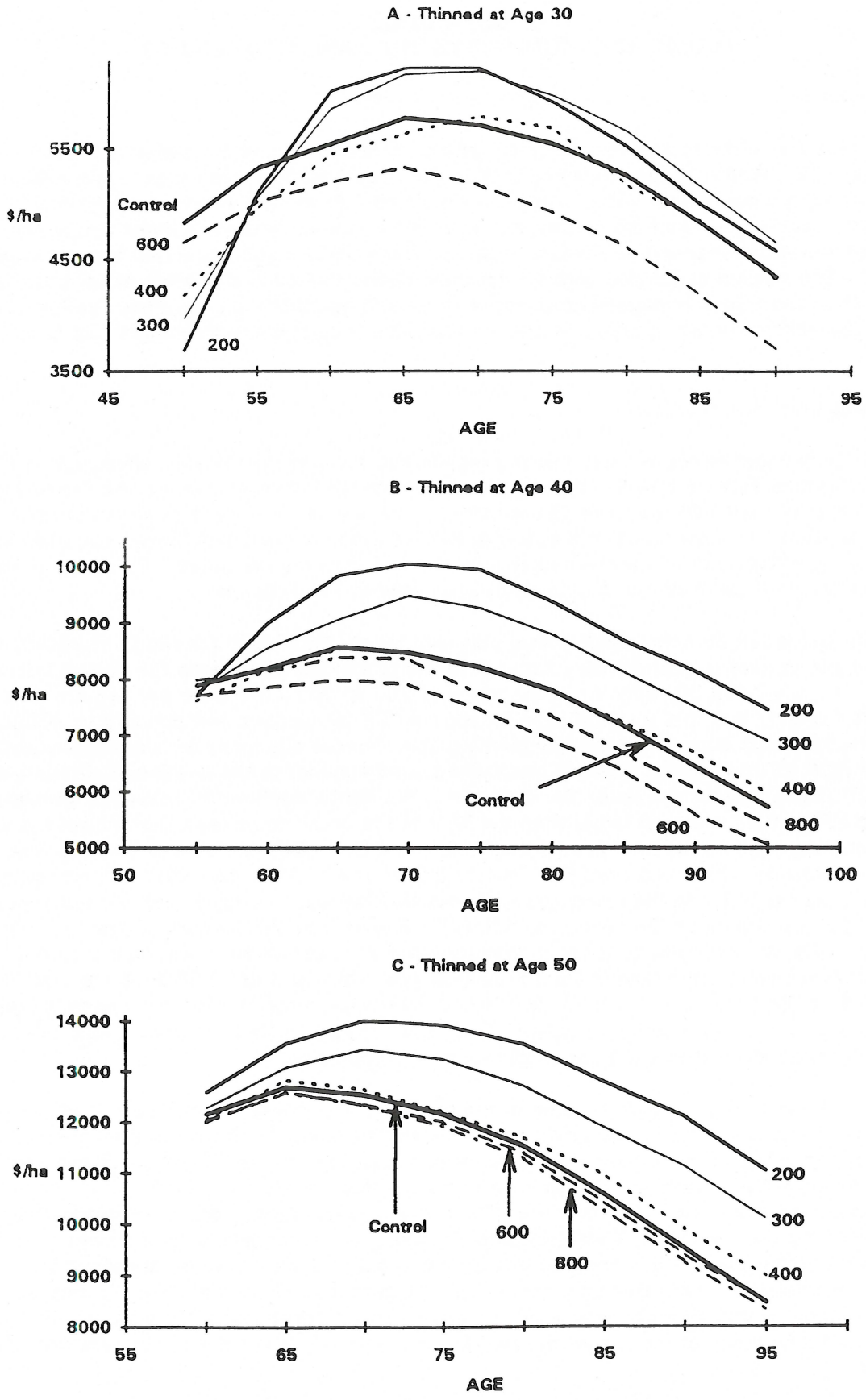


FIGURE 6-1 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES
SITE INDEX 36, NO PRE-COMMERCIAL THIN

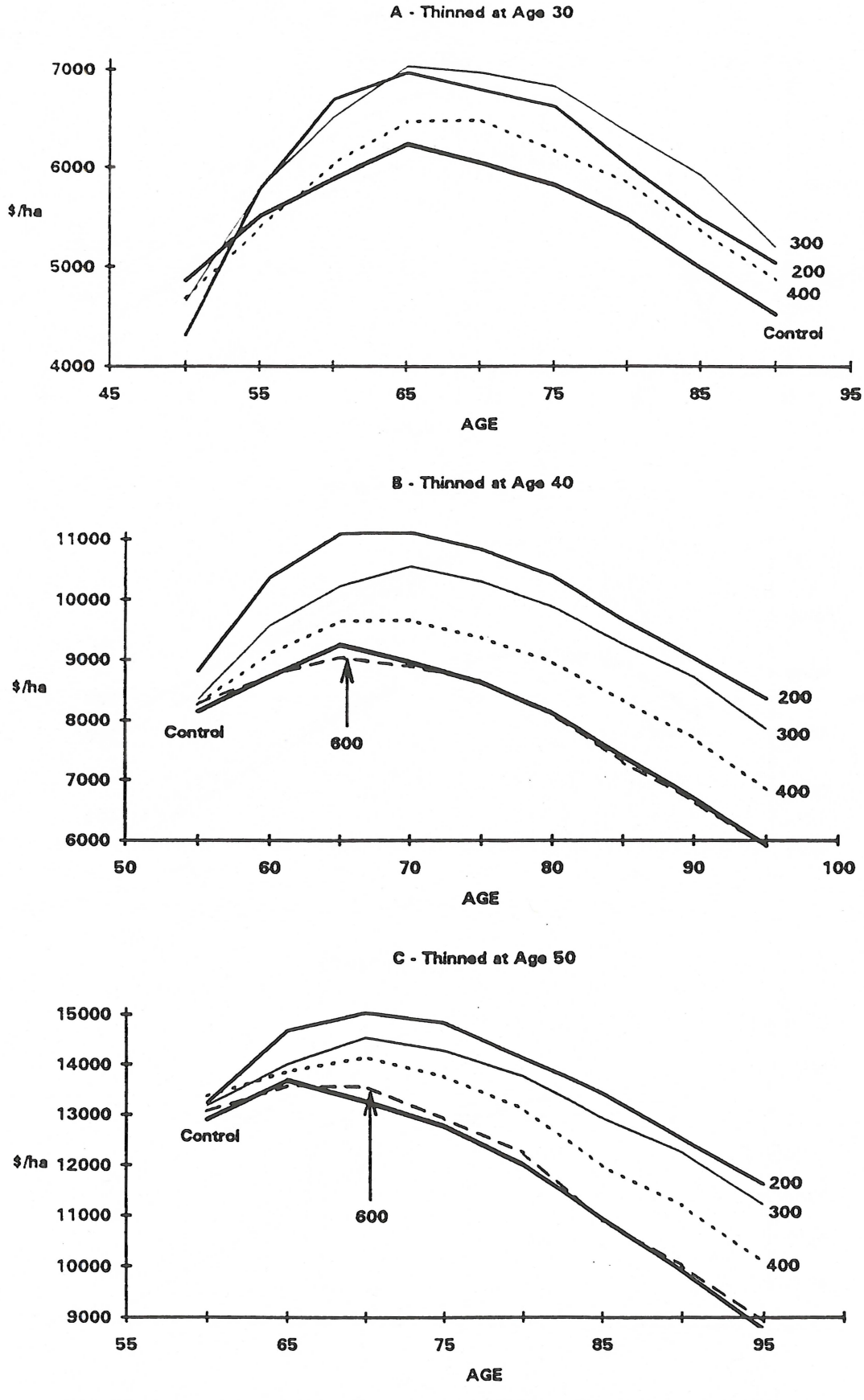
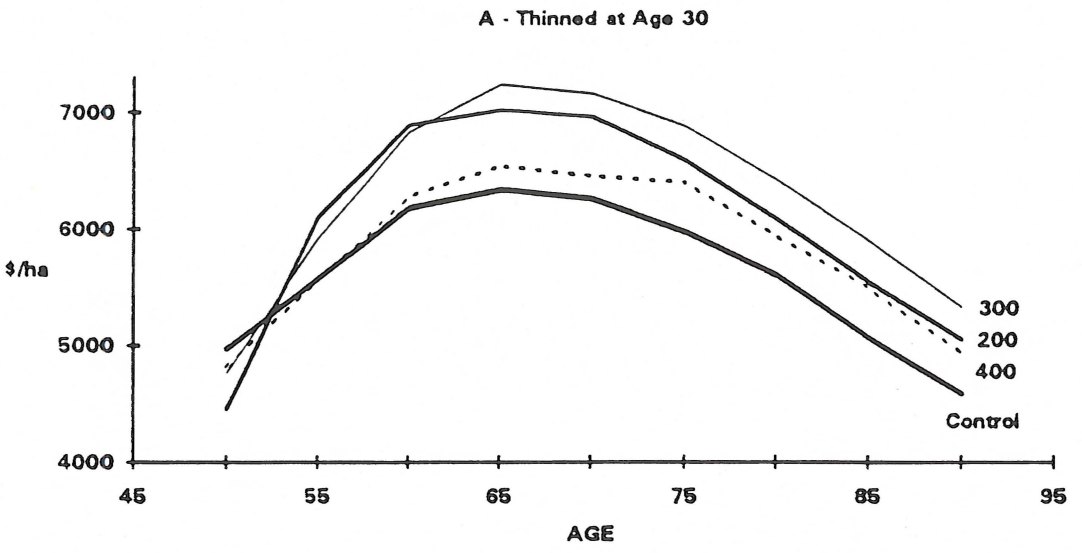
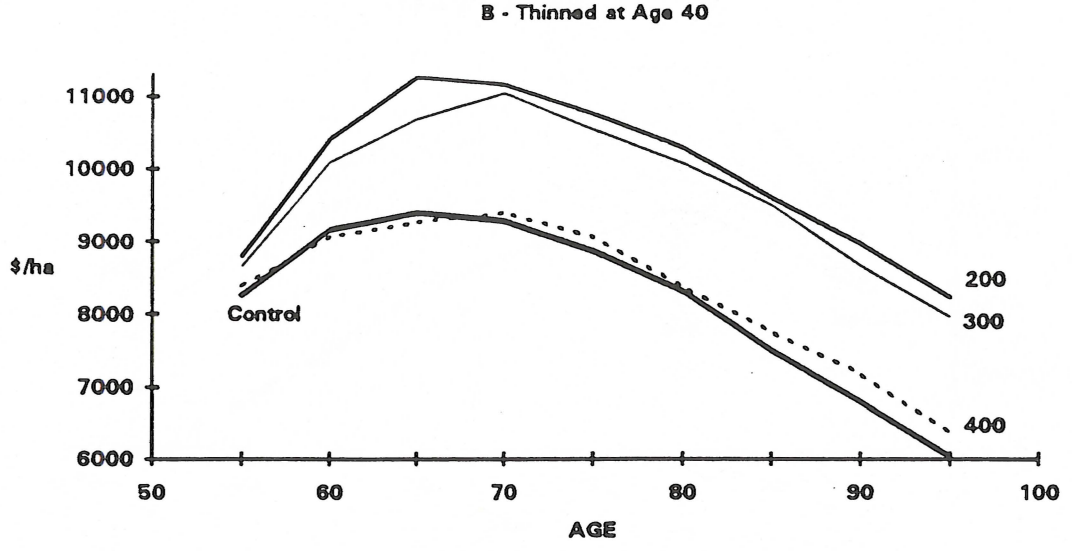


FIGURE 6-2 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 36, PRE-COMMERCIAL THINNED TO 1,100 SPH





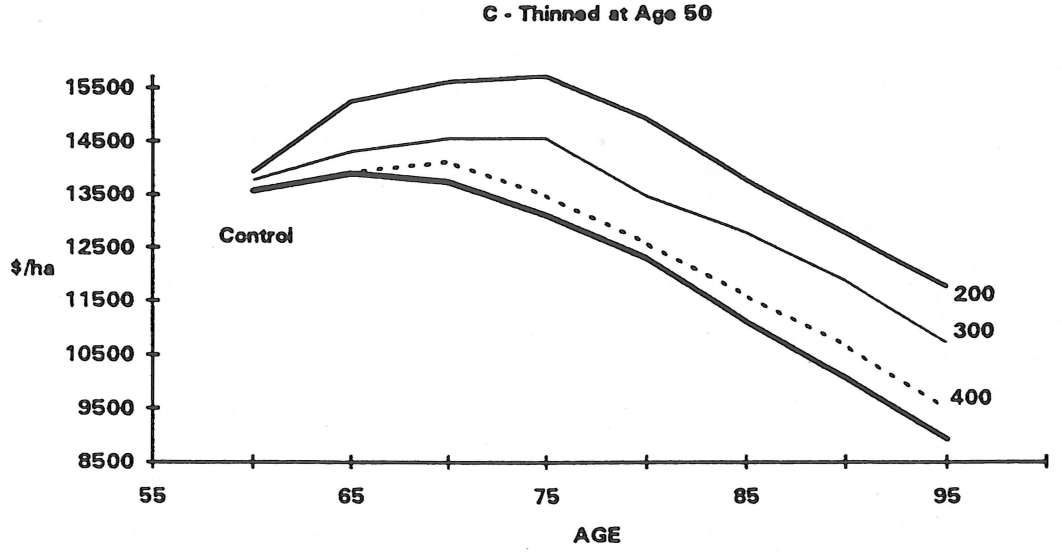
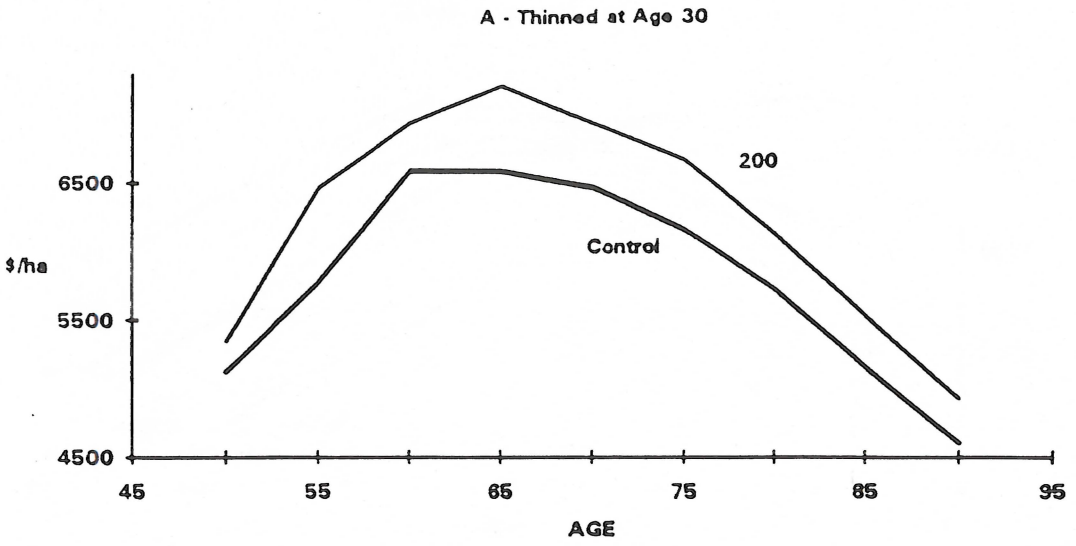
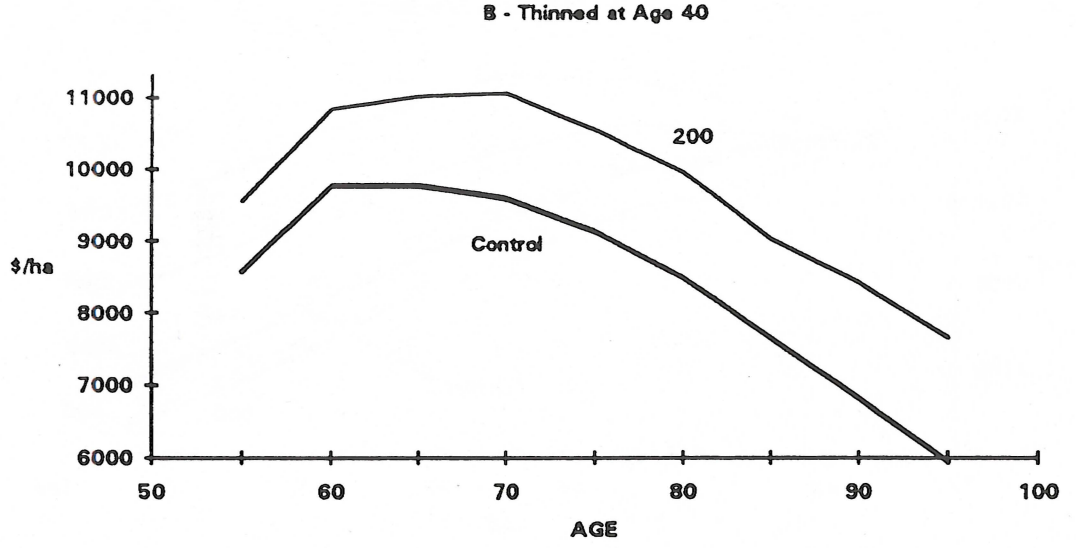


FIGURE 6-3 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 36, PRE-COMMERCIAL THINNED TO 800 SPH





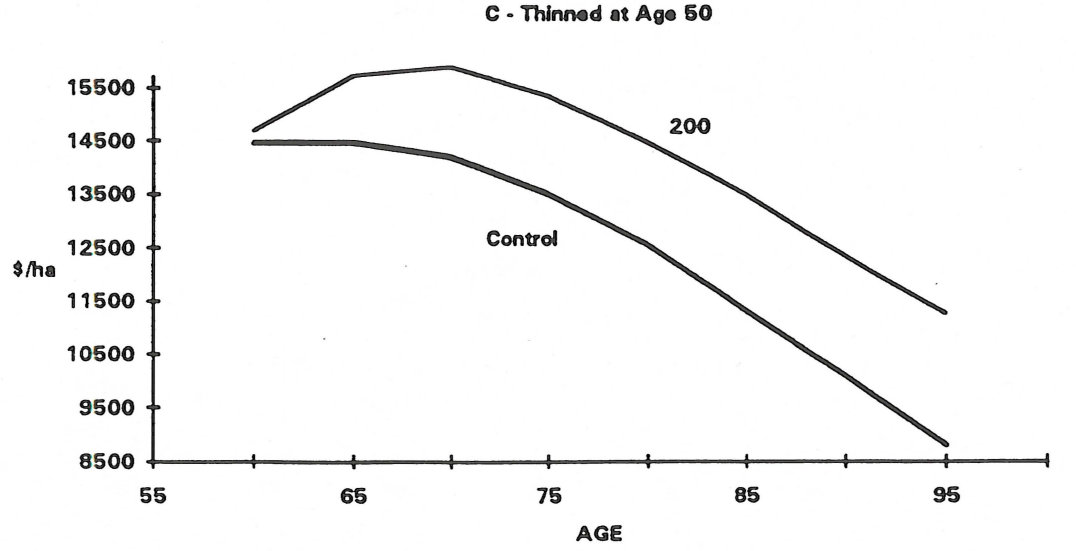


FIGURE 6-4 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES
SITE INDEX 36, PRE-COMMERCIAL THINNED TO 500 SPH

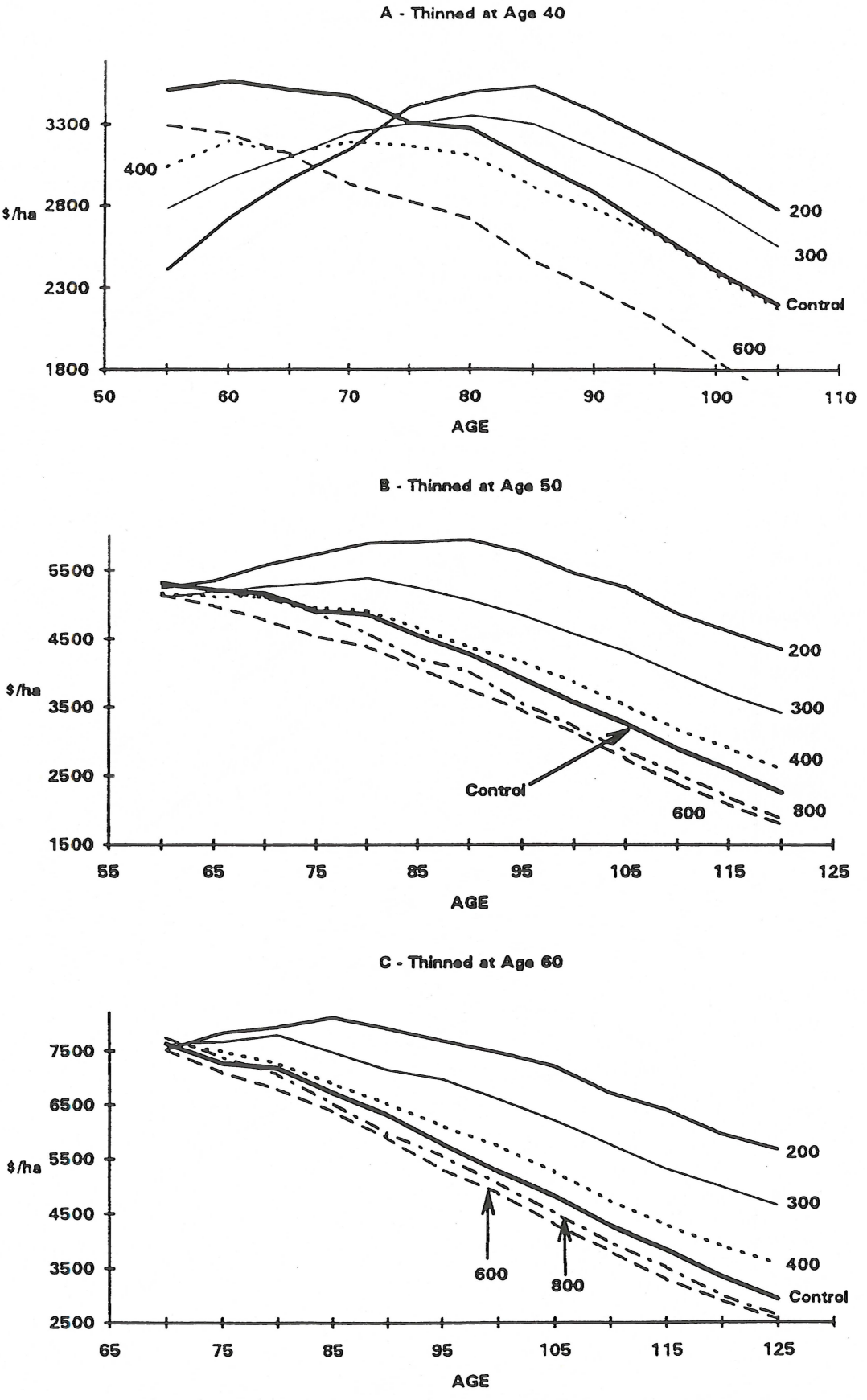


FIGURE 6-5 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 30, NO PRE-COMMERCIAL THIN

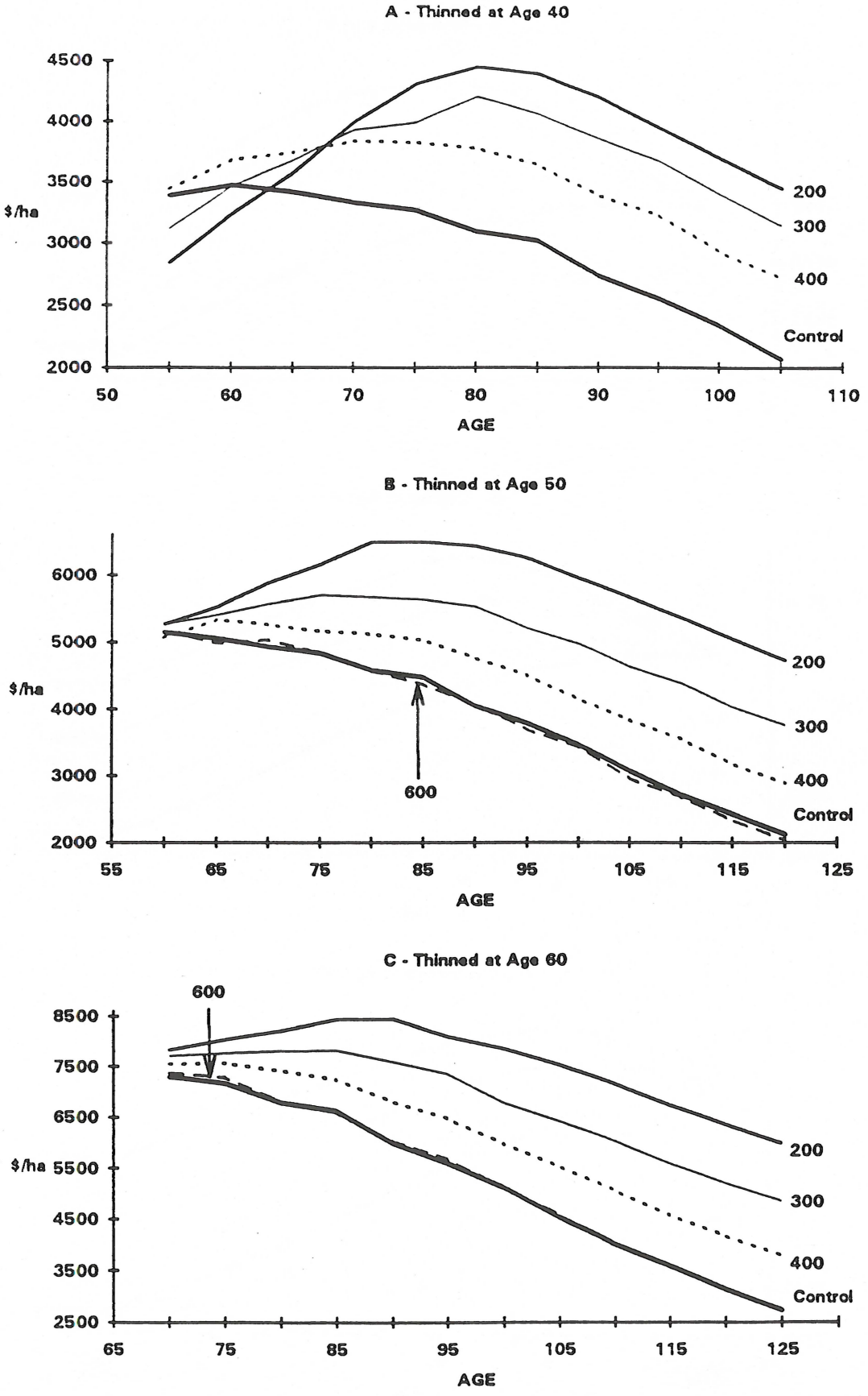
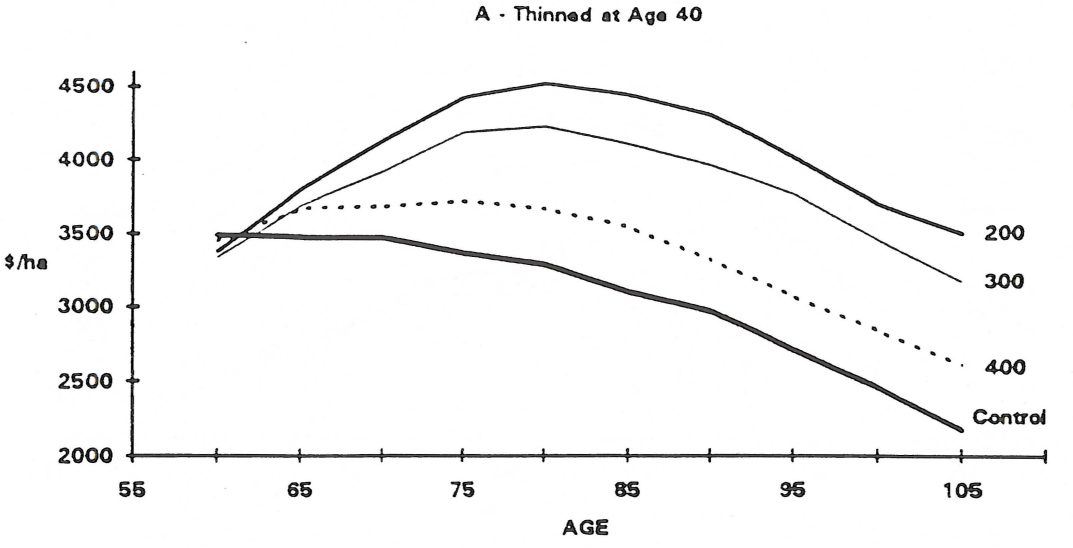
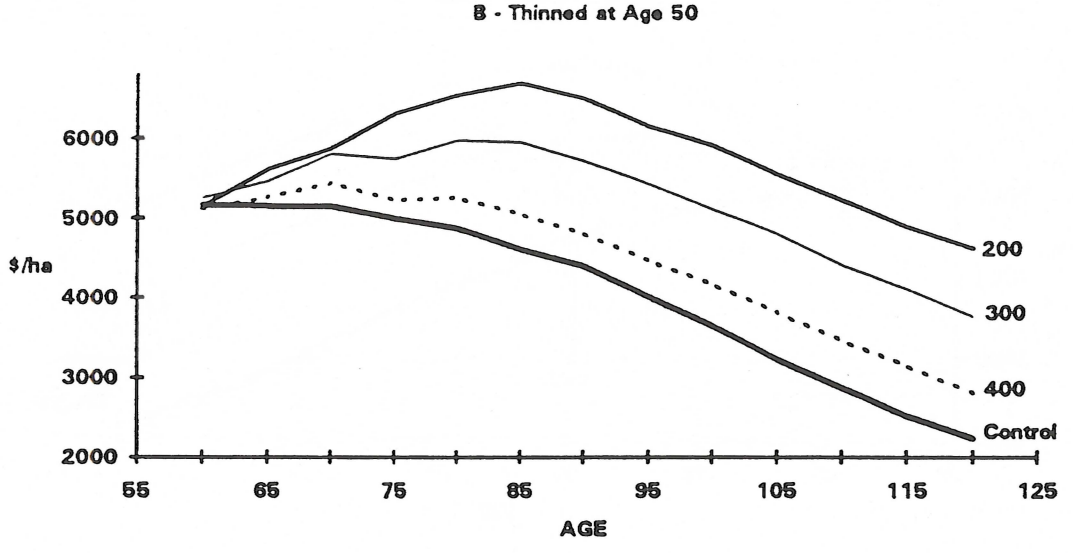


FIGURE 6-6 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 30, PRE-COMMERCIAL THINNED TO 1,100 SPH





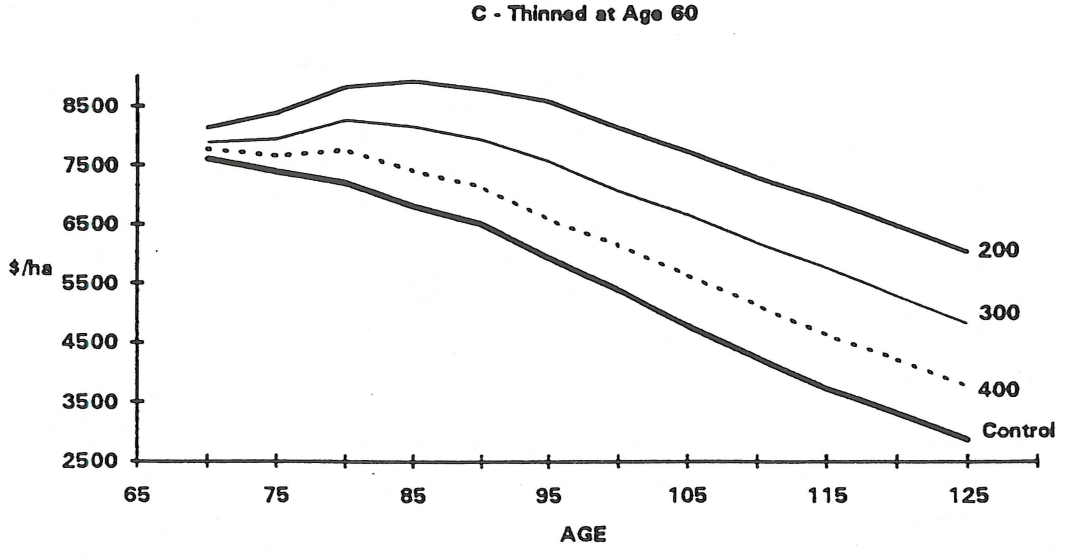


FIGURE 6-7 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 30, PRE-COMMERCIAL THINNED TO 800 SPH

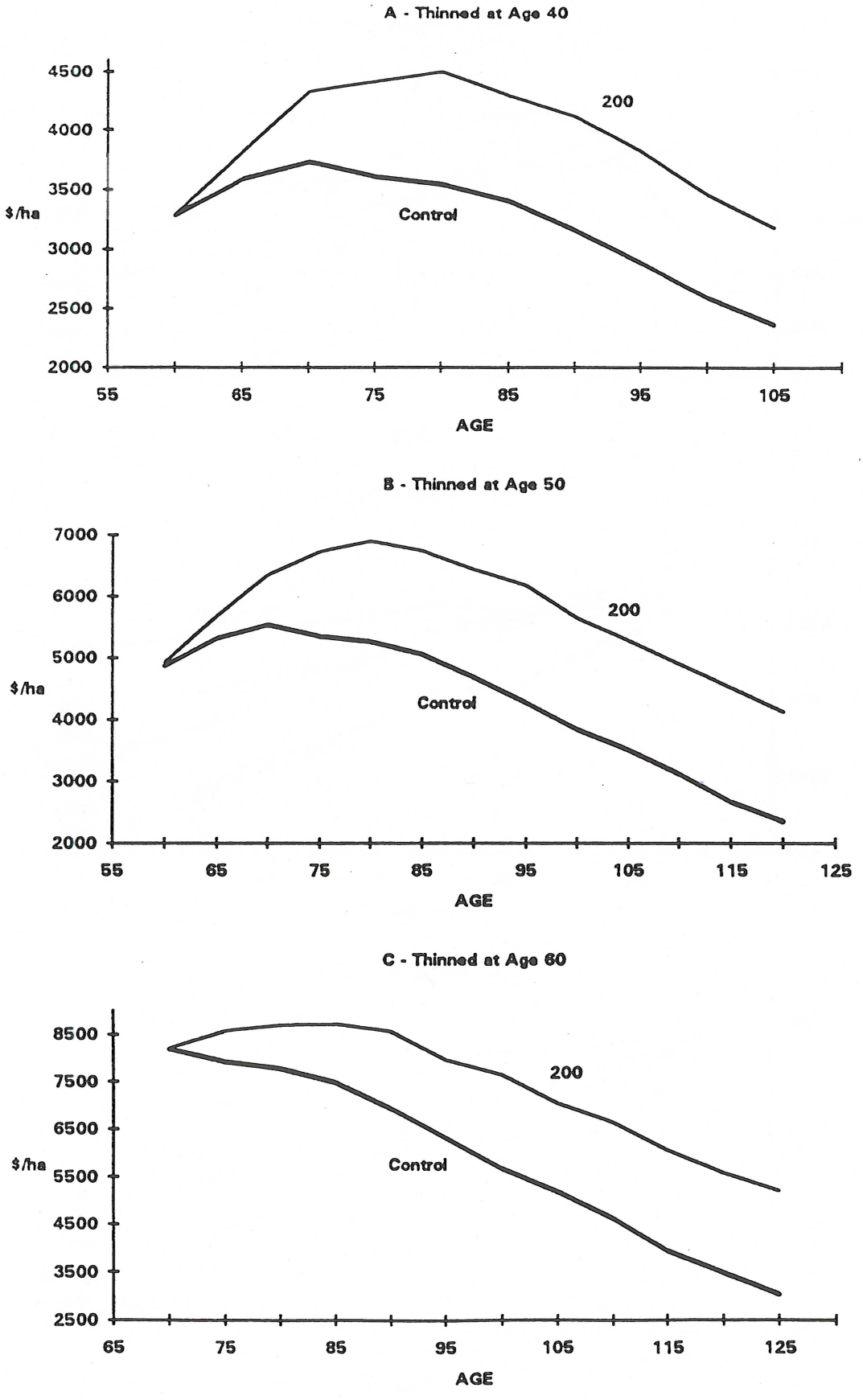


FIGURE 6-8 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 30, PRE-COMMERCIAL THINNED TO 500 SPH

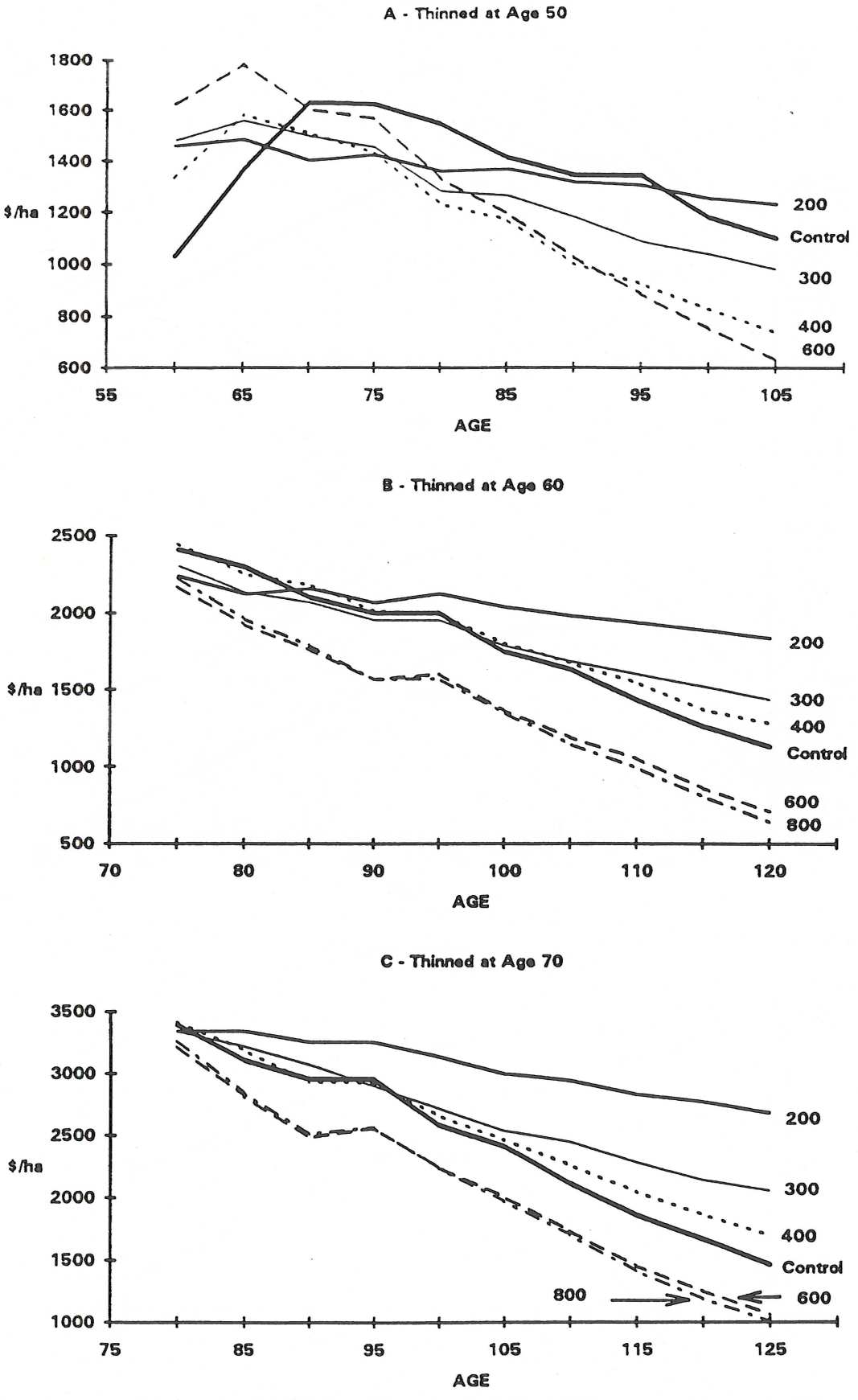


FIGURE 6-9 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 24, NO PRE-COMMERCIAL THIN

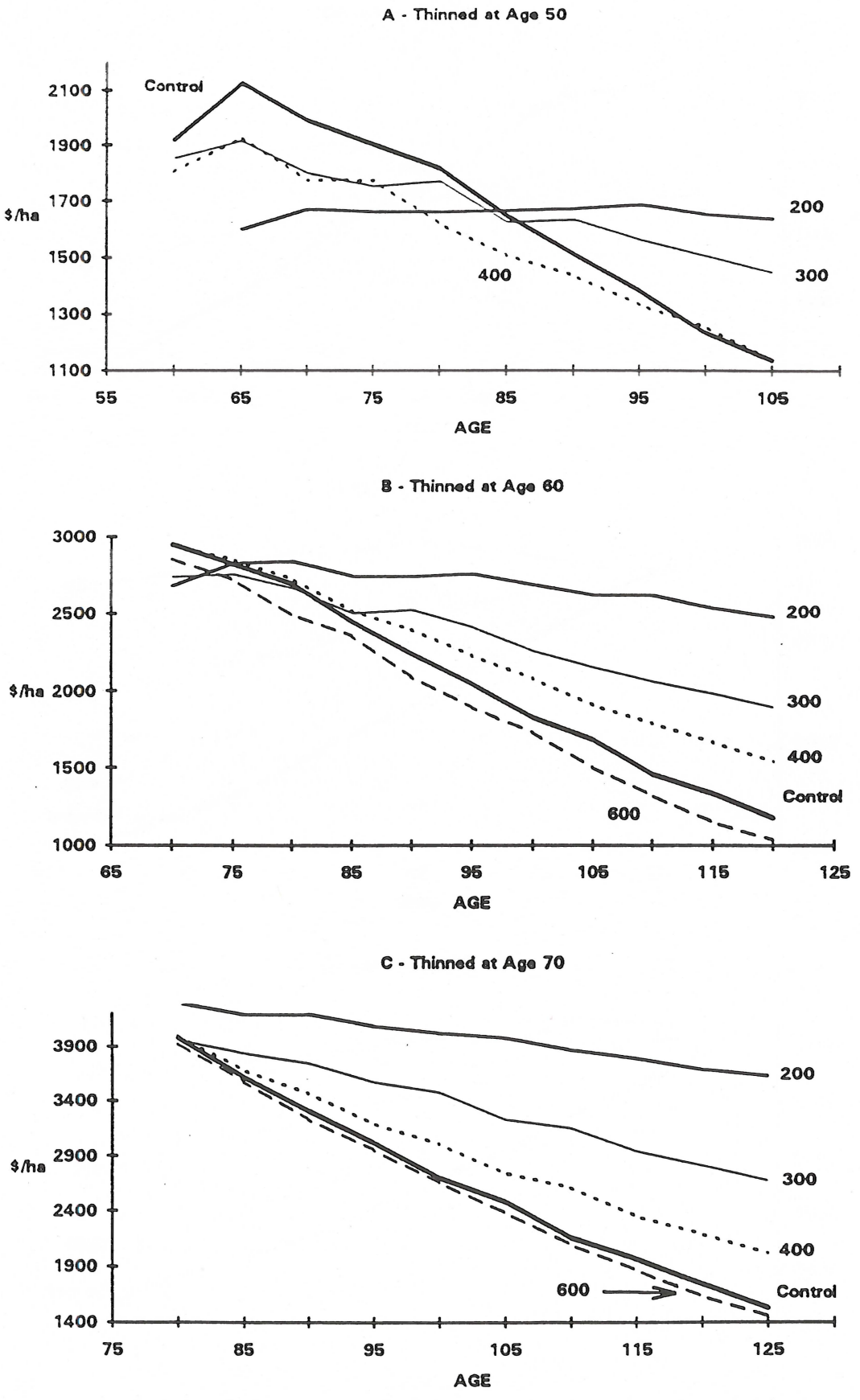


FIGURE 6-10 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 24, PRE-COMMERCIAL THINNED TO 1,100 SPH

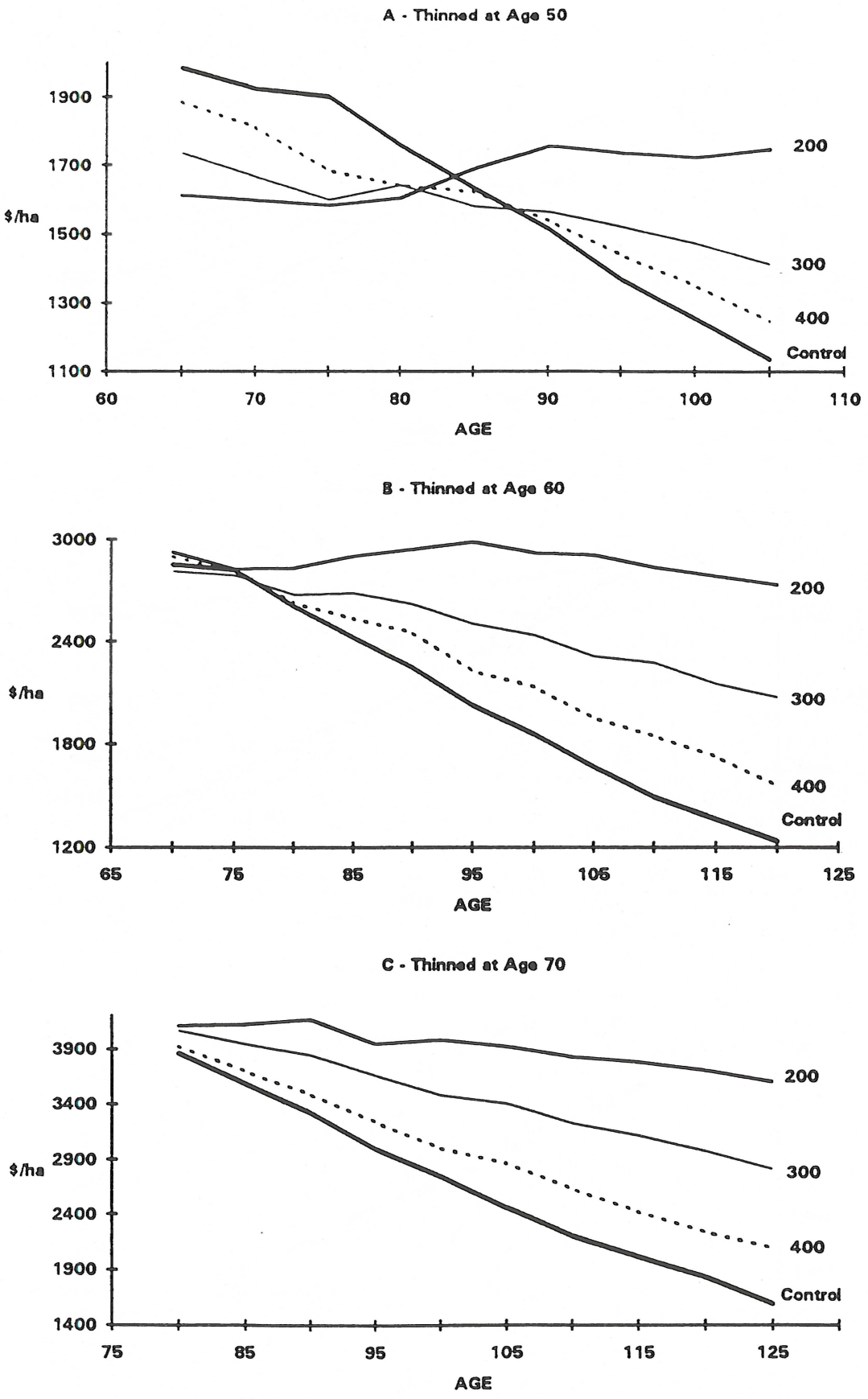


FIGURE 6-11 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES SITE INDEX 24, PRE-COMMERCIAL THINNED TO 800 SPH

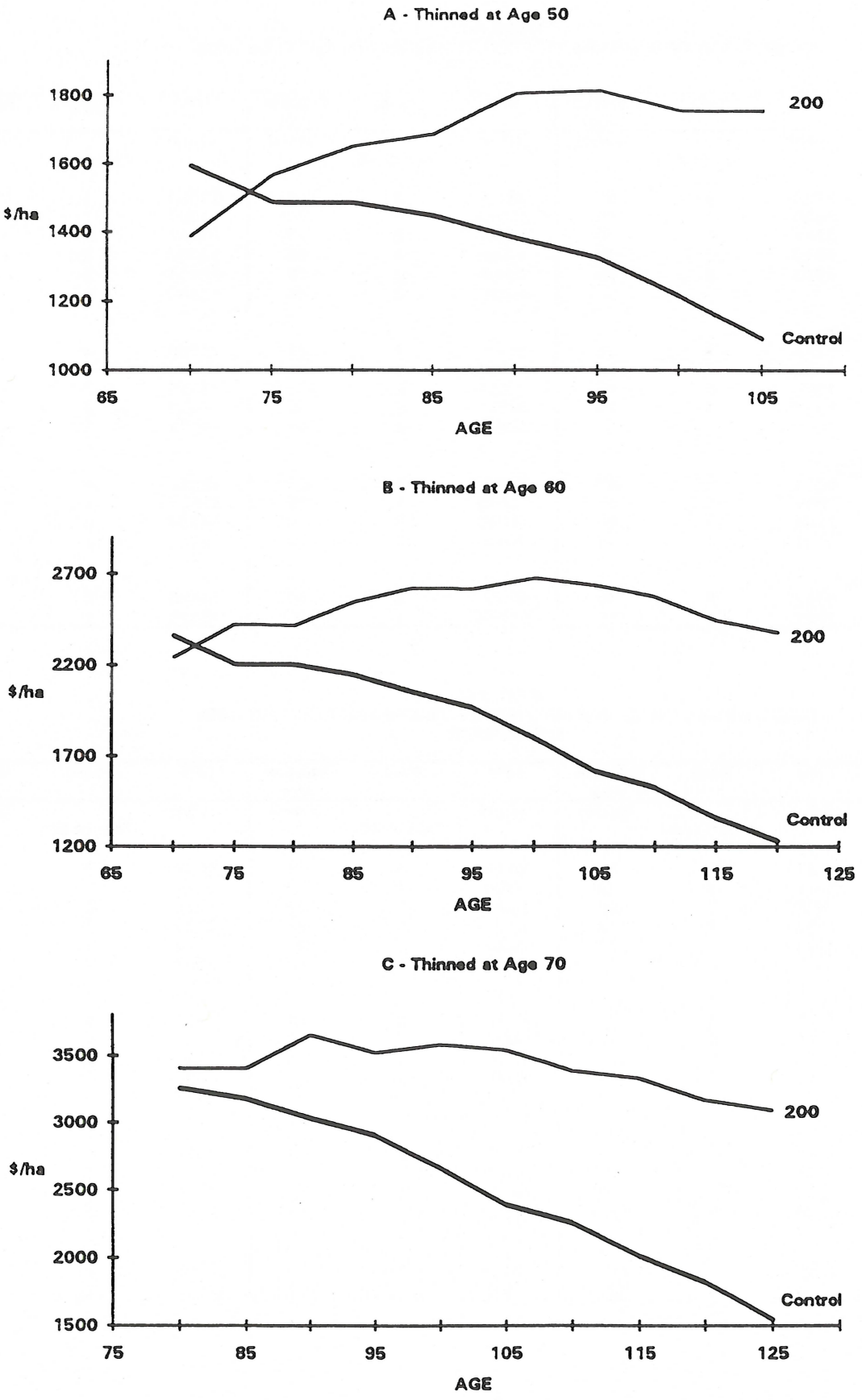


FIGURE 6-12 NET PRESENT VALUES OF ALTERNATE GROWING REGIMES
SITE INDEX 24, PRE-COMMERCIAL THINNED TO 500 SPH

TABLE 6-1
COMPARISON OF MAXIMUM NET PRESENT VALUES AND ROTATION AGES
SITE INDEX 36

Regime	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age
	($/ha)		(years)	($/ha)		(years)	($/ha)		(years)
		Thin at 30			Thin at 40			Thin at 50	
No PCT									
Unthinned	5792	4	65	8574	3	65	12692	4	65
200	6260	1	65	10049	1	70	14009	1	70
300	6232	2	70	9487	2	70	13441	2	70
400	5810	3	70	8545	4	65	12837	3	65
600	5343	5	65	7998	6	65	12606	5	65
800	-		-	8401	5	65	12590	6	65
PCT to 1,100 SPH									
Unthinned	6246	4	65	9246	4	65	13686	4	65
200	6983	2	65	11112	1	70	15029	1	70
300	7055	1	65	10551	2	70	14550	2	70
400	6497	3	70	9658	3	70	14150	3	70
600	-		-	9044	5	65	13573	5	65
PCT to 800 SPH									
Unthinned	6344	4	65	9390	4	65	13900	4	65
200	7035	2	65	11266	1	65	15695	1	75
300	7261	1	65	11040	2	70	14554	2	75
400	6551	3	65	9396	3	70	14115	3	70
PCT to 500 SPH									
Unthinned	6602	2	60	9772	2	60	14465	2	60
200	7242	1	65	11064	1	70	15886	1	70

TABLE 6-2
COMPARISON OF MAXIMUM NET PRESENT VALUES AND ROTATION AGES
SITE INDEX 30

Regime	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age
	($/ha)		(years)	($/ha)		(years)	($/ha)		(years)
		Thin at 40			Thin at 50			Thin at 60	
No PCT									
Unthinned	3582	1	60	5303	4	60	7849	2	60
200	3547	2	80	5950	1	90	8115	1	85
300	3366	3	80	5384	2	80	7798	3	80
400	3202	4	70	5171	5	60	7660	5	70
600	3301	5	55	5141	6	60	7524	6	70
800	-		-	5333	3	60	7747	4	60
PCT to 1,100 SPH									
Unthinned	3475	4	60	5144	5	60	7615	5	60
200	4456	1	80	6495	1	80	8442	1	90
300	4211	2	80	5701	2	75	7823	2	85
400	3841	3	70	5340	3	65	7566	3	75
600	-		-	5167	4	60	7377	4	70
PCT to 800 SPH									
Unthinned	3494	4	60	5171	4	60	7655	4	60
200	4544	1	80	6697	1	85	8925	1	85
300	4243	2	80	5974	2	80	8264	2	80
400	3730	3	75	5442	3	70	7781	3	70
PCT to 500 SPH									
Unthinned	3741	2	70	5538	2	70	8198	2	70
200	4512	1	80	6902	1	80	8714	1	85

TABLE 6-3
COMPARISON OF MAXIMUM NET PRESENT VALUES AND ROTATION AGES
SITE INDEX 24

Regime	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age	NPV	Rank	Rotation Age
	($/ha)		(years)	($/ha)		(years)	($/ha)		(years)
		Thin at 50			Thin at 60			Thin at 70	
No PCT									
Unthinned	1637	2	70	2422	2	70	3586	1	70
200	1489	5	65	2237	4	75	3345	3	80
300	1565	4	65	2304	3	75	3340	4	80
400	1587	3	65	2448	1	75	3418	2	80
600	1792	1	65	2170	6	75	3222	5	80
800	-		-	2226	5	75	3270	6	80
PCT to 1,100 SPH									
Unthinned	2134	1	65	3159	1	65	4676	1	65
200	1688	4	95	2840	4	80	4299	2	80
300	1921	3	65	2755	5	75	3959	4	80
400	1933	2	65	2944	2	70	4001	3	80
600	-		-	2855	3	70	3927	5	80
PCT to 800 SPH									
Unthinned	1988	1	60	2943	2	60	4356	1	60
200	1759	3	90	2982	1	95	4168	2	90
300	1737	4	65	2811	4	70	4067	3	80
400	1888	2	65	2900	3	70	3927	4	80
PCT to 500 SPH									
Unthinned	1596	2	70	2363	2	70	3497	2	70
200	1821	1	95	2677	1	100	3653	1	90

The marginal return received from the simulated thinnings of the site index 24 regimes coupled with the poor volume response detailed in Section 4 suggests that site index 24 may be the lower limit of site quality for the commercial thinning of coastal Douglas-fir.

Those familiar with economic evaluations of forestry investments in British Columbia may be surprised by the robustness of the commercial thinning results, as the analysis of investments, such as forest regeneration, typically show a low return due to the long rotation ages. This means that the revenues received at final harvest from such projects are heavily discounted. However, for commercial thinnings discounting is working in the thinnings favour as the revenue from the thinning is received at the beginning of the evaluation period while the cost of the reduced final harvest is incurred at the end of the period. Thus, there is a reversal in the ordering of costs and revenues in that the net revenues of the commercial thinning are not discounted while the net cost at final harvest are discounted.

It should also be noted that, in some cases, simulations which had a negative return to the commercial thinning, as shown in Tables 5-2 to 5-4, still produced a NPV greater than the corresponding unthinned simulation. For example, thinning to 300 or 400 leave trees per hectare in the No PCT site index 36 simulations at the early thinning age produced NPVs greater than the corresponding unthinned control simulation yet had a net loss per hectare of $120 and $368 respectively from the commercial thinning. In this case, although the commercial thinning would be unprofitable, the beneficial effect of the thinning on the net revenue of the final harvest outweighed the financial loss from the thinning. In cases like this the thinning should be considered a silvicultural treatment rather than as a true commercial thinning.

At any given thinning age and site index the regimes that included a PCT yielded the highest NPVs. At site index 36 and 30 the maximum NPV varied between the three PCT levels but at site index 24 it was the PCT to 1,100 SPH regime which always dominated. Note that the higher NPVs do not provide a justification to PCT a stand because, as we are comparing established stands well

after the PCT has taken place, the NPV would not include the cost of doing current stand's PCT. Rather the site values discussed in Section 6.5 below provide the correct means of determining the economic desirability of doing a PCT.

6.3 Optimum Rotation Ages

As noted earlier, the final harvest age corresponding to the highest NPV for the growing regime represents the optimum economic rotation for that regime. For example, for the site index 36 No PCT unthinned simulation, the highest NPV is achieved at age 65, thus age 65 would be considered the optimum economic rotation age for this regime.

At site index 36, thinning down to 200 to 400 leave trees per hectare typically had optimum economic rotation ages which were five to ten years longer than those of the corresponding unthinned stands, while the lightest thinnings had little or no effect on rotation age. At site index 30, the optimum economic rotation ages were extended considerably more by the commercial thinnings - from five to thirty years longer. For site index 24, at the early commercial thinning age, some simulations had a reduced rotation age when compared to the unthinned simulations, while at the later thinning ages the rotation were extended by five to thirty years. The age of the economic rotation typically increased with heavier thinnings. This means that the heavier thinnings increased the rate of return from the residual stand, which extends rotation age, while the lighter thinnings had little impact. The greatest difference in rotation age occurs with the site index 30 regimes and was the smallest for the site index 36 regimes.

6.4 Comparison Between Thinning Ages

Note that the NPVs for each regime were calculated using the age of the thinning as year zero, to which all discounting was calculated. Thus, when comparisons are made between the site index 36 No PCT simulations, it should be made from the view of looking at three different stands; one which is 30 years old, one which is 40 years old, and one which is 50 years old. This means that one cannot look at the higher NPV earned from the 50 year-old site index 36 stand and conclude that because it is higher than the NPV for the 40 year-old that the 40 year-old stand should be left ten years before thinning. Instead you would have to discount the NPV from the 50 year-old stand back ten years before comparing the results to the 40 year-old stand in order that they both use the same base year. However, the higher NPV for the 50 year-old stand does mean that if you have two stands, one 50 years-old and one 40 years-old, and only one can be thinned, then thin the 50 year-old stand first because of the two stands it will yield the highest return.

The results of discounting the optimum net present value of the later thinnings back to coincide with the base year of the earlest thinnings are presented in Table 6-4. The results indicate that the mid commercial thinning age was, in most cases, economically superior to the early and late thinning ages. This means, for example, that the site index 36 No PCT stands should be thinned to 200-300 SPH at 40 years of age, however from Table 6-1 we can see that if a stand has already reached 50 years of age and has not yet been thinned then the older stand should receive priority for thinning.

The economic results in favour of the mid commercial thinning age contradicts the results given in Section 4 where it was shown that if the forest management objective is volume maximization then the later thinning age would be preferred. This difference in results highlights the economic advantage of the earlier financial return obtained from the stand over the small volume gain achieved by postponing the thinning to the later thinning age.

TABLE 6-4
MAXIMUM NPV CONVERTED TO A COMMON BASE YEAR
($/ha)

Regime	Site Index 36 Thinned at			Site Index 30 Thinned at			Site Index 24 Thinned at		
	30	40	50	40	50	60	50	60	70
No PCT									
Unthinned	5792	5792	5792	3582	3582	3582	1637	1637	1637
200	6260	6789	6394	3547	4020	3704	1489	1511	1527
300	6232	6409	6134	3366	3637	3559	1565	1556	1524
400	5810	5573	5859	3202	3493	3496	1587	1654	1560
600	5343	5403	5753	3301	3473	3434	1792	1466	1470
800	-	5675	5746	-	3602	3536	-	1504	1492
PCT to 1,100 SPH									
Unthinned	6246	6246	6246	3475	3475	3475	2134	2134	2134
200	6983	7507	6859	4456	4388	3853	1688	1919	1962
300	7055	7128	6640	4211	3851	3570	1921	1861	1807
400	6497	6525	6458	3841	3608	3453	1933	1989	1826
600	-	6110	6195	-	3491	3367	-	1929	1792
PCT to 800 SPH									
Unthinned	6344	6344	6344	3494	3493	3494	1988	1988	1988
200	7035	7611	7163	4544	4524	4073	1759	2015	1902
300	7261	7458	6642	4243	4036	3772	1737	1899	1856
400	6551	6348	6442	3730	3676	3551	1888	1959	1792
PCT to 500 SPH									
Unthinned	6602	6602	6602	3741	3741	3741	1596	1596	1596
200	7242	7474	7250	4512	4663	3977	1821	1808	1667

6.5 Site Values

For those interested in examining the results of the economic analysis if the management perspective was changed from the examination of established stands to that of bare land following harvest then the site values discussed in Section 3 would provide the appropriate means of comparison. Table 6-5 presents the maximum site value for each simulation. The rotation age for each maximum site value is the same as for the maximum NPV presented in Tables 6-1 to 6-3. Table 6-5 shows that, generally, the simulations which did not include a PCT would yield the highest site values. However, this result will be highly dependant on the cost of the PCT used in the simulations. As discussed in Section 3 the average cost of PCT in the Vancouver Forest Region has been quite high and were assumed to vary from $868 to $888 per hectare in the simulations. If PCT costs could be brought down below $600 per hectare then the simulations with PCT would likely dominate at site index 36 and 30 but still be economically inferior at site index 24.

TABLE 6-5
COMPARISON OF MAXIMUM SITE VALUES
($/ha)

Regime	Site Index 36 Thinned at			Site Index 30 Thinned at			Site Index 24 Thinned at		
	30	40	50	40	50	60	50	60	70
No PCT									
Unthinned	1186	1186	1186	146	146	146	-259	-259	-259
200	1330	1493	1371	139	237	171	-390	-387	-385
300	1321	1376	1291	101	158	141	-380	-381	-386
400	1191	1180	1206	67	128	128	-377	-367	-381
600	1047	1066	1174	88	123	127	-348	-394	-393
800	-	1150	1172	-	150	136	-	-388	-390
PCT to 1,100 SPH									
Unthinned	825	825	825	-340	-340	-340	-712	-712	-712
200	1141	1213	1014	-84	-150	-261	-774	-742	-736
300	1163	1096	946	-135	-261	-320	-742	-750	-758
400	991	910	890	-212	-312	-344	-740	-732	-755
600	-	783	809	-	-336	-362	-	-741	-760
PCT to 800 SPH									
Unthinned	849	849	849	-341	-341	-341	-737	-737	-737
200	1152	1240	1101	-70	-126	-220	-769	-733	-749
300	1222	1192	941	-133	-228	-283	-772	-750	-756
400	1003	850	879	-240	-303	-329	-751	-741	-765
PCT to 500 SPH									
Unthinned	923	923	923	-295	-295	-295	-797	-797	-797
200	1211	1192	1123	-82	-103	-246	-765	-767	-787

6.6 Estimated Minimum Commercial Thinning Net Revenue Requirements

In Section 3.4 the formula for determining the minimum net revenue required from each commercial thinning in order for the thinning regime to be economically viable was derived. This net revenue represents the difference between the NPVs of the unthinned and thinned regimes (less the net revenue received from the commercial thinning), each harvested at their optimum economic rotation age, divided by the commercial thinning volume. The results of these calculations are presented in Table 6-6.

The table shows that delaying the age at which the thinning takes place generally increases the minimum net revenue requirements which indicates that the difference between the NPVs of the unthinned and thinned final harvest and future rotations increased more than the corresponding increase in the commercial thinning volume. Readers may wonder what causes the minimum net revenue requirements to change in different directions when comparing between different thinning intensities. This results from the interaction of two factors: changes in the difference between the NPVs of the final harvest and changes in the volume taken at the thinning. If the volume taken at a thinning decreases more (less) rapidly, in percentage terms, then the difference between the NPVs of final harvests then the minimum net revenue requirements will increase (decrease) as you move to lighter thinnings.

TABLE 6-6
MINIMUM NET REVENUE REQUIRED FROM THE COMMERCIAL THINNINGS
($/m³)

Regime	Site Index 36 Thinned at			Site Index 30 Thinned at			Site Index 24 Thinned at		
	30	40	50	40	50	60	50	60	70
No PCT									
200	-1.22	3.22	7.59	3.80	6.35	9.12	3.59	5.37	7.32
300	-3.94	1.90	5.98	3.59	5.85	8.64	1.42	3.67	5.64
400	-3.32	3.63	5.29	3.30	4.45	6.58	-1.03	1.86	3.81
600	0.96	3.69	-1.32	-1.22	-0.61	2.31	-6.88	-0.87	0.52
800		-4.42	-7.02		-8.89	-1.49		-4.17	-1.65
PCT to 1,100 SPH									
200	-0.47	3.90	8.78	1.24	5.43	8.88	7.69	9.23	11.94
300	-4.07	2.17	6.83	0.51	5.63	9.17	5.74	8.46	12.18
400	-3.27	2.82	5.17	1.11	4.27	7.91	3.62	6.24	10.68
600		2.10	1.41		-1.77	3.64		2.05	11.21
PCT to 800 SPH									
200	-1.30	3.11	7.47	0.59	4.46	8.16	7.26	9.01	11.59
300	-7.31	-0.27	8.84	-1.13	4.48	8.08	6.07	8.18	11.11
400	-4.25	6.67	7.79	0.94	3.07	7.52	3.19	5.25	10.26
PCT to 500 SPH									
200	-4.00	3.04	6.74	-0.75	2.52	9.19	5.40	6.88	9.45

6.7 Commercial Thinning Under Alternative Management Objectives

To this point it has been assumed that the forest management goal was the maximization of the net economic benefits derivable from timber production. To achieve this goal the stands must be harvested at their optimum economic rotation age. This is a principle that is rarely, if ever, practiced in British Columbia. There are a number of reasons for this. First, only now are some new growth stands mature enough for harvest. Second, other timber management goals, such as the maximization of timber volume production, have been given precedence. Third, non-timber management goals must also receive due consideration. For these reasons alternative management regimes are commonly used to meet these other goals. The rotation under these alternative regimes have, for example, been based on the cumulation of mean annual increment, for the maximisation of volume production, or to meet some physical characteristic, such as a minimum average stand DBH, or have been set to some arbitrarily longer rotation in order to "simulate" old growth forests.

The question for this section was how will the economic viability of commercial thinning be affected by the adoption of alternate management regimes. To answer this we must first assume that the commercial thinning does not contradict or compromise the selected management objective. If this is true then we only need concern ourselves with the changes in the final harvest age resulting from the adoption of the alternative management objective. Figures 6-1 to 6-12 show that for the three heaviest thinning regimes the difference between the NPV of the thinned and unthinned stands widens as the rotation age increases past the optimum economic rotation age. Thus, for the regimes simulated, lengthening the rotation age past the optimum economic rotation age in order to meet some other management objective improves the relative economic efficiency of the three heaviest thinning regimes in comparison to unthinned regimes. The reason for this is that the NPV of the unthinned regime declines faster, once it's past its optimum rotation age, than does the NPV of the more heavily thinned regimes. This also means that as the rotation age lengthens the minimum net revenue requirements from the thinning drops. Indeed if the rotation age is lengthened sufficiently the net revenue requirements of the thinning becomes negative meaning that the NPV of the final harvest from the thinned stand has become greater then the NPV of the final harvest of the unthinned stand. If lengthy rotation ages were used then the economic feasibility of commercial thinning would be enhanced, particularly at lower site index sites.

6.8 Commercial Thinning and Forest Level Planning

The impacts of commercial thinning have, to this point, only been assessed at the stand level and no forest level planning considerations have been assessed. Commercial thinning will be of concern in forests which are regulated with total cut controls. In British Columbia every timber supply area (TSA) and tree farms licence (TFL) has an allowable annual cut (AAC) established by the province's Chief Forester.[1] The AAC allows timber tenure licensees to harvest plus or minus 50% of their share of the AAC in any given year, but the licensee's average cut over a specified five-year period must be within 10% of the AAC. In addition, any over cut in any five-year period will be balanced by a reduction in the cut in the subsequent five-year period.

Under AAC limits it can be seen that any commercial thinning will reduce the amount of clear-cut final harvests allowed in any year. As the value derived from the clear-cutting of mature stands will typically be greater than that derived from commercial thinning the effect of the thinning in a forest under AAC control may be to reduce the flow of net revenues from the forest. This was the major reason why the State of Washington's Department of Natural Resources abandoned its policy of requiring commercial thinning as a necessary forest management activity in 1976 (Chambers, 1977).

This reversal of the economics of commercial thinning when going from a stand level to a forest level is entirely the results of using total cut controls as a major forest management tool. It also highlights some of the economic incongruities caused by cut controls. However, even with total cut controls at the forest level there are still circumstances under which commercial thinning may assist forest level planning. Currently British Columbia is in the midst of a three year process under which the AAC for all TSAs and TFLs will be reviewed. In some of these areas the AAC will be reduced over time as the current stock of old-growth timber is harvested and timber supplies fall to their long-run sustainable yield (LRSY). This is shown diagrammatically in Figure 6-13 for a hypothetical TSA. It is also possible that in some areas the AAC will temporarily drop below the LRSY due to operational constraints or to an age class imbalance in the forest's structure. This situation is shown to occur in the figure between periods t_1 and t_2.

In situations like that shown in Figure 6-13, commercial thinning may be able to assist by extending the supply of old-growth timber. This would be achieved by substituting commercial thinning harvests for old-growth harvests while still maintaining cut levels. Alternatively commercial thinning may help to relieve age class imbalance during period t_1 and t_2 by harvesting timber from immature stands without sacrificing the forest's growth potential. Of course this discussion cannot be generalised to apply to all forest level planning situations but must instead be assessed on a case by case basis.

In other cases the long-term harvest level may fall below LRSY because of operability constraints imposed to achieve integrated resource management objectives. One example may be adjacency requirements which require that a clear-cut cut block has to be reforested and reach a specified height or age before adjacent cut blocks can be harvested. This so-called "greenup" requirement may delay the harvest of some block well past their cumulation of MAI. In this case commercial thinning may be used to partially relax this "greenup" constraint and thus raise the long-term harvest level while still achieving the other integrated resource management objectives.

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[1] See Section 7 of the *Forest Act*.

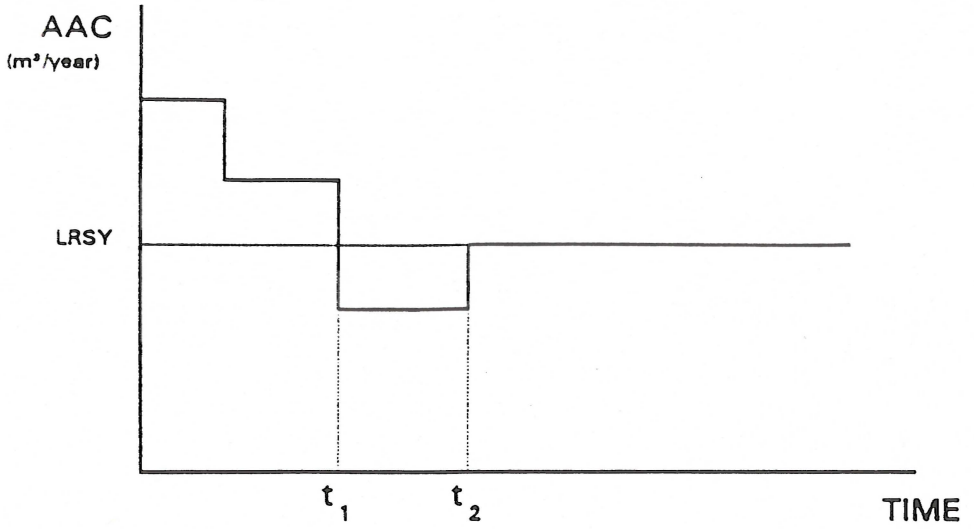


FIGURE 6-13 USING COMMERCIAL THINNING TO ADDRESS FOREST LEVEL CONCERNS

SECTION SEVEN
SENSITIVITY ANALYSIS

7.1 Introduction

The purpose of sensitivity analysis is to investigate how responsive the basic results are to changes in the key parameters used in the analysis. This is done in order to see if the ranking of the regimes would change in response to changes in any of the key parameters. For this study the major parameters tested were the discount rate, thinning costs, final harvest costs, road development costs, and basic silviculture costs. For each parameter a low and high value was chosen, as listed in Table 7-1, and the NPV for each thinning regime was recalculated in order to see if either the ranking of the regimes or the optimum rotation age changed as compared to the base case results developed above.

TABLE 7-1
SENSITIVITY ANALYSIS ASSUMPTIONS

Parameter	Low	High
Discount Rate	2%	6%
Thinning Costs	-$5/m³	+ $5/m³
Final Harvest Costs	-$5/m³	+ $5/m³
Thinning and Final Harvest Cost	-$5/m³	+ $5/m³
Road Development Costs	-$300/ha	+ $300/ha
Basic Silviculture Costs	-$300/ha	+ $300/ha

7.2 Results

The results of the sensitivity analysis are presented in Tables 7-2 to 7-13. The tables show the optimum NPV for each thinning intensity, the optimum rotation age and the ranking of the regime relative to the other thinning intensities. Overall the sensitivity of the base case results to changes in the key parameters increased as the site index declined and as initial stand density increased. This was not unexpected as the ability of a stand to respond to release will decline with lower site indexes and with higher initial densities. Simulations with older thinning ages also tended to be less sensitive to changes in the key parameters, probably due to the higher commercial thinning profits earned as a result of the greater thinning harvest volume as compared to the earlier thinning ages. The results show that a lower discount rate, higher thinning costs, or a lower final harvest cost will change some of the rankings. Specific observations on each of the parameters tested were:

- *Discount Rates* - A lower discount rate reduces the amount by which the NPV of the final harvests are discounted which makes the impact of the thinning on final harvests more important which in turn makes commercial thinning less attractive. Increasing the discount rate had the opposite effect making the heavier thinning regimes even more attractive. Reducing (increasing) the discount rate increased (reduced) the economic rotation age.

TABLE 7-2
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 36, NO PCT

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 600/ha ($/ha)	Rot. Age (yr)	Rank
							Thin at Age 30								
Base Case	5,792	65	4	6,260	65	1	6,232	70	2	5,810	70	3	5,343	65	5
2% Dis. Rate	16,738	80	5	17,040	80	4	18,258	80	1	17,586	85	2	15,453	80	3
6% Dis. Rate	3,055	55	2	3,299	60	1	3,044	60	3	2,712	60	5	2,765	50	4
Low Thin Cost	5,793	65	4	7,191	65	1	6,991	70	2	6,431	70	3	5,740	65	5
High Thin Cost	5,793	65	1	5,342	70	3	5,473	70	2	5,189	70	4	4,947	65	5
Low Harv. Cost	7,098	65	3	7,148	65	2	7,268	65	1	6,867	70	4	6,574	65	5
High Harv. Cost	4,572	70	4	5,437	70	1	5,256	70	2	4,755	75	3	4,113	65	5
Low Thin & Harv.	7,098	65	4	8,079	65	1	8,039	65	2	7,488	70	3	6,976	60	5
High Thin & Harv.	4,572	70	1	4,520	70	2	4,497	70	3	4,141	75	4	3,717	65	5
Low Road Cost	5,875	65	4	6,585	65	1	6,552	70	2	6,131	70	3	5,669	65	5
High Road Cost	5,710	65	3	5,938	70	1	5,911	70	2	5,489	70	4	5,018	65	5
Low Silv. Cost	5,875	65	4	6,342	65	1	6,298	70	2	5,877	70	3	5,426	65	5
High Silv. Cost	5,710	65	4	6,192	70	1	6,165	70	2	5,743	70	3	5,261	65	5
15% OAF	4,887	65	3	5,252	70	1	5,229	70	2	4,870	70	4	4,468	65	5
20% OAF	4,585	65	3	4,916	70	1	4,895	70	2	4,557	70	4	4,177	65	5
							Thin at Age 40								
Base Case	8,574	65	3	10,049	70	1	9,487	70	2	8,545	65	4	7,998	65	5
2% Dis. Rate	20,403	80	3	21,037	75	2	21,080	80	1	19,566	85	4	18,508	85	5
6% Dis. Rate	5,471	55	3	6,679	65	1	5,898	60	2	5,425	55	4	5,296	50	5
Low Thin Cost	8,574	65	4	10,536	60	2	10,622	70	1	9,420	65	3	8,473	65	5
High Thin Cost	8,574	65	2	8,579	70	1	8,352	70	3	7,670	65	4	7,524	65	5
Low Harv. Cost	10,507	65	3	11,165	70	1	10,838	70	2	10,185	65	4	9,881	55	5
High Harv. Cost	6,768	70	4	8,933	70	1	8,136	70	2	7,021	70	3	6,305	70	5
Low Thin & Harv.	10,507	65	4	12,635	70	1	11,973	70	2	11,060	65	3	10,376	55	5
High Thin & Harv.	6,768	70	3	7,467	75	1	7,001	75	2	6,159	70	4	5,838	70	5
Low Road Cost	8,696	65	4	10,370	70	1	9,808	70	2	8,871	65	3	8,323	65	5
High Road Cost	8,452	65	3	9,728	70	1	9,166	70	2	8,220	65	4	7,673	65	5
Low Silv. Cost	8,696	65	3	10,148	70	1	9,586	70	2	8,667	65	4	8,120	65	5
High Silv. Cost	8,452	65	3	9,950	70	1	9,388	70	2	8,423	65	4	7,876	65	5
15% OAF	7,233	65	3	8,464	70	1	7,986	70	2	7,178	65	4	6,713	65	5
20% OAF	6,786	65	3	7,936	70	1	7,486	70	2	6,722	85	4	6,285	65	5
							Thin at Age 50								
Base Case	12,692	65	4	14,009	70	1	13,441	70	2	12,837	65	3	12,606	65	5
2% Dis. Rate	24,872	80	3	25,249	80	1	25,197	80	2	24,394	85	5	24,762	80	4
6% Dis. Rate	9,798	55	3	10,612	65	1	9,875	60	2	9,491	60	4	9,222	60	5
Low Thin Cost	12,692	65	5	15,859	70	1	14,755	70	2	13,763	65	3	13,037	65	4
High Thin Cost	12,692	65	1	12,159	70	3	12,126	70	4	11,912	65	5	12,175	65	2
Low Harv. Cost	15,552	65	2	15,574	70	1	15,393	70	3	15,248	65	5	15,345	65	4
High Harv. Cost	10,019	70	4	12,489	75	1	11,488	70	2	10,468	70	3	9,894	70	5
Low Thin & Harv.	15,552	65	5	17,424	70	1	16,708	70	2	16,174	65	3	15,776	65	4
High Thin & Harv.	10,019	70	3	10,661	75	1	10,182	75	2	9,557	70	4	9,469	70	5
Low Road Cost	12,873	65	5	14,330	70	1	13,761	70	2	13,163	65	3	12,931	65	4
High Road Cost	12,511	65	4	13,689	70	1	13,120	70	2	12,512	65	3	12,280	65	5
Low Silv. Cost	12,873	65	4	14,156	70	1	13,587	70	2	13,018	65	3	12,787	65	5
High Silv. Cost	12,511	65	4	13,863	70	1	13,295	70	2	12,656	65	3	12,425	65	5
15% OAF	10,707	65	4	11,816	70	1	11,333	70	2	10,809	65	3	10,612	65	5
20% OAF	10,045	65	4	11,085	70	1	10,630	70	2	10,132	65	3	9,947	65	5

TABLE 7-3
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 36, PCT TO 1,100 SPH

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank	Thin to 600/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
							Thin at Age 30								
Base Case	6,246	65	4	6,983	65	2	7,055	65	1	6,497	70	3	-	-	-
2% Dis. Rate	17,346	80	4	18,182	75	3	19,617	85	1	18,629	80	2	-	-	-
6% Dis. Rate	3,183	55	4	3,857	60	1	3,602	60	2	3,184	60	3	-	-	-
Low Thin Cost	6,246	65	4	7,828	65	1	7,716	65	2	6,992	70	3	-	-	-
High Thin Cost	6,246	65	2	6,138	65	3	6,395	65	1	6,002	70	4	-	-	-
Low Harv. Cost	7,569	65	4	7,897	65	2	8,170	65	1	7,696	65	3	-	-	-
High Harv. Cost	4,923	65	4	6,069	65	1	5,968	70	2	5,397	70	3	-	-	-
Low Thin & Harv.	7,569	65	4	8,742	65	2	8,830	65	1	8,198	65	3	-	-	-
High Thin & Harv.	4,923	65	3	5,224	65	2	5,317	70	1	4,902	70	4	-	-	-
Low Road Cost	6,328	65	4	7,309	65	2	7,380	65	1	6,818	70	3	-	-	-
High Road Cost	6,164	65	4	6,658	65	2	6,730	65	1	6,177	70	3	-	-	-
Low Silv. Cost	6,328	65	4	7,066	65	2	7,138	65	1	6,564	70	3	-	-	-
High Silv. Cost	6,164	65	4	6,901	65	2	6,973	65	1	6,430	70	3	-	-	-
15% OAF	5,251	65	4	5,845	65	2	5,906	65	1	5,441	70	3	-	-	-
20% OAF	4,920	65	4	5,466	65	2	5,523	65	1	5,089	70	3	-	-	-
							Thin at Age 40								
Base Case	9,246	65	4	11,112	70	1	10,551	70	2	9,658	70	3	9,044	65	5
2% Dis. Rate	21,144	80	5	22,840	80	2	23,402	90	1	22,200	85	3	21,207	80	4
6% Dis. Rate	5,700	55	5	7,645	65	1	6,705	70	2	6,098	60	3	5,761	55	4
Low Thin Cost	9,246	65	5	12,505	65	1	11,574	70	2	10,382	70	3	9,354	65	4
High Thin Cost	9,246	65	3	9,723	70	1	9,527	70	2	8,934	70	4	8,734	65	5
Low Harv. Cost	11,203	65	4	12,353	65	1	11,979	70	2	11,380	65	3	10,956	65	5
High Harv. Cost	7,288	65	4	9,944	70	1	9,122	70	2	8,082	70	3	7,177	70	5
Low Thin & Harv.	11,203	65	5	13,762	65	1	13,003	70	2	12,115	65	3	11,266	65	4
High Thin & Harv.	7,288	65	4	8,555	70	1	8,099	70	2	7,358	70	3	6,872	70	5
Low Road Cost	9,368	65	5	11,432	70	1	10,871	70	2	9,979	70	3	9,370	65	4
High Road Cost	9,124	65	4	10,791	70	1	10,230	70	2	9,337	70	3	8,719	65	5
Low Silv. Cost	9,368	65	4	11,213	65	1	10,650	70	2	9,763	65	3	9,166	65	5
High Silv. Cost	9,124	65	4	11,013	70	1	10,452	70	2	9,559	70	3	8,922	65	5
15% OAF	7,773	65	4	9,342	70	1	8,866	70	2	8,107	70	3	7,572	65	5
20% OAF	7,282	65	4	8,753	70	1	8,304	70	2	7,590	70	3	7,081	65	5
							Thin at Age 50								
Base Case	13,686	65	4	15,029	70	1	14,550	70	2	14,150	70	3	13,573	65	5
2% Dis. Rate	25,775	80	5	26,145	85	4	27,605	90	1	26,937	80	2	26,333	80	3
6% Dis. Rate	10,208	55	4	11,549	65	1	10,673	65	2	10,601	65	3	10,141	60	5
Low Thin Cost	13,686	65	5	16,823	70	1	15,771	70	2	14,943	70	3	13,869	65	4
High Thin Cost	13,686	65	1	13,235	70	5	13,330	70	3	13,357	70	2	13,278	65	4
Low Harv. Cost	16,584	65	3	16,637	70	1	16,605	70	2	16,449	70	5	16,398	65	4
High Harv. Cost	10,788	65	5	13,421	70	1	12,495	70	2	11,850	70	3	11,033	70	4
Low Thin & Harv.	16,584	65	5	18,431	70	1	17,826	70	2	17,242	70	3	16,693	65	4
High Thin & Harv.	10,788	65	4	11,628	70	1	11,275	70	2	11,057	70	3	10,741	70	5
Low Road Cost	13,867	65	5	15,350	70	1	14,871	70	2	14,470	70	3	13,899	65	4
High Road Cost	13,505	65	4	14,709	70	1	14,230	70	2	13,829	70	3	13,248	65	5
Low Silv. Cost	13,867	65	4	15,175	70	1	14,697	70	2	14,296	70	3	13,754	65	5
High Silv. Cost	13,505	65	4	14,883	70	1	14,404	70	2	14,003	70	3	13,413	70	5
15% OAF	11,506	65	4	12,646	70	1	12,239	70	2	11,899	70	3	11,389	65	5
20% OAF	10,780	65	4	11,852	70	1	11,469	70	2	11,148	70	3	10,676	70	5

TABLE 7-4
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 36, PCT TO 800 SPH

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank
							Thin at Age 30					
Base Case	6,344	65	4	7,035	65	2	7,261	65	1	6,551	65	3
2% Dis. Rate	17,753	80	4	18,332	75	3	19,771	85	1	19,020	85	2
6% Dis. Rate	3,284	60	4	3,894	60	1	3,728	60	2	3,309	60	3
Low Thin Cost	6,344	65	4	7,745	65	2	7,775	65	1	6,894	65	3
High Thin Cost	6,344	65	2	6,326	65	3	6,748	65	1	6,208	65	4
Low Harv. Cost	7,654	65	4	7,973	65	2	8,400	65	1	7,790	65	3
High Harv. Cost	5,102	70	4	6,110	70	2	6,143	70	1	5,420	75	3
Low Thin & Harv.	7,654	65	4	8,683	65	2	8,913	65	1	8,133	65	3
High Thin & Harv.	5,102	70	3	5,411	70	2	5,638	70	1	5,086	75	4
Low Road Cost	6,426	65	4	7,360	65	2	7,587	65	1	6,876	65	3
High Road Cost	6,261	65	3	6,710	65	2	6,936	65	1	6,226	65	4
Low Silv. Cost	6,426	65	4	7,117	65	2	7,344	65	1	6,633	65	3
High Silv. Cost	6,261	65	4	6,953	65	2	7,179	65	1	6,469	65	3
15% OAF	5,334	65	4	5,889	65	2	6,081	65	1	5,478	65	3
20% OAF	4,998	65	4	5,507	65	2	5,688	65	1	5,120	65	3
							Thin at Age 40					
Base Case	9,390	65	4	11,266	65	1	11,040	70	2	9,396	70	3
2% Dis. Rate	21,640	80	3	22,993	80	2	24,113	85	1	20,954	75	4
6% Dis. Rate	5,881	60	4	7,633	65	1	7,003	60	2	6,034	55	3
Low Thin Cost	9,390	65	4	12,513	65	1	11,880	70	2	9,920	70	3
High Thin Cost	9,390	65	3	10,019	65	2	10,199	70	1	8,872	70	4
Low Harv. Cost	11,331	65	3	12,559	65	1	12,510	70	2	11,008	65	4
High Harv. Cost	7,552	70	4	9,973	65	1	9,569	70	2	7,831	70	3
Low Thin & Harv.	11,331	65	4	13,806	65	1	13,350	70	2	11,539	65	3
High Thin & Harv.	7,552	70	3	8,729	70	1	8,378	75	2	7,307	70	4
Low Road Cost	9,512	65	4	11,591	65	1	11,360	70	2	9,716	70	3
High Road Cost	9,268	65	3	10,941	65	1	10,719	70	2	9,075	70	4
Low Silv. Cost	9,512	65	3	11,388	65	1	11,138	70	2	9,495	70	4
High Silv. Cost	9,268	65	4	11,144	65	1	10,941	70	2	9,297	70	3
15% OAF	7,896	65	3	9,460	65	1	9,281	70	2	7,884	70	4
20% OAF	7,398	65	3	8,858	65	1	8,695	70	2	7,380	70	4
							Thin at Age 50					
Base Case	13,900	65	4	15,695	75	1	14,554	75	2	14,115	70	3
2% Dis. Rate	26,379	80	3	27,963	80	1	26,932	85	2	25,930	80	4
6% Dis. Rate	10,532	60	4	11,899	65	1	11,125	60	2	10,716	60	3
Low Thin Cost	13,900	65	4	17,324	75	1	15,594	70	2	14,706	70	3
High Thin Cost	13,900	65	2	14,065	75	1	13,520	75	4	13,524	70	3
Low Harv. Cost	16,772	65	2	17,279	70	1	16,605	70	3	16,488	65	4
High Harv. Cost	11,179	70	4	14,162	75	1	12,705	75	2	11,809	70	3
Low Thin & Harv.	16,772	65	4	18,928	70	1	17,651	70	2	17,088	65	3
High Thin & Harv.	11,179	70	4	12,533	75	1	11,671	75	2	11,218	70	3
Low Road Cost	14,081	65	4	16,012	75	1	14,870	75	2	14,435	70	3
High Road Cost	13,719	65	4	15,378	75	1	14,237	75	2	13,794	70	3
Low Silv. Cost	14,081	65	4	15,814	75	1	14,695	70	2	14,261	70	3
High Silv. Cost	13,719	65	4	15,576	75	1	14,435	75	2	13,968	70	3
15% OAF	11,688	65	4	13,227	75	1	12,257	75	2	11,868	70	3
20%OAF	10,951	65	4	12,405	75	1	11,492	75	2	11,120	70	3

TABLE 7-5
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES, ROTATION AGE AND RANK FOR SITE INDEX 36, PCT TO 500 SPH

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)	
		Thin at Age 30				
Base Case	6,602	60	2	7,242	65	1
2% Dis. Rate	18,145	80	2	18,972	75	1
6% Dis. Rate	3,501	60	2	3,858	55	1
Low Thin Cost	6,602	60	2	7,702	65	1
High Thin Cost	6,602	60	2	6,783	65	1
Low Harv. Cost	7,992	60	2	8,223	65	1
High Harv. Cost	5,357	70	2	6,262	65	1
Low Thin & Harv.	7,992	60	2	8,683	65	1
High Thin & Harv.	5,357	70	2	5,802	65	1
Low Road Cost	6,704	60	2	7,568	65	1
High Road Cost	6,518	65	2	6,917	65	1
Low Silv. Cost	6,704	60	2	7,325	65	1
High Silv. Cost	6,518	65	2	7,160	65	1
15% OAF	5,552	65	2	6,065	65	1
20% OAF	5,203	65	2	5,673	65	1
		Thin at Age 40				
Base Case	9,772	60	2	11,064	70	1
2% Dis. Rate	22,119	80	2	23,299	80	1
6% Dis. Rate	6,269	60	2	7,535	70	1
Low Thin Cost	9,772	60	2	11,941	70	1
High Thin Cost	9,772	60	2	10,186	70	1
Low Harv. Cost	11,830	60	2	12,383	65	1
High Harv. Cost	7,930	70	2	9,797	70	1
Low Thin & Harv.	11,830	60	2	13,274	65	1
High Thin & Harv.	7,930	70	2	8,920	70	1
Low Road Cost	9,923	60	2	11,384	70	1
High Road Cost	9,648	65	2	10,743	70	1
Low Silv. Cost	9,923	60	2	11,163	70	1
High Silv. Cost	9,648	65	2	10,965	70	1
15% OAF	8,218	65	2	9,301	70	1
20% OAF	7,701	65	2	8,714	70	1
		Thin at Age 50				
Base Case	14,465	60	2	15,886	70	1
2% Dis. Rate	26,962	80	2	28,087	80	1
6% Dis. Rate	11,227	60	2	11,967	65	1
Low Thin Cost	14,465	60	2	17,149	70	1
High Thin Cost	14,465	60	2	14,623	70	1
Low Harv. Cost	17,512	60	2	17,671	70	1
High Harv. Cost	11,738	70	2	14,101	70	1
Low Thin & Harv.	17,512	60	2	18,937	65	1
High Thin & Harv.	11,738	70	2	12,838	70	1
Low Road Cost	14,689	60	2	16,207	70	1
High Road Cost	14,281	65	2	15,565	70	1
Low Silv. Cost	14,689	60	2	16,032	70	1
High Silv. Cost	14,281	65	2	15,740	70	1
15% OAF	12,165	65	2	13,374	70	1
20% OAF	11,400	65	2	12,536	70	1

TABLE 7-6
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 30, NO PCT

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank	Thin to 600/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
						Thin at Age 40									
Base Case	3,582	60	1	3,547	80	2	3,366	80	3	3,202	70	4	3,301	55	5
2% Dis. Rate	8,898	90	3	9,112	100	2	9,197	100	1	8,653	95	4	7,938	95	5
6% Dis. Rate	2,517	50	1	2,050	75	5	2,029	55	4	2,124	55	3	2,187	55	2
Low Thin Cost	3,582	60	5	4,608	85	1	4,240	80	2	3,952	60	3	3,770	55	4
High Thin Cost	3,582	60	1	2,486	85	4	2,491	80	3	2,480	70	5	2,831	55	2
Low Harv. Cost	5,152	55	1	4,043	80	5	4,057	70	4	4,281	60	3	4,655	55	2
High Harv. Cost	2,322	70	4	3,071	85	1	2,728	85	2	2,387	80	3	1,994	60	5
Low Thin & Harv.	5,152	55	1	5,113	80	3	4,951	70	5	5,027	60	4	5,125	55	2
High Thin & Harv.	2,322	70	1	2,010	85	2	1,861	85	3	1,681	80	4	1,535	60	5
Low Road Cost	3,734	60	2	3,858	85	1	3,680	80	3	3,538	60	5	3,640	55	4
High Road Cost	3,431	60	1	3,236	85	2	3,052	80	3	2,881	70	5	2,962	55	4
Low Silv. Cost	3,734	60	1	3,600	85	2	3,431	80	4	3,358	60	5	3,489	55	3
High Silv. Cost	3,431	60	2	3,493	85	1	3,301	80	3	3,103	70	5	3,112	55	4
15% OAF	2,977	60	1	2,952	85	2	2,794	80	3	2,644	70	5	2,698	55	4
20% OAF	2,775	60	1	2,754	85	2	2,604	80	3	2,458	70	5	2,497	55	4
						Thin at Age 50									
Base Case	5,303	60	3	5,950	90	1	5,384	80	2	5,171	60	4	5,141	60	5
2% Dis. Rate	10,847	90	3	11,975	105	1	11,251	105	2	10,518	95	4	9,881	95	5
6% Dis. Rate	4,508	50	1	4,474	60	2	4,184	60	3	4,095	60	4	3,927	60	5
Low Thin Cost	5,303	60	5	7,356	90	1	6,494	90	2	6,068	60	3	5,641	60	4
High Thin Cost	5,303	60	1	4,544	90	3	4,274	80	5	4,275	60	4	4,641	60	2
Low Harv. Cost	7,626	55	1	6,643	80	4	6,420	60	5	6,719	60	3	6,994	60	2
High Harv. Cost	3,437	70	4	5,351	90	1	4,448	80	2	3,861	80	3	3,297	65	5
Low Thin & Harv.	7,626	55	2	8,069	80	1	7,594	60	4	7,615	60	3	7,494	60	5
High Thin & Harv.	3,437	70	2	3,945	90	1	3,338	80	3	3,013	80	4	2,806	65	5
Low Road Cost	5,527	60	3	6,259	90	1	5,586	70	2	5,503	60	4	5,473	60	5
High Road Cost	5,079	60	2	5,641	90	1	5,070	80	3	4,840	60	4	4,809	60	5
Low Silv. Cost	5,527	60	2	6,014	90	1	5,480	80	3	5,395	60	4	5,365	60	5
High Silv. Cost	5,079	60	3	5,885	90	1	5,287	80	2	4,961	70	4	4,917	60	5
15% OAF	4,407	60	3	4,992	90	1	4,500	80	2	4,279	60	4	4,253	60	5
20% OAF	4,108	60	3	4,672	90	1	4,206	80	2	3,981	60	4	3,957	60	5
						Thin at Age 60									
Base Case	7,849	60	2	8,115	85	1	7,798	80	3	7,660	70	4	7,524	70	5
2% Dis. Rate	13,222	90	3	14,288	105	1	13,626	100	2	12,939	100	4	12,468	90	5
6% Dis. Rate	8,073	50	1	6,494	70	2	6,362	70	3	6,193	70	4	5,893	70	5
Low Thin Cost	7,849	60	5	9,797	85	1	9,046	80	2	8,579	70	3	7,959	70	4
High Thin Cost	7,849	60	1	6,432	85	5	6,551	80	4	6,741	70	3	7,089	70	2
Low Harv. Cost	11,289	55	1	9,077	85	5	9,296	70	4	9,605	70	3	9,796	70	2
High Harv. Cost	5,087	70	5	7,152	85	1	6,433	80	2	5,742	75	3	5,252	70	4
Low Thin & Harv.	11,289	55	1	10,760	85	2	10,571	70	3	10,524	70	4	10,230	70	5
High Thin & Harv.	5,087	70	3	5,469	85	1	5,186	80	2	4,834	75	4	4,817	70	5
Low Road Cost	8,181	60	2	8,426	85	1	8,112	80	3	7,981	70	4	7,824	70	5
High Road Cost	7,518	60	2	7,803	85	1	7,485	80	3	7,340	70	4	7,224	70	5
Low Silv. Cost	8,181	60	2	8,231	85	1	7,941	80	3	7,872	70	4	7,741	70	5
High Silv. Cost	7,518	60	3	7,998	85	1	7,655	80	2	7,444	70	4	7,307	70	5
15% OAF	6,523	60	2	6,816	85	1	6,539	80	2	6,398	70	4	6,285	70	5
20% OAF	6,081	60	3	6,383	85	1	6,119	80	2	5,977	70	4	5,873	70	5

TABLE 7-7
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 30, PCT TO 1,100 SPH

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank	Thin to 600/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
							Thin at Age 40								
Base Case	3,475	60	4	4,456	80	1	4,211	80	2	3,841	70	3	-	-	-
2% Dis. Rate	8,497	95	4	10,478	90	1	10,397	95	2	9,642	95	3	-	-	-
6% Dis. Rate	2,558	50	3	2,742	75	1	2,516	60	4	2,564	55	2	-	-	-
Low Thin Cost	3,475	60	4	5,445	80	1	4,979	80	2	4,431	75	3	-	-	-
High Thin Cost	3,475	60	1	3,467	80	2	3,443	80	3	3,252	70	4	-	-	-
Low Harv. Cost	5,044	50	1	5,024	80	2	4,912	80	3	4,838	60	4	-	-	-
High Harv. Cost	2,272	75	4	3,889	80	1	3,510	80	2	3,010	80	3	-	-	-
Low Thin & Harv.	5,044	50	4	6,013	80	1	5,680	80	2	5,447	60	3	-	-	-
High Thin & Harv.	2,272	75	4	2,908	85	1	2,742	80	2	2,434	80	3	-	-	-
Low Road Cost	3,627	60	4	4,770	80	1	4,525	80	2	4,162	70	3	-	-	-
High Road Cost	3,324	60	4	4,143	80	1	3,897	80	2	3,521	70	3	-	-	-
Low Silv. Cost	3,627	60	4	4,522	80	1	4,276	80	2	3,940	70	3	-	-	-
High Silv. Cost	3,324	60	4	4,391	80	1	4,146	80	2	3,748	75	3	-	-	-
15% OAF	2,851	60	4	3,708	80	1	3,499	80	2	3,167	70	3	-	-	-
20% OAF	2,643	60	4	3,458	80	1	3,262	80	2	2,945	75	3	-	-	-
							Thin at Age 50								
Base Case	5,144	60	5	6,495	80	1	5,701	75	2	5,340	65	3	5,167	60	4
2% Dis. Rate	10,358	95	5	12,644	95	1	11,759	100	2	11,064	95	3	10,366	100	4
6% Dis. Rate	4,581	50	2	4,771	80	1	4,428	60	3	4,118	60	4	4,041	60	5
Low Thin Cost	5,144	60	5	7,840	80	1	6,712	75	2	6,080	65	3	5,492	60	4
High Thin Cost	5,144	60	2	5,157	85	1	4,691	75	4	4,599	65	5	4,722	70	3
Low Harv. Cost	7,467	50	1	7,262	80	2	6,776	75	5	6,842	65	4	7,110	60	3
High Harv. Cost	3,364	75	5	5,814	90	1	4,773	85	2	4,068	85	3	3,459	70	4
Low Thin & Harv.	7,467	50	4	8,608	80	1	7,786	75	2	7,583	65	3	7,435	60	5
High Thin & Harv.	3,364	75	3	4,488	90	1	3,787	90	2	3,361	85	4	3,144	75	5
Low Road Cost	5,368	60	5	6,809	80	1	6,018	75	2	5,665	65	3	5,498	60	4
High Road Cost	4,920	60	4	6,181	80	1	5,385	75	2	5,014	65	3	4,835	60	5
Low Silv. Cost	5,368	60	5	6,592	80	1	5,820	75	2	5,520	65	3	5,391	60	4
High Silv. Cost	4,920	60	5	6,413	85	1	5,583	75	2	5,159	65	3	4,943	60	4
15% OAF	4,220	60	5	5,429	85	1	4,735	75	2	4,394	65	3	4,223	60	4
20% OAF	3,912	60	4	5,075	85	1	4,414	75	2	4,079	65	3	3,908	60	5
							Thin at Age 60								
Base Case	7,615	60	3	8,442	90	1	7,823	85	2	7,566	75	4	7,377	70	5
2% Dis. Rate	12,626	95	5	14,552	105	1	14,113	95	2	13,355	95	3	12,851	95	4
6% Dis. Rate	8,204	50	1	6,856	70	2	6,533	70	3	6,209	70	4	5,869	70	5
Low Thin Cost	7,615	60	5	10,028	85	1	8,945	90	2	8,339	75	3	7,690	70	4
High Thin Cost	7,615	60	1	6,864	90	5	6,702	85	4	6,792	75	3	7,064	70	2
Low Harv. Cost	11,053	50	1	9,416	85	5	9,420	70	4	9,545	70	3	9,698	70	2
High Harv. Cost	4,979	75	1	7,570	90	1	6,584	85	2	5,830	85	3	5,222	75	4
Low Thin & Harv.	11,053	50	1	11,004	85	2	10,576	70	3	10,328	70	4	10,011	70	5
High Thin & Harv.	4,979	75	4	5,993	90	1	5,463	85	2	5,070	85	3	4,913	75	5
Low Road Cost	7,947	60	3	8,751	85	1	8,134	85	2	7,882	75	4	7,698	70	5
High Road Cost	7,284	60	3	8,133	90	1	7,512	85	2	7,249	75	4	7,056	70	5
Low Silv. Cost	7,947	60	3	8,556	85	1	7,950	80	2	7,772	70	3	7,594	70	5
High Silv. Cost	7,284	60	4	8,347	90	1	7,707	85	2	7,390	75	3	7,160	70	5
15% OAF	6,247	60	4	7,079	85	1	6,541	85	2	6,290	75	3	6,107	70	5
20% OAF	5,791	60	4	6,624	80	1	6,114	85	2	5,865	75	3	5,684	70	5

TABLE 7-8

SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES, ROTATION AGE AND RANK FOR SITE INDEX 30, PCT TO 800 SPH

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank
							Thin at Age 40					
Base Case	3,494	60	4	4,544	80	1	4,243	80	2	3,730	75	3
2% Dis. Rate	9,081	90	4	10,976	90	2	11,198	95	1	9,565	90	3
6% Dis. Rate	2,267	60	4	2,769	75	1	2,437	65	3	2,454	55	2
Low Thin Cost	3,494	60	4	5,391	80	1	4,853	80	2	4,143	75	3
High Thin Cost	3,494	60	3	3,697	80	1	3,633	80	2	3,316	80	4
Low Harv. Cost	4,902	60	3	5,127	80	1	5,015	75	2	4,776	65	4
High Harv. Cost	2,428	80	4	3,962	80	1	3,513	80	2	2,892	80	3
Low Thin & Harv.	4,902	60	4	5,974	80	1	5,632	75	2	5,201	65	3
High Thin & Harv.	2,428	80	4	3,115	80	1	2,903	80	2	2,482	80	3
Low Road Cost	3,645	60	4	4,858	80	1	4,556	80	2	4,047	75	3
High Road Cost	3,376	70	4	4,231	80	1	3,929	80	2	3,413	75	3
Low Silv. Cost	3,645	60	4	4,610	80	1	4,308	80	2	3,810	75	3
High Silv. Cost	3,376	70	4	4,479	80	1	4,177	80	2	3,650	75	3
15% OAF	2,886	70	4	3,782	80	1	3,526	80	2	3,082	75	3
20% OAF	2,690	70	4	3,528	80	1	3,287	80	2	2,866	75	3
							Thin at Age 50					
Base Case	5,171	60	4	6,697	85	1	5,974	80	2	5,442	70	3
2% Dis. Rate	11,070	90	4	12,840	100	1	12,409	95	2	11,357	100	3
6% Dis. Rate	4,060	60	4	4,766	75	1	4,399	60	2	4,124	60	3
Low Thin Cost	5,171	60	4	7,887	85	1	6,804	80	2	5,980	70	3
High Thin Cost	5,171	60	2	5,508	85	1	5,144	80	3	4,903	70	4
Low Harv. Cost	7,256	60	2	7,406	85	1	7,044	70	3	6,871	70	4
High Harv. Cost	3,594	80	4	5,988	85	1	5,064	85	2	4,115	80	3
Low Thin & Harv.	7,256	60	4	8,596	85	1	7,892	70	2	7,409	70	3
High Thin & Harv.	3,594	80	3	4,799	85	1	4,240	85	2	3,588	80	4
Low Road Cost	5,395	60	4	7,008	85	1	6,287	80	2	5,762	70	3
High Road Cost	4,997	70	4	6,386	85	1	5,660	80	2	5,121	70	3
Low Silv. Cost	5,395	60	4	6,776	85	1	6,070	80	2	5,588	70	3
High Silv. Cost	4,997	70	4	6,618	85	1	5,878	85	2	5,296	70	3
15% OAF	4,272	70	4	5,604	85	1	4,979	80	2	4,499	70	3
20% OAF	3,981	70	4	5,239	85	1	4,647	80	2	4,185	70	3
							Thin at Age 60					
Base Case	7,655	60	4	8,925	85	1	8,264	80	2	7,781	70	3
2% Dis. Rate	13,494	90	4	15,338	95	1	14,707	95	2	13,916	90	3
6% Dis. Rate	7,271	60	1	7,096	70	2	6,653	70	3	6,361	70	4
Low Thin Cost	7,655	60	4	10,375	85	1	9,229	80	2	8,373	70	3
High Thin Cost	7,655	60	1	7,475	85	2	7,298	80	3	7,189	70	4
Low Harv. Cost	10,741	60	1	9,942	80	2	9,709	80	4	9,861	70	3
High Harv. Cost	5,319	80	4	7,917	85	1	6,875	85	2	6,107	80	3
Low Thin & Harv.	10,741	60	2	11,404	80	1	10,675	80	3	10,453	70	4
High Thin & Harv.	5,319	80	4	6,467	85	1	5,917	85	2	5,528	80	3
Low Road Cost	7,987	60	4	9,236	85	1	8,577	80	2	8,101	70	3
High Road Cost	7,397	70	4	8,614	85	1	7,950	80	2	7,460	70	3
Low Silv. Cost	7,987	60	4	9,042	85	1	8,407	80	2	7,997	70	3
High Silv. Cost	7,397	70	4	8,808	85	1	8,120	80	2	7,623	80	3
15% OAF	6,323	70	4	7,477	85	1	6,900	80	2	6,478	80	3
20% OAF	5,893	70	4	6,995	85	1	6,446	80	2	6,048	80	3

TABLE 7-9
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES, ROTATION AGE AND RANK FOR SITE INDEX 30, PCT TO 500 SPH

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank
				Thin at Age 40		
Base Case	3,741	70	2	4,512	80	1
2% Dis. Rate	9,670	90	2	11,265	90	1
6% Dis. Rate	2,138	60	2	2,663	70	1
Low Thin Cost	3,741	70	2	5,075	80	1
High Thin Cost	3,741	70	2	3,948	80	1
Low Harv. Cost	4,803	70	2	5,129	80	1
High Harv. Cost	2,721	80	2	3,894	80	1
Low Thin & Harv.	4,803	70	2	5,692	80	1
High Thin & Harv.	2,721	80	2	3,331	80	1
Low Road Cost	3,840	70	2	4,825	80	1
High Road Cost	3,643	70	2	4,198	80	1
Low Silv. Cost	3,840	70	2	4,577	80	1
High Silv. Cost	3,643	70	2	4,446	80	1
15% OAF	3,112	70	2	3,754	80	1
20% OAF	2,903	70	2	3,502	80	1
				Thin at Age 50		
Base Case	5,538	70	2	6,902	80	1
2% Dis. Rate	11,788	90	2	14,038	95	1
6% Dis. Rate	3,829	60	2	4,745	70	1
Low Thin Cost	5,538	70	2	7,755	80	1
High Thin Cost	5,538	70	2	6,050	80	1
Low Harv. Cost	7,109	70	2	7,773	80	1
High Harv. Cost	4,027	80	2	6,032	80	1
Low Thin & Harv.	7,109	70	2	8,625	80	1
High Thin & Harv.	4,027	80	2	5,180	80	1
Low Road Cost	5,684	70	2	7,216	80	1
High Road Cost	5,392	70	2	6,589	80	1
Low Silv. Cost	5,684	70	2	6,999	80	1
High Silv. Cost	5,392	70	2	6,806	80	1
15% OAF	4,607	70	2	5,768	80	1
20% OAF	4,296	70	2	5,390	80	1
				Thin at Age 60		
Base Case	8,198	70	2	8,714	85	1
2% Dis. Rate	14,370	90	2	15,474	100	1
6% Dis. Rate	6,856	60	2	6,968	70	1
Low Thin Cost	8,198	70	2	9,803	85	1
High Thin Cost	8,198	70	1	7,626	85	2
Low Harv. Cost	10,523	70	1	9,909	75	2
High Harv. Cost	5,961	80	2	7,633	85	1
Low Thin & Harv.	10,523	70	2	11,017	75	1
High Thin & Harv.	5,961	80	2	6,544	85	1
Low Road Cost	8,414	70	2	9,026	85	1
High Road Cost	7,981	70	2	8,403	85	1
Low Silv. Cost	8,414	70	2	8,835	80	1
High Silv. Cost	7,981	70	2	8,598	85	1
15% OAF	6,819	70	2	7,298	85	1
20% OAF	6,360	70	2	6,826	85	1

TABLE 7-10
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 24, NO PCT

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank	Thin to 600/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
							Thin at Age 50								
Base Case	1,637	70	2	1,489	65	5	1,565	65	4	1,587	65	3	1,792	65	1
2% Dis. Rate	3,724	95	1	2,861	105	5	2,876	105	4	3,011	75	3	3,452	75	2
6% Dis. Rate	970	75	5	1,224	60	1	1,173	60	2	1,078	65	4	1,181	60	3
Low Thin Cost	1,637	70	5	2,529	70	1	2,426	65	2	2,295	65	3	2,244	65	4
High Thin Cost	1,637	70	1	449	65	5	703	65	4	879	65	3	1,340	65	2
Low Harv. Cost	2,567	75	2	1,956	65	5	2,188	65	4	2,339	65	3	2,732	65	1
High Harv. Cost	821	95	5	1,044	95	1	942	65	2	834	65	4	852	65	3
Low Thin & Harv.	2,567	75	5	3,010	60	4	3,049	65	2	3,047	65	3	3,185	65	1
High Thin & Harv.	821	95	1	62	95	5	91	75	4	126	65	3	400	65	2
Low Road Cost	1,758	70	5	1,814	65	4	1,890	65	3	1,912	70	2	2,118	65	1
High Road Cost	1,515	70	1	1,164	65	5	1,239	65	4	1,261	65	3	1,467	65	2
Low Silv. Cost	1,758	70	3	1,686	60	5	1,745	65	4	1,768	65	2	1,973	65	1
High Silv. Cost	1,515	70	2	1,311	75	5	1,384	65	4	1,406	65	3	1,611	65	1
15% OAF	1,377	70	2	1,163	65	5	1,227	70	4	1,246	65	3	1,420	65	1
20% OAF	1,290	70	2	1,033	65	5	1,114	65	4	1,132	65	3	1,296	65	1
							Thin at Age 60								
Base Case	2,422	70	2	2,237	75	4	2,304	75	3	2,448	75	1	2,170	75	5
2% Dis. Rate	4,540	95	1	3,827	120	4	3,779	95	5	4,049	100	2	4,023	95	3
6% Dis. Rate	1,738	75	4	1,883	75	1	1,806	75	3	1,841	75	2	1,481	75	5
Low Thin Cost	2,422	70	5	3,474	75	1	3,301	75	2	3,239	75	3	2,647	75	4
High Thin Cost	2,422	70	1	1,000	75	5	1,307	75	4	1,656	75	3	1,693	75	2
Low Harv. Cost	3,800	75	1	2,809	75	5	3,065	75	4	3,361	75	3	3,287	75	2
High Harv. Cost	1,215	95	5	1,748	95	1	1,542	75	2	1,534	75	3	1,054	75	4
Low Thin & Harv.	3,800	75	4	3,868	80	3	4,063	75	2	4,152	75	1	3,763	75	5
High Thin & Harv.	1,215	95	1	547	95	4	545	75	5	743	75	2	577	75	3
Low Road Cost	2,603	70	3	2,554	75	4	2,621	75	2	2,764	75	1	2,487	75	5
High Road Cost	2,242	70	1	1,920	75	4	1,987	75	3	2,131	75	2	1,854	75	5
Low Silv. Cost	2,603	70	2	2,413	75	4	2,480	75	3	2,624	75	1	2,346	75	5
High Silv. Cost	2,242	70	2	2,061	75	4	2,128	75	3	2,272	75	1	1,994	75	5
15% OAF	2,038	70	1	1,849	75	4	1,906	75	3	2,028	75	2	1,792	75	5
20% OAF	1,909	70	1	1,719	75	4	1,773	75	3	1,888	75	2	1,666	75	5
							Thin at Age 70								
Base Case	3,586	70	1	3,345	80	3	3,340	80	4	3,418	80	2	3,222	80	5
2% Dis. Rate	5,534	95	1	4,884	120	4	4,757	90	5	5,151	95	2	5,033	95	3
6% Dis. Rate	3,112	75	1	2,973	80	2	2,831	80	3	2,806	80	4	2,517	80	5
Low Thin Cost	3,586	70	5	4,752	80	1	4,439	80	2	4,262	80	3	3,704	80	4
High Thin Cost	3,586	70	1	1,948	85	5	2,240	80	4	2,574	80	3	2,740	80	2
Low Harv. Cost	5,624	75	1	4,097	80	5	4,346	80	4	4,626	80	3	4,693	80	2
High Harv. Cost	1,799	95	4	2,715	95	2	2,334	80	1	2,210	80	3	1,751	80	5
Low Thin & Harv.	5,624	75	1	5,505	80	2	5,445	80	4	5,469	80	3	5,175	80	5
High Thin & Harv.	1,799	95	1	1,335	95	3	1,235	80	5	1,366	80	2	1,269	80	4
Low Road Cost	3,853	70	1	3,658	80	3	3,654	80	4	3,732	80	2	3,536	80	5
High Road Cost	3,318	70	1	3,033	85	3	3,026	80	4	3,104	80	2	2,908	80	5
Low Silv. Cost	3,853	70	1	3,557	80	3	3,552	80	4	3,630	80	2	3,434	80	5
High Silv. Cost	3,318	70	1	3,172	85	3	3,128	80	4	3,206	80	2	3,010	80	5
15% OAF	3,016	70	1	2,791	85	3	2,775	80	4	2,842	80	2	2,675	80	5
20% OAF	2,826	70	1	2,606	85	3	2,587	80	4	2,650	80	2	2,493	80	5

TABLE 7-11
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES,
ROTATION AGE AND RANK FOR SITE INDEX 24, PCT TO 1,100 SPH

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank	Thin to 600/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
							Thin at Age 50								
Base Case	2,134	65	1	1,688	95	4	1,921	65	3	1,933	65	2	-	-	-
2% Dis. Rate	3,788	80	1	3,359	105	4	3,438	105	2	3,367	105	3	-	-	-
6% Dis. Rate	1,566	65	2	1,415	65	4	1,604	60	1	1,494	60	3	-	-	-
Low Thin Cost	2,134	65	4	2,599	70	2	2,655	65	1	2,487	65	3	-	-	-
High Thin Cost	2,134	65	1	800	95	4	1,187	65	3	1,379	65	2	-	-	-
Low Harv. Cost	3,327	65	1	2,152	75	4	2,614	65	3	2,771	65	2	-	-	-
High Harv. Cost	1,002	80	4	1,404	95	1	1,245	80	2	1,095	65	3	-	-	-
Low Thin & Harv.	3,327	65	2	3,078	70	4	3,348	65	1	3,325	65	3	-	-	-
High Thin & Harv.	1,002	80	1	541	105	3	537	80	4	543	75	2	-	-	-
Low Road Cost	2,315	65	1	1,995	95	4	2,247	65	3	2,259	65	2	-	-	-
High Road Cost	1,953	65	1	1,381	95	4	1,596	65	3	1,608	65	2	-	-	-
Low Silv. Cost	2,315	65	1	1,820	70	4	2,102	60	3	2,114	65	2	-	-	-
High Silv. Cost	1,953	65	1	1,635	95	4	1,740	65	3	1,752	65	2	-	-	-
15% OAF	1,695	65	1	1,362	95	4	1,493	65	3	1,503	65	2	-	-	-
20% OAF	1,549	65	1	1,253	95	4	1,350	65	3	1,359	65	2	-	-	-
							Thin at Age 60								
Base Case	3,159	65	1	2,840	80	4	2,755	75	5	2,944	70	2	2,855	70	3
2% Dis. Rate	4,617	80	2	4,655	135	1	4,238	95	5	4,369	90	4	4,542	85	3
6% Dis. Rate	2,804	65	1	2,512	75	2	2,399	70	4	2,482	70	3	2,284	70	5
Low Thin Cost	3,159	65	4	3,970	80	1	3,622	75	2	3,588	70	3	3,147	70	5
High Thin Cost	3,159	65	1	1,710	80	5	1,887	75	4	2,299	70	3	2,564	70	2
Low Harv. Cost	4,925	65	1	3,440	75	5	3,645	70	4	4,042	70	3	4,228	70	2
High Harv. Cost	1,484	80	5	2,356	95	1	1,932	90	2	1,860	75	3	1,493	75	4
Low Thin & Harv.	4,925	65	1	4,582	75	3	4,523	70	4	4,687	70	2	4,519	70	5
High Thin & Harv.	1,484	80	1	1,254	110	2	1,086	90	5	1,223	75	3	1,205	75	4
Low Road Cost	3,426	65	1	3,154	80	4	3,071	75	5	3,264	70	2	3,176	70	3
High Road Cost	2,891	65	1	2,526	80	4	2,438	75	5	2,623	70	2	2,535	70	3
Low Silv. Cost	3,426	65	1	3,002	75	4	2,954	70	5	3,160	70	2	3,072	70	3
High Silv. Cost	2,891	65	1	2,697	80	3	2,579	75	5	2,727	70	2	2,639	70	4
15% OAF	2,510	65	1	2,295	80	3	2,205	75	5	2,344	70	2	2,269	70	4
20% OAF	2,293	65	1	2,113	80	3	2,022	75	5	2,145	70	2	2,074	70	4
							Thin at Age 70								
Base Case	4,676	65	1	4,299	80	2	3,959	80	4	4,001	80	3	3,927	80	5
2% Dis. Rate	5,628	80	2	5,994	135	1	5,548	100	4	5,458	80	5	5,580	80	3
6% Dis. Rate	5,022	65	1	3,962	80	2	3,502	80	3	3,394	80	4	3,184	80	5
Low Thin Cost	4,676	65	4	5,612	80	1	4,931	80	2	4,693	80	3	4,221	80	5
High Thin Cost	4,676	65	1	2,986	80	5	2,988	80	4	3,309	80	3	3,632	80	2
Low Harv. Cost	7,291	65	1	5,104	80	4	5,039	80	5	5,298	80	3	5,525	80	2
High Harv. Cost	2,196	80	5	3,552	90	1	2,893	90	2	2,704	80	3	2,328	80	4
Low Thin & Harv.	7,291	65	1	6,417	80	2	6,011	80	3	5,990	80	4	5,820	80	5
High Thin & Harv.	2,196	80	2	2,261	110	1	1,936	90	5	2,012	80	4	2,034	80	3
Low Road Cost	5,072	65	1	4,613	80	2	4,273	80	4	4,315	80	3	4,240	80	5
High Road Cost	4,280	65	1	3,985	80	2	3,645	80	4	3,688	80	3	3,613	80	5
Low Silv. Cost	5,072	65	1	4,511	80	2	4,171	80	4	4,213	80	3	4,139	80	5
High Silv. Cost	4,280	65	1	4,087	80	2	3,747	80	4	3,789	80	3	3,715	80	5
15% OAF	3,715	65	1	3,500	80	2	3,211	80	4	3,247	80	3	3,183	80	5
20% OAF	3,394	65	1	3,233	80	2	2,962	80	4	2,995	80	3	2,936	80	5

TABLE 7-12
SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES, ROTATION AGE AND RANK FOR SITE INDEX 24, PCT TO 800 SPH

Parameter Tested	No Thinning	Rot. Age	Rank	Thin to 200/ha	Rot. Age	Rank	Thin to 300/ha	Rot. Age	Rank	Thin to 400/ha	Rot. Age	Rank
	($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)		($/ha)	(yr)	
						Thin at Age 50						
Base Case	1,988	60	1	1,759	90	3	1,737	65	4	1,888	65	2
2% Dis. Rate	3,749	90	2	3,803	105	1	3,666	110	4	3,720	100	3
6% Dis. Rate	1,607	55	1	1,413	65	4	1,436	60	3	1,541	60	2
Low Thin Cost	1,988	60	4	2,524	85	1	2,326	65	2	2,288	65	3
High Thin Cost	1,988	60	1	996	105	4	1,148	65	3	1,488	65	2
Low Harv. Cost	3,249	60	1	2,149	65	4	2,462	65	3	2,816	60	2
High Harv. Cost	1,008	75	4	1,520	105	1	1,138	100	2	1,046	85	3
Low Thin & Harv.	3,249	60	1	2,955	65	4	3,051	65	3	3,223	60	2
High Thin & Harv.	1,008	75	1	765	105	2	584	100	4	663	85	3
Low Road Cost	2,212	60	2	2,068	90	3	2,063	65	4	2,214	65	1
High Road Cost	1,807	65	1	1,450	90	3	1,412	65	4	1,563	65	2
Low Silv. Cost	2,212	60	1	1,823	90	4	1,918	65	3	2,095	60	2
High Silv. Cost	1,807	65	1	1,716	105	2	1,557	65	4	1,707	65	3
15% OAF	1,571	65	1	1,425	105	3	1,336	65	4	1,464	65	2
20% OAF	1,432	65	1	1,302	90	3	1,202	65	4	1,323	65	2
						Thin at Age 60						
Base Case	2,943	60	2	2,982	95	1	2,811	70	4	2,900	70	3
2% Dis. Rate	4,570	90	4	5,382	130	1	4,830	120	2	4,604	100	3
6% Dis. Rate	2,878	55	1	2,682	70	2	2,456	70	3	2,429	70	4
Low Thin Cost	2,943	60	4	3,955	95	1	3,534	70	2	3,376	70	3
High Thin Cost	2,943	60	1	2,009	95	4	2,087	70	3	2,425	70	2
Low Harv. Cost	4,809	60	1	3,626	70	4	3,763	70	3	4,056	70	2
High Harv. Cost	1,493	75	4	2,579	105	1	1,993	90	2	1,768	75	3
Low Thin & Harv.	4,809	60	1	4,474	75	4	4,487	70	3	4,532	70	2
High Thin & Harv.	1,493	75	2	1,614	105	1	1,296	90	4	1,298	75	3
Low Road Cost	3,275	60	2	3,289	95	1	3,131	70	4	3,221	70	3
High Road Cost	2,675	65	1	2,675	95	1	2,490	70	3	2,580	70	2
Low Silv. Cost	3,275	60	1	3,141	70	2	3,027	70	4	3,117	70	3
High Silv. Cost	2,675	65	3	2,904	95	1	2,614	80	4	2,684	70	2
15% OAF	2,325	65	2	2,449	95	1	2,234	75	4	2,307	70	3
20% OAF	2,119	65	2	2,271	95	1	2,049	75	4	2,109	70	3
						Thin at Age 70						
Base Case	4,356	60	1	4,168	90	2	4,067	80	3	3,927	80	4
2% Dis. Rate	5,571	90	4	6,412	135	1	5,916	120	2	5,612	105	3
6% Dis. Rate	5,154	55	1	3,773	80	2	3,571	80	3	3,309	80	4
Low Thin Cost	4,356	60	4	5,323	90	1	4,882	80	2	4,444	80	3
High Thin Cost	4,356	60	1	3,012	90	4	3,252	80	3	3,409	80	2
Low Harv. Cost	7,119	60	1	4,951	80	4	5,202	80	3	5,294	80	2
High Harv. Cost	2,209	75	4	3,488	90	1	2,945	90	2	2,560	80	3
Low Thin & Harv.	7,119	60	1	6,123	80	2	6,017	80	3	5,811	80	4
High Thin & Harv.	2,209	75	2	2,332	90	1	2,142	90	3	2,042	80	4
Low Road Cost	4,847	60	1	4,477	90	2	4,381	80	3	4,241	80	4
High Road Cost	3,960	65	1	3,859	90	2	3,754	80	3	3,613	80	4
Low Silv. Cost	4,847	60	1	4,320	80	2	4,279	80	3	4,139	80	4
High Silv. Cost	3,960	65	2	4,027	90	1	3,855	80	3	3,715	80	4
15% OAF	3,442	65	1	3,424	90	2	3,302	80	3	3,183	80	4
20% OAF	3,137	65	2	3,177	90	1	3,047	80	3	2,935	80	4

TABLE 7-13

SENSITIVITY ANALYSIS - OPTIMUM NET PRESENT VALUES, ROTATION AGE AND RANK FOR SITE INDEX 24, PCT TO 500 SPH

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank
				Thin at Age 50		
Base Case	1,596	70	2	1,821	95	1
2% Dis. Rate	3,609	110	2	4,276	105	1
6% Dis. Rate	1,256	60	1	1,214	75	2
Low Thin Cost	1,596	70	2	2,311	95	1
High Thin Cost	1,596	70	1	1,331	95	2
Low Harv. Cost	2,622	60	1	2,173	90	2
High Harv. Cost	850	95	2	1,516	105	1
Low Thin & Harv.	2,622	60	2	2,666	90	1
High Thin & Harv.	850	95	2	1,029	105	1
Low Road Cost	1,756	60	2	2,128	95	1
High Road Cost	1,450	70	2	1,514	95	1
Low Silv. Cost	1,756	60	2	1,876	90	1
High Silv. Cost	1,450	70	2	1,768	95	1
15% OAF	1,260	70	2	1,475	95	1
20% OAF	1,148	70	2	1,359	95	1
				Thin at Age 60		
Base Case	2,363	70	2	2,677	100	1
2% Dis. Rate	4,400	110	2	5,373	120	1
6% Dis. Rate	2,248	60	1	2,103	75	2
Low Thin Cost	2,363	70	2	3,326	100	1
High Thin Cost	2,363	70	1	2,027	100	2
Low Harv. Cost	3,881	60	1	3,138	90	2
High Harv. Cost	1,258	95	2	2,286	105	1
Low Thin & Harv.	3,881	60	1	3,806	75	2
High Thin & Harv.	1,258	95	2	1,639	105	1
Low Road Cost	2,599	60	2	2,983	100	1
High Road Cost	2,146	70	2	2,371	100	1
Low Silv. Cost	2,599	60	2	2,741	100	1
High Silv. Cost	2,146	70	2	2,613	100	1
15% OAF	1,865	70	2	2,197	100	1
20% OAF	1,699	70	2	2,037	100	1
				Thin at Age 70		
Base Case	3,497	70	2	3,653	90	1
2% Dis. Rate	5,363	110	2	6,277	130	1
6% Dis. Rate	4,027	60	1	3,079	80	2
Low Thin Cost	3,497	70	2	4,460	90	1
High Thin Cost	3,497	70	1	2,846	90	2
Low Harv. Cost	5,745	60	1	4,392	90	2
High Harv. Cost	1,863	95	2	3,039	105	1
Low Thin & Harv.	5,745	60	1	5,199	90	2
High Thin & Harv.	1,863	95	2	2,243	105	1
Low Road Cost	3,848	60	2	3,962	90	1
High Road Cost	3,176	70	2	3,344	90	1
Low Silv. Cost	3,848	60	1	3,794	90	2
High Silv. Cost	3,176	70	2	3,512	90	1
15% OAF	2,761	70	2	2,987	90	1
20% OAF	2,515	70	2	2,765	90	1

- *Thinning Costs* - Lower thinning costs, as expected, increased the viability of the thinned regimes while the higher thinning costs had the reverse effect making the unthinned regimes optimum except for the site index 36 simulations and some of the site index 30 PCT simulations where the heaviest thinning still dominated. The high thinning cost scenario may be representative of the costs of cable thinning which suggests that this method of thinning may only be attractive on high quality sites. The low thinning cost tests can also be used to represent the effect of a temporary increase in log prices. In this case thinning of lower site index sites becomes economically attractive thus expansion of thinning programs during times of high log prices should be encouraged and scaled back during times of low log prices.

- *Final Harvest Costs* - Lower final harvest cost would make the unthinned regimes more attractive while higher final harvest costs make the thinned regimes more appealing. Changing the final harvest costs effects the difference between the NPVs of the final harvests of the thinned and unthinned stands. Because the unthinned regimes would have the greater final harvest volume a change in final harvest cost would have a greater impact on the NPV of the unthinned regime. The lower final harvest cost test can also be used to represent the case of higher future log prices. The results suggest that if the forest manager strongly believes in rising real price increases for logs then he may not wish to do commercial thinnings.

- *Thinning and Final Harvest Costs* - Lowering both the thinning cost and final harvest costs together had little impacts on the ranking of regimes, especially for the heaviest thinning intensity regimes. However, raising both the thinning and final harvest costs raised the ranking of some of the thinned regimes for the site index 24 simulations but did not greatly effect the ranking of the other site index regimes. Of all the scenarios tested the higher thinning and final harvest cost scenario is considered by the author to be the most realistic, suggesting that the heavier thinning regimes are the best economic candidates for viable commercial thinnings.

- *Road Development Costs* - The higher road development cost test had surprisingly little effect on regime ranking. However, as the increased road development cost is the same for both the thinned and unthinned regimes the relative impact of NPV is the difference created by the discounting of road development costs under the unthinned regime.

- *Basic Silviculture Costs* - Variations in basic silviculture costs had no significant effect on regime ranking which is not surprising given that the NPV of the current rotation is unaffected by basic silviculture requirements. Only the value of future rotations, as determined by the site value, is impacted by basic silviculture costs (see Section 3.3 for an explanation).

7.3 Effects of Operational Falldown

As noted in Section 4, no adjustments were made to the simulations to account for the effects of any potential operational falldown. Given that some operational falldown is likely, although the extent to which it would occur is unknown, it seemed prudent to test the effects of a range of possible falldowns. However, how will the falldown effect stand structure - will it reduce stand volume only, will it reduce stand volume and the number of live trees per hectare, and will it effect average volume per tree? Without knowing these details we cannot predict the effect of falldown on log grades and thus our estimate of revenue, nor can we predict the effect of the falldown on thinning and harvest costs. The simplest approach was to assume that only total volume was affected and that unit costs and revenues remained constant. This was the approach adopted in the study. Nevertheless, the reader should keep this simplifying assumption in mind when reviewing the results.

Table 7-2 to 7-13 also show the optimum NPV and rank of each regime simulated using operational adjustment factors (OAF) which reduce the volume of the thinnings and the final harvests by 15% and 20%. The results indicate that the potential effect of operational falldown

should have little impact on the base case results. However, the results may be different if the operational falldown also impacted unit costs or revenues.

7.4 Effects of Stand Damage

Section 4.1 contained a brief discussion of the negative impacts any stand damage caused during the thinnings could have on the final harvest of a thinned stand. The extent to which stand damage occurs in thinnings in British Columbia is unknown but may be minimised through proper planning, selection of appropriate thinning methods, operator training and supervision. Nevertheless the potential impact of stand damage on the base case results was considered important enough to warrant further testing. This was done by reducing the final harvests of the thinned stands by 5-15%. As in the operational falldown tests no adjustments were made to unit costs or revenues.

The impacts of the simulated stand damage on regime NPVs are presented in Tables 7-14 to 7-16 along with the relative ranking and rotation age of each regime. The effect of stand damage on relative rankings was much greater for stands with higher inital stand densities and at the younger commercial thinning ages. This is important as dense stands are more likely to suffer stand damage than in the wider tree spacing found in PCT stands. Stands which are commercially thinned to a low number of residual trees may also have less potential for stand damage becasue one may be better able to substitue a tree marked for cutting for a tree marked to leave which was damaged during the thinning. The wider spacing of the residual trees in the heavier thinning should also allow for easier yarding and thus have less potential for injury to the residual stand. Overall the base case is sensitive to site damage and the results emphasise the need to minimise stand damage if commercial thinning is to remain an economically attractive management option.

TABLE 7-14
THE POTENTIAL EFFECT OF STAND DAMAGE, SITE INDEX 36

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 600/ha ($/ha)	Rot. Age (yr)	Rank
						No PCT, Thin at Age 30									
Base Case	5,792	65	4	6,260	65	1	6,232	70	2	5,810	70	3	5,343	65	5
5% Damage	5,792	65	3	5,953	65	1	5,907	70	2	5,493	70	4	5,048	65	5
10% Damage	5,792	65	1	5,647	70	2	5,583	70	3	5,176	70	4	4,752	65	5
15% Damage	5,792	65	1	5,341	70	2	5,258	70	3	4,859	70	4	4,456	65	5
						No PCT, Thin at Age 40									
Base Case	8,574	65	3	10,049	70	1	9,487	70	2	8,545	65	4	7,998	65	5
5% Damage	8,574	65	3	9,663	70	1	9,073	70	2	8,136	65	4	7,572	65	5
10% Damage	8,574	65	3	9,277	70	1	8,659	70	3	7,726	65	4	7,146	65	5
15% Damage	8,574	65	2	8,891	70	1	8,245	70	3	7,317	65	4	6,721	65	5
						No PCT, Thin at Age 50									
Base Case	12,692	65	4	14,009	70	1	13,441	70	2	12,837	65	3	12,606	65	5
5% Damage	12,692	65	3	13,505	70	1	12,873	70	2	12,234	65	4	11,947	65	5
10% Damage	12,692	65	2	13,001	70	1	12,305	70	3	11,631	65	4	11,288	65	5
15% Damage	12,692	65	1	12,497	70	2	11,737	70	3	11,028	65	4	10,630	65	5
						PCT TO 1,100 SPH, Thin at Age 30									
Base Case	6,246	65	4	6,983	65	2	7,055	65	1	6,497	70	3	-	-	-
5% Damage	6,246	65	3	6,656	65	2	6,705	65	1	6,158	70	4	-	-	-
10% Damage	6,246	65	3	6,329	65	2	6,356	65	1	5,819	70	4	-	-	-
15% Damage	6,246	65	1	6,002	65	3	6,006	65	2	5,481	70	4	-	-	-
						PCT TO 1,100 SPH, Thin at Age 40									
Base Case	9,246	65	4	11,112	70	1	10,551	70	2	9,658	70	3	9,044	65	5
5% Damage	9,246	65	3	10,692	70	1	10,097	70	2	9,199	70	4	8,565	65	5
10% Damage	9,246	65	3	10,272	70	1	9,643	70	2	8,741	70	4	8,086	65	5
15% Damage	9,246	65	2	9,852	70	1	9,189	70	3	8,282	70	4	7,607	65	5
						PCT TO 1,100 SPH, Thin at Age 50									
Base Case	13,686	65	4	15,029	70	1	14,550	70	2	14,150	70	3	13,573	65	5
5% Damage	13,686	65	3	14,480	70	1	13,926	70	2	13,481	70	4	12,860	65	5
10% Damage	13,686	65	2	13,931	70	1	13,301	70	3	12,813	70	4	12,146	65	5
15% Damage	13,686	65	1	13,382	70	2	12,676	70	3	12,144	70	4	11,439	70	5
						PCT TO 800 SPH, Thin at Age 30									
Base Case	6,344	65	4	7,035	65	2	7,261	65	1	6,551	65	3	-	-	-
5% Damage	6,344	65	3	6,698	65	2	6,896	65	1	6,206	65	4	-	-	-
10% Damage	6,344	65	3	6,360	65	2	6,532	65	1	5,861	65	4	-	-	-
15% Damage	6,344	65	1	6,023	65	2	6,167	65	2	5,516	65	4	-	-	-
						PCT TO 800 SPH, Thin at Age 40									
Base Case	9,390	65	4	11,266	65	1	11,040	70	2	9,396	70	3	-	-	-
5% Damage	9,390	65	3	10,821	65	1	10,555	70	2	8,943	70	4	-	-	-
10% Damage	9,390	65	3	10,375	65	1	10,071	70	2	8,490	70	4	-	-	-
15% Damage	9,390	65	2	9,930	65	2	9,587	70	1	8,038	70	4	-	-	-
						PCT TO 800 SPH, Thin at Age 50									
Base Case	13,900	65	4	15,695	75	1	14,554	75	2	14,115	70	3	-	-	-
5% Damage	13,900	65	3	15,105	75	1	13,930	75	2	13,439	70	4	-	-	-
10% Damage	13,900	65	2	14,514	75	1	13,306	75	3	12,764	70	4	-	-	-
15% Damage	13,900	65	2	13,924	75	1	12,683	75	3	12,089	70	4	-	-	-
						PCT TO 500 SPH, Thin at Age 30									
Base Case	6,602	60	2	7,242	65	1	-	-	-	-	-	-	-	-	-
5% Damage	6,602	60	2	6,883	65	1	-	-	-	-	-	-	-	-	-
10% Damage	6,602	60	1	6,523	65	2	-	-	-	-	-	-	-	-	-
15% Damage	6,602	60	1	6,163	65	2	-	-	-	-	-	-	-	-	-
						PCT TO 500 SPH, Thin at Age 40									
Base Case	9,772	60	2	11,064	70	1	-	-	-	-	-	-	-	-	-
5% Damage	9,772	60	2	10,588	70	1	-	-	-	-	-	-	-	-	-
10% Damage	9,772	60	2	10,112	70	1	-	-	-	-	-	-	-	-	-
15% Damage	9,772	60	1	9,637	70	2	-	-	-	-	-	-	-	-	-
						PCT TO 500 SPH, Thin at Age 50									
Base Case	14,465	60	2	15,886	70	1	-	-	-	-	-	-	-	-	-
5% Damage	14,465	60	2	15,226	70	1	-	-	-	-	-	-	-	-	-
10% Damage	14,465	60	2	14,565	70	1	-	-	-	-	-	-	-	-	-
15% Damage	14,465	60	1	13,905	70	2	-	-	-	-	-	-	-	-	-

TABLE 7-15
THE POTENTIAL EFFECT OF STAND DAMAGE, SITE INDEX 30

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 600/ha ($/ha)	Rot. Age (yr)	Rank
No PCT, Thin at Age 40															
Base Case	3,582	60	1	3,547	80	2	3,366	80	3	3,202	70	4	3,301	55	5
5% Damage	3,582	60	1	3,403	85	2	3,211	80	3	3,035	70	5	3,095	55	4
10% Damage	3,582	60	1	3,258	85	2	3,057	80	3	2,869	70	5	2,890	55	4
15% Damage	3,582	60	1	3,114	85	2	2,902	80	3	2,702	70	4	2,684	55	5
No PCT, Thin at Age 50															
Base Case	5,303	60	3	5,950	90	1	5,384	80	2	5,171	60	4	5,141	60	5
5% Damage	5,303	60	2	5,768	90	1	5,174	80	3	4,923	60	4	4,850	60	5
10% Damage	5,303	60	2	5,587	90	1	4,964	80	3	4,675	60	4	4,558	60	5
15% Damage	5,303	60	2	5,406	90	1	4,755	80	3	4,427	60	4	4,267	60	5
No PCT, Thin at Age 60															
Base Case	7,849	60	2	8,115	85	1	7,798	80	3	7,660	70	4	7,524	70	5
5% Damage	7,849	60	2	7,864	85	1	7,499	80	3	7,306	70	4	7,120	70	5
10% Damage	7,849	60	1	7,614	85	2	7,200	80	3	6,951	70	4	6,716	70	5
15% Damage	7,849	60	1	7,364	85	2	6,901	80	3	6,597	70	4	6,312	70	5
PCT TO 1,100 SPH, Thin at Age 40															
Base Case	3,475	60	4	4,456	80	1	4,211	80	2	3,841	70	3	-	-	-
5% Damage	3,475	60	4	4,286	80	1	4,032	80	2	3,659	70	3	-	-	-
10% Damage	3,475	60	4	4,116	80	1	3,853	80	2	3,476	70	3	-	-	-
15% Damage	3,475	60	3	3,945	80	1	3,674	80	2	3,293	70	4	-	-	-
PCT TO 1,100 SPH, Thin at Age 50															
Base Case	5,144	60	5	6,495	80	1	5,701	75	2	5,340	65	3	5,167	60	4
5% Damage	5,144	60	3	6,297	80	1	5,482	75	2	5,083	65	4	4,864	60	5
10% Damage	5,144	60	3	6,100	85	1	5,262	75	2	4,826	65	4	4,562	60	5
15% Damage	5,144	60	2	5,903	85	1	5,042	75	3	4,569	65	4	4,259	60	5
PCT TO 1,100 SPH, Thin at Age 60															
Base Case	7,615	60	3	8,442	90	1	7,823	85	2	7,566	75	4	7,377	70	5
5% Damage	7,615	60	2	8,186	90	1	7,525	85	3	7,215	75	4	6,968	70	5
10% Damage	7,615	60	2	7,929	90	1	7,227	85	3	6,864	75	4	6,560	70	5
15% Damage	7,615	60	2	7,673	90	1	6,929	85	3	6,513	75	4	6,151	70	5
PCT TO 800 SPH, Thin at Age 40															
Base Case	3,494	60	4	4,544	80	1	4,243	80	2	3,730	75	3	-	-	-
5% Damage	3,494	60	4	4,366	80	1	4,052	80	2	3,546	80	3	-	-	-
10% Damage	3,494	60	3	4,187	80	1	3,861	80	2	3,363	75	4	-	-	-
15% Damage	3,494	60	3	4,009	80	1	3,670	80	2	3,179	75	4	-	-	-
PCT TO 800 SPH, Thin at Age 50															
Base Case	5,171	60	4	6,697	85	1	5,974	80	2	5,442	70	3	-	-	-
5% Damage	5,171	60	4	6,481	85	1	5,737	80	2	5,175	70	3	-	-	-
10% Damage	5,171	60	3	6,264	85	1	5,500	80	2	4,908	70	4	-	-	-
15% Damage	5,171	60	3	6,047	85	1	5,264	80	2	4,640	70	4	-	-	-
PCT TO 800 SPH, Thin at Age 60															
Base Case	7,655	60	4	8,925	85	1	8,264	80	2	7,781	70	3	-	-	-
5% Damage	7,655	60	3	8,642	85	1	7,935	80	2	7,405	70	4	-	-	-
10% Damage	7,655	60	2	8,359	85	1	7,606	80	3	7,039	80	4	-	-	-
15% Damage	7,655	60	2	8,076	85	1	7,277	80	3	6,675	80	4	-	-	-
PCT TO 500 SPH, Thin at Age 40															
Base Case	3,741	70	2	4,512	80	1	-	-	-	-	-	-	-	-	-
5% Damage	3,741	70	2	4,311	80	1	-	-	-	-	-	-	-	-	-
10% Damage	3,741	70	2	4,110	80	1	-	-	-	-	-	-	-	-	-
15% Damage	3,741	70	2	3,910	80	1	-	-	-	-	-	-	-	-	-
PCT TO 500 SPH, Thin at Age 50															
Base Case	5,538	70	2	6,902	80	1	-	-	-	-	-	-	-	-	-
5% Damage	5,538	70	2	6,633	80	1	-	-	-	-	-	-	-	-	-
10% Damage	5,538	70	2	6,363	80	1	-	-	-	-	-	-	-	-	-
15% Damage	5,538	70	2	6,094	80	1	-	-	-	-	-	-	-	-	-
PCT TO 500 SPH, Thin at Age 60															
Base Case	8,198	70	2	8,714	85	1	-	-	-	-	-	-	-	-	-
5% Damage	8,198	70	2	8,385	85	1	-	-	-	-	-	-	-	-	-
10% Damage	8,198	70	1	8,055	85	2	-	-	-	-	-	-	-	-	-
15% Damage	8,198	70	1	7,725	85	2	-	-	-	-	-	-	-	-	-

TABLE 7-16
THE POTENTIAL EFFECT OF STAND DAMAGE, SITE INDEX 24

Parameter Tested	No Thinning ($/ha)	Rot. Age (yr)	Rank	Thin to 200/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 300/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 400/ha ($/ha)	Rot. Age (yr)	Rank	Thin to 600/ha ($/ha)	Rot. Age (yr)	Rank
							No PCT, Thin at Age 50								
Base Case	1,637	70	2	1,489	65	5	1,565	65	4	1,587	65	3	1,792	65	1
5% Damage	1,637	70	2	1,426	65	5	1,477	65	4	1,479	65	3	1,663	65	1
10% Damage	1,637	70	1	1,363	65	5	1,389	65	3	1,372	65	4	1,533	65	2
15% Damage	1,637	70	1	1,300	65	4	1,301	65	3	1,265	65	5	1,404	65	2
							No PCT, Thin at Age 60								
Base Case	2,422	70	2	2,237	75	4	2,304	75	3	2,448	75	1	2,170	75	5
5% Damage	2,422	70	1	2,164	75	4	2,201	75	3	2,324	75	2	2,027	75	5
10% Damage	2,422	70	1	2,091	75	4	2,099	75	3	2,200	75	2	1,883	75	5
15% Damage	2,422	70	1	2,019	75	3	1,997	75	4	2,076	75	2	1,740	75	5
							No PCT, Thin at Age 70								
Base Case	3,586	70	1	3,345	80	3	3,340	80	4	3,418	80	2	3,222	80	5
5% Damage	3,586	70	1	3,249	85	2	3,201	80	4	3,249	80	2	3,023	80	5
10% Damage	3,586	70	1	3,155	85	2	3,062	80	4	3,080	80	3	2,824	80	5
15% Damage	3,586	70	1	3,051	85	2	2,923	80	3	2,912	80	4	2,626	80	5
							PCT TO 1,100 SPH, Thin at Age 50								
Base Case	2,134	65	1	1,688	95	4	1,921	65	3	1,933	65	2	-	-	-
5% Damage	2,134	65	1	1,640	95	4	1,825	65	2	1,815	65	3	-	-	-
10% Damage	2,134	65	1	1,592	95	4	1,729	65	2	1,697	65	3	-	-	-
15% Damage	2,134	65	1	1,545	95	4	1,633	65	2	1,579	65	3	-	-	-
							PCT TO 1,100 SPH, Thin at Age 60								
Base Case	3,159	65	1	2,840	80	4	2,755	75	5	2,944	70	2	2,855	70	3
5% Damage	3,159	65	1	2,762	80	3	2,639	75	5	2,789	70	2	2,666	70	4
10% Damage	3,159	65	1	2,683	80	2	2,524	75	4	2,634	70	3	2,476	70	5
15% Damage	3,159	65	1	2,605	80	2	2,408	75	4	2,479	70	3	2,287	70	5
							PCT TO 1,100 SPH, Thin at Age 70								
Base Case	4,676	65	1	4,299	80	2	3,959	80	4	4,001	80	3	3,927	80	5
5% Damage	4,676	65	1	4,185	80	2	3,806	80	3	3,804	80	4	3,688	80	5
10% Damage	4,676	65	1	4,072	80	2	3,653	80	3	3,607	80	4	3,450	80	5
15% Damage	4,676	65	1	3,958	80	2	3,500	80	3	3,410	80	4	3,212	80	5
							PCT TO 800 SPH, Thin at Age 50								
Base Case	1,988	60	1	1,759	90	3	1,737	65	4	1,888	65	2	-	-	-
5% Damage	1,988	60	1	1,704	90	3	1,642	65	4	1,771	65	2	-	-	-
10% Damage	1,988	60	1	1,651	105	3	1,547	65	4	1,653	65	2	-	-	-
15% Damage	1,988	60	1	1,600	105	2	1,451	65	4	1,535	65	3	-	-	-
							PCT TO 800 SPH, Thin at Age 60								
Base Case	2,943	60	2	2,982	95	1	2,811	70	4	2,900	70	3	-	-	-
5% Damage	2,943	60	1	2,910	95	2	2,686	70	4	2,741	70	3	-	-	-
10% Damage	2,943	60	1	2,837	95	2	2,561	70	4	2,582	70	3	-	-	-
15% Damage	2,943	60	1	2,764	95	2	2,436	75	3	2,423	70	4	-	-	-
							PCT TO 800 SPH, Thin at Age 70								
Base Case	4,356	60	1	4,168	90	2	4,067	80	3	3,927	80	4	-	-	-
5% Damage	4,356	60	1	4,060	90	2	3,904	80	3	3,725	80	4	-	-	-
10% Damage	4,356	60	1	3,952	90	2	3,740	80	3	3,524	80	4	-	-	-
15% Damage	4,356	60	1	3,844	90	2	3,576	80	3	3,322	80	4	-	-	-
							PCT TO 500 SPH, Thin at Age 50								
Base Case	1,596	70	2	1,821	95	1	-	-	-	-	-	-	-	-	-
5% Damage	1,596	70	2	1,754	95	1	-	-	-	-	-	-	-	-	-
10% Damage	1,596	70	2	1,687	95	1	-	-	-	-	-	-	-	-	-
15% Damage	1,596	70	2	1,620	95	1	-	-	-	-	-	-	-	-	-
							PCT TO 500 SPH, Thin at Age 60								
Base Case	2,363	70	2	2,677	100	1	-	-	-	-	-	-	-	-	-
5% Damage	2,363	70	2	2,593	100	1	-	-	-	-	-	-	-	-	-
10% Damage	2,363	70	2	2,509	100	1	-	-	-	-	-	-	-	-	-
15% Damage	2,363	70	2	2,425	100	1	-	-	-	-	-	-	-	-	-
							PCT TO 500 SPH, Thin at Age 70								
Base Case	3,497	70	2	3,653	90	1	-	-	-	-	-	-	-	-	-
5% Damage	3,497	70	2	3,531	90	1	-	-	-	-	-	-	-	-	-
10% Damage	3,497	70	1	3,408	90	2	-	-	-	-	-	-	-	-	-
15% Damage	3,497	70	1	3,286	90	2	-	-	-	-	-	-	-	-	-

SECTION EIGHT
SUMMARY AND CONCLUSIONS

8.1 Summary

The purpose of this study was to conduct an economic evaluation of commercial thinning Douglas-fir in the coastal region of British Columbia, which included the estimation of the economic impacts of the thinning on the final harvest. This was done by simulating the growth and yield impacts of a commercial thinning, estimating the potential costs and revenues derived from the thinning and the final harvest, and determining the net present value of the full impacts of commercial thinning. The analysis was limited to the consideration of only one commercial thinning per rotation of an even-aged stand but included simulations in which the stand had previously been pre-commercially thinned.

The reader should keep in mind that the results presented are based on simulations of tree growth and not on actual field experiments. Wherever possible a comparison of the simulated results to actual field results was attempted. Nevertheless the major results of this study were based on the growing and harvesting of electronic trees within a computer.

The major methods and techniques used in the study were:

- The evaluation of commercial thinning was performed by assessing the economic efficiency of various thinning options, as compared to the unthinned option, using the techniques of benefit-cost analysis. The basic method used was to estimate the expected flow of benefits and cost which could be derived from the alternative growing regimes and to discount each flow back to a present value in order to determine the net present value (NPV) of each alternative. The management alternative which yielded the highest net present value was considered to be the best alternative and if the net present value was positive it was considered to be an economically efficient choice.

- The simulations of stand growth and yield used were produced by the Tree and Stand Simulator (TASS) developed by the Research Branch of the British Columbia Forest Service. The TASS model simulates the growth of trees and stands in three dimensions and was designed to be used to assess the effects of silviculture treatments and environmental factors on stand growth and yield. In selecting growing regimes it was decided to control for four factors: site index, stand density prior to the commercial thinning, thinning age, and post-commercial thinning stand density. Simulations were run for site index 36, 30 and 24. Simulations started with an initial planting density of 2,500 SPH and density prior to commercial thinning was varied by running simulations which had no pre-commercial thinning and running other simulations which had been pre-commercially thinned down to 1,100 SPH, 800 SPH and 500 SPH. At each site index a simulation was run without a thinning and three simulations were run with a commercial thinning occuring at different ages. For each commercial thinning regime up to five thinning intensities were simulated, thinning from below to 200, 300, 400, 600, and 800 leave trees per hectare. A total of 115 simulations were run.

- The revenue from the thinnings and the final harvests were estimated using a bucking simulator which optimised the value of the logs which could be bucked from the bole of the trees harvested. The value of the logs was determined using prices from the Vancouver Log Market. The average price for each log grade was calculated as the weighted average price over the period 1990-1992 using the volume of logs sold in each year as the weights. Log prices were first converted from nominal to real prices using the Industrial Producer Price Index (Statistics Canada, 1992).

- The costs of conventionally skidder logging the commercial thinnings and the final harvest of the thinned and unthinned stands were estimated using the coast and interior appraisal manuals produced by the B.C. Forest Service.

8.2 Conclusions

The conclusions of the study are discussed below under five major headings.

1. Feasible Commercial Thinning Regimes

The biological foundations for density management were reviewed and it was shown that thinnings may be used as a means of reducing stand density in order to: 1) salvage tree volume which otherwise would be lost to mortality; 2) increase the portion of total stand volume which reaches a given merchantable limit; and 3) concentrate the growth potential of the site on fewer trees which may increase the value of the stand's final harvest. Depending on the species there is a potential range of stand densities which can be maintained without sacrificing volume production. The ability of the trees left after a thinning to respond to the increased light, nutrients and water will depend on the vigour of the leave trees which is in turn determined by the size of the tree's live crown, the age of the stand, the species, and the quality of the site. The impact of each thinning method and thinning intensity on both the existing and desired stand structure must be carefully considered when determining the appropriate thinning regime for a particular stand.

Based on the discussion of thinning methods it was suggested that low thinnings would be the most appropriate thinning method for Douglas-fir stands on good and medium sites. The timing of the thinning should be just before the onset of serious tree mortality but delayed enough that sufficient merchantable volume is available in order for the thinning to be economically viable.

2. Effects of Thinning on Cumulative Merchantable Volume

The simulations of the impacts of commercial thinning Douglas-fir leads to the conclusion that commercial thinning will likely provide only a marginal increase in the cumulative merchantable volume available from a stand over a rotation. Thus, if commercial thinning is to be justified as a viable forest management option it will have to be based on either the potential of the thinning to increase the value of the stand, by concentrating the stand's growth potential on a smaller number of trees, or on the earlier financial return obtained from thinning the stand.

3. Economic Evaluation

Thinning in the range of 200 to 400 leave trees per hectare was shown by the simulations to be economically superior to the corresponding unthinned regime for almost all site index 36 simulations run and for most of the site index 30 simulations run. The optimum thinning regimes may potentially increase the NPV of the simulated stands by 10-20% at site index 36 and by 3-30% at site index 30, depending on the thinning age and initial stand density. At site index 24 only a few of the PCT simulations showed commercial thinning to be viable with the best results achieved in stands which were PCT to 500 SPH. While these increases are not trivial they are by no means massive either. Thus, the economic gain from commercial thinning will, by themselves, be modest but still potentially well worth pursuing. The poor results achieved at site index 24 indicates that this is probably the lower limit for viable commercial thinning operations, at least under current log prices and harvest costs.

The higher NPV provided by some of the commercial thinning regimes can be attributed to two factors. First, the thinnings concentrated the growth on the larger dominant trees which produced a higher value per m^3 of wood grown. Second, the thinnings produced interim revenues

through the harvesting of trees who's timber values would have grown at a rate lower than the social discount rate. Typically the NPV of the thinned regimes drops off quickly as the thinning intensity was reduced. This highlights the economic advantage obtained from an early financial return from the stand. Using an investment analogy, if the stand is viewed as an investment portfolio and each tree as a separate stock than the commercial thinning may be viewed as the liquidation of those stocks producing the poorest investment yields. In addition, the thinning has the added advantage of increasing the returns on the remainder of the investment portfolio - the leave trees.

The foregoing comparison of NPVs was based on the comparison of the maximum NPV obtainable from the unthinned stand to the maximum NPV obtainable from a thinned stand which would occur at each stand's economic rotation age. The economic rotation ages for the unthinned stands were quite short ranging from 60-65 years of age at site index 36 and ranging from 60-70 years of age at site index 30 and 24. However, current forest management practices in British Columbia would see a stand harvested at the age which cumulates, or maximizes, the stand's mean annual (volume) increment, or MAI. In the unthinned stands cumulation of MAI occurred at ages ranging from 75-100 years. Cumulation of MAI is know as the physical roation age as it is the age which maximizes volume growth. If the NPVs of the various regimes are compared at the physical rotation age then the viability of commercial thinning is even further enhanced particularily with the site index 24 simulations. Thus, when rotation ages longer than the economic rotation age are planned commercial thinning becomes an even more attractive forest management option.

4. Sensitivity Analysis

The purpose of sensitivity analysis is to investigate how responsive the basic results were to changes in the key parameters used in the analysis. This was done to see if the ranking of the regimes would change in response to changes in any of the key parameters. For this study the major parameters tested were the discount rate, thinning costs, final harvest costs, road development costs, and basic silviculture costs. Overall the sensitivity of the base case results to changes in the key parameters increased as the site index declined and as initial density increased. This was not unexpected as the ability of a stand to respond to release will decline with a lower site index and with a higher initial stand density. The results show that a lower discount rate, higher thinning costs, or a lower final harvest cost will change some of the rankings. Tests of the potential economic consequences of any stand damage, which could occur during thinning, showed the results to be sensitive to stand damage highlighting the need to take measures to reduce any stand damage if commercial thinning is to remain economically viable.

8.3 Recommendations for Further Research

The simulation of the impacts of thinning on stand development and the assessment of the economic viability of commercial thinning provides numerous suggestions for areas of further research including:

- the assessment of commercially thinning the province's other major commercial tree species, such as Western Hemlock and Lodgepole Pine;
- the sensitivity of the results to any stand damage indicates a need to quantify the effects of various levels of stand damage;
- the assessment of commercial thinning when used in conjunction with other silvicultural treatments, particularly fertilization;
- the compilation of data on actual commercial thinning revenues and costs; and
- the development of optimal thinning schedules where more than one commercial thinning per rotation is planned.

REFERENCES

Abetz, P., 1982. Zuwachsreaktion von Z-Bäumen and Durchforstungsansätze bei Auslesedurchforstung in Fichtenbeständen. Allgemeine Forstzeitchrift 47:144-146, as cited by Smith (1986).

Bickford, C.A., F.S. Baker and F.G. Wilson, 1957. "Stocking, Normality, and Measurement of Stand Density." Journal of Forestry, 55:99-104.

Braathe, P., 1957. Thinnings in Even-Aged Stands: A Summary of European Literature. Faculty of Forestry, University of New Brunswick, Fredricton.

Bradley, R.T., 1963. "Thinning as an Instrument of Forest Management." Forestry 36(2):181-194.

Borsuchowski, R., 1955. Partial Time Study of a Second-Growth Hemlock Thinning. British Columbia Forest Service, Research Note No. 30. Victoria, B.C.

Cameron, I.R., 1988. An Evaluation of the Density Management Diagram for Coastal Douglas-fir. Ministry of Forests, FRDA Report No. 024.

Chambers, C.J., 1977. "A Second Look at Thinning: The Effect of Thinning on Allowable Cut - The State Position." State of Washington, Department of Natural Resources, DNR Note No. 17.

Chambers, C.J., and D.Pierson, 1976. "Does Commercial Thinning Pay Under Sustainable Yield?" In Berg A.B. (ed.), 1976, Managing Young Forests in the Douglsa-fir Region, proceedings of a symposium held June 11-13, 1973. School of Forestry, Oregon State University, Corvallis.

Curtis, R.O., 1982. "A Simple Index of Stand Density for Douglas-fir." Forest Science, 28(1):92-94.

Daniel, T.W., J.A. Helms and F.S. Baker, 1979. Principles of Silviculture, second edition. McGraw-Hill Inc. New York.

Davis, K.P., 1966. Forest Management: Regulation and Valuation, second edition. McGraw Hill Book Company, New York.

Davis, L.S. and K.N. Johnson, 1987. Forest Management, third edition. McGraw-Hill Inc., New York.

Drew, T.J. and J.W. Flewelling, 1979. Stand Densisty Management: an Alternative Approach and Its Application to Douglas-fir Plantations. Forest Science, Vol. 25, No. 3, pp. 518-532.

Eide, E., and A. Langsaeter, 1941. Produksjonsundersökelser i granskog. Referat: Produktionsuntersuchungen von Fichtenwald. Medd. f. Det norske Skogforsökswesen, VII (356-500). As cited by Braathe, (1957).

Ferguson, C.E., and J.P. Gould, 1975. Microeconomic Theory, fourth edition. Richard D Irwin Inc., Homewood, Illinois.

Forestry Commission, 1946. The Thinning of Plantations. Forest Operations Series No. 1. His Majesty's Stationary Office, London.

Gregory, G.R., 1972. Forest Resource Economics. John Wiley & Sons Inc., New York.