TEN-YEAR GROWTH RESPONSE AND FINANCIAL EVALUATION OF COMMERCIAL STRIP THINNING OF JACK PINE: A CASE STUDY

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ABSTRACT

In 1970, a 45-year-old jack pine (*Pinus banksiana* Lamb.) stand near Chapleau, Ontario was commercially strip thinned, under contract, by means of a conventional shortwood logging system. Corridors were clear-cut to a width of 5.0 m with 6.3-m-wide residual strips.

Ten-year growth data showed good response among crop trees. An increase in mean tree volume between 18 and 22% (.02 to .06 m^3) by age 70 is predicted. Including the volume harvested from thinning, the net gain by age 70 may be about 20 m^3/ha.

On the basis of estimates of growth, costs and prices, a positive net present value (NPV) is possible as a result of strip thinning at discount rates of 4% or more. Sensitivity analysis showed that NPV is very sensitive to mean DBH and density.

Trees at or near the edge of the residual strips responded better than those near the middle. A slight narrowing of the cut and leave strips may increase the yield. However, as an alternative, it is recommended that investigations be carried out combining strip thinning with individual, selective tree thinning from below in wide residual strips to achieve a higher utilization of site productivity potential.

RÉSUMÉ

En 1970, un peuplement de 45 ans de pins gris (*Pinus banksiana* Lamb.) situé près de Chapleau, en Ontario, a subi une éclaircie commerciale en bandes suivant la méthode classique d'exploitation en bois court. Les bandes coupées à blanc faisaient 5,0 m de large et étaient espacées de 6,3 m.

Les données sur l'accroissement après 10 ans indiquent un effet positif de l'éclaircie sur les arbres du peuplement final. À 70 ans, leur volume moyen devrait avoir augmenté de 18 à 22 % (0,02 à 0,06 m^3). Si l'on inclut le volume récolté lors de l'éclaircie, le gain net à 70 ans pourrait être d'environ 20 m^3/ha.

D'après les estimations de l'accroissement, des coûts et des prix, une valeur actualisée nette positive semble possible à la suite de l'éclaircie en bandes pour un taux d'actualisation de 4 % ou plus. Une analyse de sensibilité a indiqué que la valeur actualisée nette est très sensible au dhp moyen et à la densité.

(cont'd)

RÉSUMÉ (concl.)

Les arbres situés sur la lisière de la bande non coupée ou à proximité ont été plus favorisés que ceux qui se trouvent plus près du centre. Un léger rétrécissement des bandes coupées et non coupées pourrait augmenter le rendement. Toutefois, on recommande une autre option en vue d'assurer une meilleure utilisation du potentiel de productivité des sites, soit de combiner l'éclaircie en bandes avec une éclaircie sélective, individuelle, par le bas dans les bandes larges non coupées.

ACKNOWLEDGMENTS

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Cover photo: Aerial view of strip-thinned area eight years after treatment. Line at left is Highway 129.

INTRODUCTION

In 1970, operational commercial thinning trials were conducted by staff of the Great Lakes Forestry Centre in a dense, 45-year-old jack pine *(Pinus banksiana* Lamb.) stand with a conventional shortwood harvesting system (Mattice and Riley 1975). Approximately 51.8 ha were strip thinned under contract (see cover photo and Fig. 1).

Fig. 1. Typical cut and leave strips after thinning in 1970 (from Mattice and Riley [1975]).

Because strip thinning is amenable to mechanization and simplified ground control, the thinning proved to be operationally feasible and profitable, and the contractor realized a net revenue of $7.42/m^3 (1986 dollars[2]). It was felt that strip thinning should produce some of the biological benefits of selective thinning by harvesting some of the trees that would otherwise die from overcrowding and by concentrating growth on fewer stems.

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[2]Value in 1971 dollars $2.35/m^3. Converted to 1986 dollars according to the GNE-Implicit Index (Anon. 1986).

Since the original purpose of the trial was to evaluate the operational aspects of strip thinning, minimal provisions were made for a long-term study of growth response. Because of the lack of information in Ontario on growth response of commercially thinned jack pine, it has been deemed desirable to assess 10-year growth response in the thinned stand and the adjacent unthinned portion. On the basis of observed growth trends, predictions of future growth were made for individual crop trees and the whole stand. These predictions were the basis of a case study to provide a financial analysis of commercial strip thinning. The sensitivity of the assessment to a range of relevant stand and financial variables was explored.

STUDY AREA AND STAND

The study area is located in Nimitz Township (lat. 47°38'N, long. 83°14'W) in the Chapleau District of the Ontario Ministry of Natural Resources (OMNR) and is 25 km SSE of the town of Chapleau. It lies within the Missinaibi-Cabonga Section of Boreal Forest Region B.7(2) West (Rowe 1972).

The area is a flat to gently rolling outwash plain. Soil texture is variable, but generally consists of silty to sandy loam overlying coarser sandy gravel. The soil profile is part of the Dystric Brunisol Great Group. The site is classified as Site Class 2 (Plonski 1974).

The thinned stand is of fire origin and was 45 years old at the time of thinning in October and November of 1970. It was overly dense, containing 2200 stems/ha that were more than 6.4 cm DBH. Prior to thinning, species composition was 95% jack pine and 5% other species, principally black spruce (*Picea mariana* [Mill.] B.S.P.). The treated stand, including roadways, covered 52 ha. Strip thinning removed approximately 45% of the basal area and yielded 53 m^3/ha inclusive of area in cut strips. Strips were aligned more or less north-south (162°); cut strips averaged 5.0 m in width and leave strips 6.3 m. For a description of the thinned stand following treatment see Table 1. Further details of area and stand conditions at the time of establishment of the trial are given by Mattice and Riley (1975).

METHODS

Growth Response

In the thinned stand a post-thinning timber cruise with 10-m-wide continuous strips aligned at right angles to the leave strips was conducted in 1971. Cruise lines were remeasured in 1975 and 1980, after 5 and 10 years of growth. Approximately 0.4 ha of the residual forested area was sampled. In 1975, 111 sample trees from the more prevalent DBH classes at the center and edges of the leave strips were selected and marked. Information recorded included tree location in leave strip,

Table 1. Post-treatment summary--stand.

Treatment	Age (yr)	Density[a] (no./ha)				DBH[a] (cm)		Total vol. (m^3/ha)		Merch. vol. (m^3/ha)	
		Jack pine	Other	Total	Dead standing	Jack pine	Other	Total[b] area	Within resid. strip	Total[b] area	Within resid. strip
Thinned	45	2035	132	2167	1541	11.9	8.9	91	163	67	120
	50	1699	199	1898	1483	13.9	9.7	110	198	91	164
	55	1621	250	1871	957	15.4	10.2	132	237	114	205
Unthinned	45	-	-	-	-	-	-	-	-	-	-
	50	1656	293	1949	859	14.6	9.3	233	NA	196	NA
	55	1350	369	1719	792	15.5	9.8	218	NA	189	NA

[a] Stems more than 6.4 cm DBH.
[b] Includes area within residual strips and cut strips.

crown class, height, DBH, double bark thickness and radial growth for the last five 5-year periods.

In 1975, 5 years after thinning, in an adjacent unthinned stand of the same origin, cruise lines amounting to 0.3 ha of sample were established and 69 sample trees were marked and measured as in the thinned stand. In 1980, remeasurements including radial growth for the period 1975-1980 were taken in both stands. Stand data are given in Table 1.

Height equations[3] for the thinned and unthinned stands were derived from 1980 sample tree data and were used to estimate volume (Honer et al. 1983).

To compensate for the lack of unthinned stand data at the time of trial establishment, sample tree increment core data were used to estimate the growth for 10 years after thinning of a "stand" of the largest (6.4 to 24.1 cm DBH) crop trees (in 1980) for each of the thinned and unthinned stands. The number of trees in the "stands" was arbitrarily set at 625/ha, i.e., the larger trees expected to constitute a high proportion of the volume at rotation.

Differences in stand composition and site class (the thinned stand is half a site class lower) and the lack of stand information in the unthinned stand at the time of thinning hinder the comparison of the two stands. For this reason, data from the unthinned stand were used only to assist in developing a growth response trend from thinning. **Absolute comparisons between the stands should not be made.**

Financial Evaluation

An assessment of the net present value (NPV) (1986) of the treatment is made by comparing the NPV of the thinned stand with the NPV of the same stand, on the assumption that there is no treatment. The NPV of the thinned stand is the sum of the NPV of the net revenue obtained from the thinning and the NPV of the net revenue obtained from the final harvest at age 70. The NPV of the same stand with no thinning is simply the NPV of the net revenue obtained from clearcutting at age 70.

In view of the length of time involved and uncertainties in the growth projections and financial variables (e.g., product prices and costs), appropriate ranges of values for both types of variables have been included in the analyses so that the impact of changes in these variables on the NPV of net revenue obtained from the stand **with** thinning and **without** thinning over one complete rotation can be estimated. Assumptions used in this analysis are recorded throughout the text.

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[3] Height thinned (m) $= 5.03 + 0.96$ DBH (cm) $- 0.02$ DBH^2 (cm) ($R^2 = .69$)
Height unthinned (m) $= 6.21 + 1.10$ DBH (cm) $- .02$ DBH^2 (cm) ($R^2 = .60$)

There may be various potential benefits within a broader management context, but they have not been considered in this analysis. For example, increased industrial activity as a result of an augmented or enhanced wood supply would generate greater income. Commercial thinning could be used to adjust imbalances in age class distribution and ensure an even supply of wood.

The estimates of the net revenue of the final harvest were derived by using the method of Smith et al. (1985), developed to generate estimates of revenue per stem by DBH in 1986 dollars. Lumber recovery estimates for jack pine tree lengths, provided by a local sawmill, were used to determine the total recoverable volume by DBH. Recoverable volume was apportioned to grades by DBH, on the basis of estimates developed by Flann and Petro (1984). It is assumed that the difference between total merchantable and recoverable volume will be sold as pulp chips.

Wholesale unit prices (Anon. 1985) of jack pine lumber were assigned to the sawn volumes by grade. The prices were adjusted to moderate cyclical or seasonal effects. The value of the residual pulpwood volume was determined by estimates of the pulp chip selling prices (Anon. 1983a) and inflated to 1986 dollars by using the pulp and paper selling prices index (Anon. 1986).

The net revenue from thinning recorded by Mattice and Riley (1975) was inflated by the industry price index (Anon. 1986) to 1986 dollars and was used in the analyses.

To ensure that the cost estimates were comparable with the revenue estimates (established by using wholesale prices), the total costs/m^3 including stumpage values and all harvesting, transportation and processing costs were estimated on the basis of Ontario figures (Anon. 1983b). Cost estimates were adjusted to moderate cyclical effects.

It has been assumed that in fully mechanized, efficient wood processing systems the present value of the effect of average DBH of the harvested wood on the overall costs would be more or less negligible, in view of the projection period and the limited projected increment in DBH that results from thinning. This may mean a slight overestimation of the costs for the thinned stand, because of its higher average DBH. The same net access costs were assumed. Costs of tertiary road construction on a unit product basis will be high at the time of thinning and significant carrying charges may be incurred because, in comparison with clearcutting, a large portion of the wood is not recovered. However, only upgrading of the roads will be required at the time of final harvesting.

RESULTS

Sample Tree Response

Diameter growth for three DBH (1970) classes is shown in Figure 2 for 20 years before and 10 years after treatment. Five-year DBH periodic annual increments (PAIs) for the same period and current annual increments (CAIs) for the 10th year after thinning are shown in Figure 2.

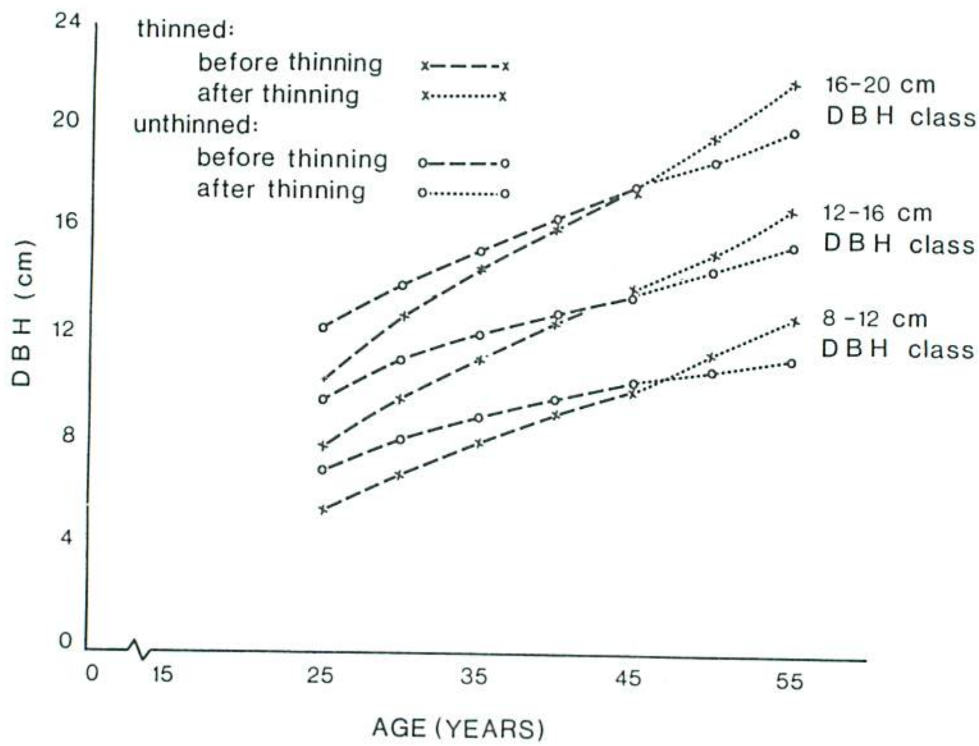

Fig. 2. Sample tree DBH (cm) over age for three 1970 DBH classes. DBH estimated from PAIs, 1970 base year.

Prior to the year of treatment, diameter increment had been decreasing and/or was levelling off in all three DBH classes, both in the thinned and in the unthinned stands (Fig. 3). In the thinned stand, the PAIs increased significantly (P = .05) during the second 5-year period after thinning in comparison with those in the 5-year period before treatment. High CAIs in the 10th year after thinning indicate a continuing trend of increases in the two larger DBH classes. In the unthinned stand, the levelling off trend continued, with no significant changes in PAIs in the 5-year period before thinning and in the 10-year period after thinning. The CAIs in the 10th year after thinning indicate no change in this trend.

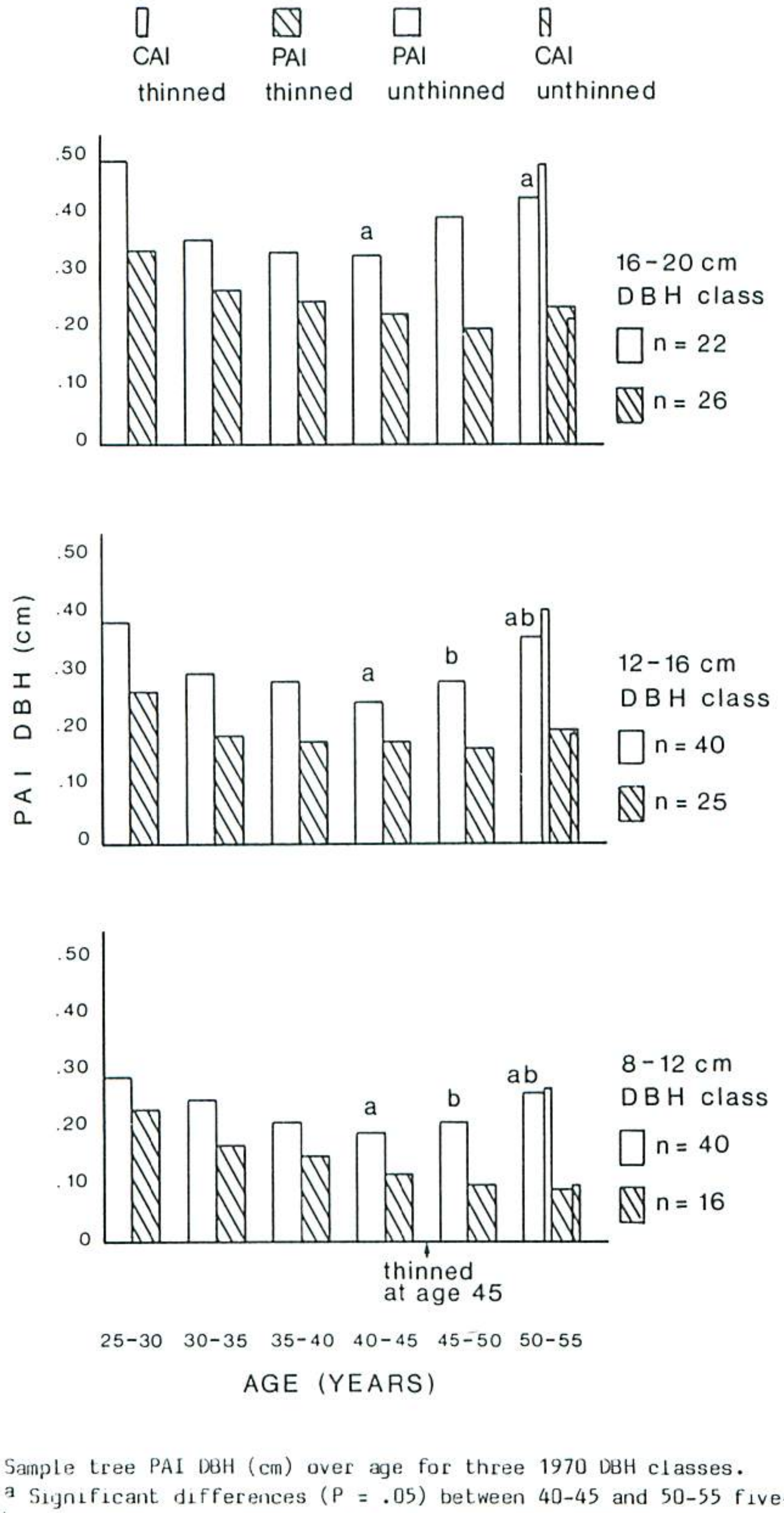

Fig. 3. Sample tree PAI DBH (cm) over age for three 1970 DBH classes.

[a] Significant differences (P = .05) between 40-45 and 50-55 five-year periods.

[b] Significant differences (P = .05) between successive five-year periods for the periods 35-40 vs 40-45, 40-45 vs 45-50, 45-50 vs 50-55.

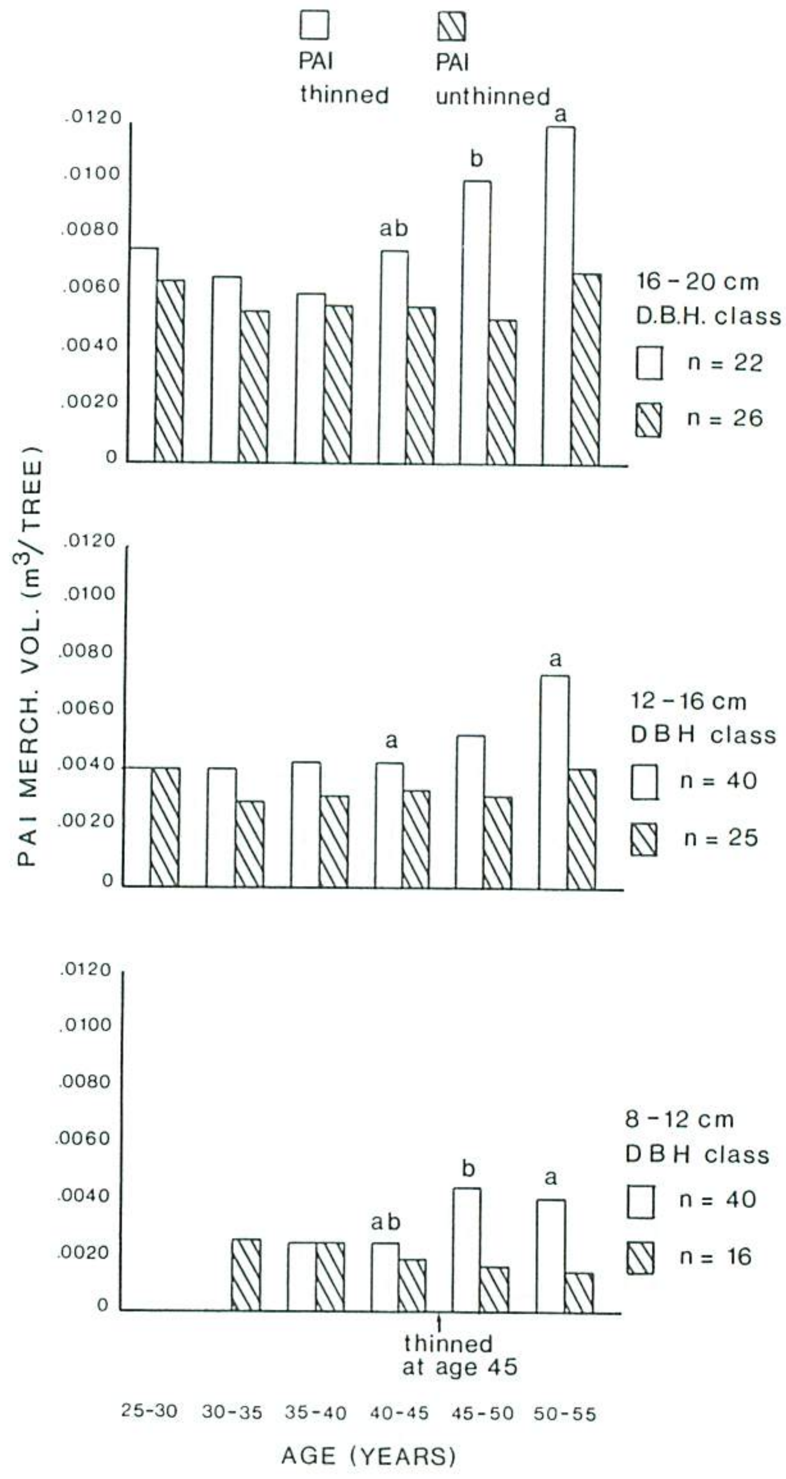

Fig. 4. Sample tree PAI merchantable volume (m^3/tree) over age for three 1970 DBH classes.

[a] Significant differences (P = .05) between 40-45 and 50-55 five-year periods.

[b] Significant differences (P = .05) between 40-45 and 45-50 five-year periods.

In the thinned stand, the volume increment of the sample trees was constant prior to thinning in the two smaller DBH classes and was increasing slightly in the largest DBH class (Fig. 4). After thinning, the PAIs increased greatly in all DBH classes, with significantly ($P = .05$) higher PAIs in the second 5-year period after treatment than in the 5-year period before treatment. Volume increment did not change significantly in the unthinned stand from age 30 to 55.

Stand Response

Jack pine mortality in the thinned stand was 17% in the first 5-year period after thinning (Table 1) when the number of jack pine stems was similar in the thinned and unthinned stands. In the second 5-year period, jack pine mortality in the thinned stand was only 5% in comparison with 18% in the unthinned stand. An understory of black spruce was forming in both stands and was somewhat denser in the unthinned stand. A cover of speckled alder *(Alnus rugosa* [D.R.] Spr.) was developing in the cut strips and in openings in the leave strips 10 years after treatment.

Average DBH of jack pine increased in the thinned stand by 3.5 cm during the 10-year period. Average, total and merchantable volume of jack pine increased steadily in the thinned stand over the 10-year period, merchantable volume increasing by 47 m^3/ha or 70% (total area, including residual and cut strips). As a consequence of mortality, the same two stand parameters decreased in the unthinned stand in the second 5-year period, merchantable volume decreasing by 7 m^3/ha. Merchantable volume per ha in the thinned stand increased from 46% of the volume in the unthinned stand 5 years after treatment to 60% 10 years after treatment.

Crop Tree Response

The estimated 10-year growth of the 625 trees that were greatest in diameter in 1980 is compared in Table 2. Diameter increment of crop trees within the leave strips was approximately double that in the unthinned stand, i.e., 3.6 vs 2.0 cm. Merchantable volume on a total area basis of 625 thinned crop trees increased by 28 m^3/ha or 74%. Because the productive area is much greater in the unthinned stand, the merchantable volume increase of the unthinned crop trees was 32 m^3/ha. However, the percentage increase was only 33%.

Growth Projections

The magnitude of the response can be estimated by predicting how the treated stand may perform without thinning. Figure 5 shows the observed mean merchantable volume in the treated stand before and after thinning for three sample tree DBH classes. If one assumes a levelling off in volume increment without thinning (as indicated in Figure 4), the growth trend is projected from age 45 to age 70. The observed growth trend as a result of thinning is projected unchanged from age 55 to age 60 and then to age 70 (OMNR rotation age) on the basis of a growth rate similar to that for the unthinned condition. By age 70 the mean merchantable volume per tree is predicted to be .40, .22 and .11 m^3 for the 16-20, 12-16 and 8-12 cm DBH classes, respectively (Fig. 5).

Table 2. Growth of 625 crop trees.[a]

			Total vol. (m^3/ha)		Merch. vol. (m^3/ha)	
Treatment	Age (yr)	DBH (cm)	Total[b] area	Within resid. strip	Total[b] area	Within resid. strip
Treated (within residual strips)	45	15.0	45	80	38	68
	50	16.7	57	102	50	90
	55	18.6	73	131	66	119
Unthinned	45	16.5	109	NA	96	NA
	50	17.5	124	NA	111	NA
	55	18.5	141	NA	128	NA

[a] Largest diameter trees between 6.4 and 24.1 cm DBH during 1980 timber cruise. The 1975 and 1971 DBHs were calculated by means of sample tree periodic increment data.

[b] Includes area within residual strips and cut strips.

Figure 5 also illustrates the effect of increased volume increment on rotation age. With thinning, trees would attain the same merchantable size at about age 62 as they normally would at age 70 if unthinned.

In Figure 6, the observed merchantable volume of the stand on a total area basis is projected to age 70. Plonski's (1974) Site Class II growth curve is used to estimate growth in the treated stand before and after age 45, assuming no treatment. The observed 10-year post-thinning growth trend is projected unchanged for an additional 5 years and to age 70 according to the same growth rate as for the unthinned condition. By age 70, because the "unthinned" and "thinned" curves do not meet, it appears that there will be about 33 m^3/ha less harvestable volume than if thinning had not been carried out. However, thinning removed about 53 m^3/ha. The estimated net gain over 25 years is therefore about 20 m^3/ha.

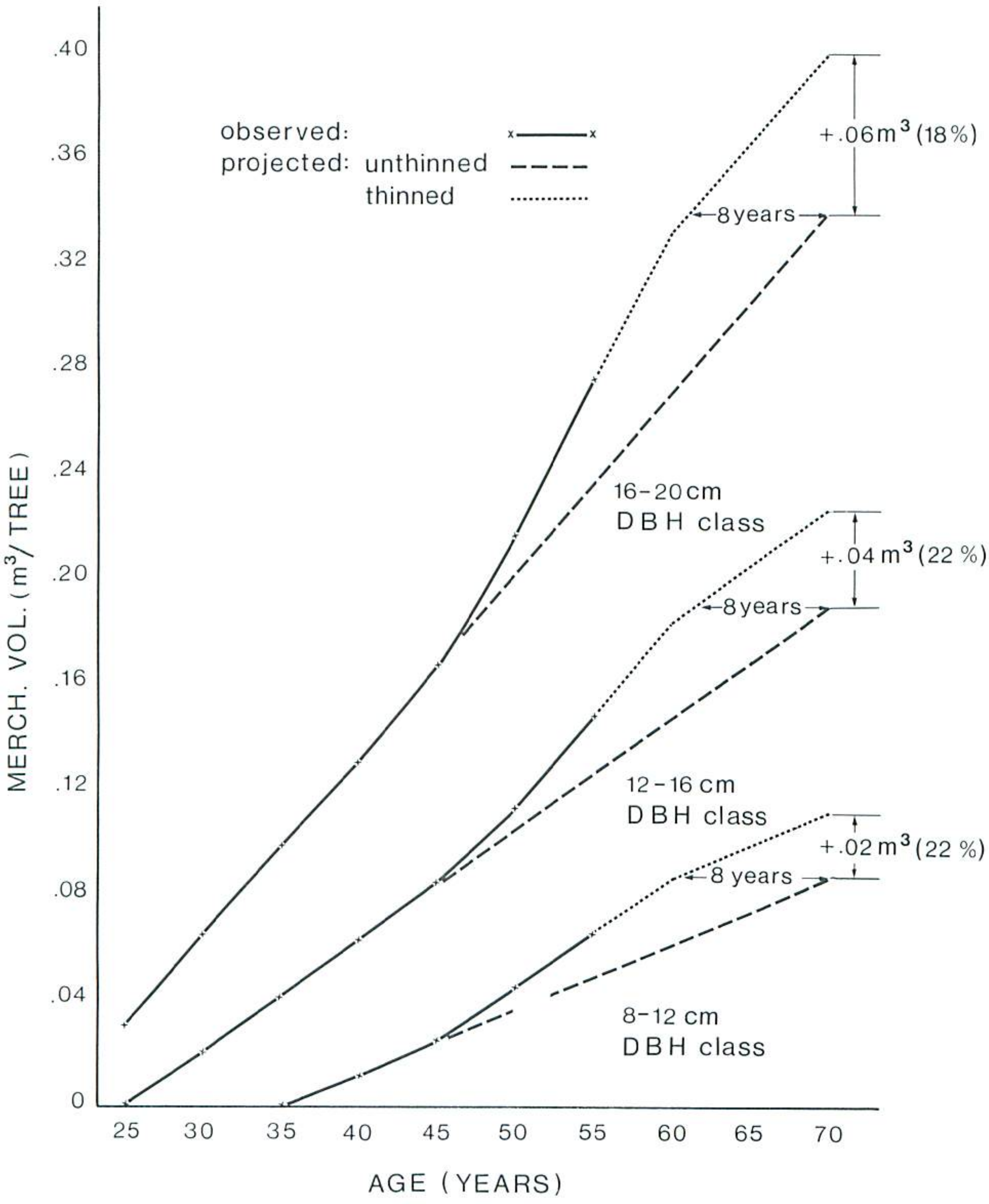

Fig. 5. Projection of sample tree merchantable volume (m^3/tree) to age 70 for three 1970 DBH classes.

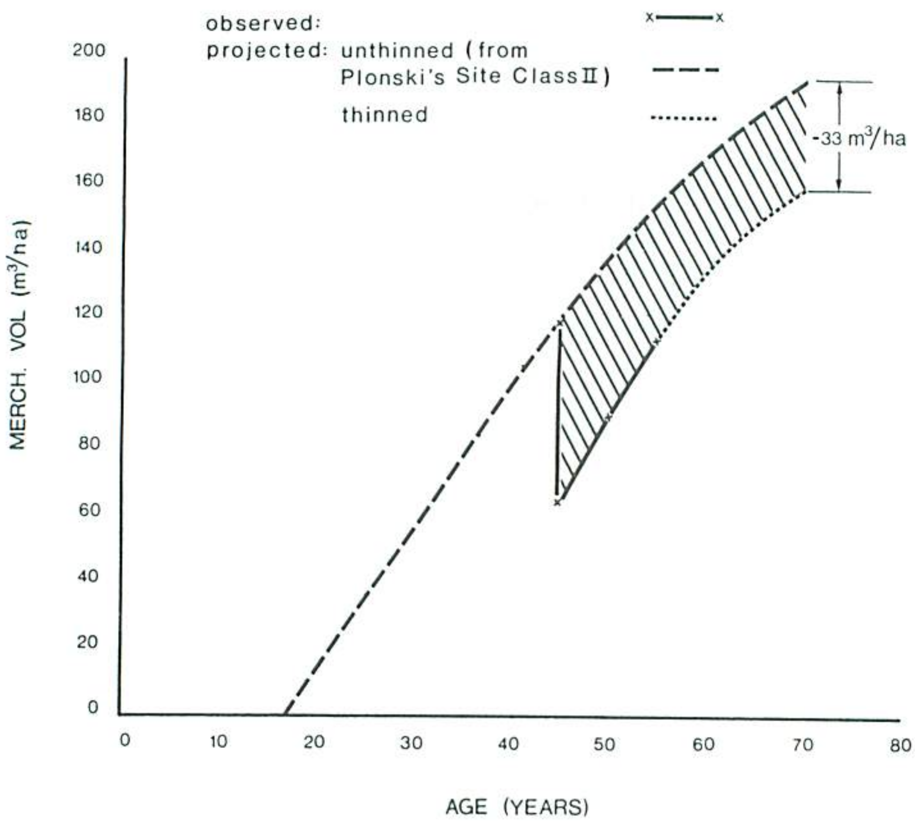

Fig. 6. Projection of stand merchantable volume (m^3/ha) to age 70. Total area basis (inclusive of area in cut strips), treated stand only.

Effect of Tree Location

There was a significantly (P = .05) higher increase in average DBH of trees in the 12- to 16-cm DBH class (codominant and intermediate crown classes) located along the edge of the leave strips than in similar trees in the center of the strips (Fig. 7). Edge trees in the 16- to 20-cm (dominants) and 8- to 12-cm (intermediate and suppressed) DBH classes also had greater, but not significant, increases in average DBH than trees in the center.

Wind and Snow Damage

Windthrow was negligible in the thinned and unthinned stands 5 and 10 years after thinning. The number of broken (usually just below the live crown) or bent stems was low in the thinned stand but higher than in the unthinned stand, i.e., 1.4 and 1.8% of stems were broken or bent in the thinned stand 5 and 10 years after thinning, respectively, versus 0 and 0.4% in the unthinned stand. Most broken and bent trees were in the suppressed and intermediate crown classes.

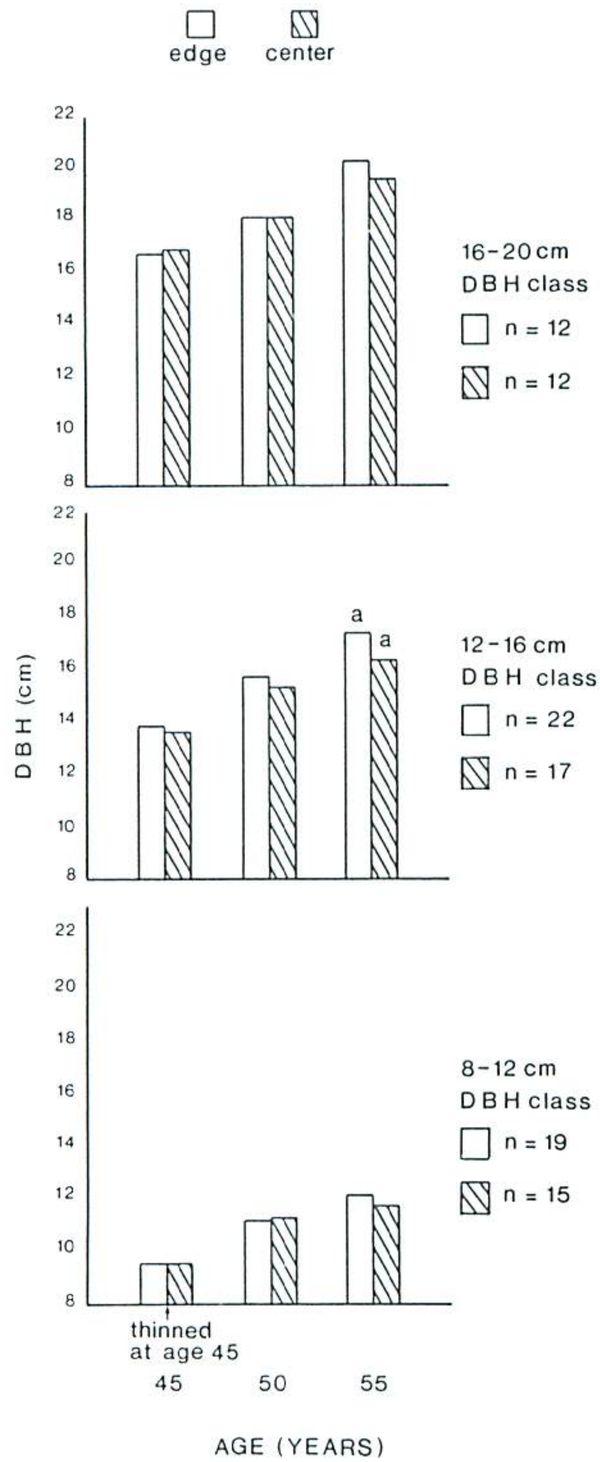

Fig. 7. DBH (cm) over age for edge- and center-located sample trees. For three 1970 DBH classes.

[a] Significant differences (P = .05) in DBH between edge and center trees at ages 45 and 55.

DISCUSSION

Increased growth from selective thinning in 30- to 60-year-old jack pine has been reported (Wilson 1951, Steneker 1969, Bella and DeFranceschi 1974, Smith 1984).

Few results are available from strip thinning jack pine at age 30 or beyond. Steneker (1969) reports that strip thinning (6-m-wide cut strips and 12-m leave strips) at age 60 resulted in diameter growth similar to that achieved with selective thinning (2.7-m spacing). Strip thinning (3-m cut and 6-m leave strips) at age 30 resulted in growth intermediate between selective (2.1 m) and unthinned conditions. Merchantable volume production was greater on strip-thinned than on selectively thinned stands at age 40 (4.5-m cut and 9-m leave strips; 2.1-m selective) and age 30, but the reverse occurred in the 60-year-old stand.

In this study, growth trends in the treated and unthinned stands indicate a positive response to thinning.

Prior to treatment, the trends of declining rates of change in DBH and volume increments were similar for sample trees in the treated and unthinned stands. In the 10 years after treatment, growth rates continued to level off in the unthinned stand but clearly increased in the treated stand. The positive response is likely to continue because of the high current annual DBH increment for trees in the dominant, codominant and intermediate crown classes in the 10th year after thinning. Bella and DeFranceschi (1974) noted that a 40-year-old crown-thinned jack pine stand had the greatest DBH increment in the third 5-year period after treatment.

It is predicted that thinning will result in a mean merchantable volume per tree at rotation age 70 of about .40, .22 and .11 m^3 for the 16-20, 12-16 and 8-12 cm DBH (1970) classes, respectively. This is a volume increase of 18, 22 and 22% in the three DBH classes.

As a consequence of higher individual tree volume, the average value per tree should be higher at age 70. Indicative of this is the observed growth of crop trees. Over the 10-year period after thinning the percentage increase in merchantable volume of the 625 trees with the greatest DBH in 1980 in the thinned stand was more than double that of the unthinned stand.

Alternatively, it should be possible to reduce the rotation age by about 8 years if rotation age is based on tree size. Thus, the harvesting schedule could be accelerated, both by the earlier utilization of wood from thinnings and by a reduced rotation age.

Although the trees in the strips responded positively to thinning, it is predicted that there will be 33 m^3/ha less volume in the stand at age 70 than if thinning had not occurred. The 45% basal area reduction through thinning has resulted in an under-utilization of site growth potential. This is shown in Figure 6, where it appears that the merchantable volume predictor curves for the thinned and unthinned conditions will not intersect by age 70. It is also evident in the stand that crown closure across the strips will not occur. Hence, the removal of 45% of the basal area in a single thinning may have been excessive. By way of comparison, Bella and DeFranceschi (1974) recommend the removal of 30 to 35% of the basal area in a single selective thinning. Benzies (1977) also recommends that not more than one-third of the basal area be removed in planted jack pine. However, it is conceivable that if two or more light thinnings were undertaken during the rotation age, more than one third of the basal area in total could be removed.

Despite the under-utilized growth potential, the estimated net gain over 25 years including the yield of 53 m^3/ha from thinnings is about 20 m^3/ha.

Edge Effect

Diameter growth was approximately 35% greater along the edge of the strips than in the center for trees in the codominant and intermediate crown classes. Strip thinning of jack pine in central Saskatchewan resulted in increased diameter growth within 1.0 m and 1.5 m of the edge in very dense 30- and 60-year-old stands, respectively (Steneker 1969). An edge effect has been observed in a 40-year-old Scots pine *(Pinus sylvestris* L.) and Norway spruce *(Picea abies* L.) stand in Sweden. Trees in the middle of 9.5-m-wide residual strips showed about 30% less volume increment than those on the edge (Anderson 1969). Edlund (1962) noted no significant edge effect in mechanized strip thinning with 4-m cut strips and 12-m residual strips in 40-year-old Scots pine in Sweden, but felt that logging had damaged root systems and hindered the growth response of border trees. Because jack and Scots pine have similar root systems, their susceptibility to mechanical root damage may be similar. Root damage was not assessed in this study, nor were the effects of strip thinning on stem form or branch diameter of the edge trees.

Wind and Snow Damage

The effects of wind and snow on natural and planted, thinned or unthinned jack pine of similar age are not well documented. Although row thinning in plantations of other pine species is clearly risky (Bradley 1969, Nelson 1969, Lynch 1985, Anon. 1986) and the heavier the thinning the greater the risk (Bradley 1969, Lynch 1985, Anon. 1986), damage from snow and wind was very low in the thinned stand and affected only the less vigorous suppressed and intermediate trees. This suggests that thinning with relatively wide, mostly undisturbed leave strips did not predispose the stand to significantly higher risk. However, the risk of blowdown is greatest immediately after thinning and decreases rapidly thereafter (Bradley 1969, Persson 1969). Also, blowdown results from the simultaneous interaction of predetermined variables such as site, stand and strip layout characteristics, and less predictable events such as storm frequency and severity (Moore 1977). Therefore, it is possible that the apparent windfirmness of the stand was the result of chance, i.e., lack of exposure to locally severe conditions during the period of greatest susceptibility.

Optimum Leave and Cut Strip Width

It is difficult to predict optimum cut and leave strip widths from the point of view of growth. Narrowing the cut strip width would probably be desirable, because crown closure is unlikely at the 5.0-m width. Strip roads 4 m wide are commonly used in young stands of Scots pine and Norway spruce in Scandinavia in conjunction with current extraction technology (Isomäki 1985). Reducing the leave strip width to take advantage of the edge effect increases the total length of edge per ha but also reduces the residual basal area (Table 3). Combining a 4-m cut strip width with a 5-m leave strip would give the same residual basal area as the 5-m by 6.3-m spacing in this trial; it would result in a 14% increase in stand edge and possibly would increase volume growth.

Table 3. Basal area removed (%) and length (m/ha) of residual strip edge for various cut and leave strip widths.

Cut strip width (m)	Leave strip width (m)							
	4	5	6	6.3[a]	7	8	10	20
				Basal Area Removed (%)				
4	50	44	40	39	36	33	29	20
5[a]	56	50	45	44	42	38	33	25
6	60	55	50	49	46	43	38	30
				Length of Edge (m/ha)				
4	2500	2222	2000	1942	1818	1667	1429	833
5[a]	2222	2000	1818	1770	1667	1538	1333	800
6	2000	1818	1667	1626	1538	1429	1250	769

[a] Trial area cut and leave strip widths.

Thinning to achieve a higher residual basal area by strip thinning only is probably not desirable. If a minimum possible cut strip width of 4 m is assumed, such a result could be achieved only if the residual strip width were increased, and that would reduce the edge effect (Table 3). This suggests that selective thinning would be desirable in wider residual strips to ensure a thinning response throughout the stand. Selective thinning with the shortwood system within 25- to 35-m-wide residual strips is common practice in Scandinavia (Hakkila 1985, Isomäki 1985). This has become more economical with the recent development of narrow, light-weight forwarders equipped with boom-mounted processing heads with a 9- to 12-m reach to extract wood from within the residual strips (Hakkila 1985). Known as single-grip harvesters, the machines work from approximately 4-m-wide cut strips. The primary purpose of the cut strips is to facilitate selective thinning in a rational and economical way.

Financial Evaluation

Since the financial evaluation must be based on projected growth, costs and prices, it is useful to include a range of values around the most probable estimate for these variables in the financial evaluation.

The merchantable volume projections were used for the stand, with and without thinning (Fig. 6), to assign appropriate ranges in merchantable volume. Density and average DBH were calculated according to volume equations (Honer et al. 1983) (Table 4). It has been assumed that the mortality rate will be lower with thinning and that the difference in average DBH at age 70 will be between 1.0 and 4.0 cm.

Table 4. Ranges of merchantable volume and associated ranges of density and average DBH for the treated stand, with and without thinning.

		Merchantable volume (m^3/ha)		
	Density	Average DBH (cm)[a]		
Treatment	(no./ha)[a]	20.75	**21.5**	22.5
Thinned	550	144	146	148
	615	158	**160**	162
	680	174	176	178
		Average DBH (cm)		
		18.25	**19.0**	19.75
Unthinned	880	178	181	184
	950	191	**194**	197
	1020	204	207	210

[a] Most probable values in boldface.

Figure 8 illustrates estimated revenue per tree by DBH. No allowance has been made for a change in wood quality as a result of thinning; e.g., a change in branch diameter or stem form. It is assumed that there will be no real changes in unit prices of products.

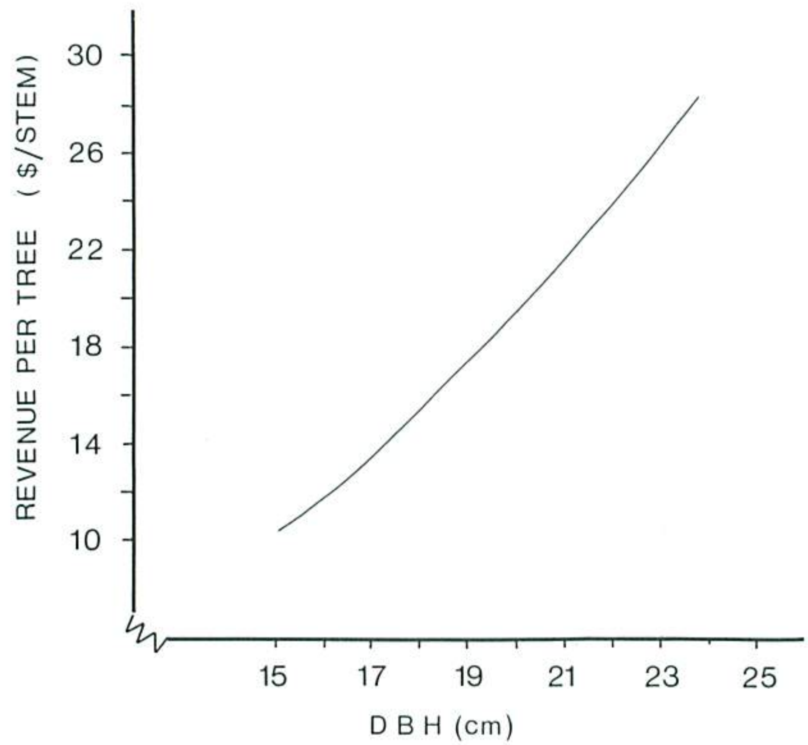

Fig. 8. Estimated revenue per stem by DBH ($/stem).

The density and average DBH values in Table 4 were used to estimate the net revenue of the final harvest with and without thinning. The net revenues with and without thinning were discounted to the present with appropriate discount rates, the net thinning revenue was added to the NPV of the thinned stand and the difference in the NPV with and without thinning was calculated by subtraction.

The major disadvantage of using NPV is the difficulty in choosing appropriate discount rates. Row et al. (1981) suggest a 4% discount rate for long-term forestry investments by the USDA. Table 5 shows the difference in the NPV of net revenue from the stand with thinning and without thinning for real discount rates of 4, 5 and 6%. See Appendix A for an expanded version of Table 5, including the complete range of average DBH per density class.

From Table 5, it appears that for the most probable growth projections a positive difference in NPV as a result of thinning is possible at discount rates of 4% or more. However, negative differences in NPV do appear in Table 5 and Appendix A, and these indicate a degree of risk in the investment.

Table 5. The difference in NPVs ($/ha) with and without thinning at different discount rates. It is assumed that the average DBH at final harvest with thinning is 21.5 cm and without thinning is 19.0 cm.

Discount rate (%)		Net present value (NPV) ($/ha)		
	Density thinned[a] (no./ha)	Density unthinned[a] (no./ha)		
		880	**950**	1020
4	550	9	-208	-426
	615	307	**90**	-128
	680	567	350	133
5	550	92	-79	-250
	615	327	**156**	-15
	680	532	361	190
6	550	158	23	-113
	615	343	**208**	72
	680	505	370	234

[a] Most probable values in boldface.

Sensitivity Analyses

Further sensitivity analyses help to predict which factors might contribute most to the uncertainty of the investment.

Figure 9 illustrates the effect on the difference in NPV of a change in discount rate on the NPV. The difference in NPV in both options increases as the discount rate is increased because higher discount rates reduce the unit NPV of the final harvest and increase the unit NPV obtained from the thinning.

The effect of change in thinning revenue is shown in Figure 10. Increases in unit thinning revenue increase the NPV of the thinning. A 20% increase in thinning revenue increases the NPV of the thinning option by nearly $100/ha.

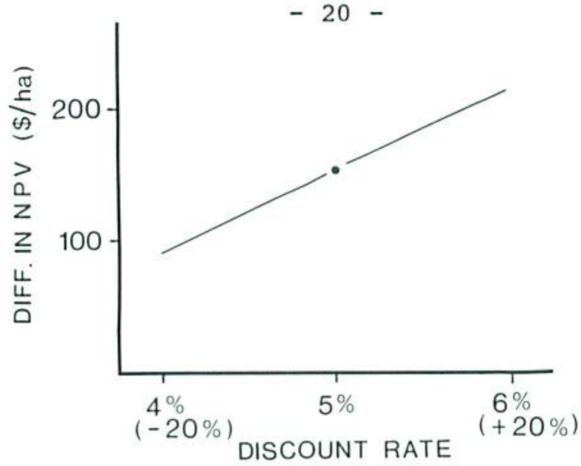

Fig. 9. Difference in NPV versus discount rate (assumptions: 615 trees/ha at 21.5 cm DBH and 950 trees/ha at 19.0 cm DBH for thinned and unthinned stands, respectively).

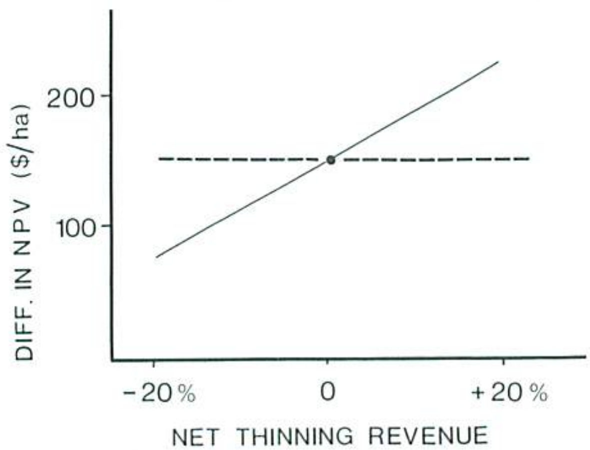

Fig. 10. Difference in NPV versus net thinning revenue (assumptions: 615 trees/ha at 21.5 cm DBH and 950 trees/ha at 19.0 cm DBH for thinned and unthinned stands, respectively, at a discount rate of 5%).

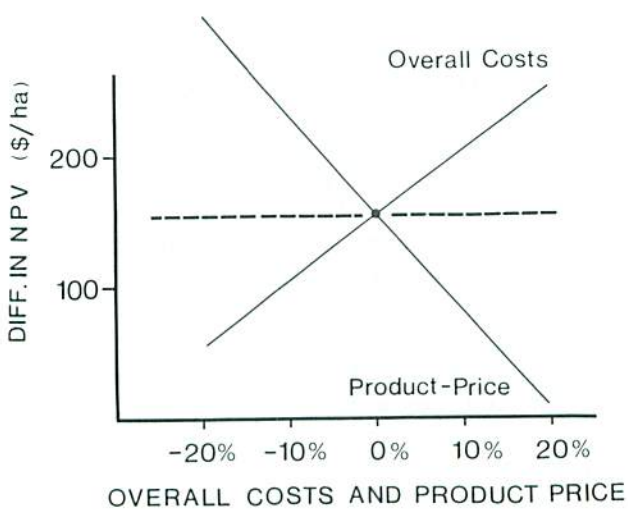

Fig. 11. Difference in NPV versus final harvest product prices and overall cost/m^3 (assumptions: 615 trees/ha at 21.5 cm DBH and 950 trees/ha at 19.0 cm DBH for thinned and unthinned stands, respectively, at a discount rate of 5%).

Figure 11 shows the sensitivity of the NPV to changes in the estimated unit costs and unit prices at the time of final harvest. An increase in unit prices at the time of the final harvest results in a decrease in the difference in NPV, because there is so much more volume and value in the unthinned than in the thinned stand at the time of the final harvest. The opposite effect occurs with an increase in unit costs.

The sensitivity of the NPV to changes in density and average DBH with and without thinning is illustrated in Figures 12 and 13. An in-

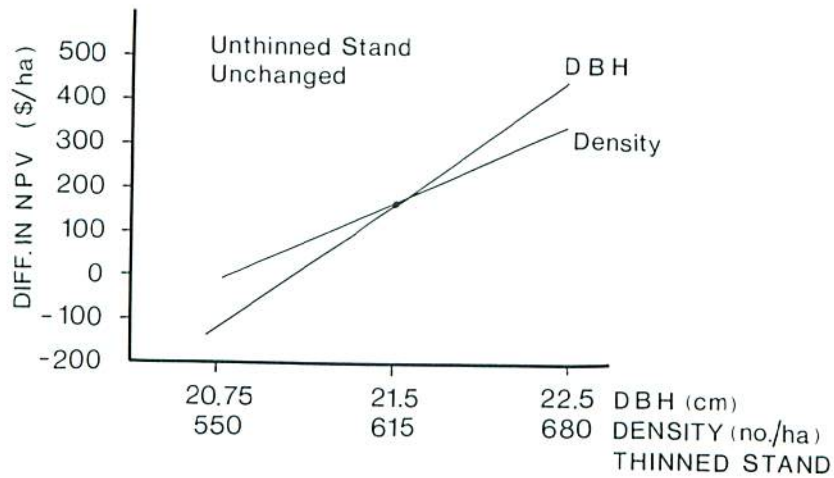

Fig. 12. Difference in NPV versus density and average DBH of the treated stand (assumptions: 950 trees/ha at 19.0 cm DBH and a discount rate of 5% for unthinned stands).

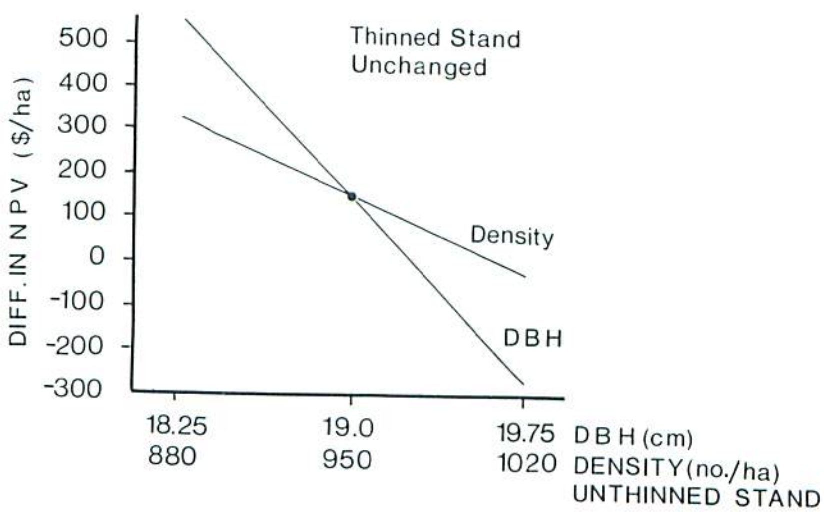

Fig 13. Difference in NPV versus density and average DBH of the stand without thinning (assumptions: 615 trees/ha at 21.5 cm DBH and a discount rate of 5% for thinned stands).

crease in the density and/or average DBH of the thinned stand causes an increase in the difference in NPV. Increasing the density and average DBH in the unthinned stand has the opposite effect. It is important to note that relatively minor changes in these two variables have a large impact on the difference in NPV. For example, a 0.75-cm (3%) decrease in average DBH in the thinned stand causes a reduction in the difference in NPV from +$156/ha to -$124/ha, a 180% change (Fig. 12).

As suggested in the section *Optimum Leave and Cut Strip Widths*. increasing the amount of leave strip edge while maintaining the same residual basal area might increase growth. If this could be accomplished without a large impact on net thinning revenue and final harvesting costs, a relatively small increase in average DBH would cause an increase in NPV.

It is difficult to predict whether the second suggestion of a combined strip and selective thinning would be more economical, i.e., whether there would be a large enough increase in growth to offset an expected reduced net revenue from thinning because of higher harvesting costs and a smaller volume of thinnings.

SUMMARY AND RECOMMENDATIONS

Individual jack pine trees responded positively to strip thinning at age 45 in terms of diameter and merchantable volume increment. Although absolute growth response figures are not available, from observed growth trends an increase of between 18 and 22% in merchantable volume per tree appears possible by age 70. As a consequence, crop trees will be more valuable at rotation. Alternatively, because of the faster growth the rotation age could be reduced by approximately 8 years. The harvesting schedule could be accelerated by harvesting the thinnings at an early age and by reducing the rotation age.

The net volume gain by age 70 on a total area basis, including the volume harvested from thinning, may be about 20 m^3/ha.

On the basis of the most probable estimates of growth, costs and prices, a positive difference in NPV was obtained at discount rates of 4% or more. However, there is a degree of uncertainty in the investment. With the exception of discount rates, the financial returns from commercial strip thinning in this case study appear to be more sensitive to changes in stand variables than in financial variables. The financial results are particularly sensitive to changes in the final harvest values of average DBH and density. In the thinned stand, a small increase in average DBH over the most probable estimate would result in a large increase in NPV while a small shortfall would result in a negative

NPV. Changes in DBH in the unthinned stand have a similar but opposite effect. Because of the degree of risk in the investment, other items not considered in the analysis such as road costs, distance from the mill as it affects delivered wood cost, site productivity, and the effect of thinning on wood supply should be part of the final decision-making process.

Strip thinning is a practicable and relatively inexpensive means of harvesting wood in an early commercial thinning. However, because of the high proportion of productive area within the cut strips, strip thinning results in an under-utilization of the overall production capacity of a site. The removal of 45% of the basal area in this trial is considered excessive and may lead to wind or snow damage, although little of either was observed in this trial. A single thinning probably should not remove more than one-third of the basal area.

Trees at or near the edge of the residual strips responded significantly better to thinning. It is not possible to achieve a much larger edge effect without a further reduction in residual basal area. However, if a minimum practicable cut strip width of 4 m and a leave strip width of 5 m (which represent an equivalent thinning intensity as applied in this trial) are assumed, the total length of edge per ha could be increased by 14%, and this might yield more volume. If this could be accomplished without a large impact on net thinning revenue and final harvesting costs, a relatively small increase in average DBH would cause an increase in NPV. The impact of the edge effect on wood quality is not known.

Selective thinning from below in wider residual strips of 25 to 35 m with 4-m cut strips would probably ensure a more even response to thinning throughout the stand, capture more volume that would otherwise be lost to mortality, and yield a higher net volume through improved utilization of the production capacity of a site. It is difficult to predict whether this method would be economically practicable in jack pine. There would have to be a sufficient increase in growth to offset an expected reduction in net revenue from the thinning operation because of higher unit harvesting costs and a smaller volume of thinnings. It is recommended that this method, with appropriate equipment, be investigated for thinning jack pine in northeastern Ontario. Trials should include studies of machine, wind and snow damage.

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Appendix A. The difference in NPV in $/ha for the most probable growth projections with and without thinning at different discount levels.[a]

Discount Rate (%)	Density thinned (no./ha)	DBH thinned (cm)	Net present value (NPV) ($/ha) — Density unthinned (no./ha): 880			950			1020		
		DBH unthinned (cm)	18.25	19.00	19.75	18.25	19.00	19.75	18.25	19.00	19.75
		20.75	134	-305	-766	-43	-523	-1023	-221	-740	-1281
4	550	21.50	449	9	-452	271	-208	-709	94	-426	-967
		22.25	775	335	-125	597	118	-383	420	-99	-641
		20.75	391	-49	-510	213	-266	-767	36	-483	-1025
	615	21.50	746	307	-154	569	90	-411	392	-128	-669
		22.25	1116	667	217	939	460	- 41	762	242	-299
		20.75	610	170	-290	432	-47	-548	255	-264	-806
	680	21.50	1007	567	108	830	350	-151	652	133	-409
		22.25	1420	980	521	1243	763	262	1065	546	5
		20.75	191	-155	-517	51	-326	-720	-89	-497	-923
5	550	21.50	439	92	-269	299	-79	-473	158	-250	-676
		22.25	695	349	-13	556	178	-216	415	7	-419
		20.75	393	47	-315	253	-124	-518	113	-295	-721
	615	21.50	673	327	-35	533	156	-238	393	-15	-441
		22.25	964	618	256	824	447	53	684	276	-150
		20.75	565	219	-142	426	48	-346	285	-123	-549
	680	21.50	878	532	170	738	361	-33	598	190	-236
		22.25	1203	857	495	1063	686	292	923	515	89
		20.75	235	-38	-324	125	-173	-484	15	-308	-644
6	550	21.50	431	158	-129	320	23	-288	210	-113	-449
		22.25	633	360	74	523	225	-86	413	90	-246
		20.75	395	122	-165	284	-13	-324	174	-149	-485
	615	21.50	616	343	56	505	208	-103	395	72	-264
		22.25	845	572	286	735	437	126	625	302	-34
		20.75	531	258	-28	420	123	-188	310	-12	-349
	680	21.50	778	505	218	667	370	59	557	234	-102
		22.25	1034	761	475	924	626	315	814	491	155

[a] Stands harvested at age 70. Harvesting, transportation and processing costs (1986 dollars) included. Revenue from thinning (1986 dollars) of $393/ha also included.