Comparative Growth and Development of Planted and Natural Stands of Jack Pine

by

P.S. Janas and D.G. Brand[1]

Abstract

This study compares growth, yield, and stem quality differences at age 21 between plantations spaced at 2.13 × 2.13 m (2204 stems/ha) and 4.27 × 4.27 m (548 stems/ha), and a nearby natural jack pine stand of identical age (initial density of 29 800 stems/ha). Merchantable volume/ha was greatest at the 2.13 m spacing, followed by the less dense plantation and natural stand. Total volume/ha (trees > 1.3 m height) was also greatest in the 2.13 m plantation, followed by the natural stand and the 4.27 m plantation. Individual tree mean merchantable volumes decreased with increasing density. Height growth decreased in both the natural stand and the 4.27 m plantation relative to the 2.13 m plantation. Stem quality of the natural stand was markedly better than in both plantations. A comparison of an older natural stand and a plantation in the same area suggests that superiority of tree form of denser natural stands will continue through to rotation. High mortality in the natural stand was largely the result of snow and ice damage which caused patchy and irregular stocking. These results imply that widely spaced plantations of unimproved jack pine will produce large individual tree sizes, but at the expense of quality.

Key words: *Pinus banksiana*, plantations, natural stands, stem quality, growth and yield, stand density, mortality, spacing, silviculture.

Résumé

La présente étude traite des différences de croissance, de rendement et de qualité des tiges entre les arbres de 21 ans d'une plantation espacée de 2,13 × 2,13 m (2204 tiges/ha) et d'une autre espacée de 4,27 × 4,27 m (548 tiges/ha) et des pins gris du même âge d'un peuplement naturel avoisinant (densité initiale de 29 800 tiges/ha). Le plus fort volume marchand par hectare se retrouvait dans la plantation espacée de 2,13 m suivie de l'autre plantation et du peuplement naturel. Le plus fort volume total par hectare (arbres de plus de 1,3 m de hauteur) se retrouvait également dans la plantation espacée de 2,13 m, suivie du peuplement naturel et de la plantation espacée de 4,27 m. Le volume marchand moyen des arbres individuels décroissait avec l'augmentation de la densité. L'accroissement en hauteur diminuait dans le peuplement naturel et dans la plantation espacée de 4,27 m comparativement à la plantation à 2,13 m. La qualité de tiges du peuplement naturel était nettement supérieure à celles des deux plantations. Une comparaison d'un peuplement naturel plus âgé et d'une plantation de la même région laisse supposer que les arbres des peuplements naturels plus denses continueront d'avoir un coefficient de forme supérieur pendant toute la rotation. Les dégâts causés par la neige et la glace sont en grande partie à l'origine du taux élevé de mortalité observé dans le peuplement naturel et de la proportion irrégulière et inégale de surface occupée. Ces résultats laissent entendre que des plantations largement espacées de pins gris non améliorés produiront des arbres de haute taille, mais au détriment de la qualité.

Mots clés: *Pinus banksiana*, plantations, peuplements naturels, qualité de la tige, accroissement et rendement, densité du peuplement, mortalité.

Introduction

Jack pine (*Pinus banksiana* Lamb.) is both the most widely distributed and economically important pine species in Canada. Its wood is used extensively for general construction, pulp, railway ties, poles, pilings, and mine timbers (Hosie 1973). It is also a principal reforestation species, with seven provinces reporting a production of 84 864 000 seedlings in 1986 (Smith and Brownright 1986); this represents 18.5% of total seedling production for all species in that year.

Although a major commercial tree species, certain characteristics of jack pine are not favourable for sawlog production. These include: 1) a relatively short life-span, coupled with a slowdown in growth between the ages of 10

[1]Petawawa National Forestry Institute, Chalk River, Ontario K0J 1J0

and 20 years in dense stands of fire-origin (Wilson 1952, Bella and DeFranceschi 1971, Armson 1978, Day 1986), which prevents many trees from attaining merchantable sawlog sizes; and 2) a high proportion of stem deformities and unacceptably high knot volumes in lower density natural stands and in plantations (Bella and DeFranceschi 1974b, 1980), downgrading wood harvested to pulpwood quality.

Owing to the desire to improve sawlog yield in very dense natural jack pine stands (which constitute the majority of this species' forested area [Armson 1978]), most past research on growth and yield of natural stands concentrated on evaluating the effects of thinning. The results from thinning research are generally in agreement, and indicate that thinned stands, compared with their unthinned controls, have: higher diameter increment (Buckman 1964, Steneker 1969, Bella and DeFranceschi 1971, 1974a, Bella 1974, Beckwith *et al.* 1984); no significant difference in height growth (Wilson 1952, Buckman 1964, Bella and DeFranceschi 1971, 1974a); lower total volume and basal area per hectare (Wilson 1952, Cayford 1961, Waldron and Cayford 1961, Buckman 1964); higher merchantable volume per hectare (Wilson 1952, Cayford 1961, Waldron and Cayford 1961); a larger percentage of stem deformities (Eyre and LeBarron 1944); and, lower mortality (Cayford 1961, Waldron and Cayford 1961, Bella and DeFranceschi 1971, 1974a).

There has been much less research on plantation spacing trials, and the results have indicated that the effect of wider initial spacing is similar in nature, but not in degree, to that of thinning in natural stands: i.e., increased diameter growth (Bella and DeFranceschi 1974b, 1980, Zavitkovski and Dawson 1977); reduced mortality (Zavitkovski and Dawson 1977); no significant height differences (Bella and DeFranceschi 1974b, Zavitkovski and Dawson 1977); and poorer stem quality, including increased branchiness and branch size, and more stem deformities resulting from multiple leadering (Bella and DeFranceschi 1974b, 1980).

Very little research has compared growth, yield, and form differences between naturally regenerated and plantation-grown jack pine stands on similar sites. The study of Beckwith *et al.* (1984) suggested that planting jack pine, followed by commercial thinning, may be preferred to management of natural jack pine. However, their results were based only on total volume yield and did not take into account differences in stem quality that may have existed between the two stand types.

Based on research to date, several questions of practical importance remain unanswered. For example, it is not clear whether planted or naturally regenerated stands produce the best compromise of high wood quality and merchantable volume yield. Also as most stands in Canada are of fire origin, it is not known whether it is advantageous to manage existing stands or allow them to develop to rotation, then to clear-cut and replant them. The prerequisite for such decision-making is the knowledge of which combination of regeneration method, spacing (in the case of plantations), and timing and intensity of thinning will maximize wood production for pulpwood, and which combination results in the highest yield of quality sawlogs.

This study compares stem quality and tree and stand growth of unthinned natural and planted stands on similar sites to ascertain answers to some of these questions.

Methods

The natural, fire-origin stand of jack pine chosen for this study is located on Sturgeon Lake Plains (latitude 46°00'N, longitude 77°24'30"W, elevation 150 m) at the Petawawa National Forestry Institute (PNFI). The site is generally rolling and the soil consists of fine aeolian sand deposits over medium to coarse sands (Engisch 1969)[2]. A fire killed the existing stand in 1964 and stimulated heavy natural jack pine regeneration in the area.

Four plots, each 0.0101 ha in size, were established in 1968. They had initial stand densities of from 9 333 to 57 664 stems/ha after two growing seasons. In two of the plots, standing snags were removed in 1969, on the assumption that this would lessen seedling mortality. Regeneration tallies were taken yearly from 1968 to 1973 and in 1975 and 1977 to assess seedling damage resulting from falling snags. In 1980, sample trees in each plot were systematically selected and numbered. The diameters of all trees were tallied, and heights within each diameter class measured at the end of the 1979, 1984, and 1986 growing seasons. For 1984, mortality due to snow and ice damage (i.e., clumps of trees fully bent over or broken under the weight of snow and ice) was also recorded. In 1986 (at age 21), each of these trees was tallied as being in one of the following stem quality classs (modified from Carter *et al.* 1986):

- Class 1: good stem quality (absence of crooks, forks, or sweep), yielding two or more 4.9 m sawlogs (minimum top diameter 9.1 cm), and small branch diameters (less than 2.5 cm);
- Class 2: fair stem quality, with no crooks or forks in the first 5 metres (at least one 4.9 m sawlog possible), and slightly undesirable branching characteristics (knot diameters exceeding 2.5 cm);
- Class 3: poor stem quality, with defects reducing yield to one 2.6 m sawlog, and poor branching characteristics;
- Class 4: multiple undesirable branching and stem form characteristics — suitable for pulpwood only; and
- Class 5: no commercial value due to very poor stem quality and branching characteristics.

A 4.1 ha plantation consisting of 2 + 2 bareroot jack pine stock from the Kemptville Nursery was established in 1965 at a spacing of 2.13 m (2200 stems/ha). The stock was of non-local provenance, but is similar in performance to local jack pine in adjacent provenance trials (C.W. Yeatman, pers. comm.). The site is located 1.30 km northwest of the natural jack pine stand and is level, with a slope less than 1%. The soil is a well-drained medium to coarse sand, overlaid by finer windblown sand (Anon. 1985)[3]. Part of this area was systematically thinned in 1970 before crown closure to a 4.27 m spacing (440 stems/ha). At this time, two permanent sample plots were established in each of the spacings. Three plots were 0.101 ha in area, and one plot (at a 2.13 m spacing) was 0.041 ha. Measurements of height and breast height diameter were conducted at periodic intervals between the ages of 5 and 21 years (corresponding to the end of the 1970 and 1986 growing seasons) in each of the plots. In 1986, each of the trees was also evaluated according to the stem quality classes described above.

Previous assessments have indicated that snags in the control plots of the natural stand caused no appreciable

[2]Engisch, R.L. 1969. Jack pine regeneration study. Can. For. Serv., PNFI, Project File Rep.

[3]Anon. 1985. Field research and demonstration areas on the PNFI Forest. Can. For. Serv., P.N.F.I.

damage to jack pine regeneration. Inspection of the data after 21 growing seasons revealed that the growth, form, and mortality in the four natural plots were similar enough in terms of trend and magnitude to allow pooling of the data. Similarly, data for the two plots at each of the plantation spacings were pooled.

To compare the crop tree characteristics of the natural and planted stands, trees in each plot were selected on the basis of the largest 400 diameters/ha. As only height data were available for ages less than 14 years for the natural stand plots, crop tree selection at these ages was based on the largest 400 heights/ha. All trees in each plot, with the exception of natural plots before age 14, were measured for dbh, and a subsample of trees were selected for height measurement in each diameter class. The height of remaining trees was estimated from height:diameter relationships calculated for each plot at each age ($H = b_0 + b_1D + b_2D^2$). (In natural plots all trees were measured for heights before age 14.) Volumes were calculated for each tree using the following equation (Berry 1981):

$$V = (3.174 \times 10^{-5} D^2H) + (8.07 \times 10^{-5} D^2) - (2.276 \times 10^{-5} DH) \quad (1)$$

where V = total volume, inside bark, stump and top included (m^3)
D = breast height diameter (cm)
H = height in metres (from regression equation).

Merchantable volumes were calculated using:

$$VM = (1 - 5.698\,[1b(10/D + 1.0)]^{4.807} - 0.0446) \quad (2)$$

(Alemdag 1987)

where VM = merchantable volume, inside bark, from stump height to merchantable top diameter inside bark (m^3)
D = breast height diameter outside bark (cm), at 1.30 m
V = total stem volume, inside bark (m^3) from equation 1.

This formula assumes a merchantable top diameter (inside bark) of 10 cm, and a stump height of 30 cm.

The older planted and naturally regnerated jack pine stands referred to in the discussion are also within the PNFI. The plantation was established in 1925 with a minor component of Scots pine (*Pinus sylvestris* L.) at a spacing of 1.52 m, followed by thinning in 1936 to approximately 3.0 m (Stiell 1955). It is situated 3.2 km south of the two 21-year-old plantations. The natural stand was established after a wildfire in 1915 (est.) and is located 0.9 km northwest of the 21-year-old natural stand. Both the natural and planted areas are found on similar substrates — fine sand over medium to coarse sand.

Results

Stand Level Summary

A comparison of stand and tree characteristics for each of the stands after 21 growing seasons is presented in Table 1. As can be expected, mortality is dirctly related to stand density, with the highest mortality (66.8%) occurring in the natural stand and lowest (0.9%) in the plantation with a 4.27 m spacing. For both the whole stand and crop tree component, the following features were inversely related to stand density: mean dbh, basal area/tree, total volume/tree, and merchantable volume/tree. Another trend evident was that the highest values for the following variables were found at the 2.13 m spacing: mean height, basal area/ha (only slightly higher than the natural stand), volume/ha, and merchantable volume/ha.

Individual tree sizes were much larger for the crop tree component than for the whole stand average, especially in the natural stands. Dominants in the 2.13 m planted stand were much closer in dimensions to those in the 4.27 m plantation than to those of the natural stand. It should be noted that data for dominant trees are of greater relevance to foresters

Table 1. Stand characteristics of plantation and naturally regenerted jack pine after 21 growing seasons (± standard error).

Stand feature	Natural stand	Plantation	
		2.13 m spacing	4.27 m spacing
Whole stand			
Number of plots	4	2	2
Plot size (ha)	0.0121	0.041 and 0.101	0.101
Mean stems/ha (age 21)	9 875 ± 1 235	1961 ± 59	544 ± 0
Total mortality to 1986 (%)	66.8	9.58	0.90
Mean dbh (cm)	5.56 ± 0.11	13.34 ± 0.15	18.52 ± 0.23
Mean height (m)	8.33 ± 0.09	12.32 ± 0.06	10.85 ± 0.05
Total basal area (m^2/ha)	28.58	28.83	14.91
Total volume (m^3/ha)	130.76	169.02	78.92
Mean basal area/tree (m^2)	0.0029 ± 0.0001	0.0145 ± 0.0003	0.0274 ± 0.0007
Mean volume/tree (m^3)	0.0132 ± 0.0006	0.0851 ± 0.0021	0.1449 ± 0.0039
Total merchantable volume (m^3/ha)	8.39	107.05	67.42
Mean merchantable volume/tree (m^3)	0.0008 ± 0.0002	0.0539 ± 0.0023	0.1238 ± 0.0041
Mean stem quality class rating (1 = highest, 5 = lowest)	2.13 ± 0.0701	3.0674 ± 0.0372	3.03 ± 0.0456
Dominant trees[1]			
Mean dbh (cm)	11.35 ± 0.26	16.79 ± 0.15	19.62 ± 0.18
Mean height (m)	10.94 ± 0.17	13.09 ± 0.03	11.11 ± 0.03
Mean basal area/tree (m^2)	0.0102 ± 0.0005	0.0223 ± 0.0004	0.0304 ± 0.0006
Total volume/tree (m^3)	0.0529 ± 0.0026	0.1355 ± 0.0026	0.1633 ± 0.0034
Mean merchantable volume/tree (m^3)	0.0175 ± 0.0034	0.1094 ± 0.0028	0.1429 ± 0.0035
Mean stem quality class rating (1 = highest, 5 = lowest)	2.05 ± 0.15	2.88 ± 0.08	3.01 ± 0.05

[1]400 largest trees per ha.

because these trees represent those most likely to survive to maturity.

Comparison of class ratings, both on whole stand and crop tree bases, indicates that stem quality is best in the natural plots, although the variation between trees is higher than for the two plantations. Differences in stem quality between the planted spacings are marginal, particularly on a whole stand basis. Crop trees at the close spacing have a slightly better quality rating (2.88) than those at the wide spacing (3.01).

Stand Structure and Distribution of Individual Tree Characteristics

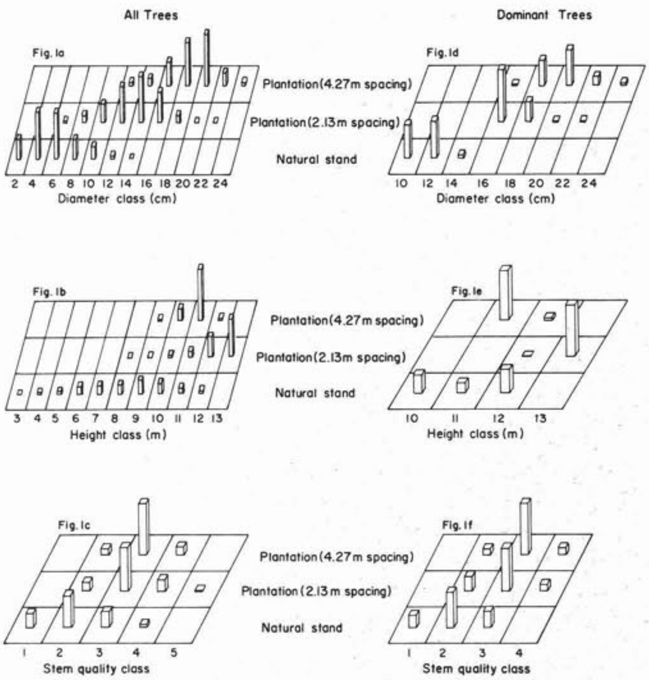
The frequency distribution charts for diameter, height, and stem quality class of all trees in each stand are presented in Figs. 1a to c. The diameter chart reveals a surprisingly similar degree of variation in both the plantations and the irregularly spaced natural stand. The height chart, however, shows a much lower variation for the plantations relative to the natural stands. This non-uniform crown structure in the natural stands may be because four different plots are averaged in the natural stand, or due to the presence of a suppressed class. This observation suggests that high stand densities have a greater impact on uniformity of height growth than moderate or low stand densities (such as in the two plantations). In stem quality, the natural stand was generally better than the planted stands. No clear differences existed between the plantations.

Distribution charts for the crop element are presented in Figures 1d to f. For the 4.27 m spaced plantation, the majority of stems remain in the 18 and 20 cm dbh classes, but for the 2.13 m plantation, most trees are in the 16 cm dbh class (up from 12 and 14 cm). Crop trees in the natural stand were also much larger in both height and diameter than the average for the whole stand. Most dominants in the natural stand were in the 10 and 12 cm diameter classes, versus a majority in the 4 and 6 cm classes for the stand, and height classes for this stand were quite similar to those of the less dense plantation. The fact that the stem quality class distributions for crop trees are similar to those for the stand as a whole indicates that stem quality differences do not appear to be related to tree size.

Stand Increment and Yield

Periodic annual increment graphs for selected measures of growth have been prepared for an equal number of dominant trees/ha in each stand (Fig. 2a-e). (Yield/ha for basal area and volume for the crop trees is 400 × mean tree values, so increment curves in Fig. 2 are also representative of yield on an area basis.) As expected, periodic diameter increment of the 4.27 m plantation is consistently higher than the 2.13 m plantation, which is higher than for the natural stand (Fig. 2a). In all stands, diameter increment appears to have already culminated (at approximately eight years for the plantations). Basal area growth follows a somewhat different trend because its increment is affected by both diameter growth and actual tree diameter (Fig. 2b). Basal area growth of the less dense plantation (larger trees) culminates at a much higher point than the closer-spaced plantation. Basal area of the natural stand appears to peak later than both plantations because of a lower rate of diameter decline than for the planted stands.

Height increment in both plantations appears to have peaked at about 12 years, followed by a higher rate of decline

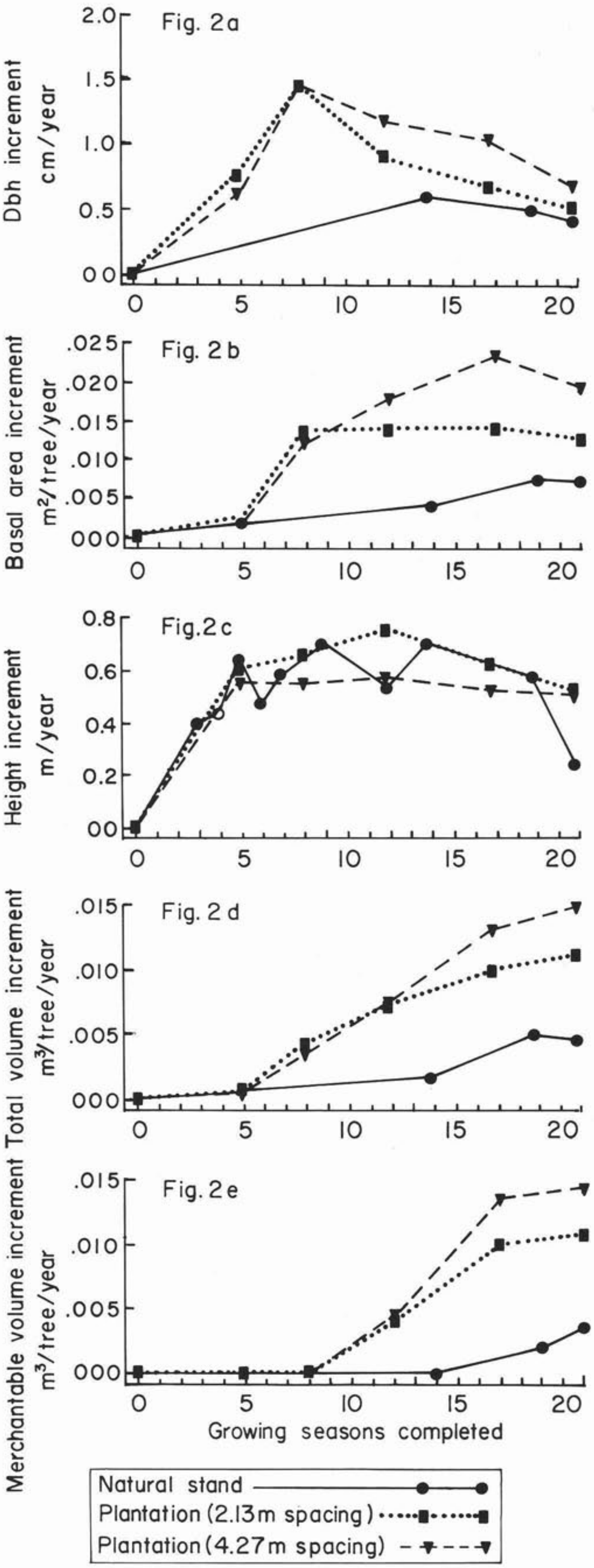


Figures 1a to f. Diameter, height, and stem quality frequency distributions for planted and naturally regenerated jack pine stands after 21 growing seasons.

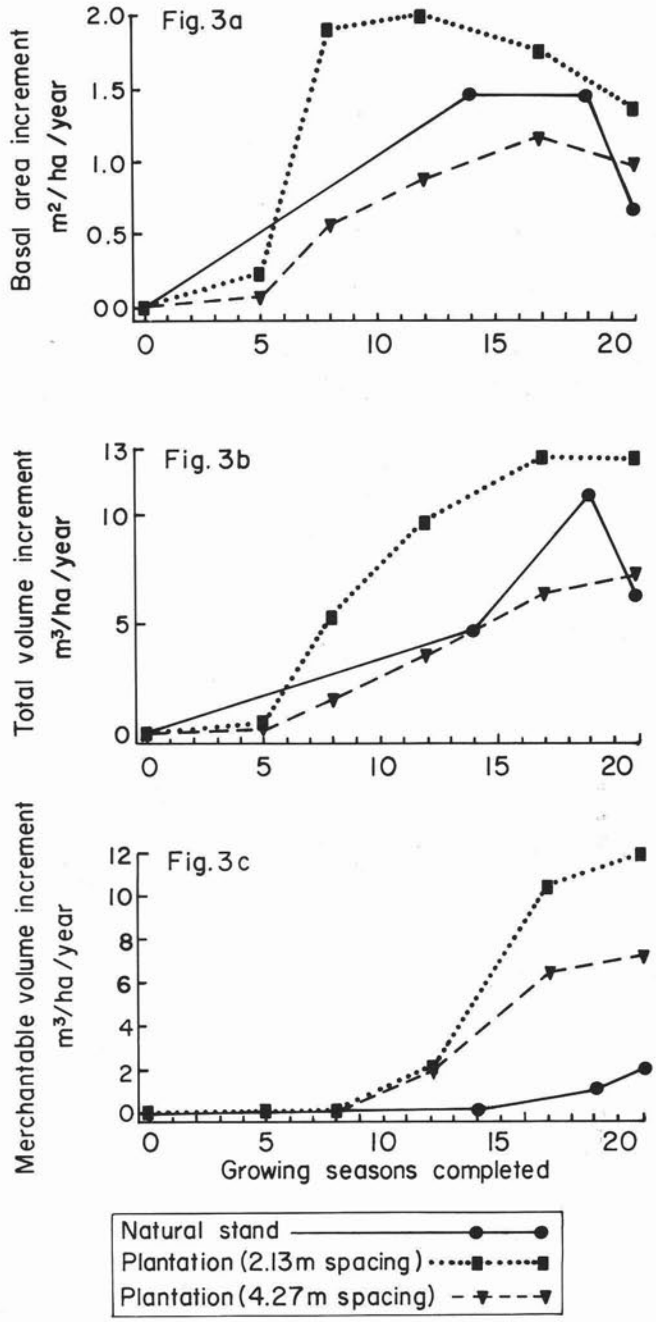
in the dense plantation (Fig. 2c). Based on these trends, the height crown in the 4.27 m stand approaches that of the denser plantation by age 21. The natural stand has much less uniform average height growth, and this growth seems to be on a general decline after age 12. Possible reasons for this fluctuation include the smaller sample size of the natural stand compared with the plantations, less uniform spacing, and the high rate of mortality of the tall spindly stems. Our results support the last factor, because the first decline in stems/ha for the natural stand occurred between ages 5 and 6 years. The two greatest declines in stand density took place between the ages of 9 and 12 years (9.6% annual mortality) and 19 and 21 years (8.6% annual mortality), corresponding to the reduction of mean height growth at ages 12 and 21.

The periodic total volume increment per tree is highest for the 4.27 m spaced plantation, followed by the 2.13 m plantation (Fig. 2d). Both the rate of volume increment and its culmination point appear related to spacing, with the average rate of increase varying inversely, and the age of culmination varying directly with density (assuming that the same increment trends for the plantations between ages 5 and 21 continue into the future). On this basis, we would expect the biological rotation, based on culmination in mean annual volume increment, to be longest for the 4.27 m plantation and shortest for the natural stand. If the rotation age is, instead, based on a minimum average tree volume for the purpose of sawlog production, the rotation age would be the reverse.

Plots of merchantable volume production/tree were fairly similar to those of total volume increment for the plantation plots, with the rate of increase in the less dense plantation being greater to age 17 (Fig. 2e). The natural stand's merchantable volume increment was much lower than for the two plantations, because of much smaller average crop tree diameters. The natural stand volume increment increases at a



Figures 2a to e. Periodic annual increment (dbh, basal area/tree, height, volume/tree, and merchantable volume/tree) for 400 dominant jack pine/ha.



Figures 3a to c. Periodic annual increment (basal area/ha, volume/ha, and merchantable volume/ha) for planted and naturally regenerated jack pine stands.

higher rate than the plantation at age 21 because an increasing proportion of growth is merchantable.

Increment per hectare is presented in Figs. 3a to c. The periodic annual increment of basal area/ha decreases for all stands, but most sharply for the natural stand, reflecting high mortality and stagnation of a large number of small stems (Fig. 3a). The volume/ha increment increases for the wider-spaced plantation, but reaches a plateau for the denser plantation, and shows a sudden and sharp decrease for the natural stand. This relates differences in mortality and in basal area growth (Fig. 3b). Merchantable volume/ha for all three stands increases, with the latest period showing a more rapid increase for the natural stand and denser plantation than for the 4.27 m spaced plantation (Fig. 3c). These trends are similar to those for the crop element.

Figure 4a illustrates the proportion of total volume for each stand that is comprised of merchantable volume. Only 6.42% of the total volume in the natural stand was merchantable, whereas 63.34% and 85.43% of total volume in the 2.13 m and 4.27 m spaced plantations were merchantable. The effect of tree size is illustrated in Figure 4b, which shows the average total and merchantable volumes per tree for each stand. For the dominant trees, only total and merchantable volume per tree were still directly related to stand spacing, but the differences were much less, with the average dominant tree in the 4.27 m plantation being 30.6% larger than the average for the 2.13 m plantation (Fig. 4c).

Stand Mortality

The mortality distribution revealed that death in the natural stand was predominantly in the smallest diameter classes (2 and 4 cm) (Fig. 5). As the data in Table 2 indicate, much of the mortality (30.2%) recorded at age 14 was attributable to snow and ice damage, which largely affected the smaller trees. Of living trees, snow damage also affected the smaller trees (2-6 cm dbh), although only 7.4% of all living trees were recorded as being damaged.

The small but evenly distributed mortality in the 2.13 m spaced plantation indicates that rather than self-thinning, mortality is probably due to natural causes not directly associated with stocking.

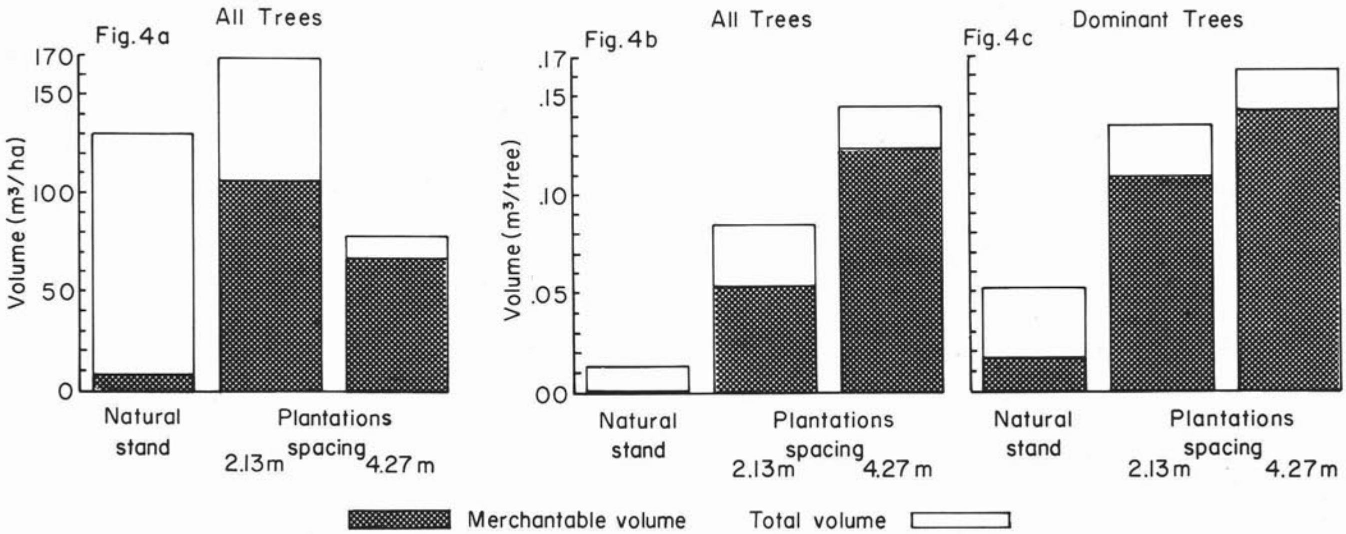
Discussion

Our results indicate that there is definitely a tradeoff between merchantable stand volume and stem quality when comparing natural and planted stands after 21 growing seasons. Better quality was attained in the natural stand, at the expense of lower total volume compared with the 2.13 m spaced plantation, and much lower merchantable volume compared with both plantations. The data also indicate planting at a very wide spacing (e.g. 4.27 m) yields trees of higher merchantable volume at the expense of lower total and merchantable stand volume and slightly poorer stem quality, compared with the closer spacing.

A major contributing factor to the lower yield at wide spacing is the lower height increment in the 4.27 m plantation, compared with the more dense plantation. The 2.13 m plantation had less uniform height increment, with increasing height growth (up to 12 years) followed by an equal rate of rapid decline from 12 to 21 years. This suggests that superiority in height growth in the dense plantation may only be temporary. In the natural stand, extreme competition may suppress total volume production because tree crowns are small and translocate only small amounts of carbohydrate to the lateral meristem responsible for diameter growth (Lanner 1985) and some proportion of growth is lost to mortality.

Our data support the view that height is relatively constant over a wide range of spacings, but that growth is less at spacing extremes. Height depression at low densities appears related to a lower degree of apical dominance, which results in a higher proportion of photosynthate being allocated for diameter and crown development than for height growth. The smaller height increment of very dense stands may be partly explained by carbohydrate source-sink physiology. The strong food sink of the apical meristem (drawing carbohydrate from both storage tissue and from current photosynthate) enables trees under a wide range of densities to maintain a fairly uniform height growth under otherwise similar environmental conditions (Lanner 1985). However, under very dense conditions, the developing shoot is not provided with sufficient stored and actively synthesized food to optimize height growth.

Continued self-thinning may lead to increase in individual tree volumes in the natural stand, although total volume yields will probably be much less than in the 2.13 m spaced plantation, according to results of Bella and DeFranceschi (1974a) and Beckwith *et al.* (1984). Whether stem quality superiority will continue in the natural stand to rotation age is less clear. If so, the high wood quality may offset economically smaller tree sizes and lower total volume yields. Even with a lower final return, the natural stand of fire origin may still be a



Figures 4a to c. Total versus merchantable volumes (volume/ha — all trees, volume/tree — all trees, and volume/tree — dominant trees) for planted and naturally regenerated jack pine stands after 21 growing seasons.

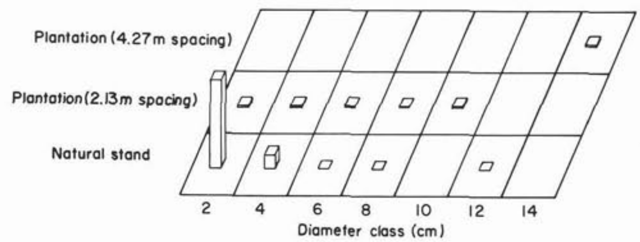


Figure 5. Cumulative percent mortality for jack pine by diameter class (plantation from 8 to 21 years; natural stand from 14 to 21 years).

better investment than, for instance, clear-cutting the stand at an early age and planting, as neither establishment nor tending costs are incurred.

Data from similar-aged, mature planted and naturally regenerated jack pine stands growing at the PNFI may be able to assist in determining whether significant changes in growth trend and stem quality occur in jack pine later in the rotation (Table 3). The results show that in 1986 the crop trees were virtually identical in height and diameter, despite a 9-year age difference, indicating that merchantable production per tree is higher in the plantation. However, the natural stand has a density 66% higher than the plantation and a much higher quality class rating. From this we can conclude that the sawlog yield on a per hectare basis from the natural stand would be of higher value than that of the plantation, if both stands were harvested today.

The older natural stand appears to have had a lower stand density at age 21 than the younger stand used in our analyses, and this may help explain the similarity in tree size with plantation trees at the later age. Thus, it can be expected that the younger, denser natural stand will continue to have smaller dominant trees than both plantation spacings and will require longer rotation. This stand will probably continue to be superior in stem quality to plantation trees through to harvest age because the older natural stand has much better stem quality than the comparably aged planted stand, despite having a much lower initial stand density than the younger jack pine natural stand.

The better stem quality in the natural stand can be partly accounted for by the finer branching resulting from a greater degree of crown suppression and by the greater degree of apical dominance existing in very dense conditions. A greater proportion of straight stems in the natural stand may also be due to a less pronounced impact by white pine weevil (*Pissodes strobi* [Peck]), which is most prevalent in poorly stocked, even-aged stands (Hacker *et al.* 1983, Rudolph 1983, Stiell 1985). Another reason may be jack pine's tendency to form late season proleptic or lammas shoot growth, which is more prevalent at low stand density (high light intensity) in other conifers (Carter *et al.* 1986, Rudolph 1964). Such shoots are more prone to early autumn frost injury, which may result in stem forking and sweep if terminal shoots are killed. Forking may also develop on the occasion when secondary flushing of lateral buds exceeds growth of the terminal buds, although this occurs infrequently in jack pine (Thomas 1958).

In spite of better overall stem quality, the more cylindrical boles in the natural stand are much more prone to wind, snow, and ice damage than are those in the plantation, and this resulted in patchy, irregular stocking in the young natural stand in this study. Similar results for jack pine were reported by Roe and Stoeckeler (1950) and Dosen *et al.* (1957). Selective, early precommercial thinning could be used to remove the suppressed and damage-prone trees, and increase growth of residuals (Bella and DeFranceschi 1971, 1974a, Riley 1973, Smith *et al.* 1985). Interruption of the crown canopy may also aid in reducing such damage to larger trees, which might otherwise be subject to domino-effect toppling (Yarranton and Yarranton 1975, Scheckenburger *et al.* 1985). A more open canopy should also reduce snow interception and lower vaporization losses from intercepted snow, thereby increasing the amount of soil moisture in the spring growing season (Gary and Watkins 1985). This would be especially important to jack pine, which occurs primarily on coarse-textured, drought-prone sites.

The favourable yield figures near rotation age we obtained for the older natural stand which had a relatively low original density indicates that some form of density control is probably useful in initially high density stands to stimulate development of individual tree size and to reduce rotation lengths. Furthermore, low taper, small branch diameters, and relatively defect-free stems of the released trees should result in a high value crop at rotation age. This suggests that management of natural stands may be preferable to planting at conventional spacings for the purpose of sawlog production.

Tree improvement programs for many conifers have attached a high trait selection priority to stem quality and crown characteristics such as branch angle and diameter

Table 2. Incidence of snow damage[1] in the natural stand at age 14 years from planting.

	Live trees				Dead trees			
	No snow damage		Snow damage		No snow damage		Snow damage	
	Number	% of total	Number	% of total	Number	% of total	Number	% of total
Diameter class (cm)								
2	126	91.30	12	8.70	194	71.59	77	28.41
4	161	87.50	23	12.50	19	55.88	15	44.12
6	145	94.77	8	5.23				
8	61	100						
10	31	100						
12	9	100						
14	1	100						

[1]Evaluation is described in the Methods section.

Table 3. Stand characteristics of older plantation and naturally regenerated jack pine stands in 1986 (± standard error).

Stand feature	Natural stand	Plantation
Number of plots	2	1
Plot size (ha)	0.04	0.04
Age in 1986 (years)	70 (average)	61
[1]Estimated stems/ha at age 21	1 400	650
Stems/ha (1986)	[2]913	[3]550
[4]Dominant trees		
Mean dbh (cm)	24.05 ± 0.41	24.09 ± 0.52
Mean height (m)	23.86 ± 0.33	23.19 ± 0.42
Mean basal area/tree (m^2)	0.0458 ± 0.0016	0.0459 ± 0020
Total volume/tree (m^3)	0.4778 ± 0.0199	0.4677 ± 0.0263
Mean merchantable volume/tree (m^3)	0.4395 ± 0.0194	0.4303 ± 0.0256
Mean form class rating (1 = highest, 5 = lowest)	1.72 ± 0.10	2.69 ± 0.12

[1]based on survivorship equation for jack pine from Buchman (1983) and 1941 to 1946 diameter growth data for trees sampled in 1986.
[2]12 stems/ha white pine also present.
[3]150 stems/ha Scots pine also present.
[4]400 largest diameter trees/ha.

because of their economic importance in sawlog production and the moderately high heritability attributed to these traits. In light of the stem deformities of jack pine in plantations, the large knot volumes at wider spacings, and the fact that this species is being widely planted, it is especially important that jack pine tree improvement programs concentrate on selection of individual trees with defect-free boles and small branch diameters (Yeatman 1975). It should also be noted that while stem quality is a major determinant of the value of solid wood products, it is also of concern in paper-making, since stem irregularities and associated compression wood may present problems in debarking and chipping and can adversely affect pulp quality and yield (Timell 1986).

Conclusions

The comparison of natural and planted jack pine stands presented here supports conventional spacing and yield theory for conifers; e.g., that volume yield per tree varies directly with stand spacing, and that total volume on an area basis is reduced at very high or low stand densities. This study also upholds the view that higher density conditions, such as those typically associated with fire-origin stands, tend to favour the production of trees with better stem quality. The latter point is especially relevant to jack pine, which is highly variable and commonly has a high frequency of stem and crown deformities.

It is apparent that selective thinning at an appropriate age in natural or direct-seeded stands produces higher quality sawlogs than planting unimproved stock at normal or wider spacings. Our study supports the need for genetic improvement of stem and crown form in jack pine in view of the aggressive planting program being conducted for this species. Immediate attention should be focussed on obtaining seed from trees of good stem and crown quality from high quality stands designated for seed collection and production.

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