FOLIAGE AND WOOD PRODUCTION IN 17- AND 32-YEAR OLD *Pinus banksiana* Lamb. OF NORTHWESTERN ONTARIO

BY

BERNARD J. PHILLION

A thesis submitted in partial fulfillment for the
requirements of the degree of
Master of Science in Forestry

Lakehead University
School of Forestry
May, 1980

Copy 1

ABSTRACT

The objectives of this study were 1) to provide information on the above ground biomass production of young jack pine (*Pinus banksiana* Lamb.) stands, and 2) to evaluate the influence of crown foliage, stand density, and age on the net current annual wood production of young jack pine trees and stands.

Two naturally regenerated jack pine stands, 17- and 32-years old, were selected for study near Thunder Bay, Ontario. In each stand, one sample plot was established at each of three density levels. Each sample plot consisted of 15 live jack pine trees. In all, 90 trees were felled in September 1978 and analyzed to determine the above ground distribution of biomass by foliage, cone, stem wood, stem bark, live branch wood, live branch bark, and dead branch (wood plus bark) components. Total current annual wood production was determined by adding the periodic annual increment of the stem for the last three years to the mean annual increment of the live branches. Stand density was determined by computing number of stems per hectare, relative spacing, and basal area.

Stem wood, stem bark, foliage and dead branch biomass increased with density in both stands. Live branch wood, live branch bark, and cone biomass were not affected by stand density and age. Total current annual wood production was closely related to the foliage dry weight supported by individual trees; stand density and age seemed to have no influence on this relationship. Total current annual wood production per hectare was linearly related to foliage dry weight and stand density. It was concluded that within the range of densities sampled, the two jack

pine stands do not give any indication of being over-crowded. Results suggest that jack pine stands, grown for maximum fibre production, should be grown as dense as possible, at least within the range of densities sampled.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Professor R. J. Day for his enthusiastic support and guidance, to Dr. J. Barker and Dr. K. M. Brown for providing encouragement and advice on various aspects of the investigation. I am particularly indebted to Mr. R. Cornell of Kakabeka Falls, Ontario for permission to work in his private woodlot.

Financial support was provided by a Canadian Forestry Service Grant and Lakehead University.

Finally, I am indebted to my wife, Alexandra, who encouraged me to undertake post-graduate studies, and whose support and assistance helped to complete this thesis.

TABLE OF CONTENTS

LITERATURE REVIEW

METHODS

STUDY AREAS

RESULTS

DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The productivity of trees growing in even-aged jack pine (*Pinus banksiana* Lamb.) stands depends to a great extent on the density of the stand (Hansen and Brown 1929, Hansen 1931, Gevorkiantz 1947, Wilson 1951, Cayford 1961, Vezina 1965, Bella 1967 and 1968). In the initial phase of stand development, jack pine seedlings develop in isolation from one another and increase in size rapidly. Their root system, crown foliage, and current annual wood production increase at a geometric rate (Armson 1974). After a few years, root competition occurs among trees, followed by closure of the crown canopy. At lower stand densities, crown closure occurs at a later age than at higher densities. With crown closure, crown foliage per unit area reaches a maximum. At the same time current annual wood production per unit area also reaches a maximum (Madgwick 1976). For some years thereafter, wood production is maintained at relatively high levels as tree height increases rapidly. Some foresters have referred to this phase as the "grand period of growth" (Baker 1950). During this phase the live crown on the trees moves up the stem as new foliage is produced in the upper parts of the crown and the lower branches die of suppression. Maximum crown size during this grand period of growth is greatly influenced by stand density. Near the end of this period, current annual wood production begins to decline rapidly as crown foliage quantities decline (Madgwick 1976). The theoretical stand rotation age is achieved shortly thereafter. For normally stocked jack pine stands, the theoretical rotation age is 28 years on Site Class I, 40 years on Site Class II, and 56 years on Site

Class III (Plonski 1974). After the grand period, height growth slows down quickly. Root mortality and crown debility are characteristic symptoms of this last phase which may persist for several decades (Armson 1974). Current annual wood production also declines rapidly during this period.

There is one general theory, dealing with forest growth, which relates stand density to stand productivity. The theory was first put forward by Moller (1947 and 1954) and restated by Langsaeter (Braathe 1957 and Smith 1962) and Assmann (1962 and 1970). Moller theorized that gross forest production increases with increasing stand density until full site occupation is achieved. Increasing stand density beyond the point of full occupancy has no effect on production. Specifically, Moller proposed that gross production in forest stands is not affected by stand density as long as the remaining basal area is fifty per cent or more of the greatest possible basal area obtainable at that age (Figure 1). Möller (1947) also postulated that forest stands, of given species composition, maintain relatively constant amounts of foliage, regardless of density, as long as they fully occupy sites of similar quality. Hence the theory suggests that foliage quantities and gross forest production must be related. This theory was derived from thinning experiments with *Fagus sylvatica* L. and *Picea abies* (L.) Karst. in Denmark.

Langsaeter (Braathe 1957 and Smith 1962) reworked Moller's hypothesis and summarized the theory of gross forest productivity in a diagram similar to the one reproduced in Figure 2. Langsaeter suggested that gross

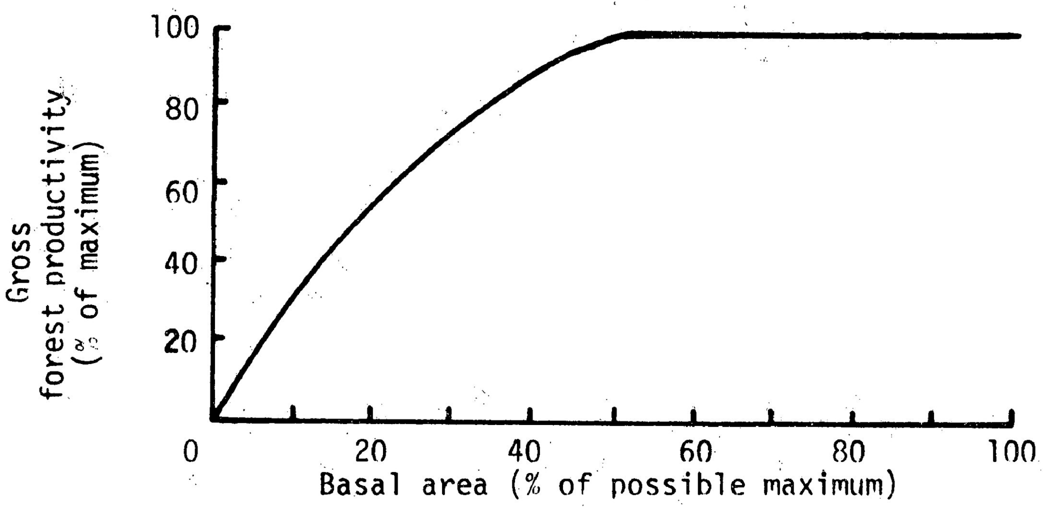

Figure 1. The relationship between basal area (per cent of possible maximum) and gross forest productivity (per cent of maximum) as theorized by Moller (1947 and 1954).

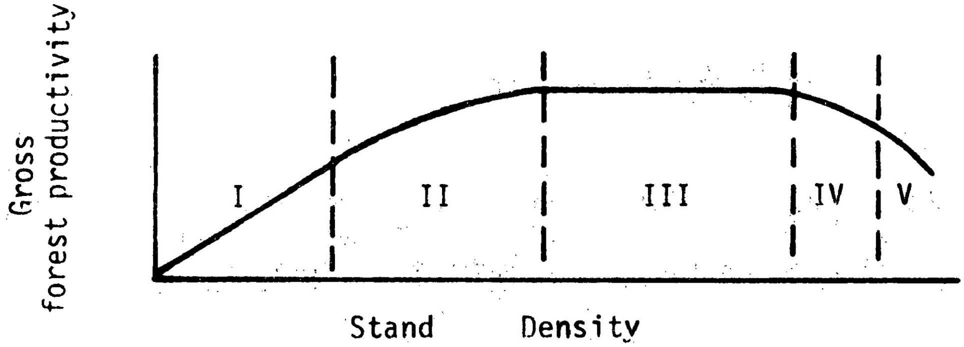

Figure 2. The relationship between stand density and gross forest productivity as proposed by Langsaeter (Braathe 1957, and Smith 1962).

forest productivity can be divided into five categories based on stand density. The roman numerals in Figure 2 represent Langsaeter's "Density Types". In Density Type I, productivity is directly proportional to stand density because the trees are so far apart that they do not influence each other. Density Type II is characterized by a slight decrease in the rate of increase in production because the trees are beginning to crowd each other. In Density Type III, stand density has no influence on productivity. Under excessive competition, production is reduced in Density Types IV and V.

Based on work with Picea abies (L.) Karst., Assmann (1962 and 1970) restated the theory of gross forest productivity. He theorized that the greatest productivity is obtained in forest stands within a narrow range of stand densities and that productivity is smaller in stands having greater or lesser densities. Assmann used basal area expressed as a per cent of the basal area of fully stocked normal stands as his measure of stand density (Figure 3). Assmann stated that optimum production occurred in stands with "optimum basal areas" which were possible only within a narrow range of stand densities. The range of optimum basal areas would vary with species, site quality, and age.

The general theory of forest productivity as postulated by Moller, Langsaeter, and Assmann suggests that there is an optimum stand density or range of stand densities at which gross forest production is maximized. This basic premise has been widely accepted by foresters. Baskerville (1965a) stated that the wide acceptance of this theory is due

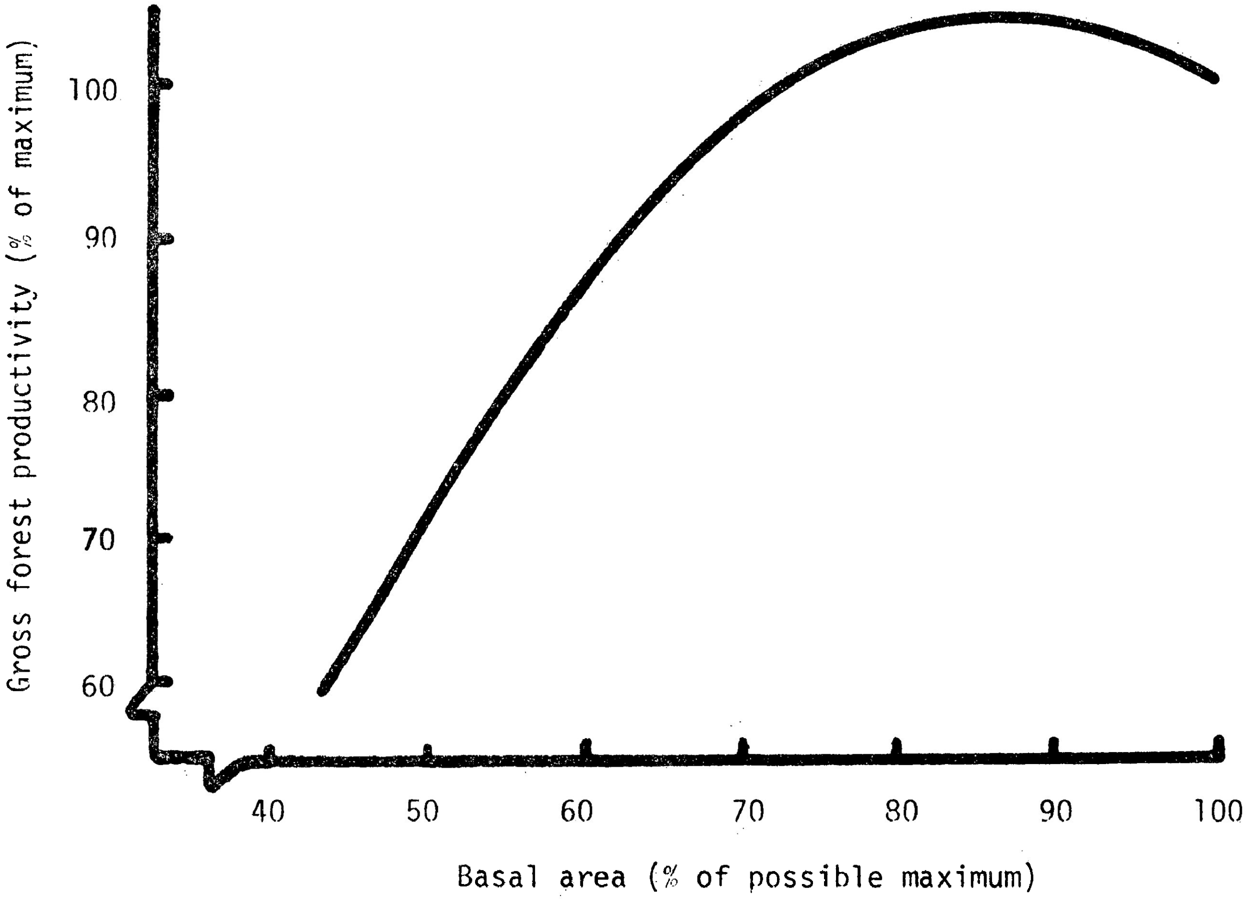

Figure 3. The relationship between basal area (per cent of possible maximum) and gross forest productivity (per cent of maximum) as postulated by Assmann (1962 and 1970).

mainly to the work of Ovington (1956 and 1957), Ovington and Madgwick (1959) in England and the work of Satoo et al. (1955 and 1956) in Japan. However, more recent work in North America by Baskerville (1965a) and Doucet et al. (1976) have reported results which do not conform to the general theory of forest productivity. Sample plots in these studies were located in a wide range of stand densities, including densities (by basal area) substantially higher than those considered silviculturally acceptable by Assmann (1970). Results of these studies suggest that forest production increases linearly with increasing density in stands of the same species and age on equivalent sites.

Results of the study reported here also suggest that net wood production increases linearly with stand density in young jack pine stands of the same age on one site. The stands studied were 17- and 32-years of age. The 17-year old stand was in the grand period of growth whereas the 32-year old stand was close to its theoretical rotation age. Sample plots were located at three different densities in each stand. The highest density plots in both stands were denser than those considered silviculturally acceptable (Plonski 1974) in northwestern Ontario. The data suggest that the optimum density in young jack pine stands, if it exists, would occur at a density higher than those currently considered to be silviculturally practical.

OBJECTIVES

The objectives of this research were 1) to provide information on the above ground biomass production of young jack pine stands, and 2) to evaluate the influence of crown foliage, stand density and stand age on wood production in young jack pine trees and stands.

LITERATURE REVIEW

Forest Biomass Studies

In recent years, wood production in forest stands has received much attention in forest biomass studies. Biomass is the living weight per unit area, and in forest biomass studies entire trees are harvested and the dry weight per unit area of roots, branches, stems and foliage are determined. These biomass studies have been carried out for a variety of reasons, for example, in quantitative ecological studies (Ovington 1956 and 1957, Baskerville 1965a, 1965b, and 1966, Whittaker 1966, Bunce 1968, Madgwick 1968, Whittaker and Woodwell 1968, Honer 1970, Zavitkovski and Stevens 1972, Ker 1974, Clark and Taras 1976, Barney et al. 1978, Taras and Phillips 1978, and Zavitkovski and Dawson 1978a); in providing information on complete tree utilization (Young 1967, Keays 1968, Johnstone 1970, and Smith and Debell 1973); and in tree nutrition studies (Ovington and Madgwick 1959, Turton and Keay 1970, Smith et al. 1971, Morrison 1974, and Madgwick et al. 1977). The objectives of these biomass studies have often been comprehensive yet their results rarely provide specific information on the relations between wood production and foliage quantities. In other forest biomass studies, workers have shown that wood production was closely related to the amount of foliage supported by individual trees (Senda and Satoo 1956, Satoo et al. 1956, Satoo and Senda 1958, Satoo et al. 1959, Weetman and Harland 1964, Stiell 1966, Satoo 1967, Satoo 1968, Satoo 1974a, Satoo 1974b, Satoo 1974c, Satoo 1974d, Satoo et al. 1974, and Stiell and Berry 1977). Satoo et al. (1955), Baskerville (1965a), Satoo (1967) and Doucet et al. (1976) have also shown that wood production and foliage quantities per unit area were closely related in forest stands.

Crown Foliage Estimation

The quantity of living foliage supported by coniferous tree crowns has in the past been related to parameters of live crown dimension such as crown shape, crown length, and crown width (Buchanan 1936, Loomis et al. 1966, Stiell 1962 and 1969, Stiell and Berry 1977). Other workers related the quantity of live crown foliage to parameters of the stem such as diameter at breast height (Kittredge 1944, Cable 1958, Ovington and Madgwick 1959, Stiell 1962 and 1969, Wile 1964, Baskerville 1965a, 1965b, and 1966, Loomis et al. 1966, Hegyi 1972, Ker 1974, Clark and Taras 1976, Doucet et al. 1976, Gary 1976, Stiell and Berry 1977, Barney et al. 1978 and Taras and Phillips 1978) and diameter at the base of the live crown (Storey et al. 1955, Loomis et al. 1966, and Stiell 1969).

The first attempt to estimate the foliage of coniferous trees with live crown measurements was made by Buchanan in 1936. Buchanan correlated the number of needles on _Pinus_ _monticola_ Dougl. trees with maximum crown length and width.

More recently, crown foliage has been estimated in terms of dry weight. This is a more desirable parameter since it eliminates the variation in moisture content in the needles (Holsoe 1948). Estimation of the foliage dry weight of coniferous trees was first performed by Kittredge (1944). Kittredge related foliage dry weight to diameter at breast height for a number of tree species including jack pine. Since then Hegyi (1972) and Zavitkovski and Dawson (1978b) have successfully used Kittredge's method with jack pine. Doucet et al. (1976) related the foliage dry weight of jack pine crowns by combining diameter at breast height and tree height in one equation.

The quantity of living foliage supported by the crowns of coniferous trees has also been determined by estimating and summing the foliage dry weight supported by individual live branches that compose the crown. The work of Loomis et al. (1966), Forrest and Ovington (1971), Laar (1973), Madgwick and Jackson (1974), and Gary (1976) showed that the diameter of a first order coniferous branch five centimetres from the bole correlated well with the foliage dry weight supported by the branch. Work at Lakehead University in Thunder Bay, Ontario by Munro (1977), Phillion (1977), and Schaerer (1978) also showed that the diameter of a first order coniferous branch at its "point of foliation" correlated well with the foliage dry weight supported by the branch. The "point of foliation" was defined as the point on any first order branch at which foliage is subtended by the branch or by branches of any subordinate order.

In relatively small scale studies, it may be more practical to determine the foliage of entire crowns by estimating and summing the foliage supported by individual branches, than relating total crown foliage quantities to live crown and stem dimensions. The main reason is that the construction of prediction equations based on branch diameter and foliage dry weight can be carried out in one to two weeks. Prediction equations involving live crown or stem dimensions with foliage dry weight can take many months and often years to construct (Stiell and Berry 1977).

Tree Growth in Jack Pine

Growth has been defined as an increase in height, diameter, basal area, volume, or value of individual trees or stands in relation to time (Society of American Foresters 1950). The complexity of tree growth has led to a variety of ways of measuring growth in jack pine trees and stands (Bickerstaff and Hostikka 1977). The traditional measure of growth in jack pine studies has been wood volume increment (Hansen and Brown 1929, Hansen 1931, Gevorkiantz 1947, Wilson 1951, Cayford 1961, Vezina 1965, Bella 1967 and 1968, Evert 1976, and Morrison et al. 1977a and 1977b). Armson (1974), and Shea and Armson (1972) have shown that current annual height increment can be used in the study of growth in jack pine trees and stands. Adams (1928) and Shea (1973) used annual ring width while Winston (1977) used diameter increment at breast height as measures of growth in jack pine trees.

More recently, growth in jack pine stands has been evaluated by estimating wood dry weight increment (Hegyi 1972, Doucet et al. 1976, Maclean and Wein 1976, and Zavitkovski and Dawson 1978b). Wood dry weight increment has been determined by multiplying wood volume increment by the specific gravity of the wood. Wood dry weight increment is a more desirable parameter than volume increment since it eliminates the variation in moisture content in the wood.

Wood Production in Naturally Regenerated Jack Pine Stands

Considerable work has already been carried out on the wood production of naturally regenerated jack pine stands at varying stand densities (Hansen and Brown 1929, Hansen 1931, Gevorkiantz 1947, and Wilson 1951). One of the first such studies in Canada was a thinning experiment initiated in 1927, in eighteen-year old jack pine stands in Saskatchewan (Cayford 1961). In 1959, when these stands were remeasured, the unthinned plots had greater net total wood volume per unit area than the thinned plots where density had been manipulated. However, the net merchantable wood volume (top diameter outside bark of 7.6 cm) on the thinned plots was twice that in the control plots.

Vezina (1965) studied the wood volume production of mature jack pine stands at various stand densities. He showed that the average height and net total wood volume of jack pine stands decreases with decreasing stand density. In another study, Hegyi (1972) documented the effect of increasing age on the total wood dry weight in jack pine stands of northern Ontario. He showed that the net total wood dry weight per unit area, in jack pine stands of normal stocking, increases with increasing age up to about sixty; after age sixty total wood dry weight per unit area decreases. This is possibly related to the fact that the rate of mortality increases substantially in jack pine stands after age fifty (Yarranton and Yarranton 1975).

Wood Production in Artificially Regenerated Jack Pine Stands

Studies in artificially regenerated jack pine plantations have been carried out mainly in young stands. Much of this work has been documented in spacing trial studies by Rudolf (1951), Ralston (1953), Guilkey and Westing (1956), Buckman (1964), Maeglin (1967), Godman and Cooley (1970), Chrosciewicz (1971), and Bella and

Francheschi (1974). Generally these studies show that as stand density decreases branch diameter, stem taper, and mean stand density increase while basal area, total volume, merchantable volume and mortality per unit area decrease.

Wood Production and Crown Foliage Relationships in Jack Pine

In an early study, Adams (1928) attempted to relate jack pine tree growth to crown foliage at four initial stand densities. The plantation for this study was established in 1919 at 2,4,6, and 8 feet (0.61, 1.22, 1.83, and 2.44 m) square spacings. At the end of the 1926 growing season, Adams selected one tree of mean diameter and height from each density. Total dry weight of the foliage, branches, stem and roots were determined for each of the four selected trees.

Results of this study show that the foliage, branches, stem, and roots of individual jack pine trees increased in size with greater initial stand density. Adams also calculated the efficiency of the foliage by adding the total branch, stem and root dry weight of each tree and dividing by its foliage dry weight. He indicated that foliage efficiency is substantially greater in the closer spacings. However, because the foliage of jack pine crowns abscisses after two or three years (Harlow and Harrar 1969), Adams misused the term foliage efficiency. His ratio was computed from total branch, stem and root biomass accumulated over a period of eight years, while his foliage measurements represent the foliage supported by trees in a single year.

Stoeckeler and Olsen (1957) related the diameter growth rate of 26- and 35-year old jack pine trees in Minnesota with live crown ratio. Live crown ratio is the per cent of the stem length which is "clothed with living branches" (Smith 1962). These workers showed that diameter at breast height growth rate (DG) in inches increased with live crown (LCR) in the following relationship: $DG = -0.203 + 0.301\ (LCR) - 0.002\ (LCR)^2$.

Another relationship between growth and crown foliage in jack pine has been reported in a biomass study by Doucet et al. (1976). The study included the measurement of net periodic annual wood increment and foliage dry weight in 40-year old jack pine stands at various densities. Foliage dry weight measured in this study ranged from 3.45 to 7.79 t/ha and periodic annual wood increment ranged from 1.48 to 2.77 t/ha. The results of this work showed that periodic annual wood increment per unit area was linearly related to the foliage dry weight supported by the trees in each jack pine stand. The study also showed that crown foliage dry weight in jack pine stands increased linearly with basal area and number of stems per unit area.

A recent study, involving jack pine growth and foliage on a short-rotation intensive culture system, has been reported by Zavitkovski and Dawson (1978b). The objective of this study was to identify a combination of densities and rotation lengths at which the mean annual biomass production of stem and branch wood reaches its maximum, on a mini-rotation. Plantations for this study were established at 9, 12, and 24 inches (22.9, 30.5, and 61.0 cm) square spacings and grown for seven years. Soil moisture was kept at field capacity by irrigation during the entire experiment. Annual fertilization also maintained a high level of soil nutrition. Foliage dry weight and mean annual biomass increments were measured at 4, 5, 6, and 7 years of age. The results of this study showed that foliage dry weight increased with age. At seven years of age, there were 9.6, 11.3, and 11.4 t/ha of foliage at the respective 9, 12, and 24 inches square spacings. Corresponding mean annual increments (total biomass) were 7.4, 8.5, and 7.7 t/ha in the seventh year. The results of this study are not conclusive because the mean annual biomass increment had not culminated at the wider spacing.

METHODS

The scarcity of young jack pine stands and the great diversity of site conditions on which they occur in northwestern Ontario, made the selection of jack pine study areas on one homogeneous site impossible. Consequently it was decided to carry out the work in outwash plains (Moore 1963) of lacustrine origin in the Boreal Forest Region B9, Superior Section (Rowe 1972), and to ensure that the study areas were Site Class I (Plonski 1974).

Field Sampling

Field sampling was carried out in September and October 1978. Two jack pine stands were selected for study: one 17 and one 32 years of age. These two stands were stratified into areas of high, medium and low stand density. One sample plot was located at random in each of these three density levels in both stands. In each sample plot, the 15 live trees closest to the centre of the plot were selected for study. In all, 90 live jack pine trees were sampled.

The above procedure has the limitation that the differences between plots cannot be analyzed statistically, since one plot offers no opportunity to determine error. To ensure statistical applicability would require more sample plots, which was beyond the scope of this study.

Before harvest, the live crown of each tree was classified dominant, co-dominant, intermediate or suppressed as defined by Baker (1950). A map was constructed of each sample plot to show the location and horizontal crown projection of each tree. For all sample trees, the distance to the nearest five competing trees was measured to enable the calculation of mean inter-tree distance. Mean inter-tree distance was computed with Hiley's (1967) formula for irregularly spaced trees as follows:

$$\text{Mean Inter-Tree Distance} = \frac{\frac{\Sigma\text{Distances to 4 nearest trees}}{4} + \frac{\Sigma\text{Distances to 5 nearest trees}}{5}}{2}$$

At harvest, the trees were sampled as close to the ground as possible. Total height and diameter at breast height were recorded for each tree. All cones were removed from each tree. All first-order live branches on each tree were measured for diameter at the point of foliation and at five centimetres from the bole. Branch diameter at point of foliation was used as an independent variable to estimate the foliage dry weight supported by a branch. Branch diameter at five centimetres from the bole was used as an independent variable to estimate the wood and bark dry weight supported by a branch. All first-order dead branches on each tree were measured for diameter at five centimetres from the bole to provide a measure of the amount of wood and bark dry weight supported in these branches. Finally, the bole of each tree was sectioned into one metre lengths and two centimetre thick disc samples were taken for stem analysis and specific gravity determination. Fresh weight of tree components were not measured at the time of harvest.

A soil pit was dug in each plot and a soil profile was drawn. The depth of each soil horizon was measured as well as the total rooting depth. Bulk density, stone content, and moisture tension soil samples were taken in the centre of each major horizon.

Sampling for the construction of branch foliage, branch bark, and branch wood prediction equations was carried out on two trees selected at random in each plot (total of 12 trees). From these 12 trees, 300 live branches and 300 dead branches were chosen at random and transported to the laboratory.

Laboratory Sampling

One hundred live branches, from each of the two stands, were randomly selected from the 300 branch sample. The 1976, 1977, and 1978 annual elongations of the main axis of these branches were measured. Analysis of variance showed that the mean elongation of the branches in 1976, 1977, and 1978 were not statistically different within each stand. It could therefore be assumed that the crown foliage, of sample trees and of the stands that they represent, had not changed significantly during the last three years (Barker 1978).

A random sub-sample of 80 live branches was selected from the 300 branch sample. Each branch was measured for diameter at its point of foliation and at five centimetres from its severed end. The foliage was removed from the branches, oven dried at 105°C for 24 hours, and weighed. The bark was removed from the branches by scraping. The separated wood and bark were oven dried at 105°C for 48 hours, and weighed. All 300 dead branches were measured for diameter at five centimetres from their severed end, oven dried at 105°C for 48 hours, and weighed (wood plus bark).

A source of error that may have affected the estimation of branch foliage, wood, and bark dry weight from branch diameter is the pooling of branch data from all three densities of both stands. However Loomis et al. (1966) showed that stand density had no effect on the foliage and wood dry weight supported by branches of *Pinus echinata* Mill. For this reason and because it took an average of four hours to sample each jack pine branch, a pooled sample of 80 branches was deemed adequate.

Sample discs were placed in a refrigerated environment (2°C) and measured as soon as possible after sectioning. For each sample disc, current diameter inside and outside bark, and diameter inside bark at three-year periods were measured on a mean disc diameter. Mean disc diameter was calculated by averaging the minimum and maximum disc diameters.

Stem wood specific gravity was determined on each tree at three locations: 1) in the live crown, 2) at the base of the live crown, and 3) in the crown-free bole. Two wood samples were taken from sample discs at each location in the bole. The specific gravity calculations were based on green volume and oven-dry weight of the wood (U. S. Forest Products Laboratory 1974). Green volume was obtained by the water weight displacement technique (Wakefield 1957) after soaking wood samples in water for 24 hours. Oven-dry weight of the wood samples was measured after drying at 105°C for 48 hours. Stem bark specific gravity was computed by the same method.

The area of each plot was estimated from plot maps with a polar planimeter.

Data Analysis

Regression equations relating branch diameters (at point of foliation and at five centimetres from the bole) with foliage, wood, and bark dry weight were computed by the conventional least squares method. Coefficients of determination, standard errors, and analysis of residuals were used to interpret goodness of fit. For branch components in this study, the following allometric model provided the best fit:

$$Y = b\,X^{a} \qquad (1)$$

where X represents the independent variable of branch diameter, Y represents the dependent variable of branch weight component, and, a and b are regression constants. The allometric model was fitted by logarithmic transformation (Zar 1968) and the retransformed values were corrected for bias by the method outlined by Baskerville (1972). The resulting equations were used to estimate the foliage, wood, and bark dry weight of every branch. By summing these values for all branches on a tree, the total dry weight of each component was estimated for each tree.

Total stem wood volume and three-year periodic annual stem wood volume increments were calculated from disc diameter measurements for each one metre section by Smalian's formula (Avery 1967). The dry weight of each one metre stem section was estimated by multiplying stem section volume by its respective specific gravity. Total stem wood dry weight for each tree was obtained by summing the dry weights of the individual stem sections. Stem bark dry weight was calculated in a similar manner.

Current annual stem wood production was estimated by the three-year periodic mean annual oven dry weight increment of the stem (produced 1976 to 1978). Annual branch wood production was estimated by calculating the mean annual wood dry weight increment of each live branch (wood dry weight of branch divided by age of branch) and summing these for each tree. This is only an approximation of the current annual branch wood increment and should produce a slight but systematic underestimation (Baskerville 1965a). Total current annual wood production was computed for each tree by adding current annual stem wood production and annual branch wood production.

Total above ground foliage, stem wood, stem bark, live branch wood, live branch bark, dead branch (wood plus bark), and cone dry weight as well as current annual stem wood production, annual branch wood production, and total current annual wood production in each plot were obtained by summing the values of these components for the 15 trees. Using the area of each plot, the total above ground dry weights of these components were converted to per hectare values.

Crown efficiencies (net assimilation rates) for dominant, co-dominant, intermediate, and suppressed trees were evaluated as relationships between total current annual wood production and foliage dry weight per tree. Crown efficiencies per hectare were calculated as the ratio of total current annual wood production and foliage dry weight per hectare.

All statistical tests were performed at the 0.05 level of significance.

STUDY AREAS

Location

Study areas were located in northwestern Ontario at approximately latitude 48°34' N and longitude 89°43' W. Figure 4 shows their accurate location.

The 17-year old jack pine stand was located in Goldie Township, Universal Transverse Mercator grid reference 15 1027 17687. This stand was established by natural seeding after the previous jack pine stand was logged by the Great Lakes Paper Company of Thunder Bay in 1960-61.

The 32-year old jack pine stand was located in Paipoonge Township, Universal Transverse Mercator grid reference 15 1099 17588. The site occupied by this stand supported a mature jack pine forest which was destroyed by wildfire in 1946. After the fire, most of the area regenerated to jack pine which makes up the present forest and study area.

Climate

The climate of the area has been classified by Chapman and Thomas (1968) as "modified continental", the modification being made by the presence of Lake Superior to the south-east. Climatic data obtained from the Atmospheric Environmental Services Branch of the Canada Department of Environment shows that the region receives an average annual precipitation of 73.84 cm (average rainfall of 55.8 cm plus an average snowfall of 222.0 cm). The area is also characterized by

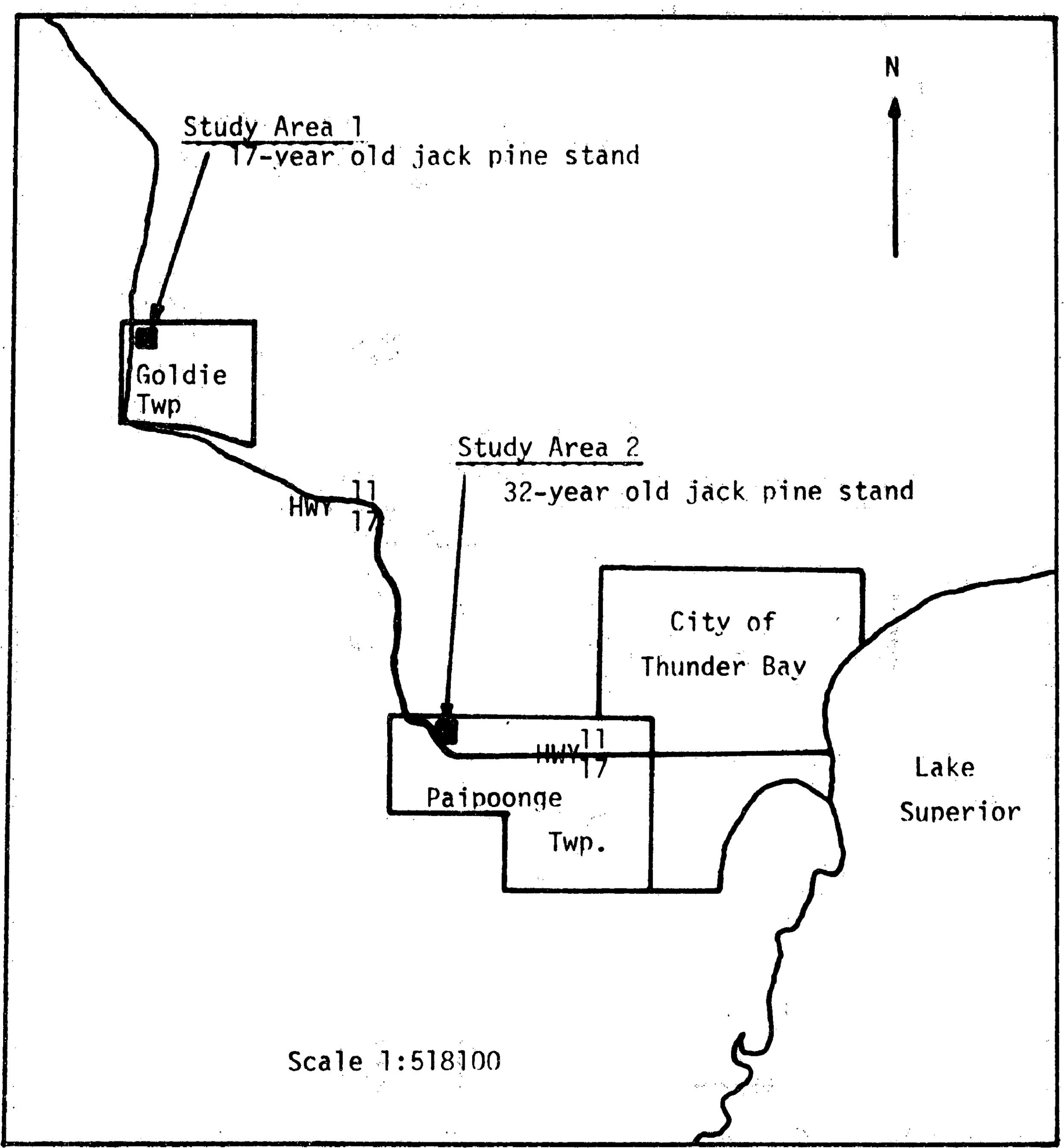

Figure 4. The location of study areas.

short, warm summers (mean daily temperature in July is 25.6°C) and long, cold winters (mean daily temperature in January is -10.0°C).

Soil Profiles

Figure 5 illustrates a typical profile of the soil in the 17-year old jack pine stand of Goldie Township. According to Burwasser (1977), this area is a lacustrine deposit of thin surficial clay which is underlain by deep sandy gravel.

Figure 6 indicates a typical profile of the soil in the 32-year old jack pine stand of Paipoonge Township. The site is a lacustrine deltaic sand which is underlain by deep sand and gravel (Burwasser 1977). The soils of both areas are podzolic and characterized by a thin humus layer.

A comparison of Figures 5 and 6 indicates major differences between the soil profile of these two stands. The soil profile for the 17-year old stand shows an irregularly occuring clay-silt deposit near the soil surface. Another feature of this soil is the irregular occurance of an iron cementation layer at approximately 80 cm depth. These two layers are absent from the soil profile supporting the 32-year old stand.

Soil-Water Relations

Soil-water relations in the two study areas were analyzed by the Thornthwaite climatic water balance. This water balance, developed in 1944, provides a procedure by which soil moisture can be evaluated over a period of time (Thornthwaite and Mather 1957). This technique converts mean precipitation and air temperature values into

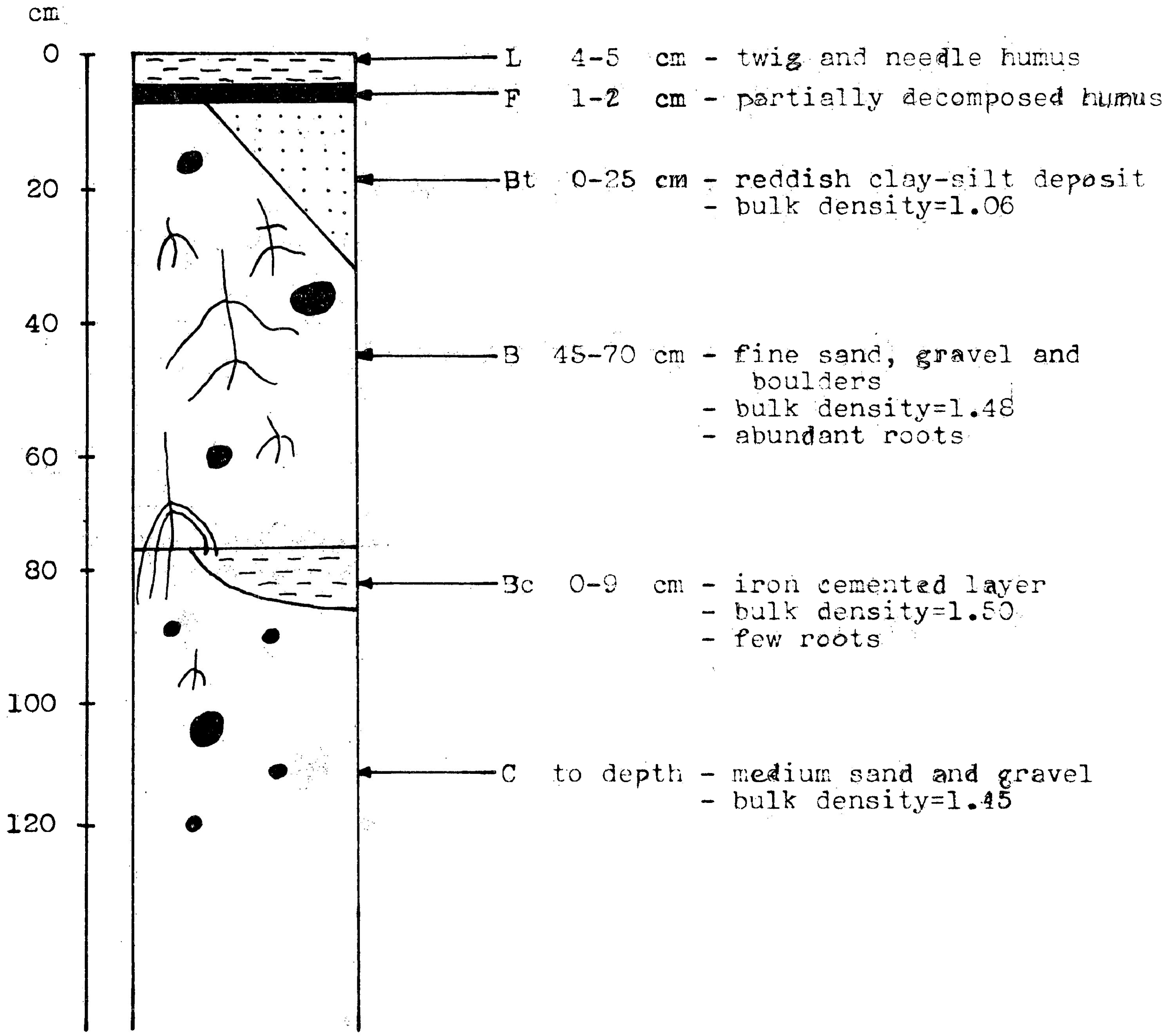

Figure **5.** Typical profile of the soil under the 17-year old jack pine stand in Goldie Township.

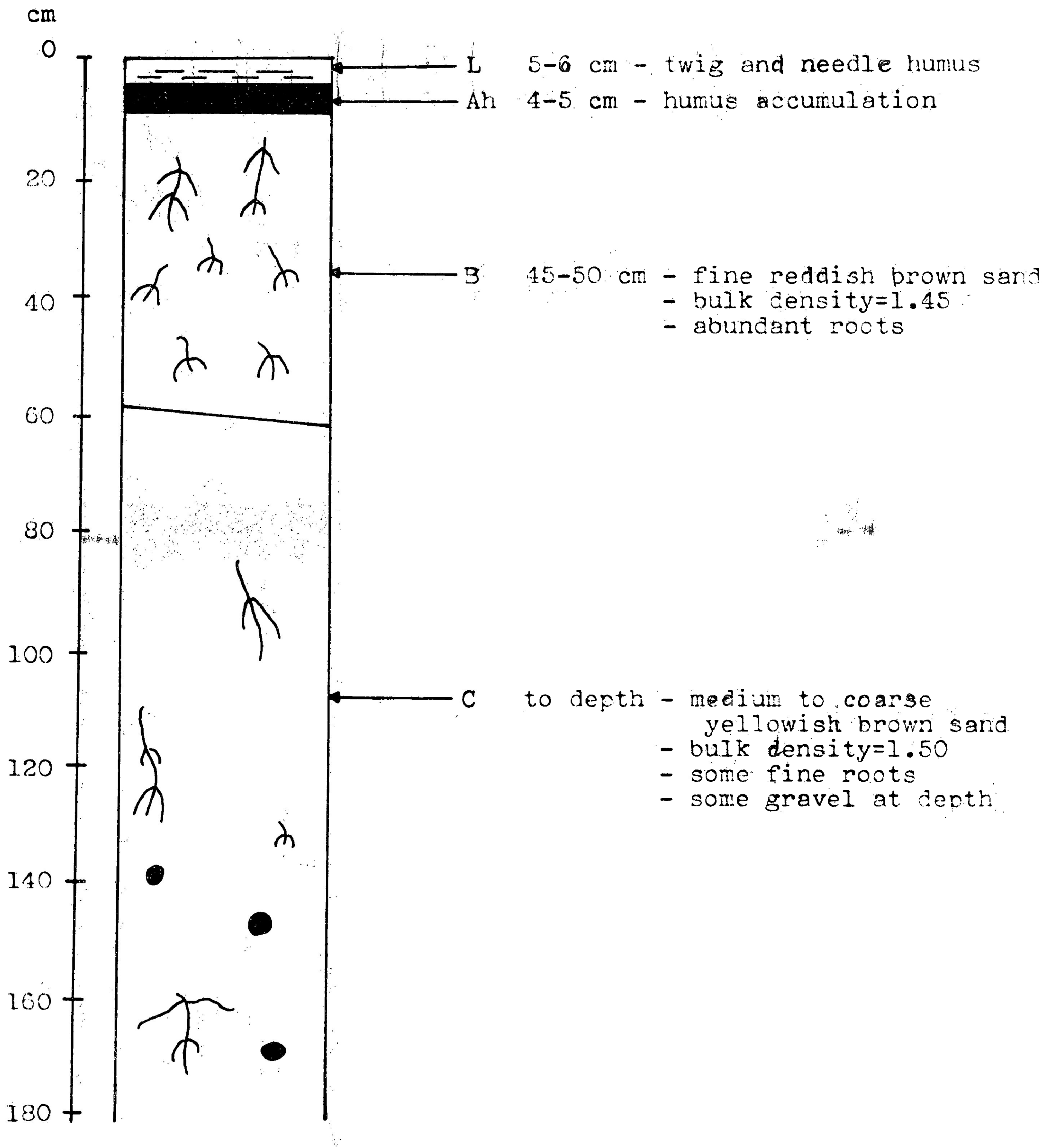

Figure 6. Typical profile of the soil under the 32-year old jack pine stand in Paipoonge Township.

potential evapotranspiration values. The method assumes that the rate of potential evapotranspiration is related to the amount of water held in the soil. By including information on the moisture retention capacity of the soil and the latitude of the study area, the technique theoretically accounts for all additions and withdrawals of moisture from the soil. Soil water surpluses or deficits can therefore be evaluated. Day and Bax (1976) have shown that this technique was useful in estimating the soil moisture relations of soils supporting jack pine forests.

In this study, the Thornthwaite monthly water balance was used to compare the soil water relations for 17 and 32 consecutive years in the respective study areas. A fortran computer program was written (Appendix A) to evaluate the monthly water balances. Because of their length, the results of the water balance evaluations for each month of each year are not presented. Instead an average monthly water balance is outlined for each study area in Appendix B. Appendix C summarizes the water balance results for both study areas.

Results of the water balance evaluations show that both study areas were highly susceptible to soil moisture deficits in the months of July and August. However, the soil moisture deficits in the 17-year old stand have been much more severe than in the 32-year old stand. The greatest soil moisture deficiencies encountered ranged up to 61.0 mm in the 17-year old stand and up to 40.5 mm in the 32-year old stand. Since the soil moisture retention capacity of the 17-year old stand was 129.2 mm, a water deficit of 61.0 mm would have reduced the soil moisture content by 47.2%. Soil moisture content reductions up to 47.2% would likely have had a negative effect on the growth of jack pine trees on this site. For the 32-year old stand, with a soil moisture retention capacity of 393.9 mm, a water deficit of 40.5 mm would have reduced the soil moisture content by a mere 10.3%. Reductions in soil moisture content up to 10.3% would likely have had little influence on the growth of jack pine trees on this site.

Stand Characteristics

Figures 7 and 8 are horizontal crown projection maps which illustrate the distribution of trees within each plot. These figures do not show the true location of each plot in relation to one another; they show the plots side by side to make comparison convenient. The figures illustrate the relative size and horizontal projection of the jack pine tree crowns at the various stand densities. Horizontal projections of the crowns were generally greater at the lower stand densities.

The number of trees by crown classes in the sample plots was as follows:

Table 1. The number of dominant, co-dominant, intermediate, and suppressed trees in each of the sample plots.

Stand Age	Density Class	Number of trees per plot			
		Dominant	Co-dominant	Intermediate	Suppressed
17	High	1	10	2	2
17	Medium	4	8	1	2
17	Low	8	3	2	2
32	High	5	3	2	5
32	Medium	4	4	3	4
32	Low	7	6	1	1

Stand density in each plot was computed as number of trees

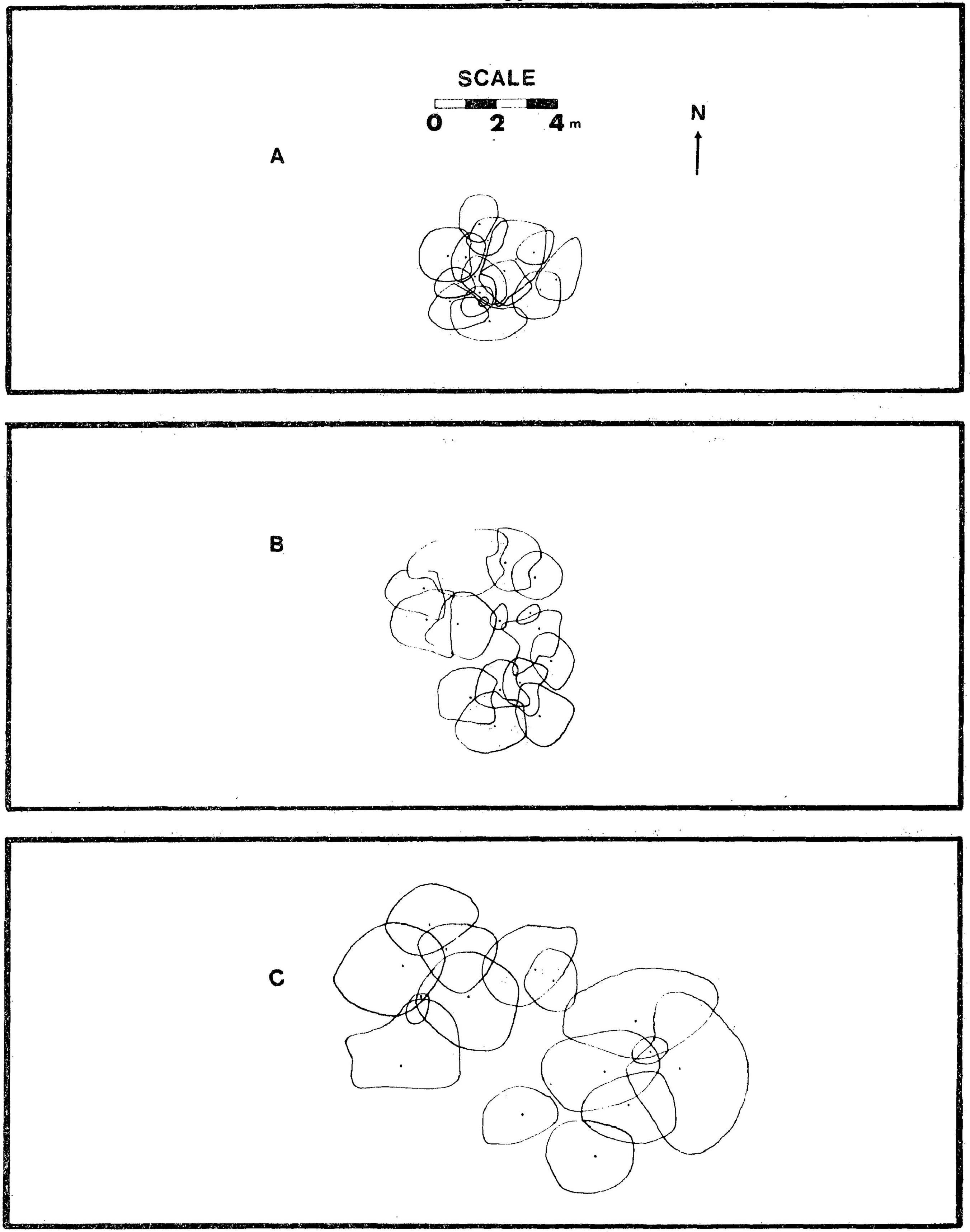

Figure 7. Location of the jack pine trees and their horizontal crown projection in the high (A), medium (B), and low (C) density sample plots of the 17-year old stand.

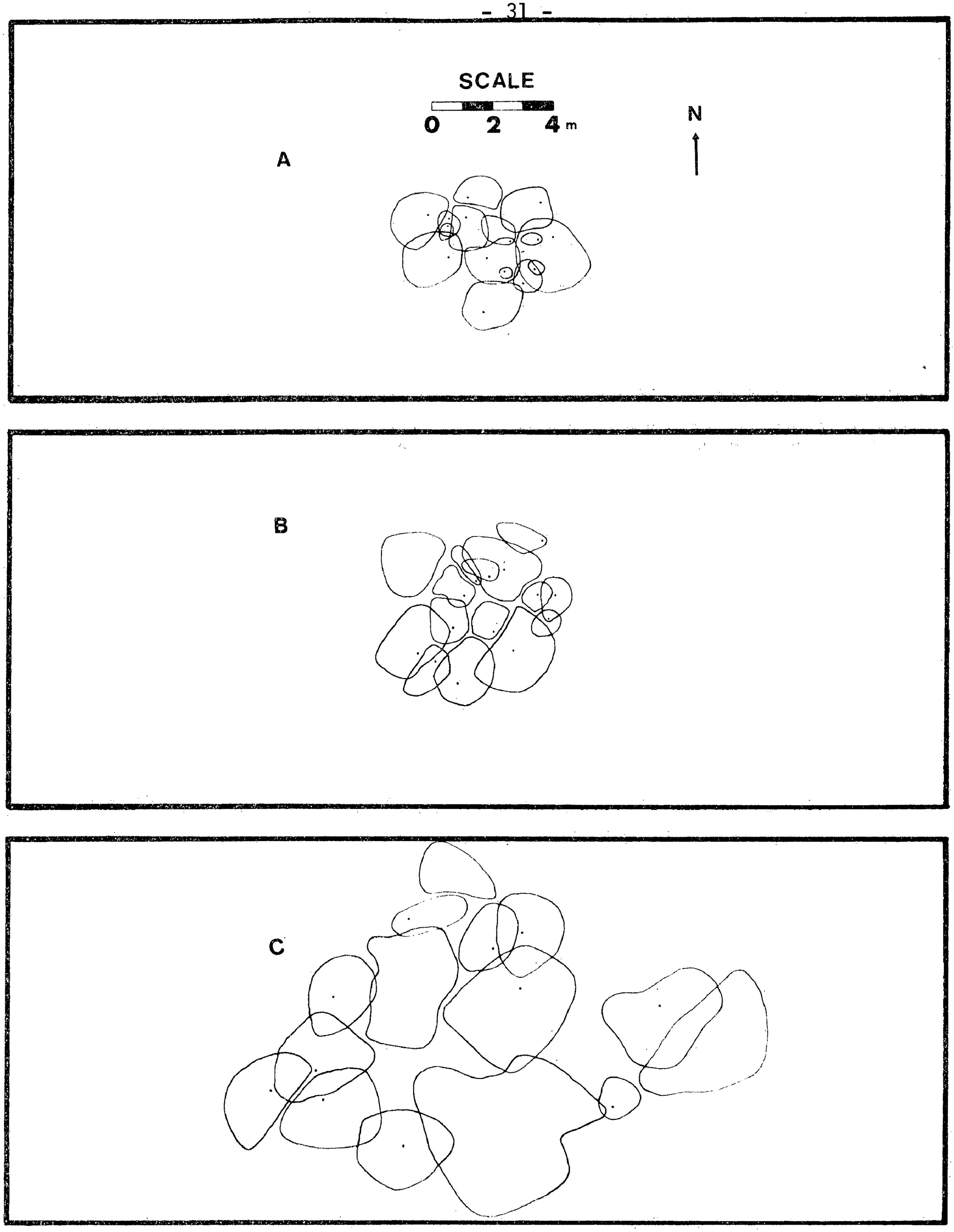

Figure 8. Location of the jack pine trees and their horizontal crown projection in the high (A), medium (B), and low (C) density sample plots of the 32-year old stand.

per unit area, relative spacing, and basal area (Table 2). In the 17-year old stand, there were 9091, 4587, and 1728 stems per hectare in the respective high, medium and low stand density plots. In the 32-year old stand, there were 7042, 4658, and 1131 stems per hectare in the respective high, medium, and low stand density plots. Relative spacing was calculated as the ratio, in per cent, of the mean distance between trees to stand height (Vezina 1963). It was 12.9, 19.3, and 30.3% in the 17-year old stand and 9.3, 11.2, and 22.3% in the 32-year old stand at respective high, medium, and low stand density classes.

Total basal area per hectare decreased with decreasing stand density and was generally greater in the older stand. From high to low density, it was 34.3, 22.4, and 14.4 m^2/ha in the 17-year old stand, and 57.8, 48.6, and 20.8 m^2/ha in the 32-year old stand (Table 2). A comparison of these basal area values to those of normally stocked jack pine stands (Plonski 1974) indicated that the stocking of the high, medium, and low density plots was 184, 120, and 77% in the 17-year old stand and 226, 190, and 81% in the 32-year old stand. Periodic annual basal area increments were similar in both stands (Figure 9A). They had culminated in all six plots, however, culmination occurred much earlier in the 17-year old stand (8-10 years) than in the 32-year old stand (17 years). Periodic annual basal area increment had declined in recent years, averaging between 0.5 and 1.5 m^2/ha/yr in both stands for the last three years. Mean annual basal area increment had recently maximized only in the 32-year old stand.

Mean diameter at breast height, outside bark, was influenced

Table 2. Stand characteristics of sample plots.

Stand age (yrs.)	Density class	Plot area (m^2)	No. trees per hectare	Relative[1] spacing (%)	Basal area per hectare (m^2)	Mean dbh (cm)	Height (m)	Total stem wood volume per hectare (m^3)
17	High	16.5	9091	12.9	34.3	6.8	8.43	136.4
17	Medium	32.7	4587	19.3	22.4	7.5	8.22	84.8
17	Low	86.8	1728	30.3	14.4	9.6	8.53	53.7
32	High	21.3	7042	9.3	57.8	9.9	15.68	391.9
32	Medium	32.2	4658	11.2	48.6	11.2	15.28	303.2
32	Low	132.6	1131	22.3	20.8	15.0	13.67	117.6

[1] After Vezina (1963)

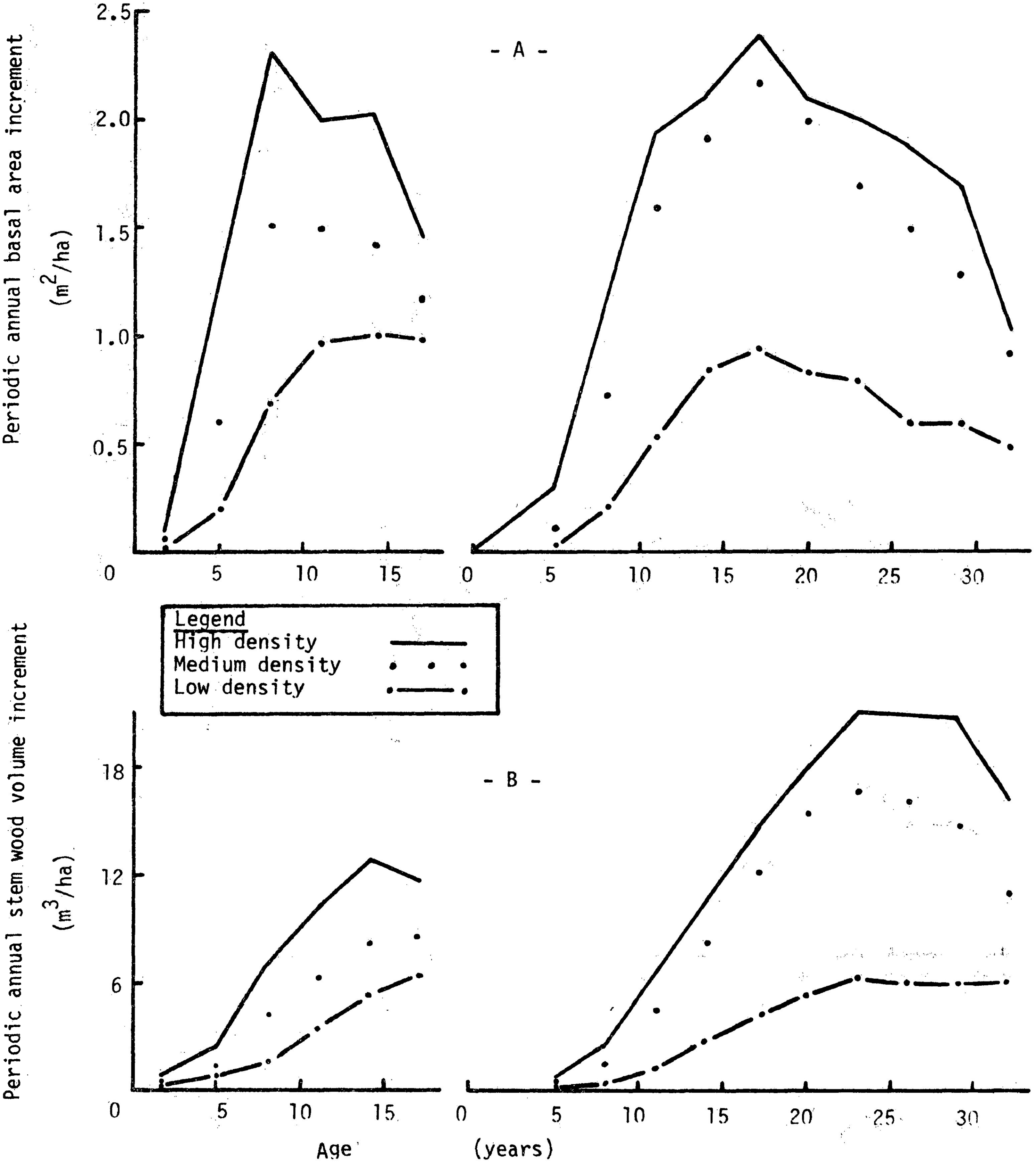

Figure 9. Periodic annual basal area (A) and stem wood volume increment (B) in the 17- and 32-year old jack pine stands (based on survivor trees).

by stand age and stand density. Mean diameter at breast height increased with decreasing stand density and was always greater in the 32-year old stand. Figure 10 illustrates the diameter class distribution of jack pine trees in the 17- and 32-year old stands. It shows that the range of diameters increased with decreasing density and with increasing stand age.

Stand height was estimated for each plot as the average height of the dominant and co-dominant trees. Stand height was not influenced by density in the 17-year old stand; it was slightly greater than 8 m in the three plots. In the 32-year old stand, average height was slightly higher than 15 m in the high and medium density plots. However, at low density the total height was significantly lower: 13.67 m.

The pattern of total stem wood volume in the six plots had much the same relation to stand density and age as basal area. Total stem wood volume was greatest in the high density plots and was generally greater in the 32-year old stand (Table 2). It was 136.4, 84.8, and 53.7 m^3/ha in the 17-year old stand and 391.9, 303.2, and 117.6 m^3/ha in the 32-year old stand for the respective high, medium, and low density plots. Periodic annual stem wood volume increments had culminated in all plots in the 32-year old stand at approximately 23 years of age (Figure 9B) and had been declining in recent years. The periodic annual stem wood volume increment in the 17-year old stand had recently culminated only in the high density plot. It had also culminated at a much lower volume (12.9 m^3/ha/yr) than the highest

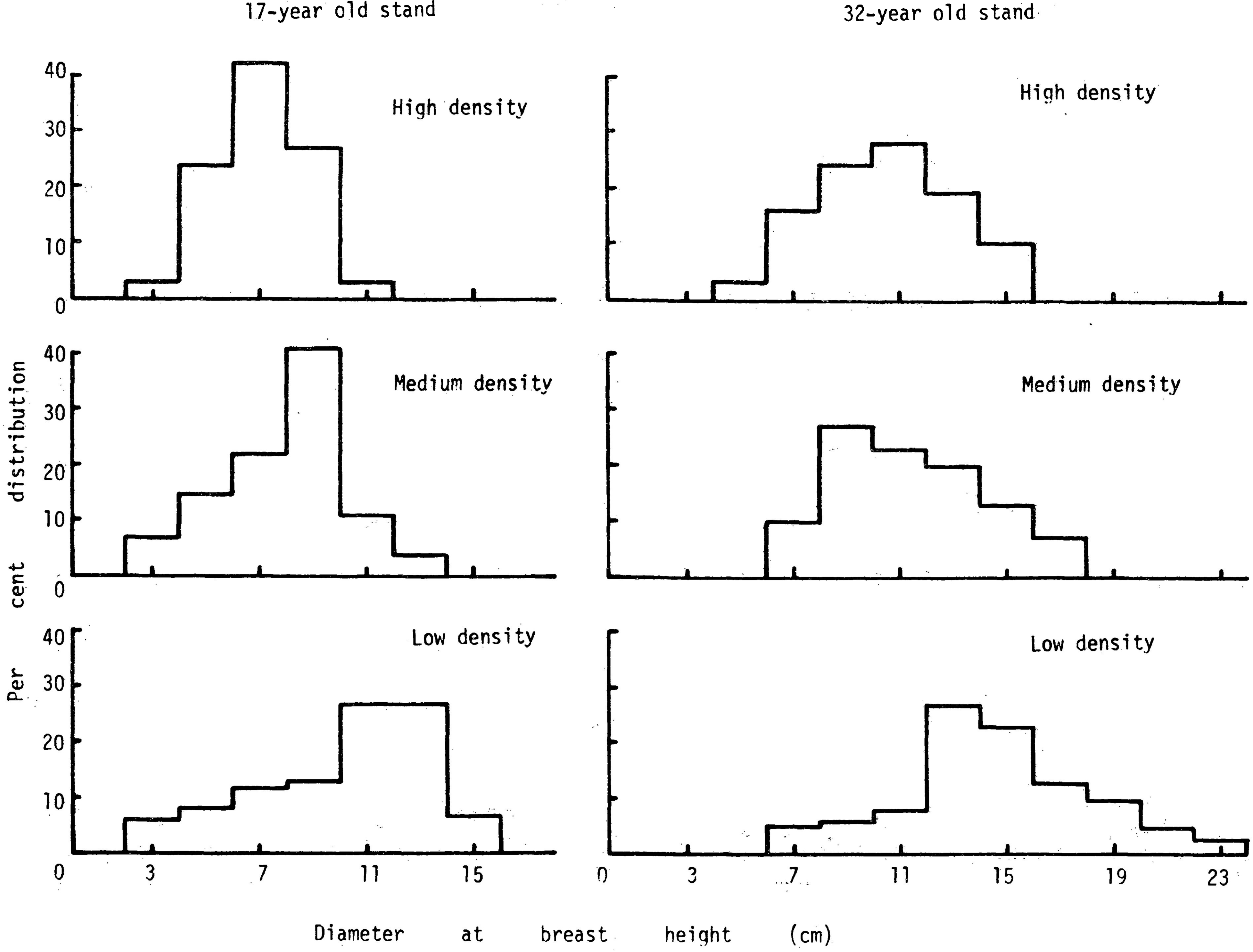

Figure 10. Diameter class distribution in the 17- and 32-year old jack pine stands.

periodic annual stem wood volume increment (21.0 m^3/ha/yr) in the 32-year old stand. Mean annual stem wood volume increment had not maximized in any of the plots at the time of study.

RESULTS

Branch Weight Relationships to Branch Diameter

Plotted data (Figure 11) revealed no differences in the foliage dry weight and branch diameter at the point of foliation relationship between the 17- and 32-year old stands. The data were therefore pooled for regression analysis. The best fit to the foliage dry weight and branch diameter at the point of foliation data was obtained with the allometric model (Table 3, Equation 1).

Wood (Figure 12) and bark (Figure 13) dry weight of jack pine sample branches were closely related to the diameter of the branches at five centimetres from their severed ends. Plotted data (Figures 12 and 13) showed no significant differences between the two stands studied. Thus, it was possible to pool these data for regression analysis. The best fitting relationships to the branch wood and bark dry weight over branch diameter data were also allometric models (Table 3, Equations 2 and 3).

The dry weight (wood plus bark) of dead sample branches was also closely related to the diameter of the branches at five centimetres from their severed ends (Table 3, Equation 4).

Stem Wood and Bark Specific Gravity

Stem wood and bark specific gravity results (Table 4) showed minor differences between the three sampling locations in the stem and also between the two stands studied. The differences were as follows: 1) stem wood specific gravity values were generally slightly higher than bark specific gravity values, 2) stem wood and bark specific gravity

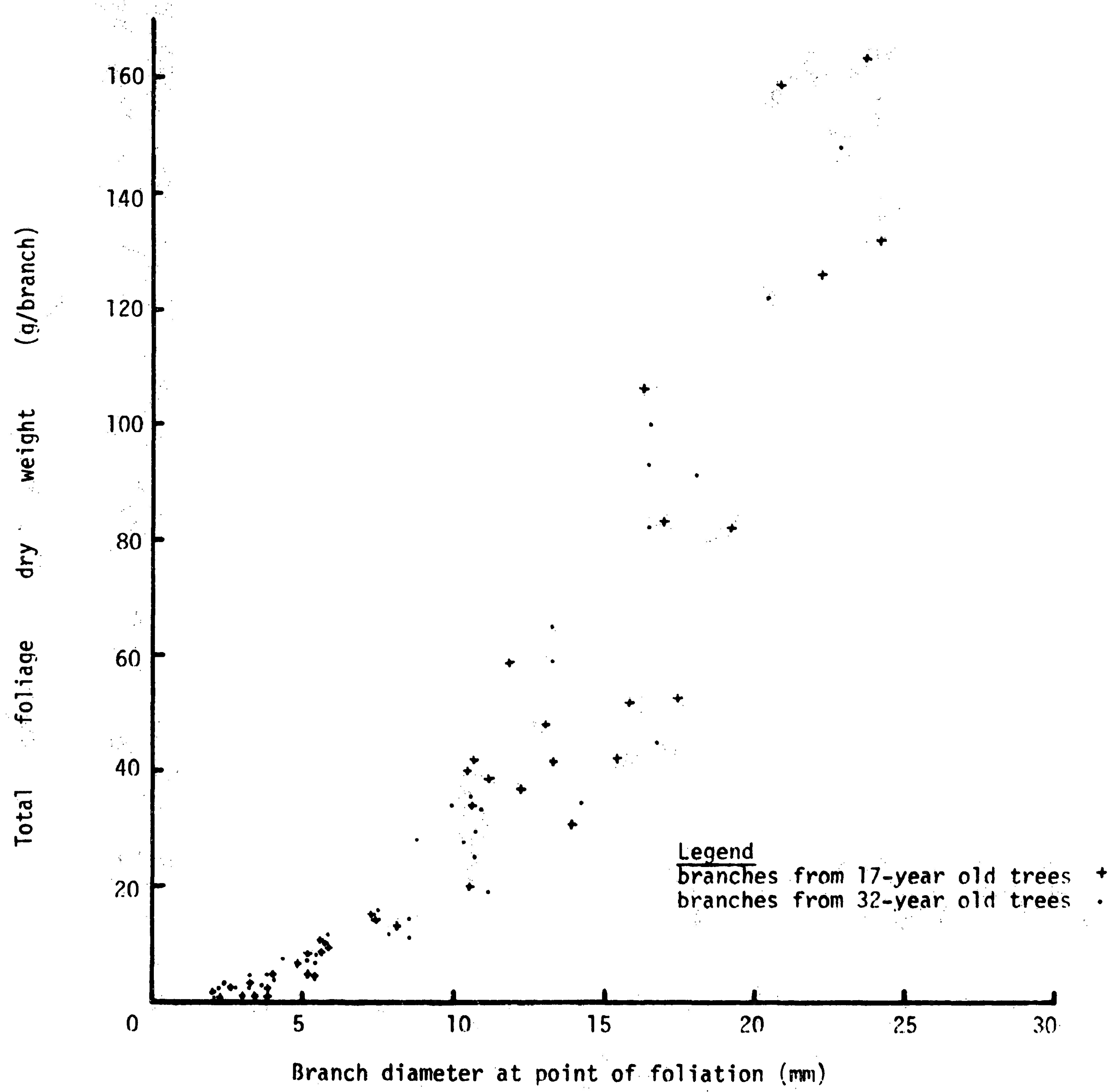

Figure 11. Relationship between branch diameter at point of foliation and the total foliage dry weight supported by jack pine sample branches.

Table 3. The relationships between branch diameter and the foliage, wood, and bark dry weight of jack pine sample branches.

Relationship[2]	Equation	R^2	$s_{y.x}$	Correction factor[1]	Equation number
FDW/DPF	$FDW = (0.222)\ DPF^{2.05}$	0.931	0.4004	1.083	(1)
BW/D	$BW = (0.0111)\ D^{3.09}$	0.959	0.4577	1.110	(2)
BB/D	$BB = (0.0377)\ D^{2.41}$	0.951	0.3900	1.079	(3)
DB/D	$DB = (0.0490)\ D^{2.67}$	0.972	0.3261	1.055	(4)

[1] After Baskerville (1972)

[2] FDW = total branch foliage dry weight
DPF = branch diameter at point of foliation
BW = branch wood dry weight
BB = branch bark dry weight
DB = dead branch dry weight (wood + bark)
D = branch diameter 5 cm from bole

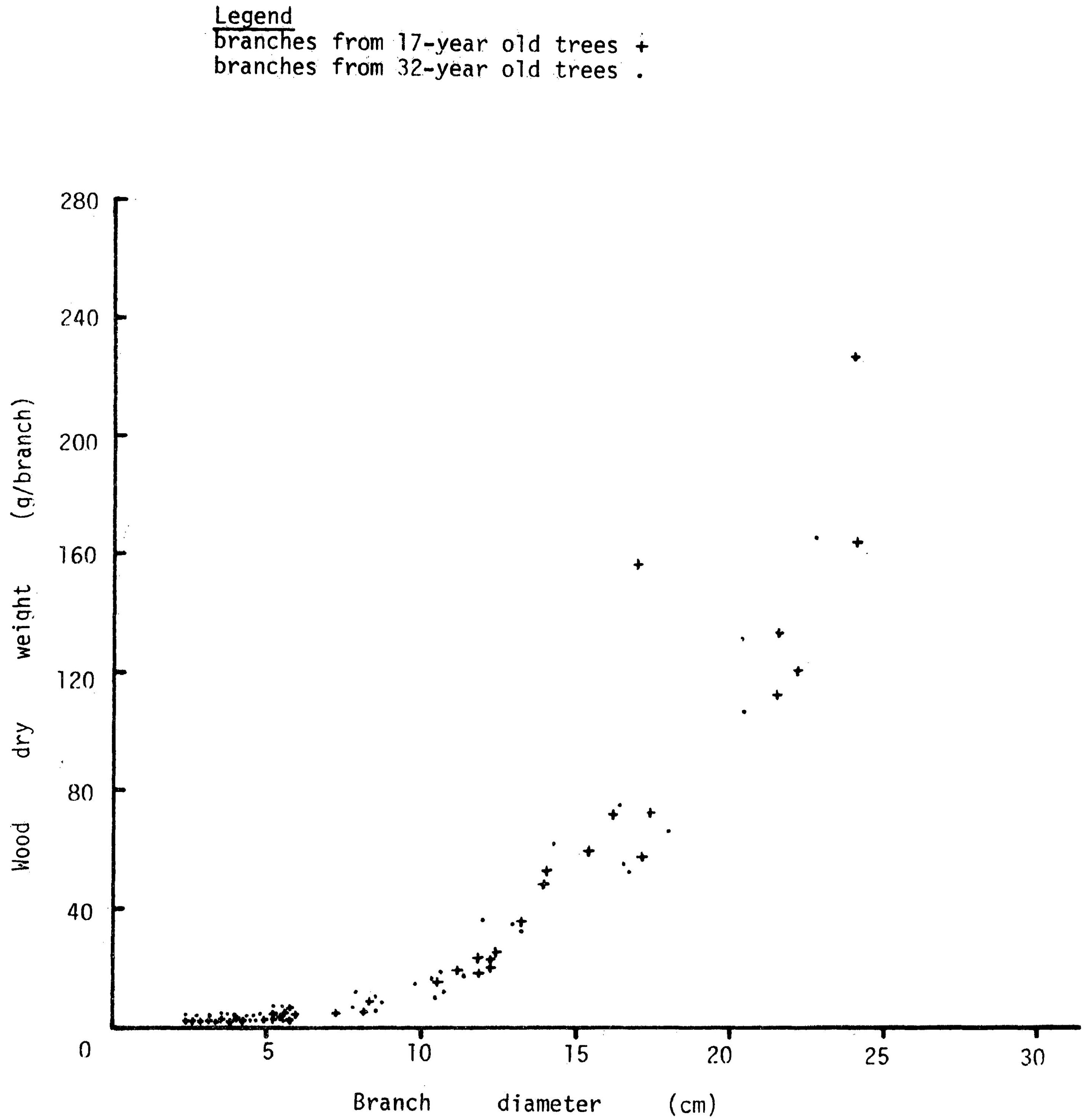

Figure 12. Relationship between branch diameter 5 cm from the bole and the wood dry weight supported by jack pine sample branches.

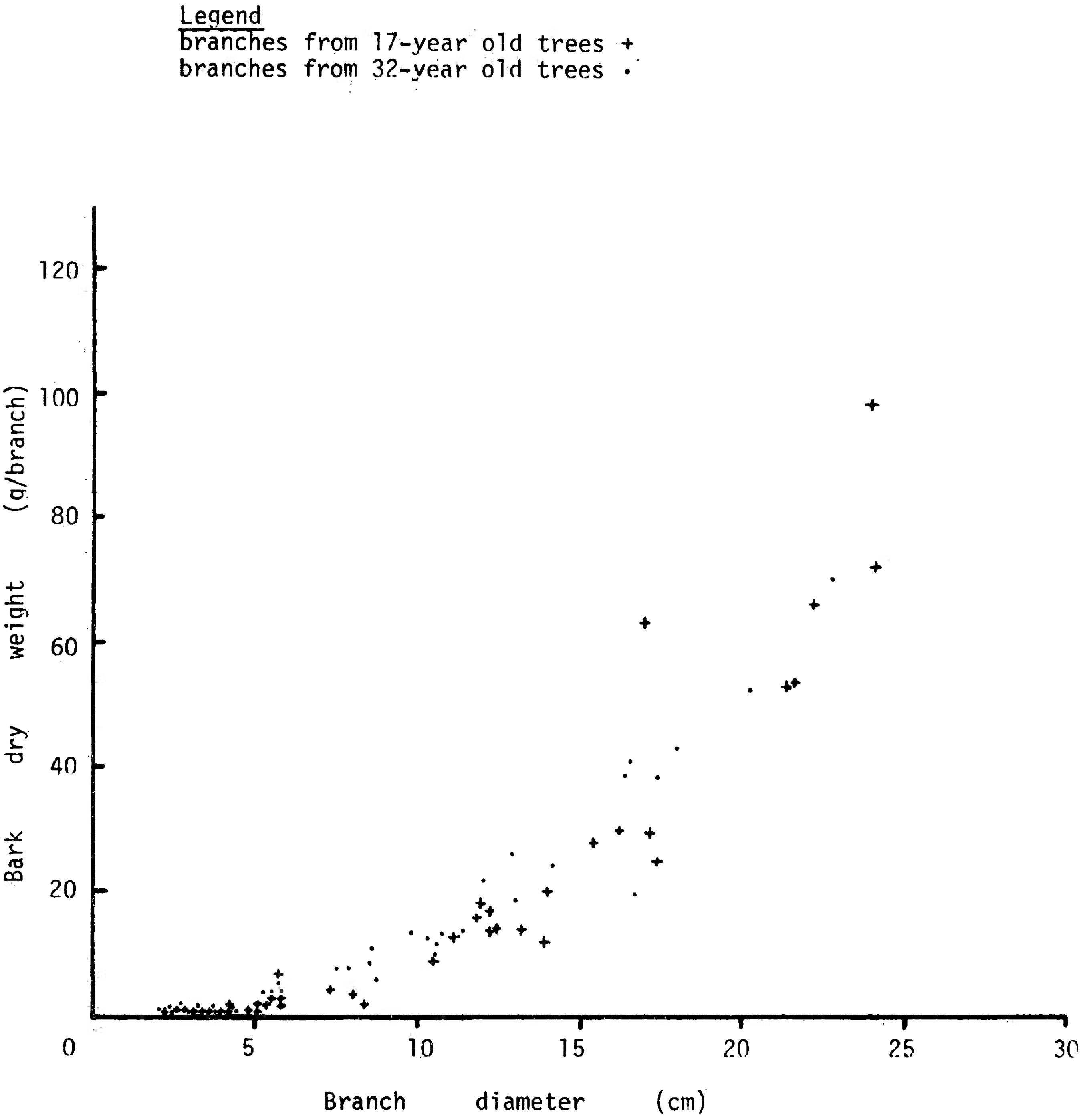

Figure 13. Relationship between branch diameter 5 cm from the bole and the bark dry weight supported by jack pine sample branches.

Table 4. Stem wood and bark specific gravity, computed from stem disc samples.

Stand age (yrs)	Density class	Specific gravity					
		Lower bole		Crown base		Live Crown	
		Mean	Range	Mean	Range	Mean	Range
				WOOD			
17	High	0.35	0.32-0.40	0.35	0.31-0.37	0.33	0.30-0.38
17	Medium	0.35	0.31-0.39	0.34	0.31-0.44	0.35	0.29-0.43
17	Low	0.33	0.26-0.36	0.32	0.26-0.39	0.31	0.29-0.36
32	High	0.37	0.34-0.40	0.35	0.32-0.38	0.34	0.30-0.38
32	Medium	0.38	0.34-0.42	0.35	0.30-0.40	0.34	0.31-0.38
32	Low	0.36	0.32-0.38	0.35	0.31-0.37	0.34	0.32-0.40
				BARK			
17	High	0.32	0.27-0.36	0.28	0.24-0.38	0.28	0.20-0.34
17	Medium	0.34	0.28-0.42	0.30	0.24-0.35	0.24	0.21-0.36
17	Low	0.34	0.21-0.42	0.33	0.20-0.37	0.26	0.20-0.40
32	High	0.35	0.26-0.46	0.31	0.26-0.40	0.28	0.23-0.38
32	Medium	0.37	0.30-0.45	0.35	0.30-0.41	0.31	0.23-0.39
32	Low	0.38	0.26-0.47	0.33	0.23-0.40	0.28	0.22-0.37

tended to be higher in the older stand, and 3) stem wood and bark specific gravity decreased slightly with increasing height in the trees. Because these differences were minor, no significant differences were detected between the three sampling locations in the stem and between the two stands. Stand density had no effect on wood or bark specific gravity.

Mean wood specific gravity, in Table 4, ranged from 0.31 to 0.35 in the 17-year old stand and from 0.34 to 0.38 in the 32-year old stand. Mean bark specific gravity ranged from 0.24 to 0.34 in the 17-year old stand and from 0.28 to 0.38 in the 32-year old stand.

Stand Biomass per Unit Area

Stand biomass data (Table 5) show a generally increasing total biomass with increasing stand density in both stands studied. Total above ground biomass was linearly related to stand basal area (Figure 14A); it increased from 35.6 to 51.1 and to 75.0 t/ha from the low, medium to high density classes in the 17-year old stand. Total above ground biomass was considerably higher in the 32-year old stand except at the wide spacing (Figures 15A and 15B); it was 67.8, 154.8, and 186.7 t/ha in the low, medium, and high density classes.

Stem wood biomass increased with increasing stand density in both stands and it was generally higher in the older stand. Stem bark biomass followed the same trend. Live branch wood and bark did not differ significantly between stands and between density classes. Dead branch wood plus bark was generally higher in the 32-year old stand. This accounted for the greater tonnage per hectare of branches

Table 5. Estimated above ground biomass by tree component in tonnes per hectare and percentages, based on sample plots.

	Stand age (yrs.)	Density class	Stand Density (# stems /ha)	Stem wood	Live branch wood	Stem bark	Live branch bark	Dead branch wood + bark	Cones	Foliage	Total
$^{t}/_{ha}$	17	High	9091	46.0	5.6	6.7	3.4	5.4	0.5	7.4	75.0
	17	Medium	4587	28.2	5.0	4.9	2.8	3.4	0.4	6.3	51.0
	17	Low	1728	16.3	6.2	3.1	2.6	2.0	0.3	5.1	35.6
	32	High	7042	139.0	6.4	15.3	3.7	13.2	0.5	8.6	186.7
	32	Medium	4658	110.2	6.8	12.8	3.6	13.0	0.6	7.8	154.8
	32	Low	1131	41.4	7.1	5.1	2.7	6.3	0.4	4.8	67.8
%	17	High	9091	61.3	7.5	8.9	4.5	7.2	0.7	9.9	100.0
	17	Medium	4587	55.3	9.8	9.6	5.5	6.7	0.8	12.3	100.0
	17	Low	1728	45.8	17.4	8.7	7.3	5.6	0.9	14.3	100.0
	32	High	7042	74.4	3.4	8.2	2.0	7.1	0.3	4.6	100.0
	32	Medium	4658	71.2	4.4	8.3	2.3	8.4	0.4	5.0	100.0
	32	Low	1131	61.1	10.5	7.5	4.0	9.2	0.6	7.1	100.0

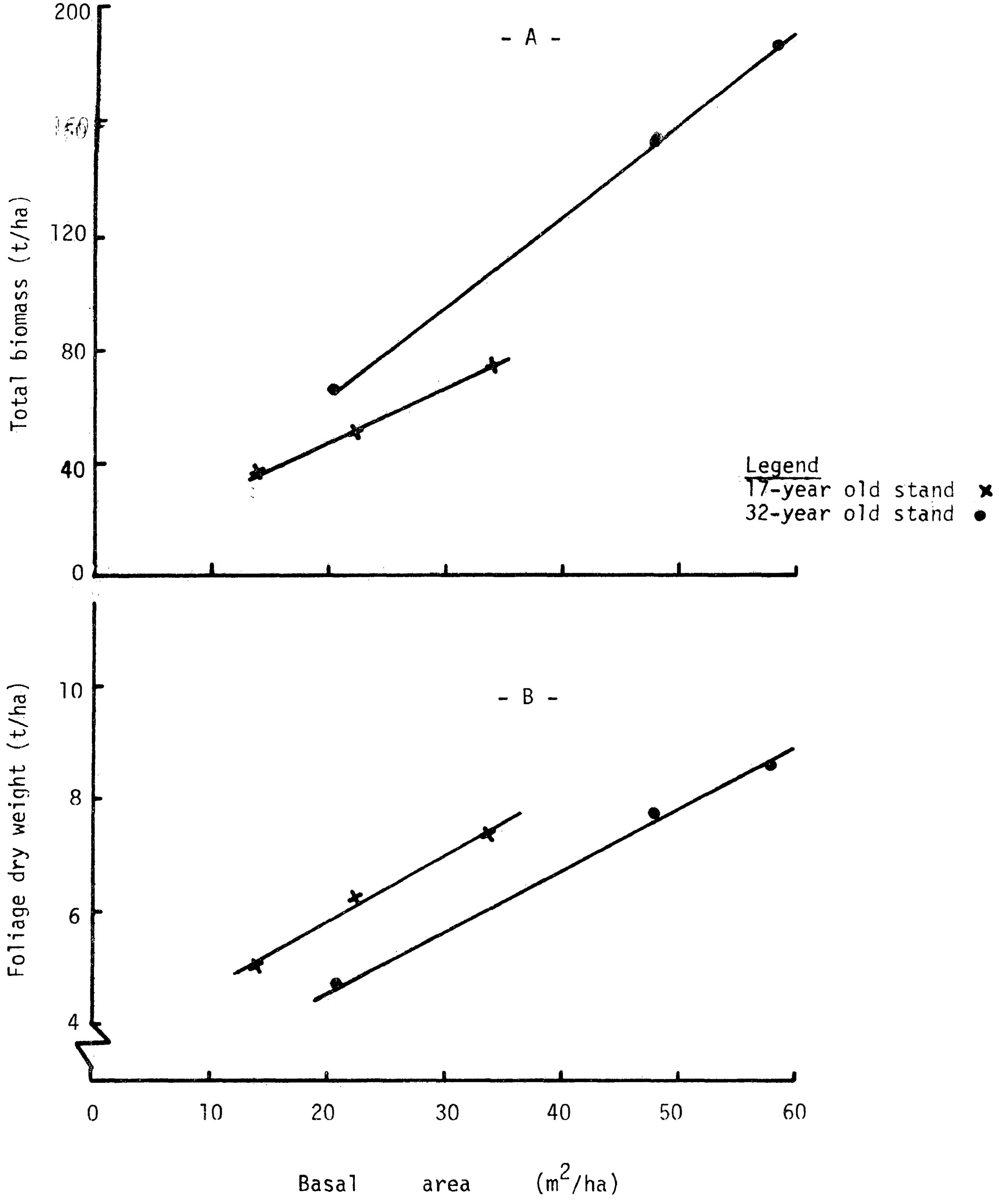

Figure 14. Relationship between total biomass (A) and foliage dry weight (B) over basal area per hectare.

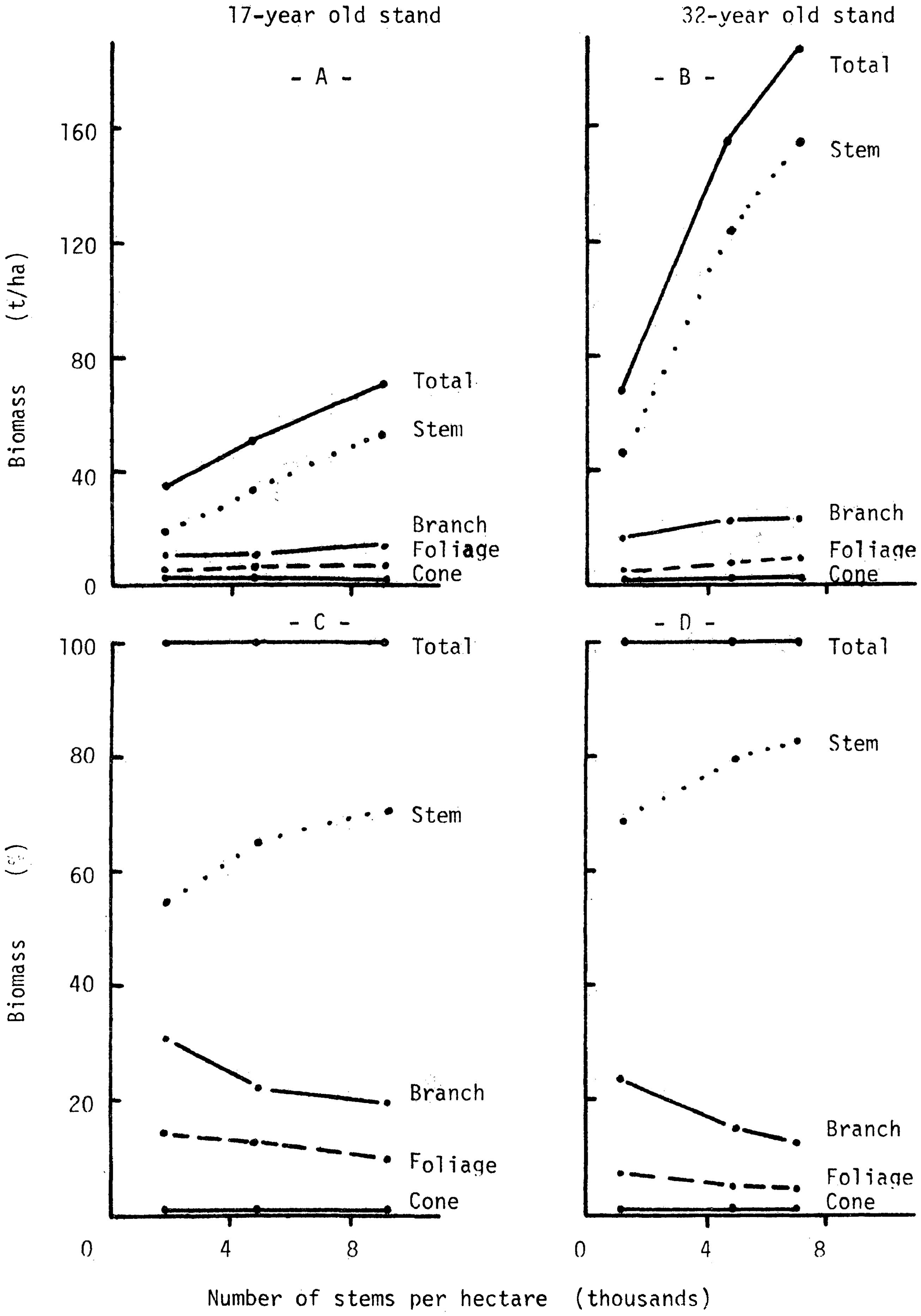

Figure 15. Distribution of above ground biomass by stem (wood and bark), branch (wood and bark), foliage, and cone component in the 17- and 32-year old jack pine stands.

in the 32-year old stand (Figure 15B) than in the 17-year old stand (Figure 15A). Cone dry matter was similar at all stand densities of both stands. Foliage biomass increased with stand density and was linearly related to stand basal area (Figure 14B). It was 5.1, 6.3, and 7.4 t/ha in the low, medium, and high density classes of the 17-year old stand. Foliage biomass was 4.8, 7.8, and 8.6 t/ha in the low, medium, and high density classes of the 32-year old stand.

The actual biomass of all jack pine tree components generally increased with stand density (Figures 15A and 15B). The pattern for the proportion that each component comprised was somewhat different (Figures 15C and 15D). While the per cent stem (wood plus bark) component increased with stand density, the per cent branch (wood plus bark) and foliage components tended to decrease with stand density in both stands. The per cent biomass also differed between both stands. The 32-year old stand contained a greater proportion (approximately 77%) of stem biomass than the 17-year old stand (approximately 63%). However, the per cent branch and foliage biomass was relatively higher in the 17-year old stand. Branch and foliage biomass comprised approximately 24% and 12% respectively of total stand biomass in the 17-year old stand, and 17% and 5% in the 32-year old stand.

For estimates of corresponding wood and bark volumes, refer to Appendix D.

Foliage and Wood Production in Individual Trees

A close linear relationship was found between annual branch wood production and the estimated foliage dry weight of individual trees in both stands studied (Figure 16A). For this relationship, differences between the 17- and 32-year old stands were not significant. Data were therefore pooled to calculate one equation relating annual branch wood increment (BI) to the estimated foliage dry weight (F) of sample trees. The equation,

$$BI = 0.139\ F - 0.0355, \tag{2}$$

had a coefficient of determination of 0.902 and a standard error of the estimate of 0.09148.

Current annual stem wood production (SI) was also related to the amount of foliage supported by individual trees in both stands (Figure 16B). For this relationship, no significant differences were detected between the 17- and 32-year old stands. Data were therefore pooled to compute the best fitting regression equation:

$$SI = 0.00726 + 0.543\ F - 0.0201\ F^2. \tag{3}$$

The coefficient of determination for this equation was 0.894 and the standard error of the estimate was 0.2568. A test of curvilinearity (Steel and Torrie 1960) showed that this quadratic equation was a significantly better fit than a linear equation fitted to the data.

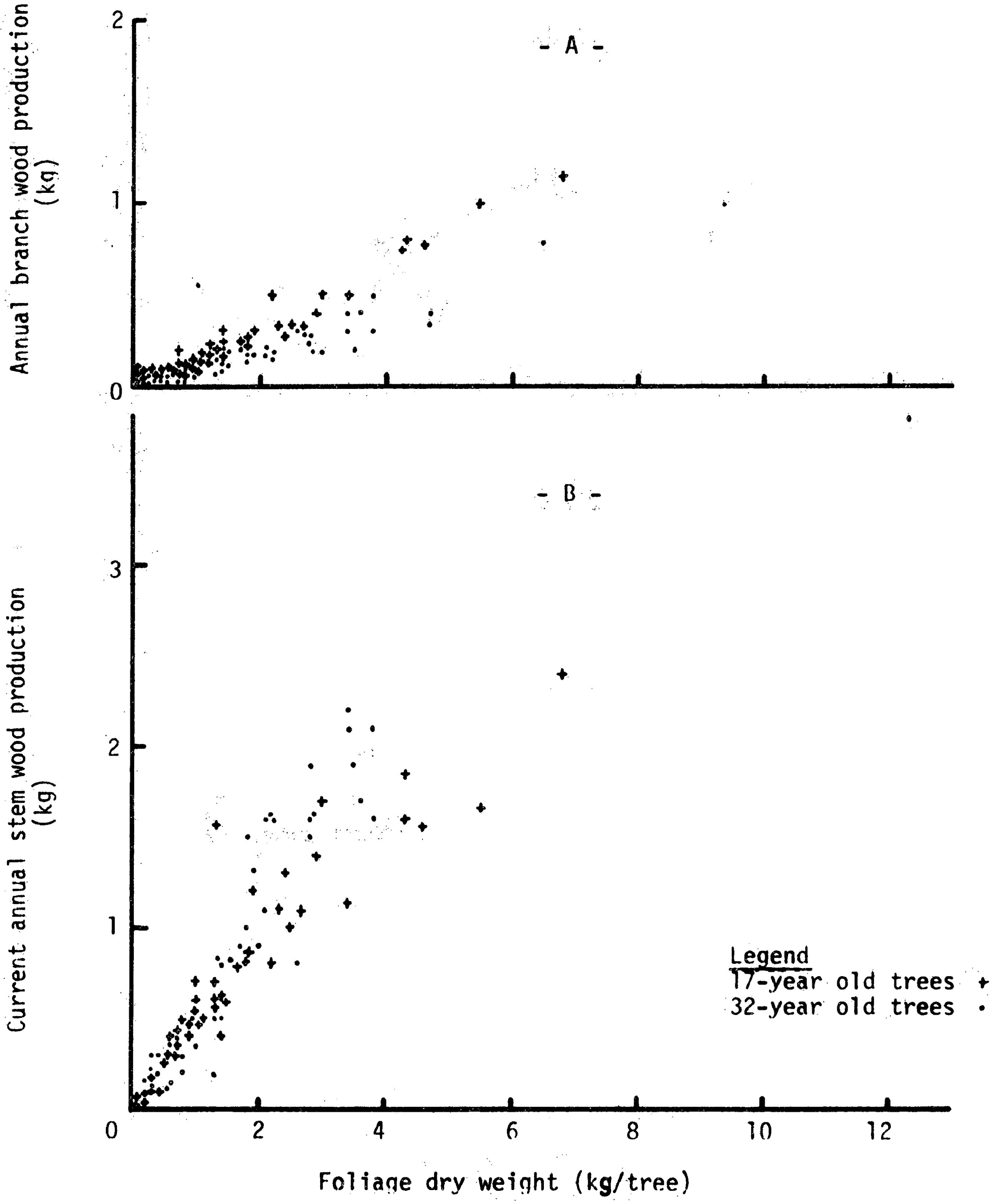

Figure 16. Relationship between annual branch wood production (A) and current annual stem wood production (B), and the estimated foliage dry weight of jack pine sample tree crowns.

When annual branch wood production was added to current annual stem wood production for each individual tree, relations with foliage dry weight (Figure 17) were closer than for stem or branch wood alone. For this relationship, there were no significant differences between the 17- and 32-year old stands and the data were pooled for regression analysis. The best fit to the total current annual wood production (TI) and foliage dry weight data was a quadratic equation:

$$(4) \qquad TI = -0.00427 + 0.661\ F - 0.0177\ F^2.$$

A test of curvilinearity showed that this quadratic equation was a significantly better fit than a linear equation fitted to the data. Regression analysis showed that stand age, relative spacing in the stand, and mean inter-tree distance did not correlate well with total current annual wood production of individual trees. Stepwise multiple regression analysis also showed that these parameters were statistically non-significant when crown foliage dry weight was included. Crown foliage dry weight, in equation 4 above, accounted for 94.8 per cent (R^2) of the variation in the total current annual wood production. The standard error of the estimate for this relationship was 0.2384.

Figure 18 illustrates that the relationship between total current annual wood production and crown foliage of individual trees was similar in the three density classes and in both stands. This figure also indicates that dominant jack pine trees supported the greatest amount of foliage and produced the greatest amount of wood at all stand

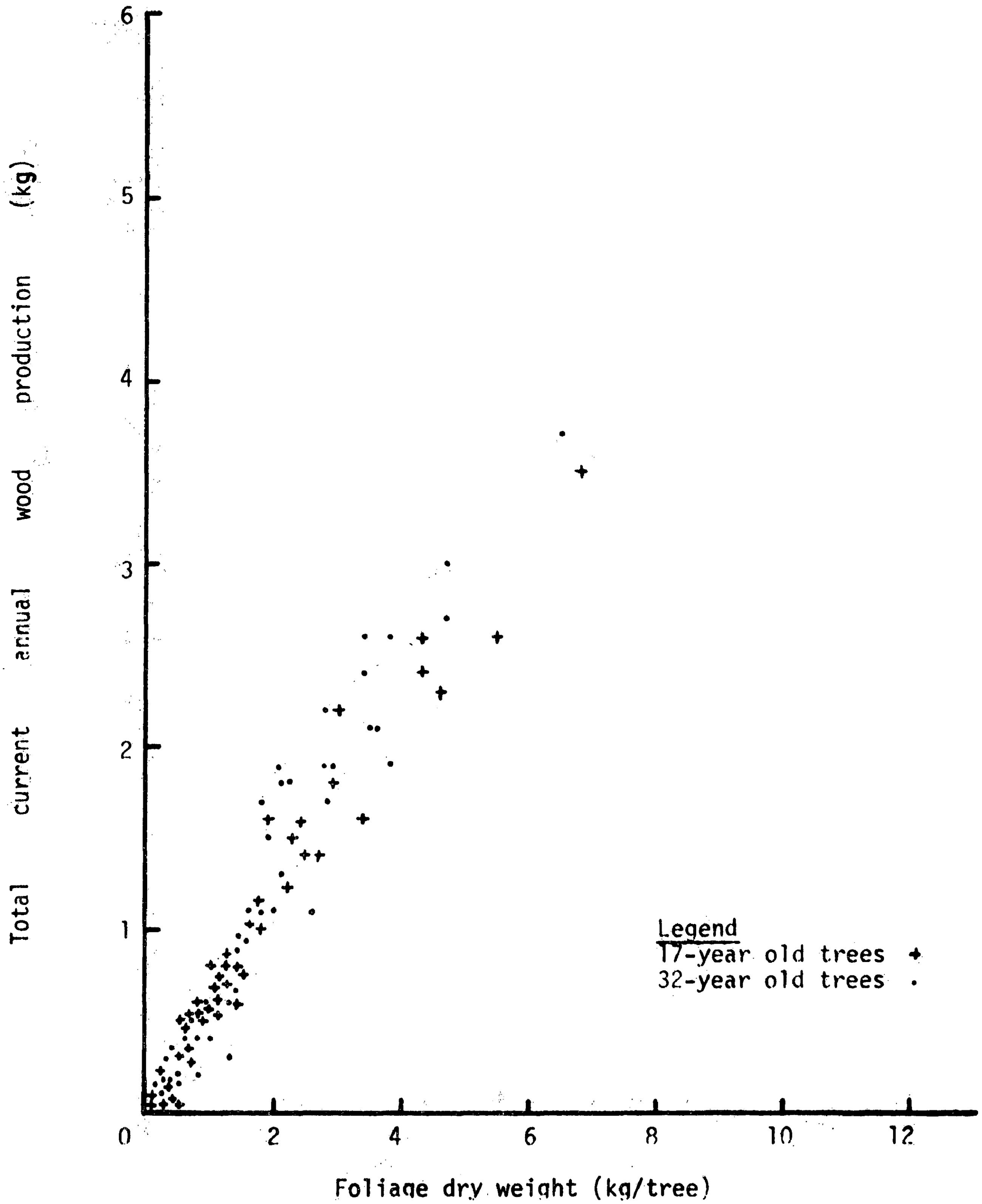

Figure 17. Relationship between total current annual wood production (branch + stem) and the estimated foliage dry weight of jack pine sample tree crowns.

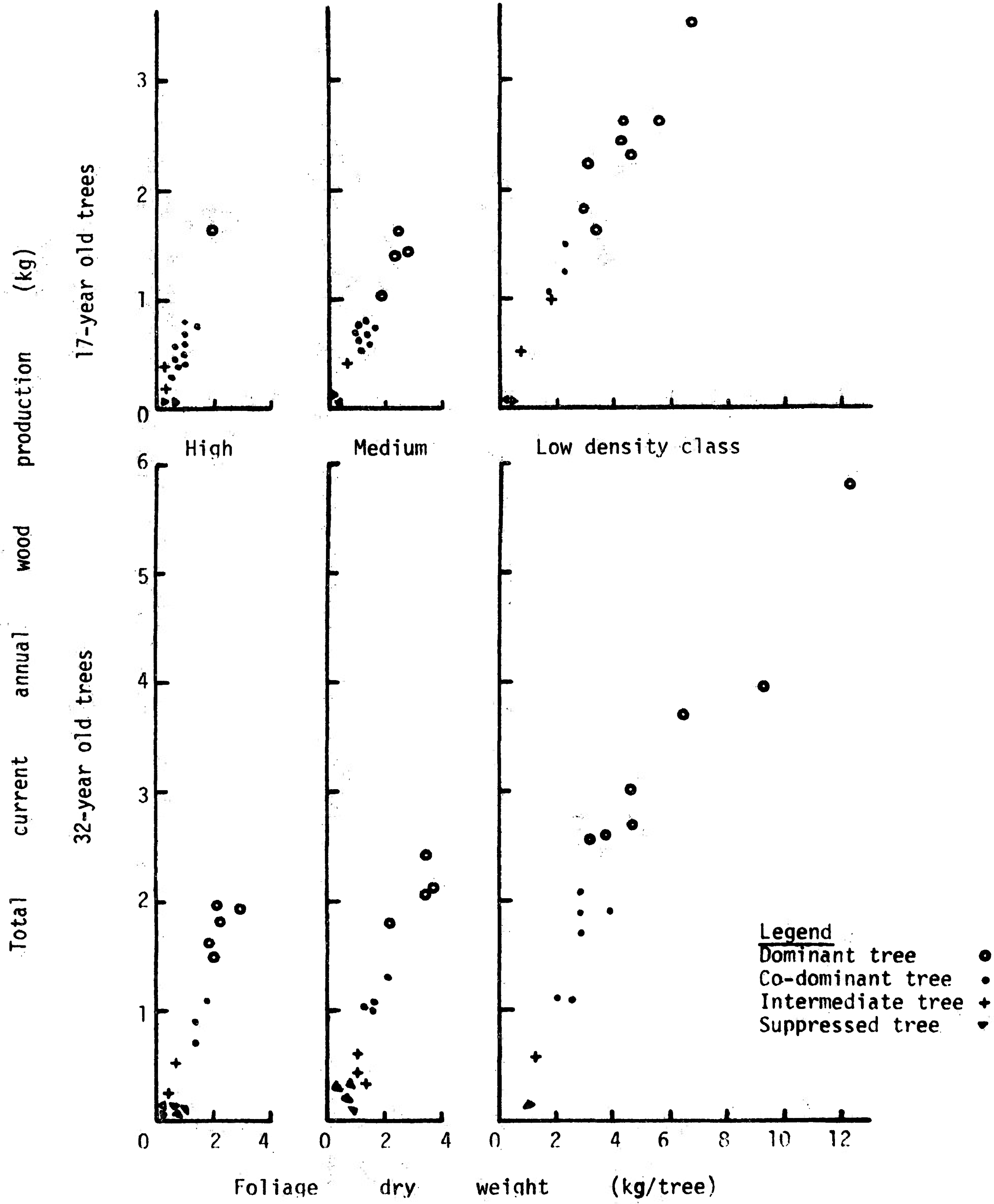

Figure 18. Relationship between total current annual wood production and the estimated foliage dry weight of sample tree crowns by stand age, stand density class, and crown class.

densities. Suppressed trees in both stands supported the least amount of foliage and produced negligible amounts of wood at all stand densities.

The trend in the plotted data of Figure 17 suggested that the rate of total current annual wood production, per unit increase in foliage dry weight, decreased slightly. Indeed the test of curvilinearity indicated that this was the case. It appeared that increases in the foliage dry weight of jack pine trees resulted in a decreased rate of total current annual wood production. This decreasing rate of wood production with increasing crown size was related to differences in the efficiency of trees in the various crown classes. Linear regression equations were computed for the total current annual wood production over foliage dry weight of dominant, co-dominant, intermediate, and suppressed trees in the two stands (Figure 19). The slope of these linear equations was used to compare the average crown efficiency of trees in the various crown classes. This analysis suggested that co-dominant trees were the most efficient, followed by intermediate, dominant, and suppressed trees. However homogeneity of regression tests (Steel and Torrie 1960) detected significant differences in crown efficiency between the dominant and co-dominant tree classes only.

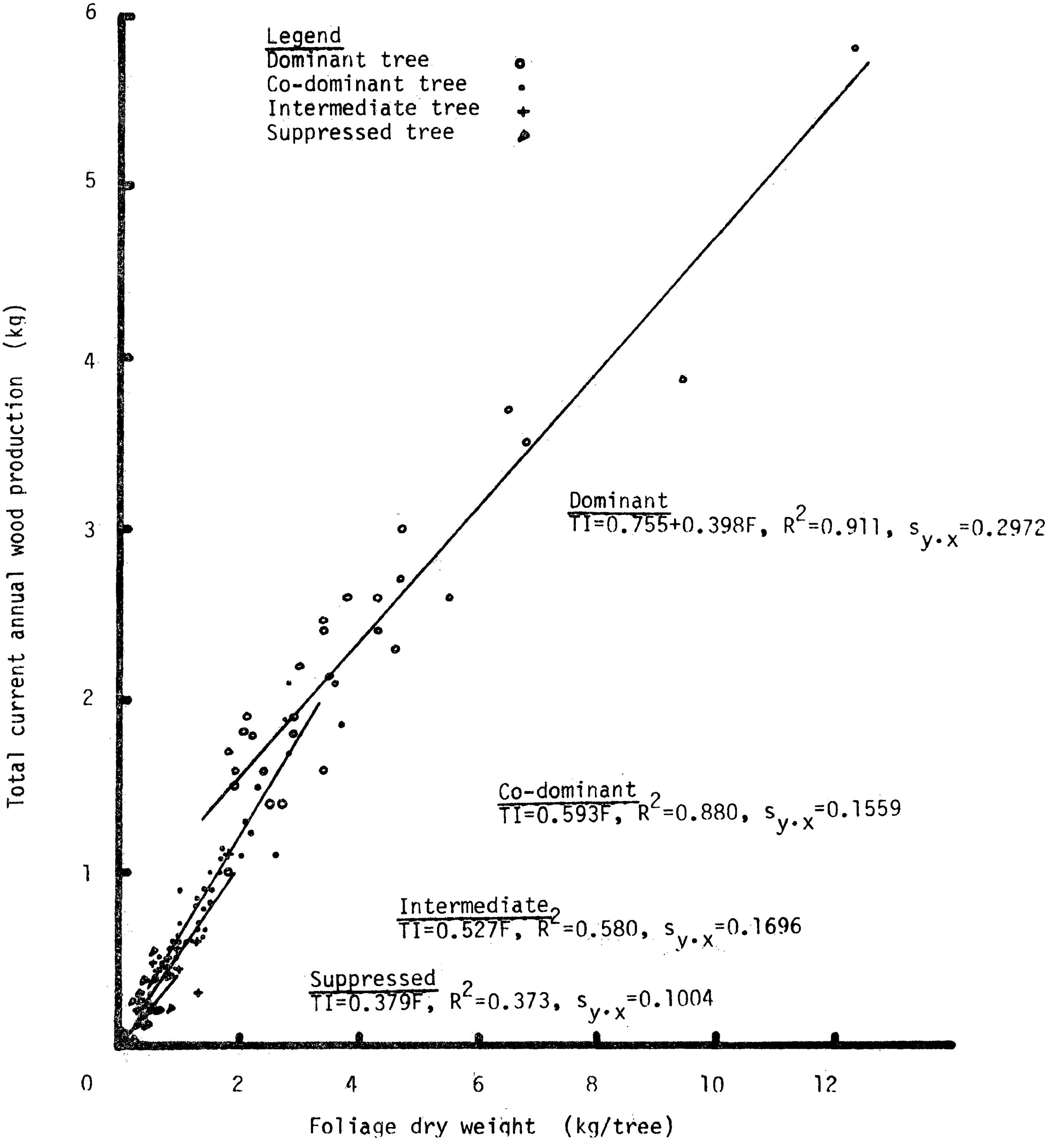

Figure 19. Relationship between total current annual wood production (TI) and the estimated foliage dry weight (F) of sample tree crowns by crown classes.

Foliage and Wood Production in Stands

Annual branch wood production per hectare did not vary with foliage dry weight per hectare (Figure 20) and stand density. It was slightly higher in the 17-year old stand. Current annual stem wood production per hectare increased with foliage weight per hectare in both stands studied and was considerably greater than branch wood production. Consequently total current annual wood production (stem plus branch) per hectare increased with foliage dry weight in both stands.

Total current annual wood production and total foliage dry weight per hectare in both stands increased in relation to increasing stand density, measured either as number of stems per hectare, relative spacing, or basal area (Figures 21, 22, and 23). With increasing number of stems per hectare, the rate of increase in wood production was similar to the corresponding rate of increase in foliage dry weight per hectare. Although this trend was evident in both stands, the rate of increase in foliage dry weight and corresponding wood production was greater in the 32-year old stand (Figure 21). When relative spacing was used as a measure of stand density, the results were similar (Figure 22). However, when basal area was used as a measure of density, results were again similar except that the increase in foliage dry weight and wood production were the same in both stands (Figure 23).

The above results suggested that the efficiencies of the crown foliage per unit area were similar at all stand densities. Crown efficiency per unit area was computed as the ratio of total current annual wood production to crown foliage dry weight per hectare.

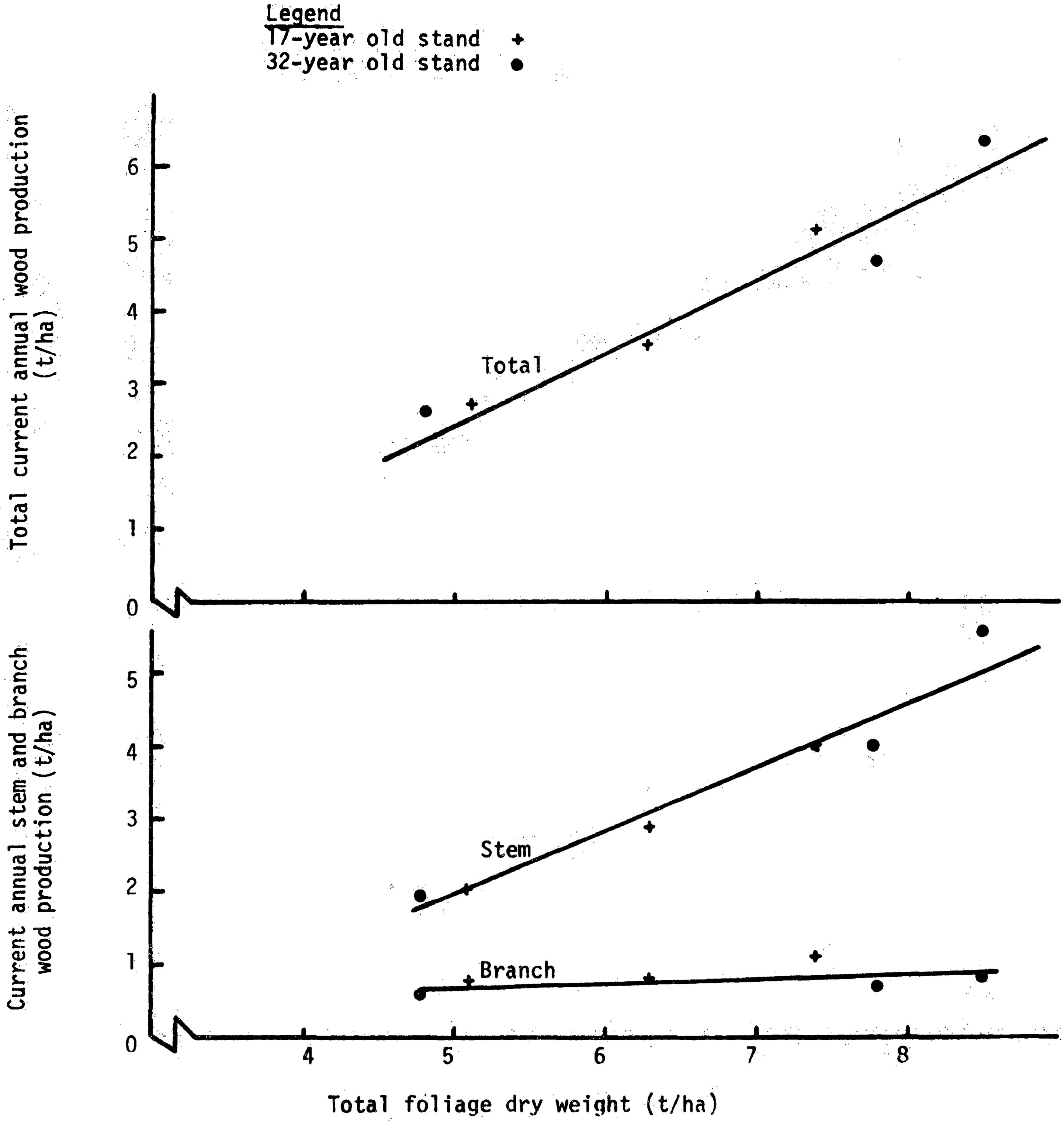

Figure 20. Relationship between current annual wood production (stem, branch, and total) and crown foliage dry weight per hectare.

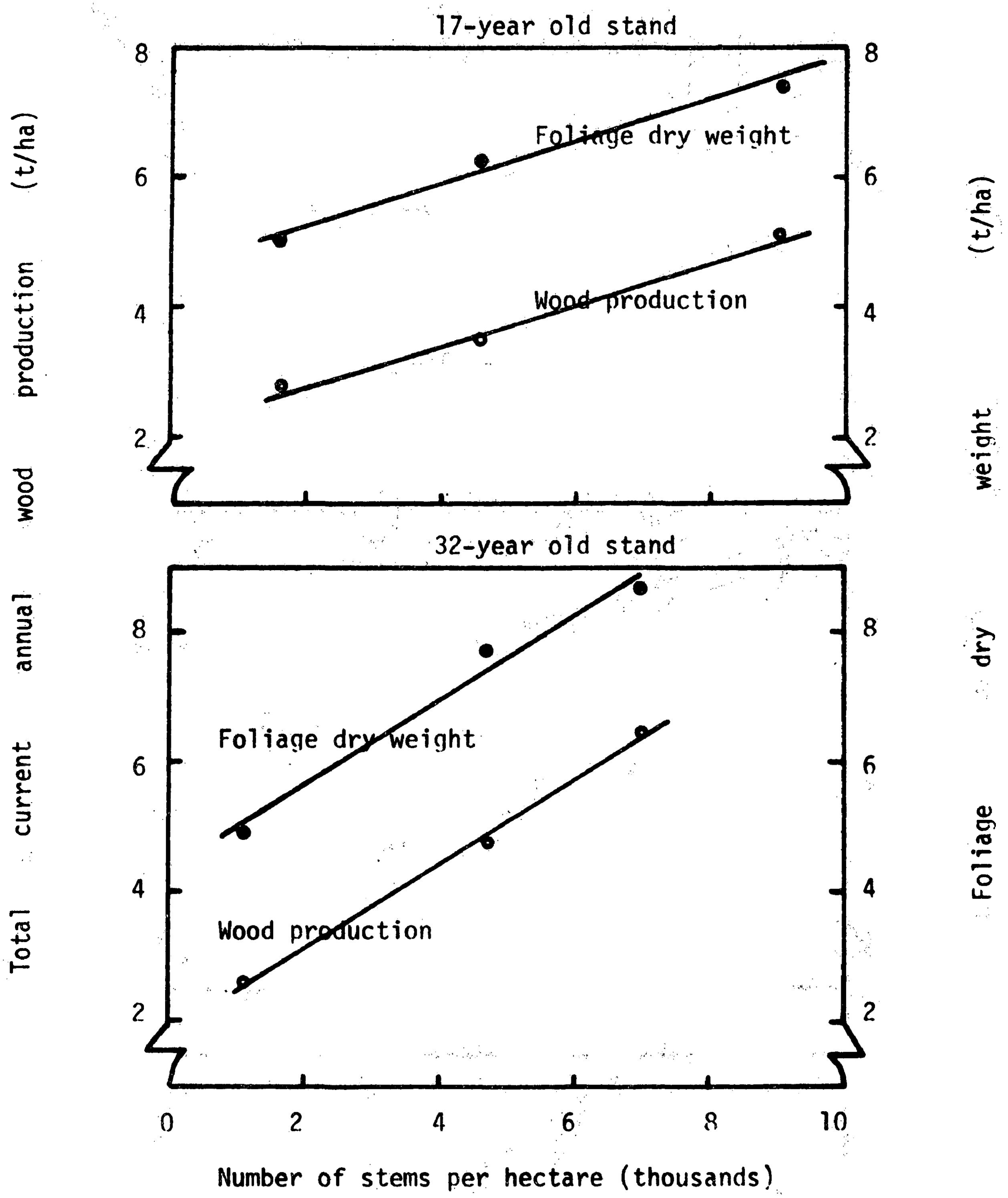

Figure 21. Relationships between total current annual wood production, crown foliage dry weight, and number of stems per hectare.

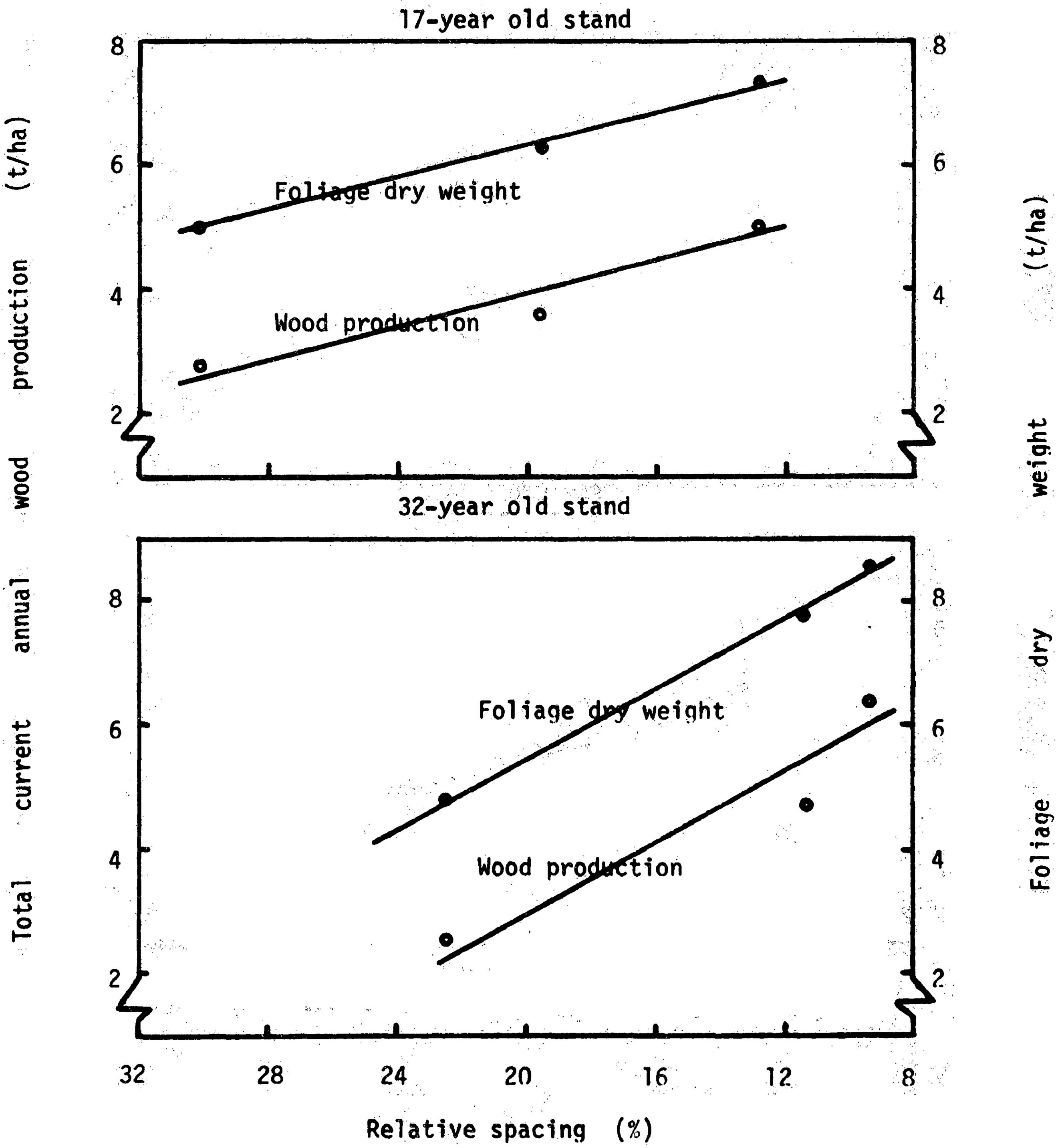

Figure 22. Relationships between total current annual wood production, crown foliage dry weight, and relative spacing per hectare.

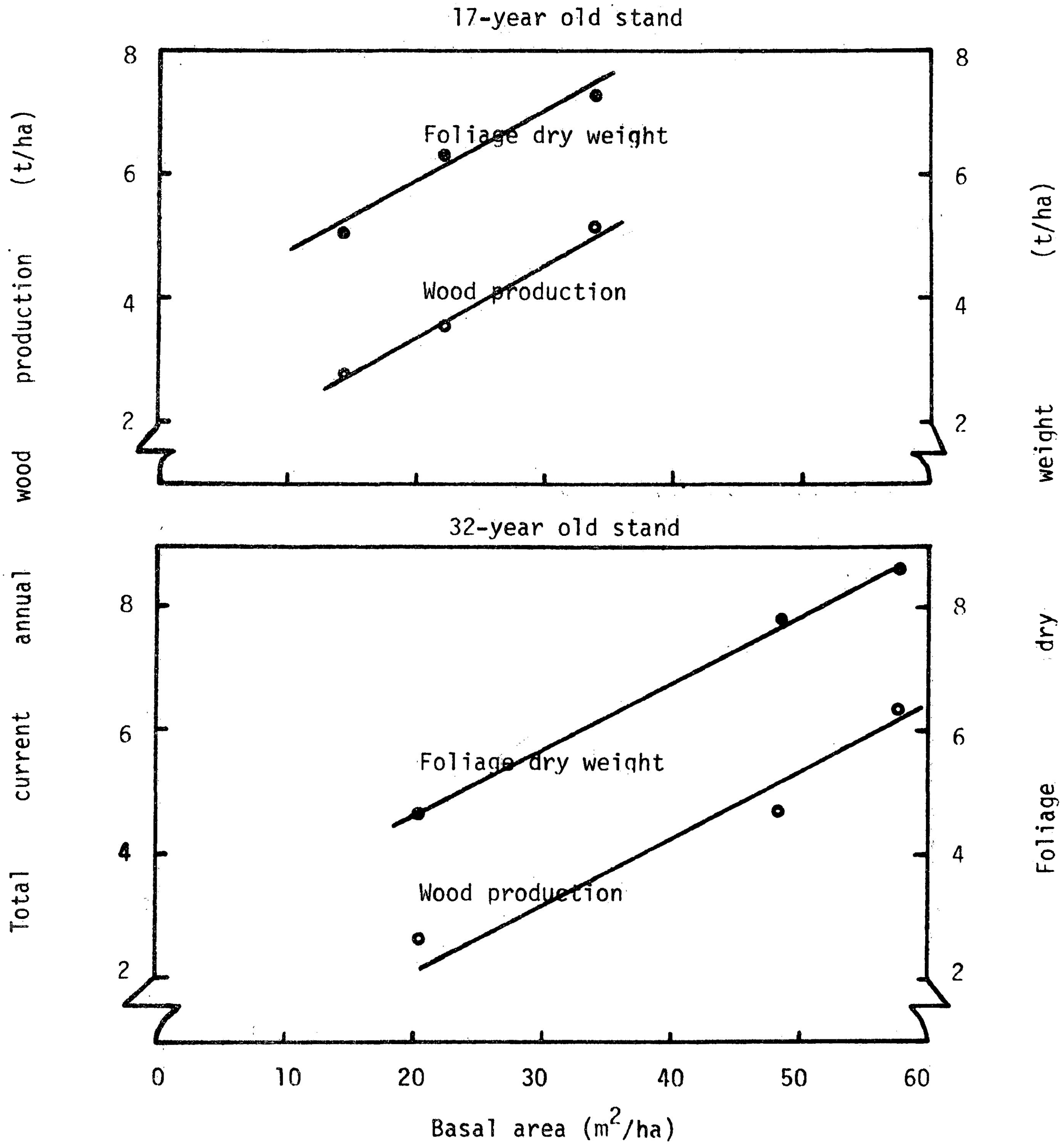

Figure 23. Relationships between total current annual wood production, crown foliage dry weight, and basal area per hectare.

Average crown efficiency in the high, medium, and low densities was 0.69, 0.56, and 0.56 in the 17-year old stand, and 0.74, 0.60, and 0.55 in the 32-year old stand. Mean crown efficiency was 0.60 in the 17-year old stand and 0.63 in the 32-year old stand.

DISCUSSION

Branch Weight Relationships to Branch Diameter

The measurement of branch diameter was a useful technique for estimating the foliage, wood, and bark dry weight supported by individual jack pine branches. Higher coefficients of determination were recorded for the relationships predicting wood and bark dry weight (Table 3, Equations 2,3, and 4) than for foliage dry weight (Table 3, Equation 1). The reason for this is that the quantity of foliage supported by a branch at any time can be affected by shading, branch age, and relative height in the crown. This explanation agrees with the previous work of Forrest and Ovington (1971) and Madgwick and Jackson (1974) with *Pinus radiata* D. Don.

Stem Wood and Bark Specific Gravity

In this study, stem wood and bark specific gravity were not affected by stand density. Stem wood and bark specific gravity were affected by relative height in the tree but the differences were not significant. Thus, stem wood and bark dry weight were primarily a function of volume and not a function of major differences in specific gravity.

The specific gravity results in this work were similar to those obtained by Maeglin (1967) for 15-year old jack pine plantations, at various stand spacings, in Wisconsin.

Stand Biomass per Unit Area

Total biomass was higher in the 32-year old stand than in the 17-year old stand, which was to be expected. Within each stand, there was also a great variation in total biomass. This variation was related to stand basal area: total biomass increased linearly with increasing basal area per hectare (Figure 14A). Hegyi (1972) demonstrated that a substantial amount of variation in the biomass of jack pine stands could be explained in terms of stocking intensity or basal area. Following Hegyi's example, the actual total biomass of each stand was adjusted to the biomass of a normal stand. Total biomass for the 17- and 32-year old stands were adjusted to the biomass of a normal stand (Plonski 1974) using the linear relationships in Figure 14A. Normal basal area for the 17-year old stand was interpolated because Plonski's Normal Yield Tables begin at 20 years of age. Total biomass in the 17-year old stand was 75.0, 51.0, and 35.6 t/ha in the high, medium, and low density classes; when adjusted to normal stocking, it was 43.8 t/ha. Total biomass in the 32-year old stand was 186.7, 154.8, and 67.8 t/ha in the high, medium, and low density classes; when adjusted to normal stocking, it was 82.1 t/ha. Comparison of adjusted total biomass values indicates that the normalized 32-year old stand supported approximately twice as much total stand biomass as the normalized 17-year old stand.

A comparison of the actual total biomass of stands in this study to the previously published actual total biomass data of Hegyi (1972), Doucet et al. (1976), and Maclean and Wein (1976) was impractical. The work of these previous investigators was carried out in a range of jack pine stands varying in age, site class, and stand density. When plotted over age, actual total biomass data from this and previous studies could not be compared, because of the great variation in the data (Figure 24A). Data presented in these previous studies were therefore adjusted to normal stocking (Table 6) by the method described by Hegyi (1972). The method involved calculating the stocking ratio of each stand by dividing the basal area of a normal stand (Plonski 1974) by the actual basal area per hectare of the stand. The actual total stand biomass was then multiplied by the respective stocking ratio to give adjusted or normal total biomass for each stand. The adjusted total biomass values from these previous studies were plotted over stand age with the results from this study.

The resulting scatter diagram (Figure 24B) illustrated the general pattern of total biomass accumulation for jack pine stands of three Site Classes (Plonski 1974) and also indicated the relative productivity of the stands in this study to the productivity of other jack pine stands. Both jack pine stands of this study, although classified as Site Class I according to Plonski (1974), supported slightly less total normal stand biomass than the Site Class I jack pine stands of Doucet et al. (1976) in Quebec and Hegyi (1972) in northern Ontario. The fact that the two stands studied had above normal heights, suggests that the slight reduction in normal total stand biomass, as compared to other normal Site Class I jack pine stands, was related to differences in stem form or in branching characteristics.

Jack pine trees from northwestern Ontario are known to have produced late season shoot growth or "lammas shoots" (Thomas 1958)

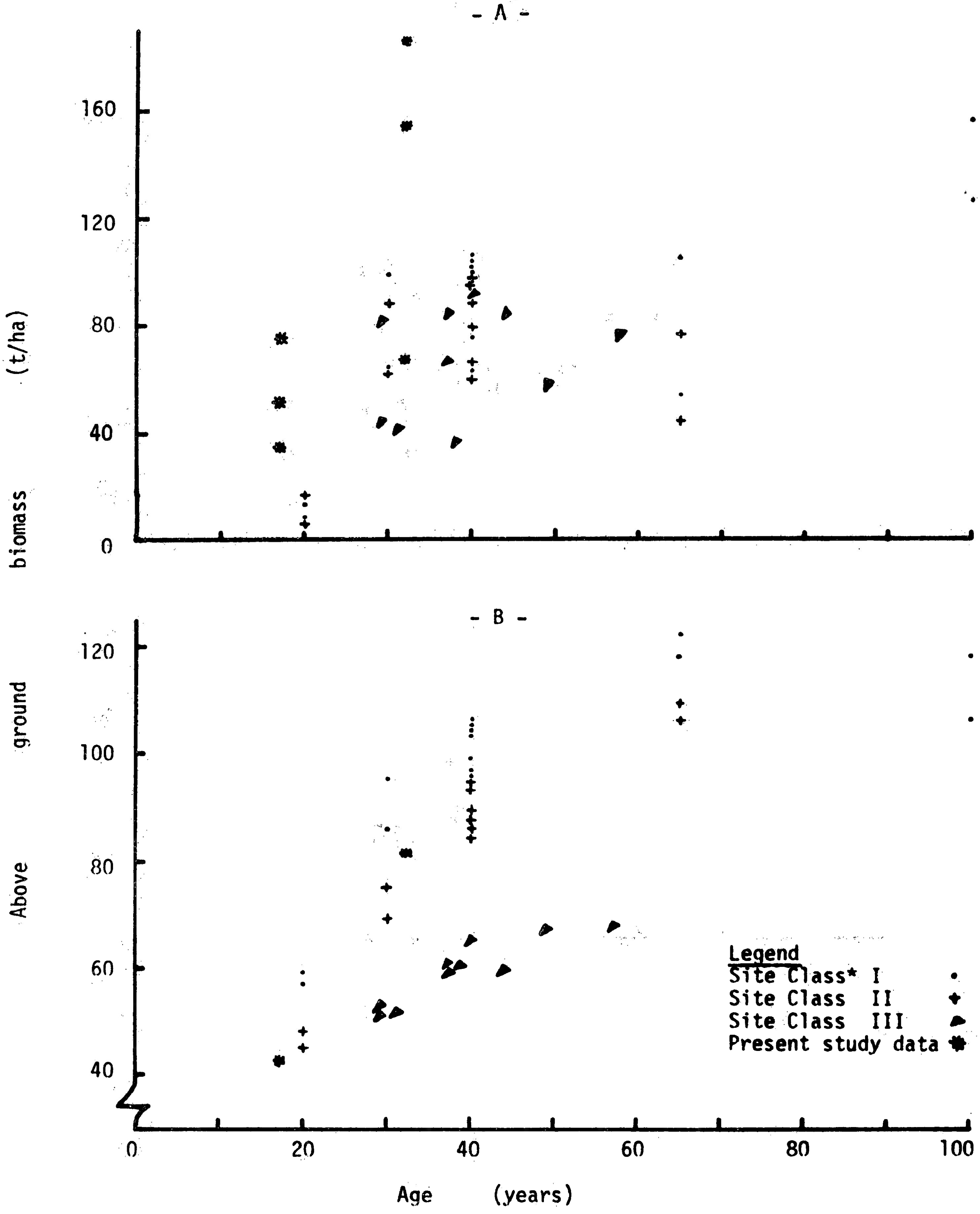

Figure 24. Estimated above ground (A) and adjusted above ground (B) biomass over age for 40 naturally regenerated jack pine stands.

*Site Classes after Plonski (1974)

Table 6. Above ground biomass of 40 jack pine stands: actual and adjusted to normal stocking data are presented.

Stand Location	Site* Class	Stand Age (yrs.)	Basal Area (m^2/ha)	Stocking** Ratio	Actual Dry Matter (t/ha)	Adjusted*** Dry Matter (t/ha)
Northwestern Ontario	1	17	34.3		75.0[a]	43.8[e]
			22.4		51.1[a]	43.8[e]
			14.4		35.6[a]	43.8[e]
Northwestern Ontario	1	32	57.8		186.7[a]	82.1[e]
			48.6		154.8[a]	82.1[e]
			20.8		67.8[a]	82.1[e]
Quebec	1	40	26.3	1.011[b]	102.548[b]	103.676[b]
Quebec	1	40	26.7	0.996[b]	106.393[b]	105.967[b]
Quebec	1	40	25.5	1.043[b]	99.344[b]	103.616[b]
Quebec	1	40	25.9	1.027[b]	102.538[b]	105.306[b]
Quebec	1	40	17.3	1.538[b]	62.880[b]	96.709[b]
Quebec	1	40	20.1	1.323[b]	74.798[b]	98.958[b]
Quebec	2	40	26.8	0.884[b]	95.520[b]	84.440[b]
Quebec	2	40	27.0	0.878[b]	98.202[b]	86.221[b]
Quebec	2	40	21.7	1.092[b]	79.812[b]	87.155[b]
Quebec	2	40	23.4	1.013[b]	88.414[b]	89.563[b]
Quebec	2	40	16.2	1.463[b]	64.492[b]	94.352[b]
Quebec	2	40	15.0	1.580[b]	60.897[b]	96.217[b]
Northern Ontario	2	20	5.9	2.807	16.002[c]	44.918[c]
Northern Ontario	1	20	4.8	4.474	13.207[c]	59.088[c]
Northern Ontario	2	20	2.4	7.058	6.865[c]	48.453[c]
Northern Ontario	1	20	2.8	7.675	7.454[c]	57.209[c]
Northern Ontario	2	30	27.6	0.782	88.498[c]	69.205[c]
Northern Ontario	1	30	28.9	0.865	99.213[c]	85.819[c]
Northern Ontario	2	30	17.6	1.224	61.000[c]	74.664[c]
Northern Ontario	1	30	16.6	1.505	63.434[c]	95.468[c]
Northern Ontario	1	40	37.2	0.712	135.733[c]	96.642[c]
Northern Ontario	1	50	31.7	0.856	126.815[c]	108.554[c]

cont'd

Table 6 (cont'd). Above ground biomass of 40 jack pine stands: actual and adjusted to normal stocking data are presented.

Stand Location	Site* Class	Stand Age (yrs.)	Basal Area (m^2/ha)	Stocking** Ratio	Actual Dry Matter (t/ha)	Adjusted*** Dry Matter (t/ha)
Northern Ontario	1	65	23.7	1.151	105.783^c	121.756^c
Northern Ontario	2	65	17.8	1.432	76.046^c	108.898^c
Northern Ontario	1	65	12.5	2.182	53.989^c	117.803^c
Northern Ontario	2	65	10.5	2.435	43.637^c	106.256^c
Northern Ontario	1	100	36.6	0.738	156.826^c	115.738^c
Northern Ontario	1	100	28.9	0.935	126.563^c	118.336^c
New Brunswick	3	29	13.5	1.190	42.78^d	50.93^d
New Brunswick	3	29	24.7	0.651	80.13^d	52.16^d
New Brunswick	3	31	13.0	1.303	39.58^d	51.59^d
New Brunswick	3	37	20.4	0.922	65.74^d	60.61^d
New Brunswick	3	37	26.7	0.704	83.94^d	59.07^d
New Brunswick	3	38	11.5	1.652	35.66^d	58.91^d
New Brunswick	3	40	28.2	0.716	91.10^d	65.26^d
New Brunswick	3	44	28.4	0.712	83.28^d	59.29^d
New Brunswick	3	49	17.8	1.184	56.96^d	67.42^d
New Brunswick	3	57	24.8	0.889	75.11^d	66.77^d

* Plonski (1974)

** Ratio of normal to actual basal area

*** Actual dry matter X stocking ratio

a Data from present study

b Calculated from data presented by Doucet et al. (1976)

c Data presented by Hegyi (1972)

d Data presented by Maclean and Wein (1976)

e Actual dry matter adjusted to normal dry matter using Figure 14A when weather conditions are favourable. These shoots give rise to "shoot internodes and uneven branch development" (Yeatman 1980). Shoot internodes increase the number of branches on trees and consequently trees will have more tapered stems. More tapered stems would contain less stem volume (Avery 1967) or less stem biomass since stem biomass for jack pine trees in this study was mainly a function of stem volume. Because total stand biomass per hectare was closely related to stem biomass (Figures 15A and 15B), this basic difference between the stands studied and those of other workers probably accounted for the lower normal stand biomass encountered in the study areas.

An alternative explanation for the lower normal biomass of jack pine stands in this study is that the differences were caused by adjustment to normal stocking. Indeed, because the two stands studied had higher than normal heights for Site Class I jack pine, it can be argued that Plonski's (1974) Normal Yield Tables are not representative of jack pine stands on these sites.

Unlike total stand biomass, which is a phenomena closely related to stem wood accretion during the entire life of the stand (Figures 15A and 15B), foliage biomass is a phenomena of periodic growth. Old foliage abscisses on a regular basis from trees and stands as new foliage is produced. In this study, three years of foliage were supported in the two jack pine stands. Because it is a periodic phenomena, attempts to adjust the foliage biomass, of the sample plots to a common base, were unsuccessful. Even if this had been possible, there was only one published work which provided actual foliage biomass data for comparison. Doucet et al. (1976) showed that 40-year old jack pine stands in Quebec supported foliage biomass ranging from 3.45 to 7.79 t/ha. These results are similar to those estimated for the 17- and 32-year old stands.

Foliage and Wood Production in Individual Trees

Total current annual wood production for jack pine trees in this study was directly related to the foliage dry weight supported by each individual tree. The more foliage carried by a tree, the more wood it produced. Stand age and stand density seemed to have no influence on this basic relationship.

The relationship between total current annual wood production and foliage was linear for tree crowns supporting up to 3 kg of foliage dry weight (Figure 17). Jack pine trees supporting up to 3 kg of foliage dry weight were primarily of suppressed, intermediate, and co-dominant crown classes. Crown foliage efficiencies of trees in these three crown classes were not significantly different. Significant differences in crown foliage efficiency were encountered for larger crowns: in trees supporting more than 3 kg of foliage dry weight. These were primarily trees of dominant crown class (Figure 19). The rate of total current annual wood production, per unit increase in foliage dry weight, was lower in dominant trees. This significant difference, in the crown efficiency of dominant trees versus the crown efficiency of trees of other crown classes, accounts for the significantly better fit of the curvilinear model (Equation 4) to the data in Figure 17.

Three possible explanations could account for the decreased rate of total current annual wood production by the dominant tree crowns. First, it is possible that the lower efficiency of the large crowns was caused by mutual shading of the foliage in the lower parts of the crown. However, in a study of the growth of Metasequoia glyptostroboides, Satoo (1974d) showed that branch wood production as a function of branch foliage was independent of branch position in the crown. Second, there may have been a greater rate of below ground wood production in the root system of larger trees. This possibility has unfortunately not been documented in the literature. The third explanation is the external configuration of the crown of dominant trees. Their crowns were more open and consequently more exposed to the wind than trees with smaller crowns. In hot and dry weather, exposure to the wind could have caused serious moisture deficits within these trees, resulting in the inhibition of their photosynthetic capacity and reducing their potential level of wood production. Since hot and dry weather is typical of the climate of northwestern Ontario in July and August, this is the most probable explanation for the decreased rate of current annual wood production in these dominant trees.

The above results lead to the following question: how should jack pine trees be grown to maximize total current annual wood production? Results of this study (Figure 19) showed that small tree crowns were the most efficient producers of wood in terms of foliage. This suggests that, to maintain maximum annual wood production on similar sites, young jack pine trees should support relatively small crowns. The size of the crowns should not exceed more than 3 kg of foliage dry weight. How can the size of jack pine tree crowns be restricted to less than 3 kg of foliage dry weight? All that can be said is that this may possibly be accomplished by specific spacing and thinning regimes, since results of this study did not provide an answer to this question.

Relationships between total current annual wood production, crown foliage, stand age, and stand density for individual trees, as presented in this work, were not evident in the literature. However, in somewhat analogous studies, results, which support those obtained for individual trees in this study, have been reported. Senda and Satoo (1956), Satoo et al. (1956, 1959, and 1974), Satoo and Senda (1958), Weetman and Harland (1964), and Satoo (1967, 1974a, 1974b, 1974c, and 1974d) showed that stem wood production of individual trees was closely related to the foliage dry weight supported by individual trees. Unlike the present work, these studies did not consider the influence of stand age or stand density on the wood production over foliage relationship.

The above studies also showed that the crown foliage of large dominant trees was generally less efficient in stem wood production than smaller trees. Weetman and Harland (1964) and Satoo et al. (1956) suggested that this was due to the greater proportion of branch wood production in the large trees. Satoo et al. (1956) and Satoo (1968) did in fact test this hypothesis and showed that, when branch wood production was included, total wood production over foliage dry weight approached a straight line relationship similar to the one presented here for jack pine.

Foliage and Wood Production in Stands

Results of this study on a per hectare basis are not conclusive. The reason is that there was only one sample plot at each of the three densities in both stands. With only one sample plot, the differences between plots could not be analyzed statistically. Despite this limitation, the study does shed some light on certain aspects of jack pine stand growth.

Inspection of sample plots, prior to field sampling, suggested that no mortality had occured during the three-year period for which stem wood production was determined. Gross wood production values, for these jack pine stands, were therefore similar to the measured net wood production values. This permitted the comparison of results from this study to the general theory of forest productivity as hypothesized by Moller, Langsaeter, and Assmann.

Total current annual wood production and foliage dry weight per unit area in the young jack pine stands seemed to be linearly related (Figure 20). This result conforms to the forest productivity theory, as postulated by Moller (1947 and 1954), that foliage quantities and forest productivity are related. However results also suggested that the foliage dry weight, and consequently the total current annual wood production, per unit area increased with increasing stand density in both stands (Figures 21, 22, and 23). The two stands therefore did not show any signs of being over-crowded. According to the general theory of forest productivity, the jack pine stands studied could be classified into Langsaeter's Density Type I (Figure 2). This density class is characterized by the fact that the trees stand so far apart that they do not influence each other. This would intimate that the jack pine stands, at the densities studied, did not fully occupy their site. Thus the optimum stand density, at which jack pine forest production could be maximized, if it exists, would occur at a density higher than those sampled in this study. But the high density plots sampled were denser than those considered to be silviculturally acceptable (Plonski 1974) for jack pine in northwestern Ontario. This suggests that, for maximum wood production, young jack pine stands on similar sites should be grown as densely as silviculturally practical, at least within the range of densities sampled here.

An alternative explanation is that the two jack pine stands fully occupied their site in the high density plots, since there was evidence of crown competition at these densities (Figures 7 and 8). This would suggest that the general theory of forest productivity does not apply to the young jack pine stands in this study. Unfortunately denser and a greater number of plots were not sampled and the theory of forest productivity,as it applies to young jack pine stands, could not be further explored.

Mean overall crown efficiencies of 0.60 for the 17-year old and 0.63 for the 32-year old jack pine stands were much lower than the 1.0 average for coniferous forests in North America (Zavitkovski 1976). Values reported here were similar to the 0.60 value given by Baskerville (1965a) for 45-year old <u>Abies balsamea</u> (L.) Mill in New Brunswick. They compared unfavourably with values of 0.94 and 0.71 for 40-year old jack pine stands in Quebec (Doucet et al. 1976).

CONCLUSION

There were major differences, in terms of site and past growth, between the 17- and 32-year old jack pine stands studied. Site differences were demonstrated in the soil profiles and by the Thornthwaite monthly water balance. Past growth differences were revealed by analysis of the periodic annual stem wood volume and basal area increments. Even with these differences, relations between total current annual wood production and foliage dry weight per tree were similar regardless of stand density or age. This suggests the existence of a basic biological relationship between wood production and foliage quantities for jack pine.

It must be concluded, that within the range of densities sampled, young jack pine trees and stands produce more wood at high stand densities. From a silvicultural viewpoint, this suggests that jack pine stands, for maximum wood fibre production on these sites, should be grown as densely as possible, at least within the range of densities sampled in this study. However from a practical point of view, this may prove to be inefficient since tree size is an important consideration in the production of wood. This is a problem which must be examined further before guidelines for stand density management of jack pine can be formulated.

LITERATURE CITED

Adams, W. R. 1928. Studies in the tolerance of New England forest trees. VIII Effect of spacing in a jack pine plantation. Vermont Agric. Expt. Sta. Bull. 282. 51 p.

Armson, K. A. 1974. Predictive techniques in relation to growth and development of conifers. Proceedings of a workshop on forest fertilization in Canada, held in Sault Ste. Marie, Ontario, Jan. 8-10, 1974. Can. Dept. Environ., Can. Forest. Serv., Technical Rept. 5. p. 17-21.

Assmann, E. 1962. The effect of different thinning intensities on growth and yield. Translated by F. W. von Althen, from p. 222-239, Waldertragskunde, Organische Production, Structur, Zuwachs and Ertrag von Waldbestanden. BLV Verlagsgesesellschaft Munchen, Bonn, Wien. 490 p.

Assmann, E. 1970. The principles of forest yield study. Pergamon Press, Oxford. 506 p.

Avery, T. E. 1967. Forest measurements. McGraw-Hill, New York. 290 p.

Baker, F. S. 1950. Principles of Silviculture. McGraw-Hill, New York. 414 p.

Barker, J. E. 1978. Unpublished manuscript. Personal communication, November 6, 1978.

Barney, R. J., K. van Cleve, and R. Schlentner. 1978. Biomass distribution and crown characteristics in two Alaskan Picea mariana ecosystems. Can. J. For. Res. 8: 36-41.

Baskerville, G. L. 1965a. Dry-matter production in immature balsam fir stands. For. Sci. Monogr. 9. 42p.

Baskerville, G. L. 1965b. Estimation of dry weight of tree components and total standing crop in conifer stands. Ecology 46: 867-869.

Baskerville, G. L. 1966. Dry-matter production in immature balsam fir stands: roots, lesser vegetation and total stand. For. Sci. 12: 49-53.

Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2: 49-53.

Bella, I. E. 1967. Development of jack pine and scots pine in the Spruce Woods Forest Reserve, Manitoba. Can. Dept. Forest. Pub. No. 1171. 15p.

Bella, I. E. 1968. Jack pine yield tables for southeastern Manitoba. Can. Dept. Fish Forest. Pub. No. 1207. 15p.

Bella, I. E., and J. P. de Francheschi. 1974. Early results of spacing studies of three indigenous conifers in Manitoba. Can. Dept. Environ. Inform. Rept. NOR-X-113. 10p.

Bickerstaff, A., and S. A. Hostikka. 1977. Growth of forests in Canada. Part I: An annotated bibliography. Can. Dept. Environ. Inform. Rept. FMR-X-98. 197p.

Braathe, P. 1957. Thinnings in even-aged stands: a summary of European literature. Faculty of Forestry, Univ. of New Brunswick. 92p.

Buchanan, T. S. 1936. An alinement chart for estimating number of needles on western white pine reproduction. J. Forest. 34: 588-593.

Buckman, R. E. 1964. Twenty-two year results of a precommercial thinning experiment in jack pine. U.S.D.A. For. Serv., Res. Note LS-46. 2p.

Bunce, R. G. H. 1968. Biomass and production of trees in a mixed deciduous woodland. 1. Girth and height as parameters for the estimation of tree dry weight. J. Ecology 56: 759-775.

Burwasser, G. J. 1977. Quaternary geology of the City of Thunder Bay and vicinity. Ontario Ministry of Natural Resources, Geological Survey Report. GR164. 70p.

Cable, D. R. 1958. Estimating surface area of ponderosa pine foliage in central Arizona. For. Sci. 4: 45-49.

Cayford, J. H. 1961. Results of a 1927 jack pine thinning in Saskatchewan. Can. Dept. Forest. Tech. Note 107. 13p.

Chapman, L. J., and M. K. Thomas. 1968. The climate of northern Ontario. Climatological studies No. 6. Can. Dept. Transport. 58p.

Chrosciewicz, Z. 1971. The growth response of young jack pine to moderate and extreme stand densities. Can. Dept. Environ., Bi-mon. Res. Notes 27(1): 6.

Clark, A., and M. A. Taras. 1976. Biomass of shortleaf pine in a natural sawtimber stand in northern Mississippi. U.S.D.A. For. Serv. Res. Pap. SE-146. 32p.

Day, R. J., and H. Bax. 1976. The water balance method for predicting soil moisture and drought free planting periods. Lakehead Univ., School of Forestry, Rept. No. 4. 12p.

Doucet, R., J. V. Berglund, and C. E. Farnsworth. 1976. Dry matter production in 40-year old *Pinus banksiana* stands in Quebec. Can. J. For. Res. 6: 357-367.

Evert, F. 1976. Management-oriented yield tables for jack pine cover types in northern Ontario. Can. Dept. Environ. Inform. Rept. FMR-X-87. 43p.

Forrest, W. G., and J. D. Ovington. 1971. Variation in dry weight and mineral nutrient content of *Pinus radiata* progeny. Silvae Genet. 20: 174-179.

Gary, H. L. 1976. Crown structure and distribution of biomass in a lodgepole pine stand. U.S.D.A. For. Serv. Paper RM-165. 20p.

Gevorkiantz, S. R. 1947. Growth and yield of jack pine in the Lake States. U.S.D.A. For. Serv. Lake States Forest Experiment Station, Paper No. 7. 11p.

Godman, R. M., and J. H. Cooley. 1970. Effect of initial spacing on jack pine growth and yield. Mich. Acad. II(4): 107-111.

Guilkey, P.C., and A. H. Westing. 1956. Effects of initial spacing on the development of young jack pine in northern Lower Michigan. Papers Michigan Acad. Sci., Arts, and Letters 41: 45-50.

Hansen, T. S., and R. M. Brown. 1929. Some results of thinning jack pine. J. Forest. 27: 275-279.

Hansen, T. S. 1931. Some results of thinning 27-year old jack pine. J. Forest. 29: 544-550.

Harlow, W. M., and E. S. Harrar. 1969. Textbook of Dendrology. McGraw-Hill. 512p.

Hegyi, F. 1972. Dry matter distribution in jack pine stands in northern Ontario. For. Chron. 48: 193-197.

Hiley, W. E. 1967. Woodland Management. Faber and Faber, London. 463p.

Holsoe, T. 1948. Crown development and basal area growth of red oak and white ash. Harvard Forest Papers I(3): 28-33.

Honer, T. G. 1970. Bole weight to volume ratio: a constant for open-grown balsam fir. Can. Dept. Forest., Bi-mon. Res. Notes 26: 37.

Johnstone, W. D. 1970. Component dry weights of 100-year-old lodgepole pine trees. Can. Dept. Forest. Inform. Rept. A-X-31. 14p.

Keays, J. L. 1968. Whole tree utilization studies: selection of tree components for pulping research. Can. Dept. Forest. Inform. Rept. VP-X-35. 31p.

Ker, M. F. 1974. Dry matter production in a young black spruce stand in western Newfoundland. Environ. Can. Inform. Rept. N-X-110. 26p.

Kittredge, J. 1944. Estimation of the amount of foliage of trees and stands. J. Forest. 42: 905-912.

Laar, A. V. 1973. Relationship between needle-biomass and growth of Pinus radiata. In IUFRO biomass studies. p. 185-193. Univ. Maine Press, Orono, Maine.

Loomis, R. M., R. E. Phares, and J. S. Crosby. 1966. Estimating foliage and branchwood quantities in shortleaf pine. For. Sci. 12: 30-39.

Maclean, D. A., and R. W. Wein. 1976. Biomass of jack pine and mixed hardwood stands in northeastern New Brunswick. Can. J. For. Res. 6: 441-447.

Madgwick, H. A. I. 1968. Seasonal changes in biomass and annual production of an old-field Pinus virginiana stand. Ecology 49: 149-152.

Madgwick, H. A. I., and D. S. Jackson. 1974. Estimating crown weights of Pinus radiata from branch variables. N.Z. J. For. Sci. 4: 520-528.

Madgwick, H. A. I. 1976. Mensuration of forest biomass. In IUFRO biomass studies. p. 13-27. Univ. Maine Press, Orono, Maine.

Madgwick, H. A. I., D. S. Jackson, and P. J. Knight. 1977. Above-ground dry matter, energy, and nutrient contents of trees in an age series of Pinus radiata plantations. N.Z. J. For. Sci. 7: 445-468.

Maeglin, R. R. 1967. Effect of tree spacing on weight yields for red pine and jack pine. J. Forest. 65: 647-650.

Moller, C. M. 1947. The effect of thinning, age and site on foliage, increment and loss of dry matter. J. Forest. 45: 393-404.

Moller, C. M. 1954. The influence of thinning on volume increment. In thinning problems and practices in Denmark, p.5-49. edited by S. O. Heiberg, State Univ. of New York, College of Forestry at Syracuse. Tech. Pub. No. 76. 91p.

Moore, W. G. 1963. A dictionary of geography. Penguin, England. 196p.

Morrison, I. K. 1974. Dry-matter and element content of roots of several natural stands of Pinus banksiana Lamb. in northern Ontario. Can. J. For. Res. 4: 61-64.

Morrison, I. K., D. A. Winston, and N. W. Foster. 1977a. Effect of nitrogen, phosphorus and potasium fertilizers on growth of semimature jack pine forest, Chapleau, Ontario: fifth-year results. Can. Dept. Environ., Can. Forest. Serv. Rept. O-X-258. 12p.

Morrison, I. K., D. A. Winston, and N. W. Foster. 1977b. Effect of nitrogen fertilization and low thinning on growth of semimature jack pine forest, Chapleau, Ontario: fifth-year results. Can. Dept. Environ., Can. Forest. Serv. Rept. O-X-267. 10p.

Munro, D. 1977. A method of measuring and correlating the crown parameters of black spruce for predicting the foliage dry weight of trees and stands. Lakehead Univ., School of Forestry, B. Sc. F. thesis. 25p.

Ovington, J. D. 1956. The form, weights and productivity of tree species grown in close stands. New Phytol. 55: 289-304.

Ovington, J. D. 1957. Dry matter production by Pinus sylvestris. L. Ann. Bot. 21: 287-314.

Ovington, J. D., and H. A. I. Madgwick. 1959. Distribution of organic matter and plant nutrients in a plantation of Scots pine. For. Sci. 5: 344-355.

Phillion, B. J. 1977. A non-destructive method of determining foliage dry weight is used to correlate photosynthetic surface and productivity of red pine at three initial stand spacings. Lakehead Univ., School of Forestry, B. Sc. F. Thesis. 32p.

Plonski, W. L. 1974. Normal yield tables (Metric). Ontario Ministry of Natural Resources. 40p.

Ralston, R. A. 1953. Some effects of spacing on jack pine development after 25 years. U.S.D.A. For. Serv., Lake States Forest Experiment Station, Tech. Note 338. 1p.

Rowe, J. S. 1972. Forest regions of Canada. Can. Dept. Environ. Pub. No. 1300. 172p.

Rudolf, P. O. 1951. Stand density and the development of young jack pine. J. Forest. 49: 254-255.

Satoo, T., K. Nakamura, and M. Senda. 1955. Materials for the studies of growth in stands. 1. Young stands of Japenese red pine (P. densiflora) of various density. Bull. Tokyo Univ. For. No. 48: 65-90. (Forestry Abstracts).

Satoo, T., R. Kunugi, and A. Kumekawa. 1956. Materials for studies of growth in stands. 3. Amount of leaves and production of wood in aspen (Populus davidiana) second growth in Hokkaido. Bull. Tokyo Univ. For. No. 52: 33-51. (Forestry Abstracts).

Satoo, T., and M. Senda. 1958. Materials for studies of growth in stands. 4. Amount of leaves and production of wood in a young plantation of Chamaecyparis obtusa. Bull. Tokyo Univ. For. No. 54: 71-100. (Forestry Abstracts).

Satoo, T., K. Negisi, and M. Senda. 1959. Materials for the studies of growth in stands. 5. Amount of leaves and growth in plantations of Zelkova serrata applied with crown thinning. Bull. Tokyo Univ. For. No. 55: 101-123. (Forestry Abstracts).

Satoo, T. 1967. Efficiency and quantity of leaves of closed stands of Cryptomeria japonica as influenced by site quality. Proc. 14th Congr. Int. Union For. Res. Organ., Munich 1967 Pt. II, Sect. 21 p. 395-404.

Satoo, T. 1968. Materials for the studies of growth in stands. 7. Primary production and distribution of produced dry matter in a plantation of Cinnamomum camphora. Bull. Tokyo Univ. For. No. 64: 241-275.

Satoo, T. 1974a. Primary production relations in a natural forest of Betula maximowicziana in Hokkaido - Materials for the studies of growth in forest stands 9. Bull. Tokyo Univ. For. No. 66: 109-117.

Satoo, T. 1974b. Primary production relations in a plantation of Larix leptolepis in Hokkaido - Materials for the studies of growth in forest stands 10. Bull. Tokyo Univ. For. No. 66: 119-126.

Satoo, T. 1974c. Primary production relations in a young plantation of Abies sachalinensis in Hokkaido - Materials for the studies of growth in forest stands 11. Bull. Tokyo Univ. For. No. 66: 127-137.

Satoo, T. 1974d. Primary production relations of a young stand of Metasequoia glyptostroboides planted in Tokyo - Materials for the studies of growth in forest stands 13. Bull. Tokyo Univ. For. No. 66: 153-164.

Satoo, T., K. Negisi, and K. Yagi. 1974. Primary production relations in plantations of Thujopsis dolabrata in the Noto peninsula - Materials for the studies of growth in forest stands 12. Bull. Tokyo Univ. For. No. 66: 139-151.

Schaerer, C. 1978. A non-destructive method of measuring and correlating foliage dry weight and productivity of white spruce in a spacing trial. Lakehead Univ., School of Forestry, B. Sc. F. Thesis. 31p.

Senda, M., and T. Satoo. 1956. Materials for the study of growth in stands. 2. White pine (Pinus strobus) stands of various densities in Hokkaido. Bull. Tokyo Univ. For. No. 52: 15-31. (Forestry Abstracts).

Shea, S. R. 1973. Growth and development of jack pine (Pinus banksiana Lamb.) in relation to edaphic factors in northeastern Ontario. Univ. Toronto, Ph. D. Thesis. 466p.

Shea, S. R., and K. A. Armson. 1972. Stem analysis of jack pine (Pinus banksiana Lamb.): techniques and concepts. Can. J. For. Res. 2: 392-406.

Smith, D. M. 1962. The practice of silviculture. Wiley, New York. 578 p.

Smith, J. H. G., and D. S. Debell. 1973. Opportunities for short rotation culture and complete utilization of seven northwestern tree species. For. Chron. 49: 31-34.

Smith, W. H., L. E. Nelson, and G. L. Switzer. 1971. Development of the shoot system of young loblolly pine. II. Dry matter production and nitrogen accumulation. For. Sci. 17: 55-62.

Society of American Foresters. 1950. Forest terminology. Washington. 93p.

Steel, R. G. D., and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York. 481p.

Stiell, W. M. 1962. Crown structure in plantation red pine. Can. Dept. Forest., Technical Note 122. 35p.

Stiell, W. M. 1966. Red pine crown development in relation to spacing. Can. Dept. Forest. Pub. 1145. 44p.

Stiell, W. M. 1969. Crown development in white spruce plantations. Can. Dept. Fish. Forest. Pub. 1249. 12p.

Stiell, W. M., and A. B. Berry. 1977. A 20-year trial of red pine planted at seven spacings. Can. Dept. Environ., Can. Forest. Serv. Inform. Rept. FMR-X-97. 25p.

Stoeckeler, J. H., and L. P. Olsen. 1957. A regression equation relating diameter growth rate of jack pine to live crown percent. J. Forest. 55: 467.

Storey, T. G., W. L. Fons and F. M. Sauer. 1955. Crown characteristics of several coniferous tree species. U.S.D.A. For. Ser., Div. For. Fire Res. Interim Tech. Rept. AFSWP-416. 93p.

Taras, M. A., and D. R. Phillips. 1978. Aboveground biomass of slash pine in a natural sawtimber stand in southern Alabama. U.S.D.A. For. Serv. Res. Pap. SE-188. 31p.

Thomas, J. B. 1958. The production of lammas shoots on jack pine in Ontario. For. Chron. 34: 307-309.

Thornthwaite, C. W., and J. R. Mather. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Inst. Tech. Pub. in Climatology 10: 184-311.

Turton, A. G., and J. Keay. 1970. Distribution of biomass and major nutrients in a maritime pine plantation. Aust. For. 34: 39-48. (Forestry Abstracts).

U. S. Forest Products Laboratory. 1974. Wood handbook: wood as an engineering material. U.S.D.A. For. Serv. Agr. Handb. 72.

Vezina, P. E. 1963. Objective measures of thinning grades and methods. For. Chron. 39: 290-300.

Vezina, P. E. 1965. Growth and yield of three pulpwood species in Quebec as affect by stocking. Pulp Paper Mag. Can. 66: WR483-WR493.

Wakefield, W. E. 1957. Determination of the strength and physical properties of Canadian woods. Can. Dept. Northern Affairs and Natural Resources Bull. No. 119. 64p.

Weetman, G. F., and R. Harland. 1964. Foliage and wood production in unthinned black spruce in northern Quebec. For. Sci. 10: 80-88.

Whittaker, R. H. 1966. Forest dimensions and production in the Great Smoky Mountains. Ecology 47: 103-121.

Whittaker, R. H., and G. M. Woodwell. 1968. Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. J. Ecology 56: 1-26.

Wile, B. C. 1964. Crown size and stem diameter in red spruce and balsam fir. Can. Dept. Forest. Pub. No. 1056. 9p.

Wilson, G. M. 1951. Thinning 30-year old jack pine. Can. Dept. of Resources and Development, Silvicultural Leaflet No. 52. 3p.

Winston, D. A. 1977. Height and diameter growth response of 10-year old jack pine to thinning and fertilization. Environ. Can., Bi-mon. Res. Notes 33: 34-36.

Yarranton, M., and G. A. Yarranton. 1975. Demography of a jack pine stand. Can. J. Bot. 53: 310-314.

Yeatman, C. W. 1980. Written communication, January 9, 1980.

Young, H. E. 1967. Complete tree mensuration. For. Chron. 43: 360-364.

Zar, J. H. 1968. Calculation and miscalculation of the allometric equation as a model in biological data. Bio-science 18: 1118-1120.

Zavitkovski, J., and R. D. Stevens. 1972. Primary productivity of red alder ecosystems. Ecology 53: 235-242.

Zavitkovski, J. 1976. Biomass studies in intensively managed forest stands. In intensive plantation culture: five years research. U.S.D.A. For. Serv. Gen. Tech. Rept. NC-21. p. 32-38.

Zavitkovski, J., and D. H. Dawson. 1978a. Structure and biomass production of 1- to 7-year-old intensively cultured tamarack plantations in Wisconsin. In TAPPI, annual meeting, March 6-8, Chicago. p. 29-35.

Zavitkovski, J., and D. H. Dawson. 1978b. Structure and biomass production of 1- to 7-year-old intensively cultured jack pine plantations in Wisconsin. U.S.D.A. For. Serv. Res. Pap. NC-157. 15p.

APPENDIX A

A computer program for the evaluation of the Thornthwaite Monthly Water Balance.

```
      REAL TEMP(12),PRECIP(12),AI(12),TOTI,A,UNPE(12),ADJPE(12),PPE(12)
      REAL TOTA,APWL(12),SUN(9,12),SNOW,SMRO(12),TOTRO(12),DT(12),SREM
      REAL SWAT,ST(12),STO,STCH(12),AE(12),D(12),SURP(12),RO(12)
      REAL XX(12),YY(12),PLPE(12),PLAE(12),PLP(12),FLT,XR
      DIMENSION LBL(6),MTHS(12),FIG(2),WB(5),LE(2),RAIN(7),RAAE(7)
      DIMENSION RAPE(7)
      DATA LBL/'MONT','HLY ','R AN','D PE',' IN ','MM  '/
      DATA MTHS/'   J ','   F ','   M ','   A ','   M ','   J ','   J ','   A ',
     1'   S ','   O ','   N ','   D '/
      DATA FIG/'FIGU','RE  '/
      DATA WB/'WATE','R BA','LANC','E FO','R   '/
      DATA LE/'LEGE','ND  '/
      DATA RAIN/'PREC','IPIT','ATIO','N   ','    ','    ','    '/
      DATA RAAE/'ACTU','AL E','VAPO','TRAN','SPIR','ATIO','N   '/
      DATA RAPE/'POTE','NTIA','L EV','APOT','RANS','PIRA','TION'/
      INTEGER STYR,NUYR,LAT,MHC,NU
      READ(5,140)((SUN(I,J),J=1,12),I=1,9)
  140 FORMAT(12F6.1)
      READ(5,141)STYR,NUYR,LAT,MHC
  141 FORMAT(4I4)
      STO=MHC
      WRITE(6,79)
   79 FORMAT('1',////////////////,33X,69('*'),////)
      WRITE (6,80)
   80 FORMAT(33X,'A COMPUTER PROGRAM TO EVALUATE THE THORNTHWAITE MONTHL
     1Y WATER BALANCE',////,33X,69('*'))
      DO 10 II=1,NUYR
      WRITE(6,82)STYR
   82 FORMAT('1',/////,41X,'MONTHLY WATER BALANCE COMPILATION SHEET FOR'
     1,3X,I4,/,'+',40X,50('_'),///)
      WRITE(6,83)
   83 FORMAT(12X,'JANUARY',2X,'FEBRUARY',4X,'MARCH',5X,'APRIL',5X,'MAY',
     17X,'JUNE',6X,'JULY',5X,'AUGUST',3X,'SEPTEMBER',2X,'OCTOBER',2X,'NO
     1VEMBER',2X,'DECEMBER',//)
      READ(5,142)(TEMP(I),I=1,12)
  142 FORMAT(12F6.1)
      WRITE(6,84)(TEMP(I),I=1,12)
   84 FORMAT(1X,'TEMP',5X,12(F8.2,2X),/)
      READ(5,143)(PRECIP(I),I=1,12)
  143 FORMAT(12F6.1)
      TOTI=0.0
      DO 11 I=1,12
      IF(TEMP(I).LE.0.0) GO TO 13
      AI(I)=(TEMP(I)/5.0)**1.514
      TOTI=TOTI+AI(I)
      GO TO 11
   13 AI(I)=0.0
   11 CONTINUE
      WRITE(6,85)(AI(I),I=1,12)
   85 FORMAT(1X,'I',8X,12(F8.2,2X),/)
      A=0.000000675*TOTI**3.0-0.0000771*TOTI**2.0+0.01792*TOTI+0.49239
      DO 14 I=1,12
      IF(AI(I).EQ.0.0) GO TO 15
      UNPE(I)=(1.6*(10.0*TEMP(I)/TOTI)**A)*10.0/30.0
      GO TO 14
   15 UNPE(I)=0.0
   14 CONTINUE
      WRITE(6,86)(UNPE(I),I=1,12)
```

```
   86 FORMAT(1X,'UNADJ PE',1X,12(F8.2,2X),/)
      NU=LAT-41
      DO 16 I=1,12
      ADJPE(I)=UNPE(I)*SUN(NU,I)
   16 CONTINUE
      WRITE(6,87)(ADJPE(I),I=1,12)
   87 FORMAT(1X,'ADJ PE',3X,12(F8.2,2X),/)
      WRITE(6,88)(PRECIP(I),I=1,12)
   88 FORMAT(1X,'PRECIP',3X,12(F8.2,2X),/)
      DO 17 I=1,12
      PPE(I)=PRECIP(I)-ADJPE(I)
   17 CONTINUE
      WRITE(6,89)(PPE(I),I=1,12)
   89 FORMAT(1X,'P-PE',5X,12(F8.2,2X),/)
      TOTA=0.0
      DO 18 I=1,12
      IF(PPE(I).GE.0.0) GO TO 19
      TOTA=ABS(PPE(I))+TOTA
      APWL(I)=TOTA
      GO TO 18
   19 CONTINUE
      APWL(I)=0.0
      TOTA=0.0
   18 CONTINUE
      WRITE(6,90)(APWL(I),I=1,12)
   90 FORMAT(1X,'A P W L',2X,12(F8.2,2X),/)
      DO 20 I=1,12
      IF(TEMP(I).GT.0.0) GO TO 21
      ST(I)=STO+PRECIP(I)
      STO=ST(I)
      GO TO 20
   21 CONTINUE
      IF(APWL(I).GT.0.0) GO TO 23
      ST(I)=ST(I-1)+PPE(I)
      IF(ST(I).GT.MHC) GO TO 24
      GO TO 20
   23 CONTINUE
      IF(MHC-50)25,26,27
   25 ST(I)=21.87905567*1.039510573**(-APWL(I))
      GO TO 40
   26 ST(I)=44.72354057*1.019783143**(-APWL(I))
      GO TO 40
   27 IF(MHC-100)28,29,30
   28 ST(I)=69.58089274*1.013226709**(-APWL(I))
      GO TO 40
   29 ST(I)=95.14670546*1.010003756**(-APWL(I))
      GO TO 40
   30 IF(MHC-150)31,32,33
   31 ST(I)=121.2749158*1.008062327**(-APWL(I))
      GO TO 40
   32 ST(I)=139.5886653*1.005531236**(-APWL(I))
      GO TO 40
   33 IF(MHC-250)34,35,36
   34 ST(I)=183.1966*1.004811539**(-APWL(I))
      GO TO 40
   35 ST(I)=246.7461314*1.004023091**(-APWL(I))
      GO TO 40
   36 IF(MHC-350)37,38,39
```

```
   37 ST(I)=301.9858011*1.003385719**(-APWL(I))
      GO TO 40
   38 ST(I)=344.1473814*1.002854065**(-APWL(I))
      GO TO 40
   39 ST(I)=388.1648*1.002473**(-APWL(I))
   40 CONTINUE
      GO TO 20
   24 CONTINUE
      ST(I)=MHC
   20 STO=ST(I)
      WRITE(6.91)(ST(I).I=1.12)
   91 FORMAT(1X.'ST'.7X.12(F8.2.2X)./)
      STO=ST(12)
      DO 41 I=1.12
      IF(TEMP(I)-0.0)42.42.43
   42 STCH(I)=0.0
      GO TO 41
   43 IF(ST(I-1).GE.MHC.AND.ST(I).GE.MHC) GO TO 44
      STCH(I)=ST(I)-ST(I-1)
      GO TO 41
   44 STCH(I)=0.0
   41 CONTINUE
      WRITE(6.92)(STCH(I).I=1.12)
   92 FORMAT(1X.'ST CH'.4X.12(F8.2.2X)./)
      DO 45 I=1.12
      IF(APWL(I)-0.0)46.46.47
   46 AE(I)=ADJPE(I)
      GO TO 45
   47 AE(I)=PRECIP(I)+ABS(STCH(I))
   45 CONTINUE
      WRITE(6.93)(AE(I).I=1.12)
   93 FORMAT(1X.'A E'.6X.12(F8.2.2X)./)
      DO 48 I=1.12
      D(I)=ADJPE(I)-AE(I)
      IF(D(I)-0.0)101.48.48
  101 D(I)=0.0
   48 CONTINUE
      WRITE(6.94)(D(I).I=1.12)
   94 FORMAT(1X.'DEFICIT'.2X.12(F8.2.2X)./)
      DO 49 I=1.12
      IF(TEMP(I)-0.0)50.50.51
   50 SURP(I)=0.0
      GO TO 49
   51 IF(ST(I-1).GE.MHC.AND.ST(I).GE.MHC) GO TO 52
      IF(ST(I)-MHC)53.54.54
   53 SURP(I)=0.0
      GO TO 49
   54 SURP(I)=ST(I-1)+PPE(I)-ST(I)
      GO TO 49
   52 SURP(I)=PPE(I)
   49 CONTINUE
      WRITE(6.95)(SURP(I).I=1.12)
   95 FORMAT(1X.'SURPLUS'.2X.12(F8.2.2X)./)
      DO 55 I=1.12
      IF(TEMP(I)-0.0)56.56.57
   56 RO(I)=0.0
      GO TO 55
   57 RO(I)=(RO(I-1)+SURP(I))/2.0
```

```
   55 CONTINUE
      WRITE(6,96)(RO(I),I=1,12)
   96 FORMAT(1X,'R O',6X,12(F8.2,2X),/)
      SNOW=0.0
      DO 58 I=1,12
      IF(TEMP(I)-0.0)59,59,60
   59 SMRO(I)=0.0
      SNOW=ST(I)-WHC
      GO TO 58
   60 SMRO(I)=SNOW*0.9
      SNOW=SMRO(I)/0.9-SMRO(I)
   58 CONTINUE
      WRITE(6,97)(SMRO(I),I=1,12)
   97 FORMAT(1X,'SMRO',5X,12(F8.2,2X),/)
      DO 61 I=1,12
   61 TOTRO(I)=SMRO(I)+RO(I)
      WRITE(6,98)(TOTRO(I),I=1,12)
   98 FORMAT(1X,'TOT RO',3X,12(F8.2,2X),/)
      DO 62 I=1,12
      IF(TEMP(I)-0.0)63,63,64
   63 DT(I)=ST(I)
      GO TO 62
   64 SREM=SMRO(I)/0.9-SMRO(I)
      SWAT=RO(I-1)+SLRP(I)-RO(I)
      DT(I)=ST(I)+SREM+SWAT
   62 CONTINUE
      WRITE(6,99)(DT(I),I=1,12)
   99 FORMAT(1X,'DT',7X,12(F8.2,2X),/)
      CALL INITAL (8)
      X=-3.0
      Y=-3.0
      IPEN=0
      CALL PLOT (X,Y,IPEN)
      X=0.0
      Y=0.0
      NC=24
      S=5.0
      SLOPE=90.0
      SMIN=0.0
      DS=50.0
      NN=0
      CALL AXIS (X,Y,LBL,NC,S,SLOPE,SMIN,DS,NN)
      X=5.0
      Y=0.0
      NC=24
      S=5.0
      SLOPE=90.0
      SMIN=0.0
      DS=50.0
      NN=0
      CALL AXIS (X,Y,LBL,NC,S,SLOPE,SMIN,DS,NN)
      X=0.0
      Y=0.0
      IPEN=3
      CALL PLOT (X,Y,IPEN)
      DO 102 I=1,12
      XX(I)=0.25+(I-1)*0.5
      YY(I)=0.0
```

```
  102 CONTINUE
      N=12
      K=1
      INCR=1
      CALL LINE (XX,YY,N,K,INCR)
      X=0.0
      Y=-0.25
      HT=0.14
      SLOPE=0.0
      N=42
      CALL SYMBOL(X,Y,HT,MTHS,SLOPE,N)
      X=0.0
      Y=0.0
      IPEN=3
      CALL PLOT (X,Y,IPEN)
      DO 169 I=1,12
      PLP(I)=PRECIP(I)/50.0
      PLPE(I)=ADJPE(I)/50.0
      PLAE(I)=AE(I)/50.0
  169 CONTINUE
      N=12
      K=1
      INCR=1
      CALL LINE (XX,PLP,N,K,INCR)
      K=5
      CALL LINE (XX,PLPE,N,K,INCR)
      K=3
      CALL LINE (XX,PLAE,N,K,INCR)
      X=0.0
      Y=-1.0
      HT=0.21
      SLOPE=0.0
      N=8
      CALL SYMBOL(X,Y,HT,FIG,SLOPE,N)
      CALL WHERE(X,Y,FACT)
      FLT=FLOAT(II)
      HT=0.21
      SLOPE=0.0
      N=0
      CALL NUMBER(X,Y,HT,FLT,SLOPE,N)
      CALL WHERE(X,Y,FACT)
      XS=X+0.75
      HT=0.21
      SLOPE=0.0
      N=20
      CALL SYMBOL(XS,Y,HT,NB,SLOPE,N)
      CALL WHERE(X,Y,FACT)
      FLP=FLOAT(STWF)
      HT=0.21
      SLOPE=0.0
      N=0
      CALL NUMBER(X,Y,HT,FLP,SLOPE,N)
      X=6.25
      Y=8.5
      HT=0.21
      SLOPE=0.0
      N=8
      CALL SYMBOL(X,Y,HT,LF,SLOPE,N)
```

```
      X=6.25
      Y=3.0
      HT=0.07
      SLOPE=0.0
      N=28
      CALL SYMBOL(X,Y,HT,RAIN,SLOPE,N)
      X=8.5
      Y=3.0
      IPEN=3
      CALL PLOT(X,Y,IPEN)
      IMK=1
      CALL MARKER(IMK)
      X=9.0
      Y=3.0
      IPEN=2
      CALL PLOT(X,Y,IPEN)
      X=6.25
      Y=2.5
      HT=0.07
      SLOPE=0.0
      N=28
      CALL SYMBOL(X,Y,HT,RAAF,SLOPE,N)
      X=8.5
      Y=2.5
      IPEN=3
      CALL PLOT(X,Y,IPEN)
      IMK=3
      CALL MARKER(IMK)
      X=9.0
      Y=2.5
      IPEN=2
      CALL PLOT(X,Y,IPEN)
      X=6.25
      Y=2.0
      HT=0.07
      SLOPE=0.0
      N=28
      CALL SYMBOL(X,Y,HT,RAPE,SLOPE,N)
      X=8.5
      Y=2.0
      IPEN=3
      CALL PLOT(X,Y,IPEN)
      IMK=5
      CALL MARKER(IMK)
      X=9.0
      Y=2.0
      IPEN=2
      CALL PLOT(X,Y,IPEN)
      CALL RSTR
      STYR=STYR+1
   10 CONTINUE
      WRITE (6,81)
   81 FORMAT('1')
      RETURN
      END
```

APPENDIX B

Average monthly water balance for
the Goldie and Paipoonge Township soil.

Average monthly water balance for the Goldie and Paipoonge Township soil

Mean monthly temperature and precipitation data, for the water balance computations were obtained from the Thunder Bay Weather Station. Moisture retention capacity of each major soil horizon was calculated from bulk density, stone content, moisture content at field capacity, and horizon depth. Moisture retention capacity for each of the six soil profiles was computed by adding together the moisture retention capacity of all horizons in the profile. A mean soil moisture retention capacity was determined for each of the two study areas.

Moisture retention capacity of the soil supporting the 17-year old jack pine stand was 122.9, 128.1, and 136.7 mm for the three soil profiles. Mean soil moisture retention for that soil was 129.2 mm in a rooting depth of 1.02 m. For the soil supporting the 32-year old jack pine stand, the moisture retention capacity was 424.3, 381.1, and 376.2 mm for the three soil profiles. Mean soil moisture retention capacity was 393.9 mm in a rooting depth of approximately 1.87 m.

The average monthly water balances were based on average mean monthly weather data computed for the 17- and 32-year periods.

Goldie Towship soil supporting 17-year old jack pine

Table B1 shows the 1962 to 1978 average monthly water balance compilation sheet for the Goldie Township soil. The important results of this table are summarized in Figure B1. This figure shows mean monthly precipitation, actual evapotranspiration and potential evapotranspiration for the 17-year period. It indicates that in an average year both actual and potential evapotranspiration exceeded precipitation from the months of May through to August. As well Figure B1 shows that in an average year, potential evapotranspiration exceeded actual evapotranspiration in the months of July and August. This resulted in a soil moisture deficit in those months. As indicated in Table B1, the average total deficits were 15.6 and 14.3 mm of water for each of July and August.

Paipoonge Township soil supporting 32-year old jack pine

Table B2 shows the 1947 to 1978 average monthly water balance compilation sheet for the Paipoonge Township soil. The major components of this table are summarized in Figure B2. The results illustrated in this figure are similar to those for the Goldie Township soil. Actual and potential evapotranspiration in an average year exceeded precipitation from May to August. Because potential evapotranspiration exceeded actual evapotranspiration in July and August, a soil moisture deficit occurred in those months in an average year. The average deficits were 5.9 and 5.1 mm for each of July and August.

Table B1. The average 1962-1978 monthly water balance compilation sheet for the Goldie Township soil based on a moisture retention capacity of 129.2 mm.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temp	-15.3	-12.9	-6.3	2.3	8.6	13.9	17.5	16.4	11.1	6.0	-2.6	-11.1
I	0.0	0.0	0.0	0.3	2.3	4.7	6.7	6.0	3.3	1.3	0.0	0.0
Unadj Pe	0.0	0.0	0.0	0.5	1.6	2.5	3.1	2.9	2.1	1.2	0.0	0.0
Adj Pe	0.0	0.0	0.0	17.3	64.8	101.2	125.4	108.7	64.8	32.7	0.0	0.0
Precip	45.0	28.1	44.1	53.4	73.4	81.5	75.8	80.1	85.0	54.5	59.9	45.9
P-Pe	45.0	28.1	44.1	36.1	8.6	-19.7	-49.6	-28.6	20.2	21.8	59.9	45.9
A P W L	0.0	0.0	0.0	0.0	0.0	19.7	69.3	97.9	0.0	0.0	0.0	0.0
St	170.0	198.1	242.2	125.0	125.0	103.5	69.5	55.3	75.4	97.2	157.1	203.0
St Ch	0.0	0.0	0.0	0.0	0.0	-21.5	-34.0	-14.3	20.2	21.8	0.0	0.0
A E	0.0	0.0	0.0	17.3	64.8	103.0	109.8	94.3	64.8	32.7	0.0	0.0
Deficit	0.0	0.0	0.0	0.0	0.0	0.0	15.6	14.3	0.0	0.0	0.0	0.0
Surplus	0.0	0.0	0.0	36.1	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R O	0.0	0.0	0.0	18.0	13.3	6.7	3.3	1.7	0.8	0.4	0.0	0.0
S M R O	0.0	0.0	0.0	105.5	10.6	1.0	0.1	0.0	0.0	0.0	0.0	0.0
Tot Ro	0.0	0.0	0.0	123.5	23.9	7.7	3.4	1.7	0.8	0.4	0.0	0.0
Dt	170.0	198.1	242.2	154.8	139.5	110.3	72.8	56.9	76.3	97.6	157.1	203.0

Table B2. The average 1947-1978 monthly water balance compilation sheet for the Paipoonge Township soil based on a soil moisture retention capacity of 393.9 mm.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Temp	-15.3	-12.9	-6.3	2.3	8.6	13.9	17.5	16.4	11.1	6.0	-2.6	-11.1
I	0.0	0.0	0.0	0.3	2.3	4.7	6.7	6.0	3.3	1.3	0.0	0.0
Unadj Pe	0.0	0.0	0.0	0.4	1.6	2.4	3.0	2.8	2.0	1.1	0.0	0.0
Adj Pe	0.0	0.0	0.0	15.1	60.8	97.3	121.9	105.3	62.5	30.7	0.0	0.0
Precip	45.0	28.1	44.1	53.4	73.4	81.5	75.8	80.1	85.0	54.5	59.9	45.9
P-Pe	45.0	28.1	44.1	38.3	12.6	-15.8	-46.1	-25.2	23.0	23.8	59.9	45.9
A P W L	0.0	0.0	0.0	0.0	0.0	15.8	61.9	87.1	0.0	0.0	0.0	0.0
St	445.0	473.1	517.2	400.0	400.0	373.3	333.1	313.1	336.0	359.9	419.8	465.6
St Ch	0.0	0.0	0.0	0.0	0.0	-26.7	-40.2	-20.1	23.0	23.8	0.0	0.0
A E	0.0	0.0	0.0	15.1	60.8	108.2	116.0	100.2	62.1	30.7	0.0	0.0
Deficit	0.0	0.0	0.0	0.0	0.0	0.0	5.9	5.1	0.0	0.0	0.0	0.0
Surplus	0.0	0.0	0.0	38.3	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
R O	0.0	0.0	0.0	19.1	15.9	7.9	4.0	2.0	1.0	0.5	0.0	0.0
S M R O	0.0	0.0	0.0	105.5	10.6	1.1	0.1	0.0	0.0	0.0	0.0	0.0
Tot Ro	0.0	0.0	0.0	124.6	26.4	9.0	4.1	2.0	1.0	0.5	0.0	0.0
Dt	445.0	473.1	517.2	430.9	417.1	381.4	337.1	315.0	337.0	360.4	419.8	465.6

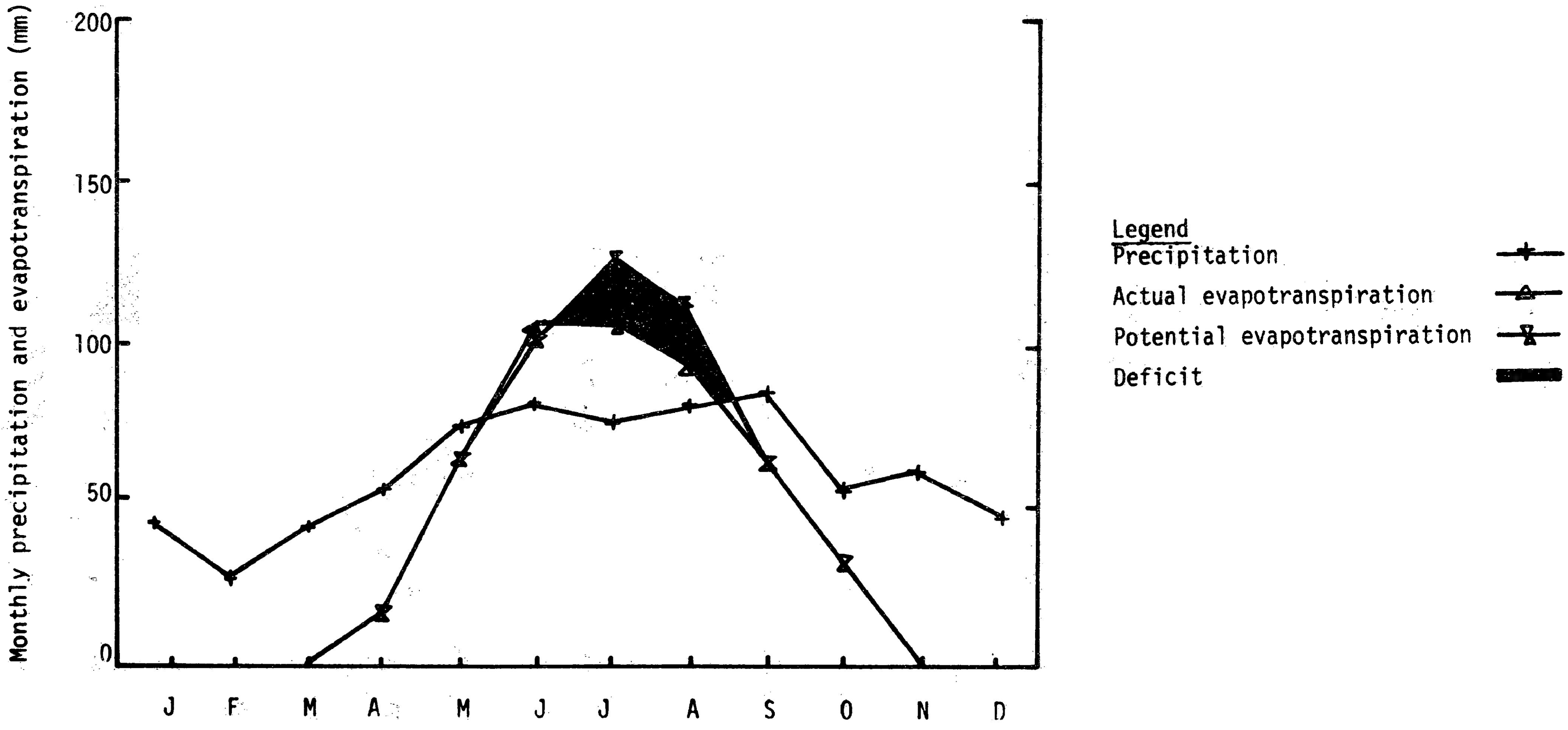

Figure B1. The average 1962-1978 water balance summary for the Goldie Township soil based on a soil moisture retention capacity of 129.2 mm.

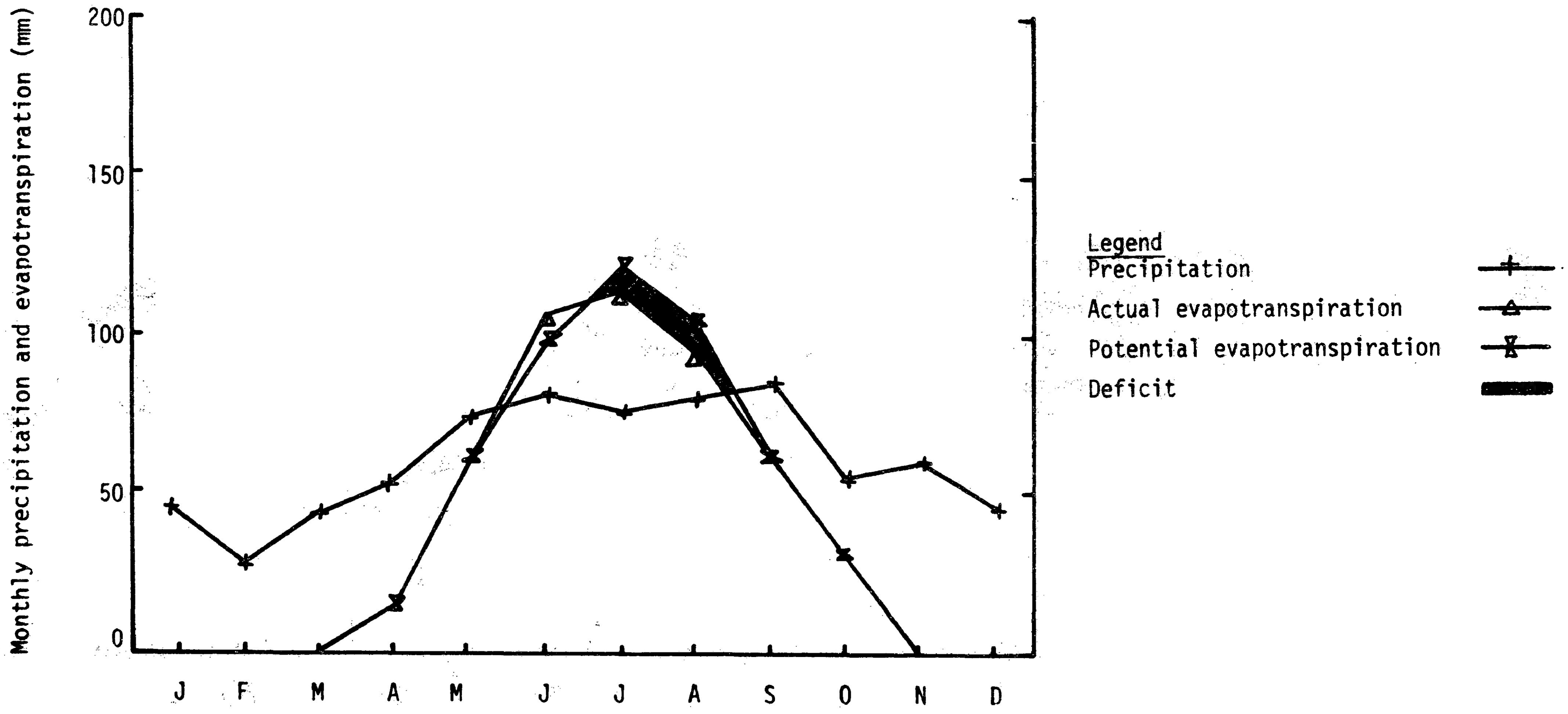

Figure B2. The average 1947-1978 water balance summary for the Paipoonge Township soil based on a soil moisture retention capacity of 393.9 mm.

APPENDIX C

Summary of monthly water balance results
for the Goldie and Paipoonge Township soil.

Summary of monthly water balance results for the Goldie and Paipoonge Township soil

Table C1 summarizes the monthly water balance computations for the Goldie Township soil. The table indicates, that in the past 17 years, moisture deficits have occurred from May to October in the Goldie Township soil. As well, there has been a soil moisture deficit in at least one month in every year. The years 1975 and 1976 experienced the greatest soil moisture deficits. In each of those years, during the month of August, nearly one half of the soil water of this area had been removed.

Table C1 also shows the probability of the occurrence of a soil moisture deficit in any month of an average year. In May, June, July, August, September, and October the respective probabilities were .24, .59, .82, .65, .35, and .29. The probability of the occurrence of a deficit was greatest in July; however the probability of a deficit in June and August was also high.

Table C2 indicates the monthly soil moisture deficits for the Paipoonge Township soil estimated in water balance calculations. The table indicates, that in the past 32 years, moisture deficits have occurred from May to October in the Paipoonge Township soil. Table C2 also shows that the probabilities of the occurrence of soil moisture deficits in the months of May, June, July, August, September, and October were .09, .41, .84, .72, .28, and .19 respectively. The probability of the occurrence of a deficit was greatest in the months of

July and August.

Table C1. The monthly soil moisture deficits in millimetres for the Goldie Township soil based on a soil moisture retention capacity of 129.2 mm.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1978						0.7	17.1	27.1	12.8	4.8		
1977					3.4		25.2					
1976					8.2		47.7	54.0	29.2	6.3		
1975					12.8	5.8	42.0	55.7				
1974							26.7	6.7		11.4		
1973						1.7						
1972					1.2	9.9		64.1				
1971						9.5	9.8	37.4				
1970						7.9	19.0	49.7				
1969							34.7	49.7	8.7			
1968									1.1			
1967						2.7	28.9	19.6	30.2			
1966						22.1	61.0					
1965						4.1	23.5	0.7				
1964							39.2					
1963							29.5	7.3	0.3	30.6		
1962						18.1	16.9			23.5		
Probability of a soil moisture deficit in any month					.24	.59	.82	.65	.35	.29		

Table C2. The monthly soil moisture deficits in millimetres for the Paipoonge Township soil based on a soil moisture retention capacity of 393.9 mm.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1978						0.3	7.2	11.7	5.8	2.4		
1977					1.9		23.6					
1976							40.5	24.4	13.6	3.3		
1975						2.4	18.7	27.5				
1974							11.8	2.7				
1973						0.8						
1972						4.2		60.2				
1971							4.1	16.5				
1970							8.0	22.7				
1969							15.0	23.0	4.3			
1968									0.6			
1967						1.2	12.3	8.6	14.3			
1966						9.7	27.8					
1965							10.0	0.1				
1964							7.4					
1963							3.1	3.0	0.1	14.4		
1962						8.0	7.1			8.6		
1961						8.9	0.4	18.2				
1960							6.5	6.9	11.1			
1959							8.7					
1958						1.8	6.0					
1957						2.1	17.1	18.6				
1956							8.5	18.7				
1955					1.9	14.9	10.7	11.8				
1954							20.4	9.8				
1953							20.8	25.4				
1952					1.9	2.7	0.9	4.0	11.8	3.2		
1951							15.6					
1950								2.4				
1949							7.4	14.5				
1948						9.2	14.1	7.1	11.6	6.5		
1947								15.6				
Probability of a soil moisture deficit in any month					.09	.41	.84	.72	.28	.19		

APPENDIX D

Distribution of wood and bark volume in the sample plots.

Table D1. The distribution of wood and bark volumes in m^3/ha, based on the sample plots.

Stand Age (yrs)	Density Class	Wood Volume			Bark Volume		
		Stem	Branch	Total	Stem	Branch	Total
17	High	136.4	12.0	148.4	21.8	8.8	30.6
17	Medium	84.8	10.4	95.2	15.3	7.3	22.6
17	Low	53.7	11.7	65.4	9.4	7.1	16.5
32	High	391.9	13.6	405.5	44.7	9.8	54.5
32	Medium	303.2	13.8	317.0	35.1	9.5	44.6
32	Low	117.6	12.8	130.4	13.4	7.4	20.8