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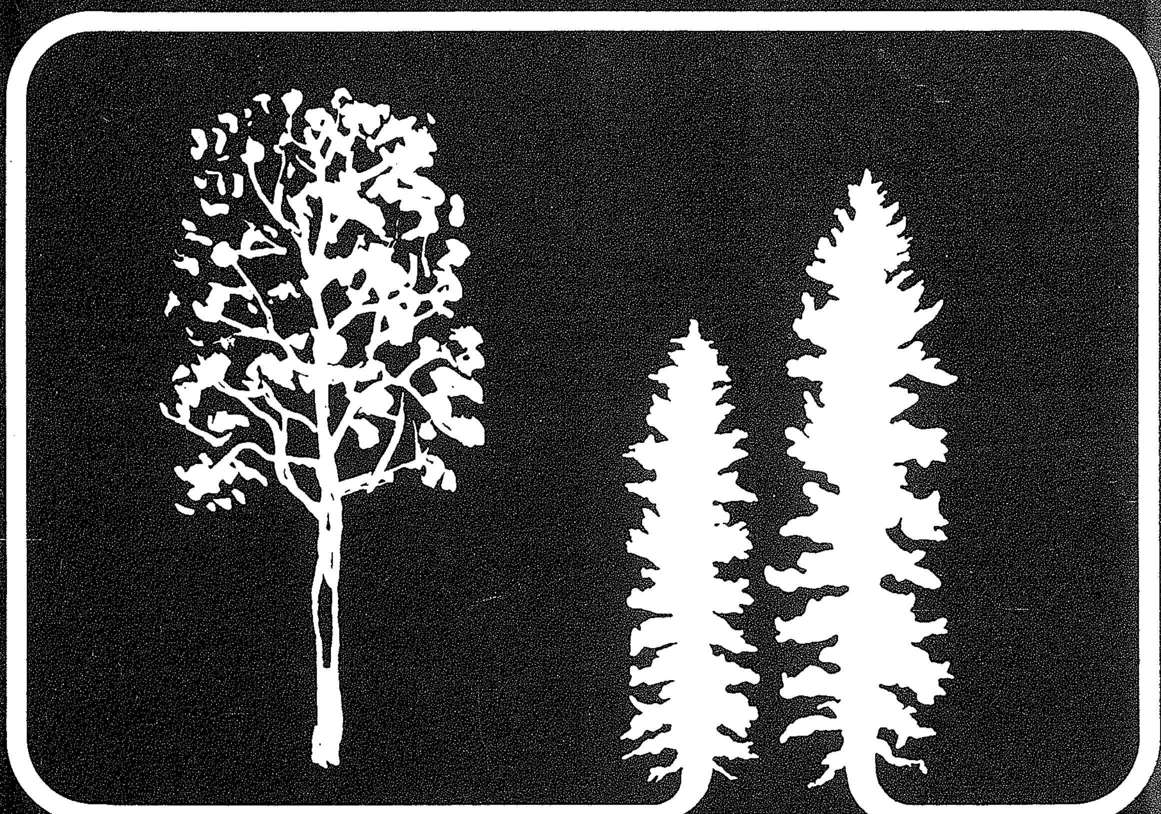

W.D. Johnstone and E.B. Peterson

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ABOVE-GROUND COMPONENT WEIGHTS IN ALBERTA *POPULUS* STANDS

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ABSTRACT

Equations for estimating the component weights and leaf area of trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*P. balsamifera* L.) are presented. Data were obtained from 254 aspen and 60 poplar trees sampled at six study locations in Alberta. The equations are based upon stem diameter at breast height and total height and provide additive component weight estimates. Although reasonable average estimates may be expected over a number of stands, large discrepancies may occur for individual stands or plots when an equation X stand-table approach is used. These discrepancies may be due to genetic variation between the different clones sampled. Stand density and total standing crop show a strong inverse relationship. The relationship for the fully stocked stands of Alberta's Boreal and Montane forest regions differs significantly from that for the grove-type stands of the aspen-grassland transition zone of southwestern Alberta.

RESUME

Le lecteur trouvera dans cet article des équations pour évaluer le poids des composantes et l'aire du feuillage du Peuplier faux-tremble (*Populus tremuloides* Michx.) et du Peuplier baumier (*P. balsamifera* L.). Les données proviennent de 254 Peupliers faux-trembles et de 60 Peupliers baumiers échantillonnés en six places d'étude de l'Alberta. Les équations sont fondées sur le dhp et la hauteur totale de la tige et fournissent des estimations supplémentaires sur le poids des composantes. Bien que l'on puisse s'attendre à des estimations moyennes raisonnables d'un certain nombre de peuplements, il peut se produire de grandes différences dans un peuplement ou une placette donnés, lorsqu'un système d'équations de X tables de peuplement est utilisé. Ces différences peuvent être dues à la variation génétique des différents clones échantillonnés. La densité du peuplement et le nombre total d'arbres sur pied indiquent une forte inversion proportionnelle. Le rapport entre les peuplements très denses des régions forestières boréales et montagnardes de l'Alberta diffère significativement de celui des peuplements genre bocage de la zone de transition Peuplier-herbage du sud-ouest de l'Alberta.

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INTRODUCTION

Interest in forest biomass has developed from rather esoteric studies in forest ecology to the present studies on chemical, food, and energy production. Early biomass studies have been well summarized by Ovington (1962), Baskerville (1965), and Johnstone (1973). In classic literature reviews, Keays (1971), Johnstone and Keays (1973), and Keays (1974a, b, c; 1976a) examined the potential of whole-tree utilization for pulp and paper products. The use of trees, particularly foliage, for the production of chemicals and a livestock food supplement has been reported by Keays and Barton (1975), Keays (1976b), and Barton (1976). Evans (1974, 1977), Marshal *et al.* (1975), Carlisle (1976), and Love and Overend (1978) have reported on the utilization of forest biomass and wood residue for energy production. All of these studies indicate changing patterns in forest utilization and an increasing need to consider forest yield in terms of total biomass.

The poplars represent one of Canada's largest yet least used forest resources. In Alberta, for example, only about 1% of the deciduous allowable annual cut was harvested in 1972 (Teskey and Smyth 1975). Many of the problems associated with the utilization of poplar and potential solutions to these problems have been discussed in detail by Keays *et al.* (1974), Neilson and McBride (1974), and Neilson (1975). Future development of Alberta's forest economy, particularly for the production of livestock food or energy, undoubtedly will result in increased use of poplars. Previous work on biomass (Bella and Jarvis 1967, Bella 1968, Pollard 1972, Bella and De Franceschi 1980) or on short-rotation management (Zsuffa *et al.* 1977, Berry and Stiell 1978) dealt mainly with young *Populus* spp. in Canada. Research by Peterson *et al.* (1970) was limited to one mature aspen clone growing in southwestern Alberta. The main purpose of the study reported here was to collect information from mature and immature stands over a range of sites and over a broad geographic range in Alberta and to use the resulting data to predict the component weights of poplar trees and stands from readily measured tree and stand characteristics.

METHODS

SAMPLE PLOT ESTABLISHMENT

A total of 28 sample plots was located in six study areas (Fig. 1). Study areas 1 to 4 occurred in the Boreal Forest Region (Rowe 1972) that makes up the major poplar area of central Alberta. Study area 5 was in the Montane Forest Region (Rowe 1972), and study area 6 was in the aspen-grassland transition zone of southwestern Alberta, which is the southwestern limit of the B.17 Aspen Grove Section of the Boreal Forest Region (Rowe 1972). Data were obtained from 254 trembling aspen (*Populus tremuloides* Michx.) and 60 balsam poplar (*P. balsamifera* L.). Sample plots were located so that (1) the plot fell entirely within one clone, (2) the stand within the plot was fully stocked, containing no distinct canopy openings, and (3) the plot contained a range of stem diameters similar to the entire clone.

Plot size varied with the age of the stand sampled. In each mature stand 40 years and older, diameter and height measurements were taken from all trees within a 300-m^2 plot, and fresh weights were obtained for all above-ground tree components within a 100-m^2 subplot. For each stand 10-39 years of age, the diameters, heights, and fresh weights of all trees within a 100-m^2 plot were measured. In each 5- to 9-year-old stand, the diameter, height, and fresh-weight measurements were obtained from a 30-m^2 plot. Within stands of suckers less than 5 years old, the same measurements were obtained from 20 1-m^2 quadrats located at regular intervals along a grid line. In the case of sucker stands it was not certain that the samples fell within one clone.

STAND AND TREE MEASUREMENT

Aggregate Harvest

In addition to measurement of the diameters and heights, all stems within each sample plot were cut at ground level, and the aggregate fresh weights of the following components were measured:

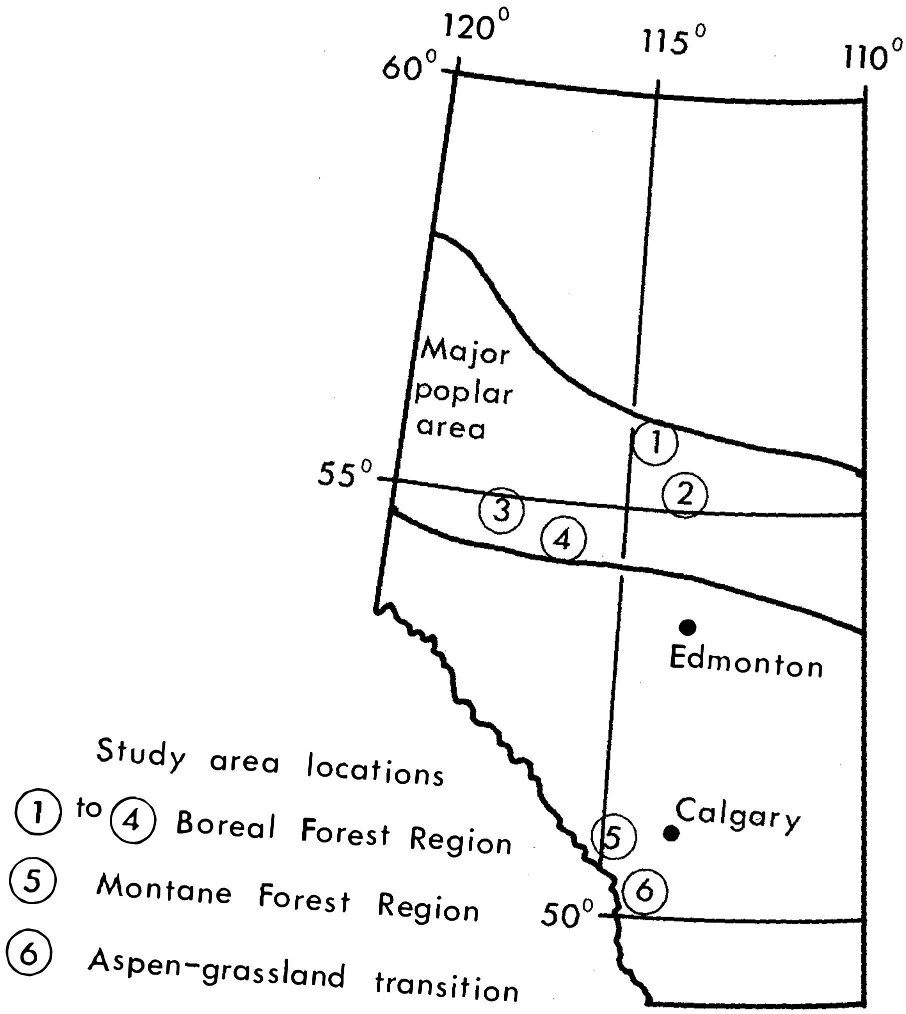

Figure 1. Approximate locations of six study areas in Alberta.

1. live stems (wood plus bark) from ground level to a 2-cm top diameter outside bark (dob),

2. live branches (wood plus bark) greater than (>) 2-cm dob,

3. live branches (wood plus bark) less than (<) 2-cm dob plus current twigs and foliage,

4. attached dead branches, and

5. dead standing trees.

Suckers less than 5 years old were cut at ground level, but only the aggregate fresh weights of foliage and woody materials were measured. In two plots only the dry weights of the suckers were determined.

Detailed Harvest

In stands older than 5 years, at least one tree from each 2.5-cm diameter class was selected for detailed fresh-weight measurement and subsampled for component dry-weight determinations. The following measurements were obtained from each of these sample trees selected for detailed sampling:

1. stump age—A,

2. diameter at breast height outside bark (dbhob)—D,

3. diameter at crown base outside bark—DC,

4. total height above ground—H,

5. height to live crown (lowest leaf-bearing branch)—HLC,

6. crown width—CW,

7. stem (wood plus bark) fresh weight from ground level to a 2-cm top dob,

8. live branch fresh weight (wood plus bark) >2-cm dob,

9. live branch fresh weight (wood plus bark) <2-cm dob plus current twigs and foliage,

10. fresh weight of dead (non-leaf-bearing) branches (wood plus bark), and

11. number of leaf bunches.

In addition, the following subsamples were collected from each sample tree for fresh-weight determination in the field:

1. two stem discs (wood plus bark) 2 to 5 cm thick obtained at breast height and at the base of the crown,

2. one wood-plus-bark disc from the base of the largest diameter branch,

3. 50 leaf bunches (25 for balsam poplar), including current twigs, and

4. 12 leaf bunches (two from the base and two from the terminal of branches at the base, midpoint, and top of the crown) for later leaf-area determinations in the laboratory.

In plots of young, dense suckers, only subsampling to obtain dry-weight estimates was carried out, and no trees were collected for detailed harvest.

Laboratory and Dry-weight Determinations

In the laboratory, oven-dry (at 105°C to constant weight) weights were obtained for the wood and for the bark of each stem and branch disc. The oven-dry weights of the 50 or 25 leaf bunches were measured, and the mean weights per leaf bunch were determined. The fresh weight of foliage was estimated by multiplying the mean fresh weight per leaf bunch by the number of leaf bunches per tree. The fresh weight of branches <2 cm was estimated by subtracting the estimated foliage fresh weight from the measured weight of foliage plus branches <2 cm. For the 12 leaf-bunch subsamples, the average number of leaves per bunch was determined, and area (one side only) of each leaf was measured with an electrical area calculator with a digital readout. These data were used to calculate dry weight to fresh weight ratios for stem, branch, and foliar materials and to calculate wood to wood-plus-bark ratios for stem and branch materials. These ratios then were used to convert sample-tree fresh weights (obtained by the detailed harvest) to tree dry weights for the following components:

1. stem wood and stem bark from ground level to a 2-cm dob top,

2. branch wood and branch bark for branches >2-cm dob,

3. branch wood and branch bark for branches <2-cm dob, and

4. foliage, including leaf blades, petioles, and current twigs.

In addition, the leaf area of each sample tree was calculated by multiplying the number of leaf bunches per tree by the mean number of leaves per bunch and the mean surface area per leaf.

Plot fresh weights, obtained by the aggregate harvest, were converted to unit-area dry weights by multiplying the measured aggregate fresh weight by the ratio of the sum of the estimated dry weights to the sum of measured fresh weights of the following components of all detailed harvest trees within each plot:

1. stem material (stem wood plus stem bark) from ground level to a 2-cm dob top,

2. crown materials (branch wood and bark plus foliage), and

3. total tree (stem plus crown materials).

ANALYSES

Individual Tree Estimates

Component and total tree weight and leaf area data from the 254 aspen and 60 poplar trees were analyzed as dependent variables in conjunction with several easily measured tree characteristics as independent variables (Tables 1 and 2). Various weighted, logarithmically transformed, and multiple regression models were tested. The weighted models subsequently were rejected because the resulting equations did not provide improved estimates and the estimates were not additive. Logarithmically transformed models also were rejected because they lacked additivity and produced systematic underestimates. The multiple regression model chosen ensured additivity of the estimates from the tree component equations and the total tree equation since the same regression model was derived for all dependent variables (Bella 1968, Kozak 1970). Some independent variables were retained in the model because they contributed significantly to some component equations.

Of the numerous models tested for estimating the component and total tree weights of both species, the following model proved most satisfactory in terms of high coefficients of determination (R^2) and low standard errors of estimate ($s_{y \cdot x}$):

$$Y_{1\text{-}3,\ 5\text{-}12} = b_0 + b_1 D + b_2 D^2 + b_3 D^3 + b_4 H + b_5 D^2 H$$

The same model proved to be equally applicable for the estimation of leaf area (Y_4) of both aspen and poplar trees. In addition, the following model was used to develop equations to predict the leaf area (Y_4) of *Populus* trees from measured foliage dry weight (Y_{11}):

$$Y_4 = b_0 + b_1 Y_{11} + b_2 Y_{11}^2$$

Stand Estimates

This study presents a rare, although somewhat limited, opportunity to compare standing crop estimates obtained by the weight-equation × stand-table method with the standing crop measurements of 17 *Populus* stands in which both detailed and aggregate harvests were conducted. These stands consisted of pure and mixed stands of both species. The measured standing crop is the sum of the detailed tree harvest plus the aggregate harvest for each plot, and adjustments to dry weight were based upon the detailed tree measurements within each plot. The estimated standing crop was calculated from a stand-table and height-diameter curve for each species in each plot and the individ-

Table 1. Statistical summary of the characteristics of the 254 trembling aspen sample trees

Characteristic	Mean	Standard deviation	Minimum value	Maximum value
Stump age (yr)—A	44.98	20.57	8.00	83.00
Dbhob (cm)—D	12.74	6.35	2.00	31.50
Diameter at crown base (cm)—DC	8.28	4.47	1.00	23.80
Total height (m)—H	13.18	5.42	4.15	27.74
Height to live crown (m)—HLC	8.03	3.66	1.36	18.60
Crown width (m)—CW	2.39	1.11	0.60	7.20
Combined variable ($cm^3/100$)—D^2H	3473.60	4614.50	17.92	27525.00
Fresh weight stem (wood + bark) >2 cm (kg)—Y_1	104.75	131.94	0.67	809.61
Fresh weight living branches + leaves (kg)—Y_2	16.08	26.47	0.31	223.77
Fresh weight living tree above ground (kg)—Y_3	120.82	154.69	1.25	1033.38
Fresh weight attached dead branches (kg)	3.09	3.97	0	26.92
Leaf area (m^2)—Y_4	15.18	17.32	0.29	125.04
Dry weight stem wood >2 cm (kg)—Y_5	47.94	63.52	0.23	372.72
Dry weight stem bark >2 cm (kg)—Y_6	11.83	14.62	0.10	84.93
Dry weight branch wood >2 cm (kg)—Y_7	2.53	6.31	0	56.05
Dry weight branch bark >2 cm (kg)—Y_8	0.96	2.30	0	21.58
Dry weight branch wood <2 cm (kg)—Y_9	2.55	3.13	0.08	20.68
Dry weight branch bark <2 cm (kg)—Y_{10}	1.07	1.18	0.04	7.48
Dry weight leaves (kg)—Y_{11}	1.08	1.39	0.01	9.37
Dry weight living tree above ground (kg)—Y_{12}	67.96	90.42	0.57	561.57

Table 2. Statistical summary of the characteristics of the 60 balsam poplar sample trees

Characteristic	Mean	Standard deviation	Minimum value	Maximum value
Stump age (yr)—A	32.12	13.20	16.00	65.00
Dbhob (cm)—D	11.67	6.07	2.30	27.40
Diameter at crown base (cm)—DC	7.00	3.44	1.60	15.50
Total height (m)—H	13.46	5.08	3.88	23.25
Height to live crown (m)—HLC	7.89	4.21	1.77	15.74
Crown width (m)—CW	2.55	1.18	0.40	5.10
Combined variable ($cm^3/100$)—D^2H	3045.87	3748.72	20.53	16554.30
Fresh weight stem (wood + bark) >2 cm (kg)—Y_1	91.96	109.84	0.53	451.38
Fresh weight living branches + leaves (kg)—Y_2	12.10	16.23	0.45	74.43
Fresh weight living tree above ground (kg)—Y_3	104.07	124.71	0.98	512.62
Fresh weight attached dead branches (kg)	2.21	3.63	0.01	19.11
Leaf area (m^2)—Y_4	14.55	14.70	0.52	63.49
Dry weight stem wood >2 cm (kg)—Y_5	35.42	43.03	0.15	178.55
Dry weight stem bark >2 cm (kg)—Y_6	8.95	10.39	0.08	41.81
Dry weight branch wood >2 cm (kg)—Y_7	1.29	3.06	0	15.10
Dry weight branch bark >2 cm (kg)—Y_8	0.54	1.16	0	5.59
Dry weight branch wood <2 cm (kg)—Y_9	1.71	1.88	0.03	7.56
Dry weight branch bark <2 cm (kg)—Y_{10}	0.81	0.82	0.02	3.07
Dry weight leaves (kg)—Y_{11}	0.98	1.02	0.05	4.44
Dry weight living tree above ground (kg)—Y_{12}	49.70	60.25	0.45	251.27

ual tree component weight equations. Comparisons of fresh and dry weights for the bole (wood plus bark), the crown (branch wood and bark plus foliage), and the total tree (all living components above ground) were made for each species in each plot and for each species in all plots combined. Comparisons were based on the estimated standing crop as a percentage of the measured standing crop.

Standing Crop Relationships

Data from 20 fully stocked stands for which aggregate harvests were available were studied to determine the effects of stand density and mean stand height on standing crop and standing crop density. Four stands were in the grove-type aspen-grassland transition zone in southwestern Alberta, and 16 stands were in the closed *Populus* forests of the Boreal and Montane forest regions (Rowe 1972). Standing crop density is determined by the total standing crop per unit area (dry weight, kg/m^2) divided by the average stand height (m); it gives the apparent density of organic matter per unit volume of forest stand space (kg/m^3). In addition, leaf area indices for these 20 fully stocked stands were determined and examined in relation to stand density and mean stand height.

RESULTS AND DISCUSSION

INDIVIDUAL TREE ESTIMATES

As shown by the results in Table 3, the stem represents the largest and least variable component of aspen and poplar trees (coefficients of variation (CV) of 7.37% and 7.45%, respectively). Foliage weight, on the other hand, was the smallest and most variable component (CV of 73.99% and 61.32%, respectively). The proportions presented in Table 3 are in close agreement with those reported by Peterson *et al.* (1970).

Of those tested, D^2H was the independent variable generally most highly correlated with the various component weights except for the crown components, which were slightly more highly correlated with various logarithmic transformations of the stem diameter at crown base (DC). Although of little practical use in conventional forest inventories, the high correlations between crown base diameter and crown component weights tend to support previous results reported by Attiwill (1966) and Peterson *et al.* (1970).

Tables 4 and 5 show the multiple regression equations and their associated statistics for the various tree component weights of aspen and poplar, respectively. As previously noted, the crown components are much more variable than the stem or whole-tree components. This is reflected in the lower coefficients of determination and relatively higher standard errors of estimate of the crown components. Nevertheless, these results indicate that reliable estimates of all the components can be made using these equations.

The equations (Tables 4 and 5) are additive; the sums of the regression coefficients of equations for Y_1 and Y_2 are equal to the corresponding regression coefficients for Y_3, and the sums of the regression coefficients for Y_5 through Y_{11} are equal to the corresponding regression coefficients for Y_{12}. It is also possible to derive new equations using the regression coefficients presented in Tables 4 and 5. For example, an equation to estimate the dry weight of all branches, wood plus bark, can be derived merely by summing the corresponding regression coefficients of the equations for Y_7 through Y_{10}. Estimates obtained from this derived equation are exactly equal to the sum of the individual estimates from equations Y_7, Y_8, Y_9, and Y_{10}. Values of R^2 and $s_{y.x}$ for the derived equation may be determined following the procedures provided by Kozak (1970).

STAND ESTIMATES

Table 6 compares the observed and estimated standing crops of 17 sample plots. Comparisons were made for the bole (wood plus bark), the crown (all branches, wood and bark, plus foliage), and the total above-ground (bole plus crown) components. Estimated standing crops were obtained using the appropriate equations (Tables 4 and 5) and stand-

Table 3. Tree components of 254 aspen and 60 poplar sample trees expressed as a relative proportion (%) of the total living tree above ground (dry weight basis)

Component	Mean	Standard deviation	Minimum value	Maximum value
Aspen				
Stem (wood + bark)	87.53	6.45	57.89	97.49
Branches (wood + bark)	10.24	5.37	2.04	33.33
Foliage	2.23	1.65	0.10	15.14
Total wood (stem + branches)	75.40	4.85	58.75	85.12
Total bark (stem + branches)	22.37	3.96	13.50	37.50
Poplar				
Stem (wood + bark)	88.08	6.56	51.11	98.23
Branches (wood + bark)	8.74	5.34	0.14	37.78
Foliage	3.18	1.95	0.16	11.11
Total wood (stem + branches)	75.21	3.93	53.33	80.77
Total bark (stem + branches)	21.61	2.91	14.59	35.56

Table 4. Regression equations† and related statistics for the various component weights (kg) and leaf area (m^2) of aspen trees, based upon 254 sample trees

Regression equation	R^2	$s_{y \cdot x}$
$Y_1 = -3.0212 - 2.5320\,D + 0.3208\,D^2 - 0.0010\,D^3 + 1.4599\,H + 0.0171\,D^2H$	0.937	33.39 kg
$Y_2 = -7.3345 + 4.6226\,D - 0.3652\,D^2 + 0.0101\,D^3 - 0.9066\,H + 0.0034\,D^2H$	0.853	10.27 kg
$Y_3 = -10.3556 + 2.0907\,D - 0.0444\,D^2 + 0.0092\,D^3 + 0.5533\,H + 0.0206\,D^2H$	0.957	32.40 kg
$Y_4 = -4.0226 + 3.0790\,D - 0.1571\,D^2 + 0.0035\,D^3 - 0.7757\,H + 0.0025\,D^2H$	0.877	8.40 m^2
$Y_5 = 1.4933 + 0.2384\,D - 0.0046\,D^2 - 0.0004\,D^3 - 0.3040\,H + 0.0144\,D^2H$	0.991	5.95 kg
$Y_6 = 0.1243 + 0.0726\,D + 0.0224\,D^2 - 0.0001\,D^3 - 0.0876\,H + 0.0023\,D^2H$	0.943	3.51 kg
$Y_7 = -1.4659 + 1.0220\,D - 0.0984\,D^2 + 0.0028\,D^3 - 0.2119\,H + 0.0009\,D^2H$	0.818	2.27 kg
$Y_8 = -0.8876 + 0.5260\,D - 0.0470\,D^2 + 0.0012\,D^3 - 0.1022\,H + 0.0004\,D^2H$	0.875	0.82 kg
$Y_9 = -0.3633 + 0.3349\,D - 0.0162\,D^2 + 0.0006\,D^3 - 0.0930\,H + 0.0003\,D^2H$	0.870	1.14 kg
$Y_{10} = -0.2682 + 0.2299\,D - 0.0113\,D^2 + 0.0003\,D^3 - 0.0650\,H + 0.0002\,D^2H$	0.857	0.45 kg
$Y_{11} = 0.0513 + 0.0839\,D - 0.0014\,D^2 + 0.0002\,D^3 - 0.0436\,H + 0.0001\,D^2H$	0.769	0.67 kg
$Y_{12} = -1.3161 + 2.5077\,D - 0.1566D^2 + 0.0045\,D^3 - 0.9072\,H + 0.0184\,D^2H$	0.989	9.53 kg
$Y_4 = 1.6129 + 13.0818\,Y_{11} - 0.1843\,Y_{11}^{2}$ ††	0.920	4.93 m^2

† Coefficients may not be additive due to rounding.

†† When estimating leaf area (Y_4) from foliage dry weight (Y_{11}), use measured, not estimated, dry weight.

Table 5. Regression equations† and related statistics for the various component weights (kg) and leaf area (m^2) of balsam poplar trees, based upon 60 sample trees

Regression equation	R^2	$s_{y \cdot x}$
$Y_1 = 15.0677 - 5.8148\,D + 0.5330\,D^2 - 0.0102\,D^3 + 0.5240\,H + 0.0251\,D^2H$	0.994	8.93 kg
$Y_2 = 7.8988 + 2.5020\,D - 0.0785\,D^2 - 0.0020\,D^3 - 2.3102\,H + 0.0084\,D^2H$	0.827	7.05 kg
$Y_3 = 22.9665 - 3.3128\,D + 0.4545\,D^2 - 0.0122\,D^3 - 1.7863\,H + 0.0335\,D^2H$	0.989	13.72 kg
$Y_4 = 3.5165 + 4.9402\,D - 0.1999\,D^2 - 0.0021\,D^3 - 2.7957\,H + 0.0104\,D^2H$	0.875	5.44 m^2
$Y_5 = 3.4377 + 0.1920\,D + 0.0108\,D^2 - 0.0032\,D^3 - 0.5730\,H + 0.0148\,D^2H$	0.993	3.81 kg
$Y_6 = 2.1308 - 0.9637\,D + 0.0867\,D^2 - 0.0024\,D^3 + 0.1141\,H + 0.0029\,D^2H$	0.990	1.09 kg
$Y_7 = 1.5068 + 0.4372\,D - 0.0386\,D^2 + 0.00004\,D^3 - 0.3905\,H + 0.0021\,D^2H$	0.742	1.62 kg
$Y_8 = 0.7246 - 0.1009\,D + 0.0061\,D^2 - 0.000001\,D^3 - 0.0521\,H + 0.0002\,D^2H$	0.783	0.57 kg
$Y_9 = 0.5808 + 0.3772\,D - 0.0042\,D^2 - 0.0004\,D^3 - 0.2852\,H + 0.0008\,D^2H$	0.820	0.83 kg
$Y_{10} = 0.3233 + 0.00002\,D + 0.0130\,D^2 - 0.0003\,D^3 - 0.0639\,H - 0.00005\,D^2H$	0.785	0.39 kg
$Y_{11} = 0.2256 + 0.3148\,D - 0.0137\,D^2 - 0.00002\,D^3 - 0.1707\,H + 0.0006\,D^2H$	0.834	0.44 kg
$Y_{12} = 8.9296 + 0.2566\,D + 0.0601\,D^2 - 0.0062\,D^3 - 1.4213\,H + 0.0213\,D^2H$	0.989	6.53 kg
$Y_4 = 0.2338 + 15.6688\,Y_{11} - 0.4996\,Y_{11}^{2}$††	0.928	4.01 m^2

† Coefficients may not be additive due to rounding.
†† When estimating leaf area (Y_4) from foliage dry weight (Y_{11}), use measured, not estimated, dry weight.

Table 6. A relative comparison (%) of estimated to observed total standing crops for 17 *Populus* stands in Alberta

	Aspen			Poplar		
	Bole	Crown	Total	Bole	Crown	Total
Dry-weight basis						
Weighted average	99.2	120.5	101.0	98.9	109.4	99.2
Range	91.9-118.9	62.1-157.6	88.7-121.1	93.3-109.7	72.9-175.1	91.8-116.5
Fresh-weight basis						
Weighted average	100.7	121.2	103.0	98.4	104.9	98.8
Range	96.3-117.2	64.0-160.5	97.6-111.9	88.9-113.4	61.6-188.9	91.7-120.4

table and height-diameter data for each individual plot. The comparison shows the range of estimated values as a percentage of observed values for individual plots and a weighted average percentage (aggregated estimated to aggregated observed) for all plots combined. Once again the crown components of both aspen and poplar trees were the most variable and difficult to predict accurately. The equations slightly overestimated the aspen component weights except for bole dry weight. For poplar, the equations generally underestimated the bole and total above-ground components and overestimated the crown component weights. The results also indicate that, although reasonably accurate average estimates may be expected over a wide range of stands, large overestimates or underestimates may occur for individual stands or plots, particularly for the crown components. These results are somewhat disconcerting, because sample trees from each of the plots included in the comparison were used to derive the equations. Because of the clonal nature of the *Populus* spp., these differences may reflect real genotypic variation in the stands sampled.

STANDING CROP RELATIONSHIPS

The measured total standing crop of *Populus* stands varied from 8.7 t/ha in a dense (128 330 stems/ha) 5-year-old stand to 325.1 t/ha in a 72-year-old stand containing 1500 stems/ha. The latter is substantially higher than any previously reported total standing crop for aspen. An inverse relationship was noted between the total standing crop and number of stems per hectare for fully stocked boreal and montane stands with no distinct canopy openings, and this relationship was statistically different from the one for the isolated groves of the aspen-grassland transition (Fig. 2). The number of stems is related inversely to age. The relationships between the number of stems per hectare and the bole, crown, and total above-ground standing crops of closed *Populus* stands of the Boreal and Montane forest regions are shown in Table 7.

Table 8 shows the relationships between the number of stems per hectare and the mean bole, mean crown, and mean total above-ground dry weights per tree for *Populus* trees grown in fully stocked stands in the Boreal and Montane forest regions. As is apparent from Fig. 3, these relationships do not apply to trees grown in the groves of the aspen-grassland transition zone.

Standing crop density, the apparent density of organic matter per unit volume of forest stand space, varied from 0.54 to 1.63 kg/m^3. This range is somewhat broader than the 1.0 to 1.5 kg/m^3 suggested for fully closed stands by Kira and Shidei (1967). Unlike Kira and Shidei, who reported that dry matter density is practically independent of stand height, we found that standing crop density increased with stand height (Fig. 4). The relationship between standing crop density and number of stems per unit area is hyperbolic (Fig. 5) and appears to become relatively constant at just over 0.63 kg/m^3 after 10 000 stems/ha. For both of these relationships (Figs. 4 and 5), the data from the grove stands of the aspen-grassland transition were not significantly different from those from the closed stands of the Boreal and Montane forest regions. This was because the lower stand heights compensated for the lower standing crops in the calculation of the standing crop densities of the grove stands.

The observed leaf area indices of the *Populus* stands varied from 2.41 to 5.39, which are slightly lower than those suggested by Tadaki (1966) for a deciduous broad-leaved forest. These results do agree, however, with the somewhat lower estimates reported for other aspen stands in Canada by Peterson *et al.* (1970) and Pollard (1972). The results tend to suggest a slightly higher leaf area index for balsam poplar than aspen stands. Leaf area index was not significantly correlated with mean height but was significantly correlated ($r = 0.501$ for 14 degrees freedom) with the number of stems per hectare. This lack of correlation between mean stand height and leaf area index may occur because live crown length seems constant once aspen trees reach 15 to 20 years of age. As a result, a young aspen stand has a large leaf system relative to the amount of respiring tissue present in the stem, branches, and leaves, so that the net difference between photosynthesis and

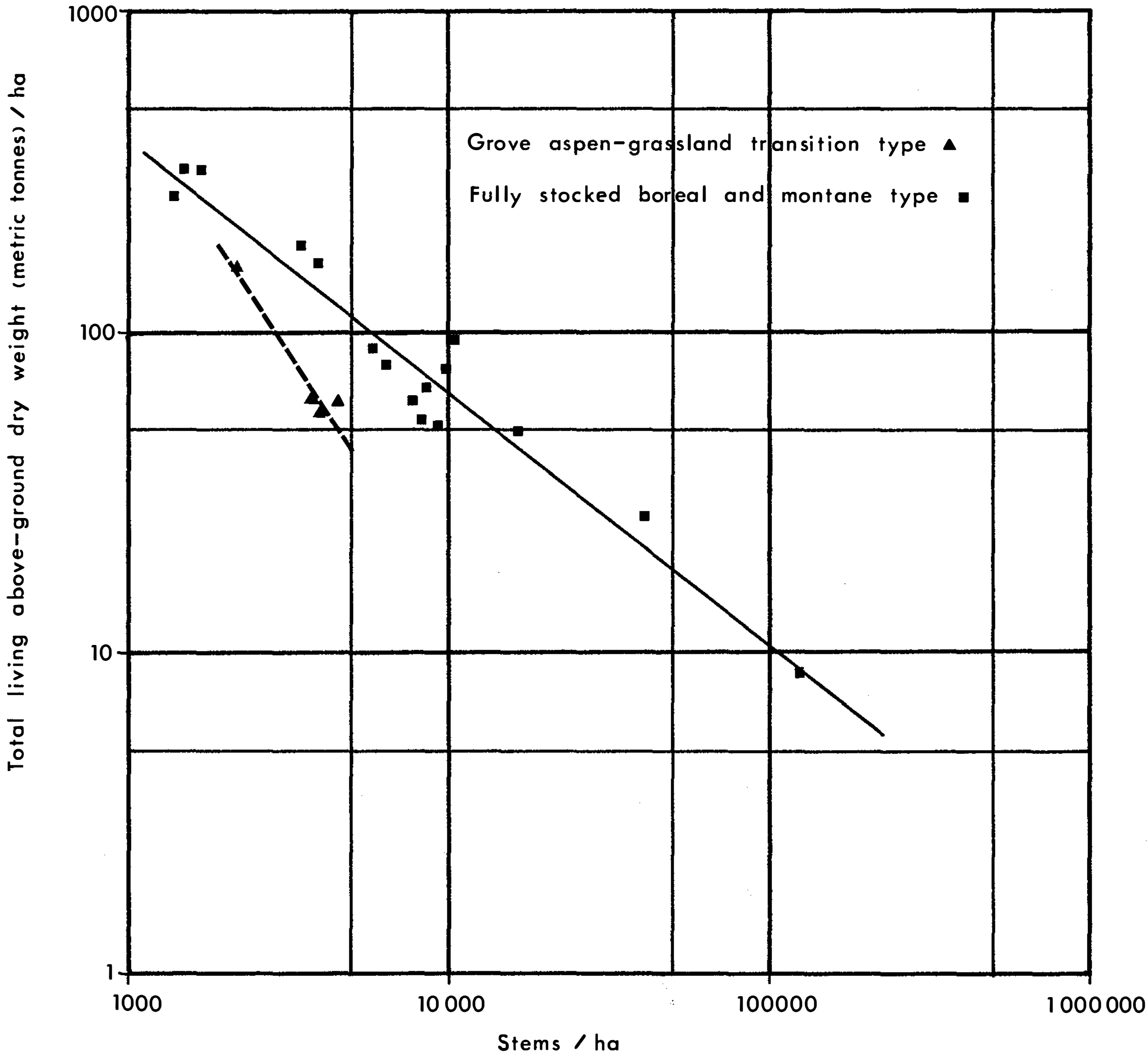

Figure 2. Relationships between total standing crop and number of stems per hectare for 20 *Populus* stands in Alberta.

Table 7. Stand density and standing crop relationships for 16 closed *Populus* stands in the Boreal and Montane forest regions

	r^2	$s_{y \cdot x}$
L_n bole dry weight (t/ha) = 14.479 - 1.1605 L_n no. stem/ha	0.892	0.490
L_n crown dry weight (t/ha) = 5.414 - 0.3352 L_n no. stem/ha	0.513	0.395
L_n total dry weight (t/ha) = 11.438 - 0.7865 L_n no. stem/ha	0.946	0.228

Table 8. Stand density and mean tree dry-weight relationships for 16 closed *Populus* stands in the Boreal and Montane forest regions

	r^2	$s_{y \cdot x}$
L_n mean bole dry weight (kg/ha/tree) = 20.670 - 2.076 L_n no. stems/ha	0.977	0.390
L_n mean crown dry weight (kg/ha/tree) = 12.365 - 1.340 L_n no. stems/ha	0.946	0.389
L_n mean total dry weight (kg/ha/tree) = 18.313 - 1.783 L_n no. stems/ha	0.989	0.228

respiration is high and results in rapid growth. In older stands, the photosynthetic component (leaf area index) is not proportionately larger relative to the much larger biomass of the respiring tissues, so that the gap between photosynthesis and respiration is smaller, and growth drops off.

CONCLUSIONS

Stem wood, stem bark, and total above-ground tree weights were most closely correlated with D^2H, and crown component weights were most closely correlated with transformations of stem diameter at crown base, which was not used in the equations because it is not a very readily measurable variable. The equations provide reasonable estimates of all component weights but are more accurate for stem rather than crown components.

When estimates of standing crop, based upon an equation × stand-table approach, were compared with the observed standing crops of 17 *Populus* stands, some large discrepancies were noted for individual stands. Thus, although this method of estimation may provide reasonable average estimates for large blocks of timber or for a number of stands combined, caution must be exercised when using this method to estimate the biomass of small stands or individual sample plots. It is possible that these discrepancies were the result of between-stand genetic variation in tree form and production structure of the clonally-distributed species studied. If precise estimates for small areas are required, some method should be undertaken to localize these general equations, which are similar to those used in volume-table estimates.

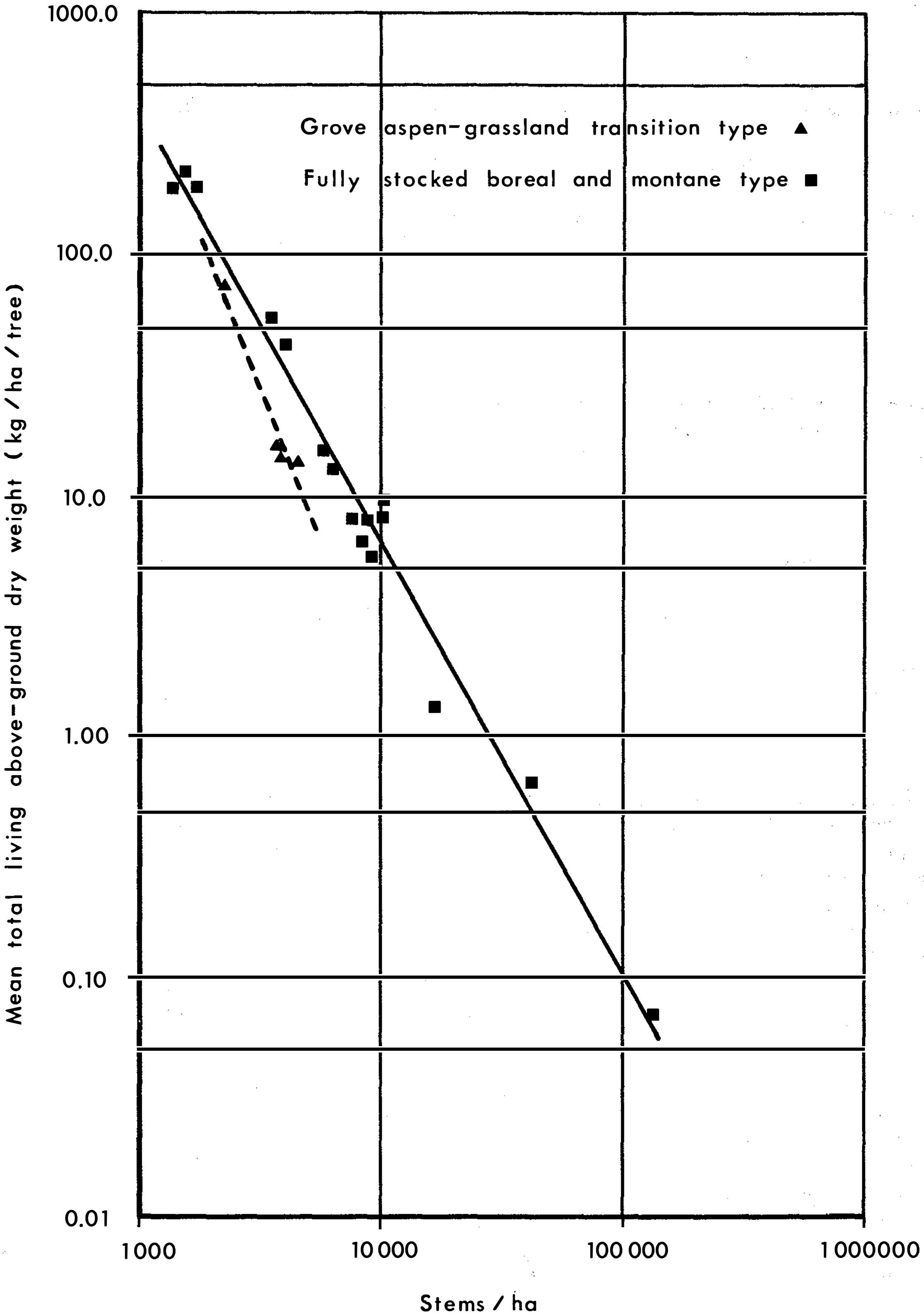

Figure 3. **Relationships between mean total standing crop per tree and number of stems per hectare for 20** *Populus* **stands in Alberta.**

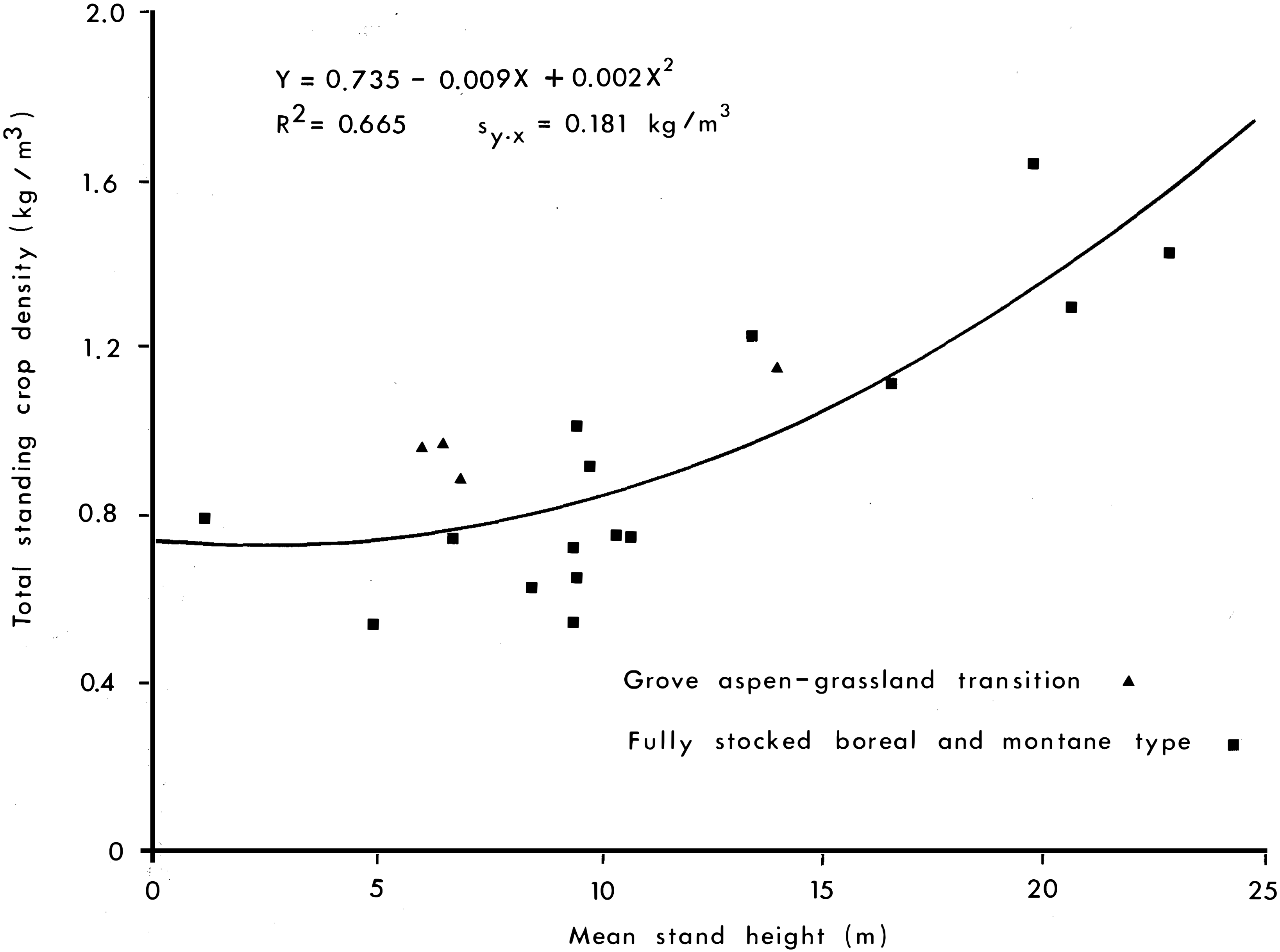

Figure 4. Relationship between total standing crop density and mean stand height for 20 *Populus* stands in Alberta.

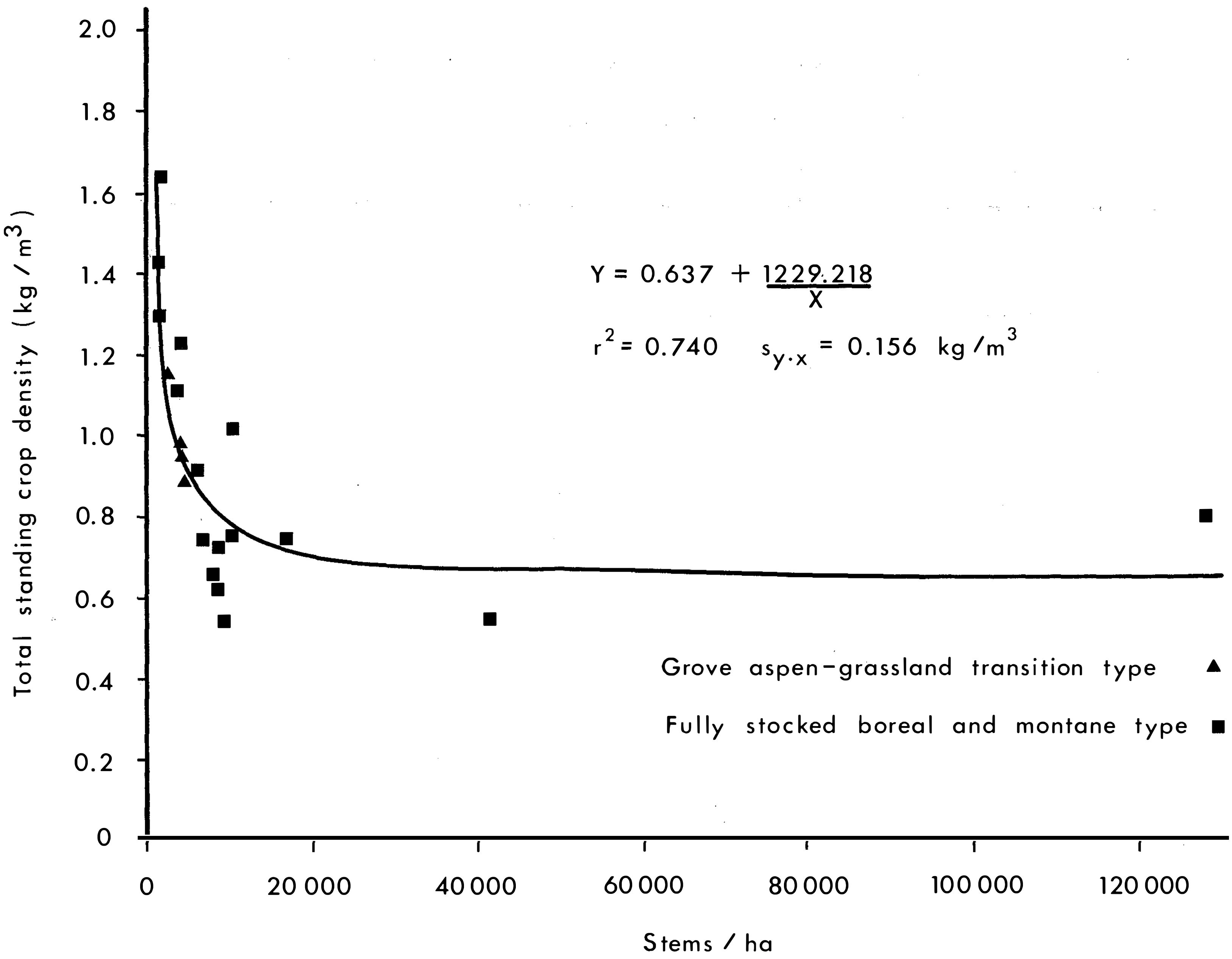

Figure 5. Relationship between total standing crop density and number of stems per hectare for 20 *Populus* stands in Alberta.

The observed total standing crop of 20 *Populus* stands ranged from 8.7 to 325.1 t/ha. Both standing crop and average standing crop per tree for the bole, crown, and total above-ground components were related inversely to stand density (number of stems per hectare). Significant differences were noted in these relationships between the fully stocked stands of the Boreal and Montane forest regions and the grove-type stands of the aspen-grassland transition zone. The observed leaf area indices of the *Populus* stands sampled in Alberta were slightly lower than those suggested for deciduous broad-leaved forests sampled elsewhere.

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