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BIOMASS PRODUCTIVITY OF YOUNG ASPEN STANDS IN WESTERN CANADA

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ABSTRACT

Equations and tables are presented for estimating above-ground tree component dry weights for fully stocked aspen (*Populus tremuloides* Michx.) stands up to 40 years old growing on different sites in the mixedwood forests of Alberta and Saskatchewan. The distribution of biomass components in relation to stand age was analyzed, which indicated that with increasing age the proportion of leaves declines while the proportion of stem wood increases. Optimum rotation lengths were calculated based on culmination of biomass mean annual increment (MAI). Optimum rotation was around 30 years for all conditions, but the estimated maximum total above-ground biomass MAI ranged from 4.8 $t\cdot ha^{-1}$ on better sites (site index 24 m at 50 years) to 2.2 $t\cdot ha^{-1}$ on poorer sites (site index 16 m).

RESUME

Des équations et tables sont proposées pour évaluer les poids anhydres des parties aériennes des arbres dans les peuplements fermés de Peuplier faux-tremble (*Populus tremuloides* Michx.) agés de 40 ans et moins venant sur diverses stations dans les forêts mixtes de l'Alberta et de la Saskatchewan. La répartition des composantes de la biomasse en rapport avec l'age du peuplement a été déterminée, en montrant que la proportion de feuilles décline à mesure avec l'âge alors que celle du bois de tige augmente. La durée optimale des révolutions a aussi été calculée en se fondant sur le point culminant de l'accroissement annuel moyen (AAM) de la biomasse. Sous toutes les conditions, la révolution optimale se situait a 30 ans environ, mais l'évaluation de 1'AAM de la biomasse aérienne maximale totale a varié entre 4.8 $t\cdot ha^{-1}$ sur les meilleures stations, (indice de station 24 m a 50 ans) et 2.2 $t\cdot ha^{-1}$ sur les stations les plus pauvres (indice de station 16 m).

FOREWORD

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INTRODUCTION

Aspen (*Populus tremuloides* Michx.) is one of the most widely distributed tree species in Canada. It is a pioneer species that becomes established quickly after a disturbance such as logging or fire, and at younger ages it generally outgrows most other companion tree species.

These desirable silvicultural characteristics notwithstanding, utilization of aspen so far has been very limited; in the early 1970's it amounted to only 1% of the annual allowable cut in Alberta and 14% in Saskatchewan[1]. The reasons for underutilization of this species for traditional forest products lie in its lower-value wood, the relative abundance of higher-value coniferous timber in the region, the remoteness from market that makes such lower-value products uneconomic, and the generally high incidence and great variability of disease (stem rot) in mature aspen stands.

With the growing interest in utilization of forest biomass for production of energy and other uses such as livestock feed, Canada's aspen resource has great potential. Forest biomass is all tree and shrub materials from root tips to leaf or needle tips.

Because the greatest production potential is at younger ages, this study was initiated to determine biomass components of aspen between stand establishment and age 40 years on a range of site and density conditions.

DESCRIPTION OF THE ASPEN FOREST SAMPLED

Sampling was restricted to the Mixedwood Section (B.18a) of the Boreal Forest Region (Rowe 1972) in Alberta and Saskatchewan. Aspen-white spruce (*Picea glauca* (Moench) Voss) is the prominent forest type, but relatively pure stands of either species are common. These forests also may contain balsam poplar (*Populus balsamifera* L.), balsam fir (*Abies balsamea* (L.) Mill.), black spruce (*Picea mariana* (Mill.) BSP.), jack pine (*Pinus banksiana* Lamb.), white birch (*Betula papyrifera* Marsh.), and willows (*Salix* spp.).

Regeneration data originated from one area in each province: close to Athabasca, Alberta, and near Hudson Bay, Saskatchewan. Data for the 6- to 40-year-old stands came from a cross section of the mixedwood forests in each province. In Alberta the greatest concentration of samples was in the vicinity of Lesser Slave Lake, where aspen appears to attain optimum development. In Saskatchewan most of the sampling was done near Hudson Bay, where substantial amounts of aspen are being utilized for wafer-board manufacture. Tree component weight regressions were derived from aspen data collected in Alberta and Saskatchewan and from balsam poplar data from Alberta only. Figure 1 shows sampling locations.

Topography and soil conditions varied considerably over the sampling areas: from rolling till in the Slave Lake region and gently undulating terrain in eastern Alberta and western and central Saskatchewan to level lake sediments around Hudson Bay in eastern Saskatchewan. Aspen stands reached best development on clay loams to fairly heavy clays on uplands with fresh-to-moist moisture status.

Most of the stands sampled originated after fire; however, some young stands under 15 years old in the vicinity of Hudson Bay had regenerated after logging, while some very young stands near Athabasca had originated following land clearing.

METHODS

Equations for estimating biomass yield per hectare generally are derived from sample plot values of dry weight per unit area. For regeneration stands up to 5 years old these were based on direct estimates of dry weight by component, obtained by harvesting and weighing all woody materials on small sample plots. For stands in the older age

[1] Personal communication, September 1979, with M. Little, Saskatchewan Department of Tourism and Renewable Resources.

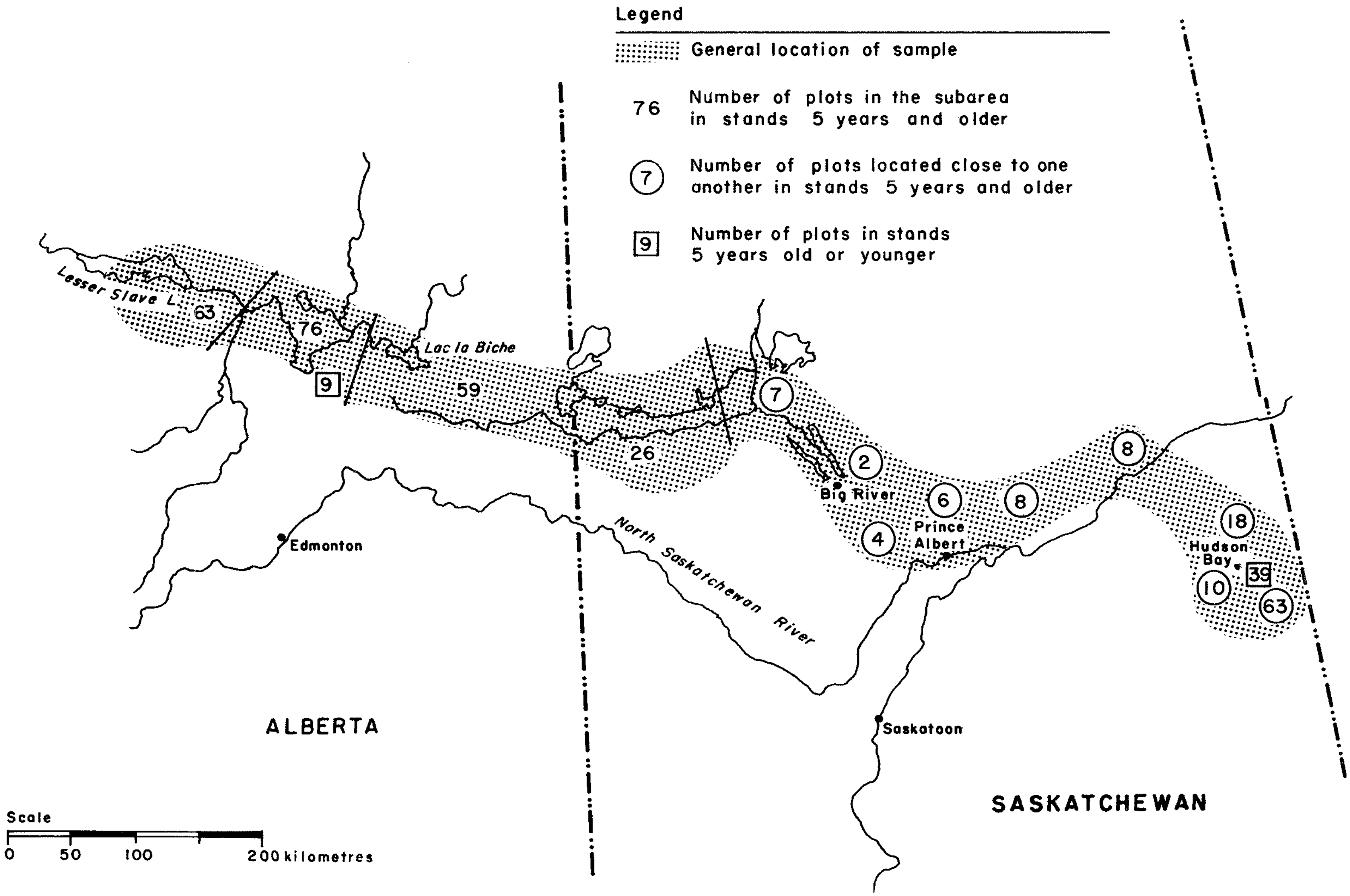

Figure 1. Sampling locations.

group, tree dimension data from sample plots together with tree component weight regressions were used.

Plot dry weights for 2- to 5-year-old aspen regeneration were estimated by harvesting all the green (fresh) material on the plot, taking subsamples of this material to obtain the green and dry weights, then working out appropriate ratios for calculating dry weight biomass for the entire plot.

Plot dry weights of stands in the older age group were estimated from stand tables and tree component dry weight regressions that expressed the component weight of individual trees in terms of easily measured dimensions such as diameter at breast height (dbh) and height. The required tree component regressions were developed using data already available in eastern Saskatchewan.

Sample Selection Criteria and Field Procedures

Aspen Regeneration 2 to 5 Years Old:

1. Plots were located in relatively homogeneous patches that may not always have had complete crown closure but represented a range of site conditions in the region.

2. Aspen was the dominant woody species.

3. No plots were located on roads, logging trails, landings, or other heavy traffic areas.

4. Plots were located far enough from adjacent older stands to avoid any direct influence on tree growth.

5. Descriptive information recorded on each plot included topography and moisture regime, occurrence and frequency of some characteristic herbs and shrubs, and any other factors that may have indicated stand productivity.

6. Plots were circular and of sufficient size to contain at least 100 aspen stems, including live trees and standing dead. Minimum plot radius was 1.5 m (7.07 m^2 area).

7. On each plot, all living and dead standing aspen trees and other living woody species—i.e., alder (*Alnus crispa* (Ait.)), balsam poplar, white birch, white spruce, willows, pin cherry (*Prunus pensylvanica* L.f.), and chokecherry (*P. virginiana* L.)—that would compete with aspen for crown space were cut at ground level.

8. After harvest:

   8.1 Living aspen were counted, and their aggregate fresh weight was determined (shoots and leaves, in g).

   8.2 Live stems of other species were counted, and their aggregate fresh weight (shoots and leaves) was determined.

   8.3 The length (height in cm) of four dominant aspen suckers per plot was measured.

   8.4 An aspen subsample of about 1 kg fresh weight was obtained from each plot to determine fresh weight/dry weight ratios. This subsample was separated into (a) shoots and (b) current year's twigs plus leaves, then it was air dried in paper bags.

Stands 6 Years and Older:

1. Stand age was between 6 and 40 years.

2. Stands were fully stocked—i.e., with more or less complete crown closure—and represented the range of site conditions in the region.

3. As much as possible, sample plots were located within one clone.

4. The same descriptive information (topography, moisture regime, etc.) was recorded as for the 2- to 5-year-old stands.

5. Plots were at least 50 m from an adjacent stand of different age and at least 25 m from the nearest living residuals.

6. Plots were within cut blocks or stands at least 5 ha in size.

7. Plots were at least 50 m from landings, logging trails, and roads and at least 50 m from one another within a stand (maximum four plots per stand).

8. Plots represented stands where at least 85% of the trees were aspen.

9. Plots were circular and of sufficient size to contain at least 100 trees but were no smaller than 20 m^2.

10. Measurements on each plot included a diameter tally (at breast height of 137 cm) of all living trees by species (also alder, willows, pin cherry, and chokecherry in stands under 15 years). Standing dead aspen and stems of other tree species (mainly balsam poplar) were also tallied. Leaning trees were tallied if their point of measurement (137 cm above base) was at least knee height above ground.

11. The four tallest aspen were cut at ground level for age determination, and their total stem length (height) was also measured to the nearest cm. For some of the oldest stands and plots established in provincial parks, ages were estimated from increment cores, which avoided cutting down trees. In addition, the heights of another 10 trees of a representative range of sizes were measured on each plot with measuring tape (by bending over the tree), height pole, or clinometer and were rounded to the nearest 5 cm.

Above-ground Weights of Individual Aspen Trees:

Data on 25 aspen sample trees from the Hudson Bay area were collected to augment tree component weight data already available for aspen in the region.

The sample trees were healthy dominant and codominant aspen from 10 to 25 cm diameter at breast height over bark (dbhob), had normal crowns, and grew in stands with more or less complete crown closure. The selected trees were felled, and detailed dimensional measurements were obtained. Each felled tree was separated into (a) bole and (b) branches plus leaves, and the respective fresh weights were determined. From the bole, disc subsamples 2- to 3-cm thick were cut, and separate green weights of the wood and bark of these discs were obtained. A subsample taken from the branches was separated into leaf bunches and branches, and their fresh weights were determined. Detailed instructions for procedures and measurements are given in Appendix 1.

Laboratory Procedures

Dry weights of subsamples were obtained after oven drying at approximately 100°C to constant weight. These data were used for calculating dry weight/fresh weight ratios for different tree components.

For the regeneration stands, the ratios were used to estimate dry weights of stem and branch materials (wood plus bark) and of leaves (including twigs) from actual fresh weights.

For the sample of 25 trees from Hudson Bay, the ratios were used to convert fresh weights to dry weights for the following components:

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

2. branch wood, branch bark, plus the stem less than 2 cm dob, and

3. leaves plus current twigs.

Development of Individual Tree Component Biomass Equations

In addition to the aspen tree data collected at Hudson Bay in the summer of 1978, aspen and balsam poplar data from another study of poplar stands in Alberta[2] also were used. Table 1 summarizes these data.

Component and total tree dry weight regressions that expressed weight in terms of dbh and height were derived using a logarithmic model. Although such regression models do not ensure fully additive component weight estimates, this was overlooked because of the inherent weighting this model provides in equalizing variances across the range of tree sizes. The regressions were adjusted for logarithm-introduced bias (Baskerville 1972).

Of the numerous combinations of independent variables tested, the most useful and consistently significant in the regressions was the combined variable term

$$\ln(D^2 H)$$

ln = natural logarithm
D = dbhob
H = total height

Other terms of the same variables had low or no significance, so were dropped from the regression. The final form of the model used for both species was

$$\ln W = a + b \ln(D^2 H)$$

W = tree component or total weight

Appropriate covariance tests were conducted to determine whether significant differences existed between the weight-size relationships of the two sets of aspen data. Furthermore, an analysis of residuals was done to detect and, if necessary, correct any bias in the final regressions.

To estimate dry weights of species other than aspen and balsam poplar on the sample plots, suitable regressions were selected from the literature. These are presented in Appendix 2.

Development of Stand Component Biomass Equations

Because of the nature of aspen stand development—the very large number of suckers and high mortality in the first 5 years (Bella and De Franceschi 1972)—and the nature of the data collected, separate analyses were done for aspen regeneration, i.e., stands 5 years old and under, and for stands 6 years and older. For the first group, most of the data came from the vicinity of Hudson Bay (Table 2), while for the second group the data were divided about equally between Alberta and Saskatchewan.

Multiple regression analyses were used to derive component yield predicting functions in terms of various traditional yield characteristics such as age, site index, Lorey's height (height of the quadratic mean diameter tree), quadratic mean dbh, basal area, number of trees, and combinations of the above. Only for the older age group were all these characteristics available; for the aspen regeneration group only dominant height (estimate of site index) and number of trees were available. Accordingly, only a very simplistic model could be developed for the latter.

For stands 6 years and older, separate biomass yield regressions were fitted for the Saskatchewan and the Alberta data. Covariance analyses were conducted to detect whether significant differences existed between stand biomass yield relationships for the east half (Saskatchewan) and the west half (Alberta) of the sampling area.

Yield tables generally are presented for chosen site quality classes, and yield estimates are derived for a sequence of ages, dominant heights, average diameters, basal areas, and numbers of trees per hectare. For the tables in this study, the requisite dominant height series was derived from aspen site index curves[3], and regression techniques were

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[2] W.D. Johnstone and E.B. Peterson, Northern Forest Research Centre, manuscript in preparation on above-ground component weights in Alberta *Populus* stands.

[3] I.E. Bella and J.P. De Franceschi, Northern Forest Research Centre, manuscript in preparation on site index curves for aspen in the Prairie provinces.

Table 1. **Summary statistics for aspen and balsam poplar sample trees**

		Aspen						Balsam poplar		
		Alberta (n = 254)			Saskatchewan (n = 25)			Alberta (n = 61)		
Statistics	Symbol	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.
Stump age (years)	A	45	8	83	37	26	51	32	13	65
Dbhob (cm)	D	12.7	2.0	31.5	16.5	10.1	25.2	11.5	0.9	27.4
Total height (cm)	H	1318	415	2774	1712	124.9	2100	1328	214	2325
Combined variable ($cm^3/1000$)	D^2H	347	1.8	2752	534	143	1327	300	0.25	1655
		Oven dry weights in kg								
Stem wood	Sw	47.9	0.23	372.7	75.9	21.1	211.5	34.8	0.090	178.5
Stem wood + bark	Sw+b	59.8	0.33	448.5	91.5	24.8	249.3	43.6	0.10	218.0
Stem wood + bark + branches	Sw+b+br	66.9	0.52	553.0	103.9	28.1	272.3	46.6	0.10	239.3
Branches + leaves	Br+l	8.2	0.14	113.0	15.2	4.1	61.1	3.9	0.020	26.3
Total tree	T	68.0	0.57	561.6	106.7	29.0	277.4	47.6	0.12	242.9

used to fit average trends to the data for the other required characteristics.

RESULTS

Component Weight Equations for Individual Trees

Component and total weight regressions developed for individual aspen and balsam poplar trees are presented in Table 3. The combined variable term, $\ln(D^2H)$, generally explained over 98% of the variation in component or total tree weight for either species. The exception was the *branches + leaves* component, for which 82.3% of the variation was explained for aspen and 86.6% for balsam poplar.

Covariance analyses conducted to test for differences between the two sets of aspen data (Alberta vs. Saskatchewan) revealed no significant differences in the regressions for *stem wood*, *stem wood + bark*, *stem wood + bark + branches*, and *total tree*; however, the two regressions for *branches + leaves* were significantly different at the 0.05 level of probability but not at the 0.01 level. Because branches and leaves constitute a relatively small and the most variable portion of the total tree biomass, it was felt that the small improvement in accuracy would not compensate for the inconvenience of using two sets of *branches + leaves* regressions. Therefore, the aspen data were pooled, and a single set of regressions was adopted.

Using the regressions derived for the two species, residuals were calculated (observed minus estimated values) and plotted. The plotting showed fairly similar dispersion and generally a lack of observable trends in the residuals over the range of the independent term. The notable exception was the *branches + leaves* component, for which the residuals indicated an underestimation of predicted values for the small trees (for dbhob around 3 cm). After considering the general suitability of the present model for describing aspen and balsam poplar component weights, it was decided to overlook this shortcoming.

Biomass of Aspen Regeneration 5 Years and Younger

Data from 50 plots were used in this analysis: 40 from Saskatchewan, 10 from Alberta. Data from two plots (one from each

Table 2. Summary statistics of aspen stands sampled

Statistics	Symbol	Avg.	Min.	Max.
Stands up to 5 years old, Alberta and Saskatchewan (n = 48)				
Stand age (years)	A	3.4	2	5
Dominant height (cm)	H_D	272.5	174.7	439.0
Number of trees (ha^{-1})	NT	134 676	34 632	389 102
Total dry weight ($kg \cdot ha^{-1}$)	T	8 494	5 144	13 363
Wood dry weight ($kg \cdot ha^{-1}$)	W	6 080	2 823	10 679
Leaf dry weight ($kg \cdot ha^{-1}$)	L	2 413	1 508	3 938
Stands 6 years and older, Alberta (n = 198)				
Stand age (years)	A	22.5	5	44
Dominant height (cm)	H_D	1 258.8	251.3	2 157.3
Lorey's height (cm)	H_L	960.3	197.1	1 976.6
Number of trees (ha^{-1})	NT	14 741	2 376	57 550
Mean dbhob (from dbh^2) (cm)	D	5.9	0.7	13.1
Basal area ($m^2 \cdot ha^{-1}$)	BA	26.01	2.01	58.04
Dry weights ($kg \cdot ha^{-1}$):				
Total tree	T	86 197	1 964	271 769
Stem wood	Sw	57 518	1 007	191 256
Stem wood + bark	Sw+b	74 175	1 508	239 576
Stem wood + bark + branches	Sw+b+br	83 818	1 846	266 579
Branches + leaves	Br+l	11 830	461	33 053
Stands 6 years and older, Saskatchewan (n = 152)				
Stand age (years)	A	21.3	5	44
Dominant height (cm)	H_D	1 169.5	297.7	2 190.0
Lorey's height (cm)	H_L	896.4	218.9	1 758.5
Number of trees (ha^{-1})	NT	14 439	2 367	53 051
Mean dbhob (from dbh^2) (cm)	D	5.7	1.0	13.1
Basal area ($m^2 \cdot ha^{-1}$)	BA	23.47	1.40	53.14
Dry weights ($kg \cdot ha^{-1}$):				
Total tree	T	73 140	1 381	229 254
Stem wood	Sw	48 577	729	160 615
Stem wood + bark	Sw+b	62 837	1 067	201 681
Stem wood + bark + branches	Sw+b+br	71 085	1 301	224 795
Branches + leaves	Br+l	10 127	310	28 324

Table 3. Tree component weight regressions of $\ln W = a + b \ln(D^2 H)$ for aspen and balsam poplar

Component dry weights* (g)	Regression statistics†		
	a⊥	b	r^2
	Aspen (n = 279)		
Y_1	-1.70703	0.979867	0.992
Y_2	-1.16921	0.955453	0.991
Y_3	-0.89667	0.942525	0.988
Y_4	-1.77476	0.848092	0.823
Y_5	-0.80319	0.936736	0.987
	Balsam poplar (n = 61)		
Y_1	-1.33769	0.936371	0.984
Y_2	-1.05307	0.931756	0.988
Y_3	-0.94500	0.927708	0.990
Y_4	-1.53009	0.777939	0.866
Y_5	-0.74651	0.913854	0.989

* Y_1 = ln (*stem wood* to 2-cm top)
Y_2 = ln (*stem wood + bark* to 2-cm top)
Y_3 = ln (*stem wood + bark + branches*)
Y_4 = ln (*branches + leaves*); leaves include twigs
Y_5 = ln (*total tree* above ground).

† D and H in cm.

⊥ Has been adjusted as in Baskerville (1972).

province) later were discarded because of apparent irregularities. Stand age varied from 2 to 5 years. In addition to age, the number of trees per hectare was the other independent variable in the analysis. Site index at this early age is a rather meaningless variable and thus was not used. An expression of average dominant height calculated from the data was tried in the analysis but showed no significance, perhaps partly because of the limited range of site conditions (generally better sites) represented by the data. After trying different combinations of variables, the following simple model was adopted:

$$DW = a + b_1 A^2 + b_2 \ln NT$$

DW = dry weight ($kg \cdot ha^{-1}$)
A = age
NT = number of trees per hectare

The three regressions derived for leaves (including twigs), wood, and total dry weights were (in $kg \cdot ha^{-1}$; n = 48):

$$\text{Leaf DW} = -3008.2 + 4.852 A^2 + 460.341 \ln NT$$
$R^2 = 0.166$ SE = 561.7

$$\text{Wood DW} = -8740.0 + 248.878 A^2 + 990.105 \ln NT$$
$R^2 = 0.523$ SE = 1566.0

$$\text{Total DW} = -11746.6 + 253.722 A^2 + 1450.390 \ln NT$$
$R^2 = 0.394$ SE = 1934.1

The underlined terms were not significant (at the 0.05 probability level); nevertheless, they were retained in the regressions to ensure the additivity of component weight estimates (Bella 1968). Using these regressions, stand component weights were estimated for regeneration 2 to 5 years old and for three density classes chosen on the basis of the available data. These estimates are presented in Table 4.

Biomass of Aspen Stands 6 Years and Older

Using standard multiple regression techniques, a number of different basic yield models and combinations of selected variables were tried with the two data sets from Alberta and Saskatchewan. The model that best described all the data and consequently was retained for use was the following:

$$W = a + b_1 D + b_2 BA + b_3 H_D + b_4 H_L + b_5 (H_D \cdot BA)$$

(See Table 2 for explanation of symbols.)

Table 5 lists appropriate statistics for these regressions. All variables were significant with the exception of D for the Saskatchewan data, which nevertheless was retained to improve additivity of biomass component estimates. The five independent variables explained over 99% of the variation in component and total biomass, and standard error of estimate ranged from 2.6% for *stem wood + bark*, *stem wood + bark + branches*, and *total tree* for the Alberta data to 4.5% for *branches + leaves* for the Saskatchewan sample. The combined variable term $H_D \cdot BA$ was by far the most important independent variable in these regressions, and dropping all other independent variables generally resulted in less than a 1% reduction in explained variation. One exception was the *branches + leaves* component, for which the related drop in explained variation for the combined variable model was around 2%. The related standard error of estimate expressed as percentage of the mean for this model was about double that of the more complex model, i.e., generally close to 6% with the exception of *branches + leaves*, which was just under 10%.

The amount of difference between component weight estimates for the two provinces was rather small; in fact, the estimates overlapped at midranges of 20 to 30 years of age (Fig. 2). Nevertheless, separate regressions for the two provinces will provide slightly more accurate estimates.

Covariance analyses showed highly significant (at the 0.01 probability level) differences between biomass yield multiple regressions for the two provinces with the exception of the *branches + leaves* component regressions, which were significantly different at the 0.05 level. Biomass regressions with only the combined variable term were significantly different at the 0.05 probability level for *stem wood + bark + branches* and *total above-ground biomass* and at the 0.01 level for *branches + leaves*. These statistical differences in the relationships may not mean substantial differences in estimated yields, but the use of appropriate individual regressions for the two provinces is likely to result in better fit and less bias, especially for stands representing more extreme conditions.

To compile biomass yield tables from this sample for the two provinces, average trends of quadratic mean dbh, Lorey's height, and number of trees per hectare were fitted to the data. Statistics for these regressions are given in Table 6, which includes separate parallel regressions for mean dbh for Alberta and Saskatchewan and common regressions (differences between individual regressions are not significant) for number of trees and Lorey's height. Stand basal area values were calculated from mean dbh and number of trees. Average dominant height values were obtained from suitable site index curves. All requisite stand statistics and biomass yields were estimated in 2-year intervals from 6 to 40 years for site index classes 16, 20, and 24 m (reference age 50 years) and are presented in Table 7 for Alberta and Table 8 for Saskatchewan.

Inherent in constructing yield tables this way is the difficulty in deriving meaningful error estimates (Table 5). To provide an indication of the precision of the estimates in these tables, two statistics, aggregate deviation (AD) and mean absolute deviation (MAD),

Table 4. Component biomass dry weight of fully stocked aspen regeneration for three density classes, Alberta and Saskatchewan combined

Age (years)	Dominant height (m)	Number of trees (ha^{-1})	Component dry weights ($kg \cdot ha^{-1}$) Woody material	Leaves	Total
2	1.7	160 000	4 120	2 527	6 648
		220 000	4 435	2 674	7 110
		280 000	4 674	2 785	7 460
3	2.4	110 000	4 993	2 379	7 373
		150 000	5 300	2 522	7 823
		190 000	5 534	2 631	8 166
4	3.0	75 000	6 356	2 237	8 594
		100 000	6 641	2 369	9 011
		125 000	6 862	2 472	9 335
5	3.5	50 000	8 195	2 094	10 289
		65 000	8 454	2 215	10 670
		80 000	8 660	2 310	10 971

Table 5. Above-ground biomass yield regression statistics for Alberta, Saskatchewan, and pooled data

Component dry weights ($kg \cdot ha^{-1}$)	Regression constant	Independent variables and their significance: $X_1 = D$		$X_2 = BA$		$X_3 = H_D$		$X_4 = H_L$		$X_5 = H_D \cdot BA$			Standard error of estimate	
		Regression coefficients and F-ratios												
	a	b_1	F	b_2	F	b_3	F	b_4	F	b_5	F	R^2	kg	% of mean
Alberta data (n = 198)														
Stem wood	933.3	-70.65	17	129.01	16	-27.02	598	38.17	680	1.440	4 774	0.998	1 558.4	2.7
Stem wood + bark	144.6	-139.14	44	391.88	97	-32.06	565	49.44	766	1.708	4 509	0.998	1 901.8	2.6
Stem wood + bark + branches	-264.8	-190.66	63	568.12	155	-34.86	506	56.64	762	1.843	3 975	0.998	2 185.4	2.6
Branches + leaves	-316.6	-60.87	145	212.43	490	-3.30	102	8.42	380	0.165	723	0.996	459.8	3.9
Total tree (above ground)	-522.8	-210.39	75	649.18	198	-34.81	493	58.11	782	1.849	3 904	0.998	2 212.1	2.6
Stem wood	665.7									1.495	22 102	0.991	3 654.3	6.4
Stem wood + bark	2 468.8									1.886	20 913	0.991	4 738.3	6.4
Stem wood + bark + branches	3 880.8									2.103	19 168	0.990	5 517.3	6.6
Branches + leaves	1 837.4									0.263	7 128	0.973	1 131.0	9.6
Total tree (above ground)	4 554.9									2.148	18 607	0.990	5 719.4	6.6
Saskatchewan data (n = 152)														
Stem wood	-203.1	-29.18	1.6	173.35	27	-22.00	287	30.87	198	1.379	3 937	0.998	1 381.3	2.8
Stem wood + bark	-1 326.6	-76.76	7.0	451.37	114	-25.56	242	39.58	203	1.625	3 415	0.998	1 747.8	2.8
Stem wood + bark + branches	-1 761.0	-111.37	10	647.22	161	-27.70	195	44.61	177	1.751	2 714	0.998	2 112.6	3.0
Branches + leaves	-365.0	-43.64	33	231.59	439	-2.58	36	6.15	72	0.157	463	0.994	457.6	4.5
Total tree (above ground)	-2 052.4	-129.18	14	729.60	204	-27.56	192	45.89	186	1.755	2 715	0.998	2 117.0	2.9
Stem wood	1 128.0									1.473	25 322	0.994	2 748.1	5.6
Stem wood + bark	3 278.5									1.849	23 668	0.994	3 567.9	5.7
Stem wood + bark + branches	4 902.9									2.054	20 949	0.993	4 214.2	5.9
Branches + leaves	2 070.8									0.250	5 797	0.975	975.2	9.6
Total tree (above ground)	5 635.3									2.096	20 215	0.993	4 375.7	6.0
Pooled data (n = 350)														
Stem wood	470.8	-71.09	29	150.87	40	-25.44	916	36.59	916	1.422	8 587	0.998	1 514.2	2.8
Stem wood + bark	-448.5	-135.84	68	421.40	206	-30.07	834	47.27	996	1 682	7 831	0.998	1 876.1	2.7
Stem wood + bark + branches	-857.6	-184.30	92	606.83	312	-32.71	719	53.92	944	1.814	6 632	0.998	2 198.2	2.8
Branches + leaves	-327.9	-58.26	206	221.31	929	-3.12	147	7.86	450	0.163	1 196	0.995	464.2	4.2
Total tree (above ground)	-1 129.7	-204.00	110	688.53	394	-32.64	703	55.36	978	1.819	6 552	0.998	2 218.2	2.8
Stem wood	864.5									1.487	45 342	0.992	3 298.1	6.1
Stem wood + bark	2 790.7									1.872	42 489	0.992	4 289.5	6.2
Stem wood + bark + branches	4 284.5									2.085	38 384	0.991	5 025.2	6.4
Branches + leaves	1 925.1									0.258	12 756	0.973	1 079.6	9.7
Total tree (above ground)	4 979.0									2.128	37 124	0.991	5 216.4	6.5

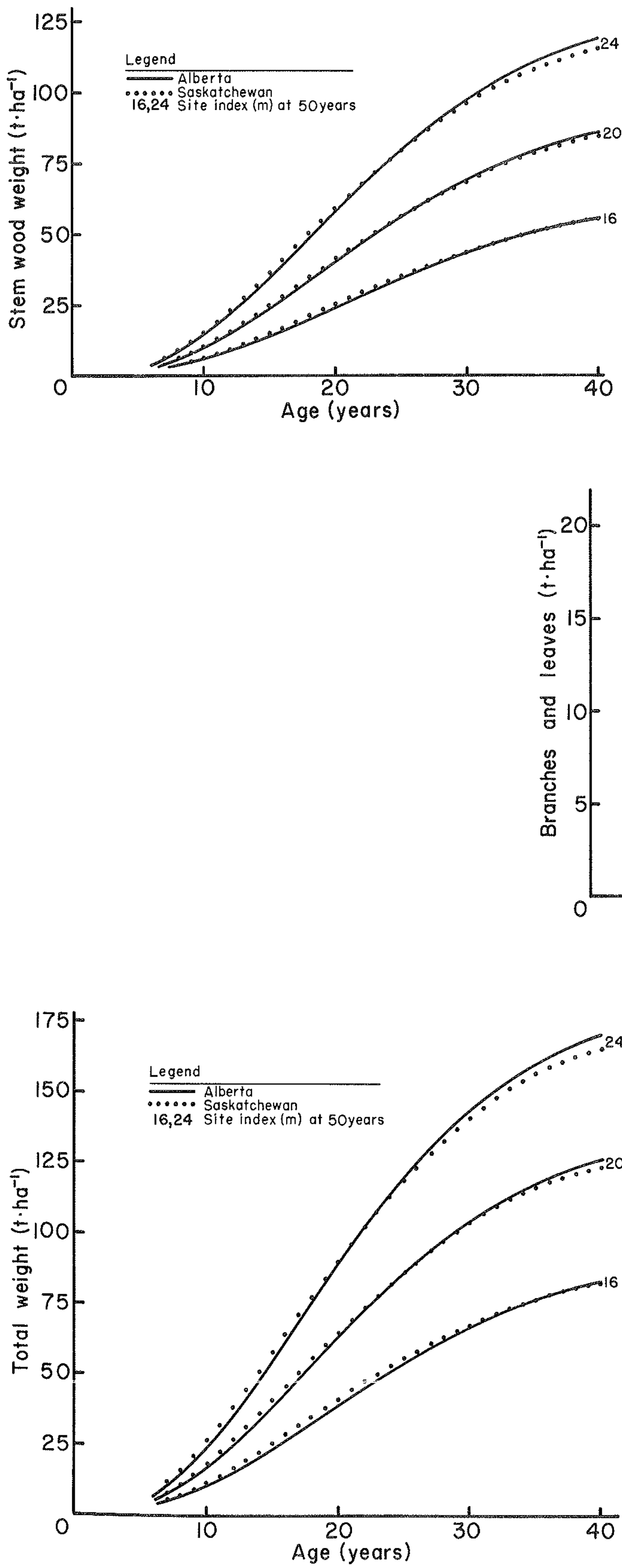

Figure 2. Biomass yield in dry weight over age of aspen stands for three site classes in Alberta and Saskatchewan.

Table 6. Regressions for estimating average stand statistics required for compiling biomass yield tables

Location	N	Variables and coefficients		R^2	SE
		Dependent	Independent		
Alberta	198	D	$3.3984 + 0.0139045\ H_D \ln A$	0.946	6.912
Saskatchewan	152	D	$5.9078 + 0.0139045\ H_D \ln A$	0.946	6.912
Common	350	ln (NT)	$11.2776 - 0.0258309\ D - 0.0419994\ A - 0.00168556\ H_D + 0.000653333\ H_D \ln A$	0.884	0.25105
Common	350	H_L	$601.891 + 0.655736\ H_D - 6.53964 \sqrt{NT} + 0.0184393\ NT$	0.964	78.35

D = Average dbh on plot in mm (weighted by D^2).
H_D = Dominant height in cm (from three tallest on plot).
H_L = Lorey's height (cm).
ln = Natural logarithm.
NT = Number of living trees per ha (all species).

Table 7. Biomass yield tables for Alberta

Age (yr)	Height: Dom. (cm)	Height: Lorey's (cm)	Mean dbh (cm)	Number of stems (ha^{-1})	Basal area ($m^2 \cdot ha^{-1}$)	Stand biomass in dry weight ($kg \cdot ha^{-1}$): Stem: Wood	Stem: Wood + bark	Stem: Wood + bark + brch.	Brch. + leaves	Total tree
a. Site index 16 m (at age 50)										
6	287	221	1.1	40 328	3.53	2 765	3 490	4 081	869	4 245
8	379	272	1.4	34 450	5.57	3 813	5 220	6 233	1 379	6 573
10	465	328	1.8	29 752	7.82	5 828	8 161	9 735	2 056	10 275
12	548	386	2.2	25 920	10.15	8 618	12 046	14 273	2 844	15 023
14	627	446	2.6	22 745	12.44	11 996	16 622	19 553	3 696	20 514
16	702	506	3.0	20 079	14.62	15 784	21 658	25 315	4 573	26 477
18	773	564	3.4	17 818	16.63	19 824	26 951	31 330	5 446	32 682
20	842	622	3.9	15 882	18.44	23 978	32 331	37 409	6 291	38 933
22	907	679	4.2	14 211	20.05	28 131	37 656	43 397	7 093	45 075
24	970	734	4.6	12 759	21.43	32 190	42 815	49 171	7 839	50 985
26	1 029	788	5.0	11 490	22.60	36 080	47 719	54 638	8 520	56 568
28	1 087	840	5.4	10 374	23.55	39 746	52 305	59 731	9 132	61 758
30	1 142	890	5.7	9 389	24.32	43 148	56 529	64 401	9 673	66 508
32	1 196	939	6.1	8 515	24.89	46 258	60 360	68 620	10 142	70 789
34	1 247	987	6.4	7 736	25.30	49 060	63 783	72 372	10 541	74 587
36	1 296	1 033	6.8	7 041	25.56	51 546	66 791	75 654	10 870	77 900
38	1 344	1 078	7.1	6 417	25.67	53 715	69 389	78 470	11 134	80 735
40	1 390	1 121	7.5	5 856	25.66	55 571	71 584	80 832	11 335	83 104
b. Site index 20 m (at age 50)										
6	366	266	1.2	36 820	4.53	3 287	4 426	5 285	1 190	5 565
8	485	340	1.7	30 720	7.33	5 653	7 938	9 494	2 032	10 030
10	599	419	2.3	26 012	10.40	9 483	13 256	15 700	3 104	16 521
12	706	500	2.8	22 287	13.52	14 464	19 952	23 402	4 320	24 515
14	808	579	3.3	19 281	16.55	20 280	27 612	32 127	5 610	33 527
16	905	658	3.8	16 818	19.38	26 636	35 859	41 455	6 918	43 124
18	998	734	4.4	14 774	21.94	33 270	44 368	51 024	8 201	52 941
20	1 085	807	4.9	13 057	24.22	39 963	52 871	60 539	9 429	62 677
22	1 168	878	5.4	11 601	26.19	46 534	61 151	69 765	10 577	72 098
24	1 248	946	5.8	10 355	27.86	52 843	69 041	78 523	11 630	81 022
26	1 323	1 010	6.3	9 282	29.24	58 781	76 417	86 681	12 579	89 319
28	1 395	1 073	6.8	8 350	30.34	64 273	83 193	94 147	13 417	96 899
30	1 463	1 132	7.3	7 537	31.19	69 265	89 311	100 864	14 144	103 705
32	1 528	1 190	7.7	6 822	31.80	73 728	94 740	106 801	14 761	109 708
34	1 590	1 244	8.1	6 191	32.20	77 646	99 469	111 949	15 269	114 902
36	1 650	1 297	8.6	5 631	32.41	81 018	103 502	116 315	15 674	119 295
38	1 707	1 347	9.0	5 133	32.44	83 854	106 854	119 921	15 982	122 910
40	1 761	1 395	9.4	4 687	32.33	86 171	109 552	122 797	16 197	125 781

Table 7 concluded.

Age (yr)	Height Dom. (cm)	Height Lorey's (cm)	Mean dbh (cm)	Number of stems (ha^{-1})	Basal area ($m^2 \cdot ha^{-1}$)	Stand biomass in dry weight ($kg \cdot ha^{-1}$) Stem: Wood	Stem: Wood + bark	Stem: Wood + bark + brch.	Brch. + leaves	Total tree
c. Site index 24 m (at age 50)										
6	445	314	1.4	33 617	5.53	4 151	5 782	6 952	1 563	7 354
8	592	413	2.0	27 394	9.06	8 139	11 427	13 595	2 767	14 322
10	732	515	2.7	22 742	12.86	14 133	19 517	22 919	4 258	24 020
12	864	617	3.3	19 162	16.65	21 655	29 411	34 184	5 917	35 651
14	990	716	4.0	16 345	20.26	30 229	40 496	46 699	7 650	48 517
16	1 109	813	4.6	14 087	23.57	39 420	52 230	59 864	9 385	62 006
18	1 222	905	5.2	12 249	26.52	48 856	64 158	73 179	11 068	75 613
20	1 329	994	5.9	10 734	29.09	58 234	75 915	86 246	12 659	88 938
22	1 430	1 078	6.5	9 470	31.28	67 315	87 220	98 763	14 132	101 676
24	1 526	1 158	7.1	8 405	33.10	75 919	97 861	110 504	15 469	113 603
26	1 616	1 234	7.7	7 499	34.58	83 914	107 689	121 313	16 661	124 566
28	1 702	1 306	8.2	6 721	35.74	91 212	116 608	131 088	17 703	134 462
30	1 784	1 374	8.8	6 050	36.60	97 758	124 558	139 772	18 596	143 238
32	1 861	1 440	9.3	5 466	37.19	103 524	131 514	147 341	19 343	150 873
34	1 934	1 501	9.8	4 954	37.55	108 503	137 475	153 799	19 948	157 373
36	2 004	1 560	10.3	4 504	37.70	112 705	142 460	159 170	20 418	162 764
38	2 069	1 616	10.8	4 106	37.66	116 153	146 502	163 495	20 763	167 089
40	2 132	1 668	11.3	3 751	37.45	118 879	149 646	166 825	20 989	170 402

Table 8. Biomass yield tables for Saskatchewan

Age (yr)	Height: Dom. (cm)	Height: Lorey's (cm)	Mean dbh (cm)	Number of stems (ha^{-1})	Basal area ($m^2 \cdot ha^{-1}$)	Stand biomass in dry weight ($kg \cdot ha^{-1}$): Stem: Wood	Stem: Wood + bark	Stem: Wood + bark + brch.	Brch. + leaves	Total tree
a. Site index 16 m (at age 50)										
6	288	216	1.3	37 797	5.07	2 648	3 529	4 289	1 055	4 503
8	379	270	1.7	32 287	7.20	4 336	6 093	7 378	1 683	7 787
10	465	329	2.1	27 885	9.48	6 845	9 664	11 580	2 440	12 200
12	548	390	2.5	24 294	11.77	9 992	13 993	16 604	3 275	17 437
14	627	451	2.9	21 317	13.98	13 605	18 849	22 183	4 146	23 224
16	702	512	3.3	18 819	16.05	17 522	24 027	28 086	5 021	29 323
18	773	572	3.7	16 699	17.94	21 601	29 347	34 113	5 874	35 530
20	842	630	4.1	14 885	19.62	25 721	34 662	40 099	6 687	41 678
22	907	688	4.5	13 319	21.08	29 783	39 850	45 914	7 446	47 636
24	970	743	4.9	11 958	22.32	33 707	44 819	51 456	8 141	53 301
26	1 030	797	5.2	10 769	23.35	37 431	49 496	56 650	8 768	58 598
28	1 087	849	5.6	9 723	24.18	40 910	53 832	61 441	9 322	63 475
30	1 142	900	6.0	8 799	24.82	44 113	57 792	65 796	9 804	67 898
32	1 196	949	6.4	7 980	25.29	47 019	61 356	69 696	10 213	71 850
34	1 247	996	6.7	7 251	25.59	49 618	64 515	73 133	10 553	75 323
36	1 296	1 042	7.0	6 599	25.75	51 905	67 269	76 110	10 825	78 323
38	1 344	1 087	7.4	6 014	25.78	53 885	69 625	78 636	11 033	80 859
40	1 390	1 130	7.7	5 489	25.69	55 564	71 597	80 728	11 182	82 951
b. Site index 20 m (at age 50)										
6	366	263	1.5	34 509	6.12	3 589	4 995	6 061	1 425	6 401
8	485	341	2.0	28 792	8.99	6 656	9 403	11 266	2 381	11 879
10	599	423	2.5	24 379	12.04	10 977	15 333	18 140	3 517	19 043
12	706	505	3.0	20 888	15.07	16 256	22 383	26 218	4 756	27 411
14	808	586	3.6	18 071	17.96	22 201	30 177	35 073	6 038	36 542
16	905	665	4.1	15 763	20.62	28 545	38 379	44 328	7 313	46 053
18	998	742	4.6	13 846	23.01	35 056	46 701	53 667	8 546	55 625
20	1 085	816	5.1	12 237	25.10	41 540	54 912	62 836	9 709	64 998
22	1 168	887	5.6	10 873	26.90	47 840	62 826	71 634	10 784	73 973
24	1 248	955	6.1	9 706	28.40	53 838	70 303	79 912	11 759	82 401
26	1 323	1 020	6.6	8 699	29.62	59 442	77 242	87 563	12 627	90 176
28	1 395	1 082	7.0	7 826	30.58	64 590	83 573	94 516	13 385	97 227
30	1 463	1 142	7.5	7 064	31.29	69 243	89 254	100 727	14 033	103 514
32	1 528	1 199	8.0	6 394	31.78	73 376	94 265	106 180	14 573	109 020
34	1 590	1 254	8.4	5 802	32.07	76 984	98 602	110 873	15 009	113 747
36	1 650	1 306	8.8	5 278	32.18	80 069	102 275	114 821	15 347	117 713
38	1 707	1 356	9.2	4 811	32.14	82 644	105 305	118 049	15 591	120 942
40	1 761	1 404	9.6	4 393	31.95	84 728	107 719	120 590	15 750	123 471

Table 8 concluded.

Age (yr)	Height Dom. (cm)	Height Lorey's (cm)	Mean dbh (cm)	Number of stems (ha^{-1})	Basal area ($m^2 \cdot ha^{-1}$)	Stand biomass in dry weight ($kg \cdot ha^{-1}$) Stem: Wood	Stem: Wood + bark	Stem: Wood + bark + brch.	Brch. + leaves	Total tree
c. Site index 24 m (at age 50)										
6	445	314	1.7	31 507	7.14	4 817	6 800	8 200	1 828	8 667
8	592	416	2.3	25 674	10.69	9 517	13 342	15 824	3 130	16 638
10	732	520	2.9	21 315	14.41	15 941	21 948	25 697	4 658	26 874
12	864	624	3.6	17 959	18.05	23 637	32 025	37 137	6 308	38 670
14	990	724	4.2	15 319	21.46	32 170	43 018	49 524	7 996	51 391
16	1 109	821	4.9	13 203	24.56	41 150	54 447	62 323	9 659	64 494
18	1 222	914	5.5	11 481	27.29	50 248	65 913	75 101	11 253	77 542
20	1 329	1 003	6.1	10 060	29.64	59 199	77 103	87 514	12 743	90 190
22	1 430	1 087	6.7	8 876	31.63	67 797	87 774	99 307	14 110	102 182
24	1 526	1 167	7.3	7 877	33.26	75 889	97 753	110 293	15 339	113 334
26	1 616	1 243	7.9	7 028	34.57	83 366	106 917	120 346	16 425	123 520
28	1 702	1 315	8.5	6 300	35.57	90 156	115 189	129 386	17 364	132 664
30	1 784	1 384	9.0	5 670	36.29	96 218	122 527	137 373	18 159	140 729
32	1 861	1 449	9.6	5 123	36.76	101 532	128 918	144 298	18 815	147 705
34	1 934	1 510	10.1	4 643	37.02	106 098	134 367	150 172	19 336	153 609
36	2 004	1 569	10.6	4 221	37.07	109 932	138 900	155 025	19 731	158 473
38	2 069	1 624	11.1	3 848	36.95	113 059	142 551	158 900	20 008	162 340
40	2 132	1 677	11.5	3 516	36.68	115 510	145 367	161 849	20 174	165 266

were calculated for the relevant independent variables and for the different biomass components using the following formulas:

$$AD = \frac{\Sigma\hat{Y}-\Sigma Y}{\Sigma\hat{Y}} \times 100$$

$$MAD = \frac{\Sigma(|\hat{Y}-Y|)}{n}$$

$\hat{Y}$ = estimated value as dependent variable

Y = observed value as dependent variable

n = number of observations from 6 to 40 years, inclusive

Aggregate deviations and mean absolute deviations for the different variables and biomass components are given in Table 9. Values of the AD close to zero indicate that the estimates are essentially free from bias, while the magnitude of the MAD indicates primarily the variability inherent in the data used.

Rotation Length

Rotation length often is based on the culmination of mean annual increment (MAI). For this reason, ages at which such maximums occur for different biomass components and for total above ground tree biomass were obtained for the three site index classes (16, 20, and 24 m) for Alberta and Saskatchewan by using the multiple (five independent variables) biomass yield equations presented in Table 5. These ages of culmination and the actual maximum MAI of biomass values are shown in Table 10 along with similar statistics for basal area.

The maximum MAI for *stem wood* and *stem wood + bark* occurs around 30 years. It takes slightly longer for stands on poor sites than on good sites to reach maximum, and on good sites MAI is more than double that on poor sites. MAI for *branches + leaves* culminates 5 to 6 years earlier than for the stem components; therefore, culmination for *total tree* occurs 1 to 2 years earlier than for the stem components.

It is worth noting, however, that MAI in terms of basal area reaches maximum considerably earlier, generally between 15 and 20 years. This period likely coincides with the onset of overcrowding and heavy mortality in young aspen stands.

There was generally little difference in age of culmination or in actual values of maximum MAI between aspen stands in Alberta and Saskatchewan. MAI seems to have culminated 1 or 2 years earlier in Saskatchewan than in Alberta, possibly because of the somewhat lower densities in Saskatchewan.

DISCUSSION AND CONCLUSION

The relationships developed here provide an accurate and reliable system for estimating biomass yield of above-ground tree components of fully stocked or nearly fully stocked young aspen stands in Alberta and Saskatchewan. Estimates are most accurate for the 20- to 30-year range, a fortunate occurrence, because around these ages MAI culminates and critical decisions have to be made on rotation length.

An examination of biomass components in Tables 4, 7, and 8 reveals that the greatest proportion of *leaves* or *branches + leaves* occurs at the youngest ages and steadily declines with age. Leaf percentage drops from just under 40% to about 20% from age 2 to 5 (Table 4) and from around 5% to under 3% between 10 and 40 years (Tables 7 and 8). Conversely, there is a steady increase in the proportion of *stem wood*. From 10 to 40 years the proportion of *stem wood* increases from 60% to 70%, and there is a corresponding drop in the proportion of biomass in bark, branches, and leaves. Similar trends for other species have been observed by a number of researchers.

A comparison of biomass estimates of aspen at 5 and 6 years (Table 4 vs. Tables 7 and 8) on medium and better sites reveals differences in values beyond what one may reasonably expect from an increase in age of 1 year. Biomass estimates of the regeneration and especially the amount of leaves are much higher than similar biomass estimates of the

Table 9. Aggregate deviations (AD) and mean absolute deviations (MAD) of different stand variables on plots with stand age 6 to 40 years, by provinces

Variable	Aggregate deviations %	Mean absolute deviations
	Alberta (n = 191)	
D	0.2	0.5 (cm)
H_L	-0.3	70.0 (cm)
NT	-6.8	3462 (trees·ha^{-1})
BA	-2.3	4.9 (m^2·ha^{-1})
Stem wood	0.1	1218 (kg·ha^{-1})
Stem wood + bark	0.1	1507 (kg·ha^{-1})
Stem wood + bark + branches	0.1	1715 (kg·ha^{-1})
Branches + leaves	0	310 (kg·ha^{-1})
Total tree	0.1	1734 (kg·ha^{-1})
	Saskatchewan (n = 146)	
D	0.5	0.5 (cm)
H_L	-0.4	59.4 (cm)
NT	-2.1	3489 (trees·ha^{-1})
BA	1.4	3.9 (m^2·ha^{-1})
Stem wood	0.1	1032 (kg·ha^{-1})
Stem wood + bark	0.1	1347 (kg·ha^{-1})
Stem wood + bark + branches	0.1	1596 (kg·ha^{-1})
Branches + leaves	0.2	326 (kg·ha^{-1})
Total tree	0.1	1610 (kg·ha^{-1})

Table 10. Age* and value of maximum MAI† of aspen stand component biomass for three site classes for Alberta and Saskatchewan

Site index	Stem wood		Stem wood + bark		Stem wood + bark + branches		Branches + leaves		Total tree		Basal area	
	Age	MAI	Age	MAI	Age	MAI	Age	MAI	Age	MAI	Age	MAI
						Alberta						
16	32	1446	31	1887	31	2147	26	328	30	2217	19	0.924
20	30	2309	29	2977	29	3366	25	485	29	3462	18	1.219
24	29	3261	28	4165	28	4682	24	645	28	4802	17	1.476
						Saskatchewan						
16	31	1471	30	1926	29	2196	23	339	29	2267	16	1.003
20	29	2310	28	2985	28	3376	23	491	27	2474	16	1.209
24	28	3220	27	4117	27	4629	22	641	26	4751	15	1.537

* In years.
† MAI in kg·ha^{-1}; basal area MAI in m^2·ha^{-1}.

older age group. There may be several contributing factors for this difference. One could be that in the diameter tally of the older group—and particularly at ages 6 and 7—shrubs and small trees under 137 cm high were ignored that might have made a substantial contribution to biomass. Another cause could be underestimation of the *branches + leaves* weights of small trees in the older age group, as was mentioned previously.

Although these factors probably contributed to the differences in estimates, they likely account for only a fairly small part. A perhaps more important source could be the inadvertent bias that may have been introduced by the use of very small plots. When full stocking is specified for the sample, there is likely to be a tendency by the fieldman to choose the densest clumps within the stand for the sample plots. It is easy to see how this positive bias is amplified with reduction in plot size.

It should be remembered also that, especially for the older group, biomass estimates at, for example, ages 6, 7, and 8 are at the low extreme of the data range. The nature of regression techniques implies inherently greater error in estimated values as one moves toward the extremes of independent variables.

The above inconsistencies notwithstanding, the results give an indication of expected trends and still are well within the range of biomass productivity values found in other studies of aspen (Pollard 1972, Perala 1973, Berry and Stiell 1978).

The relationships developed here provide information for determining rotation age for aspen managed for maximum biomass production. These results indicate a rotation age of around 30 years for fully stocked, dense aspen stands, slightly longer on poor sites and shorter on good sites. This compares quite favorably with Perala's (1973) results that indicated a rotation age of about 25 years for stands growing on relatively good sites (site index 21 m at 50 years) in north-central Minnesota.

To obtain the best possible aspen biomass yield estimates from the equations developed in this study, one should use the individual multiple regressions for Alberta and Saskatchewan. Although these regressions may appear somewhat complex, they present no difficulty for estimating biomass productivity using a computer. All the independent variables in these regressions are readily available.

In the field, quick and quite accurate estimates may be obtained by using the appropriate simple regressions with only the combined variable term ($H_D \cdot BA$; dominant height times stand basal area), especially for ages 10 to 35. The equations presented here are suitable for estimating biomass yield of individual stands within the range of the data, and the tables are useful for providing information on average yields for mean stand values in this study.

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APPENDIX 1

SAMPLING PROCEDURES FOR COMPONENT WEIGHTS OF ASPEN TREES

1. Select healthy, wholesome (i.e., no broken tops, etc.), dominant and co-dominant trees up to about age 50 years that are growing in fully stocked stands.
2. Mark dbh (at 137 cm), and measure dob in mm with tape.
3. Fell the tree, obtain dead branch weight (g).
4. Measure total height (cm), height to 2 cm dob, and height to 1.3 cm dob.
5. Measure height to crown base (cm).
6. Measure crown width (cm).
7. Mark and measure dob (mm) at crown base.
8. Mark one-half of the length between dbh and crown base, and measure dob (mm) there.
9. Cut live branches flush with the stem; obtain total fresh weight of branches and leaves (g). Include any stem top that is less than 2 cm dob.
10. Cut the stem at breast height, the marked half-way point, and crown base; obtain fresh weight of the four individual sections (g).
11. Cut 2- to 3-cm discs at breast height, the half-way point, and crown base.
12. Obtain the fresh weight of each disc with and without bark. Using indelible pencil, mark tree and section number on the wood and bark. Store bark samples individually in paper bags.
13. Record diameter inside bark (mm) of the three discs.
14. Rank branches by size, and pick out two branches nearest to the median.
15. Obtain the fresh weight of the two branches with leaves (g).
16. Strip leaves (with leaf bunches), and obtain the fresh weight of the two branches without leaves (g).
17. Store leaves loosely in paper bags, and ventilate.
18. Chop up branches, and store loosely in burlap bags.

APPENDIX 2

TREE COMPONENT BIOMASS EQUATIONS USED FOR COMPANION SPECIES

For white birch, by Baskerville (1965) (dbh in inches, common logs):

Stem wood	(lbs)	Log Y	= 0.132 + 2.36 Log D
Stem bark	(lbs)	Log 100Y	= 1.32 + 2.35 Log D
Branches	(lbs)	Log Y	= -1.006 + 3.30 Log D
Foliage	(lbs)	Log 100Y	= 0.730 + 2.94 Log D
Total tree	(lbs)	Log Y	= 0.236 + 2.48 Log D

For white and black spruce and balsam fir, Baskerville's (1965) white spruce regressions were used (dbh in inches, common logs):

Stem wood	(lbs)	Log Y	= 0.028 + 2.36 Log D
Stem bark	(lbs)	Log 100Y	= 0.885 +2.61 Log 100 D
Branches	(lbs)	Log Y	= -0.855 + 2.78 Log D
Foliage	(lbs)	Log 10Y	= 0.066 + 2.85 Log 10 D
Total tree	(lbs)	Log Y	= 0.150 +2.48 Log D

For jack pine, regressions by Doucet *et al.* (1976) (dbh in cm, height in m, common logs):

Stem wood	(g)	Log Y	= 1.34812 + 2.05210 Log D + 0.79368 Log Ht
Stem bark	(g)	Log Y	= 1.16816 + 1.85229 Log D + 0.30682 Log Ht
Branches	(g)	Log Y	= 1.23713 + 4.53918 Log D - 2.28027 Log Ht
Foliage	(g)	Log Y	= 0.07733 + 4.00823 Log D - 0.91490 Log Ht

For minor species and larger shrubs, weights were estimated using regressions for willows by Ribe (1973) (dbh in inches, common logs):

Stem	(g)	Log Y	= 2.7610 + 2.3391 Log D
Branches	(g)	Log Y	= 2.4822 + 1.6624 Log D
Foliage	(g)	Log Y	= 2.1879 + 1.6442 Log D