# BIOMASS PRODUCTIVITY OF YOUNG ASPEN STANDS IN WESTERN CANADA

I.E. BELLA and J.P. De FRANCESCHI

INFORMATION REPORT NOR-X-219
JANUARY 1980

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
5320 - 122 STREET
EDMONTON, ALBERTA, CANADA
T6H 3S5

ADDENDUM

"Biomass productivity of young aspen stands in Western Canada" by I.E. Bella and J.P. DeFranceschi. 1980. Canadian Forestry Service, Information Report NOR-X-219.

(1) The units of the independent variables of the biomass yield regressions in Table 5 are not clearly stated. They are: D in mm; BA in $m^2$; $H_D$ and $H_L$ in cm.

(2) $H_L$, height of tree of quadratic mean diameter is incorrectly called Lorey's height in the report.

Bella, I.E. and J.P. De Franceschi. 1980. Biomass productivity of young aspen stands in western Canada. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-219.


## 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

ENFOR is the bilingual acronym for the Canadian Forestry Service's ENergy from the FORest (ENergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate in the medium to long term a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing our dependence on petroleum and other non-renewable energy sources.

ENFOR projects are selected from among proposals submitted by private and public research organizations according to scientific and technical merit, in the light of program objectives and priorities. Regardless of proposal source, projects are carried out primarily by contract. For further information on the ENFOR program, contact

ENFOR Secretariat
Canadian Forestry Service
Environment Canada
Ottawa, Ontario
K1A 0E7.

This report, based on ENFOR project P 22, was prepared by the Canadian Forestry Service. Field data were collected under contract (DSS File No. 05SS.KL015-7-0549) by Western Ecological Services Ltd., Edmonton, Alberta.

## CONTENTS


| | Page |
|---|---|
| INTRODUCTION | 1 |
| DESCRIPTION OF THE ASPEN FOREST SAMPLED | 1 |
| METHODS | 1 |
| Sample Selection Criteria and Field Procedures | 3 |
| Aspen Regeneration 2 to 5 Years Old | 3 |
| Stands 6 Years and Older | 3 |
| Above-ground Weights of Individual Aspen Trees | 4 |
| Laboratory Procedures | 4 |
| Development of Individual Tree Component Biomass Equations | 4 |
| Development of Stand Component Biomass Equations | 5 |
| RESULTS | 6 |
| Component Weight Equations for Individual Trees | 6 |
| Biomass of Aspen Regeneration 5 Years and Younger | 6 |
| Biomass of Aspen Stands 6 Years and Older | 9 |
| Rotation Length | 18 |
| DISCUSSION AND CONCLUSIONS | 18 |
| REFERENCES | 20 |
| APPENDIX 1. Sampling Procedures for Component Weights of Aspen Trees | 22 |
| APPENDIX 2. Tree Component Biomass Equations Used for Companion Species | 23 |


## FIGURES


1. Sampling locations ... 2
2. Biomass yield in dry weight over age of aspen stands for three site classes in Alberta and Saskatchewan ... 12


## TABLES


1. Summary statistics for aspen and balsam poplar sample trees ... 6
2. Summary statistics of aspen stands sampled ... 7
3. Tree component weight regressions of $\ln W = a + b \ln(D^2 H)$ ... 8
4. Component biomass dry weight of fully stocked aspen regeneration for three density classes, Alberta and Saskatchewan combined ... 10

Page

5. Above-ground biomass yield regression statistics for Alberta, Saskatchewan, and pooled data . . . . 11

6. Regressions for estimating average stand statistics required for compiling biomass yield tables . . . . 13

7. Biomass yield tables for Alberta . . . . 14

8. Biomass yield tables for Saskatchewan . . . . 16

9. Aggregate deviations (AD) and mean absolute deviations (MAD) of different stand variables on plots with stand age 6 to 40 years, by provinces . . . . 19

10. Age and value of maximum MAI of aspen stand component biomass for three site classes for Alberta and Saskatchewan . . . . 19

## 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.

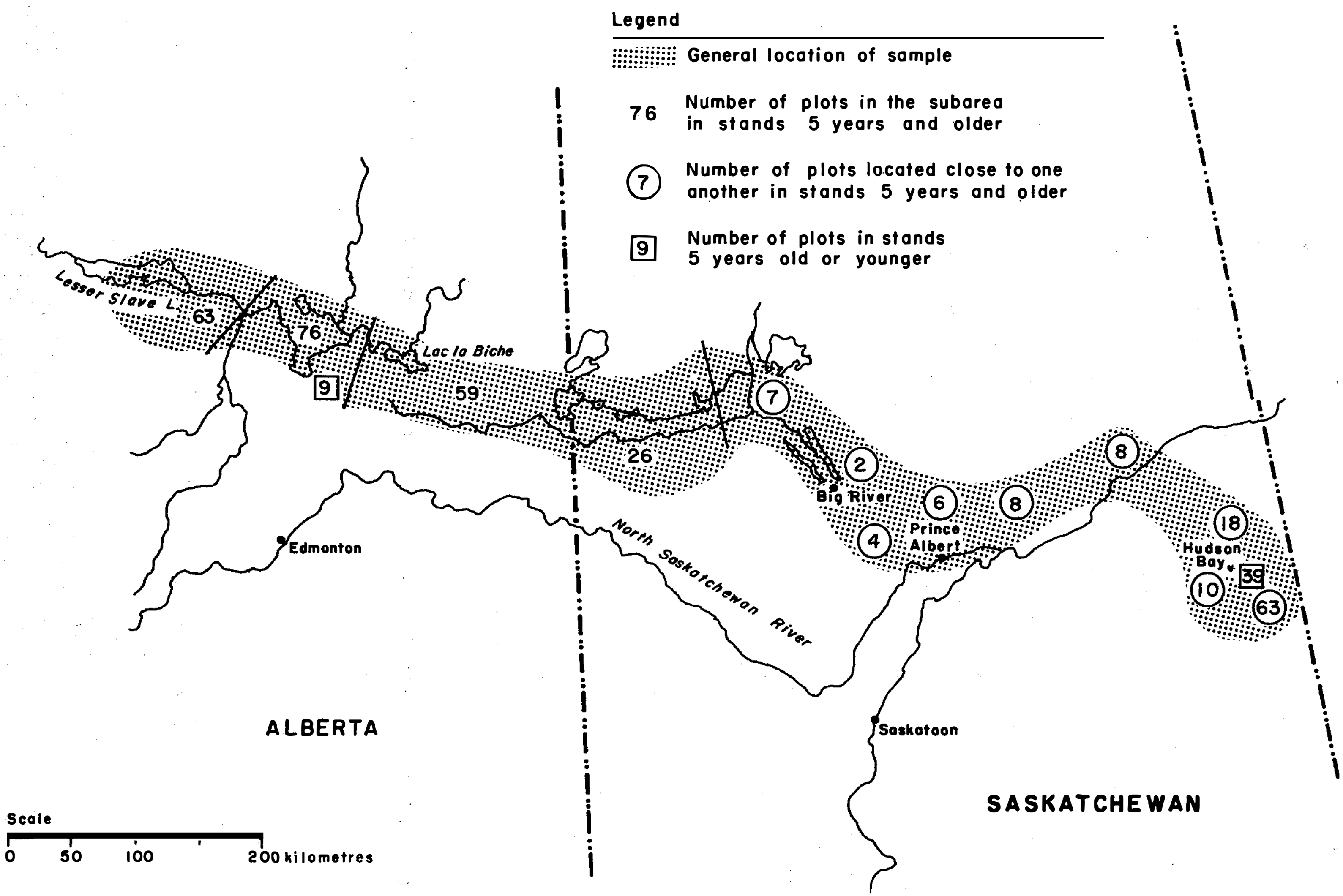


**Figure 1. Sampling locations.**

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

[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($D^2H$) 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·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·ha⁻¹; n = 48):

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

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

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

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 |

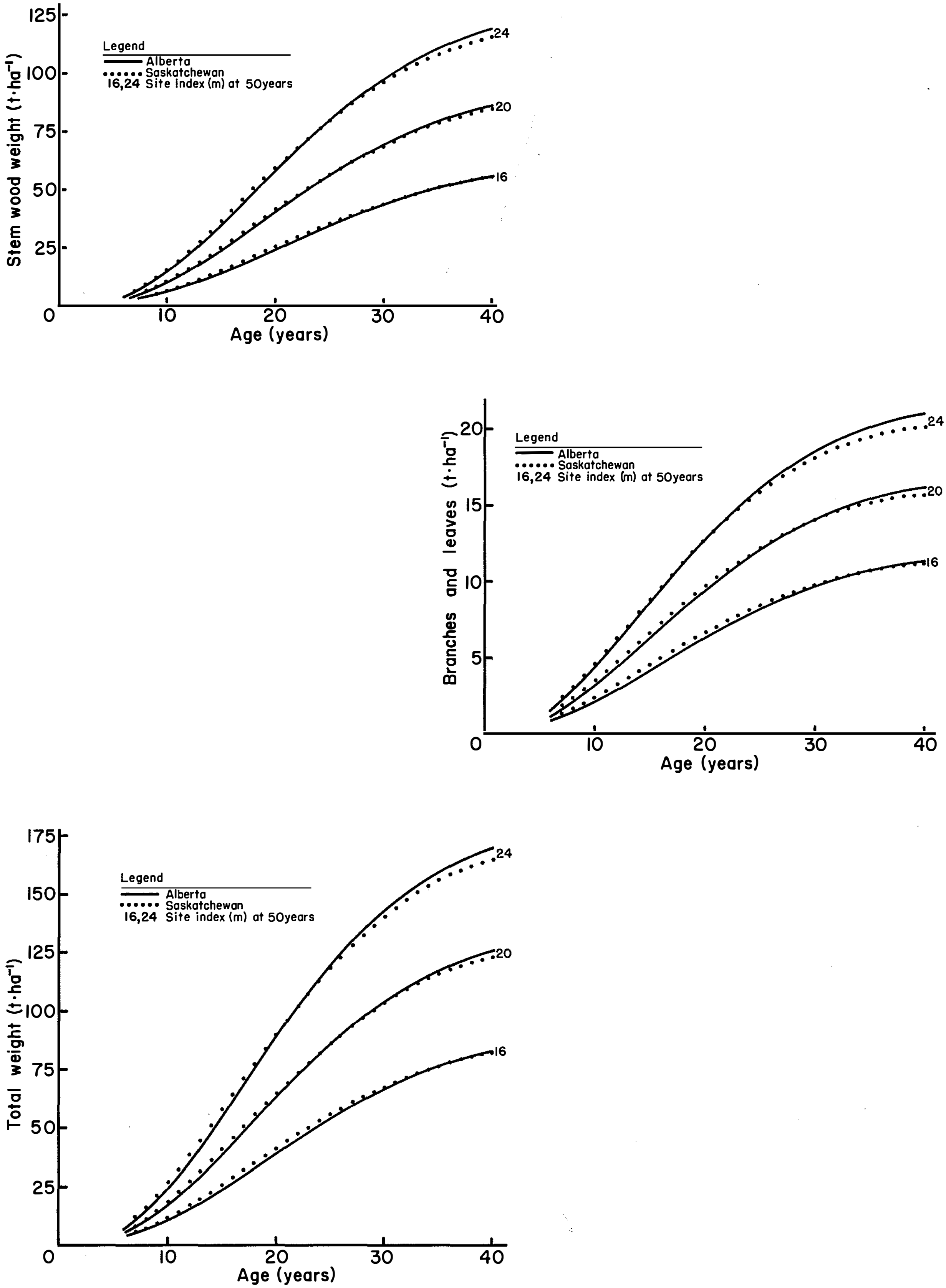


**Figure 2. Biomass yield in dry weight over age of aspen stands for three site classes in Alberta and Saskatchewan.**

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

| Location | N | Variables and coefficients: Dependent | Independent | $R^2$ | SE |
|---|---|---|---|---|---|
| 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**

| | Height | | Mean | Number | Basal | Stand biomass in dry weight (kg•ha$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Stem | | | | |
| Age (yr) | Dom. (cm) | Lorey's (cm) | dbh (cm) | of stems (ha$^{-1}$) | area (m$^2$•ha$^{-1}$) | Wood | Wood + bark | 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.**

| | Height | | Mean | Number | Basal | Stand biomass in dry weight ($kg \cdot ha^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Stem | | | | |
| Age (yr) | Dom. (cm) | Lorey's (cm) | dbh (cm) | of stems ($ha^{-1}$) | area ($m^2 \cdot ha^{-1}$) | Wood | Wood + bark | 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

| | Height | | Mean | Number | Basal | Stand biomass in dry weight (kg·ha$^{-1}$) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Stem | | | | |
| Age | Dom. | Lorey's | dbh | of stems | area | | Wood + | Wood + | Brch. + | Total |
| (yr) | (cm) | (cm) | (cm) | (ha$^{-1}$) | (m$^2$·ha$^{-1}$) | Wood | bark | bark + brch. | leaves | 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 ($trees \cdot ha^{-1}$) |
| BA | -2.3 | 4.9 ($m^2 \cdot ha^{-1}$) |
| Stem wood | 0.1 | 1218 ($kg \cdot ha^{-1}$) |
| Stem wood + bark | 0.1 | 1507 ($kg \cdot ha^{-1}$) |
| Stem wood + bark + branches | 0.1 | 1715 ($kg \cdot ha^{-1}$) |
| Branches + leaves | 0 | 310 ($kg \cdot ha^{-1}$) |
| Total tree | 0.1 | 1734 ($kg \cdot ha^{-1}$) |
| | Saskatchewan (n = 146) | |
| D | 0.5 | 0.5 (cm) |
| $H_L$ | -0.4 | 59.4 (cm) |
| NT | -2.1 | 3489 ($trees \cdot ha^{-1}$) |
| BA | 1.4 | 3.9 ($m^2 \cdot ha^{-1}$) |
| Stem wood | 0.1 | 1032 ($kg \cdot ha^{-1}$) |
| Stem wood + bark | 0.1 | 1347 ($kg \cdot ha^{-1}$) |
| Stem wood + bark + branches | 0.1 | 1596 ($kg \cdot ha^{-1}$) |
| Branches + leaves | 0.2 | 326 ($kg \cdot ha^{-1}$) |
| Total tree | 0.1 | 1610 ($kg \cdot ha^{-1}$) |

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

| Site | Stem wood | | Stem wood + bark | | Stem wood + bark + branches | | Branches + leaves | | Total tree | | Basal area | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| index | 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 $kg \cdot ha^{-1}$; basal area MAI in $m^2 \cdot ha^{-1}$.

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.

## REFERENCES

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

————. 1972. Use of logarithmic regressions in the estimation of plant biomass. Can. J. For. Res. 2:49-53.

Bella, I.E. 1968. Estimating aerial component weights of young aspen trees. Can. Dep. For. Rural Dev., For. Br. Inf. Rep. MS-X-12. 36 pp.

Bella, I.E. and J.P. De Franceschi. 1972. The effect of logging practices on the development of new aspen stands, Hudson Bay, Saskatchewan. Environ. Can., Can. For. Serv. Inf. Rep. NOR-X-33. 20 pp.

Berry, A.B. and W.M. Stiell. 1978. Effect of rotation length on productivity of aspen sucker stands. For. Chron. 54:265-267.

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.

Perala, D.A. 1973. Stand equations for estimating aerial biomass, net productivity and stem survival of young aspen suckers on good sites. Can. J. For. Res. 3:288-292.

Pollard, D.F.W. 1972. Above-ground dry matter production of three stands of trembling aspen. Can. J. For. Res. 2:27-33.

Ribe, J.H. 1973. Puckerbrush weight tables. Life Sci. Agric. Exp. Stn., Univ. Maine. Misc. Rep. 152. 92 pp.

Rowe, J.S. 1972. Forest regions of Canada. Environ. Can., Can. For. Serv. Publ. No. 1300. 172 pp.

# 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 |