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Parent stand age and harvesting treatment effects on juvenile aspen biomass productivity

by H. Grewal¹

The objectives of this study were to characterize parent stand age and harvest method treatment effects on biomass production of aspen and other species, and to construct equations for the prediction of aspen stemwood, branch, and foliage biomass production. Aspen from young parent stands (30–40 years) generally regenerated taller and denser stands, and produced higher total aspen biomass and larger proportions of branch biomass than those regenerated from older parent stands. Stands regenerated after total biomass removal were taller and had larger diameters and average densities than stands regenerated by conventional logging. Aspen biomass component production was predicted consistently by various combinations and transformations of height and diameter.

Key words: aspen, biomass equations, biomass production, harvest method, logging method, parent age

Les objectifs de cette étude visaient à établir l'âge du peuplement à la base de la régénération actuelle ainsi que les effets de la méthode de récolte sur la production de biomasse issue du peuplier faux-tremble et d'autres espèces, et de générer les équations de prédiction de la production de biomasse au niveau de la tige, des branches et du feuillage chez le peuplier faux-tremble. Les peupliers faux-trembles issus de jeunes peuplements (30–40 ans) forment généralement des peuplements dont la hauteur et la densité sont supérieures et produisent plus de biomasse totale de peuplier faux-tremble ainsi qu'une biomasse issue des branches en plus grande proportion que les peupliers issus de peuplements plus âgés. Les peuplements régénérés après une récolte complète de la biomasse atteignaient une hauteur, des diamètres supérieurs et une densité supérieurs aux peuplements régénérés suite à une récolte conventionnelle. L'élément de production de biomasse de peuplier faux-tremble a été prédit dans tous les cas par diverses combinaisons et transformations de la hauteur et du diamètre.

Mots clés: équations de biomasse, production de biomasse, méthode de récolte, méthode d'exploitation, âge des parents

Introduction

Aspen (*Populus tremuloides* Michx.) has become an important resource for forest managers in the prairie region of Canada. Aboveground and belowground development of seedling-origin and sucker-origin stands of aspen is identified as a high priority research need for boreal aspen (Peterson and Peterson 1992). This study focused on the growth of juvenile stands after logging. To characterize the biomass production of aspen cutovers following different harvest regimes, several trials were established in 1984 near Slave Lake and Calling Lake, Alberta. The study was designed to quantify the effects of parent stand age and harvest methods on subsequent biomass productivity of regenerating aspen and other species.

Original field methods and the two year results were reported previously (Grewal 1988); but, aspen density and stocking are known to change rapidly five to ten years after harvest. The original treatment areas were revisited in 1990 to assess overall aspen performance six years after treatment.

The objectives of the 1990 study were:

1. To determine the biomass productivity of aspen suckers, other tree species, grasses, forbs, and shrubs in 6-year-old aspen stands near Calling Lake and Slave Lake.
2. To test the effects of stand age and previous harvesting methods on biomass productivity.
3. To construct biomass equations for above ground components of aspen suckers, namely stemwood, foliage, and branches.

Methods

The plots for the trials were located in two distinct geographic locations. Plots for the young and medium aged stands were southwest of Slave Lake, and those for the old stands were located north of Calling Lake, Alberta (Figure 1).

For each parent stand age, (young: 10–15 years since harvest; medium 30–35 years; old 55–60 years), four major treatment plots were harvested in 1984. In each case, two plots were conventionally logged. Trees were hand felled, limbed and topped on site, and later skidded to road side with a grapple skidder. This harvesting treatment removed only stems, as debris from limbing and topping in the plots was left on site. The remaining two plots were subjected to total biomass removal, with all stems and branches being moved off site during harvest. This was done by hand falling and grapple skidding entire trees to road side without limbing and topping any trees.

Data Collection

In 1990, within each major treatment plot, (parent stand age by harvesting treatment combination), four circular subplots measuring 1.38 m radius (6 m²) were established in representative locations of the treatment areas. These locations were chosen so as best to represent the tree species composition and performance (i.e. density and height growth) of the treated blocks. One subplot was used for intensive sampling and measurement, while the remaining three were used for composite sampling and fewer measurements.

For all subplots, ecosystem association, soil drainage class, and ecological moisture regime were recorded. These ecological parameters were evaluated using the methods detailed by Archibald (1986), and by Corns and Annas (1986).

Within each subplot, the total per cent of ground covered by

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Figure 1. Locations of trial plots in central Alberta.

crown widths for all trees was estimated visually by species. Each live tree was identified by species, counted and tallied. For those subplots designated as intensive, each tallied tree was measured for total height (to the nearest cm) and diameter at breast height outside bark (to the nearest mm).

For all subplots, aspen sucker components were clipped and separated into stemwood, branches and foliage. The fresh weight of the separate components was determined (± 5 g) in the field. This was done aggregately for all trees in extensive subplots, and separately by individual trees for intensive subplots.

Within all subplots, a further sub-subplot measuring 0.56 m radius (1 m^2) was established. For each sub-subplot, all lesser vegetation was identified, clipped, and the fresh weight weighed aggregately (± 2 g) by vegetation classes (shrubs, forbs, and grasses).

For one extensive subplot chosen at random within each major treatment plot, a sample of all live aspen sucker and other tree components, (stemwood, foliage, branches) and lesser vegetation components (shrubs, forbs, and grasses), was bagged aggregately, oven dried to constant weight, and subsequently weighed to determine oven dry weights.

Data Analysis

The experimental design consisted of two interactive treatment factors. These factors were stand age with three levels, (young, medium and old parent aspen stands), and harvest method with two levels (total biomass removal, and conventional logging). There were two replications of each age by harvesting combination. The one exception to this was that there was only one replication of the old age by conventional logging combination. This was due to one treatment block near Slave Lake being destroyed because of road construction.

Oven dry weight to fresh weight ratios or reduction factors were generated for each of the six biomass components sampled in the field at each plot (aspen stems, branches, foliage,

and shrubs, forbs and grasses). These ratios were generated specifically for each major treatment plot which was assessed in the field. The ratios were then applied to all aggregate and all individual fresh weight values on a subplot by subplot basis. The result was the generation of an oven dry weight equivalent estimate for each fresh weight recorded in the field.

The data were tested for normality and homogeneity of variance. The effects of parent stand age and harvest method on various parameters of interest were tested by analysis of variance (ANOVA) using SPSS/PC+, version 2.0, statistical software (Norusis 1988). All tests of significance were performed at $P = 0.05$. The data used in these tests were the aggregate whole plot data. The ANOVA model used in the analysis was a replicated three by two interactive factorial design. The dependent variables of interest included in the ANOVA test were aspen density (number of stems ha^{-1}), percent cover, total biomass, foliage biomass, branch biomass, stem biomass, average height, average diameter as well as shrub, grass and forb biomass.

Multiple linear regression was used to build predictive biomass equations on an individual tree basis. Both forward and stepwise selection regression procedures with SPSS/PC+ (Norusis 1988) were used to select variables to be included in the regression equations. The dependent variables of interest included aspen foliage, branch, stemwood and total biomass dry weights. The independent variables used as predictors in the regression analysis included total height, diameter at breast height, height times diameter, height/diameter, height squared, diameter squared and log of height. The rationale of including these variables were that they are biologically meaningful. The level of significance to reject/include variables was $P = 0.05$.

Results

Ecological classification

A comprehensive list of all vegetation encountered in sampling for this study (Table 1) was broken into categories for trees, shrubs, and forbs and grasses. Scientific as well as common names are listed for all species found.

The evaluation of ecosystem association on an individual treatment block basis did not indicate extensive differences among blocks. All blocks occurred within the Aspen (*Populus tremuloides* Michx.)/White Spruce (*Picea glauca* (Moench) Voss) variant of the Boreal Mixedwood - Lower subzone as described by Archibald (1986). As well, the indicated plant association for all blocks, and for all subplots within blocks was the Aspen (*Populus tremuloides* Michx.)/Low-bush cranberry (*Viburnum edule* (Michx.) Raf.)/Wild sarsaparilla (*Aralia nudicaulis* L.) association (Archibald 1986).

Similarly, there was not a large degree of variation in soil drainage among blocks or among subplots within blocks. Except for one replication of the young age/conventional harvesting treatment (all subplots), and one subplot of the medium age/conventional harvesting treatment, all blocks and subplots were moderately well drained. The exceptions noted above occurred near Slave Lake and were imperfectly drained.

The same pattern seen for soil drainage was also evident for the evaluation of ecological moisture regime. That is, the large majority of blocks and subplots were found to be mesic in ecological moisture regime. Those subplots found to be imperfectly drained were all classed as having sub-hygic ecological moisture regime.

Table 1. List of vegetation found within study area

Trees	
<i>Populus balsamifera</i> L.	balsam poplar
<i>Populus tremuloides</i> Michx.	trembling aspen
Shrubs	
<i>Alnus crispa</i> (Ait.) Pursh.	green alder
<i>Amelanchier alnifolia</i> Nutt.	saskatoon
<i>Arctostaphylos uva-ursi</i> (L.) Spreng.	bearberry
<i>Cornus stolonifera</i> Michx.	red osier dogwood
<i>Ledum groenlandicum</i> Oeder	Labrador tea
<i>Lonicera involucrata</i> (Richards.) Banks	bracted honeysuckle
<i>Ribes lacustre</i> (Pers.) Poir.	bristly black current
<i>Ribes</i> spp.	currant, gooseberry
<i>Rosa acicularis</i> Lindl.	prickly rose
<i>Rubus idaeus</i> L.	wild red raspberry
<i>Salix</i> spp.	willow
<i>Sambucus pubens</i> (Michx.) Koehne	red elderberry
<i>Shepherdia canadensis</i> (L.) Nutt.	Canadian buffalo-berry
<i>Vaccinium myrtilloides</i> Michx.	blueberry
<i>Viburnum edule</i> (Michx.) Raf.	low-bush cranberry
Forbs and Grasses	
<i>Aralia nudicaulis</i> L.	wild sarsaparilla
<i>Aster conspicuus</i> Lindl.	showy aster
<i>Calamagrostis canadensis</i> (Michx.) Beauv.	marsh reed grass
<i>Cornus canadensis</i> L.	bunchberry
<i>Epilobium angustifolium</i> L.	fireweed
<i>Equisetum arvense</i> L.	common horsetail
<i>Fragaria virginiana</i> Duchesne	wild strawberry
<i>Galium boreale</i> L.	northern bedstraw
<i>Gymnocarpium dryopteris</i> (L.) Newm.	oak fern
<i>Heracleum lanatum</i> Michx.	cow-parsnip
<i>Lathyrus ochroleucus</i> Hook.	pea vine
<i>Linnaea borealis</i> L.	twin-flower
<i>Maianthemum canadense</i> Desf.	wild lily-of-the-valley
<i>Mertensia paniculata</i> (Ait.) G. Don.	tall mertensia
<i>Mitella nuda</i> L.	bishop's-cap
<i>Petasites palmatus</i> (Ait.) A. Gray	palmate-leaved coltsfoot
<i>Pyrola</i> spp.	wintergreen
<i>Rubus pubescens</i> Raf.	running raspberry
<i>Smilacina racemosa</i> (L.) Desf.	false Solomon's-seal
<i>Streptopus amplexifolius</i> (L.) DC.	twisted stalk
<i>Vicia americana</i> Muhl.	wild vetch

Nomenclature for the vascular plants follows Moss and Packer (1983).

Aspen Biomass Components

Details of parent stand age and harvest treatment effects on measured aspen biomass response variables are shown in Table 2. Parent stand age is significant for differences in branch biomass dry weight ($P = 0.036$). The youngest stands consistently produced the highest branch biomass ($1341.5 \text{ kg ha}^{-1}$), followed by the oldest stands ($1193.1 \text{ kg ha}^{-1}$) and finally, the medium aged stands (763.8 kg ha^{-1}). Total aspen stem biomass was significantly different among treatments ($P = 0.075$). Aspen stem biomass production ranged from $3417.3 \text{ kg ha}^{-1}$ to $6621.2 \text{ kg ha}^{-1}$ among the various treatment combinations. Total aspen biomass was significantly different ($P = 0.088$, Table 2).

For other variables, the mean values were not significantly different among treatments in the ANOVA. This is not surprising considering the large standard deviations (Table 2).

Unlike parent stand age, harvest methods were not seen to be significantly different in the analysis except for total stems ha^{-1} ($P = 0.189$). Harvest effect is significant for aspen height and diameter at breast height but there was significant interaction between age and harvest methods.

Tree Height and Tree Diameter

For tree height there was a significant interaction ($P = 0.001$) between parent age and harvest treatment. This implies inconsistent treatment effect across parent stand ages. For the young parent age stands and the old parent stand ages, total biomass removal produced taller subsequent aspen juvenile stands than did conventional logging. However, for the medium aged parent stands, conventional harvest resulted in greater aspen heights than total biomass removal. Stands from young parent ages had the highest average total height (2.66 m), followed by those from medium aged stands (2.51 m) and old stands (2.28 m).

Similarly, there was significant interaction ($P = 0.001$) between harvest method and parent stand age for aspen diameter (at breast height outside bark). For young and old parent stands, total biomass removal resulted in larger aspen diameters

Table 2. Mean treatment effects on aspen biomass components

Aspen biomass components	Parent stand age						Treatment effects			
	Old		Medium		Young		Age effect		Harvest effect	
	CH	TH	CH	TH	CH	TH	F	P	F	P
Height (m)	2.04 (<0.01)	2.52 (<0.01)	2.76 (0.17)	2.25 (0.15)	2.15 (0.12)	3.18 (0.57)	4.79	0.015	11.39	0.002
Density (stems ha^{-1})	22916.7 (17393.9)	22916.7 (17393.9)	22291.1 (7178.9)	28750.0 (8533.3)	25416.7 (8852.9)	30208.3 (9234.1)	0.59	0.562	1.80	0.189
Diameter (cm)	1.1 (<0.01)	1.7 (<0.01)	1.4 (<0.01)	1.2 (0.21)	1.25 (0.16)	1.55 (0.27)	1.63	0.21	8.70	0.006
%Cover	26.3 (23.2)	35.0 (24.8)	16.3 (9.5)	26.9 (17.7)	23.8 (10.6)	33.1 (16.5)	1.09	0.345	3.60	0.066
Stem biomass (kg ha^{-1})	3417.3 (1665.1)	4831.7 (5175.0)	4000.2 (2363.2)	3645.8 (1772.6)	5221.5 (2300.2)	6521.2 (2659.8)	2.79	0.075	0.71	0.406
Branch biomass (kg ha^{-1})	1030.1 (340.2)	1356.1 (1488.6)	787.3 (489.9)	740.3 (413.9)	1239.6 (479.5)	1443.3 (456.8)	3.67	0.036	0.43	0.516
Foliage biomass (kg ha^{-1})	592.1 (345.9)	706.0 (705.9)	709.3 (357.2)	705.0 (289.7)	833.4 (280.7)	816.1 (330.0)	0.72	0.493	0.02	0.902
Total biomass (kg ha^{-1})	5039.5 (2294.9)	6893.8 (7366.3)	5496.7 (3192.0)	5092.1 (2414.9)	7294.5 (2933.0)	8880.6 (3295.6)	2.62	0.088	0.57	0.457

() denotes standard deviation

Harvest methods: CH, conventional harvest; TH, total harvest.

Table 3. Mean treatment effects on lesser vegetation biomass

Lesser vegetation biomass (kg ha ⁻¹)	Parent stand age						Treatment effects			
	Old		Medium		Young		Age effect		Harvest effect	
	CH	TH	CH	TH	CH	TH	F	P	F	P
Shrub	527.9 (190.0)	388.5 (266.8)	581.1 (523.8)	457.5 (285.3)	328.8 (324.0)	313.1 (250.8)	1.42	0.258	1.05	0.315
Herb	205.4 (180.4)	275.4 (265.8)	223.8 (89.4)	206.6 (76.6)	218.9 (120.5)	145.4 (43.9)	0.29	0.75	1.23	0.277
Grass	1035.1 (751.2)	327.6 (477.0)	504.7 (299.2)	570.3 (240.9)	300.8 (358.5)	144.6 (85.1)	4.57	0.019	1.24	0.276
Total	1769.4 (798.3)	763.8 (639.4)	1189.6 (553.4)	1234.4 (462.9)	855.4 (718.7)	576.6 (243.2)	3.72	0.037	2.24	0.146

() denotes standard deviation

Harvest methods: CH, conventional harvest; TH, total harvest.

Table 4. Regression equations for aspen biomass component prediction

Dependent variable (kg ha ⁻¹)	Biomass equation	Sample size	R ²	F	P
Stem biomass	SB = 44.51 - 78.29 (D) + 89.79 (D ²) + 9.74 (H ²)	203	0.91	700.1	<0.001
Branch biomass	BB = 25.52 - 31.26 (D) + 45.46 (D ²) - 10.4 (HD)	203	0.76	211.3	<0.001
Foliage biomass	FB = 4.4 + 12.23 (D ²)	203	0.79	767.6	<0.001
Total biomass	TB = 83.73 - 124.75 (D) + 142.41 (D ²) + 7.19 H ²	203	0.89	558.0	<0.001

SB, stem biomass; BB, branch biomass; FB, foliage biomass; TB, total biomass; D, diameter breast height (cm); D², diameter breast height squared; H, total height (m); H², total height squared; HD, total height × diameter breast height.

than conventional harvesting. For medium aged stands, however, conventional harvesting produced larger aspen diameters.

Lesser Vegetation Biomass Components

Neither shrub nor forb biomass production was significantly affected by either parent stand age or harvesting treatment (Table 3). However, for grass biomass production, there was a significant interaction between age and harvest method. The old parent stands produced the most grass biomass (732.5 kg ha⁻¹), followed by medium aged stands (537.5 kg ha⁻¹) and young stands (233.8 kg ha⁻¹).

Identical trends to those for grass biomass were seen for total lesser vegetation biomass production. The significant parent stand age effect resulted in the oldest stands producing the most total lesser vegetation biomass (1338.4 kg ha⁻¹), with medium aged stands producing 1215.2 kg ha⁻¹ and the youngest stands producing 727.2 kg ha⁻¹. Again there were no statistically significant harvest treatment effects.

Aspen Biomass Component Regression Equations

Both forward and stepwise selection procedures produced identical equations in all instances, therefore only one equation for each biomass component is shown (Table 4).

The equations, based on transformations of total height and diameter at breast height, accounted for 76% to 91% of the variation in the various biomass components. All regression relationships were highly significant ($P < 0.001$).

All of the biomass components were found to be functions of diameter or some transformation of diameter. As well, some of the relationships were strengthened by including height or a transformation of height as an additional predictor.

Discussion

There were no major apparent differences among the major treatment plots by using ecological site classification criteria

in spite of the geographic separation of about 150 km. All but a few subplots were found to be essentially the same in terms of ecosystem association, soil drainage, and ecological moisture regime. The reason for the old age parent stands located in Calling Lake was because of lack of these stands in the Kinuso area.

It also was somewhat surprising not to have seen significant stand age and harvesting method effects for more dependent variables than actually was the case. One explanation for this may be the large degree of variation inherent in the data. The magnitude of that variation can be seen by considering the large standard deviation for most variables (Table 2).

The younger parent stands produced not only relatively more branch biomass, but also the tallest aspen stands. That trend was also seen for both total aspen biomass production as well as for aspen density. In the latter cases, however, the age effects were not statistically significant, although the effects were almost significant for total aspen biomass production ($P = 0.088$). It may be the case that stands of younger age are inherently more resilient in terms of ability to respond to disturbance. Further, soil nutrient availability may have been higher in young stands, as the older stands would have been removing and storing nutrients from the site for a relatively longer period of time.

Generally, the young parent stands produced relatively less shrub, forb and grass biomass in comparison to the old parent stands. For grass and total lesser vegetation biomass, there was significant interaction between parent stand age and harvest method. Intuitively, this finding makes ecological sense. Although pre-harvest data is not available in the context of this analysis, it is likely that the younger aged stands have a higher density of trees per hectare than old stands. When the stands are cut, it follows that older stands would have fewer stumps per hectare, from which to generate suckers. Therefore, the forest floor on older cutovers would be more exposed to direct sunlight and produce more grass and shrubs. This accounts for the

higher levels of lesser vegetation biomass after harvest in the older stands in this study.

For most of the treatment combinations, both aspen height and aspen diameter were larger for total biomass removal than for conventional logging treatments. From this data, total biomass removal was not detrimental to either aspen diameter or height growth. In fact, the total removal of biomass may have resulted in greater warming of the soil after disturbance relative to conventional logging, which would have left a good deal of slash on site. Higher soil temperatures would likely have led to more vigorous regrowth following harvest. That may have led to more productive growth following sucker establishment, including both height as well as diameter growth. Further, the density data also point to this effect, although the effects were not statistically significant. The total biomass removal treatments showed higher aspen densities relative to the conventional logging treatments.

In the regression analyses to generate biomass prediction equations, both forward and stepwise selection procedures yielded exactly the same models. Although that is not always the case in the general sense, it does yield some degree of confidence in the analysis when it does occur. In the context of this study, we can be confident of the results of these analyses, not only because of the degree of consistency between the two techniques, but also because of relatively high R^2 values of all models (Table 4). Although a variable is found to be important in predicting or explaining variation in another parameter, that relationship is not necessarily causal. However, there may be good biological reasons for many relationships which are defined by regression analysis.

The point of major interest from these regression analyses is that the first variable entered into every single model was diameter squared. In each case, it accounted for the vast majority of the explained variation in the dependent model. This is not surprising when considering the role of diameter in calculating tree volume.

It is apparent that diameter squared plays a key role in predicting tree biomass. It is also interesting to note that it is the most important variable for the prediction of all biomass components, whether it is stem, foliage, branch or total aspen biomass.

Conclusions

Using the principles of biogeoclimatic site classification, it was not possible to adequately resolve site differences among treatment blocks and subplots in this study. For this reason the geographic separation of the old-parent stands in Calling Lake and the young-, and medium-aged parent stands near Slave Lake did not seem to matter. Since these variables did not vary, the observed variance could be attributed to the treatments.

Parent stand age was significant for certain biomass components such as branch, total stem biomass, and total aspen biomass. Harvesting method does not seem to affect aspen biomass but may affect grass and other lesser vegetation. The harvest method effect was not statistically significant ($P > 0.05$) as was the case when the stands were two years old (Grewal 1988). Alban and Perala (1990) studied the effects of harvesting on three mature aspen stands in Minnesota and Michigan and found that whole tree and conventional harvesting methods did not influence the weight of forest floor carbon or organic carbon (to a depth of 50 cm) for up to 8 years. Furthermore litterfall and vegetative biomass recovered to near pre-harvest levels within

5 years in both harvesting treatments in all study sites (Alban and Perala 1990).

Although there were not many measured parameters for which there were clear stand age and harvest method effects, the observed effects seemed logical. Younger parent stands may be inherently more capable of responding to disturbance in terms of aspen sucker establishment and growth than older parent stands. Total removal of biomass was not detrimental to aspen regeneration for up to six years following harvest, and it may have been preferential to conventional logging in terms of both number of regenerated aspen stems as well as their size and volume.

As expected in a natural system, variation is large and treatment effects difficult to bear out. Further research into the relationship between parent stand age and harvest method on biomass productivity should be done before possible management policies can be developed.

Juvenile biomass component equations were developed that relate biomass to height and diameter. Diameter squared was the most useful parameter for the prediction of aspen biomass component production. Payandeh (1981) found that biomass is primarily a function of diameter at breast height and appeared to be insensitive to tree height across broad regions.

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