UPPER LIMITS OF STANDING CROP DENSITY FOR WOODY SPECIES IN THE PRAIRIE PROVINCES

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INFORMATION REPORT NOR-X-243

NORTHERN FOREST RESEARCH CENTRE
CANADIAN FORESTRY SERVICE
ENVIRONMENT CANADA
1982

Catalogue No. Fo46-12/243E
ISBN 0-662-12167-8
ISSN 0704-7673

This publication is available at no charge from:

Northern Forest Research Centre
Canadian Forestry Service
Environment Canada
5320-122 Street
Edmonton, Alberta, Canada
T6H 3S5

Peterson, E.B., V.M. Levson, and R.D. Kabzems. 1982. Upper limits of standing crop density for woody species in the prairie provinces. Environ. Can., Can. For. Serv., North. For. Res. Cent. Edmonton, Alberta. Inf. Rep. NOR-X-243.

ABSTRACT

Young tree and shrub stands in Alberta, Saskatchewan, and Manitoba were sampled in 1979 to obtain estimates of maximum standing crop density. Aboveground standing crop values double the regional averages were found, with upper limit dry weights of 16.9 t/ha for a 3-year-old aspen-alder stand, 18.1 t/ha for a 4-year-old aspen-alder stand, and 29.6 t/ha for a 5-year-old aspen stand. Some young stands achieved standing crop densities comparable to those of fully closed mature stands. Recorded standing crop densities included 2.16 kg/m^3 for an 8-year-old willow stand, 1.66 kg/m^3 for an 8-year-old lodgepole pine stand, and 1.19 kg/m^3 for a 9-year-old alder stand. Equations for predicting foliage dry weight, wood dry weight, and total aboveground dry weight from independent variables of stem diameter, stem height, stand age, and number of stems per hectare yielded results of low reliability.

RÉSUMÉ

En 1979, on a étudié par places-échantillons des peuplements de jeunes arbres et arbrisseaux en Alberta, en Saskatchewan et au Manitoba afin d'estimer la densité maximale des tiges sur pied. Les valeurs obtenues pour les parties aériennes étaient le double des moyennes régionales, les chiffres les plus élevés du poids anhydre étant de 16,9 t/ha et de 18,1 t/ha pour des peuplements d'aulne-peuplier de trois ans et quatre ans, respectivement, et de 29,6 t/ha pour un peuplement de peuplier de cinq ans. Quelques jeunes peuplements ont atteint des densités comparables à celles des peuplements de grande densité parvenus à maturité. On a enregistré des densités de 2,16 kg/m^3 pour un peuplement de saule de huit ans, de 1,66 kg/m^3 pour un peuplement de pin tordu latifolié de huit ans et de 1,19 kg/m^3 pour un peuplement d'aulne de neuf ans. Les équations servant à calculer le poids anhydre du feuillage, du bois et de l'ensemble des parties aériennes à partir de variables indépendantes, c'est-à-dire le diamètre et la hauteur de la tige, l'âge du peuplement et le nombre de tiges par hectare ont donné des résultats peu satisfaisants.

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.

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This report, based on ENFOR project P-51, was prepared by the Canadian Forestry Service. Field data were collected under contract (DSS Contract No. OSS 79-00031) by Western Ecological Services (B.C.) Ltd.

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INTRODUCTION

Canada's program to estimate potential energy yield from forest biomass has focussed to date primarily upon tree-size raw materials and wood wastes associated with harvesting and processing operations. To supplement the growing data base, a sampling program was undertaken in 1979 to obtain information on several biomass characteristics of a variety of young tree and shrub stands under 30 years of age in the Mixedwood Forest Section of Alberta, Saskatchewan, and Manitoba and the Lower Foothills Section of Alberta.

The focus was on dense young stands of trees or shrubs because many such stands give the visual impression of a large amount of woody biomass packed into a given volume of stand space and also because they frequently present problems for coniferous regeneration plans or for other silvicultural programs. Various silvicultural treatments require the expenditure of money and fossil fuel energy to remove or control the growth of unwanted woody species in forest stands.

Where dense young tree stands or shrubs are a silvicultural problem, the magnitude of the problem is often proportionate to the density of woody stems (number of stems per unit area of land). It is therefore desirable to assess the potential for using some or all of the harvested woody biomass for local bioenergy production when unwanted woody material is being handled for silvicultural reasons. This rationale is not to suggest that shrubs and young stands of tree species are necessarily competitive with larger trees or wood wastes as bioenergy sources. The goal instead should be a search for ways to convert present silvicultural commitments for shrub control into methods that might recover at least part of the energy cost of removing or otherwise handling unwanted woody biomass.

With this goal in mind, the study undertaken in 1979 set out to estimate the maximum standing crop densities in young stands, with two practical objectives:

1. to search out ecosystems in which the most woody biomass is packed into the least growing space (standing crop density, kg/m^3) in the least growing time; and
2. to record the physical factors, stand histories, and types of disturbances that contribute to ecosystems with both high standing crop densities and rapid growth rates.

In scientific terms, the objective was to test the following two hypotheses advanced by Kira and Shidei (1967):

1. that standing crop density is virtually independent of stand height in forests, with most fully closed stands tending to have a dry matter density of 1.0 to 1.5 kg/m^3; and
2. that exceptionally high dry matter density occurs in certain shrub communities and dense stands of conifer saplings, with dry matter density up to 10 times as great as that in normal forest stands.

The 170 sample locations from which biomass data were obtained (Fig. 1) were located mainly within Section B.18a (Mixedwood) and Section B.19a (Lower Foothills) of the Boreal Forest Region (Rowe 1972).

RELATION TO CANADA'S BIOENERGY PROGRAM

This study related closely to the inventory aspects of Canada's bioenergy research and development program. Most of the other ENFOR projects that have aimed at simplified methods of biomass inventory have focussed on mathematical conversion of tree volume data to a weight estimate or have developed equations that predict individual tree weights from readily measurable variables such as tree height, stem basal area, stem diameter, or tree age. Some of the mensurational studies have included sampling of very small stems in young stands, 5 years of age or less, and this has resulted in a significant downward extension of the lower size limit of conventional tree volume tables. As a result of these ENFOR studies, there is now a sufficient data base for many of Canada's tree species to allow prediction of weights of individual trees and of standing crop (kg/ha) for stands of

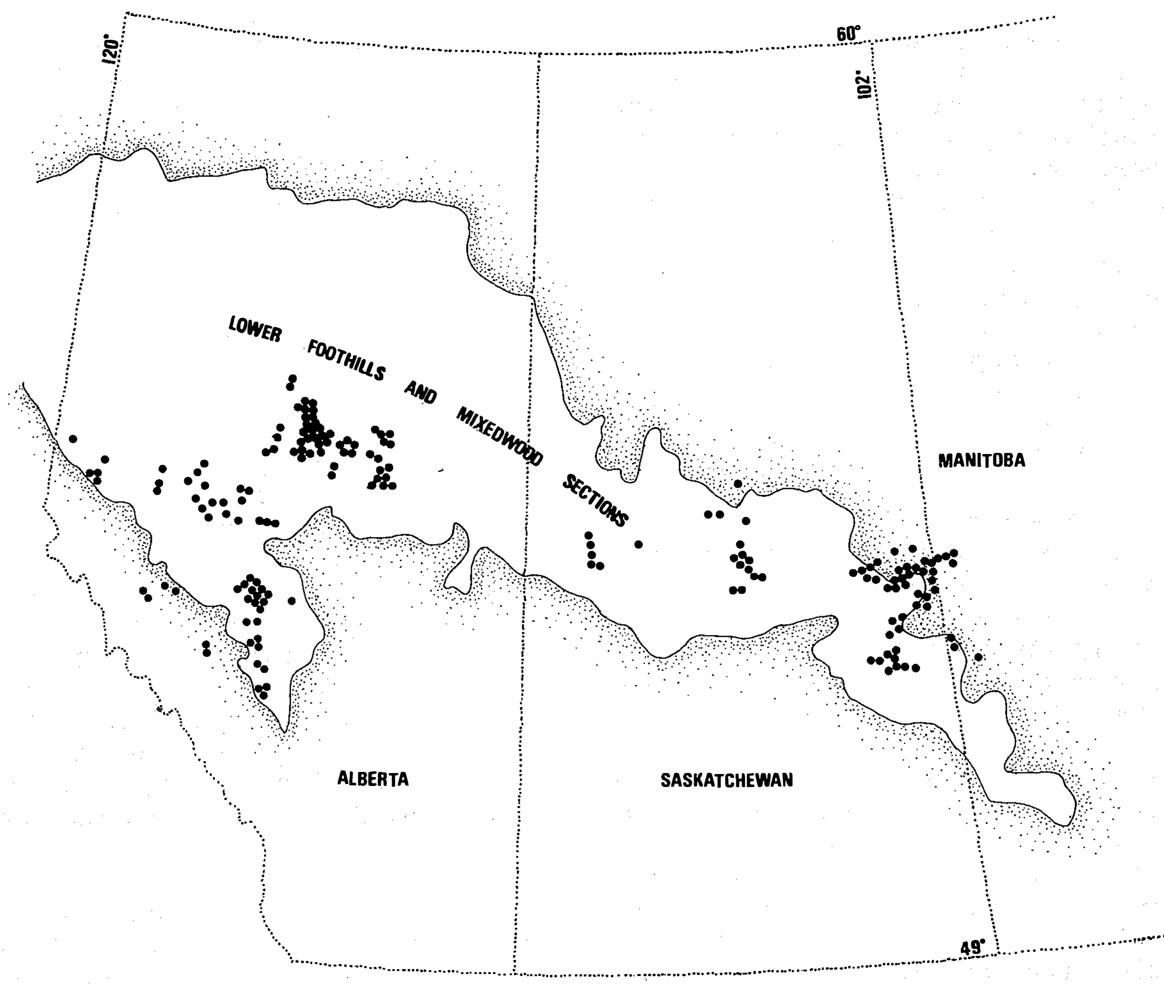

Figure 1. Locations of 170 biomass sample plots, mainly within the Mixedwood and Lower Foothills sections of the Boreal Forest Region in Alberta, Saskatchewan, and Manitoba.

various ages and sites of varying productivity. The recent report by Bella and De Franceschi (1980) dealing with biomass productivity of young aspen stands in western Canada is representative of these recent advances in biomass inventory methods.

The study outlined here differs from other recent biomass inventory projects in several ways. First, considerable emphasis was given to standing crop estimation in stands of shrub species. Most forest biomass inventory projects focus mainly on tree species, often only those used for conventional forest products. Although shrub stands in forested areas were given special attention in this study, identical sampling methods were also applied to young stands of several tree species so that data could be related to other biomass inventory projects that have dealt with tree species.

A second point of difference was the emphasis placed upon estimation of standing crop density (kg/m^3), for reasons outlined later. Third, there was no attempt in this study to develop regression equations for prediction of weight of **individual** shrubs or young trees on the basis of height or stem diameter; data are expressed only in terms of standing crop per unit volume of occupied growing space and in terms of standing crop per unit land area.

Finally, this study sought data on apparent **upper limits** of standing crop and standing crop density in young stands. This bias was a deliberate attempt to obtain information of possible use for the design of small biomass harvesters. Because of this bias, the estimates provided here should not be extrapolated to large land areas. The data should be taken only as an indication of the maximum standing crop per unit land area and maximum standing crop density per unit volume of stand space that could be expected to be encountered by any mechanical biomass harvester in the Mixedwood and Lower Foothills sections of the Boreal Forest Region.

Such departures from the traditional approach of other forest biomass inventory projects have several implications for Canada's bioenergy research and development program. The emphasis on dense stands of young tree species and on dense shrub stands was meant to aid the setting of priorities when there are choices in the source of biomass available for energy production. It was assumed that for some time to come the first priority will be bioenergy production based on use of wastes associated with currently harvested materials; many of the present ENFOR projects emphasize this priority.

The next priority involves a choice of: (a) harvest of material that is normally used for other forest products and use of this biomass for energy production instead; (b) harvest of woody materials that are not conventionally used for other forest products; or (c) development of plantations specifically for bioenergy harvesting purposes. The first of these three choices was de-emphasized in this study because there are concerns that any large-scale gasification projects or production of methanol from traditionally harvested wood supplies could drive up wood prices for other forest-based industries.

This study was based on the assumption that Canada's first priority for forest biomass procurement will continue to be industrial wood wastes and that the second priority source should be woody materials not now used for other forest products, with emphasis upon those species that are already being handled in stand improvement or regeneration programs. This is not necessarily an argument that shrub species or dense young stands of tree species should be specifically promoted for use in energy plantations (choice (c) above), although there could be justification for this objective in the future. The suggestion instead is that there should be an assessment of the potential biomass yield from those currently unused woody species that are already receiving silvicultural attention where forest lands are being managed. Usually this attention focusses on methods to remove unwanted woody species during right-of-way maintenance or site preparation for regeneration of high-priority tree species or on methods to reduce the competition created by dense stands of shrubs or young trees. If money is being spent to get rid of unwanted shrubs or small trees, and particularly if this is a step that consumes conventional fuels, there are compelling reasons to estimate the potential bioenergy yield of the biomass that is being weeded out. In some cases, especially where unwanted species are growing in very accessible areas along rights-of-way, plans to eliminate or reduce such woody material may need only modest changes to convert a weeding operation into an energy-yielding operation.

RELATION TO OTHER FOREST BIOMASS STUDIES

Within Canada's ENFOR program, the projects most closely related to the work described here are: ENFOR Project P-30 by Horton Forestry Services Ltd., Stouffville, Ontario, dealing with native poplars and white birch as an unexploited biomass source in Ontario (Environment Canada 1980); ENFOR Project P-41 by Dr. A.J. Kayll, formerly of the University of New Brunswick, on the rate of growth of biomass in young, naturally regenerated stands of different species and origins (Environment Canada 1980); and the recently initiated work by Perreault, Larouche, Houde Associes, Quebec, to assess the potential and feasibility of producing forest biomass using brushwood for energy production (Supply and Services Canada 1980). A project to assess the impact on wildlife of short-rotation management of boreal aspen stands by D.A. Westworth and Associates Ltd., Edmonton, (Supply and Services Canada 1980) also recognized that young forest stands may have a significant future role in planned forest biomass production programs.

Beyond Canada's ENFOR program, two general groups of studies provide data that can be compared to those gathered in this study. The first group includes those that focus on shrub biomass in relation to wildlife use or in relation to nutrient cycling in forest ecosystems; reports by Brown (1976), Tappeiner and John (1973), and Telfer (1969, 1972) typify such studies. The second group is characterized by more general studies that have recognized shrubs as a neglected resource (McKell 1975) or as a significant component of the "complete forest concept" (Young 1980). The latter concept incorporates the idea that all shrub and tree species should be considered in forest biomass inventories. In other cases, shrub biomass has gained recent attention in relation to silvicultural problems and successional trends following forest harvesting (Irwin and Peek 1979).

Among these diverse interests in shrub biomass, the work by Young (1980) appears to be the most optimistic about the future role of shrubs for bioenergy production. His work in Maine has included biomass estimates of deciduous successional species such as pin cherry, chokecherry, gray birch, red maple, and aspen - a collection of little used species locally known as "puckerbrush". Young's advocacy of "puckerbrush power" is based on the observation that the annual dry matter production of such successional stands, when fully stocked, is comparable to stands of climax deciduous species. Young's estimate of an average 50 oven dry tonnes per hectare (5 kg/m^2) of wood and bark, above ground, indicates that in Maine alone there are millions of tonnes of puckerbrush immediately available for use as energy. The widespread occurrence of similar deciduous successional stands in most other forest regions of North America suggests a wide geographic scope for the complete forest concept advocated by Young. The data summarized in this report provide additional quantitative estimates of the relative importance of young tree and shrub stands as potential sources of usable biomass.

Another purpose of this study was to test further the hypothesis that exceptionally high standing crop densities (kg/m^3) occur in certain shrub communities and in dense stands of conifer saplings. For example, Kira and Shidei (1967) reviewed a large number of biomass studies that indicated that certain shrubby stands may have standing crop densities up to ten times as great as the 1.0 to 1.5 kg/m^3 that is considered the normal range for fully closed stands of mature forests. This hypothesis is of practical significance to Canada's bioenergy research program because mechanical removal of aboveground biomass should be least costly where the greatest amount of energy-producing materials can be removed from a unit volume of growing space.

It could be argued that standing crop per unit land area, rather than standing crop per unit of forest stand space, is the most important inventory measure, since space available for woody plants to grow upward is not limited. If stands of low stature pack as much biomass into a unit volume of growing space as do mature forests, and particularly if such stands require only several years to achieve a standing crop density that equals or exceeds that of mature forests, then these become important considerations for the length of rotation required for successive biomass harvests and for the size and design of mechanized biomass harvesters. For example, if a dense shrub stand only 2 m tall packs as many kilograms of wood into a cubic metre of growing space as does a forest stand 10 m tall, then a smaller, more maneuverable, and less expensive harvester designed for the 2 m material should be able to harvest biomass at a lower unit cost than a heavier machine needed for the 10 m material. Such considerations may be unimportant for large-scale biomass harvesting operations, but for small operations the size and cost of harvester will be of concern. The maximum packing of woody material within a given volume of growing space is a variable that indicates the capacity that should be designed into the cutting mechanisms and other parts of biomass harvesters.

If stands of young trees and shrubs are eventually used as sources of energy-producing materials, this study's estimates of some naturally occurring maxima for packing of woody biomass indicate the productivity goals that should be sought where vegetation management programs are initiated to increase biomass production per unit area of land. If vegetation is to be managed for energy production, the management goal should be to achieve naturally occurring upper limits. The data summarized here provide estimates of such upper limits for several woody species in the Lower Foothills and Mixedwood forest sections of the prairie provinces.

METHODS

Selection of Sample Stands

Because the main objective of this study was to obtain estimates of maximum standing crop densities in young stands of woody species, field methods were not designed to ensure a random or stratified selection of sample locations, as is done in conventional inventory work. The four main criteria used in selection of sample plot locations were as follows:

1. stands that appeared to be densely packed (high standing crop density);
2. complete canopy closure over the sample plot area;
3. uniform stem ages within the stand; and
4. stands dominated by only one species.

The first and second of these selection criteria were always met, and the third and fourth criteria were met wherever possible. Some of the selected stands were closer to open areas (such as roads, cutlines, or petroleum exploration well sites) or to edges of mature forest stands than would normally be accepted in a systematic forest inventory program, but this disadvantage was overlooked in favor of meeting the four selection criteria listed above.

In some cases, stands that did meet the four criteria listed above were not sampled. Some of the reasons for rejections were heavy coatings of road dust on the foliage and stems, wetness of the foliage and stems, significant defoliation by insects, significant browsing by wild or domestic ungulates, or the presence of autumn-colored foliage with evidence of leaf drop already in progress.

Stand size was generally not a factor in selection of sample stands except that a minimum area of about 15 m^2 was required to contain the main sample plot and three nearby 1-m^3 sample frames. The sampling program did seek a significant number of sample plots in locations that involved relatively large uniform stands such as burned or logged areas. In an operational biomass inventory program, emphasis would be given to larger, more uniform areas than was done in this study because of the logistic suitability of such stands for mechanized biomass harvesting. In this study, however, vegetation types that occurred in small patches or linear strips were not ignored because they often appeared to possess high standing crop densities. The entire linear zone of vegetation on a cleared right-of-way is generally considered to be a result of "edge effect". Such sites were not ignored; sample plots were located within the central parts of such linear vegetation types.

Another objective of this study was to record the range of habitat conditions that appeared to support woody vegetation with high growth rates and high standing crop densities. The types of stands sampled are listed in Table 1.

Table 1. Sample plots for estimation of upper limits of woody standing crop density, grouped according to types of stand sampled

Origin of stand	No. of plots	Plot numbers*
1. Regenerated after clear-cut logging	23	41,74,101,102,103,300,315,316,319,323, 334,335, 352,353,354,356,357,358,359, 360,361,362,363
2. Regenerated after partial clearing of tree overstory	12	42,43,314,336,338,339,341,342,344,347, 355,364
3. Regenerated after fire	39	2,3,5,6,7,8,9,10,11,12,16,20,27,28,30, 31,36,47,53,54,56,57,58,61,62,66,82, 83,84,85,95,96,98,104,303,304,306,313,317
4. Regenerated after fire and logging	6	32,86,87,88,105,308
5. Regenerated after shallow bulldozing (generally land clearing)	14	1,4,17,18,45,50,51,59,65,70,301,322,327, 330
6. Regenerated on road, railroad, or power-line right-of-way	42	14,15,19,22,23,24,25,26,29,33,46,48,49,64, 67,68,69,71,72,76,77,79,80,89,92,93,94, 97,100,309,311,318,321,326,329,331,332, 333,337,343,349,365
7. Regenerated on roadside landings, borrow pits, and well-site clearings	17	21,34,39,40,44,52,75,81,90,91,99,302,307, 320,328,340,350
8. Natural shrub areas without tree overstory (no obvious recent disturbance)	12	13,35,55,60,63,78,305,310,312,324,325,345
9. Natural shrub areas with a tree overstory (no obvious recent disturbance)	5	38,73,348,351,366

* Plots 1 to 105 were in Alberta and plots 300 to 366 were in Saskatchewan and Manitoba. Data from plots 37 and 346 were not usable.

Summaries of the sample plots by vegetation type, moisture class, soil texture, and origin of habitat (type of disturbance) are provided for Alberta (Appendix 1) and for Saskatchewan and Manitoba (Appendix 2). Two sample plots (37 and 346) did not yield usable data. Sample plot 37 contained only two stems in one sampling frame and the requirement to record basal diameter of the three largest stems could therefore not be met. Sample plot 346 was not used because it was the only pin cherry (**Prunus pensylvanica**) stand sampled.

At a number of locations an effort was made to sample a range of moisture conditions within one stand of uniform age and origin. This was accomplished by placing sample plots along a topographic sequence where there appeared to be significant elevational controls over moisture conditions. For example, sample plot 5 was on a mesic site at the base of a sandy outwash ridge, whereas plot 6 was located on the drier crest of the same ridge. Other paired plots that were located on comparable topographic or soil moisture gradients included plots 30 and 32, 53 and 54, 86 and 87, 315 and 316, and 334 and 335.

In a few instances it was possible to sample stands of contrasting origins in areas where physical factors appeared to be relatively constant. For example, plots 47 and 48 were located in adjacent balsam poplar stands, with the former being burned over and the latter cleared for a road right-of-way.

Some sample stands were selected in areas where shrubs were known to be a silvicultural problem. For example, plots 46 and 49 were on sites planted to white spruce by the Alberta Forest Service but which were heavily overgrown by balsam poplar and willow. In some cases, there was evidence of repetitive attempts to control the rapid growth of young trees or shrubs. In this context, plot 326 was a young balsam poplar stand that had originated after mowing of a previous young stand; the stand was less than 10 years of age when it was mowed at 10 to 20 cm above ground level, after which it developed an exceptionally dense regrowth of sprouts. This stand history is similar to that which might be expected from repetitive short-rotation biomass harvesting; the field data from plot 326 may be taken as one sample of the potential yield from a second biomass harvest of small woody materials.

Although the number of samples is limited, several paired plots were originally selected to provide comparisons of relationships between standing crop density and number of stems per unit area of land. Plots 82 and 83 were in two adjacent lodgepole pine stands; the former had 338 000 stems per hectare and the latter only 113 000 stems per hectare. Comparable variations in number of stems per unit area occurred in plots 95, 96, and 98 and in plots 104 and 105.

All sample locations were recorded on National Topographic Series maps at a scale of 1:250 000.

Field Plot Descriptions

Descriptive information recorded for each sample plot included plot number, date, location, and photograph number if the sample site was photographed prior to destructive sampling.

The soil immediately below the organic horizon was sampled for texture on the basis of hand analysis. Total depths of organic horizons (L, F, and H layers) were also recorded. Each stand was subjectively categorized into one of four moisture classes: wet, wet/mesic, mesic, and dry. Other information recorded but not analysed in this report included a list of the main species of the herb layer and notes on the suitability of the area for movement of wheeled harvesters.

Stand histories were grouped into nine classes:

1. regenerated after clearcut logging;
2. regenerated after selective logging;
3. regenerated after fire;
4. regenerated after fire and logging;
5. regenerated after bulldozing for agricultural clearing;
6. regenerated on road, railroad, or power-line rights-of-way;
7. regenerated on roadside landings, borrow pits, and petroleum exploration well-site clearings;
8. natural shrub areas without a tree overstory (no obvious recent disturbance); and
9. natural shrub areas with a tree overstory (no obvious recent disturbance).

Assignment of sample plots to these nine categories is summarized in Table 1.

Field Sampling and Laboratory Methods

Each selected stand was sampled by harvesting, weighing, and subsampling the woody material on one main plot of 2-m radius (12.57 m^2) and within a 1-m^3 sample frame placed at three locations near the main plot. On the 12.57 m^2 plot, fresh weights were obtained by direct weighing of the following components:

1. dead standing woody stems (all species combined);
2. all live stems of the most abundant woody species;
3. all live stems of the second most abundant woody species;
4. all live stems of the third most abundant woody species; and
5. all live stems of all other woody species.

The objective of the three additional 1-m^3 samples was to obtain a more direct measurement of standing crop density (kg/m^3) as an indication of the maximum packing of woody material that could be encountered by the cutting bar of a biomass harvester. The 1-m^3 sampling frames were placed so that they were more or less fully occupied by stem material from top to bottom (Fig. 2). In contrast, standing crop density calculated on the main plot involved much unoccupied volume since the stand volume was arbitrarily calculated from the height of the tallest dominant, which was often considerably taller than the general height of the stand.

Three types of subsamples for which there were field fresh weights were measured, oven-dried, and weighed in the laboratory:

1. three wood plus bark segments from the bases of the three largest stems within each of the 1-m^3 sample frames;
2. one foliage subsample of the dominant species on the main sample plot; and
3. one wood plus bark subsample of the dominant species on the main sample plot.

Detailed descriptions of all field sampling methods and laboratory procedures are provided in Appendix 3.

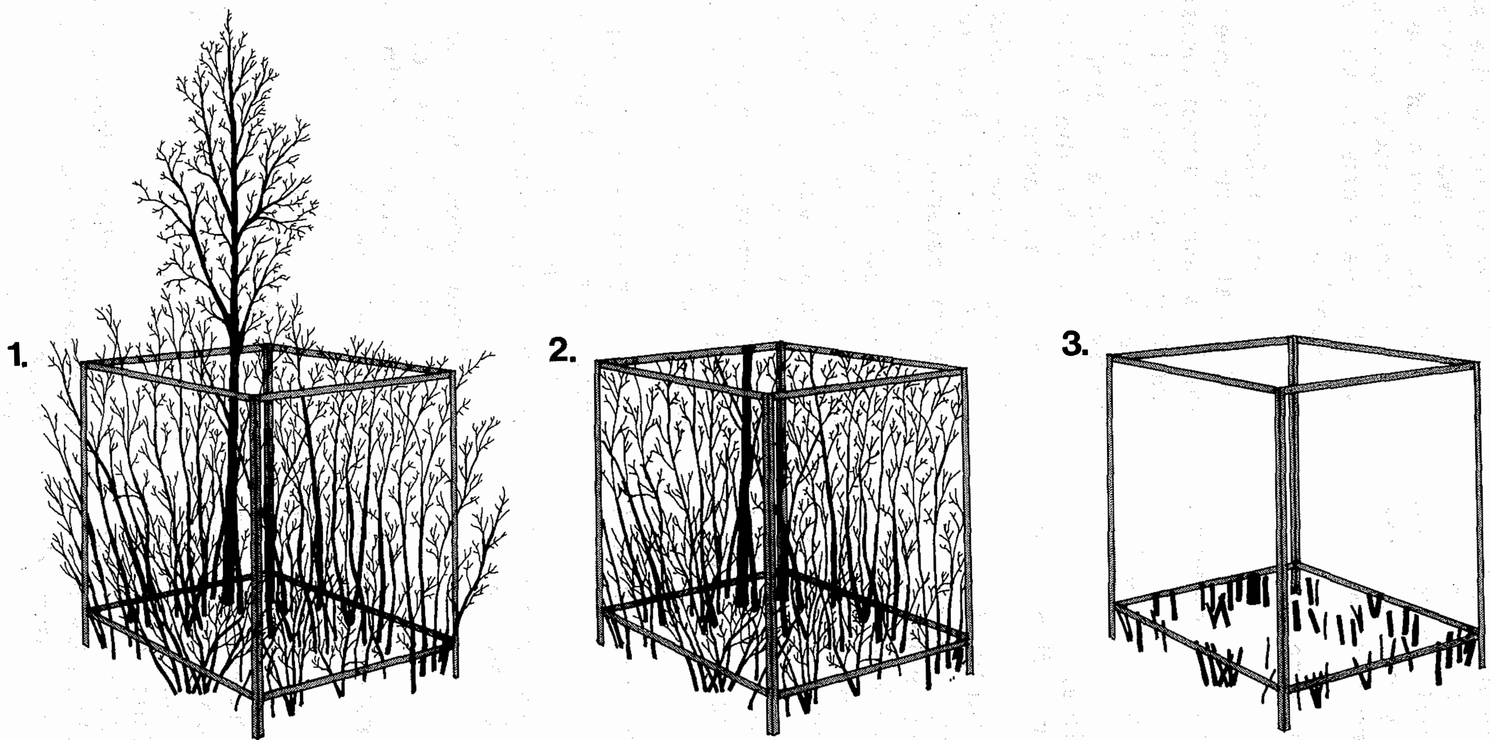

Figure 2. Sampling sequence to estimate standing crop density in 1-m^3 frame: 1. sampling frame assembled with base of cube 20 cm above ground level; 2. woody biomass trimmed to retain only that within 1 m^3; 3. stubble remaining after standing crop within 1 m^3 removed for weighing.

Statistical Analyses

One objective was to determine if combined terms, such as stem diameter squared times tree height (D^2H), would aid prediction of standing crop on a stand basis where standing crop measurements involve aggregate weighing of all woody material on a unit sample area rather than weighing of individual living stems. For example, it would be practical to be able to predict the standing crop in a young forest stand or in a shrub stand on the basis of the measured height of one or several dominants in the stand and basal diameters of several dominant stems, without resorting to weight prediction for individual stems in the stand. This study's data on any one species or vegetation type were not considered adequate for testing diverse combinations of independent variables for prediction of component or total stand dry weights. Instead the combined variables that Bella and DeFranceschi (1980) found to be most suitable for prediction of component and total weights of individual aspen trees were arbitrarily selected to test for prediction of weights on a stand basis. This involved testing of the equation

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

in which

- ln = natural logarithm
- W = component weight or total weight
- D = mean diameter outside bark of the nine largest stems measured at 20 cm above ground level
- H = height of the tallest dominant on the sample plot.

Such a model, which is intended for prediction of individual tree weights, cannot be expected to serve well for prediction of stand weights if stems in the stand are of highly variable diameters. Many of the dense young stands sampled in this study, however, were composed of even-aged stems of relatively uniform size, and application of the combined term (D^2H) to stands, rather than to individual stems, seemed worth testing.

The other combination of variables proposed by Bella and DeFranceschi (1980) for prediction of dry weights on an area basis involved the following equation

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

in which

- ln = natural logarithm
- DW = dry weight per unit land area
- A = age
- NS = number of stems per unit land area.

This model was also tested for the data gathered in this study. The two regression equations cited above, plus another based only on basal stem diameter

$$\ln W = a + b \ln (D)$$

were tested for the data available from this study.

Summary statistics for the stands sampled are listed in Table 2. Regression equations to predict foliage dry weight, wood dry weight, and total aboveground dry weight are presented for all sample plots combined (Table 3) and for those vegetation types for which 10 or more samples were available, including aspen (Table 4), alder (Table 5), willow (Table 6), balsam poplar (Table 7), lodgepole pine (Table 8), and white birch (Table 9). Summaries of data on foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3) are listed in Appendix 4 by increasing stand age for each of the major types of stands sampled. Criteria used to stratify data by vegetation type are outlined in Appendix 5.

Table 2. Summary statistics of 170 stands sampled

Statistic	Mean	Standard deviation	Min.	Max.
ALL SPECIES(n = 170)				
Stand age (years)	10.9	5.8	2	43
Dominant height (cm)	413.3	162.3	132	968
Basal diameter (cm) *	3.43	1.65	0.86	10.82
Number of stems per hectare **	166,684	115,188	21,500	853,100
Foliage dry weight (kg/m^2)	0.4318	0.3979	0.0813	2.6530
Wood dry weight (kg/m^2)	2.6984	2.0596	0.2539	12.7227
Standing dead weight (kg/m^2)	0.1534	0.1990	0	1.2828
Total dry weight (kg/m^2) ***	3.2837	2.3204	0.3353	14.1673
ASPEN (n = 24)				
Stand age (years)	11.1	5.8	2	29
Dominant height (cm)	554.4	187.0	167	968
Basal diameter (cm)	4.60	1.73	1.49	8.08
Number of stems per hectare	100,892	88,551	21,500	432,900
Foliage dry weight (kg/m^2)	0.3269	0.1601	0.1569	0.7050
Wood dry weight (kg/m^2)	3.2805	1.914	0.4933	6.6186
Standing dead weight (kg/m^2)	0.0972	0.0799	0.0034	0.2578
Total dry weight (kg/m^2)	3.7046	2.0671	0.6977	7.3310
Percent foliage (%) ****	14.0	6.2	7.9	32.5
ALDER (n = 21)				
Stand age (years)	9.7	3.9	4	19
Dominant height (cm)	393.2	125.8	173	681
Basal diameter (cm)	2.93	1.04	1.42	4.73
Number of stems per hectare	191,219	94,890	81,200	398,600
Foliage dry weight (kg/m^2)	0.2587	0.1355	0.1225	0.7233
Wood dry weight (kg/m^2)	2.3535	1.4246	0.4323	5.8874
Standing dead weight (kg/m^2)	0.1680	0.1920	0.0008	0.7727
Total dry weight (kg/m^2)	2.7802	1.5982	0.5885	6.8658
Percent foliage (%)	15.2	5.7	8.3	31.8
WILLOW (n = 18)				
Stand age (years)	9.8	4.8	3	19
Dominant height (cm)	398.7	170.6	139	750
Basal diameter (cm)	2.64	1.06	0.86	4.58
Number of stems per hectare	206,594	142,260	44,500	606,400
Foliage dry weight (kg/m^2)	0.2848	0.1282	0.0813	0.5756
Wood dry weight (kg/m^2)	2.8928	2.0186	0.2539	6.9115
Standing dead weight (kg/m^2)	0.2168	0.3399	0	1.2828
Total dry weight (kg/m^2)	3.3944	2.3055	0.3353	7.7053
Percent foliage (%)	16.2	4.2	5.2	30.1
BALSAM POPLAR (n = 15)				
Stand age (years)	8.9	2.9	3	13
Dominant height (cm)	473.1	151.9	200	710
Basal diameter (cm)	3.86	1.50	1.76	6.09
Number of stems per hectare	127,647	67,060	42,100	241,900
Foliage dry weight (kg/m^2)	0.3252	0.1199	0.1642	0.5544
Wood dry weight (kg/m^2)	2.8266	2.0219	0.5634	7.2635
Standing dead weight (kg/m^2)	0.0846	0.0792	0	0.2873
Total dry weight (kg/m^2)	3.2363	2.1772	0.7443	7.9967
Percent foliage (%)	19.1	7.05	12.0	35.6
LODGEPOLE PINE (n = 15)				
Stand age (years)	11.9	5.3	7	25
Dominant height (cm)	361.4	148.7	143	615
Basal diameter (cm)	4.44	2.25	2.37	10.82
Number of stems per hectare	132,433	83,531	35,800	338,200
Foliage dry weight (kg/m^2)	0.9274	0.3069	0.3227	1.3979
Wood dry weight (kg/m^2)	3.7483	3.5085	0.9999	12.7227
Standing dead weight (kg/m^2)	0.0951	0.0898	0.0004	0.3462
Total dry weight (kg/m^2)	4.7708	3.7893	1.3767	14.1673
Percent foliage (%)	25.9	9.8	9.3	42.7
WHITE BIRCH (n = 10)				
Stand age (years)	10.7	3.9	5	15
Dominant height (cm)	469.7	100.4	248	580
Basal diameter (cm)	3.46	1.10	1.40	4.90
Number of stems per hectare	131,140	54,543	70,900	251,400
Foliage dry weight (kg/m^2)	0.3037	0.1030	0.1436	0.4411
Wood dry weight (kg/m^2)	2.6590	1.2561	0.7873	4.2658
Standing dead weight (kg/m^2)	0.1067	0.1086	0.0048	0.2801
Total dry weight (kg/m^2)	3.0694	1.4004	0.9357	4.8408
Percent foliage (%)	17.3	4.4	11.7	25.8

* At 20 cm above ground level.
** Includes dead standing stems.
*** Total of wood dry weight, foliage dry weight and standing dead weight.
**** Foliage fresh weight as a percent of total above-ground live weight.
n = number of stands sampled.

Table 3. Regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight for all species combined

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -2.0536 + 0.8424 \ln D$	170	0.35
Wood dry weight, kg	$\ln Y = -0.6990 + 1.2740 \ln D$	170	0.67
Total aboveground dry weight, kg*	$\ln Y = -0.3636 + 1.1786 \ln D$	170	0.66
Foliage dry weight, kg	$\ln Y = -3.3796 + 0.2774 \ln D^2H$	170	0.28
Wood dry weight, kg	$\ln Y = -3.3495 + 0.4983 \ln D^2H$	170	0.74
Total aboveground dry weight, kg	$\ln Y = -2.7580 + 0.4540 \ln D^2H$	170	0.70
Foliage dry weight, kg	$\ln Y = 1.2448 + 0.0008 A^2 - 0.0568 \ln NS$	170	0.17
Wood dry weight, kg	$\ln Y = 16.7395 + 0.0030 A^2 - 0.8826 \ln NS$	170	0.19
Total aboveground dry weight, kg	$\ln Y = 17.2082 + 0.0040 A^2 - 0.8850 \ln NS$	170	0.20

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 4. Aspen regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -2.1833 + 0.6666 \ln D$	24	0.41
Wood dry weight, kg	$\ln Y = -1.3393 + 1.5962 \ln D$	24	0.85
Total aboveground dry weight, kg*	$\ln Y = -1.0085 + 1.4705 \ln D$	24	0.85
Foliage dry weight, kg	$\ln Y = -3.3736 + 0.2356 \ln D^2H$	24	0.42
Wood dry weight, kg	$\ln Y = -4.1842 + 0.5637 \ln D^2H$	24	0.87
Total aboveground dry weight, kg	$\ln Y = -3.6273 + 0.5191 \ln D^2H$	24	0.87
Foliage dry weight, kg	$\ln Y = 0.3839 + 0.0006 A^2 - 0.0097 \ln NS$	24	0.44
Wood dry weight, kg	$\ln Y = -1.2018 + 0.0072 A^2 + 0.2119 \ln NS$	24	0.35
Total aboveground dry weight, kg	$\ln Y = -0.9844 + 0.0079 A^2 + 0.2183 \ln NS$	24	0.36

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 5. Alder regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -2.0202 + 0.5591 \ln D$	21	0.21
Wood dry weight, kg	$\ln Y = -0.8258 + 1.4643 \ln D$	21	0.59
Total aboveground dry weight, kg*	$\ln Y = -0.5246 + 1.3508 \ln D$	21	0.56
Foliage dry weight, kg	$\ln Y = -3.3668 + 0.2406 \ln D^2H$	21	0.26
Wood dry weight, kg	$\ln Y = -4.2185 + 0.6133 \ln D^2H$	21	0.70
Total aboveground dry weight, kg	$\ln Y = -3.6610 + 0.5666 \ln D^2H$	21	0.67
Foliage dry weight, kg	$\ln Y = 0.9533 - 0.0003\, A^2 - 0.0399 \ln NS$	21	0.45
Wood dry weight, kg	$\ln Y = 23.8567 - 0.0027\, A^2 - 0.0127 \ln NS$	21	0.18
Total aboveground dry weight, kg	$\ln Y = 25.0296 - 0.0020\, A^2 - 1.3225 \ln NS$	21	0.16

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 6. Willow regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -1.9483 + 0.6591 \ln D$	18	0.38
Wood dry weight, kg	$\ln Y = -0.7620 + 1.7082 \ln D$	18	0.78
Total aboveground dry weight, kg*	$\ln Y = -0.4534 + 1.5754 \ln D$	18	0.75
Foliage dry weight, kg	$\ln Y = -3.2401 + 0.2445 \ln D^2H$	18	0.41
Wood dry weight, kg	$\ln Y = -4.0571 + 0.6266 \ln D^2H$	18	0.84
Total aboveground dry weight, kg	$\ln Y = -3.4780 + 0.5601 \ln D^2H$	18	0.81
Foliage dry weight, kg	$\ln Y = 1.0159 + 0.0005 A^2 - 0.0475 \ln NS$	18	0.24
Wood dry weight, kg	$\ln Y = 24.8548 + 0.0084 A^2 - 1.3796 \ln NS$	18	0.44
Total aboveground dry weight, kg	$\ln Y = 24.1954 + 0.0114 A^2 - 1.3315 \ln NS$	18	0.45

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 7. Balsam poplar regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -1.9571 + 0.6031 \ln D$	15	0.44
Wood dry weight, kg	$\ln Y = -1.1439 + 1.5122 \ln D$	15	0.68
Total aboveground dry weight, kg*	$\ln Y = -0.8202 + 1.3915 \ln D$	15	0.67
Foliage dry weight, kg	$\ln Y = -3.2060 + 0.2332 \ln D^2H$	15	0.50
Wood dry weight, kg	$\ln Y = -4.4178 + 0.6012 \ln D^2H$	15	0.80
Total aboveground dry weight, kg	$\ln Y = -3.8183 + 0.5515 \ln D^2H$	15	0.80
Foliage dry weight, kg	$\ln Y = 2.5225 - 0.0001 A^2 - 0.1349 \ln NS$	15	0.40
Wood dry weight, kg	$\ln Y = 35.3471 + 0.0137 A^2 - 2.0799 \ln NS$	15	0.71
Total aboveground dry weight, kg	$\ln Y = 38.4559 + 0.0140 A^2 - 2.2483 \ln NS$	15	0.69

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 8. Lodgepole pine regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -\ 0.9434 + 0.5765\ \ln D$	15	0.63
Wood dry weight, kg	$\ln Y = -\ 1.3062 + 1.6403\ \ln D$	15	0.74
Total aboveground dry weight, kg*	$\ln Y = -\ 0.6298 + 0.3954\ \ln D$	15	0.74
Foliage dry weight, kg	$\ln Y = -\ 1.8759 + 0.2021\ \ln D^2H$	15	0.41
Wood dry weight, kg	$\ln Y = -\ 4.0323 + 0.5835\ \ln D^2H$	15	0.79
Total aboveground dry weight, kg	$\ln Y = -\ 2.9307 + 0.4942\ \ln D^2H$	15	0.78
Foliage dry weight, kg	$\ln Y = 1.7944 + 0.0013\ A^2 - 0.0665\ \ln NS$	15	0.54
Wood dry weight, kg	$\ln Y = -\ 2.0178 + 0.0214\ A^2 + 0.1345\ \ln NS$	15	0.97
Total aboveground dry weight, kg	$\ln Y = 0.1413 + 0.0229\ A^2 + 0.0494\ \ln NS$	15	0.96

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

Table 9. White birch regression equations and related statistics for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight

Dependent variable	Regression equation**	n	R^2
Foliage dry weight, kg	$\ln Y = -2.1541 + 0.7640 \ln D$	10	0.65
Wood dry weight, kg	$\ln Y = -0.8708 + 1.4461 \ln D$	10	0.89
Total aboveground dry weight, kg*	$\ln Y = -0.6617 + 1.3990 \ln D$	10	0.91
Foliage dry weight, kg	$\ln Y = -3.7087 + 0.2894 \ln D^2H$	10	0.63
Wood dry weight, kg	$\ln Y = -3.7770 + 0.5436 \ln D^2H$	10	0.86
Total aboveground dry weight, kg	$\ln Y = -3.4679 + 0.5252 \ln D^2H$	10	0.86
Foliage dry weight, kg	$\ln Y = 3.3869 - 0.0004 A^2 - 0.1858 \ln NS$	10	0.42
Wood dry weight, kg	$\ln Y = 32.1604 - 0.0004 A^2 - 1.8047 \ln NS$	10	0.30
Total aboveground dry weight, kg	$\ln Y = 38.3970 - 0.0018 A^2 - 2.1507 \ln NS$	10	0.32

* Total aboveground dry weight includes field weight of dead standing wood.

** D = mean of nine maximum stem diameters (cm) at 20 cm above ground level.

H = height (cm) of the tallest dominant on the sample plot.

A = mean age (years) of nine largest stems.

NS = number of stems per hectare, including dead standing stems.

RESULTS

Estimates of Standing Crop

Dry standing crop estimates, based on harvests of the 2-m diameter sample plots, are listed in Appendix 4 in order of increasing age for each of the species or species groups sampled. Some of the extreme upper limits obtained are summarized in Table 10.

Exhaustive comparisons have not been made with other published standing crop estimates for young stands of the species listed in Table 10; however, the degree to which the estimated upper limits of standing crop exceed regional averages for a given species is indicated by two examples. Hazel stands sampled in 1979 had dry standing crops that ranged from 9.7 to 28.2 t/ha, whereas hazel standing crop estimates by Tappeiner and John (1973) ranged from 4.6 to 15.0 t/ha. The 14-year-old aspen stand with the highest dry standing crop in 1979 (73.3 t/ha) had an estimated 65.6 t/ha of wood alone (based on an estimate that 89.5% of the standing crop was in the form of wood (Appendix 4, Table A), whereas Perala (1973), citing work by other researchers, recorded 42 t/ha of wood alone for a 15-year-old aspen stand and 36 t/ha of wood and bark for a 13-year-old aspen stand.

The best comparative base line from which to judge the degree to which the 1979 data are apparent upper limits is the summary of biomass productivity of young aspen stands by Bella and De Franceschi (1980). Their study was based on data from a portion of the Mixedwood Section of the Boreal Forest that coincided closely with the sample area for this study; the present study differed only in its inclusion of a significant number of samples from the Lower Foothills Section of western Alberta. Since a primary interest in bioenergy production will be to obtain the maximum yield as quickly as possible, Table 4 from Bella and De Franceschi (1980) was selected as a basis of comparison because it provides data on standing crop (kg/ha) for aspen stands 2 to 5 years of age. Table 11 lists some examples of apparent upper limits of aboveground standing crops for unmanaged stands 3, 4, or 5 years of age for vegetation types sampled in 1979 and includes, for comparison, standing crops for the highest density classes of fully stocked aspen stands of the same age as derived from Bella and De Franceschi (1980). The 1979 study was not sufficiently detailed to provide standing crop data for each 1-year age class for each vegetation type. Table 11, however, does identify several vegetation types and age classes that yielded maximum standing crop values greater than the regional averages for the most dense aspen stands analyzed by Bella and De Franceschi. In extreme cases, some young stands in each of the 3-, 4-, and 5-year-old age classes have standing crop values double the regional average for the Mixedwood Section; such variability should be noted when goals are set for the maximum potential biomass yield in certain forest sites.

The maxima indicated in Table 11 should not be extrapolated to large land areas that may be dominated by such vegetation types. The main value of these apparent upper limits is to indicate the naturally occurring standing crops that could be locally encountered by biomass harvesters in certain areas within the Lower Foothills and Mixedwood forest sections. By comparison, these high values for unmanaged stands still fall short of

Table 10. Extreme upper limits of dry standing crop above ground for stands sampled in 1979

Species	Stand age yrs	Standing crop t/ha
Aspen **Populus tremuloides** Michx.	14	73.3
Alder **Alnus** spp.	9	68.7
Willow **Salix** spp.	9	77.1
Balsam poplar **Populus balsamifera** L.	13	80.0
Lodgepole pine **Pinus contorta** Dougl. var. **latifolia** Engelm.	25	141.7
White birch **Betula papyrifera** Marsh.	13	48.4
Hazel **Corylus cornuta** Marsh.	18	28.2
White spruce **Picea glauca** (Moench) Voss	17	93.5
Red-osier dogwood **Cornus stolonifera** Michx.	8	23.0
Bog birch **Betula glandulosa** Michx.	18	31.2
Mountain maple **Acer spicatum** Lam.	16	49.1
Jack pine **Pinus banksiana** Lamb.	43	34.1
Larch **Larix laricina** (Du Roi) K. Koch	11	23.6
Alpine fir **Abies lasiocarpa** (Hook.) Nutt.	25	55.7
Balsam poplar-alder **Populus balsamifera** L. - **Alnus** spp.	13	53.1
Balsam poplar-willow **Populus balsamifera** L. - **Salix** spp.	13	130.6
Aspen-alder **Populus tremuloides** Michx. - **Alnus** spp.	9	32.6
Aspen-hazel **Populus tremuloides** Michx. - **Corylus cornuta** Marsh.	12	39.5

Table 11. Examples of apparent upper limits of dry aboveground standing crop for unmanaged 3-, 4-, and 5-year-old stands of woody species in the prairie provinces

Vegetation type	Standing crop, t/ha at age 3	at age 4	at age 5
A. Apparent upper limits based on the 1979 study			
Balsam poplar	12.0	?	?
Balsam poplar-willow mixture	13.5	?	?
Aspen-hazel mixture	14.0	?	?
Willow	10.8	?	?
Aspen-alder mixture	16.9	18.1	?
Aspen	11.3	12.5	29.6
Red-osier dogwood	?	?	12.5
Mountain maple	?	?	16.2
B. Comparative base line for fully stocked aspen*	8.2	9.3	11.0

* Comparative standing crop data for dense young aspen are from Table 4 of Bella and De Franceschi (1980).

the exceptionally high standing crop values recorded for young managed stands. For example, Nautiyal (1979) cited data from one hybrid poplar clone in Ontario which produced 28.7 t/ha of leafless biomass on a 2-year rotation. Siren (1979) indicated that natural willow stands in Sweden may produce up to 6 t/ha of dry standing crop per year and that genetic selection of superior willow clones could result in dry matter production as great as 20 t/ha per year, a biomass accumulation rate that would yield standing crops much higher than those listed for 3-, 4-, and 5-year-old stands in Table 11.

The relative proportions of foliage and wood in the aboveground standing crop did not reveal a distinct trend with increasing stand age when all species were analyzed. For several of the deciduous species -- particularly aspen, alder, willow, and balsam poplar -- foliage tended to make up more than 20% of aboveground biomass for stands 4 years or younger and generally under 20% for stands over 4 years of age. Other deciduous species -- such as white birch, hazel, red-osier dogwood, bog birch, and mountain maple -- retained a relatively high proportion of foliage for a period beyond 4 years, or else showed no distinct trend with age. Lodgepole pine, jack pine, and larch had a relatively high proportion (over 20%) of aboveground biomass in the form of foliage until approximately 10 years of age, but white spruce and alpine fir did not reveal any trend toward a decrease in the relative proportions of foliage and wood up to age 24 (Appendix 4).

Generally, however, most individual species followed a detectable trend of young stands containing a relatively greater proportion of aboveground standing crop in the form of foliage than was the case with older stands sampled.

An 8-year-old lodgepole pine stand displayed the highest relative amount of foliage with 42.7% of the aboveground standing crop in the form of needles; a 12-year-old willow stand was at the other extreme with only 5.2% of the standing crop as foliage (Appendix 4).

Estimates of Standing Crop Density

Examples of woody stands under 20 years of age with standing crop densities of 1.0 to 1.5 kg/m^3 that are characteristic of fully closed forest stands are listed in Table 12. Figures in the first two columns of Table 12 are the most representative of standing crop densities that could be encountered over extended areas of land surface. Although these data were derived from the total harvest of 2-m radius sample plots, they should be viewed as maximum rather than average values because the selection of sample areas was biased in the search for upper limits. On the other hand, calculation of standing crop density based on volume of growing space defined by the tallest stem on the plot, rather than by mean height of stems on the plots, would produce underestimates of standing crop density.

Estimates in the second two columns of Table 12 were derived from the mean standing crop harvests from three 1-m^3 sample frames that were placed where stem clumping or other forms of exceptionally dense stem distribution occurred. These estimates of extreme upper limits of standing crop density can be taken as a guide to the harvesting capacity that should be incorporated into biomass harvesters intended for work in dense young stands of tree species or shrubs. Such extreme standing crop densities do not occur over large areas; however, for species that grow in clumps, such as alder, the loci of high standing crop densities may be well distributed throughout the large stands, even if they occupy only a small portion of the total land area, suggesting

Table 12. Examples of woody stands under 20 years of age in the prairie provinces with standing crop densities that reach levels typical of mature, fully closed forest stands (at least 1.0 kg/m^3)

Vegetation type	Aboveground standing crop density*, dry wt.,			
	Stand age yr	Based on total harvest of 2-m radius plot kg/m^3	Stand age yr	Highest average of three 1-m^3 samples kg/m^3
Balsam poplar-alder mixture	13	1.02	13	3.03
Bog birch	18	1.04	18	3.81
Balsam poplar	11	1.05	12	5.26
Alpine fir	15	1.14	18	5.77
Alder	9	1.19	11	4.55
Lodgepole pine	8	1.66	16	6.88
Balsam poplar-willow mixture	13	1.73	13	5.33
Willow	8	2.16	19	5.95
White spruce	12	2.30	17	6.33

* Includes dead standing stems.

that mechanized biomass harvesters would frequently encounter areas of high amounts of biomass per unit volume of stand space.

The data presented in Table 12 confirm the hypothesis of Kira and Shidei (1967) that exceptionally high standing crop densities occur in certain shrub stands as well as in young stands of some coniferous and deciduous tree species. There were insufficient data to confirm or reject the hypothesis that standing crop density is almost independent of stand height in forests (Kira and Shidei 1967). A previous analysis of **Populus** stands in Alberta indicated that standing crop density increased with stand height (Johnstone and Peterson 1980).

Biomass Prediction Equations for Shrubs and Small Trees

In general, the regression equations developed for prediction of foliage dry weight, wood dry weight, and total aboveground dry weight using stem diameters, stem heights, stand ages, and numbers of stems per hectare as independent variables yielded results of low reliability. Only rarely did tested regression equations yield R^2 values of 0.90 or higher (Tables 8 and 9).

The validity of using combined terms such as D^2H for prediction of volume or weight of individual shrubs or small trees is not in doubt (Buckman 1966), but the relatively small variation in standing crop accounted for by the regressions tested (Tables 3 to 9) suggests that there is little to be gained from extension of this approach to stands of shrub-sized material. The low reliability of the regression equations tested by the 1979 data may have resulted in part from deriving D from a mean of diameters of the nine largest stems sampled and H from the height of the tallest dominant on the sample plot. Although it was not tested in this study, it is likely that more reliable weight predictions could be obtained if D and H represented mean values of a wider range of stem sizes on each sample plot.

For practical use it would be desirable to have general guidelines to allow visual estimates of shrub standing crop or estimates based on a minimum of rapid measurements. For example, Young (1980) stressed that there are direct relationships between the average height of a stand and the dry weight of aboveground portions of shrubs and trees; his suggested rule of thumb is 2.0 dry tonnes per hectare (t/ha) for each 30 cm of average height. Application of this guideline suggests that a fully stocked stand of deciduous species with an average height of 9.0 m should have a dry weight of 60 t/ha above ground. Spot checks of the data listed in Appendix 4 suggest the general validity of such a guideline: for example, plot 20 (Appendix 4, Table A) contained 70 t/ha of standing crop, of which 90% (63 t/ha) was wood, and the stand height was 9.68 m. It is tempting to suggest a general mathematical relationship such as that stated by Young (1980), but the variability portrayed by data in Appendix 4 and by the R^2 values in Tables 3 to 9 indicates that there are no simple ways to estimate standing crop in dense young stands of shrubs and trees.

DISCUSSION AND CONCLUSIONS

Theoretical Implications

The rapid growth rates characteristic of young stands of pioneer species are widely documented in the ecological literature. A high number of stems per unit area of land and rapid achievement of "full occupancy" are also characteristic of woody species that occupy the early successional stages of disturbed sites. It is therefore not surprising, from a theoretical point of view, that young stands of shrubs or tree species can rather quickly achieve a high packing of woody biomass per unit volume of growing space. This study indicated that within 10 years from the date of stand establishment most tree or shrub species that characteristically occupy disturbed sites can achieve standing crop densities at least equal to those of mature forest stands. It must be stressed, however, that this study's estimates of high standing crop (Table 11) and high standing crop density (Table 12) should not be extrapolated to large land areas for purposes of inventory estimates. The maxima recorded here are derived from stands and sites that occur frequently in the Lower Foothills Section of Alberta and the Mixedwood Forest Section of Alberta, Saskatchewan, and Manitoba, but nowhere are there large, uninterrupted young stands with such high standing crop values throughout.

Standing crop density is not a frequently used measure in the biomass literature; however, stand density (degree of crowding of trees within stocked areas) has been shown to be associated with variations in tree size and biomass of fully stocked stands. Measurements of stand density in addition to stocking (the fraction of area occupied by trees) allow better comparisons of biomass results with existing information from spacing studies and yield tables (Smith and DeBell 1974). Standing crop density, as defined by Kira and Shidei (1967) and as used in this study, is one measure of density that can be incorporated into future biomass inventories with little extra effort.

The limited analyses carried out in this study revealed some of the difficulties of estimating standing crops of shrub or young tree stands by use of readily measurable variables such as stem diameter or height, although the latter has proved to be reliable for weight prediction of individual shrubs or trees. Because this study sought data on naturally occurring upper limits of biomass accumulation rates, the decision was made to record diameter and height of the largest individuals in a stand. The common use of height data from dominant or codominant trees for estimation of site index in forest stands suggested that measurements from the largest individuals in a stand may be meaningful in young stands as well. Data gathered in this study indicated that only a small proportion of standing crop variation among stands of shrubs or young trees can be accounted for by use of combined terms such as D^2H, which have been used successfully for prediction of volume or weight of individual stems.

As needs develop for more accurate predictions of standing crop in stands of shrubs or young trees, alternative approaches to those tested in this study should be tried. For example, nonlogarithmic equations for estimation of biomass parameters may be more meaningful than the logarithmic equations tested here (Tables 3 to 9). Furthermore, mean stem diameter and mean stand height, for which data were not gathered in this study, might be expected to yield more reliable predictions of stand weight than was the case with D based on mean diameter of the nine largest stems in the stand and H based on height of the tallest dominant in the sample stand.

A secondary objective of this study, as originally perceived, was to define the physical factors and stand histories that contribute to high amounts of standing crop in a short period of time and high standing crop densities per unit volume of forest stand space. The 170 locations sampled did not allow this objective to be achieved; the main value of the geographically broad sampling completed in 1979 is as background data to aid the setting of hypotheses that would require detailed study at a few selected sites in the field. Now that there are standardized methods for collection and processing of forest biomass data (Alemdag 1980), there should be systematic attempts to document several areas where currently unmanaged stands of shrubs or young trees show exceptionally high standing crops and biomass accumulation rates; many of the stands listed in appendixes of this report would fall into this category. Some of these sites would be suitable locations for detailed studies that could test various hypotheses about the relative importance of genotypic variation, physical site features, and stand histories as factors responsible for rapid accumulation of woody biomass.

As opportunities develop for use of shrubs and young tree stands as bioenergy sources, there should be specific surveys to document the full range of circumstances that contribute to high standing crop densities. If vegetation management steps can be designed to encourage the lateral spread of young stands that have exceptionally high standing crop densities, such stands could take on increasingly important roles. Some stands of woody species that are now considered to be silvicultural problems may turn out to be resources worthy of special management as their bioenergy potential comes to be better understood.

Practical Implications

Biomass harvests by small machines could take advantage of the relatively rapid accumulation of woody material such as that recorded in this study. Although the 1979 fieldwork did not examine the ecological consequences of successive short-rotation biomass harvests, it was assumed that the use of shrubby materials as bioenergy sources was going to be dependent upon the use of many small harvesters instead of fewer large harvesters. For this reason special attention was given in this study to characteristics of dense young stands, particularly stem diameters, stand heights, and standing crop densities, that will influence the operation of small harvesters. Biomass harvesters for shrubs and small trees should be small enough to use in the sites that support some of the vegetation types sampled in this study and should be sufficiently lightweight to be used in wet sites. On the other hand, such harvesters must be sturdy enough to have a cutting capacity that can handle the relatively high standing crop densities recorded in young woody stands.

Imaginative development of multistem harvesters (Koch and Savage 1980; Young 1980) for use on small trees and shrubs could change our concepts and definitions of nonproductive forest land. It has been stated frequently that Canada has allowed much of its productive forest land to revert to a nonproductive state. Admittedly, productive forest land in some cases may have become nonproductive because of erosional losses of humus and topsoil or because of raised water tables after tree removal. In other cases, however, use of the term nonproductive simply refers to occupation of forest lands by shrubs or tree species not normally harvested in commercial forestry operations. The relatively rapid rate at which standing crop develops in successional stands after disturbances, as indicated by data gathered in this study, suggests that many sites designated as nonproductive are, in reality, highly productive. Development of appropriate harvesting equipment for small materials appears to be the major obstacle to use of relatively large areas of shrub-dominated forest lands that are now classified as nonproductive lands requiring silvicultural treatment.

Although wildlife biologists have gathered considerable standing crop data on shrub and tree species that serve as browse in forest areas (Telfer 1969, 1972), interest in shrubs by foresters has generally been in the context of their competition with desired tree species. Energy-consuming brush control steps are an integral part of silvicultural operations; similar energy-consuming steps are used for brush control along power lines and road rights-of-way. To date, there appears to have been little effort devoted to a search for ways in which such energy-consuming steps could be subsidized by bioenergy from the woody material being removed. In this study a relatively large number of the 170 sample plots occurred on man-made disturbances such as rights-of-way or on logged areas. Often in such sites the removal of unwanted woody stands is a vegetation management or silvicultural practice. Where there is already a commitment to handling such woody material for vegetation management reasons, trials should be conducted to assess the feasibility of using some or all of the harvested woody material for small-scale localized bioenergy production.

ACKNOWLEDGMENTS

This project was sponsored by the ENergy from the FORest (ENFOR) Program of the Canadian Forestry Service, Environment Canada. For technical advice and editorial review we are indebted to the following personnel of the Northern Forest Research Centre, Canadian Forestry Service, Edmonton: J. Samoil, L.G. Brace, C.L. Kirby, I.E. Bella, and I.K. Edwards. We also want to thank Paul Mersky, Bruce Peterson, Geoffrey Smith, and Blair Peterson for field assistance and Glenda Mersky for manuscript preparation.

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APPENDIXES

The following five appendixes contain data summaries, methods for field sampling, laboratory procedures, and criteria used to stratify data by vegetation type. These appendixes are included for those who may be interested in greater detail than is presented in the body of the report.

1. Summary of 104 Alberta sample plots by vegetation type, moisture class, soil texture, and origin of habitat (type of disturbance)

2. Summary of 66 Saskatchewan and Manitoba sample plots by vegetation type, moisture class, soil texture, and origin of habitat (type of disturbance)

3. Detailed descriptions of field sampling methods and laboratory procedures

4. Foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age for species and species mixtures sampled in 1979 (Tables A to R)

5. Criteria used to stratify data by vegetation type

APPENDIX 1

SUMMARY OF 104 ALBERTA SAMPLE PLOTS BY VEGETATION TYPE, MOISTURE CLASS, SOIL TEXTURE, AND ORIGIN OF HABITAT (TYPE OF DISTURBANCE)

Plot no.	Vegetation type	Moisture class	Soil texture*	Origin of habitat**
1	aspen	mesic	silty clay	bulldozed
2	aspen	mesic	clay loam	burned
3	balsam poplar-willow	wet/mesic	loam	burned
4	balsam poplar-willow	mesic	clay loam	bulldozed
5	aspen-alder	dry	sand	burned
6	alder	dry	sand	burned
7	aspen	mesic	loamy sand	burned
8	jack pine	dry	sand	burned
9	jack pine	dry	sand	burned
10	aspen	mesic	loam	burned
11	alder	wet/mesic	silt loam	burned
12	balsam poplar	wet/mesic	sandy loam	burned
13	bog birch	wet	clay loam	natural shrub
14	alder	wet	silty clay loam	road r/w
15	alder	wet	silt loam	road r/w (b)
16	bog birch	wet	organic	burned
17	larch	wet	organic	bulldozed
18	larch	wet	organic	bulldozed
19	willow	wet	organic	road r/w
20	aspen	wet/mesic	silt loam	burned
21	balsam poplar-willow	mesic	loam	well-site clearing(b)
22	alder	wet	clay	road r/w
23	alder	wet	clay	road r/w

* Based on soil texture classes as defined by the National Soil Survey Committee of Canada (1974).

** b = bulldozed; bp = borrow pit; r/w = right-of-way

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APPENDIX 1 continued

Plot no.	Vegetation type	Moisture class	Soil texture	Origin of habitat
24	balsam poplar-willow	mesic	clay loam	road r/w
25	willow	wet	clay loam	road r/w
26	alder	wet/mesic	clay	road r/w (b)
27	aspen	mesic	sandy loam	burned
28	balsam poplar	wet/mesic	silty clay loam	burned
29	willow	wet/mesic	organic	road r/w
30	aspen	mesic	loam	burned
31	aspen	mesic	sandy loam	burned
32	aspen	mesic	loam/gravel	cutover and burned
33	alder	wet	sand/gravel	road r/w
34	balsam poplar-alder	mesic	sandy loam	roadside clearing
35	red osier dogwood	wet/mesic	loamy sand	natural shrub
36	aspen	dry	sand	burned
37	data not usable	--	--	--
38	alder	dry	sand	understory
39	balsam poplar	mesic	clay loam	roadside clearing
40	balsam poplar	mesic	clay loam	roadside clearing
41	alder	mesic	clay loam	cutover
42	alder	mesic	clay loam	cutover (selective)
43	balsam poplar-alder	wet/mesic	silt loam	cutover (selective)
44	alder	wet/mesic	sand	roadside clearing (bp)
45	white birch	mesic	sand	bulldozed
46	balsam poplar-willow	wet/mesic	sand	road r/w (b)
47	balsam poplar	wet/mesic	clay	burned
48	balsam poplar-alder	mesic	clay	road r/w (b)
49	willow	wet/mesic	loam	road r/w (b)
50	balsam poplar	mesic	silt	bulldozed
51	balsam poplar	mesic	loam	bulldozed
52	balsam poplar-alder	mesic	sandy loam	roadside clearing
53	aspen	mesic	clay	burned

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APPENDIX 1 continued

Plot no.	Vegetation type	Moisture class	Soil texture	Origin of habitat
54	aspen	mesic	clay	burned
55	bog birch	wet	organic	natural shrub
56	lodgepole pine	mesic	silt	burned
57	aspen	mesic	silt	burned
58	white birch	mesic	silt	burned
59	balsam poplar	dry	sand	bulldozed
60	alder	mesic	gravel/sand	natural shrub
61	lodgepole pine	dry	sand	burned
62	lodgepole pine	dry	sandy loam	burned
63	willow	wet/mesic	organic	natural shrub
64	white birch	wet/mesic	silt loam	road r/w
65	balsam poplar-willow	wet/mesic	clay	bulldozed
66	white birch	mesic	silt	burned
67	white spruce	wet/mesic	sandy loam	road r/w (b)
68	alder	dry	sand	road r/w
69	alder	wet	organic	road r/w
70	balsam poplar	mesic	sandy loam	bulldozed
71	balsam poplar	mesic	sand/gravel	railroad r/w
72	alder	dry	sand	road r/w
73	alpine fir	wet	silt	understory
74	white birch	wet/mesic	sandy loam	cutover
75	alder	dry	silty clay	well site (b)
76	alder	mesic	silty clay	road r/w
77	alpine fir	mesic	silty clay	road r/w
78	willow	wet	organic	natural shrub
79	white birch	wet/mesic	loam	road r/w
80	balsam poplar	mesic	clay	road r/w
81	white spruce	wet/mesic	silt	roadside clearing(bp)
82	lodgepole pine	dry	sand	burned
83	lodgepole pine	dry	sand	burned

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APPENDIX 1 continued

Plot no.	Vegetation type	Moisture class	Soil texture	Origin of habitat
84	lodgepole pine	dry	sandy loam	burned
85	lodgepole pine	mesic	sandy loam	burned
86	lodgepole pine	dry	sandy loam	cutover and burned
87	lodgepole pine	dry	sandy loam	cutover and burned
88	white spruce	mesic	clay	cutover and burned
89	white spruce	mesic	clay	road r/w
90	aspen	mesic	clay loam	roadside clearing
91	aspen	mesic	clay loam	roadside clearing
92	white spruce	wet/mesic	clay loam	road r/w
93	white spruce	wet/mesic	clay loam	road r/w
94	white spruce	mesic	sandy loam	power-line r/w
95	lodgepole pine	dry	loam	burned
96	lodgepole pine	dry	loam	burned
97	aspen	wet/mesic	silty clay	road r/w
98	lodgepole pine	mesic	sandy loam	burned
99	larch	wet/mesic	sand	roadside clearing(bp)
100	white spruce	wet/mesic	loam	power-line r/w
101	alpine fir	wet/mesic	loam	cutover
102	alpine fir	wet/mesic	sandy loam	cutover
103	lodgepole pine	mesic	loam	cutover
104	lodgepole pine	mesic	sandy loam	burned
105	lodgepole pine	mesic	sandy loam	cutover and burned

APPENDIX 2

SUMMARY OF 66 SASKATCHEWAN AND MANITOBA SAMPLE PLOTS BY VEGETATION TYPE, MOISTURE CLASS, SOIL TEXTURE, AND ORIGIN OF HABITAT (TYPE OF DISTURBANCE)

Plot no.	Vegetation type	Moisture class	Soil texture*	Origin of habitat**
300	aspen	mesic	clay loam	cutover
301	willow	wet/mesic	clay loam	bulldozed
302	aspen-alder	mesic	sandy loam	roadside clearing
303	jack pine	dry	fine sand	burned
304	jack pine	dry	sand	burned
305	bog birch	wet	organic	natural shrub
306	jack pine	dry	sand	burned
307	alder	mesic	sandy loam	roadside clearing
308	aspen	mesic	loamy sand	cutover and burned
309	balsam poplar	wet	clay	road r/w
310	willow	wet	loamy sand	natural shrub
311	aspen	mesic	loamy sand	power-line r/w
312	bog birch	wet	organic	natural shrub
313	willow	wet	sand	burned
314	willow	wet/mesic	silt	cutover (selective)
315	alder	mesic	loamy sand	cutover
316	alder	wet/mesic	loamy sand	cutover
317	aspen	mesic	silty clay	burned
318	willow	wet	organic	power-line r/w
319	hazel	wet/mesic	clay	cutover
320	balsam poplar-willow	wet	clay	roadside clearing(bp)
321	balsam poplar-willow	wet/mesic	loamy sand	road r/w
322	red osier dogwood	wet/mesic	organic	bulldozed
323	red osier dogwood	wet	clay	cutover
324	bog birch	wet	organic	drained fen
325	red osier dogwood	wet	clay	natural shrub
326	balsam poplar	wet/mesic	clay	road r/w

* Based on soil texture classes as defined by the National Soil Survey Committee of Canada (1974).

** b = bulldozed; bp = borrow pit; r/w = right-of-way

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APPENDIX 2 continued

Plot no.	Vegetation type	Moisture class	Soil texture	Origin of habitat
327	aspen	mesic	clay	bulldozed
328	willow	wet	loamy sand	roadside clearing (bp)
329	white birch	dry	loamy sand	road r/w
330	aspen	mesic	silty clay	bulldozed
331	willow	wet	clay	road r/w
332	willow	wet	clay	road r/w
333	willow	wet	clay	road r/w
334	white birch	mesic	sand	cutover
335	white birch	mesic	sand	cutover
336	mountain maple	wet/mesic	loam	cutover (selective)
337	mountain maple	wet/mesic	loam	road r/w (b)
338	mountain maple	mesic	sand	cutover (selective)
339	balsam poplar	mesic	gravel/sand	cutover (selective)
340	balsam poplar-willow	mesic	sand	former sawmill landing(b)
341	hazel	mesic	sand	cutover (selective)
342	hazel	mesic	fine sand	cutover (selective)
343	white birch	mesic	sandy loam	road r/w
344	mountain maple	wet/mesic	silt	cutover (selective)
345	willow	wet	sand	natural shrub
346	data not usable	-	-	-
347	hazel	wet/mesic	clay	cutover (selective)
348	hazel	mesic	silty clay	understory
349	willow	wet	gravel/clay	road r/w
350	hazel	mesic	loam	roadside clearing
351	mountain maple	mesic	sandy loam	understory
352	aspen-hazel	mesic	clay loam	cutover
353	balsam poplar	mesic	silty clay	cutover
354	aspen-hazel	mesic	loam	cutover
355	hazel	dry	sand	cutover (selective)
356	hazel	mesic	loamy sand	cutover
357	aspen-hazel	mesic	sandy loam	cutover

Continued on next page

APPENDIX 2 continued

Plot no.	Vegetation type	Moisture class	Soil texture	Origin of habitat
358	aspen-hazel	mesic	loam	cutover
359	aspen	mesic	sand	cutover
360	aspen-alder	wet/mesic	clay loam	cutover
361	aspen-alder	wet/mesic	clay loam	cutover
362	aspen-alder	wet/mesic	clay loam	cutover
363	aspen	mesic	loamy sand	cutover
364	mountain maple	wet/mesic	clay loam	cutover (selective)
365	willow	wet/mesic	clay	road r/w
366	hazel	mesic	clay loam	understory

APPENDIX 3

DETAILED DESCRIPTIONS OF FIELD SAMPLING METHODS AND LABORATORY PROCEDURES

Field Sampling Methods

Each selected stand was sampled by harvesting, weighing, and subsampling the woody material on one main plot and within three 1-m^3 sample frames. The main plot was circular with a radius of 2 m 12.57 m^2). Because the objective of this study was to seek out maximum rather than representative standing crop densities, plot centers were not located by rigidly defined criteria as would be used in a systematic or random method of plot establishment. The main criterion was to locate the center so that the plot fell within a part of the stand where stem density was high and was as far as possible from stand edges or openings in the stand. In inventory work, minimum distances from stand edges are commonly specified as a way to ensure the absence of an edge effect bias; instead of avoiding this bias, many of the sample sites of this study were deliberately placed to sample edge vegetation if it displayed a high standing crop density. In cases where there was an overstory of mature forest or residual mature trees after selective logging, plot centers were located to avoid any overstory stems whenever possible. In the few cases where an overstory stem did occur within the 12.57-m^2 main plot, the mature stem was not harvested.

Within the main plot, all live and dead standing woody stems were harvested at ground level. The total number of live stems was recorded and fresh weights were obtained for each of the following components:

1. dead standing woody stems (all species combined);
2. all live stems of the most abundant woody species;
3. all live stems of the second most abundant woody species;
4. all live stems of the third most abundant woody species; and
5. all live stems of all other woody species.

These various stand component fresh weights to the nearest 10 g were recorded on a portable platform scale.

Height of the tallest dominant was recorded for each of the three most abundant species, but the single stem exhibiting the extreme height on the plot was arbitrarily taken as the height for calculation of volume of growing space during subsequent computations of standing crop density (standing crop per unit volume of growing space, kg/m^3). This estimate of standing crop density was obtained as a check against which to compare standing crop density estimates from 1 m^3 sample frames.

A fresh weight subsample was collected from the main plot and weighed after all of the harvested woody material had been weighed. The subsample was taken from the most abundant harvested species and occasionally from one or both of the second and third most abundant species. The subsample consisted of sufficient stem and foliage material to provide a fresh weight sample between 1500 and 2000 g for each of foliage and woody material for each species being sampled. For deciduous species, leaves and petioles (including flowers or fruits, if present) were separated from the woody material in the field and the foliar and woody subsample components were each weighed to the nearest gram on a triple beam balance. The foliar and woody subsamples were stored separately in bags for air drying and later oven-drying. For coniferous species, foliage could not be separated from stem material until the needles had air dried when subsamples were stored in the laboratory. For coniferous species, therefore, calculations of foliage/wood ratios are based on dry weight data, but for deciduous species these ratios were calculated from fresh weight data.

Three additional estimates of standing crop density were obtained from three separate 1-m^3 sample frames. As with the main plot, there was no attempt to randomly locate these three sampling locations. Instead, the areas of greatest apparent stem density were sampled. The objective of additional sampling by cubic frames was to obtain a more direct measurement of standing crop density in a unit volume of space (1 m^3) as an indication of the maximum packing of woody material that could be encountered by the cutting bar of a biomass harvester. The 1-m^3 sampling frames were placed so that they were virtually fully occupied by stem material from top to bottom (Fig. 2). In contrast, standing crop density calculated on the main plot involved much unoccupied volume since the stand volume was arbitrarily calculated from the height of the tallest dominant, which was often considerably taller than the general height of the stand.

To obtain the three separate 1-m^3 samples, a metal frame was assembled with its base 20 cm above ground level. The 20-cm cutting height was selected over ground level because it was thought to approximate the practical lower limit of stubble height that could be expected to result from removal of shrubs or small trees by mechanical biomass harvesters. The woody material that occurred within the 1-m^3 frame was harvested (Fig. 2), and fresh weights were obtained for all dead standing stems (all species combined) and all live material (foliar and wood portions of all species combined). The number of live stems growing on 1 m^2 (within each frame) was also recorded.

Subsamples were taken from each of the 1-m^3 samples by cutting approximately 10 cm of wood from the basal end of the three largest live stems within the sampling frame. For each of these three stem subsamples the following were recorded: fresh weight, to the nearest gram; basal diameter outside bark, cm; and preliminary age count. Thus, for each sample location nine ages and nine stem diameters were obtained and these data were used in subsequent calculations of equations that used basal stem diameter (combined with stand height) for prediction of standing crop per unit land area. The aggregate fresh weight of the three stem subsamples was obtained for each 1-m^3 sample and these stem segments were subsequently oven-dried for calculation of fresh weight/dry weight ratios.

On the main plot, harvesting and weighing was done for only those woody species capable of attaining heights and densities considered applicable to biomass harvesting. Scattered stems of smaller woody species such as wild rose (**Rosa** sp) or Labrador tea (**Ledum groenlandicum**) were not harvested. On the 1-m^3 plots, however, these smaller woody species plus coniferous seedlings were also harvested where they exceeded 20 cm in height and extended into the 1-m^3 sample frame.

On the main plot and in the three 1-m^3 sample frames dead branches that were attached to live stems were always weighed together with the living material instead of being included with the total fresh weight of dead standing stems.

Laboratory Methods

The three types of subsamples for which field fresh weights were available were measured and weighed in the laboratory as follows:

1. three wood plus bark stem segments, each about 10 cm long, from the bases of the three largest stems on each of the 1-m^3 sample frames;

2. one foliage subsample of the dominant species, taken from one or more stems on the main plot and having an aggregate fresh weight between 1500 and 2000 g (for some plots with two or more codominant woody species, one or two additional leaf subsamples were also taken to provide data for other codominant species); and

3. one wood plus bark subsample of the dominant species, taken from one or more stems on the main plot and having an aggregate fresh weight between 1500 and 2000 g (for some plots with two or more codominant woody species additional wood subsamples were obtained for the other codominants).

Laboratory procedures for these three categories of subsamples are described below.

Stem subsamples from 1-m^3 sample frames

Stem subsamples were air dried for about 2 months and then were oven-dried to constant weight at 105°C. Oven-drying generally required 48 hr. Oven-dried samples were transferred directly from the oven to an electronic balance and were weighed to the nearest 0.1 g.

Preliminary field counts of stem ages were verified or amended by checking the stem subsamples under a dissecting stereoscope. In rapidly growing deciduous species, especially those that regenerate from root suckers, first-year growth generally exceeds 20 cm, so that age determined on a stem cut at 20 cm above ground level was considered to be synonymous with total age. For coniferous species, which take a longer time than vegetatively reproduced deciduous stems to reach a height of 20 cm, ages recorded from stems cut 20 cm above the ground would be underestimates of true age; however, no adjustments were made to the laboratory age counts for coniferous species to adjust for this possible underestimate.

Foliage subsamples

Foliage subsamples were air dried in the laboratory for a shorter period than stem subsamples. After at least 3 weeks of air drying, foliage subsamples could be oven-dried to constant weight within 3 hr. Immediately after removal of samples from drying ovens, foliage oven-dry weight was read to the nearest 0.1 g.

Wood and bark subsamples from main plot

Woody subsamples were air dried in the laboratory for about 2 months. Samples were oven-dried at 105°C for about 24 hr or until they reached a constant weight. The time required to reach a constant weight varied from 8 to 48 hr for the smallest and largest subsamples respectively. Oven-dried samples were transferred directly from the oven to an electronic balance and weighed to the nearest 0.1 g.

APPENDIX 4

FOLIAGE/WOOD RATIOS, STANDING CROP (KG/M^2), AND STANDING CROP DENSITY (KG/M^3), LISTED BY INCREASING STAND AGE FOR SPECIES AND SPECIES MIXTURES SAMPLED IN 1979 (TABLES A TO R)

Table A. Aspen foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
330	2	167	32.5	67.5	432.9	1.73	0.70	0.42
317	3	258	23.0	77.0	95.5	1.73	0.76	0.29
327	3	293	17.0	83.0	108.3	3.41	1.49	0.48
363	3	283	20.1	79.9	201.4	2.36	1.13	0.40
1	4	462	25.0	75.0	44.6	3.03	1.25	0.27
97	5	412	14.3	85.7	101.1	6.40	2.96	0.72
308	11	735	11.0	89.0	69.2	7.96	3.72	0.51
311	11	527	11.7	88.3	95.5	5.17	2.31	0.44
27	12	643	10.0	90.0	38.2	6.86	2.84	0.44
30	12	621	8.5	91.5	67.6	11.86	5.83	0.94
31	12	701	12.5	87.5	52.5	12.07	6.02	0.86
32	12	541	9.2	90.8	66.8	9.71	4.87	0.90
53	12	410	10.8	89.2	75.6	4.96	2.27	0.55
54	12	551	7.9	92.1	36.6	6.54	3.28	0.59
300	12	464	18.4	81.6	67.7	4.68	2.05	0.44
2	13	670	19.4	80.6	38.2	7.95	3.26	0.49
7	13	695	10.6	89.4	39.0	6.53	3.08	0.44
90	13	628	10.4	89.6	100.3	8.75	4.28	0.68
10	13	761	8.0	92.0	70.8	13.63	6.63	0.87
57	13	530	9.1	90.9	152.8	8.78	4.21	0.79
91	14	748	10.5	89.5	79.6	15.57	7.33	0.95
359	14	610	11.9	88.1	105.9	10.59	5.20	0.85
20	18	968	9.7	90.3	25.5	15.02	7.04	0.73
36	29	628	14.5	85.5	21.5	14.74	6.40	1.02

* Percentages based on fresh weight.

Table B. Alder foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
41	4	173	26.8	73.2	398.6	1.64	0.59	0.34
42	4	246	31.8	68.2	253.9	1.67	0.59	0.24
44	6	321	15.3	84.7	270.6	5.16	2.36	0.73
33	7	380	17.7	82.3	97.1	6.26	2.51	0.66
68	7	360	13.2	86.8	397.8	5.43	2.50	0.69
76	7	280	15.9	84.1	336.5	4.46	1.96	0.70
23	8	435	11.7	88.3	121.8	8.41	3.58	0.82
69	8	520	12.1	87.9	206.9	8.64	3.66	0.70
307	8	681	19.9	80.1	213.3	2.71	1.33	0.20
11	9	545	9.9	90.1	110.6	7.68	3.54	0.65
14	9	539	8.8	91.2	96.3	11.42	4.99	0.93
15	9	575	15.4	84.6	132.9	15.86	6.87	1.19
6	10	249	13.5	86.5	109.0	2.37	1.02	0.41
26	10	443	12.2	87.8	128.1	6.65	2.97	0.67
60	10	380	11.5	88.5	81.2	5.95	2.69	0.71
75	11	413	10.8	89.2	180.6	10.49	5.39	1.31
22	12	392	18.3	81.7	149.7	5.32	2.18	0.56
72	13	302	16.1	83.9	218.1	7.72	3.79	1.31
38	15	416	8.3	91.7	125.7	4.63	2.61	0.63
316	17	320	16.2	83.8	192.6	2.90	1.48	0.46
315	19	288	13.4	86.6	194.2	2.90	1.60	0.56

* Percentages based on fresh weight.

Table C. Willow foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
331	3	293	30.1	69.9	118.5	3.45	1.39	0.48
333	3	139	29.5	70.5	304.0	0.76	0.34	0.24
349	3	213	27.5	72.5	606.4	3.33	1.50	0.71
332	4	192	28.3	71.7	444.0	1.04	0.47	0.24
314	6	294	19.8	80.2	311.2	2.38	1.18	0.40
25	7	423	12.5	87.5	157.6	4.45	2.12	0.50
318	8	372	22.1	77.9	94.7	4.68	0.58	2.16
345	9	750	9.8	90.2	113.8	15.00	7.71	1.03
301	11	320	16.1	83.9	160.0	5.52	2.77	0.87
328	11	426	13.3	86.7	148.8	5.90	2.77	0.65
29	12	577	6.3	93.7	44.5	11.61	5.23	0.91
78	12	554	5.2	94.8	150.4	14.49	7.20	1.30
313	12	367	9.4	90.6	141.6	7.44	3.86	1.05
49	13	587	13.7	86.3	52.7	10.22	4.38	0.75
365	13	604	10.8	89.2	122.5	9.95	5.37	0.89
19	14	544	10.7	89.3	227.6	8.70	4.37	0.80
310	17	225	12.3	88.7	258.6	2.60	1.65	0.73
63	19	297	14.7	85.3	261.8	12.10	6.64	2.23

* Percentages based on fresh weight.

Table D. Balsam poplar foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
326	3	296	35.6	64.4	148.8	3.71	1.30	0.44
353	3	275	26.1	73.9	197.4	2.48	1.09	0.40
71	7	610	14.3	85.7	146.5	7.82	3.41	0.56
339	7	200	32.2	67.8	163.9	1.96	0.74	0.37
309	8	373	19.8	80.2	179.1	4.00	1.88	0.50
70	9	460	17.3	82.7	235.5	9.09	3.85	0.84
80	9	480	16.2	83.8	79.6	6.43	2.86	0.59
40	10	345	18.3	81.7	241.9	2.80	1.28	0.37
47	10	546	17.5	82.5	101.9	4.78	2.19	0.40
50	10	647	12.0	88.0	54.1	10.22	4.36	0.67
28	11	641	12.0	88.0	56.5	14.97	6.72	1.05
39	11	444	15.9	84.1	131.3	3.84	1.67	0.38
59	11	580	20.8	79.2	48.5	8.77	5.66	0.98
51	12	489	13.2	86.8	87.6	7.89	3.53	0.67
12	13	710	15.2	84.8	42.1	11.53	8.00	1.13

* Percentages based on fresh weight.

Table E. Lodgepole pine foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
62	7	381	34.9	65.1	40.6	7.18	2.61	0.68
56	8	250	24.4	75.6	216.5	3.92	1.38	0.55
82	8	143	42.7	57.3	338.2	4.93	2.37	1.66
84	8	286	33.7	66.3	112.3	5.68	2.44	0.85
85	8	263	34.5	65.5	108.2	5.12	2.08	0.79
87	8	223	28.8	71.2	149.6	6.86	2.84	1.27
61	9	380	30.5	69.5	68.4	8.17	2.93	0.77
83	9	235	23.4	76.6	113.0	5.47	2.27	0.97
86	9	213	36.8	63.2	235.6	5.35	2.19	1.03
103	11	346	21.4	78.6	197.4	10.57	4.95	1.43
95	15	471	17.1	82.9	117.0	13.54	5.82	1.24
96	16	506	15.6	84.4	79.6	16.49	7.71	1.52
98	16	510	22.4	77.6	35.8	14.49	6.35	1.25
105	20	599	12.3	87.7	124.2	23.85	11.60	1.94
104	25	615	9.3	90.7	50.1	26.36	14.17	2.30

* Percentages based on ovendry weight.

Table F. White birch foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
334	5	446	20.8	79.2	91.5	6.78	3.51	0.79
335	5	498	16.8	83.2	161.6	8.78	4.47	0.90
343	7	352	25.8	74.2	168.7	2.40	1.07	0.30
329	9	248	21.3	78.7	251.4	2.05	0.94	0.38
58	12	540	14.3	85.7	94.7	8.30	4.46	0.83
74	12	485	11.7	88.3	109.9	5.57	2.85	0.59
45	13	515	12.8	87.2	84.3	9.21	4.84	0.94
79	14	553	17.1	82.9	120.9	6.04	1.86	0.34
64	15	480	18.2	81.8	70.9	6.04	3.04	0.63
66	15	580	14.4	85.6	157.5	6.91	3.66	0.63

* Percentages based on fresh weight.

Table G. Hazel foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
342	6	301	19.1	80.9	351.0	3.73	2.36	0.78
356	7	490	21.4	78.6	249.8	3.27	1.96	0.40
347	8	194	23.5	76.5	224.4	2.13	1.23	0.63
341	9	317	25.8	74.2	206.9	2.77	1.44	0.45
348	10	284	20.8	79.2	158.3	1.90	1.04	0.37
350	10	233	28.1	71.9	236.3	1.78	0.97	0.42
319	12	312	27.2	72.8	187.8	2.38	1.22	0.39
366	14	362	17.8	82.2	181.5	4.03	2.41	0.67
355	18	393	22.2	77.8	245.1	4.81	2.82	0.72

* Percentages based on fresh weight.

Table H. White spruce foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
88	12	216	37.0	63.0	262.6	10.86	4.96	2.30
89	13	274	32.8	67.2	381.9	8.37	3.70	1.35
94	17	382	30.5	69.5	228.4	22.13	9.35	2.45
100	17	482	18.7	81.3	65.3	19.63	8.97	1.86
67	18	374	31.0	69.0	150.4	10.16	4.26	1.14
81	23	284	29.6	70.4	171.1	9.56	5.14	1.81
92	24	374	19.4	80.6	162.3	12.57	6.21	1.66
93	24	337	37.0	63.0	165.6	13.83	6.22	1.85

* Percentages based on ovendry weight.

Table I. Red osier dogwood foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
35	5	243	29.9	70.1	134.5	2.13	1.25	0.51
322	8	311	26.8	73.2	194.1	5.17	2.30	0.74
323	9	295	11.4	88.6	129.7	3.39	1.80	0.61
325	9	273	21.3	78.7	89.9	2.90	1.28	0.47

* Percentages based on fresh weight.

Table J. Bog birch foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
16	10	228	16.3	83.7	377.2	2.01	1.13	0.50
55	11	206	17.0	83.0	309.6	2.27	1.34	0.65
13	12	132	24.1	75.9	323.1	1.60	0.85	0.64
305	12	141	18.3	81.7	507.7	1.55	0.98	0.69
312	18	204	21.7	78.3	853.1	2.66	1.79	0.88
324	18	300	14.5	85.5	364.5	5.09	3.12	1.04

* Percentages based on fresh weight.

Table K. Mountain maple foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing Crop density kg/m^3
338	5	194	29.2	70.8	320.7	2.67	1.46	0.75
344	5	392	25.9	74.1	66.8	3.70	1.77	0.45
351	9	333	25.6	74.4	188.6	2.56	1.45	0.43
337	13	446	20.0	80.0	105.8	6.61	3.35	0.75
336	16	511	16.6	83.4	105.0	8.51	4.91	0.96
364	16	424	14.1	85.9	159.2	6.06	3.46	0.82

* Percentages based on fresh weight.

Table L. Jack pine foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
8	6	220	35.3	64.7	56.5	2.44	0.89	0.40
9	7	244	38.4	61.6	53.3	3.92	1.44	0.59
304	12	246	17.3	82.7	189.4	3.29	1.23	0.50
306	13	428	25.1	74.9	124.9	7.05	3.06	0.72
303	43	322	9.8	90.2	97.8	5.92	3.41	1.06

* Percentages based on ovendry weight.

Table M. Larch foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
17	8	200	21.2	78.8	116.2	2.90	1.17	0.58
18	8	261	18.4	81.6	158.4	3.56	1.28	0.49
99	11	389	17.1	82.9	54.9	7.28	2.36	0.61

* Percentages based on ovendry weight.

Table N. Alpine fir foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
77	15	430	20.4	79.6	85.2	12.88	4.89	1.14
101	18	283	28.4	71.6	89.9	9.59	4.22	1.49
102	25	515	19.9	80.1	75.6	12.70	5.57	1.08
73	33	368	26.4	73.6	85.2	8.96	3.79	1.03

* Percentages based on ovendry weight.

Table O. Balsam poplar - alder foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
34-1**	4	181	30.6	69.4	135.3	2.11	0.82	0.45
-2			33.7	66.3				
48	4	291	27.0	73.0	101.0	2.49	0.99	0.34
43-1	13	640	12.6	87.4	96.3	12.02	5.23	0.82
-2			8.2	91.8				
52-1	13	620	11.9	88.1	148.0	12.20	6.31	1.02
-2			10.4	89.6				

* Percentages based on fresh weight.

** 1 = Foliage/wood percentages for balsam poplar.

2 = Foliage/wood percentages for alder.

Table P. Balsam poplar - willow foliage/wood ratios, standing crop (kg/m^2), and standing crop density (kg/m^3), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m^2	Dry standing crop kg/m^2	Dry standing crop density kg/m^3
4-1**	3	260	30.5	69.5	176.2	2.70	0.96	0.37
-2			30.4	69.6				
65	3	320	28.1	71.9	119.4	4.49	1.73	0.54
340-1	6	334	-	-	178.3	3.85	1.89	0.56
-2			20.9	79.1				
24-1	7	393	20.8	79.2	81.1	3.90	1.42	0.36
-2			31.6	68.4				
321-1	8	403	-	-	256.2	4.92	2.21	0.55
-2			23.6	76.4				
320-1	10	572	-	-	195.8	7.07	3.16	0.55
-2			12.7	87.3				
3-1	12	650	13.6	86.4	74.0	5.59	3.51	0.54
-2			20.1	79.9				
21-1	13	755	4.3	95.7	34.2	26.31	13.06	1.73
-2			9.4	90.6				
46-1	13	434	-	-	218.0	7.66	3.70	0.85
-2			12.5	87.5				

* Percentages based on fresh weight.

** 1 = Foliage/wood percentages for balsam poplar.

2 = Foliage/wood percentages for willow.

Table Q. Aspen - alder foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m²	Dry standing crop kg/m²	Dry standing crop density kg/m³
362	3	332	25.1	74.9	202.9	3.74	1.69	0.51
360-1**	4	310	17.9	82.1	111.5	3.81	1.75	0.57
-2			21.1	78.9				
361	4	379	18.2	81.8	148.8	4.40	1.87	0.49
302-1	9	576	13.0	87.0	133.7	6.67	3.26	0.57
-2			15.9	84.1				
5-1	12	628	11.2	88.8	77.2	6.65	3.01	0.48
-2			15.3	84.7				

* Percentages based on fresh weight.
** 1 = Foliage/wood percentages for aspen.
2 = Foliage/wood percentages for alder.

Table R. Aspen - hazel foliage/wood ratios, standing crop (kg/m²), and standing crop density (kg/m³), listed by increasing stand age

Plot no.	Age	Stand ht. cm	% foliage*	% wood*	Stems per ha '000	Fresh standing crop kg/m²	Dry standing crop kg/m²	Dry standing crop density kg/m³
352	3	245	19.7	80.3	396.3	3.05	1.40	0.57
357-1**	8	579	12.9	87.1	175.0	6.25	3.16	0.55
-2			22.8	77.2				
358-1	10	639	13.9	86.1	380.4	6.56	3.55	0.56
-2			28.5	71.5				
354	12	621	6.3	93.7	175.0	7.39	3.95	0.64

* Percentages based on fresh weight.
** 1 = Foliage/wood percentages for aspen.
2 = Foliage/wood percentages for hazel.

APPENDIX 5

CRITERIA USED TO STRATIFY DATA BY VEGETATION TYPE

A relatively high proportion of the sample stands in this study were from sites that were in early stages of successional development following a disturbance. The woody species that dominate such sites are extremely variable in species makeup. For example, balsam poplar occurs sometimes in pure stands, sometimes mixed with willow, and sometimes with alder on areas where there are no obvious site differences to explain such variations in species composition. Because such young stands lacked the characteristic and predictable species composition of more mature stands, it was necessary to select several arbitrary criteria for assignment of sample stands to specific classes of vegetation type.

The sampled stands were divided into three main categories: (1) stands dominated by tree species only; (2) stands dominated by both tree and shrub species; and (3) stands dominated by shrub species only. Vegetation types recognized within each of these three categories are listed below.

1. Stands dominated by tree species:

aspen	lodgepole pine
balsam poplar	jack pine
white birch	white spruce
larch	alpine fir

2. Stands dominated by both tree and shrub species:

aspen-alder	balsam poplar-willow
aspen-hazel	balsam poplar-alder

3. Stands dominated by shrub species:

alder	red osier dogwood
willow	mountain maple
bog birch	

Within categories 1 and 3, only the name of the dominant species was used to name the vegetation type. In every case the dominant species made up at least 50% of the total fresh weight of live stems. Category 1 generally included those stands where no shrub species made up more than 10% of the fresh weight of the dominant tree species, except in plots 6, 18, 57, 90, 326, 329, and 344, as explained in the table below. Category 3 included those stands where no tree species made up more than 10% of the weight of the dominant shrub species, except in plots 19, 25, 35, 307, and 356, as explained on the following page.

Plot no.	Original classification	Reclassification (category)	Fresh wt. proportion, tree/shrub	Total no. live stems on plot, tree/shrub
6	jack pine-alder	alder (shrub)	1.0/1.7	12/110
18	larch-bog birch	larch (tree)	6.0/1.0	73/103
57	aspen-willow	aspen (tree)	8.0/1.0	97/29
90	aspen-willow	aspen (tree)	4.5/1.0	35/56
326	balsam poplar-chokecherry	balsam poplar (tree)	6.0/1.0	97/63
329	white birch-pin cherry	white birch (tree)	5.0/1.0	280/15
344	balsam poplar-mountain maple	mountain maple (shrub)	1.0/4.0	15/48

Within category 2, names of the dominant tree and the dominant shrub were used to designate the vegetation type. The tree name was always listed first even though the total fresh weight of the dominant shrub sometimes exceeded the total fresh weight of the dominant tree species, as in plots 24, 25, 34, 46, 52, 320, 321, 340, and 360. In only two cases (plots 25 and 34) did the dominant tree species weigh less than 25% of the weight of the dominant shrub. This method of naming the mixed stands of category 2, with emphasis on tree species rather than shrubs, was adopted because tree species have potential to be of commercial value and would eventually dominate the stand even though at present they may be only codominant with shrubs on a standing crop basis.

The arbitrary method used to name the mixed tree/shrub stands of category 2 created several anomalies. At five sample locations (plots 19, 25, 35, 307, and 356) the dominant tree species, although weighing more than 10% of the dominant shrub species, occurred too sparsely within the stand to justify inclusion of the plot in category 2. For example, in plot 307 the dominant tree (aspen) weighed 26% of the weight of the dominant shrub (alder) but only four aspen stems occurred on the plot, compared to 235 alder stems. Consequently, plot 307 was assigned to the alder vegetation type of category 3 and not the aspen-alder type of category 2.

The final assignments of sample plots to specific vegetation types are shown in Appendix 4.