Landscape Management Network

Canada's Forest Biomass Resources: Deriving Estimates from Canada's Forest Inventory

M. Penner, K. Power, C. Muhairwe, R. Tellier, and Y. Wang

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The Landscape Management Network (LMN)

Managing Canada's forests for the benefit of present and future generations is a complex undertaking. To achieve this goal we need a better understanding of how the environment, human activities and natural disturbances interact to shape the country's forest landscape. Our forests and the environment do not adhere to the artificial boundaries between provinces and land owners, pointing to the need for well-informed forest management that includes "the big picture." As Canada's major national forest research organization, the Canadian Forest Service (CFS) has a major role to play in developing tools, technologies, and data bases to ensure sustainable forest management in Canada. The Landscape Management Network (LMN) has been established to lead this effort.

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Abstract

The importance of Canada's forest biomass in the global carbon cycle needs to be better understood as part of Canada's efforts to meet its objective of sustainable forestry. The distribution of biomass, as well as the changes associated with different management scenarios, have implications for the long-term sustainability of the forest resource. The purpose of the national biomass inventory initiative is to provide efficient and timely estimates of the aboveground biomass components on forest land in Canada. This study builds on existing data and knowledge to generate spatially referenced biomass estimates for use in carbon budget modeling and resource assessment.

The results of the national biomass inventory focus on generating aboveground biomass estimates for the inventoried forest land. Different methods were used for low productivity forests (productivity class I) and higher productivity forests (productivity class II). For productivity class II, volume:biomass conversion factors are derived for unique combinations of site class and age (or maturity) class by species within province. The non-merchantable aboveground biomass components are estimated as fractions of the merchantable biomass. These conversion factors and fractions were computed by constructing hypothetical stands for each site, age, species and province combination, and estimating the merchantable volume and all of the aboveground biomass components from suitable published equations. The biomass of submerchantable trees is given for the same unique combinations of site class and age (or maturity) class by species within province. Biomass estimates for productivity class I forests are given by ecozones within each province.

The conversion factors are relatively insensitive to changes in stand age, density, site quality, and size distribution. This may be a function of the published biomass and volume prediction equations which use only dbh and height as the independent variables. Consequently, the resulting estimates are relatively stable and should provide good regional summaries of aboveground biomass components at the time of inventory. The conversion factors and fractions are used, in conjunction with the current national forest inventory, to produce spatially referenced biomass estimates for the inventoried forest land in Canada.

This report documents the procedures for deriving the national biomass inventory and gives examples of the results. The complete results are available from the Pacific Forestry Centre, 506 West Burnside Road, Victoria, B.C. V8Z 1M5.

Résumé

Pour que le Canada puisse atteindre son objectif d'aménagement forestier durable, il doit mieux comprendre l'importance de sa biomasse forestière dans le cycle planétaire du carbone. La répartition de la biomasse ainsi que les changements liés aux différents scénarios d'aménagement ont des incidences sur la pérennité des ressources forestières. L'initiative d'inventaire de la biomasse du Canada a pour but de fournir des estimations efficaces et à jour des composantes de la biomasse aérienne des terrains forestiers du Canada. La présente étude s'appuie sur les données et les connaissances existantes pour produire des estimations à référence spatiale de la biomasse qui serviront à la modélisation du bilan du carbone et à des évaluations des ressources.

L'inventaire national de la biomasse s'attache à fournir des estimations de la biomasse aérienne des terrains forestiers inventoriés. Des méthodes différentes ont été utilisées selon qu'il s'agissait de forêts à productivité faible (classe I) ou plus élevée (classe II). Dans le deuxième cas, les facteurs de conversion volume/biomasse ont été calculés au regard de combinaisons uniques de classe de station et de classe d'âge (ou de maturité) par essence dans une province. Les composantes non marchandes de la biomasse aérienne sont estimées en fractions de la biomasse marchande. Pour calculer ces facteurs de conversion et ces fractions, on a construit un peuplement hypothétique pour chaque combinaison de station, d'âge, d'essence et de province et on a estimé le volume marchand et le total des composantes de la biomasse aérienne à partir des équations publiées appropriées. La biomasse des essences marchandes secondaires est donnée au regard des mêmes combinaisons uniques de classe de station et d'âge (ou de maturité) par essence dans une province. Les estimations de la biomasse des forêts appartenant à la classe de productivité I sont présentées par écozone et par province.

Les facteurs de conversion sont relativement insensibles aux modifications de l'âge du peuplement, de la densité, de la qualité de la station et de la répartition des classes de dimensions. Cette situation pourrait être attribuable aux équations publiées de prévision de la biomasse et du volume qui utilisent comme seules variables indépendantes le dhp et la hauteur. Par conséquent, les estimations obtenues sont relativement constantes et devraient dresser un sommaire adéquat des composantes de la biomasse aérienne régionale au moment de la tenue de l'inventaire. Conjugués aux données les plus récentes de l'Inventaire des forêts du Canada, les facteurs de conversions et les fractions servent à obtenir des estimations à référence spatiale de la biomasse des terrains forestiers inventoriés du Canada.

Le présent rapport expose les méthodes utilisées pour calculer l'inventaire national de la biomasse et donne des exemples des résultats obtenus. Pour obtenir les résultats complets, vous devez vous adresser au Centre de foresterie du Pacifique, 506 West Burnside Road, Victoria (C.-B.) V8Z lM5.

1 Introduction

Historically, forest managers and policy makers have always required information about the wood volume of forest resources and have conducted periodic volume inventories to obtain this information. Since the 1970's, in response to the energy crisis and search for alternate energy sources, increased attention has been directed toward forest biomass. Now the importance of Canada's forest biomass in the global carbon cycle is being recognized. More efforts are being made to quantify the biomass resource and its dynamics (e.g., Kurz and Apps 1993). The role of Canada's forests in the global carbon cycle needs to be better understood to guide stewardship of 10% of the world's forests.

The growing use of biomass inventories for modeling carbon budgets (Botkin and Simpson 1990; Kurz and Apps 1994) and for determining the contribution of Canada's forests to the global carbon cycle necessitates maintaining a current biomass inventory. The national volume inventory has been repeated on a 5-year cycle since 1976 but a biomass inventory has been compiled only once. A current biomass inventory is needed in addition to the volume inventory to provide information on aboveground tree components.

The overall objective of the biomass inventory project is to produce and implement a national method for converting volume estimates to biomass. The method ensures that updates can be produced from new volume estimates. The method of converting volume to biomass must be repeatable, standard across the country, efficient, and well documented. This report describes the derivation of the conversion factors to convert pulpwood volumes (available in Canada's national forest inventory for productive forest land, here referred to as productivity class II) to merchantable stem biomass estimates. The resulting biomass estimates are related to the rest of the aboveground biomass components (merchantable stem, bark, branches, leaves, stump, and top). Also derived are estimates of biomass on productivity class I forest lands (see Table 1 for definitions).

Table 1. Glossary

Term	Definition
Biomass	the oven-dry weight in tonnes/ha of various biological components of an ecosystem
Merchantability limits	size or quality limits at and beyond which a tree is suitable for harvesting
Productivity class I land	forest land that is incapable of producing a merchantable stand within a reasonable length of time
Productivity class II land	forest land that is capable of producing a merchantable stand within a reasonable length of time
Pulpwood	wood of a size or quality that the reporting jurisdiction generally considers as suitable for pulp, fibre, chip, commercial chemical, or commercial fuel use, or is used only in smaller sizes such as posts or rails
Site class	any interval into which the site index range is divided for purposes of classification and use
Site index	an expression of forest site quality based on the height, at a specified age, of dominant and codominant trees in a stand
Stemwood	unless otherwise noted, the wood portion of the tree stem minus bark, stump, and top
Stocking	description of the density of forest cover

(continued)

Table 1. Glossary *(continued)*

Term	Definition
Submerchantable	small trees, below a set dbh limit
Unmerchantable	non-commercial parts of the stem (e.g., bark, stump, top)
Volume	the gross merchantable pulpwood standing volume of stocked timber productive forest

2 Background

Canada's national forest inventory (CanFI) contains standardized summaries of provincial inventories. They include merchantable volume estimates for most of the productivity class II forest land. CanFI81 was published in 1982 (Bonnor 1982) based on the provincial inventories available in 1981. Under the energy from forests program (ENFOR), the 1981 volume inventory was reworked into a national biomass inventory (Bonnor 1985) using tree biomass and volume equations and volume to biomass conversion factors. In some provinces, the biomass equations were applied to the field survey data and compiled in a manner similar to a volume inventory. In the rest of the provinces, the merchantable stem volume in the inventory was converted to mass using volume:mass conversion factors. The results were compiled and became the national biomass inventory.

A current biomass inventory for Canada was undertaken to address some of the data needs of carbon budget modelers. The basis for the biomass inventory remains the national volume inventory. However, the volume inventory focuses only on reporting merchantable stemwood volumes. To address the needs of carbon budget modelers, the biomass inventory also provides estimates of the other aboveground tree components as well as for non-merchantable trees. All estimates are given in oven-dry tonnes.

Prince Edward Island (PEI), as part of its forest inventory, reports on aboveground biomass (Prince Edward Island 1992). Their results are based on field plots and are more reliable than the estimates reported here, which are derived from the volume inventory and require more assumptions. To meet the objectives of repeatability and efficiency, biomass estimates for PEI were computed in the same manner as for the rest of the country However, in the summary tables (Tables 6–8), PEI's biomass inventory results were reported as well.

3 Productivity Class II Forest Land

3.1 Methodology

The methods for converting volume to biomass for productivity class II forest land were designed to maximize use of existing published data including CanFI and provincial biomass equations. CanFI is the most comprehensive, current forest inventory information available in a standard format for all of Canada. Therefore, the methods described here for the biomass inventory were designed to use CanFI information about type and location of wood volume resources, in conjunction with published tree biomass equations, to provide efficient estimators of biomass at the national level. Tree biomass equations for predicting aboveground biomass components from tree diameter and height are available for most of the important commercial tree species in Canada. The methods and results presented here can convert any inventoried pulpwood data to the corresponding biomass estimates for the species and regions covered.

CanFI reports the pulpwood volume per hectare based on unique combinations of classifiers within a spatially referenced national inventory polygon, typically 10 × 10 km (Canada 1988; Gray and Nietmann 1989). For the biomass project, the inventory classifiers of interest were site class and age (or maturity) class as well as species (or species group) composition. For each combination of inventory classifiers, volume:biomass conversion factors were estimated as well as the proportion of biomass in the unmerchantable components relative to the stemwood biomass.

The method selected for obtaining volume:biomass conversion factors consisted of constructing hypothetical 1-ha "stands" for each combination of species, site class and age in the national inventory. Each of these hypothetical stands consisted of a list of trees each with associated diameter at breast height (dbh) and height. Diameters were generated using a normal distribution with the mean equal to the average stand dbh and a coefficient of variation of 20%. Heights were generated in a similar manner. Single-tree volume equations were used to predict individual tree volumes from height and diameter and then summed to estimate the "stand" volume. In a similar manner, the aboveground biomass components were estimated from individual tree biomass equations and summed to the "stand" level. Merchantable volume to stemwood biomass conversion factors were computed as the ratio between merchantable "stand" volume and "stand" stemwood biomass. The remaining biomass components were predicted from the dbh and height for each tree and reported as a fraction of the "stand" stemwood biomass (Figure 1). In the case of Quebec, the biomass of the top was estimated by subtracting the merchantable stem and bark biomass from the total stem biomass. If at any point a negative estimate for a biomass component ensued it was set to zero.

The influence of stocking and density on the conversion factors was recognized. If the influence was strong, separate conversion factors would be needed for different stocking classes. To explore the effect of density, two detailed case studies were conducted: one for jack pine in Ontario and one for coastal Douglas-fir in British Columbia (see section 3.1.3).

All conversion factors were developed for single-age pure stands. In applying the results, the volume:biomass ratio and the biomass fractions were assumed to be invariant with respect to the presence or absence of other species. The assumption is also made that the conversion factors for uneven-aged stands can be approximated as the average conversion factor across all age classes. In the current version of CanFI, less than 0.1% of productivity class II forest is classified as uneven-aged; most of this occurs in Quebec (Lowe *et al.* 1994).

A literature search was conducted to obtain single-tree biomass and volume equations and published yield tables appropriate for the species encountered in CanFI86. The literature search focused on larger studies that produced biomass or volume equations by province/territory or broader regions (e.g., the Prairie provinces) rather than smaller studies based on samples from a limited geographic range. Some unpublished equations were obtained from the provincial agencies. The equation sources are given in Table 2 and previously unpublished volume equations are given in Appendix 1.

3.1.1 Constructing stand tables to estimate volume and biomass components

To construct the stand tables, the following procedure was followed. For each province or territory, and for each combination of species, site, and age class of interest, average diameter, dominant height, and density were obtained from yield tables as available. Then a hypothetical 1-ha stand was constructed, consisting of a tree diameter and height distribution. These distributions are generated by assuming that the tree dbh and height are normally distributed variables with a mean equal to the average dbh or dominant height predicted by a yield table, and a variance equal to some specified value (e.g., a coefficient of variation (CV) of 20%). The generated distributions were truncated to avoid negative values. Where a height range was available from the yield tables (e.g., Plonski 1981), it was used to approximate the variance of the height distribution using Freese's (1962) approximation where variance = (data range / 4).

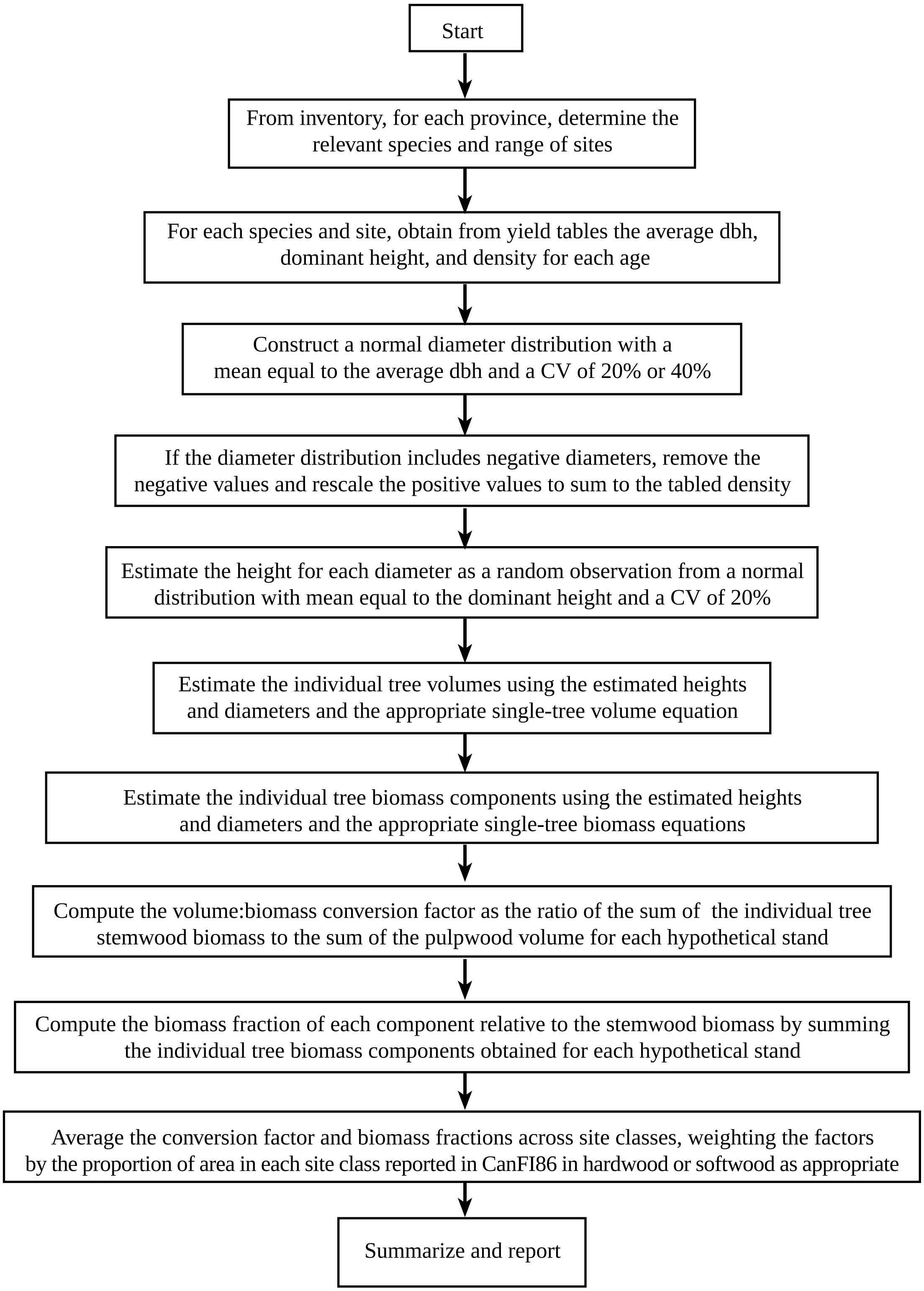

Figure 1. Method used to derive volume:biomass conversion factors and unmerchantable biomass fractions

Table 2. Source documents of biomass and volume equations used to obtain conversion factors[a]

Province/Territory	Source of volume equations	Source of biomass equations
Newfoundland	Ker (1974) – white spruce, aspen, white birch, yellow birch	Warren and Meades (1986) – black spruce and balsam fir Lavigne (1982)
Nova Scotia	Honer *et al.* (1983)	Ker (1984)
New Brunswick	Timber Management Branch – softwood species (see Appendix I) Honer *et al.* (1983) – hardwood species	Ker (1984)
Quebec	Perron (1986)	Ouellet (1983a,1983b)
Ontario	Plonski (1981) black spruce, jack pine, aspen, white birch Honer *et al.* (1983) red pine, white pine, white cedar, yellow birch, red oak, sugar maple, eastern hemlock, tamarack, balsam poplar, balsam fir	Alemdag (1983,1984a)
Manitoba	Dep. of Natural Resources (see Appendix I)	Singh (1982) submerchantable trees < 5 cm – Alemdag (1983, 1984a) submerchantable equations
Saskatchewan	taper functions from the Forest Evaluation Section, Dep. of Environment and Resources Management (see Appendix I)	Singh (1982) submerchantable trees < 5 cm – Alemdag (1983, 1984a) submerchantable equations
Alberta	Forest Service (see Appendix I)	Singh (1982) submerchantable trees < 5 cm – Alemdag (1983, 1984a) submerchantable equations
Northwest Territories	Dep. of Renewable Resources (see Appendix I)	Singh (1982) submerchantable trees > 5 cm – Singh (1984a) submerchantable trees < 5 cm – Alemdag (1983, 1984a) submerchantable equations
Yukon Territory	Massie *et al.* (1983)	Manning *et al.* (1984)
British Columbia	Ministry of Forests, Inventory Branch (see Appendix I)	Standish *et al.* (1985)

[a] Appendix I contains the equations for species for which the province did not use published equations.

Yield tables were not available for all species in all provinces (see Table 3). Consequently, substitutions were made. Where possible, yield tables for the same species from an adjoining province were used. Otherwise, yield tables for a similar species (within the same genus or with similar stand dynamics) were used (see Table 4).

Plonski's (1981) yield tables for red and white pine and for tolerant hardwoods do not contain information on average stand diameter. For red and white pine stands, diameters were estimated using the dbh and height data given in Berry (1984, 1987), respectively. In the absence of any other information, the relationship between diameter and height for white pine was also applied to the tolerant hardwoods. Each of these levels of estimation introduces additional assumptions and uncertainties.

3.1.2 Computing volume:biomass conversion factors and biomass fractions

Pulpwood volumes and stemwood biomass were estimated from dbh and height for each "tree" in the artificially generated stand table. The merchantability limits (stump height and top diameter) were the same for the biomass and volume computations for each stand table unless noted. Although merchantability is more relevant to timber production than biomass estimation, the merchantability limits are applied here to use the volume estimates from CanFI. In addition, separate biomass equations were sometimes used for small and large trees and the merchantability limits provided a convenient split. Where possible, these limits were set to correspond to the merchantability limits reported in the national inventory and are reported for each province. The unmerchantable biomass components were also estimated from diameter and height in the stand table. Not all provinces/territories separated the unmerchantable biomass into the same components. The most detailed breakdowns of submerchantable biomass for which equations were available were retained.

Factors for converting pulpwood volume to stemwood biomass were estimated for each combination of species (within province), site, age, and CV of dbh. For each of the combinations, a hypothetical stand was generated as outlined in the previous section. The conversion factor is the ratio of the sum of the individual tree stemwood biomass divided by the sum of the individual tree pulpwood volumes for each of the hypothetical stands.

$$conversion\_factor = \frac{\sum (stemwood\_biomass\_of\_the\_individual\_trees\_in\_the\_hypothetical\_stand)}{\sum (pulpwood\_volumes\_of\_the\_individual\_trees\_in\_the\_hypothetical\_stand)}$$

When expressed as g/cm^3, the conversion factors correspond to the oven-dry wood specific gravity. The conversion factors were checked to ensure they remained within 20% of published values of Alemdag (1984b), Gonzalez (1989), Singh (1986) and Singh and Kostecky (1986). Not all of the conversion factors can be interpreted as specific gravity; in some cases the biomass equations predicted the biomass of the whole stem (including stump and top) while the volumes were only calculated for the merchantable part of the bole. Only the merchantable volume was computed since it corresponds to the pulpwood volume in the volume inventory.

Each of the biomass components was computed for each tree in the hypothetical stand and then summed to the "stand level." The unmerchantable biomass components are reported as a fraction of stemwood biomass. For example,

$$foliage\_biomass\_fraction = \frac{\sum (foliage\_biomass\_of\_the\_individual\_trees\_in\_the\_hypothetical\_stand)}{\sum (stemwood\_biomass\_of\_the\_individual\_trees\_in\_the\_hypothetical\_stand)}$$

Table 3. Species and geographic coverage of yield tables used to derive conversion factors

Yield table	Table species	Applied to	Geographic coverage
Plonski (1981)	jack pine	jack pine, tamarack, western larch	all provinces and territories except larch in Newfoundland and B.C.
	black spruce	black and white spruce, white and red cedar, red spruce	Ontario, the Prairies, the Northwest Territories, Yukon Territory, and the Maritimes
	trembling aspen	aspen, balsam poplar, black cottonwood	all provinces and territories except Newfoundland and the Maritimes
	white birch	white birch	all provinces and territories except Newfoundland
	tolerant hardwoods	yellow birch, oaks, maples	Ontario and Quebec
	white pine	white pine	Ontario and Quebec
	red pine	red pine	Ontario and Quebec
Vezina and Linteau (1968)	black spruce	black spruce	Quebec
	balsam fir	balsam fir	all provinces except Newfoundland and the Maritimes
	balsam fir	alpine fir	Alberta
	balsam fir/spruce mixture	red spruce, eastern hemlock	Ontario and Quebec
	balsam fir/spruce mixture	white spruce	Quebec
Ker (1974)	balsam fir	balsam fir	Newfoundland and the Maritimes
	black spruce	black spruce	Newfoundland
	softwood/hardwood	white spruce and larch	Newfoundland
	hardwood/softwood	yellow birch, red maple	Newfoundland and the Maritimes
	trembling aspen	aspen	Newfoundland and the Maritimes
	white birch	white birch	Newfoundland
Smithers (1961)	lodgepole pine	lodgepole pine	Alberta, B.C. and Yukon Territory
		shore pine, larch	B.C.
Meyer (1937)	sitka spruce	sitka spruce	B.C.
Meyer (1938)	ponderosa pine	ponderosa pine	B.C.
University of British Columbia	Douglas-fir	interior Douglas-fir	B.C.
Forest Club (1953)	western hemlock	western hemlock, grand fir, pacific silver fir, mountain hemlock, yellow-cedar, western redcedar	B.C.

(continued)

Table 3. Species and geographic coverage of yield tables used to derive conversion factors *(continued)*

Yield table	Table species	Applied to	Geographic coverage
	white spruce	white, black and Engelmann spruce, subalpine fir	B.C.
	white pine	western white pine	B.C.
Mitchell and Cameron (1985)	Douglas-fir	coastal Douglas-fir	B.C.

This use of ratios to estimate the unmerchantable tree components ensures that the biomass components reflect the relatively constant functional and mechanistic balance between the various components. As the stemwood biomass increases, so does the leaf, branch, and bark biomass. In some cases, the conversion factors and fractions will be applied outside the range for which they were developed. By including the check on specific gravity and using proportions rather than absolute values for the unmerchantable components, the risk associated with extrapolation will be minimized. The conversion factors and ratios are only assumed to be constant for a given combination of species (within province), site, and age.

In cases where the merchantable dbh limit was greater than the average stand dbh predicted from yield tables, the resulting conversion factors were unstable, typically very large. This was likely due to the conversion factors being based on a small number of fairly small trees (those just above the merchantability limit). Therefore, conversion factors were not calculated when the average stand dbh was less than the merchantability limit. In these cases, using the conversion factor for the youngest age at which the average dbh from the yield table is greater than the merchantability limit is recommended. For example, in Ontario the minimum diameter limit is 9.0 cm. For jack pine on site class 2 at age 20, the average dbh from stand tables is 4.4 cm, below the merchantability limit, so the conversion factor is not calculated. Instead, the conversion factor at age 40 (when the average dbh is 11.4 cm) should be adopted.

Site class is not available for all the data from productivity class II forests in CanFI. Therefore, a conversion factor for those records that reported volumes but not the site class of species was needed. A weighted average of the site-specific conversion factors for these cases was adopted. CanFI86 reported the area in coniferous and deciduous forest by site class for each province. The conversion factors were averaged across all site classes and weighted by the coniferous or deciduous area in each site class, as appropriate.

Age or maturity class is not available for all the productivity class II forests either. The average of all the age-class conversion factors was weighted by the width of the age class. This weighted average was used for forests with no age or maturity class and for uneven-aged forests.

Table 4. Species used to convert the pulpwood volumes to biomass[a]

	nf	ns	pei	nb	pq	on	mb	sk	al	bc	yk	nwt
black spruce	nfbs	nsbs (nsrs)	*nsbs*	nbbs	pqbs (pqrs)	onbs	mbbs	skbs	albs	bcbs	ykbs	nwtbs
other spruce	nfws	nsws	*nsws*	nbws	pqws	onws	mbws	skws	abws	bces(14[b]) bcss(13) bcws	ykws	nwtws
white pine	*pqwp*	*pqwp*	*pqwp*	*pqwp*	pqwp	onwp	*onwp*	NA *skuc*	*bcwp*	bcwp	*bcwp*	NA *nwtuc*
jack pine	NA *nfuc*	nsjp	*nsjp*	nbjp	pqjp	onjp	mbjp	skjp	(*aljp*) ablp	bclp (bcsp)	yklp	nwtjp
other pine	*pqrp*	*nsjp*	*nsjp*	*nbjp*	pqrp	onrp	*mbjp*	*skjp*	ablp	bcpp	yklp	NA *nwtuc*
fir	nfbf	nsbf	*nsbf*	nbbf	pqbf	onbf	mbbf	skbf	albf (abaf)	bcpf(13) (bcgf) bcaf	*bcaf*	NA *nwtuc*
hemlock	NA *nbuc*	nsuc	*nsuc*	*nbuc*	*onhk*	onhk	NA *mbuc*	NA *skuc*	bcmh	bchk (bcmh)	*bchk*	NA *nwtuc*
Douglas-fir	NA *nbuc*	NA *nsuc*	NA *nsuc*	NA *nbuc*	NA *pquc*	NA *pquc*	NA *mbuc*	NA *skuc*	bcidf	bcdf(13) bcidf	*bcidf*	NA *nwtuc*
larch	nfla	*nsuc*	*nsuc*	*nbuc*	pqla	onla	mbla	skla	abla	bcla	*bcla*	nwtla
cedar and other conifers	NA *nbuc*	*nsuc*	*nsuc*	*nbuc*	*pquc*	onwc	*mbuc*	*skuc*	*abuc*	bcwr (bcyc)	*ykuc*	NA *nwtuc*
unspecified conifer	bs_6bf_4	bs_5ws_2 bf_3	*nsuc*	bs_5 ws_1bf_4	bs_6ws_1 jp_1bf_2	bs_6ws_1 jp_2bf_1	bs_5ws_1 jp_4	bs_3ws_3 jp_4	bs_1ws_5 lp_4	$s_2lp_2f_2hk_2df_1$ wr_1	bs_2ws_5 lp_3	bs_3ws_6 jp_1
aspen	nfas	nsas	*nsas*	nbas	pqas	onas	mbas	skas	abas	bcas	ykas	nwtas
poplar	*nfas*	NA nsub	*nsub*	*nbas*	*pqas*	onbp	mpbp	skbp	abbp	bcbc	*ykas*	nwtbp
yellow birch	nfyb	*pqyb*	*pqyb*	*pqyb*	pqyb	onyb	NA *mbub*	NA *skub*	NA *abub*	NA *bcub*	NA *ykub*	NA *bcub*
other birch	*nfwb*	*nswb*	*nswb*	*nbwb*	*pqwb*	*onwb*	*mbwb*	*skwb*	*abwb*	*bcwb*	*bcwb*	*bcwb*
sugar maple	NA *nfub*	*nsub*	*nsub*	*nbub*	pqsm	onsm	NA *mbub*	NA *skub*	NA *abub*	NA *bcub*	NA *ykub*	NA *bcub*
other maple	*nbub*	nsrm	*nsrm*	nbrm	pqrm	onrm	*mbub*	*skub*	*abub*	*bcub*	*ykub*	NA *bcub*

(continued)

Table 4. Species used to convert the pulpwood volumes to biomass[a] *(continued)*

	nf	ns	pei	nb	pq	on	mb	sk	al	bc	yk	nwt
other broadleaved	*nbub*	*nsub*	*nsub*	*nbub*	*pqub*	onro	*mbub*	*skub*	*abub*	*bcub*	*ykub*	NA *bcub*
unspecified broadleaved	as_1wb_9	as1wb_2 rm_7	*nsub*	as_3 wb_3 rm_4	as_2wb_4 sb_3rm_1	as_2bp_3 wb_2sm_1 rm_1ro_1	as_8bp_1 wb_1	as_8bp_1 wb_1	as_8bp_2	$as_8bc_1wb_1$	as_8bp_2	as_8bp_2
unspecified species	bs_6bf_3 wb_1	bs_4ws_2 bf_2rm_2	*nsus*	bs_4bf_3 as_1sb_1	bs_5bf_3 as_1wb_1 rm_1	$bs_5jp_2as_1$ bp_1sm_1	bs_4ws_1 jp_2as_3	bs_2ws_2 $jp_2as_2bp_1$	ws_3lp_3 as_3bp_1 wb_1	$s_2lp_2f_2hk_2$ df_1wc_1	bs_2ws_4 lp_3as_1	bs_2ws_4 $jp_1as_2bp_1$

[a] The entries are made up of a province code followed by a two letter species code.
The provinces codes are: nf=Newfoundland; ns=Nova Scotia; nb=New Brunswick; pq=Quebec; on=Ontario; mb=Manitoba; sk=Saskatchewan; al=Alberta; bc=British Columbia; yk=Yukon Territory; nwt=Northwest Territories. The species codes are: bs=black spruce; ws=white spruce; es=Engelmann spruce; ss=Sitka spruce; s=spruce; wp=white pine; jp=jack pine; lp=lodgepole pine; sp=shore pine; rp=red pine; pp=ponderosa pine; bf=balsam fir; pf=pacific silver fir; gf=grand fir; af=alpine fir; f=fir; hk=hemlock; mh=mountain hemlock; idf=interior Douglas-fir; df=coastal Douglas-fir; la=larch; wr=western redcedar; yc=yellow-cedar; as=aspen; bp=balsam poplar; bc=black cottonwood; yb=yellow birch; wb=white birch; sm=sugar maple; rm=red maple. The conversion factors for those entries in normal font were obtained using provincial equations and yield tables. For species without appropriate yield tables and/or equations, the suggested substitutions are given in italics. The “NA” entries represent species/province combinations for which no data are anticipated. The entries for unspecified conifer, unspecified broadleaved, or unspecified species give the approximate proportions (in tenths) by species of the provincial volumes as given in CanFI91. These values are used to compute weighted averages.

[b] Forest Inventory Zone.

3.1.3 Case studies

The volume:biomass conversion factors were not expected to differ a great deal from the published specific gravities. However, since the biomass and volume prediction are possibly being extrapolated outside the range of calibration data, the behaviour of the conversion factor was examined to ensure that the estimates were relatively stable. Two case studies were undertaken to investigate the sensitivity of the volume:biomass conversion factors to changes in site index, age, density, and CV of dbh. The conversion factors for jack pine in Ontario and coastal Douglas-fir were examined in more detail. The procedures outlined in the previous sections were followed with the following exceptions: (1) the CV of dbh ranged from 0 to 50% in increments of 10%; and (2) for Douglas-fir, variable density yield tables were used to construct stand tables corresponding to three initial densities: 1110, 2500, and 4440 stems/ha. The results of the case studies are reported in section 3.2.1.

3.1.4 Estimating beyond the range of data

Yield tables were not available for all species, age, and site class combinations found in the national inventory. In general, yield tables do cover the most frequently encountered combinations and give an indication of the trends beyond the range of data. Therefore, estimates of the conversion factors and biomass fractions were obtained by fitting a surface to the available data and interpolating or extrapolating. For a given site class, the conversion factor corresponding to the oldest age was used for ages beyond the range of the yield table. Then, a smoothing spline was fit to the available data, and used as a guide curve relating the conversion factor to age. A scaling factor was then computed as the average ratio of two consecutive site qualities. The conversion factors were then estimated for each site quality by scaling the guide curve using this scaling factor. The procedure is illustrated in Figure 2. This approach worked well within the range of data (i.e., predicted values closely approximated the computed values). Although extrapolated beyond the range of the yield tables, conversion factors are consistent with the available data. In addition, most of the records in the national inventory should be within the range of the yield tables.

3.1.5 Biomass of submerchantable trees

To obtain desired parameters for the biomass of the submerchantable trees, the following modifications in the procedures used in phase 1 were made: (1) since the variation in tree volume usually decreases as tree size (i.e., dbh or height) decreases, the same relationship between the variation of tree biomass and tree size is expected, and a CV of 20% was used to generate the tree dbh distribution; (2) the estimates of biomass are for the entire aboveground tree, and not divided into the biomass components (e.g., stemwood, stem bark, top, foliage); and (3) no submerchantable volume:biomass conversion factors were calculated—instead, per-hectare estimates of submerchantable biomass were derived from the phase 1 stand table data. Since CanFI91 does not report submerchantable volume, per-hectare estimates of submerchantable biomass were needed rather than the biomass:volume ratios.

For the Prairie provinces and the Northwest Territories, the biomass data compilation was not as straight forward as had been expected. The main problem was that some of the biomass equations used for merchantable trees were inappropriate for the submerchantable trees, which have small dbh and height. As a result, these equations sometimes produced erratic estimates (e.g., extreme large or negative estimated values) for small trees. This problem resulted from the fact that most biomass equations were developed for forest inventories in which merchantable trees are the main concern. To estimate the biomass for submerchantable trees, some alternative methods or equations to those used for merchantable trees were needed. These alternative equations are given in Table 2.

To calculate the submerchantable biomass for national inventory data, the submerchantable biomass for each species group was multiplied by the fraction of pulpwood volume in that species group. For example, for a record with 40% jack pine and 60% white spruce, the appropriate submerchantable biomass for jack pine was multiplied by 0.4 and the white spruce by 0.6.

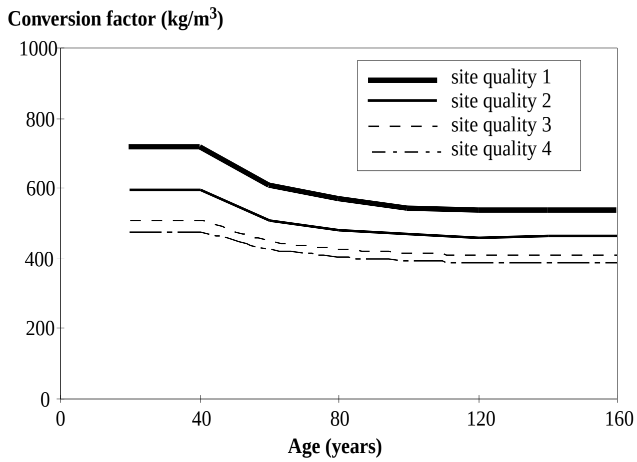

Figure 2(a). Conversion factors obtained from yield tables are extrapolated to cover the range of ages by substituting the closest value.

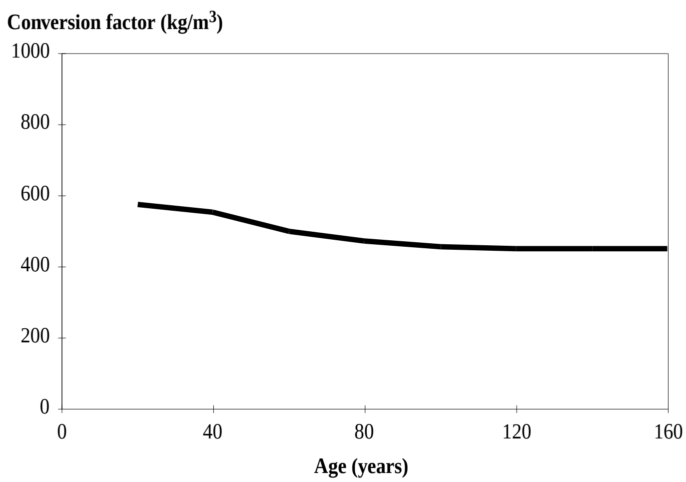

Figure 2(b). A cubic spline is fit as a guide curve.

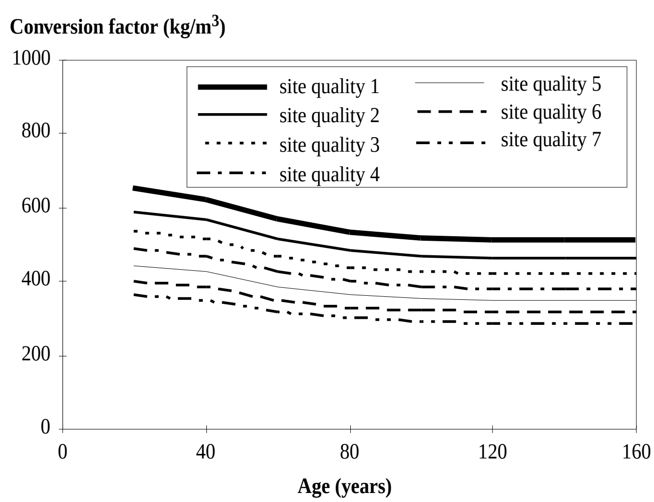

Figure 2(c). Conversion factors for all sites are estimated.

3.2 Results and Discussion

The results (see sample in Table 5) show very little variation in the volume:biomass conversion factor within a given species. The only instability occurred for hypothetical stands with very small trees and correspondingly small total volumes and biomass. When the stands that had average diameters less than the merchantability limit were removed, the variation in conversion factors over sites and ages was minimal.

The biomass equations were best at predicting stemwood biomass so the volume:biomass conversion factor is the most reliable. The equations for the other biomass components were not as precise. Hence, in specific cases the estimates may be rather poor. However, all of the aboveground biomass estimates should be sound when aggregated on a regional basis when local differences in factors such as stocking, microsite, and species composition are replaced by the average.

A reliable conversion factor should, everything else being equal, reflect changes in wood density. In general, wood density decreases with increasing growth rate (Gonzalez 1989) and, for softwoods, with increasing size (Mullins and McKnight [editors] 1981). Therefore, the following trends would be expected: (1) decreased conversion factor with increased site quality, and (2) increased conversion factor with increased stand density. However, Singh (1984b) found that commonly measured tree attributes such as dbh, age, and height were not reliable and consistent estimators of wood density. The minor trends noted here are consistent with other reported results. Extrapolating the results beyond the range of data is unlikely to lead to errors of more than a few percent. In a few cases, the conversion factors differed more than 20% from published specific gravities. The most notable deviations were in Ontario where black spruce, white spruce, white birch, and trembling aspen had conversion factors considerably higher than the relevant specific gravities. These are also the only species-province combinations for which the gross merchantable yield table volumes were used. Had the main stand volume to a 7 cm top been used in place of the gross merchantable volume, the conversion factors would have been closer to the published specific gravities. As well, for no apparent reason, the conversion factors for balsam poplar in Manitoba are low. Similar arguments apply to the spruces in the Northwest Territories. The conversion factors for mountain hemlock in B.C. are high relative to specific gravity figures published by Gonzalez (1989).

3.2.1 Case studies

For jack pine in Ontario, the volume:biomass conversion factor with age, CV of dbh, and site class ranged from about 457 to 480 kg/m^3 or approximately 5% of the mean. The slight ($2kg/m^3$) increase in conversion factor with increase in site index is contrary to expectations and could be an artifact of the equations used. On the better sites, as the trees approach maturity, the conversion factor should increase as the growth rate slows down. After the trees reach about 80 years of age, the conversion factor decreases as the proportion of heartwood increases. This trend closely approximates the change in wood specific gravity from pith to bark at breast height reported by Doerner (1964). The derived conversion factors appear to decrease slightly with increases in the CV of dbh.

The conclusion from this examination of jack pine in Ontario is that the volume:biomass conversion factor decreases slightly with increases in the CV of dbh and decreases as the site class improves. This may be an artifact of the method of constructing the hypothetical stands.

Table 5. An example of factors used to convert volume to biomass using black spruce in Newfoundland[a]

Province	Species	Site	Age	dbh (cm)	Density (stems/ha)	Pulpwood volume[b] (m^3/ha)	CF20[c]	Stem bark[d]	Branches	Foliage[e]	Submerch-antable (t/ha)
1	BS	1	20	3.7	6821	0	0.00	0.0000	0.0000	0.0000	33.026
1	BS	1	40	6.8	5682	8.834	462.30	0.1435	0.2522	0.3863	72.804
1	BS	1	60	7.7	5380	36.407	462.76	0.1438	0.2475	0.3464	69.272
1	BS	1	80	8.1	5242	54.010	463.33	0.1440	0.2456	0.3302	64.724
1	BS	1	100	8.4	5163	75.725	464.26	0.1441	0.2440	0.3166	60.055
1	BS	2	20	6.0	5943	0.953	466.07	0.1430	0.2582	0.4377	67.113
1	BS	2	40	8.7	5029	89.678	464.54	0.1442	0.2431	0.3091	53.644
1	BS	2	60	9.5	4863	150.785	467.75	0.1444	0.2397	0.2804	42.500
1	BS	2	80	9.9	4769	180.653	471.20	0.1445	0.2382	0.2673	36.124
1	BS	2	100	10.2	4700	207.695	472.50	0.1446	0.2372	0.2587	32.371
1	BS	2	20	7.1	5567	14.677	463.27	0.1436	0.2508	0.3748	73.127
1	BS	2	40	9.6	4835	155.118	468.48	0.1444	0.2394	0.2775	41.155
1	BS	2	60	10.4	4641	221.422	474.79	0.1447	0.2365	0.2530	29.680
1	BS	2	80	10.8	4552	257.707	478.71	0.1448	0.2353	0.2434	24.483
1	BS	2	100	11.1	4502	291.585	481.46	0.1448	0.2343	0.2348	21.910

[a] The yield tables for Newfoundland black spruce cover type by Ker (1974) were used.

[b] Pulpwood volume is total volume and includes top and stump. This will result in an underestimation of the conversion factor. However, this underestimation is expected to be very small and it is assumed not to affect the biomass estimation significantly. Stump height = 15 cm, top diameter = 7.6 cm (diameter inside bark), submerchantable limit = 9.0 cm (diameter at breast height, dbh).

[c] The CF20 is the pulpwood volume:stemwood biomass conversion factor using a coefficient of variation (CV) of 20% for diameter.

[d] The stem bark, branches, and foliage columns contain the biomass of these components expressed as a fraction of stemwood biomass.

[e] Foliage category includes twigs.

For coastal Douglas-fir, the volume:biomass conversion factor with age, CV of dbh, and site class ranged from about 423 to 438 kg/m^3 or approximately 4% of the mean. Here the expected decrease in conversion factor with increase in site index is observed. There is a slight decline in conversion factor with age which tapers off at approximately 100 years. No clear correlation is found between conversion factors and various levels of initial stand density and CV of dbh because the prediction equations do not include density.

The conclusion from examining coastal Douglas-fir is that the volume:biomass conversion factor decreases slightly with increases in age and site index.

3.2.2 Conversion factors and biomass fractions

Examples of the final conversion factors and biomass fractions are given in Table 5 for black spruce in Newfoundland. The complete results are available on diskette from the Forest Inventory and Analysis Project (FIAP) at the Canadian Forest Service, Victoria, B.C.

3.2.3 Variations in conversion factors

Only a small variation in the conversion factors with changes in age, site, and CV of dbh in the case studies was found. There was no clear correlation with stand density. This result may be due to the insensitivity of the provincial/territorial volume and biomass equations to variation in stand structure. Because the equations were developed for broad geographic areas with only dbh and height as predictors, they may not be sensitive to changes in stand dynamics which could affect the wood specific gravity. The absence of significant and/or consistent trends in conversion factors was such that the factors, for producing regional biomass estimates, can be applied over a broad geographic range and set of conditions and provide reasonable estimates. The biomass fractions are more sensitive to changes in stand density. However, the limitation of using available data and equations did not allow the incorporation of density. Therefore, the biomass fractions represent average conditions.

3.2.4 Submerchantable biomass

The existing biomass equations compiled for the merchantable trees are generally inappropriate for small trees, and the quality of the estimates of submerchantable trees depends on the model form and the actual relationship between the oven-dry biomass of small trees and tree size. In general, the segmented regression model developed by Lavigne (1982), or a simple non-linear model provided better consistent estimates of tree biomass. Multiple regression models performed poorly in extrapolating for small trees.

3.2.5 Missing values

The biomass conversion factors that have been obtained in this study provide most of the information needed to convert CanFI91 to an updated biomass inventory. Where information is missing, data from similar species or adjacent provinces have been substituted (see Table 4). As more volume and biomass information becomes available, these tables can be revised and updated.

3.3 Conclusions

The results presented here can be used to convert merchantable tree volumes on productivity class II forest lands to the aboveground biomass components. This is the first step towards a revised biomass inventory of Canada. The resulting biomass estimates provide regional estimates which are not sensitive to local variations in stand density, age, site, or CV of dbh.

4 Productivity Class I Forest Land

Managers of forest inventories generally concentrate their resources on obtaining data on forest land considered productive for growing timber. Likewise most growth and yield studies have concentrated on estimation procedures for merchantable, mature trees. As well, the provinces/territories generally maintain very little inventory information on productivity class I forests. Therefore, the following estimates are subjective and may be revised as new information becomes available. The ranges in biomass presented here provide reasonable estimates for the likely biomass amounts encountered. However, more caution is advised when using the average values reported here as they are based on fewer studies than the productivity class II forest estimates and subject to greater error.

4.1 Methodology

Biomass estimates were obtained by stating the provincial/territorial definition of productivity class I forest land, describing the forests associated with these areas, and then estimating the biomass. Since each province/territory maintains its own forest inventory and classification system, each province/territory was treated separately.

4.1.1 Provincial definition of productivity class I forest land

The definitions of productivity class I forest land for each province/territory were obtained from their respective inventory procedures. Differences sometimes occur between the provincial and national inventory, particularly about the boundary between productivity class I forest and non-forest types. For example, some provinces consider rock as productivity class I forest while other provinces classify rock as non-forest. The table to convert provincial forestry classes to national inventory land classes is given in Appendix I of Gray and Nietmann (1989, pp. 69–148).

4.1.2 Description of the productivity class I forest types

A literature search was conducted on biomass of productivity class I sites: vegetation types, biomass estimates and equations, volume, productivity, height, density, etc. The productivity class I forest land was described in broad terms for each province/territory using the latest classification of ecozones of Canada (Wiken *et al.* 1993). The extent of each productivity class I type was estimated by ecozone within province/territory using the 1991 national inventory.

4.1.3 Biomass estimates

Two sets of biomass ranges are defined and reported here. The first one, “Individual stand – estimated range,” is the theoretical range of biomass values for individual areas of productivity class I forest. The biomass of productivity class I stands could range from slightly above 0 t/ha for recently disturbed sites to the lower limit of productivity class II stands for mature, stocked stands respectively. Hence, maximum biomass on a given productivity class I type is set to equal the minimum expected biomass of productivity class II sites (as computed in the first part of this project). In general, biomass estimates for productivity class I forests are bounded by non-forest at the lower end and productivity class II forests at the higher end.

The second set of biomass estimates deals with the probable range of biomass for average stands on productivity class I forest land. These “average” stands are intended to represent typical productivity class I cover types in terms of average age, dbh, height, and a range of densities. When available, these ranges and averages are based on published results. However, little quantitative information on productivity class I sites is available. To obtain estimates, hypothetical productivity class I cover types were therefore constructed.

The biomass estimates include trees and tall shrubs (e.g., alder, willows, dwarf birch). Smaller woody shrubs and herbaceous vegetation are not included. The biomass estimates include all aboveground tree components including stem, foliage, and branches. The following procedure was used to construct representative productivity class I stands and estimate the biomass for each ecozone.

Step 1. For each cover type, an average dbh was arbitrarily set at approximately two-thirds of the merchantable dbh limit based on the province/territory merchantability limits.

Step 2. Associated average height and density were set using data from existing yield tables.

Step 3. A probable stocking range was set based on the province/territory's definition of productivity class I sites. If the information was unavailable, the stocking range was set to vary between 10 and 75% with an average stocking of 50%. Here, stocking is defined as the number of stems compared to a fully stocked stand of the same age.

Step 4. Biomass ranges and averages were estimated using existing biomass equations.

Step 5. The weighted average for each ecozone was computed as the average of the productivity class I cover types weighted by the estimated proportion of area in each productivity class I type.

4.2 Results and Discussion

Appendix 2 contains the biomass estimates for the major productivity class I cover types within an ecozone by province and territory. Note that the limit between productivity classes I and II forest is sometimes unclear and subjective and may vary between regions in the province. Also, since productivity class I sites are usually not a priority for provinces, the quality of information can be quite low. The results presented are therefore subject to revision as better data become available.

The main problems associated with estimating biomass on productivity class I sites are obtaining valid quantitative data and biomass equations. The literature search revealed little information related to biomass or descriptions of productivity class I stands. As a result, most of the biomass estimates rely on hypothetical stands constructed to represent "average" productivity class I stands. Biomass equations for the major tree species are available for all provinces and territories. However, the equations were usually developed to estimate biomass of merchantable trees on productivity class II sites; applying those equations to smaller stems may cause a major bias, particularly for non-stem components such as branches and foliage. Differences in wood density and tree allometry between productivity class II and productivity class I sites might also affect the results. As well, tall shrubs have not been included.

5 National Biomass Results

Summaries of the national biomass inventory by forest type, maturity class, and site class are given in Tables 6–9 and the accompanying maps. These results strongly reflect the trends in the national volume inventory (Lowe *et al.* 1994). Some of the trends are unexpected and may be due to trends in classifiers not explicitly referenced in the table. Each cell in the table is the average of all the inventory records corresponding to that cell's classification. In Table 7, for example, each cell contains all site classes so any trends between average biomass and maturity class are also confounded with any trends between maturity class and site.

Table 6. Total biomass, area, and average biomass by ecozone for productivity class II forests

Ecozone	Total biomass (t)	Total area (ha)	Average biomass (t/ha)
Southern Arctic	390 833	9 096	42.97
Taiga Plains	1 076 094 483	15 954 723	67.45
Taiga Shield	371 387 583	9 348 214	39.73
Boreal Shield	6 728 739 735	93 711 524	71.80
Atlantic Maritime	1 153 459 516	13 784 873	83.68
Mixedwood Plains	238 710 825	2 682 084	90.83
Boreal Plains	2 438 554 214	31 130 376	78.33
Prairies	130 033 207	1 715 608	75.79
Taiga Cordillera	31 344 716	555 654	56.41
Boreal Cordillera	953 246 665	11 417 553	83.49
Pacific Maritime	2 198 208 447	9 225 447	238.28
Montane Cordillera	4 830 780 075	31 753 080	152.14
Hudson Plains	89 150 711	1 490 858	59.80
Canada	20 240 101 010	222 725 090	90.87

Table 7. Average biomass (t/ha) by province and forest type

Province/Territory	Softwood	Mixedwood	Hardwood	Unclassified	Average
Newfoundland	52	76	84	80	54
Nova Scotia	71	70	83	–	75
Prince Edward Island	73(103)[a]	83(126)	99(145)	–	84(127)
New Brunswick	87	87	90	16	81
Quebec	59	89	105	43	70
Ontario	83	85	101	84	87
Manitoba	46	74	72	–	55
Saskatchewan	35	67	89	–	54
Alberta	82	92	68	–	78
British Columbia	169	111	80	55	158
Yukon Territory	76	60	60	–	72
Northwest Territories	62	48	55	–	52
Canada	101	81	88	28	94

[a] The numbers in parentheses are from Prince Edward Island (1992).

Table 8. Average biomass (t/ha) by province and maturity class

Province/ Territory	Maturity class						Average
	Regen- eration	Immature	Mature	Over- mature	Uneven- aged	Unclass- ified	
Newfoundland	2	53	80	83	–	–	54
Nova Scotia	2	74	90	110	53	–	75
Prince Edward Island	–	–	–	–	–	84(127)[a]	84
New Brunswick	15	80	96	110	103	62	82
Quebec	30	87	71	62	101	10	70
Ontario	–	69	102	114	91	84	87
Manitoba	–	57	68	87	–	48	55
Saskatchewan	39	68	81	99	–	12	54
Alberta	2	51	105	114	–	–	78
British Columbia	4	102	194	175	–	–	158
Yukon Territory	9	55	97	141	–	–	72
Northwest Territories	–	49	66	27	–	–	52
Canada	15	73	124	105	98	100	94

[a] The numbers in parentheses are from Prince Edward Island (1992).

Table 9. Average biomass (t/ha) by province and site class

Province/ Territory	Site class								Total
	1	2	3	4	5	6	7	Unclass.	
Newfoundland	57	71	94	–	–	–	–	48	54
Nova Scotia	76	55	68	–	–	–	–	–	75
Prince Edward Island	–	–	–	–	–	–	–	84(127)[a]	84
New Brunswick	86	85	83	87	–	–	–	80	82
Quebec	–	–	–	–	–	–	–	70	70
Ontario	82	80	97	120	98	–	–	56	87
Manitoba	42	48	60	–	–	–	–	–	55
Saskatchewan	107	100	116	–	–	–	–	53	54
Alberta	57	84	114	–	–	–	–	–	78
British Columbia	141	39	192	218	185	256	305	–	158
Yukon Territory	65	113	121	134	–	–	–	103	72
Northwest Territories	45	83	115	–	–	–	–	–	52
Canada	92	74	129	204	107	256	305	74	94

[a] The numbers in parentheses are from Prince Edward Island (1992).

Differences between Bonnor's (1985) biomass inventory and the results reported here do not necessarily reflect actual changes in the biomass of Canada. The differences may be due to different assessment and compilation methods and due to an increase in the extent of the CanFI from 1981 to 1991. The increase in average biomass per ha on productivity class II forest land from Bonnor's report reflects a general increase in reported volume per ha and a reduction in the area reported as unclassified maturity class or unclassified site class.

Botkin and Simpson (1990) reported much lower average biomass values for the boreal forest than those reported here. Much of this may be due to different reporting methods. The summaries reported here are of the biomass relative to the area it grows on, while Botkin and Simpson (1990) summarize the biomass relative to the total area including water and non-forest land.

The results reported here for PEI and those compiled by the PEI government (Prince Edward Island 1992) differ for several reasons, most notably the different compilation methods. The average biomass per hectare reported here is considerably lower than the provincial estimates (see Tables 6–9). This result is partly due to the total merchantable volume reported in CanFI91 being 20% lower than that reported by the province (Prince Edward Island 1992). The provincial estimates are based on field data and are more reliable.

6 Other National Biomass Inventories

Due to increasing interest in the global carbon budget, much attention has been directed toward estimating the biomass and productivity of forests around the world. Most attempts at national biomass inventories fall into two approaches: conversion of existing volume inventories to biomass based on broad strata (Birdsey 1992; Alexeyev *et al.* 1995; Isaev *et al.* 1995) or direct sampling to measure biomass (e.g., Box *et al.* 1989; Botkin and Simpson 1990).

Converting existing national volume inventories to biomass inventories takes advantage of existing information but all attempts suffer from some of the same weaknesses encountered in this study—the need to estimate all the forest biomass components (including non-merchantable parts of the tree stem, understorey, and roots) from stemwood volume. In Russia, Isaev *et al.* (1995) have taken the approach of using plot data to derive volume to biomass conversion factors based on the predominant species, stocking, and maturity class of the stand. The stem volume and area in each of these broad classes are then obtained from the national inventory and converted to biomass components. Alexeyev *et al.* (1995) used a similar approach but stratified Russia into administrative units and ecoregions. Birdsey (1992) used the same approach in the United States. As with this study, these biomass inventories are intended to provide reasonable regional and national estimates, not local estimates. This approach was used due to the lack of studies on the non-stem biomass components of stands and the use of regional estimates.

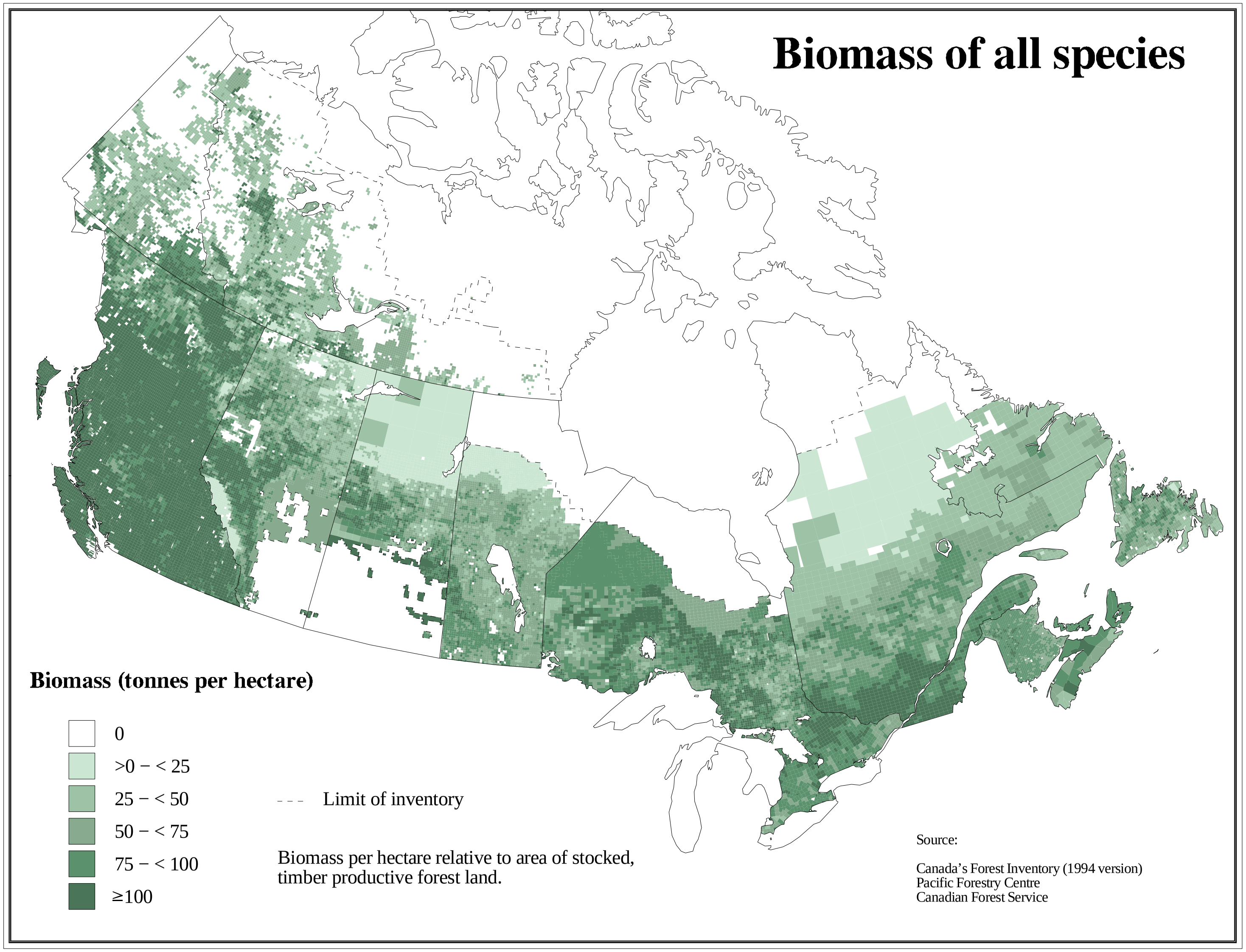

Figure 3. Biomass of all species.

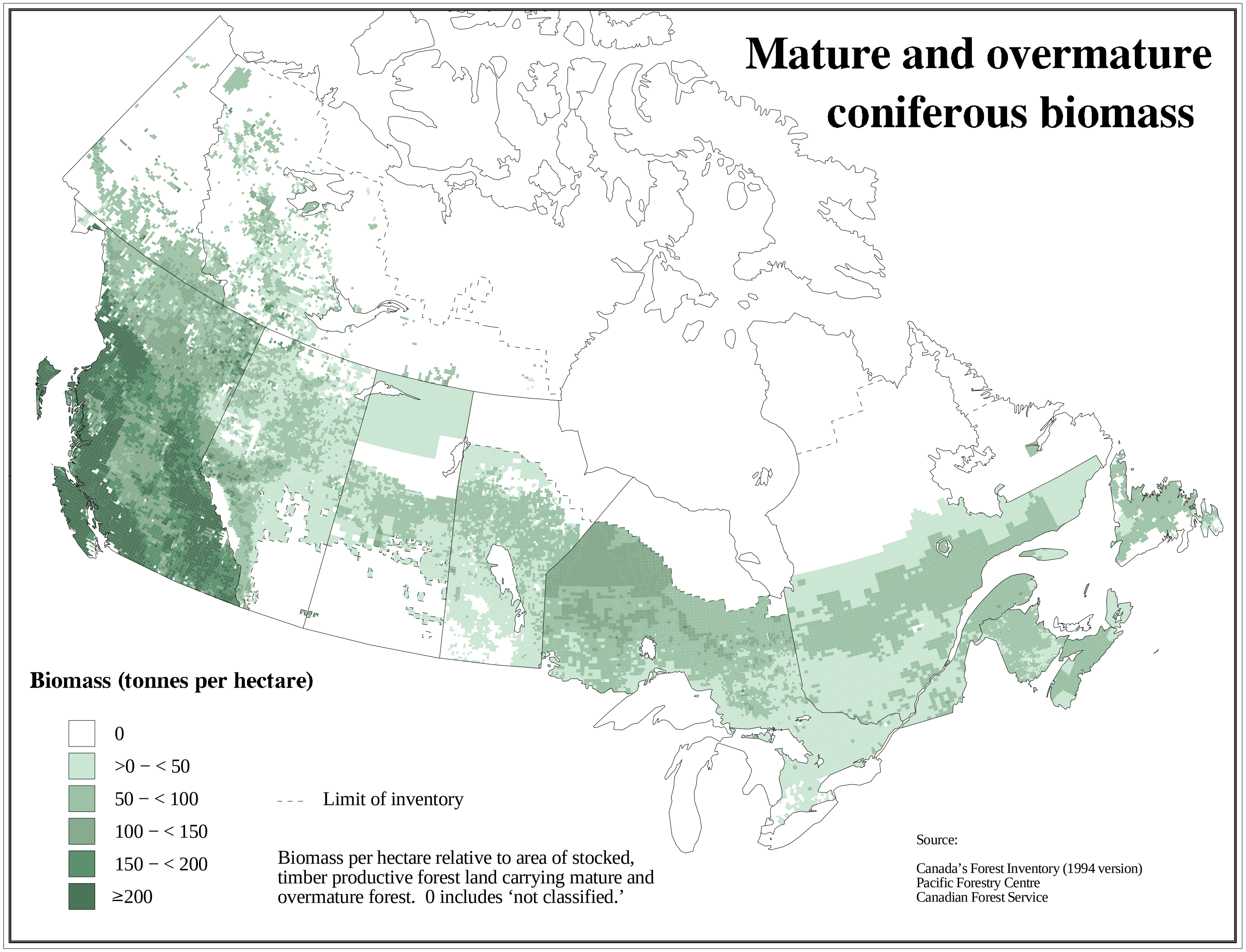

Figure 4. Mature and overmature coniferous biomass.

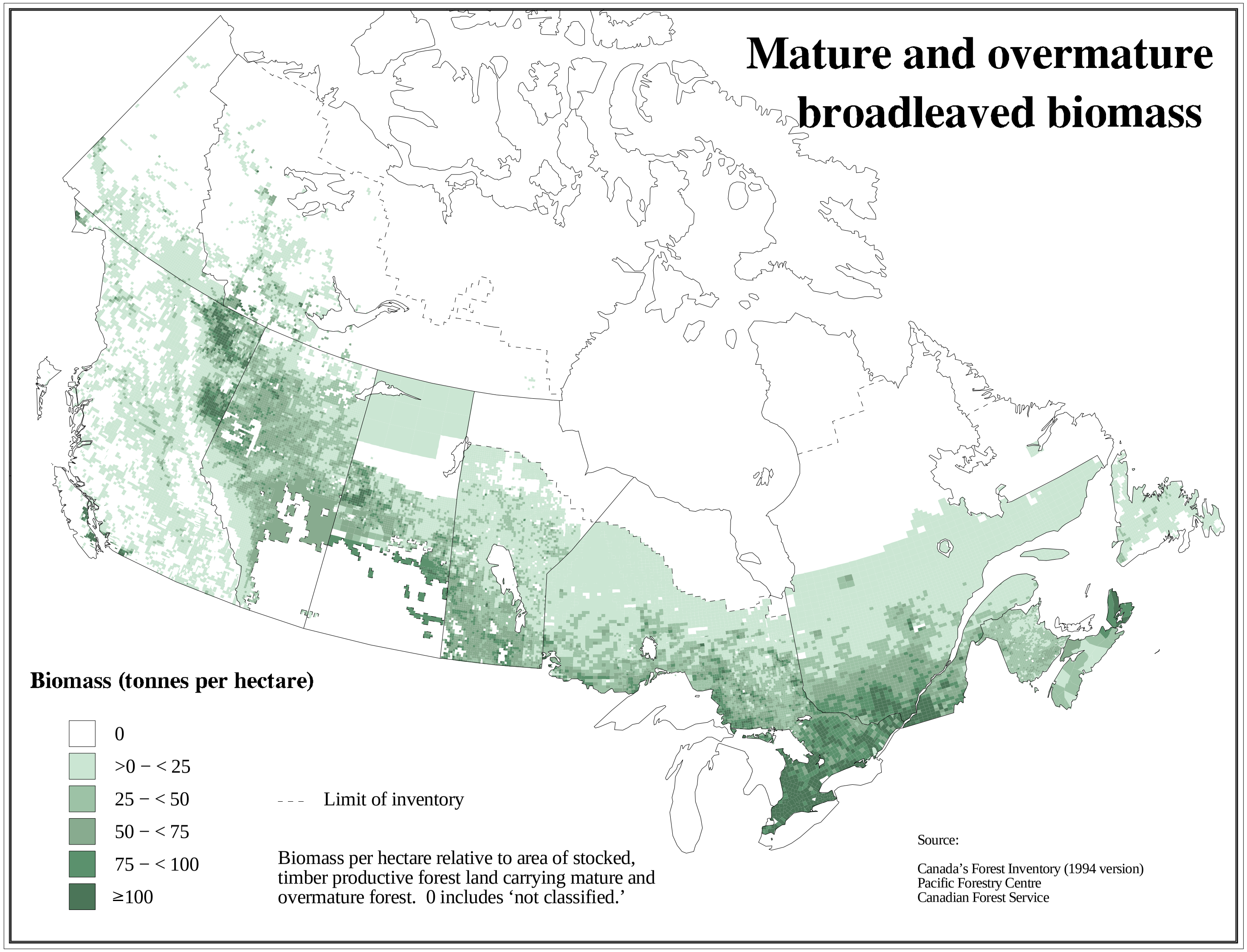

Figure 5. Mature and overmature broadleaved biomass.

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Appendix 1. Previously unpublished volume equations used in this study[a]

Province/Territory	Species	Volume equation
New Brunswick	all softwood species	$V = 7.9422 * 10^{-5} D^{1.7788} H^{0.9627}$
Manitoba	white spruce	$V = -1.331 * 10^{-3} + 3.292128 * 10^{-3} (D^2H)/100$
	black spruce	$V = -1.0307 * 10^{-2} + 3.361824 * 10^{-3} (D^2H)/100$
	jack pine	$V = -1.6254 * 10^{-2} + 3.424306 * 10^{-3} (D^2H)/100$
	trembling aspen	$V = 4.276 * 10^{-3} + 3.317746 * 10^{-3} (D^2H)/100$
	balsam fir	$V = 4.276 * 10^{-3} + 3.317746 * 10^{-3} (D^2H)/100$
	larch	$V = -1.0307 * 10^{-2} + 3.361824 * 10^{-3} (D^2H)/100$
	white birch	$V = -1.4496 * 10^{-2} + 3.425386 * 10^{-3} (D^2H)/100$
	balsam poplar	$V = -1.3139 * 10^{-2} + 3.387226 * 10^{-3} (D^2H)/100$
	white birch (submerchantable)	$V = 0.415959 D^2H$
	white spruce (submerchantable)	$V = 0.408552 D^2H$
	black spruce (submerchantable)	$V = 0.406110 D^2H$
	larch (submerchantable)	$V = 0.406110 D^2H$
	jack pine (submerchantable)	$V = 0.413375 D^2H$
	balsam fir (submerchantable)	$V = 0.407202 D^2H$
Saskatchewan	all species	volume calculated using a taper equation program written in Fortran obtained from the Saskatchewan government.
Alberta	white spruce	$V = 4.328336 * 10^{-5} D^{1.882751} H^{1.02411}$
	black spruce	$V = 4.328336 * 10^{-5} D^{1.882751} H^{1.02411}$
	jack pine	$V = 4.421585 * 10^{-5} D^{1.926909} H^{1.00304}$
	trembling aspen	$V = 7.491573 * 10^{-5} D^{1.877086} H^{0.850270}$
	lodgepole pine	$V = 4.421585 * 10^{-5} D^{1.926909} H^{1.00304}$
	balsam fir (also used for alpine fir)	$V = 7.491573 * 10^{-5} D^{1.877086} H^{0.850270}$
	larch	$V = 4.328336 * 10^{-5} D^{1.882751} H^{1.020411}$
	white birch	$V = 5.634793 * 10^{-5} D^{1.976455} H^{0.803794}$
	balsam poplar	$V = 2.472902 * 10^{-5} D^{1.871307} H^{1.179970}$
Northwest Territories	white spruce	$V = 4.316 * 10^{-2} + 3.1526 * 10^{-5} D^2H$
	black spruce	$V = 4.32 * 10^{-3} + 3.5718 * 10^{-5} D^2H$
	jack pine	$V = 1.3387 * 10^{-1} + 3.6106 * 10^{-5} D^2H$
	trembling aspen	$V = 4.591 * 10^{-1} + 3.1133 * 10^{-5} D^2H$
	larch	$V = 1.142 * 10^{-2} + 3.4212 * 10^{-5} D^2H$
	balsam poplar	$V = -1.008 * 10^{-2} + 2.9254 * 10^{-5} D^2H$

(continued)

Province/Territory	Species	Volume equation
British Columbia	white spruce	$V = 5.079336672*10^{-5} D^{1.858590} H^{1.007790}$ (FIZ[b]: D to J)
		$V = 4.170834911*10^{-5} D^{1.783940} H^{1.146280}$ (FIZ: K & L)
	black spruce	$V = 5.079336672*10^{-5} D^{1.858590} H^{1.007790}$ (FIZ: D to J)
		$V= 4.170834911*10^{-5} * D^{1.783940} H^{1.146280}$ (FIZ: K & L)
	trembling aspen	$V = 3.804275847 * 10^{-5} D^{1.894760} H^{1.053730}$ (FIZ: A to J)
		$V = 2.891318933 * 10^{-5} D^{1.834410} H^{1.208970}$ (FIZ: K & L)
	Engelmann spruce	$V = 5.079336672*10^{-5} D^{1.858590} H^{1.007790}$ (FIZ: D to J)
		$V= 4.170834911*10^{-5} D^{1.783940} H^{1.146280}$ (FIZ: K & L)
	sitka spruce	$V = 4.893098969*10^{-5} D^{1.822840} H^{1.057290}$ (AGE<=120)
		$V = 4.280110684*10^{-5} D^{1.646990} H^{1.282450}$ (AGE>120C)
	western white pine	$V = 5.005851938 * 10^{-5} D^{1.857800} H^{1.022250}$
	lodgepole pine	$V = 5.259349113 * 10^{-5} D^{1.898400} H^{0.996793}$ (FIZ K to L)
		$V = 4.47194033 * 10^{-5} D^{1.822760} H^{1.108120}$ (FIZ A to J)
	ponderosa pine	$V = 3.292418248 * 10^{-5} D^{1.894760} H^{1.053730}$
	pacific silver fir	$V = 5.417488524*10^{-5} D^{1.782960} H^{1.103820}$
	grand fir	$V = 5.417488524 * 10^{-5} D^{1.782960} H^{1.103820}$ (FIZ: A, B, C)
		$V = 5.106002228 * 10^{-5} D^{1.872930} H^{0.998274}$ (FIZ: D to J)
	subalpine fir	$V = 5.417488524 * 10^{-5} D^{1.782960} H^{1.103820}$ (FIZ: A, B, C)
		$V = 5.106002228 * 10^{-5} D^{1.872930} H^{0.998274}$ (FIZ: D to J)
		$V = 4.458697411 * 10^{-5} D^{1.698090} H^{1.231200}$ (FIZ: K and L)
	coastal Douglas-fir	$V = 4.796550265*10^{-5} D^{1.813820} H^{1.042420}$ (AGE< =120)
		$V= 4.483580793*10^{-5} D^{1.692440} H^{1.181970}$ (AGE>120)
	interior Douglas-fir	$V = 4.139024528 * 10^{-5} D^{1.742940} H^{1.156410}$
	western hemlock and mountain hemlock	$V = 3.812237947 * 10^{-5} D^{1.867780} H^{1.099890}$ (AGE< =120 FIZ: A to C)
		$V = 4.597788609 * 10^{-5} D^{1.783500} H^{1.120230}$ (AGE>120 FIZ: A to C)
		$V = 4.030574937 * 10^{-5} D^{1.94290} H^{0.990275}$ (FIZ: D to K)
	western larch	$V = 4.461840076*10^{-5} D^{1.723600} H^{1.135270}$ (FIZ: D to I)
		$V= 4.260494412*10^{-5} D^{1.724890} H^{1.192450}$ (FIZ: K and L)
	western redcedar	$V = 7.259086976*10^{-5} D^{1.716770} H^{1.047420}$ (AGE< =120 FIZ: A to C)
		$V= 7.886657849*10^{-5} D^{1.743240} H^{0.981729}$ (AGE>120 FIZ: A to C)
		$V = 6.630846891* 10^{-5} D^{1.759950} H^{1.019080}$ (FIZ: D to J)
	Yellow-cedar	$V = 6.499396018*10^{-5} D^{1.777360} H^{1.032990}$
	white birch	$V = 3.60460765*10^{-5} D^{1.909560} H^{1.052050}$ (FIZ: A to J)
		$V = 1.992209469*10^{-5} D^{1.912030} H^{1.246160}$ (FIZ: K and L)
	black cottonwood	$V = 2.246823719*10^{-5} D^{1.735180} H^{1.356010}$ (FIZ: A to J)
		$V = 2.593444748*10^{-5} D^{1.778590} H^{1.250760}$ (FIZ: K and L)

[a] All volumes are total volumes unless otherwise indicated. D = diameter at breast height (cm); H = height (m), V = volume (m^3).

[b] FIZ = forest inventory zone, a provincial zonation.

Appendix 2. Biomass estimates for productivity class I forest land by ecozone and cover type within provinces and territories[a]

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
Newfoundland	Boreal Shield	coniferous scrub	97	1–85	6–47 (32)
		hardwood scrub	3	1–120	8–50 (29)
		weighted average			32
	Taiga Shield –Labrador	coniferous scrub	99	1–85	2–50 (21)
		hardwood scrub	1	1–120	8–50 (29)
		weighted average			21
Nova Scotia	Atlantic Maritime	softwoods	96	1–125	6–95 (34)
		mixedwoods	4	1–125	6–95 (34)
		weighted average		1–125	6–95 (34)
New Brunswick	Atlantic Maritime	non-productive	55	0.5–125	5–40 (26)
		alder	45		8–50 (29)
		weighted average			27
Prince Edward Island	Atlantic Maritime	alder	100		22
Quebec	Arctic Cordillera	spruce woodland	100	0.5–70	1–30 (11)
	Southern Arctic	spruce woodland	100	0.5–70	1–30 (11)
	Taiga Shield	spruce woodland	100	0.5–70	2–50 (21)
	Boreal Shield	alder	5		8–50 (29)
		dry barren land	47	0–25	0–12 (2)
		wet barren land	48	0–18	0–9 (2)
		weighted average			4
	Atlantic Maritime	alder	41		8–50 (29)
		dry barren land	30	0–25	0–12 (2)
		wet barren land	29	0–18	0–9 (2)
		weighted average			13
	Mixedwood Plains	alder	12		8–50 (29)
		dry barren land	2	0–25	0–12 (2)
		wet barren land	85	0–18	0–9 (2)
		weighted average			5

(continued)

[a] The coverage of each cover type was estimated from the provincial inventories and the literature. The biomass range estimates for individual stands represent a best guess at what may be encountered within that cover type, including a range in sites and ages. The biomass range estimates for average stands represent a best guess at the biomass corresponding to a “typical” stand within that cover type. See the text for further explanation of the methods.

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
	Hudson Plains	spruce muskeg	98	0–25	1–9 (4)
		brush and alder	2	0–18	8–50 (29)
		weighted average			4
Ontario	Boreal Shield	open muskeg	28	0–10	1.2–3 (1.5)
		treed muskeg	52	0.5–30	2–9 (5)
		rock	10	0–35	0.2–10 (4)
		protection forest	2	1–115	6–29 (15)
		brush and alder	8		8–50 (29)
		weighted average			6
	Mixewood Plains	open muskeg	3	0–10	1.2–3 (1.5)
		treed muskeg	29	0.5–30	2–9 (5)
		rock	6	0–35	0.2–10 (4)
		protection forest	2	1–115	6–29 (15)
		brush and alder	60		8–50 (29)
		weighted average			19
	Hudson Plains	open muskeg	26	0–10	1.2–3 (1.5)
		treed muskeg	71	0.5–30	2–9 (5)
		rock			
		protection forest			
		brush and alder	2		8–50 (29)
		weighted average			5
Manitoba	Taiga Shield	treed muskeg	90	1–75	12–54 (33)
		treed rock	8	1–65	10–38 (27)
		willow/alder/shrubs	2		3–70 (37)
		protection forests			
		weighted average			33
	Boreal Shield	treed muskeg	86	1–75	3–44 (18)
		treed rock	10	1–65	3–35 (23)
		willow/alder/shrubs	3		3–72 (37)
		protection forests	< 1	1–170	1–170 (115)
		weighted average			19
	Boreal Plains	treed muskeg	79	1–75	3–44 (19)
		treed rock	< 1	1–65	3–35 (23)
		willow/alder/shrubs	20		3–72 (35)
		protection forests	< 1	1–170	1–170 (115)
		weighted average		23	

(continued)

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
	Prairies	treed muskeg	3%	1–75	3–44 (22)
		treed rock	< 1%	1–65	3–35 (20)
		willow/alder/ shrubs	85% (mostly willows 2/3, shrubs–1/3)		3–72 (32)
		protection forests	13% (mostly shelter belts)	1–170	1–170 (115)
		weighted average			43
	Hudson Plains	treed muskeg	98	1–75	3–25 (17)
		treed rock			
		willow/alder/shrubs	2		3–70 (37)
		protection forests			
		weighted average			17
Saskatchewan	Taiga Shield	treed muskeg			
		treed rock	100	1–75	10–38 (27)
		weighted average			27
	Boreal Shield	treed muskeg	35	1–75	3–26 (17)
		treed rock	65	1–75	6–55 (28)
		weighted average			24
	Boreal Plains	treed muskeg	90	1–75	3–26 (17)
		treed rock	10	1–75	5–35 (23)
		weighted average			18
	Prairies	treed muskeg	100	1–75	1–42 (19)
		treed rock			
		weighted average			19
Alberta	Taiga Plains	treed muskeg	23	0.5–20	3–10 (7)
		coniferous scrub	65	0.5–60	2–35 (20)
		deciduous scrub	12	1–125	1–42 (19)
		weighted average			18
	Taiga Shield	treed muskeg			
		coniferous scrub	50	0.5–60	10–38 (27)
		deciduous scrub	50	1–125	1–42 (19)
		weighted average			23

(continued)

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
	Boreal Shield	treed muskeg	27	0.5–20	3–10 (7)
		coniferous scrub	65	0.5–60	9–60 (22)
		deciduous scrub	8	1–125	1–42 (19)
		weighted average			18
	Boreal Plains	treed muskeg	15	0.5–20	3–10 (7)
		coniferous scrub	19	0.5–60	3–35 (23)
		deciduous scrub	65	1–125	1–42 (19)
		weighted average			18
	Prairies	treed muskeg			
		coniferous scrub			
		deciduous scrub	» 100	1–125	1–42 (19)
		weighted average			19
	Montane Cordillera	treed muskeg			
		coniferous scrub	» 100		0.4–5 (3)
		deciduous scrub			
		weighted average			3
Northwest Territories	Southern Arctic	black spruce woodland	100	1.5–130	1–30 (11)
	Taiga Plain	black spruce	85	1.5–130	5–60 (27)
		white spruce	10	2–99	6–62 (25)
		balsam poplar	5	0–75	0–5 (1)
		weighted average			26
	Taiga Shield	black spruce	90	1.5–130	10–38 (27)
		white spruce	10	2–99	2–10 (5)
		weighted average			25
	Boreal Plains	coniferous	35	1–130	3–35 (27)
		deciduous	65	1–102	1–42 (19)
		weighted average			18
	Taiga Cordillera	white spruce	35	2–99	26–38 (32)
		black spruce	35	1.5–130	9–26 (18)
		open black and white spruce	10	1.8–115	2–40 (12)
		open black spruce woodland	0 1	0.5–39	1–18 (9)
		balsam poplar	10	2–77	2–27 (19)
		weighted average			22

(continued)

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
	Boreal Cordillera	white spruce	20	2–99	2–35 (19)
		black spruce	20	1.5–130	9–34 (23)
		white spruce and black spruce	20	1.8–115	10–32 (21)
		lodgepole pine	10	2–100	2–35 (19)
		aspen	10	1.2–102	15–42 (27)
		Lodgepole pine and aspen	10	1.2–101	2–35 (19)
		alpine (alpine fir, black spruce, white spruce, lodgepole pine)	10		1.5–32 (13)
		weighted average			19
Yukon	Pacific Maritime	white spruce	20	2–99	2–35 (19)
		aspen	20	1.2–102	2–36 (19)
		balsam poplar	20	2–77	2–27 (15)
		lodgepole pine	20	2–100	2–35 (19)
		mountain hemlock and alpine fir	20	1–84	2–34 (18)
		weighted average			18
	Boreal Cordillera	white spruce	20	2–99	2–35 (19)
		black spruce	20	1.5–130	9–34 (23)
		white spruce and black spruce	20	1.8–115	10–32 (21)
		lodgepole pine	10	2–100	2–35 (19)
		aspen	10	1.2–102	15–35 (17)
		lodgepole pine and aspen	10	1.2–101	2–35 (19)
		alpine (alpine fir, black spruce, white spruce, lodgepole pine)	10		1.5–32 (13)
		weighted average			19
	Taiga Cordillera	white spruce	35	2–99	26–38 (32)
		black spruce	35	1.5–130	9–26 (18)
		white spruce and black spruce	10	1.8–115	2–40 (12)

(continued)

Province/ Territory	Ecozone	Cover type	Estimated coverage (%)	Individual stand estimated range (t/ha)	Average stand: estimated range (t/ha) (average)
		black spruce woodland	10	0.5–39	1–18 (9)
		balsam poplar	10	2–77	
		weighted average			22
	Taiga Plains	black spruce	70	2–130	2–46 (22)
		white spruce and balsam poplar	15	2–90	2–34 (17)
		balsam poplar	15	2–77	2–11 (7)
		weighted average			19
British Columbia	Taiga Plains	swamp forest (black spruce)	100	1–150	18–135 (90)
	Boreal Plains	swamp forest (black spruce)	100	1–150	18–135 (90)
	Boreal Cordillera	alpine forest:	25	1–200	15–114 (75)
		subalpine fir			
		Engelmann spruce	25	1–230	26–198 (132)
		white spruce	25	1–210	22–168 (112)
		mountain hemlock	25	1–255	15–110 (73)
		weighted average			98
	Montane Cordillera	alpine forest: subalpine fir	25	1–200	15–114 (75)
		Engelmann spruce	25	1–230	26–198 (132)
		white spruce	25	1–210	22–168 (112)
		mountain hemlock	25	1–270	15–110 (73)
		weighted average			98
	Pacific Maritime	lowland forest: yellow-cedar	40	1–270	16–122 (81)
		western redcedar	20	1–290	20–147 (98)
		shore pine	40	1–210	10–76 (51)
		weighted average			72