The carbon fraction in biomass and organic matter in boreal open woodlands of Eastern Canada

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Abstract: In Canada, boreal open woodlands (OWs) show interesting afforestation potential, but no detailed studies are available regarding the carbon fraction (CF) in dry matter – tonne of C per tonne of dry mass – of biomass and litter reservoirs. This study aims at providing the very first specific CF values of C reservoirs and compartments in OWs, with the main hypothesis that given the particular stand characteristics of OWs, more precise CF values than IPCC's default values will significantly change the calculation of C stocks in OWs. Results indicate that even though the CF values measured in this study were significantly different among the different C reservoirs and compartments in OWs, they match the IPCC default CF values for biomass (0.50) and humus (0.37) reservoirs. Therefore, the main hypothesis of this study – that more precise CF values than IPCC's default values will significantly change the calculation of C stocks in OWs – was not supported by the results obtained. Consequently, the IPCC default values of CF in the biomass and litter (humus) reservoirs can be used when estimating the C stocks in boreal OWs, for example, when using OWs as the baseline scenario in afforestation projects.

Résumé: Les terrains dénudés secs (DS) boréaux du Canada montrent un potentiel de boisement intéressant, sauf qu'aucune étude détaillée n'est disponible à propos de la fraction carbonique (FC) de la matière sèche – tonne de C par tonne de masse sèche – dans les réservoirs biomasse et litière. La présente étude vise à fournir les toutes premières valeurs spécifiques de FC des réservoirs et compartiments de C des DS, avec l'hypothèse principale qu'étant donné les caractéristiques particulières de peuplement propres aux DS, des valeurs de FC plus précises que celles par défaut fournies par le GIEC changeront significativement le calcul des stocks de C dans les DS. Les résultats obtenus indiquent que bien que les valeurs trouvées de FC étaient significativement différentes entre les réservoirs et compartiments des DS, elles étaient similaires aux valeurs par défaut du GIEC, tant pour les réservoirs biomasse (0.50) que litière (0.37). Ainsi, l'hypothèse principale de l'étude – des valeurs de FC plus précises que celles par défaut fournies par le GIEC changeront significativement le calcul des stocks de C dans les DS – n'est pas soutenue par les résultats obtenus. Par conséquent, les valeurs de FC par défaut du GIEC pour les réservoirs biomasse et litière (humus) peuvent être utilisées pour les estimations de stocks de C des DS boréaux, par exemple, lorsque les DS font office de scénario de référence dans des projets de boisement.

Keywords: Open Woodland; Carbon fraction; Afforestation; Black spruce; Carbon stocks; Carbon reservoirs; Greenhouse gas; IPCC default values.
Mots clés: Dénudé sec; Fraction carbonique; Boisement; Épinette noire; Stocks de carbone; Réservoirs de carbone; Gaz à effet de serre; Valeurs par défaut du GIEC.

1. Introduction

When calculating carbon (C) stocks in forest reservoirs, the measured or estimated dry mass in four out of five forest C reservoirs – aboveground biomass, belowground biomass, litter (including humus), and deadwood – need to be multiplied by a carbon fraction (CF) value to obtain the equivalent C content in each reservoir. The authoritative guidance from the Intergovernmental Panel on Climate Change (IPCC) regarding C stock calculations recommends two default values of CF in dry matter – tonne of C per tonne of dry mass – that can apply to these four reservoirs: 0.5 in the biomass (aboveground and belowground) as well as the deadwood reservoirs, and 0.37 in the litter reservoir (Penman and others, 2003). These values can be used in most situations, except if one can show that other CF values should be used in specific C reservoirs or forest types. For example, more precise CF values than the IPCC default values were found in the biomass of different tree species in some studies, with CF varying from 0.44 to 0.59 (Laiho and Laine, 1997; Lamlom and Savidge, 2003; Zhang and Wang, 2010). The use of inaccurate CF values may lead to under or overestimations in C stocks, especially when extrapolating C stocks at the landscape or even the stand level.

The contribution of the forest sector to climate change mitigation strategies can be significant (Nabuurs and others, 2007; Smith and others, 2014; United Nations Environment Programme. UNEP, 2017). As for any other sector's specific contribution, national greenhouse gas (GHG) inventories or project activities in the Land Use, Land-Use Change and Forestry (LULUCF) sector need quantitative estimations in which uncertainties are reduced as much as possible (ISO 14064-2:2006; Penman and others, 2003). In Canada, the afforestation of boreal open woodlands (OWs) has recently been suggested as a potential GHG mitigation strategy. However, few detailed studies are yet available, especially regarding C content of biomass and litter reservoirs (Boucher and others, 2012; Dufour and others, 2016; Gaboury and others, 2009; Tremblay and others, 2013). The distinctive stand characteristics of OWs – particularly the combination of a low tree density, a dense ericaceous shrub layer, a dense cover of ground-dwelling lichens, and a relatively thin humus layer (Gonzalez and others, 2013; Hébert and others, 2014; Ouimet and others, 2018) – includes C reservoirs for which no reliable data presently exist regarding the different reservoir-specific CFs, and hence their cumulative impact on C stock calculations at the stand level.

This study aimed at providing the very first specific CF values of C reservoirs and compartments (sub-reservoirs) in OWs, with the main hypothesis that given the particular stand characteristics of OWs (Dufour and others, 2016; Gonzalez and others, 2013; Hébert and others, 2006; Hébert and others, 2014; ISO 14064-2:2006; Payette, 1992; Saucier and others, 2009; Tremblay and others, 2013; Woodall and others, 2008), more precise CF values than IPCC's default values will significantly change the calculation of C stocks in OWs.

2. Material and methods

2.1 Study sites and sampling

Four sites (experimental blocks) within the spruce-moss and balsam fir-paper birch bioclimatic domains (Saucier and others, 2009) of Québec's continuous boreal forest were selected (Fig. 1) among a network of experimental plantations in OWs (Hébert and others, 2014). The mean annual temperature ranges between -2.5 and 0°C in this area, and mean annual precipitation is 1000-1200 mm, with 300 mm falling as snow. Soil types in these stands were moderately deep (50-100 cm) to deep (> 100 cm) coarse glacial till deposits, overtopped by a mor humus with humo-ferric podzolic profiles. Stands were mainly composed of black spruce (*Picea mariana* (Mill.) B.S.P.), with jack pine (*Pinus banksiana* Lamb.) as companion species. Mature tree densities ranged between 112 and 363 stems ha^{-1}, corresponding to 1.11 to 2.52 m^2 ha^{-1} of basal area (Madec and others, 2012). For more details on site characteristics, see Hébert and others (2014).

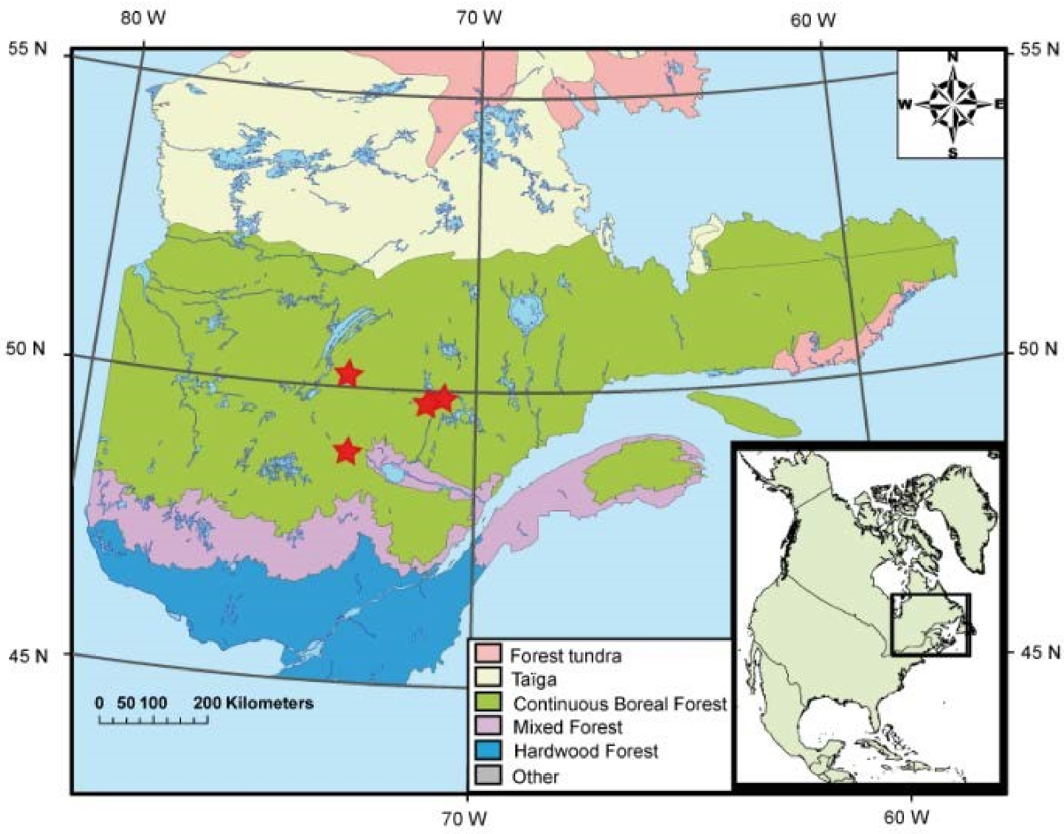

Figure 1. Location of the four study sites (red stars) in Québec, Canada.

On each site, a 400 m^2 plot was established in a representative area of each stand. Species, diameter at breast height (dbh) and total height were noted for every tree over 1.3 m high. After the measurement of all trees within plots, trees over 1.3 m were subdivided in 4 classes: dominant, co-dominant, intermediate and suppressed. Two individuals in each class were then randomly selected, and their diameter measured at 0 m, 0.3 m, 0.6 m, 1 m, 1.3 m, 2 m and every meter to the apex. Cross section discs, 25 mm thick, were sampled at the same height the diameter was measured on trees. The number of branches was counted between diameter measurements, and two randomly selected branches were measured (length) and sampled, to be later analysed in the lab. One of the two randomly selected trees of each class was carefully uprooted, to a minimal 5 mm root diameter. Harvested root systems were then brought back to the laboratory to be stored in a freezer (-15 °C) until processing.

A 1 m^2 subplot was established in one of the four corners (randomly selected) of each plot, and all of the above and belowground biomass and litter (including humus) were collected, and then separated into the following compartments: ericaceous shrubs, ground vegetation (mosses and lichens), and litter. All root and organic soil material was collected until the mineral soil was reached. The depth of the humus layer was recorded in the 1 m^2 subplot, and also in two perpendicular transects of 10 sampling points per plot, to obtain the mean depth of the humus layer in each plot.

For the black spruce trees analysed, samples of stems, branches and foliage were collected from the dominant trees at a height of 5 m. Cross sections were collected on tree stem discs (3 mm wide), from the bark to the center of each disc. Samples of branches were 1 cm wide, and foliage was randomly selected on each branch. Cross section discs of roots between 0.3 m and 1 m from the trunk were also collected. Subsamples of ericaceous shrubs (stems, foliage and roots), ground vegetation (pooled mosses and lichens), and litter (with humus) were collected from the 1 m^2 subplots. See Fradette (2012) for more details on the sampling and measurement of vegetation and soil compartments.

Oven dried (65ºC until constant mass) material were finely milled and passed through a grading screen of 500 µm mesh sieves. Subsamples of 200 mg of material were then placed in 1.5 ml plastic tubes and sent to the lab (Direction de la Recherche Forestière, Québec, QC, Canada) for the determination of C concentrations. Samples were treated at 1350ºC for 180 seconds in the presence of high purity oxygen and C concentration analyses were performed using a LECO RC-412 carbon analyzer (LECO Corporation, St-Joseph, MI, USA).

2.2 Statistical analyses

Analysis of variance (ANOVA) was performed on a 4 complete block experimental design for the CF of the different vegetation strata: trees (both black spruce and jack pine), ericaceous shrubs, ground vegetation and humus. ANOVAs were also performed on CF in compartments of trees and ericaceous shrubs (stems, foliage, branches, roots). When the ANOVAs revealed a significant difference (α=0.05), a Student's T-test was performed to determine how dissimilar the different strata and compartments analysed were.

A last ANOVA was performed using a 7-blocks subset of the larger plantation network in Hébert et al. (2014), where the dry mass determined in all biomass and litter reservoirs was multiplied by the specific CF values measured to obtain the stand C stocks (tonne ha^{-1}), and compared to the C stocks obtained using the IPCC default values (Penman and others, 2003).

For each variable, homogeneity of the variance was verified by visual analysis of the residuals (Devore and Peck, 1994). When necessary, data were transformed in order to respect ANOVA assumptions (Zar, 1999) but original data are presented. ANOVAs were performed using the REML procedure of JMPin 7.0 software (SAS institute, Cary, NC).

3. Results and discussion

The average CF of trees (0.50) and ericaceous shrubs (0.50) were significantly different from that of ground vegetation (0.43) and humus (0.37) (Table 1, Fig 2a). CF values in trees significantly differed among compartments, independently from tree species (Table 2, Fig 2b). Branches and foliage presented the highest CF with values approximately 0.25 higher than that in stems and roots (Fig 2b). Overall, the average of our measured tree CF values (0.50) matches exactly the IPCC default values (Penman and others, 2003), and falls within the observed range by Lamlom and Savidge (2003) for 21 species of North American coniferous trees (0.472 to 0.552).

Table 1. Summary of ANOVA (degrees of freedom and *P*-values) on the carbon fraction (CF) of different vegetation strata (trees, ericaceous shrubs, ground vegetation, humus) in boreal open woodlands (OWs). Abbreviations: NDF = numerator degrees of freedom, DDF = denominator degrees of freedom.

Source of variation	**NDF**	**DDF**	***P*-value**
Block	3	6.828	0.4714
Vegetation strata	3	6.998	**0.0009**

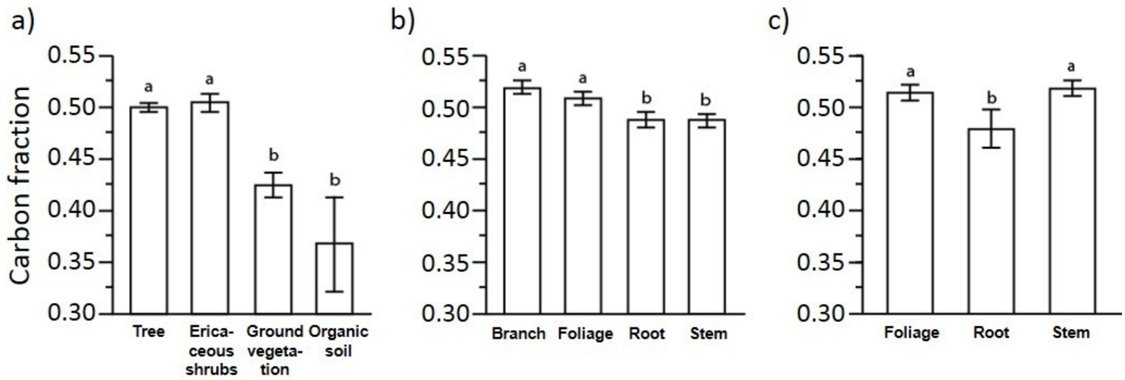

Figure 2. Effect of (a) vegetation strata, (b) tree biomass compartments, and (c) ericaceous shrubs biomass compartments, on carbon fraction (CF) values in boreal open woodlands (OWs). Different letters over bars indicate significant (P < 0.05) differences between means.

Table 2. Summary of ANOVA (degrees of freedom and *P*-values) on the carbon fraction (CF) of different tree species (black spruce and jack pine) and related biomass

compartments (foliage, branches, stem, roots) growing in open woodlands (OWs). Abbreviations: See Table 1.

Sources of Variation	**NDF**	**DDF**	***P*-value**
Blocks	3	1.125	0.7174
Tree species (Sp)	1	1.386	0.1304
Tree compartments	3	13.92	**0.0016**
Sp*Compartments	3	14.39	0.9737

The ericaceous shrubs showed significant differences in CF values between the different compartments (Table 3), with stems and foliage CF values approx. 0.40 higher than that in roots (Fig. 2c). Globally, the ericaceous shrubs averaged CF values (0.50) that were identical to that from IPCC default values (Penman and others, 2003).

Table 3. Summary of ANOVA (degrees of freedom and *P*-values) on the carbon fraction (CF) of biomass compartments (foliage, branches & stems, roots) of ericaceous shrubs (*Kalmia angustifolia* L. and *Rhododendron groenlandicum* (Oeder) Kron & Judd) growing in boreal open woodlands (OWs). Abbreviations: See Table 1.

Sources of variation	**NDF**	**DDF**	***P*-value**
Blocks	3	5.892	0.3221
Shrub compartments	2	5.895	**0.0173**

The comparison between C stocks (t ha^{-1}) in 7 OWs calculated using specific CF values in this study (Fig. 2), with C stocks calculated using IPCC default values revealed no significant difference ($P>0.05$), with almost identical C stocks averaging 18.4 t ha^{-1}. Both approaches also yielded identical proportions in C stocks between the four (4) C reservoirs estimated, with approx. two-third of stocks in trees and one-quarter in the humus layer (Fig. 3). These results indicate that despite significantly different values of CF between reservoirs and compartments obtained in this study, the two IPCC default values of CF for biomass (0.50) and dead organic matter (0.37) reservoirs appear to averaging out adequately the pool of more refined CFs in OWs, and hence the C stocks at the stand level.

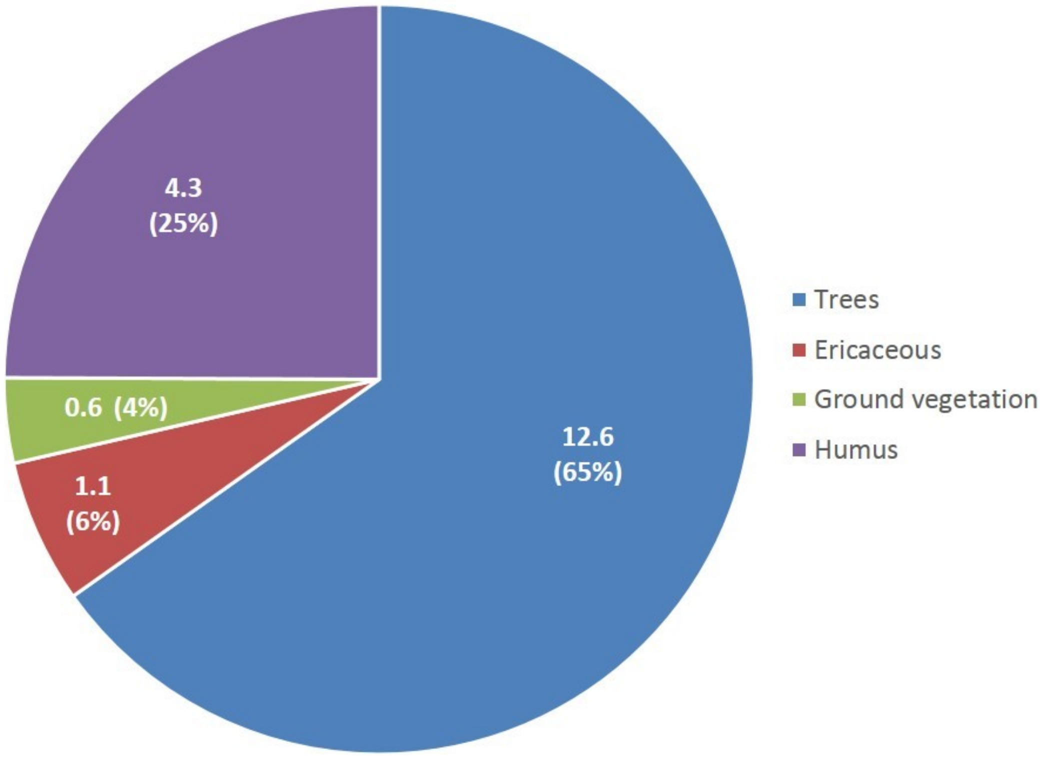

Figure 3. Estimated C stocks (t ha^{-1}) and proportions (in parentheses) in four C reservoirs averaged from seven boreal open woodlands (OWs), in Québec (Canada).

4. Conclusion

Results obtained in this study are the very first providing precise and specific carbon fraction (CF) values for four (4) C reservoirs and different vegetation and humus compartments in boreal open woodlands (OWs), a relatively abundant stand type in the boreal forest of Canada, and elsewhere in the boreal zone (Boucher and others, 2012; Shvidenko and others, 1997). Even though the CF values measured in this study were significantly different among the different C reservoirs and compartments in OWs, they match the IPCC default CF values for biomass (0.50) and humus (0.37) reservoirs. Therefore, the main hypothesis of this study – that more precise CF values than IPCC's default values will significantly change the calculation of C stocks in OWs – was not supported by the results obtained. It is then concluded that the IPCC default values of CF in the biomass and litter (humus) reservoirs, 0.50 and 0.37 respectively, can be used when estimating the C stocks in boreal OWs, for example, when using OWs as the baseline scenario in afforestation projects (Boucher and others, 2012; Dufour and others, 2016; Shvidenko and others, 1997).

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Conflicts of Interest

The authors declare no conflict of interest

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