Quantification protocol for afforestation projects in open woodlands of the closed-crown boreal forest

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CHAIRE DE RECHERCHE ET D'INTERVENTION
UNIVERSITÉ DU QUÉBEC À CHICOUTIMI

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Foreword

The document is intended to provide guidelines for afforestation projects in the boreal forest, and is subject to constant revisions according to progress from research activities or new arising information, as part of a commitment to continuous improvement. This document is not a substitute for the provincial or national legislation. Please consult the greenhouse gas emission-related legislations for the purposes of interpreting and applying the law. In the event that there is a difference between this document and the legislation, the legislation prevails.

Any comments, questions, or suggestions regarding the content of this document may be directed to:

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About the Chaire en éco-conseil (Chair on eco-advising):

As part of the fundamental sciences department at the University of Québec in Chicoutimi, the Chair on eco-advising is a research body that aims to develop knowledge issued from the implementation of sustainable development projects. The Chair also assists organizations that are willing to develop projects within a sustainable development framework. The Chair is exclusively involved in projects that present innovative aspects thus generating new knowledge that can be taught to eco-advising students and that can be communicated to the scientific community. The Chair has developed a recognized expertise in climate change, carbon quantification and greenhouse gas projects quantification. The Chair is also a member of the CIRAIG, an interuniversity research center for the life cycle of products, processes and services based at the University of Montreal[1].

[1] http://www.groupes.polymtl.ca/ciraig/en/index_e.html

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Part I. Identification of the Protocol Developer

1.1 Title of the Quantification Protocol

Quantification protocol for afforestation projects in open woodlands of the closed-crown boreal forest.

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1.3 Purpose of this protocol

The rationale for initiating the development of this quantification protocol is twofold. First, the protocol aims at providing any project proponent interested in the afforestation of boreal open woodlands (for example the Carbone boréal offset project) with a thorough and specific quantification protocol that has undertaken each step and process leading to the generation of serialized carbon offset credits under CSA's GHG CleanProjects™ Registry. Secondly, the present protocol intends to comply with the highest quality standards of carbon credits in the carbon market in order to offer to regulatory organisms – in particular the Western Climate initiative (WCI) – the best guidance and guidelines available in the forestry sector for the afforestation of boreal open woodlands.

1.4 Suggested citation

The correct citation for this document is:

Chair on eco-advising, 2012. Quantification protocol for afforestation projects in open woodlands of the closed-crown boreal forest. Université du Québec à Chicoutimi, Québec, Canada. This document is also available at http://carboneboreal.uqac.ca/protocole

Part II. Quantification Protocol Applicability and Development Approach

2.1 Applicability

a) Description of the project area

Most of the scientific literature on the natural history of boreal open woodlands (hereafter OWs) is based on studies carried out in Canada's Eastern boreal zone, particularly in the province of Québec. In this province, the spruce-feathermoss (SFM) domain (between the 49th and the 52nd parallels) covers 28% of the forested lands, and black spruce (*Picea mariana* (Mill.) B.S.P.) is the dominant tree species, representing more than 75% of the forest cover in the SFM domain (Bergeron, 1996; Gagnon and Morin, 2001). While black spruce is generally well adapted to regenerate after wildfire (Heinselman, 1981; Viereck and Johnston, 1990), poor regeneration can sometimes occur, resulting in the irreversible conversion of closed-crown BSFM stands to open black spruce woodlands (hereafter shortened to open woodlands or OWs) (Payette, 1992; Gagnon and Morin, 2001; Jasinski and Payette, 2005). To this day, there is no evidence of natural redensification of OWs, i.e. a shift from an OW to a closed-crown BSFM stand (Payette, 1992; Jasinski and Payette, 2005). Moreover, a recent study showed a gradual increase in OW generation over the past 50 years (Girard et al., 2008). The most recent Québec forest inventory (photo-interpretation) reveals that approximately 7% (1.6 M ha) of the SFM domain is made up of OWs (MRNF, 3rd decennial forest inventory), of which nearly 10% are less than 5 km from the existing road network in 2002 (Plante, 2003). Moreover, satellite imagery of Canada's forest provides indications on the potential availability in boreal OWs throughout Canada (Canada's National Forest Inventory, 2006): the total area of sparse forests (tree crown cover between 10 and 25%) within the three Canadian boreal ecozones (boreal shield, boreal plains, boreal cordillera) is estimated at 23.2 M ha (7.4% of the total area). While the realistic OW availability to afforestation (ecologically and economically) still needs to be addressed, these estimates show some significant OWs availability in Canada's boreal forest region (Fig. 1).

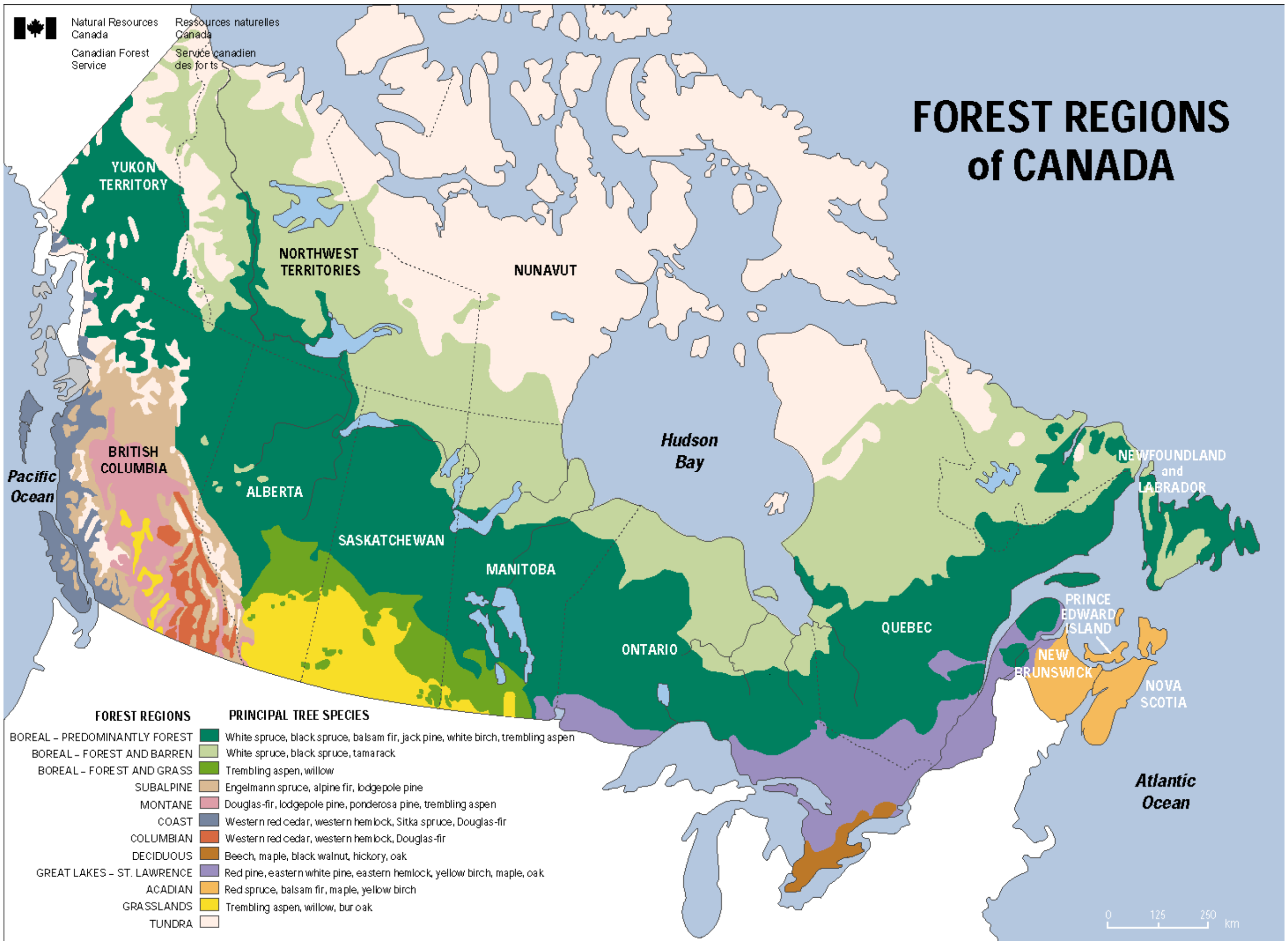

Figure 1. Map of forest regions of Canada, with the closed-crown boreal forest in dark green. Source: Natural Resources Canada.

Afforestation of OWs has been first tested only recently, with an experimental plantation network within Québec's central boreal zone, where site-prepared OWs were compared to adjacent and managed BSFM stands (Girard, 2004; Hébert et al., 2006; Tremblay, 2009; Tremblay, 2010). The initial results show appreciable seedling survival and growth, within the 3-year post-plantation establishment window (Hébert et al., 2006; Tremblay, 2010). A recent study using the CO2FIX v.3.1 model to calculate the biological C balance between the baseline (natural OW) and afforestation (black spruce plantation) revealed a potential C sequestration of 77.0 t C ha^{-1}, for an average net sequestration rate of 1.1 t C ha^{-1} $year^{-1}$ (or 4.0 t CO_2e ha^{-1} $year^{-1}$), 70 years following the afforestation of a typical OW (Gaboury et al., 2009). Using the life cycle analysis (LCA) method to evaluate all the GHG emissions related to the OW afforestation, the study indicated that, in the context of boreal A/R in the province of Québec, all afforestation-related operations (near 40 different processes, from seed production and road construction to tree planting and plantation monitoring) represent less than 0.5% of the biological C balance after 70 years. However, this last study did not account for possible emissions from uncommon silvicultural treatments in northern Québec's forestry, like slash burning, fertilizer application, and land drainage (IPCC 2003).

b) Description of the project type and eligibility

The project type covered by this quantification protocol (QP) is afforestation/reforestation (A/R). Such projects consist of tree planting[2] on land that has not been forested since December 31, 1989. To comply with the Kyoto Protocol and national and provincial inventory reports on greenhouse gas sources and sinks, evidence is needed to demonstrate that:

- ❖ the acceptable project type area is within the boreal forest region (see fig. 1) and is considered an open woodland (hereafter OW), i.e. has not met the definition of forest[3] since at least December 31, 1989, and currently does not meet the definition of a forest;
- ❖ the acceptable project type area is greater than or equal to 1 hectare in size, with a minimum width of 20 metres, measured tree-base to tree-base (stump to stump);
- ❖ the trees established under the acceptable project type are capable of achieving a minimum height of 5 metres and a crown cover higher than 25% at maturity.

This quantification protocol only pertains to afforestation of OWs:

- ❖ in the Canadian boreal forest, so that A/R project in other regions are not covered by this protocol (see Fig. 1);
- ❖ on mesic to xeric sites, i.e. well-drained site conditions in terms of water regime, which excludes wet sites like ferns, bogs, etc., that often require land drainage and cause NH_4 emissions;
- ❖ that excludes – at the beginning of and during the project – silvicultural treatments deemed inappropriate or unnecessary for this project type in the boreal forest region, namely: tree harvesting operations (prior to A/R), slash burning, and land drainage.

[2] Throughout this QP, afforestation includes both tree planting and human induced natural seeding, but only tree planting will be mentioned in the text.
[3] A "forest" is a land area of 1 ha or more where tree formations of more than 5 m in height are higher than 25% of crown cover at maturity, in accordance with the Canadian definition of "forest" (Environment Canada 2006).

c) Additionality, leakage and reversibility

The additionality of the project can be secured by two means. The compliance with the eligibility criteria (in section 2.1b) – where an OW would remain a non-forest indefinitely by definition, without the human intervention – is a basic principle behind the additionality requirement. Second, the project proponent must be able to demonstrate that the only way the OWs of a project could have been afforested/reforested by a human intervention is through the implementation of the project. In other words, no program or incentive from the provincial, federal, or any other jurisdiction, would have resulted in the afforestation/reforestation of the same OWs without the project.

In jurisdictions where boreal OWs are unmanaged lands by definition – hence are not accounted in the annual allowable cuts like in the province of Québec (MRNF 2003) – and are inappropriate as croplands or for grazing activities, no displaced emissions (leakage) need to be accounted for by an afforestation project. In jurisdictions where no particular land tenure or status protects the OWs from harvesting or other land use, or where boreal OWs can be used as croplands or for grazing activities, the project proponent then needs to determine a "leakage" risk percentage for the project. In that case, it is recommended to use the leakage risk assessment and calculations detailed in the Climate Action Reserve's Forest Project Protocol v3.2 (2010) (section 6.1.5 therein).

Eventual natural disturbance events (such as wildfire, insects, diseases, and windthrow) in the plantations may cause emissions and potential reversal of credited removals. The intrinsic risk of reversal by natural means in forest projects is threatening the "permanence" of a project, i.e. that the C associated with credited GHG removals remains stored for at least 100 years[4]. Each project proponent has to explain how the risk of reversal is dealt with in his project, but it is suggested to address the risk of reversal by at least these two means:

- ❖ By providing each project with a buffer pool, i.e. extra (uncredited) planted trees that allow for the eventual replacement of reversed credited removals by any natural means. The size of the

[4] In the present QP, the project duration is of "at least" 100 years, but the reader should note that some program can ask for longer project duration, for example the WCI (CAR 2010).

buffer pool is project-specific, so that each project proponent should determine his project risk rating to get the number of planted trees to allocate to the project' buffer pool. It is recommended to use a recognized methodology to determine the risk rating of a specific project, such as the one included in the CAR (2010) Forest Project Protocol (see the Section 7.2.2 therein). Otherwise, a conservative approach would be to always dedicate half of the planted trees to the project' buffer pool, ideally by keeping the buffer plantations as far as possible from the project plantations.

- By planning the different plantations within a project as widely distributed as possible, so that the risk of a large reversal caused by one or a few large events (eg. wildfires) is minimized. Thus, a project proponent is advised to plan several smaller but isolated plantations within a project, instead of a few larger plantations of equivalent total area. This "passive" measures to reduce the reversal risk of a project is particularly relevant in the boreal forest zone, where large wildfires or insect outbreaks are relatively frequent, and land access is often difficult. If the extra planted trees are disseminated remotely from the network of offset plantations, this will all together increase the effectiveness of the buffer pool.

Finally, the project proponent is requested to secure the plantation network from any eventual man-make reversal (for example harvesting or construction of infrastructure) by any means that protect on the long term the project plantations. For example, the Carbone boréal project (carboneboreal.uqac.ca) has obtained from the MRNF the "experimental forest" status for its offset plantations, so that no other activity than C sink and measurements can be done on the long term.

d) List of GHG(s) that will be reduced (sequestered)

This protocol pertains to net removals of carbon dioxide (CO_2) from the atmosphere via natural biosequestration. The other Kyoto gases – hydrofluorocarbons (HFCs), methane (CH_4), perfluorocarbons (PFCs), nitrous oxide (N_2O), and sulphur hexafluoride (SF_6) – will not be reduced nor impacted through the implementation of low tending projects on mesic to xeric sites, where land drainage, slash burning, or fertilizer application are normally not required (Schiller and Hastie 1996, Savage et al. 1997, Basiliko et al. 2009, Doucet et al. 2009, Matson et al. 2009, Ullah et al. 2008 and

2009, Frasier et al. 2010). However, N_2O emissions need to be accounted for in jurisdictions or in specific projects where soil fertilisation may be used.

e) Description of how real reductions will be achieved

Afforestation of OWs results in additional biosequestation of atmospheric CO_2, compared to the baseline scenario (i.e. intact OW). Due to the mechanism of photosynthesis, CO_2 will be sequestered from the atmosphere and the growing dense forest will act as a net carbon sink through the five carbon reservoirs therein – live aboveground biomass, live belowground biomass, litter and humus, mineral soil, and dead wood (IPCC 2003). Since GHG reductions will be achieved through long term sequestration, the project proponent needs to secure the plantation permanence by the different ways mentioned in the part III of this QP. Both scenarios (baseline and project) are briefly described hereafter.

Baseline scenario

Prior to project implementation, the project area is a boreal open woodland (OW). OWs, typically covered by a lichen mat and/or ericaceous shrubs in the Eastern boreal forest of Canada (Thiffault et al. 2005, Hébert et al. 2006), have been described as an “alternative stable-state”, as stand shifting naturally from OWs to closed-crown stands has not been yet reported (Payette 1992, Jasinsky and Payette 2005). At any point in time after the initial formation of an OW in the boreal forest – that is, whether the OW was formed several hundred years ago or following a recent fire – there is no evidence of OW inherent capability to naturally re-establish a dense forested stand (Payette 1992, Riverin and Gagnon 1996, Payette et al. 2000, Jasinsky and Payette 2005, Girard et al. 2008). In other words, the baseline scenario applies to any boreal OW respectful of the non-forest definition described previously (see section 2.1 b).

Afforestation of naturally OWs will increase carbon stocks over time. Initial carbon stocks in OWs may vary, but in all cases the increase in stocks over time is expected to be much lower than that in the project scenario, particularly in both the above and belowground C stocks (Gaboury et al. 2009). Below, an example of the estimated growth of an intact black spruce-lichen type of OW that presents the highest possible tree crown cover (25% of projected crown), while respecting the definition of non-forest at the end of project (70 years in this example; see Fig. 2).

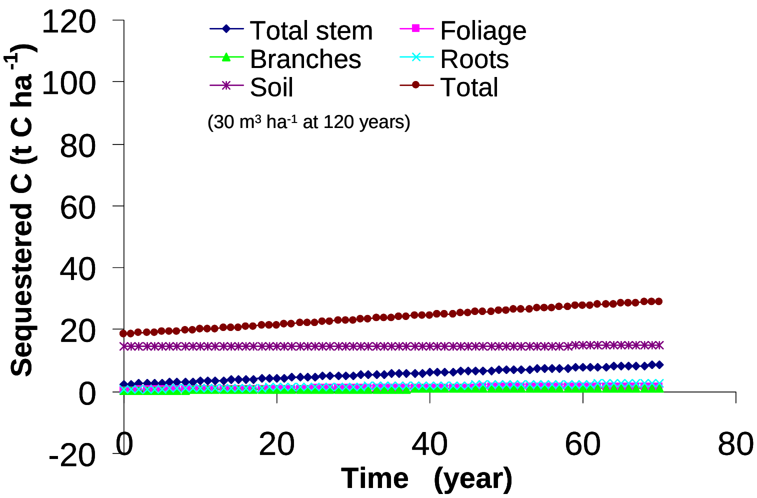

Figure 2. Example of simulated C growth in the different biomass compartments of an OW (which initial tree density corresponds to a 25% crown cover), described as the baseline scenario. Simulation is from the CO2FIX model (Gaboury et al., 2009).

The project proponent should describe the baseline scenario in details, including project area, state of land and any other relevant details.

Project scenario

The afforestation of OWs is expected to result in the increase in carbon stocks of the five reservoirs identified in the IPCC guidelines for LULUCF (IPCC 2003). This carbon accrual is caused directly (stems, roots, branches, foliage) and indirectly (soil, dead wood) by the growth of planted trees (and induced natural tree regeneration) on OWs (Gaboury et al. 2009). While the initial baseline carbon stocks may vary spatially, they are all expected to be lower than the carbon stocks in the project scenario at the end of the project (70 years for the example in Fig. 3).

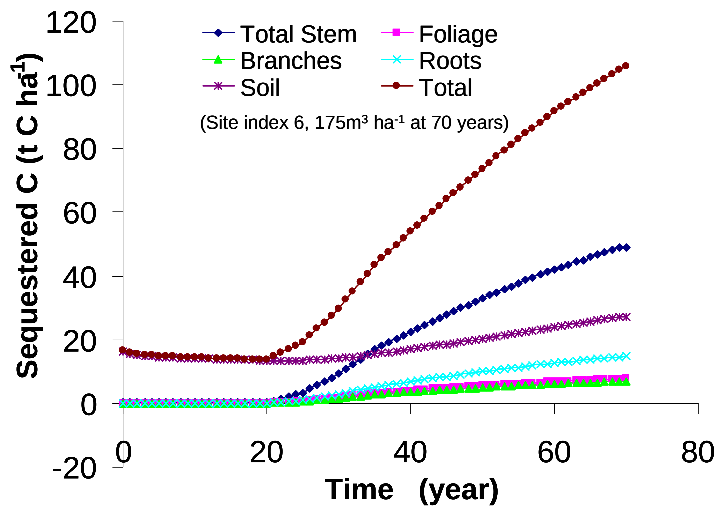

Figure 3. Example of simulated C growth in the different biomass compartments of an afforestation project over 70 years, with black spruce seedlings planted at 2000 trees/ha and a growth yield associated to the lowest plantation site index (MRNF, 2003). Simulation is from the CO2FIX model (Gaboury et al., 2009).

The net accounting of the afforestation project example below shows an initial 26 years of net emissions (fig. 4), mainly because the modelized afforestation scenario included the harvesting of the 30 m^3 ha^{-1} tree cover prior to tree planting (Gaboury et al. 2009). However, harvesting operations are not necessarily recommended nor required for a successful and plausible afforestation scheme in boreal OWs, since the mature trees of the baseline scenario are scattered, allowing for the site preparation and planting (or natural seeding) of up to 2 000 seedlings per ha in between the initially present overstory trees (Hébert et al. 2006; Tremblay 2009).

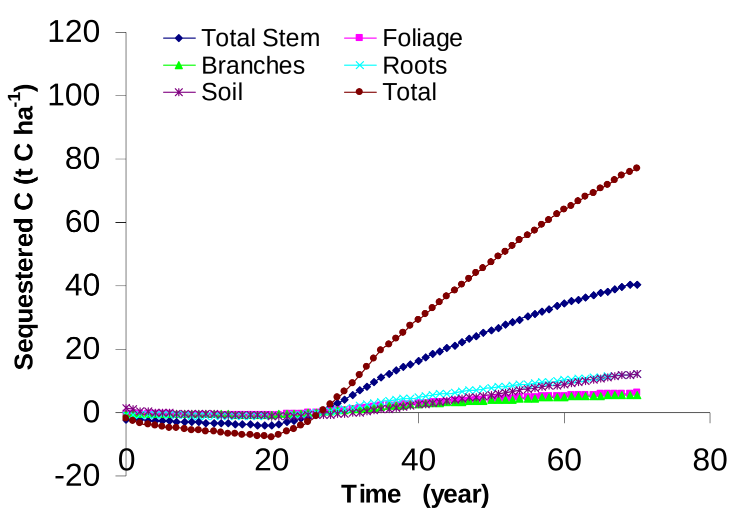

Figure 4. Example of net carbon balance of an afforestation project over 70 years with black spruce planted seedlings in an OW. Results are from the CO2FIX model (Gaboury et al. 2009).

The project proponent should describe the project scenario in details, including project area, planned activities within the project and any other relevant details.

2.2 Development Approach

The UQAC's Chair on eco-advising initiated the development of this QP in December 2008. Following an agreement with the Canadian Standard Association (CSA) to eventually register the Chair's Carbone boréal project in the CSA GHG CleanProjects™ Registry, the Chair and CSA agreed that a specific and credible quantification protocol, based on approved methodologies, needed to be developed to insure that OW afforestation projects in the boreal forest meet the highest standards and complies with the specifications and guidelines of the International Organization for Standardization 14064-2 (ISO 2006).

The general approach of the present QP is also based on ISO 14040 guidelines for life cycle assessment (ISO 1997), and on the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The Good practices guidance for land-use, land-use changes and forestry (IPCC, 2003), and the Winrock International' Methods for Measuring and Monitoring Forestry Carbon Projects in California (Brown et al. 2004) were used for the biological C calculation and methodology of both the project and baseline scenarios. The Chair, through the elaboration of this QP, considered other afforestation protocols, especially the Climate Action Reserve's Forest Project Protocol v3.2 (2010). The Chair also reviewed Tree Canada's Forest Carbon Project Protocol draft #2 (March 2009).

From September 2010 to June 2011, this QP went through a technical evaluation and validation process managed by CSA that included a thorough revision by an expert committee. The members of this committee were: Pierre Bernier (Canadian Forest Service), Myriam Blais (Québec's Ministère du Développement économique, de l'Innovation et de l'Exportation), Michel Campagna (Québec's Ministère des Ressources naturelles et de la Faune), Karen Clark (Natsource), Tim Moore (McGill University), Rock Ouimet (Québec's Ministère des Ressources naturelles et de la Faune), and Moustapha Ouyed (Golder Associates). The Chair on eco-advising wishes to thank all members of the expert committee, and Namat Elkouche from CSA, for their helpful comments and advices on earlier versions of this QP.

Part III. Identification of relevant sources, sinks and reservoirs (SSRs)

3.1 Presentation of Project SSRs

Based on ISO 14064-2 specifications and ISO 14040 guidelines for life cycle assessment, all relevant sources, sinks and reservoirs (SSRs) ought to be quantified with the most appropriate guidelines, methodologies, and emission factors available. Accordingly, the following documents were used to determine the SSRs related to the project activities in both the project and baseline scenarios: A LCA study that accounted for virtually all emissions associated to the afforestation of one hectare of OW in Québec's boreal forest (Gaboury et al. 2009), the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006), the Good practices guidance for land-use, land-use changes and forestry (IPCC, 2003), and the Winrock International' Methods for Measuring and Monitoring Forestry Carbon Projects in California (Brown et al. 2004).

For all projects, the five on-site C reservoirs of a forest ecosystem are considered under the direct responsibility of the project proponent in the present QP. Since C absorption in boreal forest plantations is considered relatively small compared to that in other biomes (FAO 2010), the measurement and estimation of C increment in all five known reservoirs in forest ecosystems – live aboveground biomass, live belowground biomass, litter and humus, mineral soil, and dead wood (IPCC 2003) – for both baseline and afforestation (project) scenarios is recommended. On the other hand, expected emissions from the project operations are deemed negligible in the present QP, when a project does not include soil fertilisation, land drainage, and slash burning. However, soil fertilisation has to be accounted for in projects where it is used (land drainage and slash burning are not eligible treatments in this QP, see section 2.1 b). Emissions from road construction and maintenance beyond that calculated in Gaboury et al. (2009), i.e. if roads are constructed specifically for the project, also need to be accounted for in the present QP.

3.2 Identification of Project SSRs

SSRs for all activities related to a project occurring offsite prior to implementation, upstream and downstream during project implementation, upstream and downstream prior and after project implementation were identified. These SSRs are listed in Table 1, which also specifies whether the SSRs are controlled, related or affected by the project proponent. Table 1).

Table 1. Identification of SSR controlled by, related to, or affected[5] by a boreal OW afforestation project (i.e. project scenario).

SSR	Description	Controlled, Related or Affected
Upstream SSRs		
P1. Seed production	Cone harvesting, transportation and processing, building and installation heating, seed storage, extraction and drying, etc.	Related
P2. Seeding production	Container production and transportation, peat moss extraction and transportation, herbicide production and transportation, fertilizer production and transportation, perlite and vermiculite extraction, processing and transportation, building and nursery heating, use and maintenance, etc.	Related
P3. Land access	Road construction and maintenance, employee housing and accommodation	Controlled
Onsite SSRs during operations		
P4. Harvesting operations	Logging, hauling and lopping, loading, roundwood and machinery transportation	Controlled
P5. Site preparations and silvicultural treatments	Machinery and operator transportation, soil scarification, fertilizer applications, drainage, slash burning, herbicide applications	Controlled
P6. Tree planting	Seedling and tree planter transportation	Controlled
P7. Aboveground C reservoir	Biomass in live trees, branches, foliage	Controlled
P8. Belowground C reservoir	Live root biomass	Controlled
P9. Litter and humus C reservoir	Biomass in litter and humus	Controlled
P10. Soil organic C reservoir	Organic C content of mineral soil	Controlled
P11. Dead wood C reservoir	Biomass in dead wood (both above and belowground)	Controlled
P12. Plantation monitoring	Transportation and housing	Controlled
Downstream SSRs		
P13. Afforestation/reforestation (A/R)	Market-related changes in A/R rates	Affected

[5] See Appendix 4 (Glossary) for a better understanding of the terms «Controlled, «Related» and «Affected».

3.3 Identification of Baseline SSRs

a) Baseline selection approach

Based on the WRI-WBCSD Land Use Land Change and Forestry (LULUCF) protocol, the GHG reductions associated with a LULUCF project are quantified according to a reference level of GHG removals. That reference level is calculated using baseline candidates, the alternative land uses or management practices (and their associated GHG removal levels) that could be implemented on the project activity site. Baseline candidates are identified by exploring potential land uses or management practices within a specified geographic area and over a defined temporal range. Once feasible alternatives have been identified, one of two different procedures may be used to derive baseline GHG removals from the baseline candidates.

Based on ISO 14064-2, the baseline scenario is a long-term projection of the forest management practices, activities, and conditions that would have occurred within the project's physical boundaries in the absence of the project. The project baseline is a counterfactual scenario that depicts the likely stream of emissions or removals expected to occur if the Project Proponent does not implement the project. Change in carbon stocks or emissions of GHGs over time relative to the baseline is the basis for GHG reductions and removals. The quantity of offsets that a project generates is the difference between actual emissions or removals and the baseline emissions or removals resulting from the project action.

The baseline condition here is considered to be a boreal OW, within the limits of allowable cuts territory, that presents a tree (of at least 5 m of height) crown cover of less than 25% on a minimum land area of 1 ha. In the absence of the afforestation project, the stand structure will remain open (less than 25% of tree cover) during the duration of the project (i.e. 100 years), while small changes in the level of the carbon reservoirs are expected (Gaboury et al. 2009). There are no plans, directives, regulations or programs that require the site to be afforested, and there is no management activity on these OWs (MRNF 2003). The five carbon pools identified in the IPCC guidelines for land use and land use change and forestry (LULUCF) are expected to change slowly enough to be accounted for over time, considering the relatively modest C stock growth over time in the afforestation scenario (Gaboury et al. 2009). For that reason, the most appropriate baseline approach used in the present QP is the comparison-based approach.

The validity of the baseline condition proposed above can be assessed either with the Kyoto protocol CDM guidelines (UNFCCC 2004) to which ISO 14064-2 refers, or with the GHG Protocol (WRI-WBCSD 2005). The GHG Protocol guidelines for project accounting indeed present, in the section 8.1 therein, a complete set of indications on how to perform a comparative assessment of conditions that would represent barriers discouraging a project promoter to implement project activities.

Under the comparison-based approach, the baseline scenario is dynamic since it is assumed that it may change its absorption profile over time. Since an OW associated to a specific project may present a stand structure, composition, stem density, size, age, etc., that differ from site to site, it is recommended to track every 10 years the stock changes during the project duration (100 years).

b) Identification of Baseline SSRs

Based on the baseline selection (see section 3.3a), no operation or activity are associated to a boreal OW (the baseline scenario), and all SSRs are onsite and directly under the control of the project proponent (Table 2).

Table 2. Identification of baseline SSRs controlled by, related to, or affected (baseline scenario).

SSR	Description	Controlled, Related or Affected
Onsite SSR during Baseline Operation		
B1. Aboveground C reservoir	Biomass in live trees, branches, foliage	Controlled
B2. Belowground C reservoir	Live root biomass	Controlled
B3. Litter and humus C reservoir	Biomass in litter and humus	Controlled
B4. Soil organic C reservoir	Organic C content of mineral soil	Controlled
B5. Dead wood C reservoir	Biomass in dead wood (both above and belowground)	Controlled

3.4 Selection of relevant Project and Baseline SSRs

All afforestation-related operations (from P1 to P6, P12 and P13) are deemed irrelevant SSRs in the context of silvicultural and monitoring operations in the boreal forest of Canada, since these emissions were only a fraction of 1% of the total C budget of a simulated afforestation project in a LCA approach study (Gaboury et al. 2009). However, exceptions can be found for the land access (P3) and silvicultural treatments (P5) SSRs, in circumstances that are not covered by this LCA study (Gaboury et al. 2009). As mentioned in section 2.1 (b and e), harvesting operations (P4) are not eligible because they are not required – nor advisable considering the resulting emissions (Gaboury et al. 2009) – for a successful site preparation and planting among the scattered overstory trees in OWs (Hébert et al. 2006; Tremblay 2009).

The land access (P3) SSR, may become relevant in the case where road construction and maintenance is required exclusively for a project. This circumstance was not addressed in Gaboury et al. (2009) LCA study, because the emissions from road construction and maintenance were allocated among all hectares of managed forest reached by each km of road, in the context of Québec's managed boreal forest. Since the gross (total) emissions for each km of constructed and maintained road can be obtained from this LCA study (S. Gaboury, person. comm.), a project proponent will be able to use a credible emission factor for this SSR (21 t CO_2eq km^{-1}) if a project requires specifically a road to reach and monitor an afforested OW. In this circumstance, the deforestation resulting from the road construction also needs to be accounted for in this SSR.

The P5 site preparations and silvicultural treatments, almost all analyzed in Gaboury et al. (2009), can be reduced to one type of relevant treatments, i.e. fertilizer applications. The other treatments, land drainage and slash burning, are excluded from the list of SSRs for the following reasons (which contribute to the rationale behind the exclusion of these treatments in the project eligibility in section 2.1 b). For land drainage, since this site preparation treatment is designed to reduce the water table height on humid sites, it will in virtually all circumstances reduce the methane emissions, since humid site conditions promote the incomplete oxidation of the organic matter and the consequent methane emissions (IPCC 2006). It can be hence considered conservative – and certainly convenient considering the difficulty associated to the measurement of the impact of land drainage on emissions – to exclude this treatment from the list of treatment under P5. The slash burning treatment can be also excluded from the P5 list of treatments, since this treatment is obviously unadvised under a C management scheme because it corresponds to massive emissions at the beginning of a project. The project proponent is then better advised to either leave on-site the slash material – so that it will be captured by the regular monitoring in the dead wood or litter reservoirs – or pile the slash beside the plantation, so that the "exportation" of that biomass will be at worst captured as loss of biomass in the project scenario compared to the baseline scenario. Finally, no significant emissions need to be accounted for herbicide applications, based on IPCC (2006) and UNFCCC (2011) guidelines.

Only onsite C reservoirs (B1 and P7 to B5 and P11) are comparable and functionally equivalent between both scenarios (Table 3). Since the afforestation of OWs leads to a significant increase in tree density (Gaboury et al. 2009), both above and belowground C reservoirs are the most important SSRs. Because even a modest C growth in an afforested OW could have a contribution in the overall C budget at the end of a project, all C reservoirs of both scenarios are considered relevant SSRs, with the exception of the dead wood C reservoir (B5 and P11). This latter reservoir is expected to contribute little to the overall C budget, since no harvesting operations are recommended prior to planting, and the 100 year long-time frame of an afforestation project in the boreal forest will generate low tree mortality. Consequently, this C reservoir is excluded from the quantification. This exclusion can be considered conservative with regards to the C balance of the project, since the quantity of dead wood will be minimally equal between both scenarios, or higher in the project scenario in most conditions (due to the higher number of growing, and dying, trees in the project compared to the baseline scenario). However, a project proponent should include this reservoir if a higher quantity of dead wood is noticed in the baseline than in the project scenario during the project monitoring. In that particular circumstance, it is recommended to use Brown et al. (2004) methodology to quantify both downed and standing dead wood (sections 5.1 and 5.2 therein).

Table 3. Comparison and relevance of Afforestation Project and Baseline Scenario SSRs. Abbreviations: C = controlled, R = related, A = affected, n/a = not applicable, Y = yes, N = no.

Identified SSR	Baseline (C,R,A)	Project (C,R,A)	Assessment of comparability	Relevance of SSRs (Y/N)
Upstream SSRs				
P1. Seed production	n/a	C	n/a	N
P2. Seeding production	n/a	C	n/a	N
P3. Land access	n/a	C	n/a	Y/N
Onsite SSRs during operation				
P4. Harvesting operations	n/a	C	n/a	N
P5. Site preparations and silvicultural treatments	n/a	C	n/a	Y/N
P6. Tree planting	n/a	C	n/a	N
B1. P7. Aboveground C reservoir	C	C	Functionally equivalent. Baseline and project scenarios will be compared with the same metrics, i.e. carbon sequestered per ha.	Y
B2. P8. Belowground C reservoir	C	C	Idem	Y
B3. P9. Litter and humus C reservoir	C	C	Idem	Y
B4. P10. Soil organic C reservoir	C	C	Idem	Y
B5. P11. Dead wood C reservoir	C	C	Idem	Y/N
P12. Plantation monitoring	n/a	C	n/a	N
Downstream SSRs				
P13. Afforestation/ reforestation (A/R)	n/a	A	n/a	N

Part IV. Quantification of GHG sequestration

The general approach of the present QP is based on ISO 14064-2 (GHG specifications and guidance; ISO 2006a) and ISO 14040 (guidelines for life cycle assessment; ISO 1997), and the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006). The Good practices guidance for land-use, land-use changes and forestry (IPCC, 2003), and the Winrock International' Methods for Measuring and Monitoring Forestry Carbon Projects in California (Brown et al. 2004) were used for the biological C calculation and methodology of both the project and baseline scenarios.

The quantification methodology is centered on the field quantification of relevant SSRs of both project and baseline scenarios. This detailed methodology is intended to provide the actual net GHG absorption/emission of a specific project, at a particular point in time. It aims at providing all necessary measurements from both baseline and project scenarios to accurately estimate C stocks with the best allometric equations from the relevant scientific literature.

4.1 Quantification of project and Baseline SSRs

a) Equation for each relevant SSR in the baseline scenario

B1. Baseline aboveground C reservoir

This reservoir is split into four different vegetation groups, namely: trees higher than 2.0 m, trees lower than 2.0 m, shrub vegetation, and non-vascular organisms (mosses and lichens). The equation for the aboveground C reservoir is:

[1] $TA_{B1} = (AGBM_{TR\geq 2.0} + AGBM_{TR<2.0} + AGBM_{BR} + BM_{NV}) * CD * CO2_{CONV}$

where:
- TA_{B1} is the total absorptions for the baseline aboveground reservoir (in tonne CO_2 per ha);
- $AGBM_{TR\geq 2.0}$ is the aboveground biomass of all trees with height ≥ 2.0 m (in Mg ha^{-1});
- $AGBM_{TR<2.0}$ is the aboveground biomass of all trees with height < 2.0 m (in Mg ha^{-1});
- $AGBM_{BR}$ is the aboveground biomass of all brush vegetation (in Mg ha^{-1});
- BM_{NV} is the biomass of all non-vascular organisms (mosses and lichens) (in Mg ha^{-1});

- CD is the carbon density of the biomass (0.5, see (IPCC 2003));
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);

A specific set of equations is associated to each of these four vegetation groups. First, for $AGBM_{TR\geq2.0}$ the equations from Lambert et al. (2005) are recommended, with all boreal forest tree species included therein (see Appendix 2). Since estimated biomasses from these equations are in kg and from a 400 m^2 sampling plot, cumulated biomasses need to be multiplied by 10^{-3} (from kg to Mg) and by 25 (from 400 m^2 to 1 ha) before using equation [1].

Then, the equations provided in Tremblay et al. (2006) are recommended for both $AGBM_{TR<2.0}$ and $AGBM_{BR}$ (see Appendix 3). Since estimated biomasses from these equations are in g and from 1 or 400 m^2 subplots and sampling plots, cumulated biomasses need to be multiplied by 10^{-6} (from g to Mg) and by 25 (from 400 m^2 to 1 ha) for $AGBM_{TR<2.0}$ or by 10^4 (from 1 m^2 to 1 ha) for $AGBM_{BR}$, before using equation [1].

Finally, BM_{NV} needs to be estimated by the project proponent, since no simple and reliable equations (eg. based on % cover visual evaluation) are available in the literature for this group of organisms. The methodology for the measurement of BM_{NV} is provided in section 4.1e. There again, the calculated biomasses in g need to be multiplied by 10^{-6} (from g to Mg) and by 10^4 (from 1 m^2 to 1 ha) before using equation [1].

B2. Baseline belowground C reservoir

This reservoir is split into two different vegetation groups, namely: tree and brush species. The equation for the belowground C reservoir is:

[2] $TA_{B2} = (BGBM_{TR} + BGBM_{BR}) * CD * CO2_{CONV}$

where:
- TA_{B2} is the total absorptions for the baseline belowground reservoir (in tonne CO_2 per ha);
- $BGBM_{TR}$ is the total belowground biomass of all trees (in Mg ha^{-1});
- $BGBM_{BR}$ is the total belowground biomass of all brush vegetation (in Mg ha^{-1});
- CD is the carbon density of the biomass (0.5);

- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);

Belowground biomass of trees ($BGBM_{TR}$) is estimated according to Li et al. (2003) calculations. The equations for the belowground biomass of trees are:

[2.1] $BGBM_{STR} = AGBM_{STR} * 0.222$
[2.2] $BGBM_{HTR} = AGBM_{HTR}^{0.615} * 1.576$

where $BGBM_{STR}$ and $BGBM_{HTR}$ are belowground biomass of softwood and hardwood tree species, respectively, and where $AGBM_{STR}$ and $AGBM_{HTR}$ are aboveground biomass of softwood and hardwood tree species, respectively, both calculated with equation [1]. The belowground biomass of brush vegetation ($BGBM_{BR}$) needs to be estimated by the project proponent, since no simple and reliable equations are available in the literature for this group of vegetation. The methodology to determine $BGBM_{BR}$ is provided in section 4.1e. The calculated biomass in g needs to be multiplied by 10^{-6} (from g to Mg) and by 10^4 (from 1 m^2 to 1 ha) before using equation [2].

B3. Baseline litter and humus C reservoir

Litter and humus C reservoir is estimated by the project proponent (see methodology below) before using the following equation:

[3] $TA_{B3} = BM_{LH} * CD * CO2_{CONV} * SEF$

where:
- TA_{B3} is the total absorptions for the baseline litter and humus reservoirs (in tonne CO_2 per ha);
- BM_{LH} is the total litter and humus biomass (in Mg m^{-2});
- CD is the carbon density of the biomass (0.5 [6]);
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);
- SEF is the surface expansion factor, from 1 m^2 to 1 ha (10^4).

The methodology for BM_{LH} is described in section 4.1e. The calculated biomass in g needs to be multiplied by 10^{-6} before using equation [3].

[6] To be determine precisely with the LECO, see the Step 4 in next section.

B4. Baseline soil organic C reservoir

The soil organic C reservoir is estimated by the project proponent (see methodology below) before using the following equation:

[4] $TA_{B4} = CO2_{SOC} * CO2_{CONV} * SEF$

where: - $TA_{B4.P10}$ is the total absorptions for the baseline soil organic C reservoir (in tonne CO_2 per ha);

- $CO2_{SOC}$ is the total CO_2 measured from the soil organic C combustion (in g per m^2);
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);
- SEF is the surface expansion factor, from 1 m^2 to 1 ha (10^4).

The methodology for $CO2_{SOC}$ is based on Brown et al. (2004) and described in section 4.1e.

b) Equation for each relevant SSR in the project scenario

P3. Land access

The emissions from road construction are estimated by the project proponent (see methodology below) before using the following equation:

[5] $TE_{P3} = (KM_{RD} * RD_{EF}) + CO2_{DEF}$

where: - TE_{P3} is the total emissions for the project road construction (in tonne CO_2);

- KM_{RD} is the road length constructed specifically for the project (in km);
- RD_{EF} is the emission factor for each km of road constructed (21 t CO_2eq km^{-1});
- $CO2_{DEF}$ is the total emissions by the road construction resulting deforestation, equivalent to the C stocks removed for the new road (in tonne CO_2).

The RD_{EF} of 21 t CO_2eq km^{-1} is obtained from the data used in Gaboury et al. (2009). For $CO2_{DEF}$, the project proponent is required to apply equations [1] to [4], and the associated methodology, to establish the C stocks (in tonne CO_2) removed specifically for the new road.

P5. Soil fertilisation applications

The emissions from soil fertilisation are estimated by the project proponent (see methodology below) before using the following equation:

$$[6]\ TE_{P5} = F_{SN} * N2O_{EF} * N2O_{CONV} * CO2_{CONV}$$

where:
- TE_{P5} is the total emissions for the project soil fertilisation applications (in tonne CO_2 per ha);
- F_{SN} is the total amount of synthetic fertiliser N applied to soils, kg N;
- $N2O_{EF}$ is the emission factor for N_2O emissions from N inputs, kg N_2O–N (kg N input)$^{-1}$ (0.01);
- $N2O_{CONV}$ is the N_20 conversion factor, from N_2O–N to N_2O (44/28);
- $CO2_{CONV}$ is the CO_2 conversion factor, from N_20 to CO_2 (298).

The $N2O_{EF}$ of 0.01 is the IPCC (2006) default value for N additions from mineral fertilisers, and the $N2O_{CONV}$ is obtained from the same document. The $CO2_{CONV}$ is based on the 100-year time horizon Global Warming Potential (GWP) of N_2O compared to the GWP of CO_2 (Forster et al. 2007).

P7. Project aboveground C reservoir

This reservoir is split into four different vegetation groups, namely: trees higher than 2.0 m, trees lower than 2.0 m, shrub vegetation, and non-vascular organisms (mosses and lichens). The equation for the aboveground C reservoir is:

$$[7]\ TA_{P7} = (AGBM_{TR\geq 2.0} + AGBM_{TR<2.0} + AGBM_{BR} + BM_{NV}) * CD * CO2_{CONV}$$

where:
- TA_{P7} is the total absorptions for the project aboveground reservoir (in tonne CO_2 per ha);
- $AGBM_{TR\geq 2.0}$ is the aboveground biomass of all trees with height ≥ 2.0 m (in Mg ha^{-1});
- $AGBM_{TR<2.0}$ is the aboveground biomass of all trees with height < 2.0 m (in Mg ha^{-1});
- $AGBM_{BR}$ is the aboveground biomass of all brush vegetation (in Mg ha^{-1});
- BM_{NV} is the biomass of all non-vascular organisms (mosses and lichens) (in Mg ha^{-1});
- CD is the carbon density of the biomass (0.5);

- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);

A specific set of equations is associated to each of these four vegetation groups. First, for $AGBM_{TR\geq2.0}$ the equations from Lambert et al. (2005) are recommended, with all boreal forest tree species included therein (see Appendix 2). Since estimated biomasses from these equations are in kg and from a 400 m^2 sampling plot, the project proponent needs to multiply the cumulated biomasses by 10^{-3} (from kg to Mg) and by 25 (from 400 m^2 to 1 ha) before using equation [7].

Then, the equations provided in Tremblay et al. (2006) are recommended for both $AGBM_{TR<2.0}$ and $AGBM_{BR}$ (see Appendix 3). Since estimated biomasses from these equations are in g and from 1 or 400 m^2 subplots and sampling plots, cumulated biomasses need to be multiplied by 10^{-6} (from g to Mg) and by 25 (from 400 m^2 to 1 ha) for $AGBM_{TR<2.0}$ or by 10^4 (from 1 m^2 to 1 ha) for $AGBM_{BR}$, before using equation [7].

Finally, BM_{NV} needs to be estimated by the project proponent, since no simple and reliable equations (eg. based on % cover visual evaluation) are available in the literature for this group of organisms. The methodology for the measurement of BM_{NV} is provided in section 4.1e. There again, the calculated biomasses in g need to be multiplied by 10^{-6} (from g to Mg) and by 10^4 (from 1 m^2 to 1 ha) before using equation [7].

P8. Project belowground C reservoir

This reservoir is split into two different vegetation groups, namely: tree and brush species. The equation for the belowground C reservoir is:

[8] $TA_{P8} = (BGBM_{TR} + BGBM_{BR}) * CD * CO2_{CONV}$

where: - TA_{P8} is the total absorptions for the project belowground reservoir (in tonne CO_2 per ha);

- $BGBM_{TR}$ is the total belowground biomass of all trees (in Mg ha^{-1});
- $BGBM_{BR}$ is the total belowground biomass of all brush vegetation (in Mg ha^{-1});
- CD is the carbon density of the biomass (0.5);
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);

Belowground biomass of trees ($BGBM_{TR}$) is estimated according to Li et al. (2003) calculations. The equations for the belowground biomass of trees are:

[8.1] $BGBM_{STR} = AGBM_{STR} * 0.222$
[8.2] $BGBM_{HTR} = AGBM_{HTR}^{0.615} * 1.576$

where $BGBM_{STR}$ and $BGBM_{HTR}$ are belowground biomass of softwood and hardwood tree species, respectively, and where $AGBM_{STR}$ and $AGBM_{HTR}$ are aboveground biomass of softwood and hardwood tree species, respectively, both calculated with equation [7]. The belowground biomass of brush vegetation ($BGBM_{BR}$) needs to be estimated by the project proponent, since no simple and reliable equations are available in the literature for this group of vegetation. The methodology to determine $BGBM_{BR}$ is provided in section 4.1e. The calculated biomass in g needs to be multiplied by 10^{-6} (from g to Mg) and by 10^{4} (from 1 m^2 to 1 ha) before using equation [8].

P9. Project litter and humus C reservoir

Litter and humus C reservoir is estimated by the project proponent (see methodology below) before using the following equation:

[9] $TA_{P9} = BM_{LH} * CD * CO2_{CONV} * SEF$

where:
- TA_{P9} is the total absorptions for the project litter and humus reservoir (in tonne CO_2 per ha);
- BM_{LH} is the total litter and humus biomass (in Mg ha^{-1});
- CD is the carbon density of the biomass (0.5 [7]);
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667).

The methodology for BM_{LH} is described in section 4.1e. The calculated biomass in g needs to be multiplied by 10^{-6} before using equation [9].

[7] To be determine precisely with the LECO, see the Step 4 in next section.

P10. Project soil organic C reservoir

The soil organic C reservoir is estimated by the project proponent (see methodology below) before using the following equation:

[10] $TA_{P10} = CO2_{SOC} * CO2_{CONV} * SEF$

where:
- TA_{P10} is the total absorptions for the project soil organic C reservoir (in tonne CO_2 per ha);
- $CO2_{SOC}$ is the total CO_2 measured from the soil organic C combustion (in g per m^2);
- $CO2_{CONV}$ is the conversion factor, from C to CO_2 (3.6667);
- SEF is the surface expansion factor, from 1 m^2 to 1 ha (10^4).

The methodology for $CO2_{SOC}$ is based on Brown et al. (2004) and described in section 4.1e.

c) Entire set of equations used to quantify total emissions and/or removals

The total GHG removals of an OW afforestation project is obtained by subtracting the net removals of the baseline scenario from the net removals of the project scenario at each of the measurement period ("at time X"):

[11] $Afforestation_{OW\ at\ time\ X} = \Sigma\ net\ removals_{project\ at\ time\ X} - \Sigma\ net\ removals_{baseline\ at\ time\ X}$

The total net removals of the baseline and the project scenarios at time X are defined by:

[12] $\Sigma\ removals_{baseline\ at\ time\ X} = TA_{B1} + TA_{B2} + TA_{B3} + TA_{B4}$

where:
- TA_{B1} is the total absorptions for the baseline aboveground reservoir at time X (in tonne CO_2 per ha) (see equation [1]);
- TA_{B2} is the total absorptions for the baseline belowground reservoir at time X (in tonne CO_2 per ha) (see equation [2]);

- TA_{B3} is the total absorptions for the baseline litter and humus reservoir at time X (in tonne CO_2 per ha) (see equation [3]);
- TA_{B4} is the total absorptions for the baseline soil organic C reservoir at time X (in tonne CO_2 per ha) (see equation [4]);

[13] $\Sigma \text{ removals}_{\text{project at time X}} = -TE_{P3} - TE_{P5} + TA_{P7} + TA_{P8} + TA_{P9} + TA_{P10}$

where:
- TE_{P3} is the total emissions for the project road construction (in tonne CO_2) (see equation [5]);
- TE_{P5} is the total emissions for the project soil fertilisation (in tonne CO_2 per ha) (see equation [6]);
- TA_{P7} is the total absorptions for the project aboveground reservoir at time X (in tonne CO_2 per ha) (see equation [7]);
- TA_{P8} is the total absorptions for the project belowground reservoir at time X (in tonne CO_2 per ha) (see equation [8]);
- TA_{P9} is the total absorptions for the project litter and humus reservoir at time X (in tonne CO_2 per ha) (see equation [9]);
- TA_{P10} is the total absorptions for the project soil organic C reservoir at time X (in tonne CO_2 per ha) (see equation [10]);

d) Method for uncertainty assessment and sampling plot number

As recommended in Brown et al. (2004), a reasonable level of precision for the estimate of C stock change with time in A/R projects can be achieved by targeting ±10% of the true value of the mean. Since they represent a significant proportion of the total C stocks and they can be easily measured (Brown et al. 2004), trees of height ≥ 2.0 m (from the ground line to the top of the apical shoot) will serve as representatives of the overall C stock uncertainty, and hence help finding the number of permanent sampling plots that needs to be established in both scenarios.

An adaptation of the cluster sampling method (Blais et al. 1996) is recommended to determine the overall variability in each scenario. Firstly, the contour of the total project area (including the area that will be secured for the baseline scenario) has to be delineated, and a series of parallel transects separated by 25 m each is then sketched on the entire area. At every 10 m in each transect, the stem diameter at breast height (DBH, at 1.3 m from the ground level) of the nearest tree (of height ≥ 2.0 m) is measured and recorded, in order to establish the average tree DBH of the total project. Then, four representative 400 m^2 sampling plots are selected, two for each scenario. The selection of each representative sampling plot must comply with the two following criteria: i) average measured tree DBH of all trees (of height ≥ 2.0 m) in the plot within 10% of the average tree DBH of the whole project (previously determined with the transects), ii) equivalent tree density (number of trees of height ≥ 2.0 m per 400 m^2 plot), dominant tree age (with an increment borer at 1 m-height, using the 4 largest trees per plot), soil deposit and drainage (visual evaluation of soil texture in small ground pits), and site slope and aspect (with a clinometer and a compass), between plots of each scenario.

Once the sampling plots are established, the perimeter of the baseline can be determined and secured for the complete duration of the project. A buffer (undisturbed) strip at least 20 m of width between the afforestation and baseline scenarios has to be planned, in order to keep the baseline area unaffected by the adjacent afforestation activities (or any other activities around). Only one sampling plot per scenario is kept for detailed measurement and quantification (hereafter) and considered as the permanent plot for the complete duration of the project. The second sampling plot per scenario is kept as a backup plot, in case of an accidental reversal in the first selected plot. However, tree DBH of all trees (of height ≥ 2.0 m) in the backup plots must be remeasured at each decennial quantification period, to insure that each backup plot is still within 10% of the average DBH of the correspondent permanent plot. In case of deviation from this 10% uncertainty, an other backup must then be selected on the basis of both criteria described earlier.

The total height (in cm) is then measured on all trees of height ≥ 2.0 m in each sampling plot, using a flexible ruler when possible, or a clinometer for taller trees. The stem diameter (in cm) is measured on all remaining trees (less than 2 m-high), using a calliper – except for tree species for which an equation is provided by Roussopoulos and Loomis (1979) in Appendix 3, where stem diameter is measured at 15 cm height. The same measurement specifications apply for shrubs, except that they are measured only within the four subplots per sampling plot detailed hereafter.

Within each sampling plot, four 4-m^2 subplots (one in each of the 4 corners of the sampling plot at the beginning of the project) will be used for the determination of shrubs, mosses, and lichens biomass, as well as for the extraction of the litter, humus, mineral soil, and roots. Since these subplots are used for destructive measurements, adjacent 4-m^2 subplots are sequentially used (clock-wise rotation) at every 10-year measurement period (see Fig. 5).

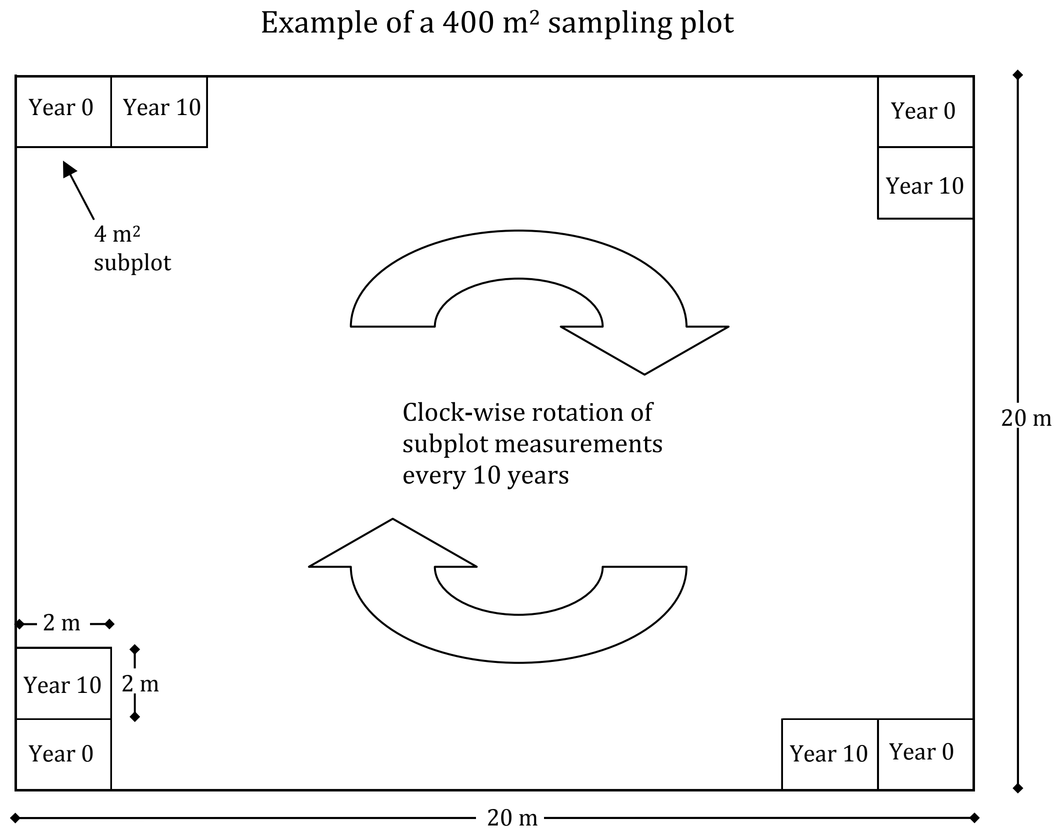

Figure 5. Example of a 400 m^2 sampling plot, also showing the 4 m^2 subplots therein (4 per measurement period every 10 years).

e) Methods for quantification of each SSR or parameter

Once the sampling plots and subplots therein are established, the methodology consists of four main phases:

1. the measurement of the height and diameter of all trees within the sampling plots and of the shrubs in the subplots;
2. the extraction of mosses and lichens in the subplots for their dry mass determination;
3. the extraction of the litter and humus layers in the subplots, followed by their sieving to remove and weight the roots of brush vegetation and weight the humus and litter;

4. the sampling of mineral soil cores within the subplots for the measurement of CO_2 from combustion.

Starting from year 0 to year 100 of the project, all steps need to be made every 10 years (except when a reversal occurs, see section 4.1f), because of the slow change expected from the C stock growth.

Step 1- The measurement of the height and diameter of all trees within the sampling plots and of the shrubs in the subplots has already been explained in the previous section (4.1c). Here again the method: the total height (in cm) is measured on all trees of height ≥ 2.0 m in each sampling plot, using a flexible ruler when possible, or a clinometer for taller trees. The stem diameter (in cm) is measured on all trees, using a calliper, at the stump height for trees less than 2 m high – except for tree species for which an equation is provided by Roussopoulos and Loomis (1979) in Appendix 3, where stem diameter is measured at 15 cm height – or at breast height (DBH) for trees of height ≥ 2.0 m. The same measurement specifications apply for shrubs, except that they are measured only within the four subplots per sampling plot.

Step 2- Mosses and lichens are carefully extracted from 1 m^2 in the center of each of the 4 subplots per sampling plot, for their dry mass determination. Beforehand, all aboveground brush vegetation (already measured in step 1) shall be cut. Then, care must be taken to extract only the living part of mosses and lichens, and to leave the litter on the surface of the humus layer. The extracted mosses and lichens are then allowed to desiccate during 48 hours at 65 ºC, or at constant weight. The dry mass determination is done to the nearest g and then reported in g m^{-2} for the entire sampling plot.

Step 3- The litter and the entire humus layer, including the roots therein, are extracted from 1 m^2 in the center of each of the 4 subplots per sampling plot. To accurately extract 1 m^2 of humus (and litter) just on the top of the mineral soil surface, the subplot perimeter should be first sliced up to the mineral soil with a sharpen shovel, or by other means. Once air-dried, the humus is then sieved with a 2 mm wide-mesh, in order to extract all non-decomposed roots. These roots are considered the belowground biomass from the brush vegetation, unless the roots from trees can be identified (and thus removed from the sample). The humus, litter and the brush roots are then allowed to desiccate during 48 hours at 65 ºC, or at constant weight. The dry mass determination of the humus and litter, on one hand, and the brush roots, on the other hand, is done to the nearest g and then reported in g m^{-2} for the entire sampling plot. It is recommended to keep a subsample of the litter and humus to determine more precisely the C content of this biomass with the LECO (see next step). It is possible that the C content of the humus and litter can be significantly different from the normally accepted 50% of the dry mass in organic material (unpublished data).

Step 4- As described in Brown et al. (2004), for an accurate determination of organic C stocks in the mineral soil, three types of variables must be measured: (i) the soil depth, (ii) the soil bulk density (calculated from the oven-dry weight of soil from a known volume of sampled material), and (iii) the concentration of organic carbon within the sample. Since most of boreal forest podzols are relatively shallow (less than 1 m) and that the bulk of tree root systems are within 30 cm of depth, it is recommended to characterize the mineral soil to a depth of 30 cm. Two different soil samplings are made in each of the 4 subplots per sampling plot: one sampling for the soil bulk density determination, and the other sampling for the C concentration. The sampling for the bulk density shall be made using a 30 cm-long soil corer of known volume. The bulk density is determined by weighting (to the nearest g) the oven-dried soil sample at 105 ºC for a minimum of 48 hrs. If the soil contains coarse rocky fragments, they must be retained and weighed. For soil carbon determination, the material is air-dried and then sieved through a 2-mm sieve and a composite sample (from the 4 subplot samples) is then thoroughly mixed to obtain one C concentration per sampling plot. The dry combustion method using a specialized controlled-temperature furnace (eg. a LECO CHN-2000) is the recommended method for determining total C in the soil (Nelson and Sommers 1996). Soil samples should then be sent to a professional lab for analysis. Finally, the C concentrations (in % of dry mass) obtained are multiplied by the mean bulk density measured in the 4 subplots (in g cm^{-3}) and by the soil depth (30 cm), to result in g C cm^{-2}, which is then expended to g m^{-2} by multiplying by 10^4, before being used in equations [4] and [10].

f) Monitoring of reversals

As reversals by natural means can occur at any moment between the measurement periods (every 10 years), the project proponent is required to monitor every sampling plots of a project on a yearly basis in order to capture any reversal in a timely manner. A reversal occurs when the result of ($\text{Afforestation}_{\text{OW at time X}} = \Sigma$ net $\text{removals}_{\text{project at time X}} - \Sigma$ net $\text{removals}_{\text{baseline at time X}}$) in Equation [11] of the QP is lower than that at the preceding measurement period. Once a reversal is confirmed, a buffer plantation (and its corresponding baseline scenario) of equivalent C stocks (compared to those in the reversed plantation) is identified from the buffer pool as a replacement plantation in the project. Measures are then taken to estimate the residual C stocks in the reversed plantation (and its baseline counterpart), and to evaluate the need to eventually regenerate the disturbed site. The re-established C stocks in the reversed plantation can ultimately contribute in the introduction of this plantation in the buffer pool.

Part V. Quality assurance / Quality control

5.1 Field sampling, crew member, material and lab measurement

In order to collect reliable data, field crew should be adequately formed and familiar with sampling protocol and method before getting to the field. Any new field crew member should work with an experienced member before being allowed to fly on his own.

Data collecting form (electronic media or field sheet) should be stepwise and include a “Check list” in order to avoid missing data. This form should also include reference note, table or figure describing each step of the sampling method with a particular attention to special case, i.e. how to measure diameter a breast height or how to adjust plot size in terrain with strong slope. Any sheet of the collecting form must be sign by the member of the field crew in order to be able to contact these persons if any trouble is detected during the computation of the data. Cross checking of the sampling or measuring method between field crew members is strongly recommended. This cross checking should be done as frequently as possible in order to avoid error that can originate from repetitive routine measurement.

Field measurement should be done using the most precise tool available. For example, diameter tape should be preferred to graduated calliper for tree greater than 4 cm in diameter. For height measurement, measuring tape, graduated telescopic pole and electronic devise such as hypsometer should be preferred to clinometers because they give directs and precise data without any calculation. Electronics measurement tool must be calibrated at least every year.

Determining mineral soil bulk density and carbon content required rigorous sampling and preparation. Soil carbon content sample should be air dried and passes through a 2 mm sieve before combustion. Periodically, sample of known concentration should be included in combustion run to confirm method efficiency. Bulk density sample must be collected with special device which allow collecting a soil sample of known volume without affecting sample density and this kind of sampling should be done by an experienced technician. Sample must be oven dried at 105 °C till constant mass before weighting. Balance used to determine sample weight should be calibrated against known weights periodically.

5.2 Data entry and data archiving

When entering field data (electronic or paper) in a work sheet, it is important to use software that allows checking the data to detect if any is over or under values observed in the field. Anomalies should be discussed with the field crew in order to correctly integrate these anomalies to the final dataset. It is also strongly recommended to have a sub-sample of the dataset double-check by another person and immediately correct the dataset. If too many errors are found, the entire dataset should be reviewed.

Once computed, field sheet must be kept in a safe place and photocopy of these sheets should be stored in physically distant place to avoid complete loss of the data in case of fire. Numerical version of the dataset, scanned field sheet, electronic work sheet, GIS product and result of sequestrated carbon, must be kept in at least one computer and one external hard drive especially dedicated to the project and protected by a strong antivirus. Protected copies of all these data must also be burned on cd-rom or dvd-rom and kept in two different places with the field sheet. It is also strongly recommended to work with an enterprise who offers numerical data storage space to insure the permanence of the dataset. It is of primordial importance to update dataset frequently and to kept every data “backup” in order to be able to go ‘back in time’ if computer or dataset get infected by virus.

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Appendix 1. List of operations and processes analyzed in Gaboury et al. (2009) LCA study

Process
Seed production
Black spruce cone harvesting
Cone transportation
Building and installation heating
Cone processing
Seed storage
Seed extraction and drying

Process
Seedling production
Seed production
Seedling handling
Seedling box production
Seedling box transportation
Peat moss uses
Peat moss extraction
Peat moss transportation
Herbicide uses
Herbicide production
Herbicide transportation
Fertilizer uses
Fertilizer production
Fertilizer transportation
Perlite and vermiculite uses
Perlite extraction
Perlite processing
Vermiculite extraction
Vermiculite processing
Perlite and vermiculite transportation
Building and nursery heating, electricity uses and maintenance

Processes
Harvesting operations
Logging, hauling and lopping
Loading
Roundwood transportation
Machinery transportation
Total
Site preparation
Machinery transportation
Soil scarification
Operator transportation
Total
Plantation
Seedling transportation to camp
Tree planter transportation
Seedling transportation to site

Processes
Land access
Road construction
Road maintenance
Total
Housing and accommodation
Tree planters
Land preparation operators
Other employees
Total
Monitoring
Transportation

Appendix 2. Equations from Lambert et al. (2005) used to estimate aboveground biomass of trees with height ≥ 2.0 m

Find the parameter estimates and error terms corresponding to each tree species in the table 4 hereafter (next 5 pages), then use the following dbh- and height-based equation:

$$y_{\text{wood}} = \beta_{\text{wood1}} D^{\beta\text{wood2}} H^{\beta\text{wood3}} + e_{\text{wood}}$$

$$y_{\text{bark}} = \beta_{\text{bark1}} D^{\beta\text{bark2}} H^{\beta\text{bark3}} + e_{\text{bark}}$$

$$y_{\text{foliage}} = \beta_{\text{foliage1}} D^{\beta\text{foliage2}} H^{\beta\text{foliage3}} + e_{\text{foliage}}$$

$$y_{\text{branches}} = \beta_{\text{branches1}} D^{\beta\text{branches2}} H^{\beta\text{branches3}} + e_{\text{branches}}$$

$$y_{\text{total}} = \hat{y}_{\text{wood}} + \hat{y}_{\text{bark}} + \hat{y}_{\text{foliage}} + \hat{y}_{\text{branches}} + e_{\text{total}}$$

where y_i is the dry biomass compartment i of a living tree (kilograms); i is wood, bark, stem, foliage, branches, crown, and total; $\hat{y}_i$ is the prediction of y_i; D is the dbh (centimetres); β_{jk} are model parameters with coefficient estimates b_{jk}; j is wood, bark, foliage, and branches; k = 1 or 2; and e_i are the error terms.

where H is the height in metres; stem, crown, and total aboveground biomasses are obtained by adding their respective compartments (k = 1, 2, or 3).

Table 4. Model parameter estimates and their standard error (SE) for the dbh- and height-based set of equations per species, genus, and all species combined.*

Species	Parameter	Estimate	SE
Alpine fir	b_{wood1}	0.0268	0.0023
	b_{wood2}	1.7579	0.0577
	b_{wood3}	0.9871	0.0794
	b_{bark1}	0.0009	0.0004
	b_{bark2}	1.4460	0.2504
	b_{bark3}	1.8839	0.3653
	$b_{branches1}$	0.0470	0.0085
	$b_{branches2}$	2.9288	0.2044
	$b_{branches3}$	–1.1588	0.2155
	$b_{foliage1}$	0.0551	0.0151
	$b_{foliage2}$	1.7585	0.0885
	$b_{foliage3}$	—	—
Balsam fir	b_{wood1}	0.0294	0.0008
	b_{wood2}	1.8357	0.0163
	b_{wood3}	0.8640	0.0213
	b_{bark1}	0.0053	0.0004
	b_{bark2}	2.0876	0.0388
	b_{bark3}	0.5842	0.0506
	$b_{branches1}$	0.0117	0.0008
	$b_{branches2}$	3.5097	0.0667
	$b_{branches3}$	–1.3006	0.0773
	$b_{foliage1}$	0.1245	0.0073
	$b_{foliage2}$	2.5230	0.0750
	$b_{foliage3}$	–1.1230	0.0878
Balsam poplar	b_{wood1}	0.0117	0.0015
	b_{wood2}	1.7757	0.0541
	b_{wood3}	1.2555	0.0883
	b_{bark1}	0.0180	0.0036
	b_{bark2}	1.8131	0.0939
	b_{bark3}	0.5144	0.1438
	$b_{branches1}$	0.0112	0.0028
	$b_{branches2}$	3.0861	0.1464
	$b_{branches3}$	–0.7164	0.2179
	$b_{foliage1}$	0.0617	0.0103
	$b_{foliage2}$	1.8615	0.1264
	$b_{foliage3}$	–0.5375	0.1855
Basswood	b_{wood1}	0.0168	0.0014
	b_{wood2}	1.9844	0.0494
	b_{wood3}	0.8989	0.0767
	b_{bark1}	0.0057	0.0010
	b_{bark2}	1.5881	0.0788
	b_{bark3}	1.1472	0.1290
	$b_{branches1}$	0.0039	0.0021
	$b_{branches2}$	2.0084	0.1700
	$b_{branches3}$	0.8588	0.2993
	$b_{foliage1}$	0.0147	0.0039
	$b_{foliage2}$	1.8300	0.0753

Table 4 (*continued*).

Species	Parameter	Estimate	SE
	$b_{foliage3}$	—	—
Beech	b_{wood1}	0.0432	0.0053
	b_{wood2}	2.0378	0.0443
	b_{wood3}	0.7000	0.0816
	b_{bark1}	0.0049	0.0015
	b_{bark2}	1.9057	0.0905
	b_{bark3}	0.6770	0.1709
	$b_{branches1}$	0.0355	0.0045
	$b_{branches2}$	2.3749	0.0381
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0452	0.0080
	$b_{foliage2}$	1.5567	0.0529
	$b_{foliage3}$	—	—
Black ash	b_{wood1}	0.0306	0.0081
	b_{wood2}	2.1836	0.0575
	b_{wood3}	0.5740	0.1344
	b_{bark1}	0.0897	0.0452
	b_{bark2}	2.2634	0.1301
	b_{bark3}	–0.5670	0.2761
	$b_{branches1}$	0.0994	0.0273
	$b_{branches2}$	2.1630	0.1432
	$b_{branches3}$	–0.4809	0.2285
	$b_{foliage1}$	0.0124	0.0047
	$b_{foliage2}$	1.0325	0.1425
	$b_{foliage3}$	0.8747	0.2638
Black cherry	b_{wood1}	0.0181	0.0050
	b_{wood2}	1.7013	0.0571
	b_{wood3}	1.3057	0.1157
	b_{bark1}	0.0101	0.0034
	b_{bark2}	1.5956	0.0767
	b_{bark3}	0.9190	0.1401
	$b_{branches1}$	0.0005	0.0004
	$b_{branches2}$	2.8004	0.1592
	$b_{branches3}$	0.8603	0.3067
	$b_{foliage1}$	0.1976	0.0291
	$b_{foliage2}$	1.4421	0.1099
	$b_{foliage3}$	–0.5264	0.1743
Black spruce	b_{wood1}	0.0309	0.0005
	b_{wood2}	1.7527	0.0120
	b_{wood3}	1.0014	0.0144
	b_{bark1}	0.0115	0.0004
	b_{bark2}	1.7405	0.0266
	b_{bark3}	0.6589	0.0303
	$b_{branches1}$	0.0380	0.0024
	$b_{branches2}$	3.2558	0.0543
	$b_{branches3}$	–1.4218	0.0606
	$b_{foliage1}$	0.2048	0.0087
	$b_{foliage2}$	2.5754	0.0496
	$b_{foliage3}$	–1.3704	0.0561

Table 4 (*continued*).

Species	Parameter	Estimate	SE
Eastern hemlock	b_{wood1}	0.0257	0.0019
	b_{wood2}	1.9277	0.0357
	b_{wood3}	0.8576	0.0549
	b_{bark1}	0.0118	0.0012
	b_{bark2}	1.9893	0.0614
	b_{bark3}	0.4700	0.0928
	$b_{branches1}$	0.0215	0.0044
	$b_{branches2}$	2.6553	0.1087
	$b_{branches3}$	–0.4682	0.1564
	$b_{foliage1}$	0.1471	0.0179
	$b_{foliage2}$	2.0108	0.0959
	$b_{foliage3}$	–0.6080	0.1416
Eastern redcedar	b_{wood1}	0.0520	0.0069
	b_{wood2}	1.7731	0.0347
	b_{wood3}	0.7054	0.0871
	b_{bark1}	0.0283	0.0040
	b_{bark2}	1.7079	0.0488
	b_{bark3}	—	—
	$b_{branches1}$	0.0219	0.0063
	$b_{branches2}$	2.3585	0.0899
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.2575	0.1128
	$b_{foliage2}$	2.5136	0.1784
	$b_{foliage3}$	–1.5565	0.3393
Eastern white-cedar	b_{wood1}	0.0295	0.0018
	b_{wood2}	1.7026	0.0355
	b_{wood3}	0.9428	0.0600
	b_{bark1}	0.0076	0.0008
	b_{bark2}	1.7861	0.0628
	b_{bark3}	0.6132	0.1045
	$b_{branches1}$	0.0501	0.0066
	$b_{branches2}$	2.5165	0.1117
	$b_{branches3}$	–0.8774	0.1719
	$b_{foliage1}$	0.0813	0.0105
	$b_{foliage2}$	2.2180	0.1124
	$b_{foliage3}$	–0.7907	0.1708
Eastern white pine	b_{wood1}	0.0170	0.0008
	b_{wood2}	1.7779	0.0197
	b_{wood3}	1.1370	0.0305
	b_{bark1}	0.0069	0.0005
	b_{bark2}	1.6589	0.0369
	b_{bark3}	0.9582	0.0534
	$b_{branches1}$	0.0184	0.0020
	$b_{branches2}$	3.1968	0.0665
	$b_{branches3}$	–1.0876	0.0874
	$b_{foliage1}$	0.0584	0.0113
	$b_{foliage2}$	2.2389	0.0772
	$b_{foliage3}$	–0.5968	0.1038
Grey birch	b_{wood1}	0.0295	0.0022

Table 4 (*continued*).

Species	Parameter	Estimate	SE
	b_{wood2}	1.9064	0.0375
	b_{wood3}	0.9139	0.0604
	b_{bark1}	0.0148	0.0036
	b_{bark2}	1.8433	0.1463
	b_{bark3}	0.5021	0.2200
	$b_{branches1}$	0.0150	0.0058
	$b_{branches2}$	3.0347	0.2225
	$b_{branches3}$	–0.7629	0.3448
	$b_{foliage1}$	0.0455	0.0056
	$b_{foliage2}$	2.6447	0.1905
	$b_{foliage3}$	–1.4955	0.2381
Hickory	b_{wood1}	0.0139	0.0020
	b_{wood2}	1.5913	0.0472
	b_{wood3}	1.5080	0.0797
	b_{bark1}	0.0081	0.0021
	b_{bark2}	1.4943	0.0886
	b_{bark3}	1.1324	0.1413
	$b_{branches1}$	0.0050	0.0014
	$b_{branches2}$	3.0463	0.0900
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0121	0.0025
	$b_{foliage2}$	2.0865	0.0623
	$b_{foliage3}$	—	—
Hop-hornbeam	b_{wood1}	0.0083	0.0033
	b_{wood2}	1.6534	0.0532
	b_{wood3}	1.7479	0.1630
	b_{bark1}	0.0012	0.0009
	b_{bark2}	1.1486	0.1174
	b_{bark3}	2.2903	0.3428
	$b_{branches1}$	0.0009	0.0009
	$b_{branches2}$	1.9152	0.1380
	$b_{branches3}$	1.7769	0.4215
	$b_{foliage1}$	0.0247	0.0085
	$b_{foliage2}$	2.0056	0.1271
	$b_{foliage3}$	—	—
Jack pine	b_{wood1}	0.0199	0.0010
	b_{wood2}	1.6883	0.0185
	b_{wood3}	1.2456	0.0280
	b_{bark1}	0.0141	0.0010
	b_{bark2}	1.5994	0.0388
	b_{bark3}	0.5957	0.0553
	$b_{branches1}$	0.0185	0.0021
	$b_{branches2}$	3.0584	0.0551
	$b_{branches3}$	–0.9816	0.0654
	$b_{foliage1}$	0.0325	0.0035
	$b_{foliage2}$	1.7879	0.0359
	$b_{foliage3}$	—	—
Largetooth aspen	b_{wood1}	0.0128	0.0011
	b_{wood2}	2.0633	0.0314
	b_{wood3}	0.9516	0.0480
	b_{bark1}	0.0240	0.0022
	b_{bark2}	2.3055	0.0325
	b_{bark3}	—	—
	$b_{branches1}$	0.0131	0.0017
	$b_{branches2}$	3.1274	0.0766
	$b_{branches3}$	–0.8379	0.0902
	$b_{foliage1}$	0.0382	0.0028
	$b_{foliage2}$	2.1673	0.0547
	$b_{foliage3}$	–0.6842	0.0647
Lodgepole pine	b_{wood1}	0.0202	0.0008
	b_{wood2}	1.7179	0.0242
	b_{wood3}	1.2078	0.0341
	b_{bark1}	0.0099	0.0007
	b_{bark2}	1.6049	0.0535
	b_{bark3}	0.7456	0.0710
	$b_{branches1}$	0.0440	0.0066
	$b_{branches2}$	3.7190	0.1449
	$b_{branches3}$	–2.0399	0.1699
	$b_{foliage1}$	0.0785	0.0114
	$b_{foliage2}$	2.5377	0.1291
	$b_{foliage3}$	–1.1213	0.1558
Red ash	b_{wood1}	0.0224	0.0048
	b_{wood2}	1.7845	0.0816
	b_{wood3}	1.0660	0.1202
	b_{bark1}	0.0219	0.0051
	b_{bark2}	1.4190	0.0882
	b_{bark3}	0.8963	0.1307
	$b_{branches1}$	0.0176	0.0077
	$b_{branches2}$	2.3313	0.1358
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0761	0.0263
	$b_{foliage2}$	1.3077	0.1043
	$b_{foliage3}$	—	—
Red maple	b_{wood1}	0.0315	0.0042
	b_{wood2}	2.0342	0.0423
	b_{wood3}	0.7485	0.0770
	b_{bark1}	0.0283	0.0029
	b_{bark2}	2.0907	0.0332
	b_{bark3}	—	—
	$b_{branches1}$	0.0225	0.0034
	$b_{branches2}$	2.4106	0.0475
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0571	0.0064
	$b_{foliage2}$	1.4898	0.0358
	$b_{foliage3}$	—	—
Red oak	b_{wood1}	0.0285	0.0049
	b_{wood2}	1.8501	0.0368
	b_{wood3}	1.0204	0.0732

Table 4 (*continued*).

Species	Parameter	Estimate	SE
	b_{bark1}	0.0326	0.0066
	b_{bark2}	1.8100	0.0610
	b_{bark3}	0.4153	0.1090
	$b_{branches1}$	0.0013	0.0005
	$b_{branches2}$	3.0637	0.0863
	$b_{branches3}$	0.3153	0.1273
	$b_{foliage1}$	0.0582	0.0048
	$b_{foliage2}$	1.5438	0.0295
	$b_{foliage3}$	—	—
Red pine	b_{wood1}	0.0106	0.0005
	b_{wood2}	1.7725	0.0143
	b_{wood3}	1.3285	0.0229
	b_{bark1}	0.0277	0.0018
	b_{bark2}	1.5192	0.0425
	b_{bark3}	0.4645	0.0519
	$b_{branches1}$	0.0125	0.0010
	$b_{branches2}$	3.3865	0.0403
	$b_{branches3}$	–1.1939	0.0551
	$b_{foliage1}$	0.0731	0.0068
	$b_{foliage2}$	2.3439	0.0494
	$b_{foliage3}$	–0.7378	0.0639
Red spruce	b_{wood1}	0.0143	0.0016
	b_{wood2}	1.6441	0.0340
	b_{wood3}	1.4065	0.0690
	b_{bark1}	0.0274	0.0041
	b_{bark2}	2.0188	0.0481
	b_{bark3}	—	—
	$b_{branches1}$	0.0005	0.0001
	$b_{branches2}$	3.3136	0.0779
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0106	0.0022
	$b_{foliage2}$	2.2709	0.0649
	$b_{foliage3}$	—	—
Silver maple	b_{wood1}	0.0274	0.0055
	b_{wood2}	1.7126	0.0581
	b_{wood3}	1.1086	0.1198
	b_{bark1}	0.0123	0.0044
	b_{bark2}	1.8250	0.0955
	b_{bark3}	0.5010	0.1990
	$b_{branches1}$	0.0543	0.0391
	$b_{branches2}$	3.7343	0.2311
	$b_{branches3}$	–1.6497	0.4651
	$b_{foliage1}$	6.6808	3.3429
	$b_{foliage2}$	2.1092	0.2006
	$b_{foliage3}$	–2.1697	0.3733
Sugar maple	b_{wood1}	0.0301	0.0040
	b_{wood2}	2.0313	0.0307
	b_{wood3}	0.8171	0.0717

Table 4 (*continued*).

Species	Parameter	Estimate	SE
	b_{bark1}	0.0103	0.0037
	b_{bark2}	1.7111	0.0749
	b_{bark3}	0.8509	0.1772
	$b_{branches1}$	0.0661	0.0161
	$b_{branches2}$	2.5940	0.0706
	$b_{branches3}$	–0.4933	0.1490
	$b_{foliage1}$	2.5019	0.2763
	$b_{foliage2}$	2.4527	0.0698
	$b_{foliage3}$	–2.3008	0.1089
Tamarack larch	b_{wood1}	0.0276	0.0010
	b_{wood2}	1.6724	0.0208
	b_{wood3}	1.1443	0.0271
	b_{bark1}	0.0120	0.0004
	b_{bark2}	1.7059	0.0243
	b_{bark3}	0.5811	0.0318
	$b_{branches1}$	0.0336	0.0028
	$b_{branches2}$	3.1335	0.0694
	$b_{branches3}$	–1.1559	0.0864
	$b_{foliage1}$	0.1324	0.0107
	$b_{foliage2}$	2.1140	0.0770
	$b_{foliage3}$	–0.8781	0.0983
Trembling aspen	b_{wood1}	0.0142	0.0005
	b_{wood2}	1.9389	0.0176
	b_{wood3}	1.0572	0.0271
	b_{bark1}	0.0063	0.0005
	b_{bark2}	2.0819	0.0354
	b_{bark3}	0.6617	0.0527
	$b_{branches1}$	0.0137	0.0012
	$b_{branches2}$	2.9270	0.0445
	$b_{branches3}$	–0.6221	0.0633
	$b_{foliage1}$	0.0270	0.0018
	$b_{foliage2}$	1.6183	0.0231
	$b_{foliage3}$	—	—
White ash	b_{wood1}	0.0224	0.0046
	b_{wood2}	1.7438	0.0364
	b_{wood3}	1.1899	0.0917
	b_{bark1}	0.0126	0.0034
	b_{bark2}	1.6456	0.0607
	b_{bark3}	0.7893	0.1361
	$b_{branches1}$	0.0354	0.0084
	$b_{branches2}$	2.3046	0.0739
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0195	0.0093
	$b_{foliage2}$	1.0509	0.1073
	$b_{foliage3}$	0.7836	0.1980
White birch	b_{wood1}	0.0338	0.0011
	b_{wood2}	2.0702	0.0157
	b_{wood3}	0.6876	0.0233

Table 4 (*continued*).

Species	Parameter	Estimate	SE
	b_{bark1}	0.0080	0.0006
	b_{bark2}	1.9754	0.0320
	b_{bark3}	0.6659	0.0466
	$b_{branches1}$	0.0257	0.0020
	$b_{branches2}$	3.1754	0.0492
	$b_{branches3}$	–0.9417	0.0684
	$b_{foliage1}$	0.1415	0.0086
	$b_{foliage2}$	2.3074	0.0513
	$b_{foliage3}$	–1.1189	0.0723
White elm	b_{wood1}	0.0207	0.0039
	b_{wood2}	2.2276	0.0632
	b_{wood3}	0.6488	0.1171
	b_{bark1}	0.0078	0.0024
	b_{bark2}	2.4540	0.0954
	b_{bark3}	—	—
	$b_{branches1}$	0.0393	0.0059
	$b_{branches2}$	2.1880	0.0456
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.0516	0.0028
	$b_{foliage2}$	1.4511	0.0187
	$b_{foliage3}$	—	—
White oak	b_{wood1}	0.0442	0.0049
	b_{wood2}	1.6818	0.0457
	b_{wood3}	1.0310	0.0844
	b_{bark1}	0.0308	0.0050
	b_{bark2}	1.7479	0.0672
	b_{bark3}	0.3504	0.1137
	$b_{branches1}$	0.0022	0.0006
	$b_{branches2}$	2.0165	0.0598
	$b_{branches3}$	1.3953	0.1278
	$b_{foliage1}$	0.0053	0.0017
	$b_{foliage2}$	1.2822	0.1077
	$b_{foliage3}$	1.1323	0.1905
White spruce	b_{wood1}	0.0265	0.0007
	b_{wood2}	1.7952	0.0180
	b_{wood3}	0.9733	0.0208
	b_{bark1}	0.0124	0.0006
	b_{bark2}	1.6962	0.0459
	b_{bark3}	0.6489	0.0517
	$b_{branches1}$	0.0325	0.0016
	$b_{branches2}$	2.8573	0.0522
	$b_{branches3}$	–0.9127	0.0578
	$b_{foliage1}$	0.2020	0.0094
	$b_{foliage2}$	2.3802	0.0524
	$b_{foliage3}$	–1.1103	0.0586
Yellow birch	b_{wood1}	0.0259	0.0038
	b_{wood2}	1.9044	0.0305
	b_{wood3}	0.9715	0.0709

Table 4 (*concluded*).

Species	Parameter	Estimate	SE
	b_{bark1}	0.0069	0.0015
	b_{bark2}	2.0834	0.0534
	b_{bark3}	0.5371	0.1178
	$b_{branches1}$	0.0325	0.0025
	$b_{branches2}$	2.3851	0.0231
	$b_{branches3}$	—	—
	$b_{foliage1}$	0.1683	0.0222
	$b_{foliage2}$	1.2764	0.0380
	$b_{foliage3}$	—	—
Hardwood	b_{wood1}	0.0359	0.0009
	b_{wood2}	2.0263	0.0100
	b_{wood3}	0.6987	0.0168
	b_{bark1}	0.0094	0.0005
	b_{bark2}	1.8677	0.0201
	b_{bark3}	0.6985	0.0327
	$b_{branches1}$	0.0433	0.0024
	$b_{branches2}$	2.6817	0.0309
	$b_{branches3}$	–0.5731	0.0461
	$b_{foliage1}$	0.0859	0.0038
	$b_{foliage2}$	1.8485	0.0266
	$b_{foliage3}$	–0.5383	0.0412
Softwood	b_{wood1}	0.0284	0.0003
	b_{wood2}	1.6894	0.0065
	b_{wood3}	1.0857	0.0086
	b_{bark1}	0.0100	0.0003
	b_{bark2}	1.8463	0.0174
	b_{bark3}	0.5616	0.0218
	$b_{branches1}$	0.0301	0.0008
	$b_{branches2}$	3.0038	0.0201
	$b_{branches3}$	–1.0520	0.0252
	$b_{foliage1}$	0.1554	0.0036
	$b_{foliage2}$	2.4021	0.0218
	$b_{foliage3}$	–1.1043	0.0271
All	b_{wood1}	0.0348	0.0005
	b_{wood2}	1.9235	0.0070
	b_{wood3}	0.7829	0.0092
	b_{bark1}	0.0139	0.0004
	b_{bark2}	1.5429	0.0176
	b_{bark3}	0.8189	0.0242
	$b_{branches1}$	0.0346	0.0008
	$b_{branches2}$	2.6706	0.0194
	$b_{branches3}$	–0.6033	0.0252
	$b_{foliage1}$	0.1822	0.0039
	$b_{foliage2}$	2.2864	0.0183
	$b_{foliage3}$	–1.1203	0.0239

*Missing values (—) correspond to parameter estimates not significantly different from zero (α = 0.05).

Appendix 3. Equations from Tremblay et al. (2006) used to estimate aboveground biomass of shrub vegetation and trees with height < 2.0 m

Table A1. Allometric equations used to estimate aboveground biomass for each species found in the 57 plantations.

		Equation parameter value				
	Equation	b_0	b_1	a_{15}	b_{15}	Reference
Abies balsamea	A5, A6	72.715	2.25	0.0684	1.1302	Roussopoulos and Loomis 1979; Ker 1984
Abies balsamea	A1	0.1746	2.1555			Ker 1984
Acer pensylvanicum	A4	–3.518	2.878			Telfer 1969
Acer rubrum	A1	0.197	2.1933			Ker 1984
Acer rubrum	A4	–4.194	2.094			Telfer 1969
Acer saccharum	A1	0.1599	2.3376			Ker 1980
Acer saccharum[a]	A4	–4.194	2.094			Telfer 1969
Acer spicatum	A5, A6	73.182	2.259	0.1645	1.0485	Roussopoulos and Loomis 1979
Acer spicatum	A1	0.204	2.2524			Whittaker et al. 1979
Alnus rugosa	A5, A6	63.28	2.38	0.1409	1.0225	Roussopoulos and Loomis 1979
Alnus rugosa	A1	0.2612	2.2087			Young et al. 1980
Amelanchier sp.[b]	A5, A6	71.534	2.391	0.0142	1.1037	Roussopoulos and Loomis 1979
Amelanchier sp.	A1	0.2612	2.2087			Young et al. 1980
Betula alleghaniensis	A2	–1.8337	2.1283			Ker 1980
Betula papyrifera	A5, A6	73.316	2.279	0.713	1.0452	Roussopoulos and Loomis 1979; Ker 1984
Betula papyrifera	A1	0.1545	2.3064			Ker 1984
Cornus stolonifera	A5, A6	74.114	2.457	0.0243	1.0828	Roussopoulos and Loomis 1979
Cornus stolonifera[c]	A1	0.0616	2.5094			Perala and Alban 1994
Corylus cornuta	A5, A6	62.819	2.42	0.1894	0.9226	Roussopoulos and Loomis 1979
Crataegus sp.	A5, A6	63.28	2.38	0.1409	1.0225	Roussopoulos and Loomis 1979

Table A1 (*concluded*).

	Equation	Equation parameter value				Reference
		b_0	b_1	a_{15}	b_{15}	
Crataegus sp.	A1	0.2612	2.2087			Young et al. 1980
Diervilla lonicera	A5, A6	14.211	1.217	0.1062	0.8818	Roussopoulos and Loomis 1979
Fagus grandifolia	A1	0.1958	2.2538			Ker 1980
Fagus grandifolia	A4	–3.647	2.906			Telfer 1969
Juniperus communis	A3	59.205	2.202			Smith and Brand 1983
Larix laricina	A1	0.0946	2.3572			Ker 1980
Lonicera canadensis	A4	–2.427	2.77			Telfer 1969
Nemopanthus mucronatus	A4	–3.04	2.819			Telfer 1969
Picea abies	A1	0.0777	2.472			Harding and Grigal 1985
Picea glauca	A1	0.0777	2.472			Harding and Grigal 1985
Picea glauca	A5, A6	65.757	2.287	0.0715	1.1241	Roussopoulos and Loomis 1979
Picea abies	A5, A6	65.757	2.287	0.0715	1.1241	Roussopoulos and Loomis 1979
Picea mariana	A1	0.1683	2.1777			Ker 1980
Picea mariana	A3	0.5072	1.9246			Wagner and Ter-Mikaelian 1999
Picea rubens	A1	0.166	2.2417			Freedman et al. 1982
Picea rubens[d]	A3	0.5072	1.9246			Wagner and Ter-Mikaelian 1999
Pinus banksiana	A1	0.152	2.273			Ker 1980
Pinus banksiana	A3	0.1694	2.3002			Wagner and Ter-Mikaelian 1999
Pinus resinosa	A1	0.0847	2.3503			Ker 1980
Pinus resinosa	A3	0.1219	2.4618			Wagner and Ter-Mikaelian 1999
Pinus strobus	A1	0.1617	2.142			Ker 1980
Pinus strobus	A3	0.1404	2.2918			Wagner and Ter-Mikaelian 1999
Populus balsamifera[e]	A5, A6	46.574	2.527	0.1294	1.0517	Roussopoulos and Loomis 1979
Populus tremuloides	A1	0.1049	2.391			Ker 1984
Populus tremuloides	A4	–2.92	2.715			Telfer 1969
Prunus pensylvanica	A5, A6	68.041	2.237	0.1151	1.0676	Roussopoulos and Loomis 1979
Prunus pensylvanica	A1	0.1556	2.1948			Young et al. 1980
Prunus sp.	A5, A6	68.041	2.237	0.1151	1.0676	Roussopoulos and Loomis 1979
Prunus virginiana	A1	0.2643	1.7102			Young et al. 1980
Prunus virginiana	A3	9.934	2.92			Brown 1976
Quercus rubra	A1	0.1335	2.422			Perala and Alban 1994
Quercus rubra	A4	–2.299	2.649			Telfer 1969
Ribes sp.	A3	49.001	3.112			Brown 1976
Rubus idaeus	A3	43.992	2.86			Brown 1976
Salix sp.	A1	0.0616	2.5094			Perala and Alban 1994
Salix sp.	A4	–1.519	2.325			Telfer 1969
Sorbus americana	A5, A6	44.394	3.253	0.0263	1.1373	Roussopoulos and Loomis 1979
Sorbus americana[f]	A1	0.1556	2.1948			Young et al. 1980
Thuja occidentalis	A5, A6	68.423	1.863	0.1853	1.0906	Roussopoulos and Loomis 1979; Ker 1984
Thuja occidentalis	A1	0.1148	2.1439			Ker 1980
Vaccinium angustifolium	A4	–3.978	3.706			Telfer 1969
Viburnum alnifolium	A4	–4.079	3.243			Telfer 1969
Viburnum cassinoides	A4	–2.613	2.774			Telfer 1969
*Kalmia angustifolia**	A4	–2.205	2.384			Telfer 1969
*Rhododendron groenlandicum**	A4	–2.894	2.832			Telfer 1969

*Missing species in Tremblay et al.'s (2006) list.

Note: Six different equations were used to predict aboveground woody vegetation biomass (*B*) (DBH is diameter at breast height; DSH is diameter at stump height; D15 is diameter at 15 cm height).

[A1] $B = b_0 \times \mathrm{DBH}^{b1}$
[A2] $B = b_0 + b_1 \times \log \mathrm{DBH}$
[A3] $B = b_0 \times \mathrm{DSH}^{b1}$
[A4] $B = b_0 + b_1 \times \log \mathrm{DSH}$
[A5] $B = b_0 \times \mathrm{D15}^{b1}$
[A6] $\mathrm{D15} = (\mathrm{DSH} - a_{15})/b_{15}$

[a]The equation for *A. rubrum* was used.
[b]The equation for *A. rugosa* was used.
[c]The equation for *Salix* sp. was used.
[d]The equation for *P. mariana* was used.
[e]The equation for *Populus* sp. was used.
[f]The equation for *P. pensylvanica* was used.

Appendix 4. Glossary, Abbreviations and Key terms

Accuracy - Reduce bias and uncertainties as far as practical.

"Affected" GHG source, sink or reservoir - GHG source, sink or reservoir influenced by a project activity by changes in market demand or supply for associated products or services, or through physical displacement.

Baseline Scenario - A hypothetical reference case against which the performance of a project will be measured.

BSFM - Black Spruce-Feathermoss forest stand type.

Carbon dioxide equivalent - A unit that expresses any greenhouse gas in terms of carbon dioxide that is calculated using the mass of a given greenhouse gas multiplied by its global warming potential.

Carbon stock – The quantity of carbon held within a reservoir at a specified time, expressed in units of mass.

CBM-CFS3 – The Carbon Budget Model of the Canadian Forest Sector, version 3.

Conservativeness - Use of conservative assumptions, values and procedures to ensure that GHG emission reductions are not over-estimated.

"Controlled" GHG source, sink or reservoir - GHG source, sink and reservoir whose operation is under the direction and influence of a Project Proponent through financial, policy, management or other instruments.

CSA – The Canadian Standard Association.

"Downstream" Source, Sinks and Reservoirs (SSRs) - Transportation of product(s) from the project/baseline site

Dynamic Baseline – A baseline is dynamic if the method to quantify the baseline's emissions depends on parameters that will change during the registration period. For example the amount of energy needed to heat a building varies due to the weather. The level of emissions of a Dynamic Baseline is determined ex-post (i.e., once the parameters have been quantified) but the formula to calculate the baseline's emissions is provided in the Project application form.

Emission Factor – An emission factor (EF) is a representative value that can be used to estimate the rate (or quantity) at which a pollutant is released into the atmosphere (or captured) as a result of a process or activity. The EFs used may be average or general EFs, or technology-specific.EFs. They are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (e. g., kilograms of particulate emitted per megagram of coal burned).

FAO – The Food and Agriculture Organization of the United Nations (www.fao.org).

Forest - Area of 1 ha or more where tree formations can reach at least 25% crown cover and 5 m in height in situ (Environment Canada 2006).

Functional equivalence - The quantity and quality of the services or products in the project case must be equivalent to the quantity and quality of the services or products in the baseline scenario.

Global Warming Potential (GWP) - A GWP is a measure of how much a given mass of greenhouse gas is estimated to contribute to global warming. By definition the GWP of carbon dioxide is 1. The GWP values for all other greenhouse gases are greater than 1, and are provided in the last IPCC guidelines (IPCC 2006).

Good Practice Guidance - A set of recognized criteria, methodologies tools and guidance for a specific project type or sector.

Greenhouse gas (GHG)- A gas emitted to the atmosphere from natural sources and /or as the result of human activity. GHGs both absorb and reflect the sun's radiation. GHGs normally covered under most protocol are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perflurocarbons, and sulphur hexafluoride.

Incremental - An eligibility criterion defining the conditions beyond which Offset Projects can create reductions. Conditions include the start date, baseline, legislative and voluntary requirements, and treatment of incentives.

IPCC – The Intergovernmental Panel on Climate Change (www.ipcc.ch).

Justify – To include a reasonable explanation of why decisions were made; how decisions are appropriate to the specific circumstances of the GHG project and why alternative options were declined.

"Key" Sources, Sinks and Reservoirs – GHG source, sink or reservoir that are determined to be high risk and/or which have the potential for a large amount of reductions/removals.

LCA - Life-cycle assessment.

Monitor - To observe any changes that may occur over time.

MRNF – The *Ministère des Ressources naturelles et de la Faune*, Province of Québec, Canada.

Offset Credit - A credit issued by Environment Canada to a Project Developer for eligible GHG reductions/removals achieved from an Offset Project. One credit represents one tonne of carbon dioxide equivalent emissions reduced or removed.

Offset Project - A GHG reduction project that has been registered in the Offset System.

"On-site" Sources, Sinks and Reservoirs – Activities related to the operation of the project/baseline that occur in the physical location of the project and/or baseline.

OW – An open woodland stand type.

Quantifiable - An eligibility criterion requiring that the emissions and removals in both the baseline and project scenarios can be measured or estimated in accordance with an approved Offset System Quantification Protocol.

Real - An eligibility criterion requiring that the Offset Project be a specific and identifiable action that results in net GHG emission reductions or removals after leakage (emissions being shifted to another site or source) is taken into account.

Reduction (greenhouse gas reduction) - A decrease in GHG emissions released into the atmosphere by a source.

"Related" source, sinks and reservoirs - GHG source, sink or reservoir that has material or energy flows into, out of, or within the project.

Note 1. A related GHG source, sink or reservoir is generally upstream or downstream from the project, and can be either on or off the project site.

Note 2. A related GHG source, sink or reservoir also may include activities related to design, construction and decommissioning of a project.

"Relevant" greenhouse gas sources, sinks and reservoirs - The set of controlled, related and affected GHG sources, sinks and reservoirs for the baseline and project scenarios, which must be measured or estimated to quantify the greenhouse gas reduction or removal achieved by the project.

Removal (emission removal) - The process of increasing the carbon stock in a reservoir other than the atmosphere.

Reservoir – For the purpose of this *Guide*, a reservoir means a physical unit or component of the biosphere, geosphere or hydrosphere with the capability to store or accumulate GHGs.

Reversal – A reversal is a decrease in the stored carbon stocks associated with quantified GHG reductions and removals that occurs before the end of the Project Life. In this QP, a reversal is deemed to have occurred if there is a decrease in the difference between project and baseline onsite carbon stocks from one measurement period to the next, regardless of the cause of this decrease – i.e. if the result of ($\text{Afforestation}_{\text{OW at time X}} = \Sigma \text{ net removals}_{\text{project at time X}} - \Sigma \text{ net removals}_{\text{baseline at time X}}$) in Equation [11] is lower than that at the preceding measurement period.

Sink - For the purpose of this *Guide*, a sink means any process, activity or mechanism that removes a GHG from the atmosphere.

Source - For the purpose of this *Guide*, a source means any process or activity that releases GHGs into the atmosphere.

Sequestration - The holding or storage of carbon in a reservoir.

Static Baseline - Baseline emission estimates that do not change during the registration period.

Unique - An eligibility criterion requiring that a greenhouse gas reduction or removal be used only once to create an Offset Credit.

UQAC – The *Université du Québec à Chicoutimi*, Qc, Canada.

Variable - A number or amount that can change over time.

Verifiable - An eligibility criterion requiring that government-recognized third-party Verification Bodies be able to confirm that the reductions or removals have been achieved as claimed.

Verification Body – An independent entity, similar to an auditor, that has been recognized as having the qualifications and experience to verify the greenhouse gas reduction/removal claims related to specified project types.

"Upstream" Sources, Sinks and Reservoirs - include the production of project inputs used on an ongoing basis during project/baseline system operation.