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Cost to produce Carbon credits by reducing the harvest level in British Columbia, Canada

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ABSTRACT

This paper uses the inventory of three actively managed forest estates located in the Coastal, Central Interior, and Northern Interior forest regions in British Columbia to estimate the cost to produce Carbon credits ($ per Carbon credit) when the harvest is reduced below the baseline level. The financial analysis was conducted over a range of discount rates (0–16%) and the total cost included the opportunity cost due to harvest reduction and the Carbon project cost (the Carbon project initial establishment and validation cost and the ongoing verification cost for two frequencies (1-year and 5-year)). When the opportunity cost was not included, the cost per Carbon credit was similar to previous findings (lower cost per Carbon credit for higher site index (i.e. top height in meters at age 50)). However, when the opportunity cost was included the cost per Carbon credit was higher for higher site indices which corresponded to higher average value per hectare harvested (AVHH) (i.e. timber revenue multiplied by average harvested volume per hectare per year). The reversal of trends is the result of the average timber revenue being higher for higher site indices which resulted in a higher opportunity cost and higher AVHH. The opportunity cost represented 58% to 97% of the cost per Carbon credit. Compared to the 5-year verification, the 1-year verification frequency increased the total cost per Carbon credit by 1% to 22%, with the smallest increase being when the Carbon project cost represented a small percent of the total cost. The estimates for the three forest estates analyzed here represent three points from a larger spectrum, and they identify the cost per Carbon credit over a range of site indices (14.7 to 25.6 meters top height at age 50), AVHH (12.2 to 63.7 thousand $ ha^{-1} year^{-1}), and timber net revenues ($4 to $35 m^{-3}). Further research is required to determine if the trends found in this study hold over a more densely populated spectrum.

1. Introduction

The Intergovernmental Panel on Climate Change (2007) suggests forests can be used to store additional Carbon producing Carbon credits (where a Carbon credit equals 1 Mg of CO_2e) to help offset recent human induced global warming. Management strategies used to enhance the amount of Carbon stored in existing forests can be organized into two major categories: (1) harvest reduction and (2) increased forest growth strategies. Harvest reduction strategies have a higher potential for producing Carbon credits in the short term (25 to 50 years). Man et al. (2013) found little difference in the number of Carbon credits produced between different harvest reduction strategies, and suggested that reducing the harvest level to a fixed target below the baseline provides the forest manager with more flexibility. Strategies to increase forest growth rates above the baseline levels include fertilization and planting genetically improved stock; however, these strategies store significantly less Carbon than the harvest reduction strategies (Man et al., 2013) and pose the risk of not being able to deliver the projected growth increase. The past financial analyses conducted on theoretical forests developed indicators to determine the financial viability of forest based Carbon projects (Richards and Stokes, 2004; van Kooten et al., 2009). Given the large number of factors involved in developing such indicators (Golden et al., 2011; Greig and Bull, 2011; Galik and Cooley, 2012) there is still a debate on which financial indicators are best suited for forest based Carbon projects.

A useful indicator to determine the financial viability of forest based Carbon projects is the Carbon supply curve (i.e. plotting the Carbon credits produced against the marginal cost to produce them) (Boyland, 2006). Marginal cost to produce Carbon credits at a landscape level has been estimated between $0 to over $200 depending on the location and the forest management strategy used (van Kooten et al., 2009). Usually, only the average costs and revenues are available in a financial analysis of a forest estate (e.g. timber price, harvesting cost, Carbon project costs, and Carbon credit price). The marginal costs derived from the average costs and revenues can be misleading because they can overestimate the number of Carbon credits that can be produced at a given Carbon credit price (Boyland, 2006). An alternate strategy to determine the financial viability of forest based Carbon projects where the average

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costs and revenues are known is to compare the market price of a Carbon credit to the break-even Carbon credit price (i.e. the total cost of the project divided by the number of Carbon credits produced). The average Carbon credit market price for improved forest management projects (i.e. IFM) in 2012 varied between \$5 and \$16 depending on the contract type and project stage (Peters-Stanley et al., 2013). Richards and Stokes (2004) and Boyland (2006) discussed in detail the equations used to determine the break-even Carbon credit price. Typically, the total cost of the project includes harvesting, silviculture, opportunity, Carbon project initial establishment and validation, and Carbon project verification costs. In the case of the harvest reduction strategies, the opportunity cost of the timber left standing, as opposed to generating revenue from harvesting, is not always included in the financial analysis. For example, Huang and Kronrad (2001) did not include the opportunity cost and this resulted in lower average costs to store one additional mg of Carbon for stands with higher site index (i.e. top height in meters at age 50). In a different study that analyzed the increased forest growth strategies, which do not have opportunity costs due to harvest reduction, Bull (2010) also found lower break-even Carbon credit prices for higher site indices.

Financial analyses of forest based Carbon projects that include the opportunity cost due to harvest reduction are needed in order to provide better estimates for the break-even Carbon credit price when considering actual forest estates. However, using site index as the universal measure of site productivity can be problematic when comparing different forest estates composed of different species and site conditions. Thus, it is necessary to develop a metric that represents the opportunity cost of reducing harvests in favor of storing Carbon. This new metric will have to be sensitive to site productivity, tree species, and log quality.

In this study, three small-scale actively managed forest estates located in the Coastal, Central Interior, and Northern Interior forest regions in British Columbia that cover a wide range of species, forest types, and timber net revenues are considered. The objectives of this study are: (1) to propose a new metric that represents the opportunity cost of reducing harvests in favor of storing Carbon, (2) to determine the break-even Carbon credit price for three small-scale actively managed forest estates when reducing the harvest below the baseline level, and (3) to examine how the break-even Carbon credit price varies with the new metric developed in (1) for the three forest estates. These are important questions for jurisdictions such as British Columbia where there are large tracts of publicly owned forests that might be considered for Carbon projects.

2. Methods

2.1. Forest estates

Three actively managed forest estates were used to conduct the analysis in this paper. The Alex Fraser Research Forest (AFRF) (average site index of 22.1 (range 15–26)) located in the Central Interior forest region of British Columbia and the Malcolm Knapp Research Forest (MKRF) (average site index of 25.6 (range 20–40)) located in the Coastal forest region of British Columbia are described in detail in Man et al. (2013). The third forest estate (FE3) is 14,920 ha in size and is located in the boreal plains, approximately 40 km South East of Dawson Creek, British Columbia. It falls entirely into the Boreal White and Black Spruce Biogeoclimatic Ecosystem Classification (BEC) zone, with the Western third in the dry cool subzone and the rest in the moist warm subzone. Lodgepole pine (*Pinus contorta*) covers approximately half of the land base while the other half is covered by mixed stands of white spruce (*Picea glauca*), black spruce (*Picea mariana*), and trembling aspen (*Populus tremuloides*). Mountain pine beetle (*Dendroctonus ponderosae*) disturbed most of the lodgepole pine stands since 2003 at an average attack rate of 30%. Wildfires and forest harvesting since 1978 have created a mosaic of even aged stands, 76% of the land base being covered by 80 to 160 year old stands. The average site index at FE3 estimated from the existing inventory excluding all non-forested areas is 14.7 (range 6–22).

2.2. Simulation models

Two forest-level models (the Forest Planning Studio (FPS-ATLAS) (Nelson, 2003) and the Carbon Budget Model for Canadian Forest Sector (CBM-CFS3) (Kurz et al., 2009)) were used to forecast the timber supply, standing volume, and Carbon stocks. The growth and yield curves were either extracted from the Timber Supply Area Analysis Reports where the forest estate resides (British Columbia Ministry of Forests, 2001, 2002, 2003) or developed from the existing inventory using stand level yield prediction systems. The Variable Density Yield Prediction (VDYP) was used to generate the growth and yield curves for the stands regenerated naturally following a stand replacing disturbance (e.g. wildfire) and the Table Interpolation Program for Stand Yields (TIPSY) was used to generate the growth and yield curves for the stands regenerated artificially following harvesting–planting events (British Columbia Ministry of Forests, Lands and Natural Resource Operations, 2012). In the case of the AFRF and MKRF, the methodology used to build the timber supply model in FPS-ATLAS and to transfer the disturbance schedule into CBM-CFS3 was documented in Man et al. (2013). A similar methodology was used in the case of the FE3 where 2737 spatially explicit polygons were grouped into 32 stand types based on species composition, regeneration type (natural or artificial through planting), BEC, and site index. In order to increase forest response flexibility to predicted climate changes (Burton and Cumming, 1995; Hamann and Wang, 2006; Swift and Ran, 2012), lodgepole pine dominated stands with small pockets of trembling aspen and white spruce were promoted at FE3. These factors combined with the management objective of timber production determined the implementation of the clearcut system (one cut at age 60–170 depending on site productivity and quality of harvested products) on the entire timber harvest land base.

2.3. Forest management strategies to generate Carbon credits

2.3.1. Baseline determination

Using the approach detailed by Man et al. (2013), the baseline long term sustainable yields for 100 years were determined to be 14,800 m^3 $year^{-1}$ at AFRF, 27,000 m^3 $year^{-1}$ at FE3, and 33,000 m^3 $year^{-1}$ at MKRF, while satisfying a series of constraints imposed by the forest management objectives of the forest estates (e.g. minimum harvest ages, protected areas, retention levels, and harvesting priorities). The simulations were run for 100 years with the harvesting algorithm being programmed to treat oldest stands (and infested mountain pine beetle stands at FE3) first and the commercial thinning before final cuts (e.g. clearcuts, shelterwood, uneven aged management system).

2.3.2. Reduced harvest to a fixed target level

The various strategies to reduce the harvest below the baseline level have been investigated in the past (Harmon and Marks, 2002; Seely et al., 2002; Peng et al., 2002; Harmon et al., 2009; Nunery and Keeton, 2010) and little difference in Carbon stocks has been found between these strategies (Man et al., 2013). Man et al. (2013) suggested that reducing the harvest to a fixed target level provides more flexibility to the forest manager since it poses fewer constraints than increasing rotation ages or increasing area in reserves. Thus, this study uses harvest reduction to a fixed target level for analysis. In order to continue to meet the objectives of the actively managed forest estates considered in this paper, a minimum accepted harvest level had to be determined. For the three forest estates analyzed in this paper, the minimum accepted harvest level varied between 50% and 30% of the baseline harvest level. To permit comparison between the forest estates considered