Forest Ecology and Management 305 (2013) 239–247

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Potential of alternate forest management practices to sequester and store Carbon in two forest estates in British Columbia, Canada

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ARTICLE INFO

Article history:
Received 22 January 2013
Received in revised form 30 April 2013
Accepted 24 May 2013
Available online 3 July 2013

Keywords:
Harvest level
Carbon storage
Carbon sequestration
Carbon credits
Carbon offsets
Forest management

ABSTRACT

This paper uses the inventory of two different actively managed forest estates located on the Coast and Interior forest regions in British Columbia to analyze the potential of alternate forest management practices to sequester and store Carbon while achieving a range of management objectives. Strategies that increase growth rates (fertilization and the use of genetically improved growing stock) and a fixed reduction in the harvest level were analyzed to determine the magnitude of the difference in terms of stored Carbon. The performance of the harvest reduction strategies (fixed harvest level, increased rotation age, and increased area in reserves) was analyzed in more detail to determine if there is a reason for the forest manager to favor one of these strategies over the others, and whether this choice is the same for both forests considered in this paper. Strategies that reduce harvest levels stored significantly more Carbon over the 100-year planning horizon as compared to strategies that increase growth rates. For both forest estates, little difference was observed between the harvest reduction strategies (less than 4.1% over 100 years). However, the fixed harvest level strategy allows the forest manager to shift the harvesting to various areas in order to respond to an uncertain future while accommodating the various management objectives of the forest estate.

1. Introduction

Various authors have suggested that properly managed forest ecosystems can become Carbon sinks and continue to meet the timber, fiber, and energy needs of society (Cooper, 1983; Smith et al., 1993; Parker et al., 2000; Kurz et al., 2002). It is generally accepted that there are three major strategies to sequester and store Carbon in forest ecosystems (reported in Mg of Carbon Dioxide equivalent (CO_2e)[1] throughout this paper); (1) conserve the existing forest landbase by avoiding conversion to other uses, (2) increase the forest landbase through afforestation or reforestation, and (3) use of alternate forest management practices. Alternate forest management practices can either reduce harvest levels from the business as usual (baseline) level, or maintain the baseline harvest level while promoting higher growth rates. It is also possible to have a combination between these two groups of strategies. Understanding the mechanisms that trigger the accumulation of CO_2e in a forest ecosystem when alternate forest management practices are implemented is a complex problem. Factors that affect the complexity of modeling CO_2e storage include; the starting inventory, forecasting the inventory, harvesting schedule based on constraints resulting from management objectives, and the transfer of all these from a spatially explicit timber supply model into a Carbon budget model.

There are examples in the literature and on the ground of using alternate forest management practices to sequester CO_2e. Studies considering strategies that increase growth rates found that the use of genetically improved stock and fertilization can add up to 48% more volume to the trees and thus more stored CO_2e (Schroeder, 1991; Lai et al., 2002; Jassal et al., 2010; Stoehr, 2011). CO_2e storage can be increased by 13% over 40 years using genetically improved stock (Aspinwall et al., 2012) and by 9% after 300 years using fertilizers (Seely et al., 2002). Studies on harvest reduction strategies have been mainly focused on switching from even aged to uneven aged management systems, a fixed reduction of the harvest level from the baseline level, and increased rotation length, while strategies to increase the portion of a forest that is excluded from harvesting (i.e. increasing the area in reserves) has received little attention. Previous authors have found that switching from even aged to uneven aged management systems can increase CO_2e storage from 6% over 140 years (Taylor et al., 2008) to more than 100% over longer periods of time (Harmon et al., 2009; Nunery and Keeton, 2010). CO_2e storage can be increased by 5% over 100 years if the harvest level is reduced by 52% (Colombo et al.,

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[1] One Mg of CO_2e indicates the global warming potential of one Mg of Carbon Dioxide for various greenhouse gases as defined in ISO 14064-1 (2006). In a forest ecosystem, the Carbon storage is estimated in Mg of Carbon and then converted to Mg of CO_2e (1 Mg of Carbon is 3.667 Mg of CO_2e).

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http://dx.doi.org/10.1016/j.foreco.2013.05.059

2012), to more than 140% over 500 years when harvested biomass is reduced by 20% (Harmon and Marks, 2002), or 40% over 500 years when leaves and branches are not harvested (Peng et al., 2002). Previous authors demonstrated that increasing rotation length by 50% increased stored CO_2e by 23% over 160 years (Nunery and Keeton, 2010), if the rotation length was increased by 100%, the stored CO_2e over 500 years was increased by 31% (Peng et al., 2002), and if the rotation length was increased by 200%, the stored CO_2e over 300 years was increased by 81% (Seely et al., 2002), or 150% over 500 years (Harmon and Marks, 2002). These results depended largely on study location, intensity of the strategy considered, accounting for natural disturbance dynamics (e.g. wildfire), and the length of the planning horizon. When comparing the performance of the harvest reduction strategies the emphasis has been on CO_2e storage, with less emphasis being placed on the ability of the forest manager to meet other management objectives. For example, in the case of increased rotation length, these studies did not consider whether there would be a reduction in the annual harvest volume if the forest manager tried to maintain baseline harvest levels. The literature on the alternate forest management practices to sequester CO_2e seems to indicate that in temperate forests, strategies that increase growth rates are less efficient at storing CO_2e than harvest reduction strategies.

On the ground, there are two examples of Carbon offset projects in British Columbia; Darkwoods Forest Carbon Project (The Nature Conservancy of Canada, 2011) and the TimberWest Strathcona Ecosystem Conservation Project (Pacific Carbon Trust, 2011). These projects were established respectively on approximately 55,000 ha for 100 years, and 25,000 ha for 25 years. The Darkwoods project estimated a 100% increase in stored CO_2e over 100 years, when the harvest level was reduced below the baseline; however, the reduction level varied greatly (0–97%) as the baseline level was not constant throughout the planning horizon. While the stored CO_2e increase from the baseline is relatively high after 100 years, comparison with other findings is difficult due to the baseline calculation. The TimberWest project uses a strategy that conserves old-growth forest that would be logged in the absence of the project. The TimberWest project forecasts an increase of 8.75 M Mg of CO_2e over the baseline, and given the project area of 25,000 ha the CO_2e stored per hectare is 350 Mg after 25 years. Based on its project plan summary document (Pacific Carbon Trust, 2011), 350 Mg of additional CO_2e per hectare indicates that the baseline for the TimberWest project assumes most of the old growth area is operable, and that the harvest level for this old growth is reduced to zero. However, since the remaining old growth tends to be at higher elevations and in more difficult terrain, it is likely a portion of the old growth is not accessible, and the baseline harvest level could be overestimated. Thus, the magnitude of the additional CO_2e stored could also be overestimated.

Some of the past studies have compared strategies that reduce harvest levels or promote growth rates on somewhat theoretical forests. Such theoretical forests were comprised of a reduced number of species or having a normal age class distribution. This paper will compare these Carbon sequestration strategies on two different, real forest estates in British Columbia that are being actively managed for a range of values, to determine if the finding that harvest reduction will outperform increased growth rate holds true. Furthermore, for the forest management practices that employ harvest reduction strategies, this paper will consider the performance of four strategies; fixed harvest level, increased rotation age, and two strategies that increase area in reserves. These four strategies will be compared based on CO_2e and forest age class distribution over a range of harvest levels. The objective here is to determine if there is a reason for a forest manager to favor one of these strategies over the other three, and whether this choice is the same for both of the forests considered in this paper.

2. Methods

2.1. Forest estates

The Alex Fraser Research Forest (AFRF) is a 9812 ha forest subdivided into two blocks near Williams Lake, British Columbia. The Knife Creek block (3487 ha) is adjacent to the San Jose Valley in the Interior Douglas Fir Biogeoclimatic Ecosystem Classification zone (BEC). Most of this block is in the dry-cool variant with small components of very-dry variant and Sub-Boreal Pine-Spruce BEC zone, moist-cool variant on site classes between 15 and 26 (height in meters at age 50). Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) and lodgepole pine (*Pinus contorta*) dominate these forests which have been shaped since the mid-1940's by frequent wildfires and logging activity into an uneven aged stand condition. The Gavin Lake block (6315 ha) is located adjacent to the Beaver Valley in the Sub-Boreal Spruce BEC zone, dry-warm variant with a significant component of Interior Cedar-Hemlock BEC zone, moist-cool variant on site classes ranging from 15 to 20. Interior Douglas-fir (*P. menziesii* var. *glauca*), hybrid spruce (*Picea galuca x Picea engelmanii*) and western redcedar (*Thuja plicata*) dominate these mid-seral and mature stands. The Western half of the Gavin Lake block has been shaped since the early 1960s to an uneven aged stand condition by the wildfires and logging activity, while the Eastern half has been converted to a timber production area of even aged stands with age classes ranging from 20 to 250+ years.

The Malcolm Knapp Research Forest (MKRF) is a 5157 ha forest estate located in the foothills of the Coast Mountains, approximately 60 km East of Vancouver, British Columbia. It falls entirely into the Coast Western Hemlock BEC zone, with the Southern half in the dry maritime subzone, and the Northern half in the very wet maritime subzone, with most of the site classes between 20 and 40. Coniferous trees dominate these stands, the most common being Coastal Douglas-fir (*P. menziesii* var. *menziesii*), western redcedar (*T. plicata*) and western hemlock (*Tsuga heterophylla*). Wildfires and logging have created a mosaic of even aged stands, with the Western half being covered by 120 year old stands and the Eastern half by 70 year old stands, and some small patches of 400+ year old stands are spread throughout the Northern portion of the forest estate. In addition, forest harvesting since 1949 has led to a range of second and third growth age classes from 1 to 40 years.

2.2. Simulation models

Forest Planning Studio (FPS-ATLAS) (Nelson, 2003), a spatially explicit forest-level planning model, was used to report for each planning period and for every spatial unit the volume harvested, the standing volume, and the area by age class for 100-year planning horizon. Two major sources of information were required to build the FPS-ATLAS database; (1) GIS databases for the forest estates, and (2) growth and yield information of the forest inventory. The GIS databases provided spatial (e.g. coordinates, area), ecological (e.g. BEC zone), forest inventory (e.g. species, site class, age), and planning information (e.g. land-use change) that was used to develop the spatial planning units (i.e. polygons) in FPS-ATLAS. At AFRF, there are 8670 such polygons grouped into 213 stand types based on forest inventory variables, ecological, and planning information. There are three silviculture systems at AFRF; (1) the clearcut system, which is implemented on 15% of the timber harvest landbase (THLB), consists of one 40% commercial thinning at age 60 and final cut at age 100, (2) the shelterwood system, which is implemented on 2% of the THLB, consists of one 40% commercial thinning at age 60, a seeding cut (50% volume removal) at age 100, and a final cut at age 110, and (3) the uneven aged system, which is