APPENDIX 2
CARBON MODELLING

ENHANCED TYPE 2 SILVICULTURE ANALYSIS
BOUNDARY TSA

Timberline
Natural Resource Group

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1.0 INTRODUCTION

It is widely believed that greenhouse gasses (GHG) such as carbon dioxide ($C0_2$), in the atmosphere can contribute to climate change. Forest ecosystem carbon sequestration accounts for 80–90% of terrestrial plant carbon; and 30–40% of soil C in the world (Schlesinger 1997) and they have large capacities to both store and release carbon (Kurz et al. 2002). Our forests can sequester carbon to reduce the accumulation rate of $C0_2$ in the atmosphere or do the contrary and be a net source of carbon (stemming from $C0_2$ emitted during normal plant respiration and more importantly, decomposition) that increases the accumulation rate of atmospheric $C0_2$.

The province of British Columbia (BC) has experienced an overwhelming epidemic of mountain pine beetle (MPB), which has affected over 530 million m^3 of pine throughout the BC Interior (MoFR, 2007). The epidemic is expected to continue until it has affected over 1 billion m^3 of pine (MoFR, 2007). Natural Resource managers are obligated to make timely management decisions such as where, when and how to salvage MPB affected stands and alternatively what stands to leave for future timber supply or other landbase objectives such as hydrology, biodiversity, habitat, and seral stage distribution. To date there has been little consideration for the impact that forest management decision have on carbon stocks.

In the Boundary TSA a Type 2 Silviculture Analysis was carried out to look for opportunities to mitigate timber supply impacts and environmental impacts of the MPB epidemic. In the analysis the ‘status quo’ management regime is modeled as a basecase, upon which there are many modeling runs done to test the timber supply impact of management decisions and modelling assumptions. Using all the findings from the analysis a proposed scenario was created, which is a recommended management regime. This recommended scenario is done without considering the impacts on carbon budgets.

The purpose of this section of the analysis is to understand how the proposed scenario impacts forest ecosystem carbon budgets. This is done by recreating both scenario, the basecase and the recommended scenario, in the Carbon Budget Model (CBM) of the Canadian Forest Sector (CBM-CFS3) and analyzing the results.

1.1 Background

The CBM (CFS3) is a landscape level carbon accounting framework that simulates, for a selected period of time, carbon dynamics of above-ground and below-ground forest biomass and dead organic matter. Landscape-level forest carbon accounting is carried out in the CBM-CFS2 by tracking the carbon dynamics associated with both stand-level and landscape-level processes[1]. It is also considered an inventory-based model, which relies on growth and yield data to estimate carbon stock budgets (Kurz & Apps 1992, 1996). The model can be used either to assess past changes in carbon stocks or to evaluate future changes (monitor) that would result from different management scenarios.

The CBM can simulate carbon dynamics at multiple scales, and is able to process harvest schedules and management assumptions to model and report on the carbon stocks. The CBM (CFS3) has 2 main roles, 1. monitoring past forest carbon stocks and changes in carbon stocks, and 2. predicting future carbon stocks and changes in carbon stocks through scenario and risk analyses.

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[1] http://carbon.cfs.nrcan.gc.ca/cbm/index_e.html - accessed June 17, 2008

Carbon stock is the absolute quantity of carbon held within a pool at a specified time. A pool is a reservoir or system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils, the atmosphere and dead organic matter (DOM). The carbon stock change is the difference in the amount of carbon in a given carbon pool over a period of time. The CBM (CFS3) accounts for carbon stocks and carbon stock changes in two pools;

1. Tree biomass; and
2. DOM.

2.0 METHODOLOGY

2.1 Conceptual Model and Input Data

Figure 3.2.1 shows the modelling approach used in this case study for utilizing timber supply analysis inputs and outputs to run CBM-CFS3 carbon modelling. The top box with the dashed line is a summary of the sources and types of information used by the CBM-CFS3 model. This process was designed so that the sources of information would fit into a timber supply analysis framework such as:

- Species, age and height are from the vegetation resource inventory (VRI),
- Variable Density Yield Prediction (VDYP – version 7.0 2007) was used for natural stand yield curves;
- the Table Interpolation Program for Stand Yields (TIPSY – version 4.1 2007) was used for managed stand yield curves
- Harvest schedules were an output of the timber supply model;
- MPB stands were affected as projected by the MoFR BC MPB Beetle projections; and
- Natural disturbances were implemented at rates consistent with Biodiversity Guidebook (1995).

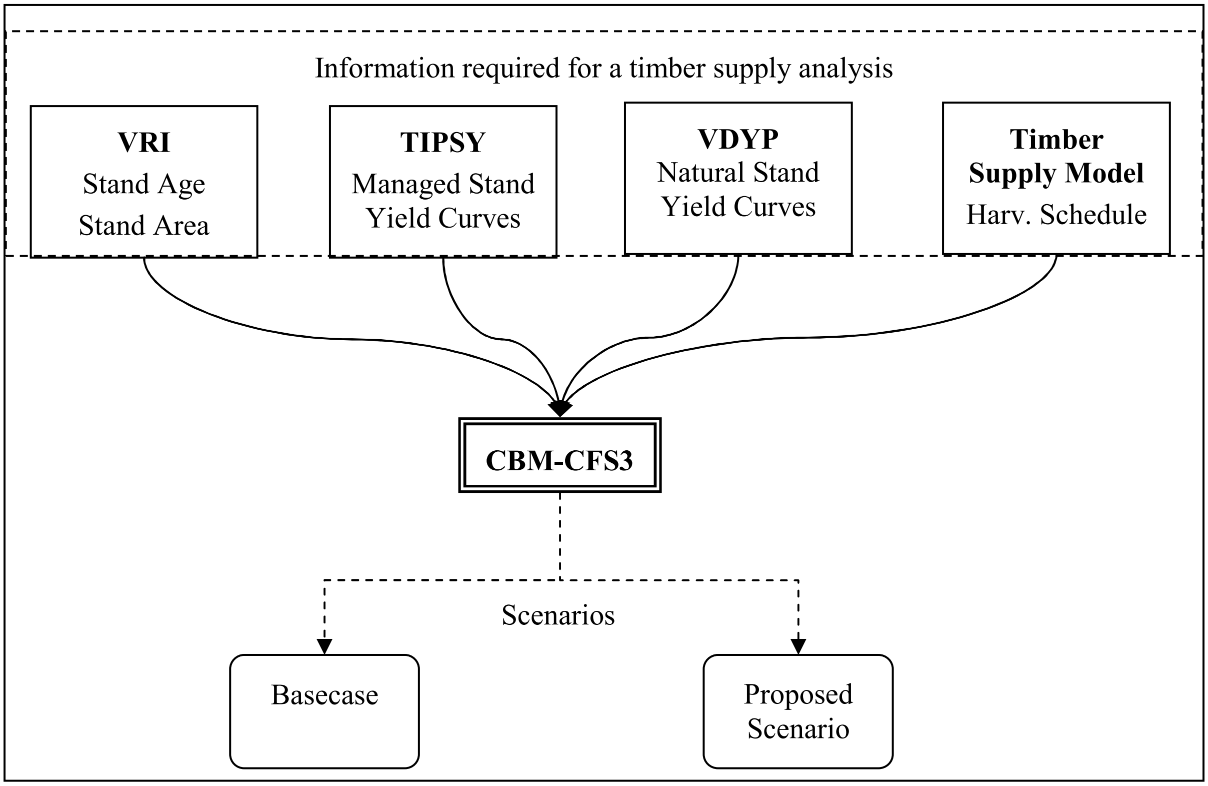

Figure 3.2.1 Modelling approach for Implementing Carbon Scenarios

2.2 Scenario Descriptions

In this study, two main scenarios were modelled:

1. MPB basecase; and
2. Proposed scenario.

The following paragraphs describe the major assumptions and differences in assumptions between the two scenarios. The modeling assumptions are documented in detail in the *Information Package* (Timberline, 2008).

2.2.1 Basecase

The basecase uses the best information available and models the current management regime. In brief, this includes:

- Using the 2003 VRI version updated for disturbances (using 2007 RESULTS data) and projected to 2007;
- A netdown resulted in 276,457 ha of timber harvesting land base (THLB) and 180,405 ha of non-THLB productive land;
- MoFR MPB projections to 2017 were used to estimate the MPB impacts on the Boundary TSA; they were enacted after 10 years (2017). Consistent with the timber supply analysis, the percentage killed was dependent upon the projected severity of MPB infection. Depending on infection levels, stands could be 100%, 40%, 20% or 5% killed;
- Initial harvest rate of 700,000 m^3/year with 30% targeting MPB affected stands;
- Harvest systems are mostly clear cut with a small amount of partial harvesting;
- Resource Management Zones (RMZ) used are: connectivity corridors, community watersheds, KBHLPO mature requirements, mule deer winter range (MDWR), moose and visual quality objectives (VQO) (*Information Package*, Timberline, 2008);
- Disturbing a proportion of the non-THLB[2] productive landbase to mimic natural disturbances such as fire and achieve a natural range of variation as expected in the Biodiversity Guidebook (1995). The annual disturbance area was calculated from the area weight average fire return interval (by BEC-NDT). This results in an annual non-THLB disturbance of 10,000 ha; and
- Climatic assumptions were based on the 30 year (1971 – 2000) average normal temperature (7.7˚C) and precipitation (509.8mm) obtained from the Grand Forks weather station (www.climate.weatheroffice.ec.gc.ca).

2.2.2 Proposed Scenario

The proposed scenario has been made in consultation with the Ministry of Forests and Range (MoFR) considering all the finding in the analysis. The following points outline the main changes made from the basecase.

- Increase the harvest in MPB affected stand to 275,000 m^3/year in the short term;
- Decrease the harvest level for the first 10 years to a value of 550,000 m^3/year.

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[2] The non-THLB is defined as productive forest that is not eligible or suitable for harvesting. The determination of the THLB and non-THLB is described in detail in the Boundary TSA Type 2 Information Package (Timberline, 2008).

- Aggressively reforest unsalvaged severely affected MPB stands with a site index (SI) >= 15 (approximately 38,601 ha in the project area);
- Harvest levels adjusted in short and mid-term as shown in Section 2.2.3;
- Fertilize Douglas-fir and spruce leading stands with an SI >= 18 leading (approximately 10,076 ha in the project area); and
- Proposed wildlife habitat areas are not available for harvest (removed from the THLB) (approximately 668 ha in the project area).

2.2.3 Harvest Levels

A major difference between the two scenarios is the harvest level. Figure 3.2.2 shows the harvest level for both scenarios. The basecase harvest level is initially at the current AAC of 700,000 m^3/year for 10 years before dropping down to a post MPB epidemic level of 422,000 m^3/year in the mid term. In contrast, the proposed scenario has a harvest level of 550,000 m^3/year for 70 years. The long term harvest level is similar between the two scenarios with a supply of 746,000 m^3/year in the basecase and 754,000 m^3/year in the proposed scenario.

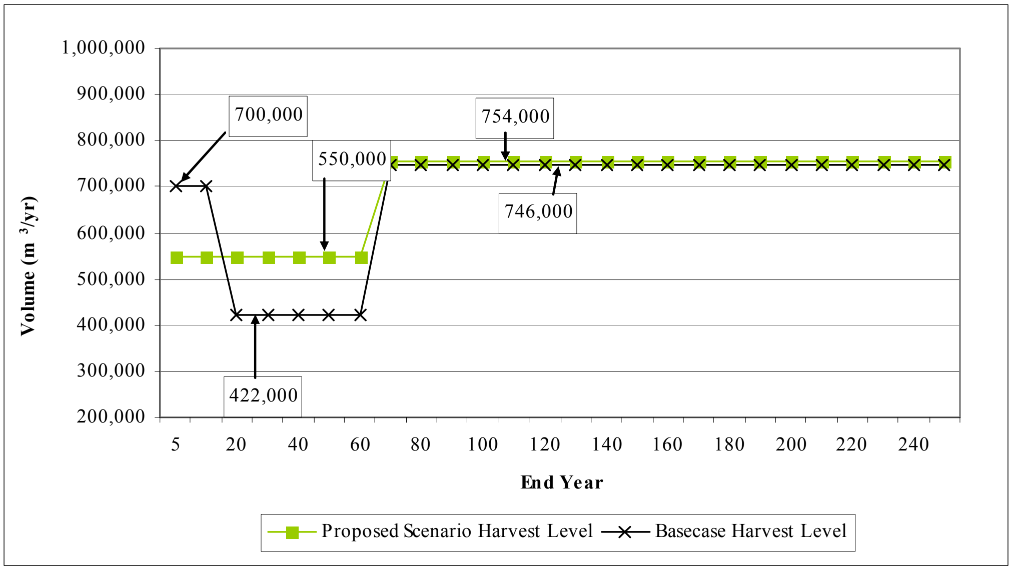

Figure 3.2.2 Harvest Level for Basecase and Proposed Scenario

3.0 RESULTS AND DISCUSSION

This section presents the results from the CBM-CFS3 for the Boundary TSA. The results are organized into the following sections:

1. Disturbances;
2. Carbon Stock Changes;
3. Carbon Stocks (below ground, above ground DOM and total ecosystem); and
4. Green House Gases Emission (specifically CO_2 (carbon dioxide) and CH_4 (methane gas)).

3.1 Disturbances

Carbon stock changes are dependent on the predicted disturbance schedule. Figure 3.2 and Figure 4.2 show the area disturbed over the 200 year modelling horizon by disturbance type for the basecase and proposed scenario, separately. A brief description and interpretation of the predicted disturbances that are shown in Figure 3.2 and Figure 4.2 is as follows:

- Mountain pine beetle. The large spike of area in year 10 is the lodgepole pine death as a result of the MPB epidemic. There is ~75,000 ha disturbed by MPB, whereas the proposed scenario has, ~20,000 ha disturbed by MPB. The difference is associated with the proposed scenario having increased harvest in the MPB affected stands and implemented and aggressive reforestation program in the MPB affected stands.
- Wildfire. As mentioned above, an average of ~10,400 ha/period was modelled to burn on the non-THLB in both scenarios. This number is based on the average fire return interval in the biodiversity guidebook (1995).
- Clear cut harvesting. This disturbance is the largest accumulative disturbance across the modelling horizon. The line that represents this disturbance in Figure 3.2 and Figure 4.2, follows the harvest level found in the Type 2 timber supply analysis (Analysis Report, Timberline, 2008) but fluctuates due to harvest area being reported instead of harvest volume. In the basecase, around 2,000 ha/year are harvested in the mid term and 3,750 ha/year in the long term. The increased area in the long term is a function of the increased harvest level as well as the reduced volume per hectare.
- Partial harvesting. The small dashed line shows the area partially harvested by year across the planning horizon. This area is relatively small when compared to the lines representing clear cut or fire activity.

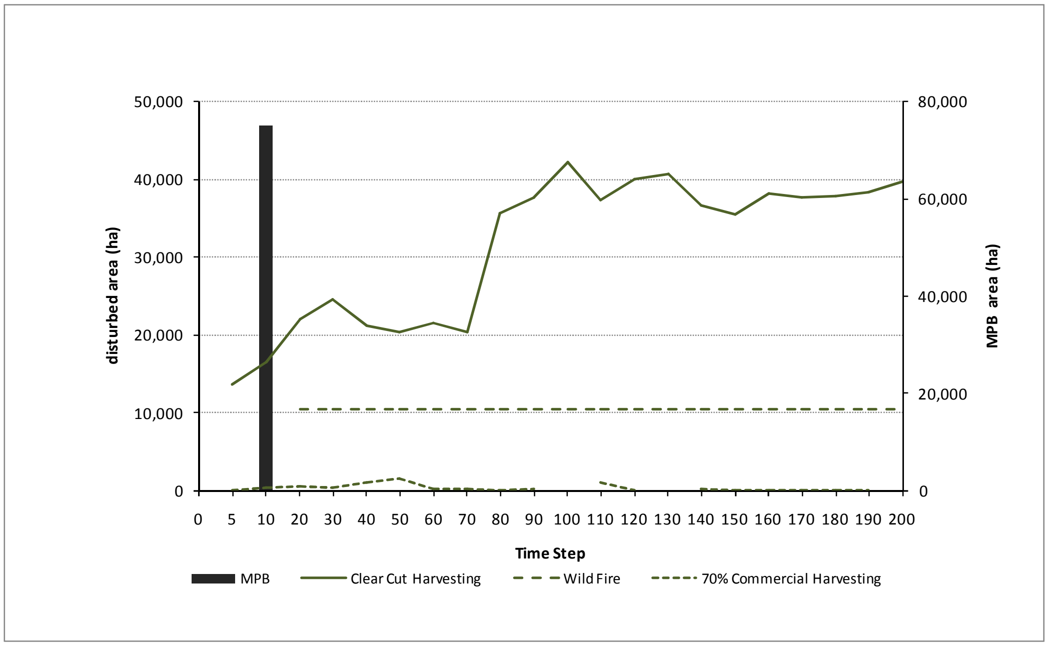

Figure 3.1 Basecase Scenario Disturbance Area

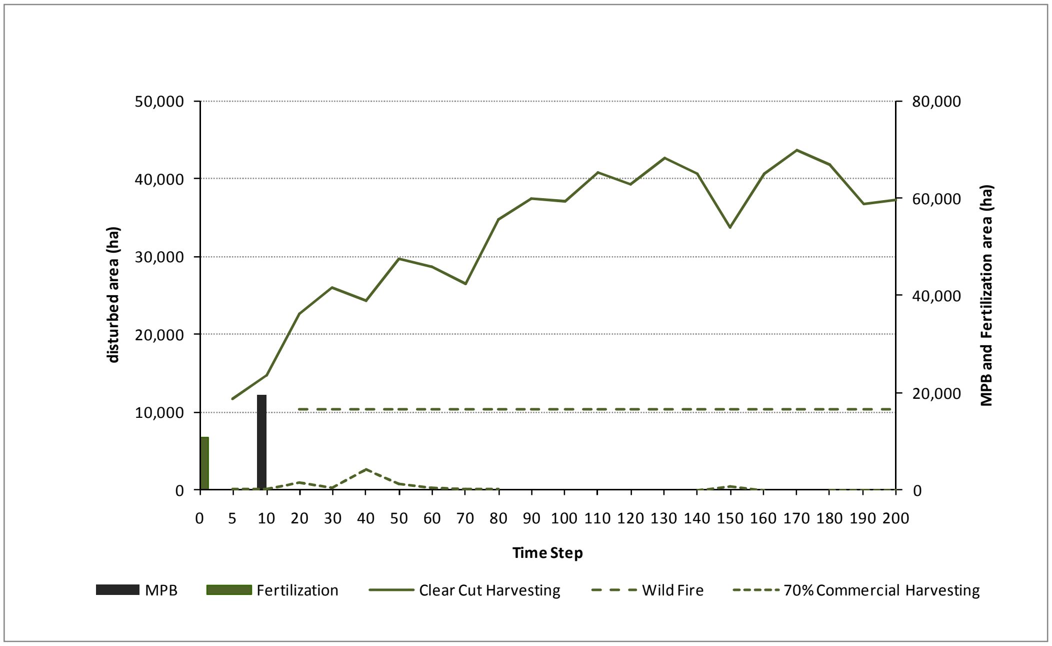

Figure 3.2 Proposed Scenario Disturbance Area

3.2 Carbon Stock Changes

This section is comprised of four sub-sections:

1. Biomass stock changes (below-ground, above-ground, and total);
2. DOM stocks changes (below-ground, above-ground, total DOM, and snag);
3. Total ecosystem carbon stocks changes; and
4. Carbon stock changes over the first 20 years

3.2.1 Biomass Carbon Stock Changes

Figure 3.4 shows the changes in carbon stock by biomass (living organic matter) over the modelling horizon. Living biomass is the only component that directly absorbs atmospheric CO_2. The proposed scenario realizes a fertilization burst at year one, and less timber harvesting in the first 10 years, thus, the net biomass carbon stock changes are higher in the proposed scenario than the basecase (Figure 4.3). The higher spike of biomass carbon loss (over 900,000 tonnes of carbon (T C)) was in scheduled MPB attacked stands (10 years, black line). However, the low harvest level and high growth rate in young regenerating forests lead the living biomass to be a carbon sink after 15-17 years (at year 35). In the proposed scenario the resumed higher harvest levels between years 20 and 70 turn the stands into a net source of carbon. Over the modelling period, the basecase and proposed scenario are net sources of carbon approximately 54,000 and 3,600 T C/year, respectively.

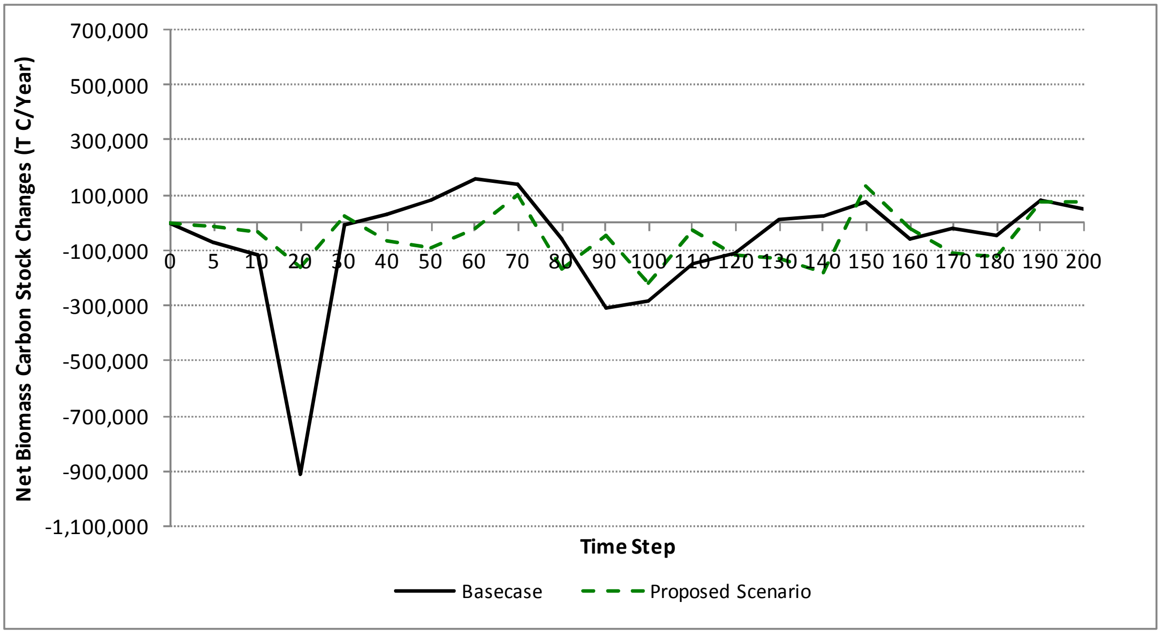

Figure 3.3 Biomass Carbon Stock Changes

3.2.2 Dead Organic Matter Carbon Stock Changes

Figure 4.4 shows the changes in carbon stock by dead organic matter (DOM) over the modelling horizon. DOM results from natural forest senescence and disturbances such as harvesting slash, insect attacks, and storm damage. Dead organic matter releases CO_2 through decomposition processes at a relative low rate. Thus, ecosystem transfer of living biomass into DOM is a means of extending carbon resident time in a fixed status. The DOM spikes at scheduled MPB attack for both the basecase and proposed scenario (Figure 4.4). The harvest level determines DOM variations in other years. For example, the first basecase has a higher DOM because of its low harvest level, while between 30 and 70 years, the proposed scenario harvest drives the DOM much higher than basecase. Over the modelling horizon, about 36,000 and 40,000 T C/year were lost from DOM in the Boundary TSA land base in the basecase and proposed scenario, respectively.

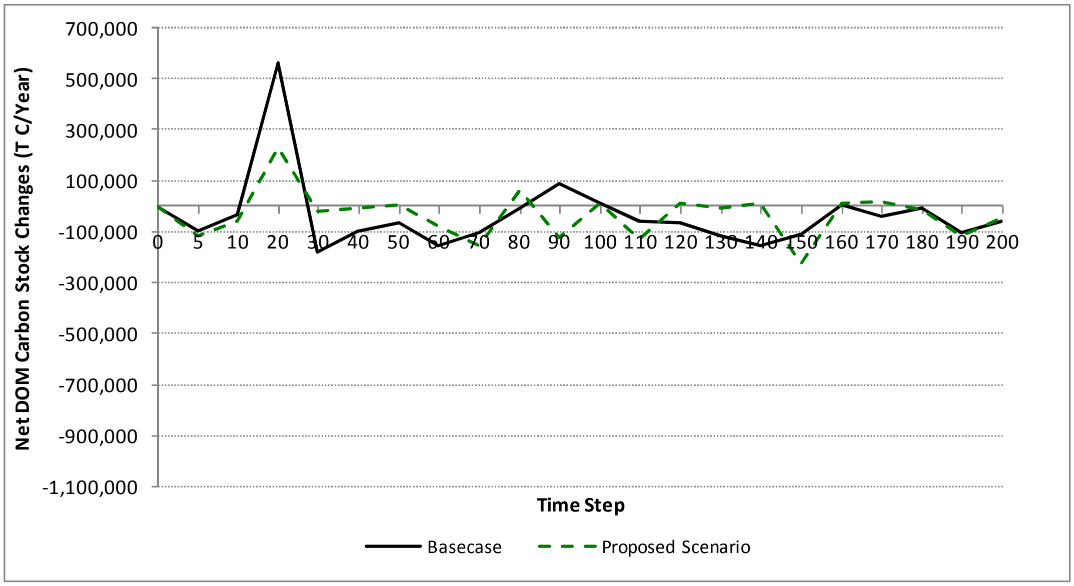

Figure 3.4 Dead Organic Matter Carbon Stock Changes

3.2.3 Ecosystem Carbon Stock Changes

Figure 3.5 shows total ecosystem carbon stock changes. The proposed scenario has a higher net ecosystem carbon stock change (green dished line) due to:

- Fertilization effects on over 10,000ha of land, which directly prompts biomass production[3];
- Aggressive reforestation in some MPB affected areas speeds up regeneration and increases biomass production; and
- Lower harvest levels in non-MPB affected stands.

The basecase on the contrary, becomes a net sink with an average of 22,000 T C/year between 50 and 70 years because of the lowered harvest levels (Figure 3.2 above). However, as the young stands become harvestable, timber harvesting increases making the ecosystem a net carbon source. Over the modelling period, the ecosystem as a carbon source of 90,000 and 76,000 T C/year for the basecase and proposed scenario, respectively.

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[3] The carbon used for making and applying the fertilization was not considered, however this can and would be considered in full carbon accounting.

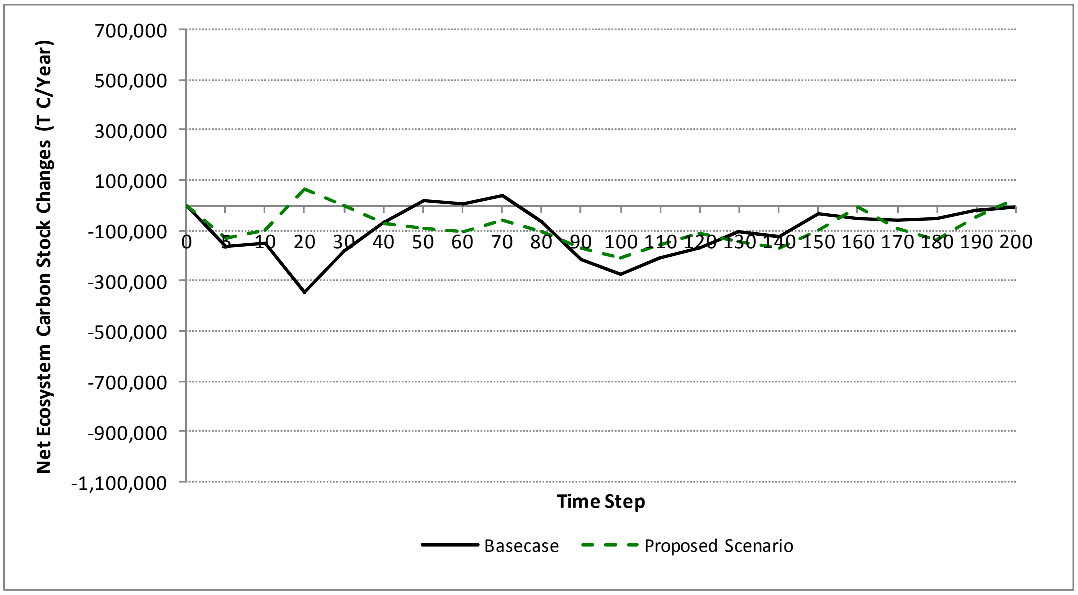

Figure 3.5 Ecosystem Carbon Stock Changes

In summary, the ecosystem is a carbon source for both scenarios over the simulated time frame. Living biomass gains carbon through photosynthesis, but it is less than the disturbance rate removing biomass carbon from the ecosystem. The DOM losses carbon through decomposition processes, while gaining carbon through natural senescence (especially as DOM returns to the soil), and occasionally it can gain large amounts of carbon through extreme events such as MPB attack.

3.2.4 Carbon Stock Changes Over the First 20 Years

This section shows the biomass, DOM and total carbon stock changes over the first 20 years (instead of 200 years). This is the short term difference in carbon stocks resulting from implementing the proposed management regime. The graphs exclude the mid and long-term differences in carbon stock, which are largely due to different harvest levels[4].

Figure 3.6 shows the changes in biomass carbon stock over the first 20 years in five year increments. Both scenarios have a negative change in biomass over the 20 years. The biomass levels in the MPB basecase declines at a faster rate because of a higher initial harvest levels and no reforestation activity. In the basecase scenario, the biomass ecosystem carbon loss is at a rate of 94,000 T C/year for the first ten years, and 908,000 T C/year for the second ten year period. However, in the proposed scenario, the ecosystem biomass carbon loss is at a rate of 22, 000 T C/year for the first ten years, and 162,000 T C/year for the second ten year period. The fertilization and aggressive reforestation still cannot compensate harvesting biomass removal in the proposed scenario. Over the 20 year period, loss of carbon from biomass is at rates of 69,000 and 366,000 T C/year in proposed and basecase scenario, respectively.

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[4] The future harvest level is a future management decision so it has been excluded from this graph. The proposed changes in the current management regime will improve the timber supply in the future, but it is not fair to conclude that the future carbon stocks will be less because the proposed scenario allows for more harvest.

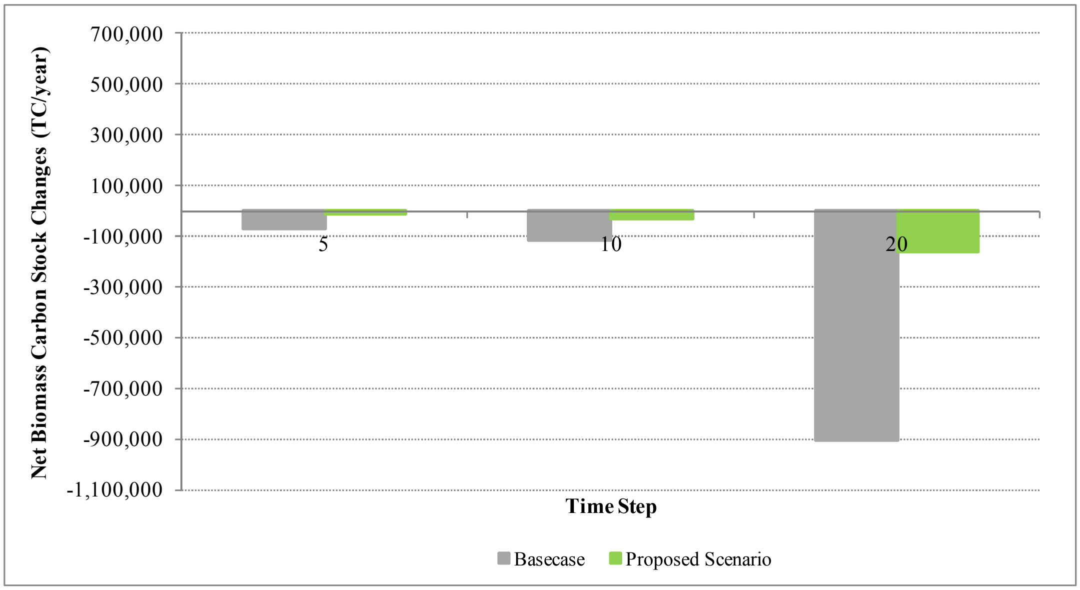

Figure 3.6 Biomass Carbon Stocks Changes Over the First 20 years

Figure 3.7 shows the changes in DOM carbon stock over the first 20 years. The net DOM carbon loss after compensating for harvest inputs is through decomposition processes, at rates of 92,000 and 63,000 T C/year over the first ten years for proposed and basecase scenario, respectively. However, the net DOM carbon gain of 565,000 and 228,000 T C/year during the second ten year period for basecase and proposed scenarios, respectively, is largely due to the MPB attack, aggressive reforestation, and higher initial harvest level.

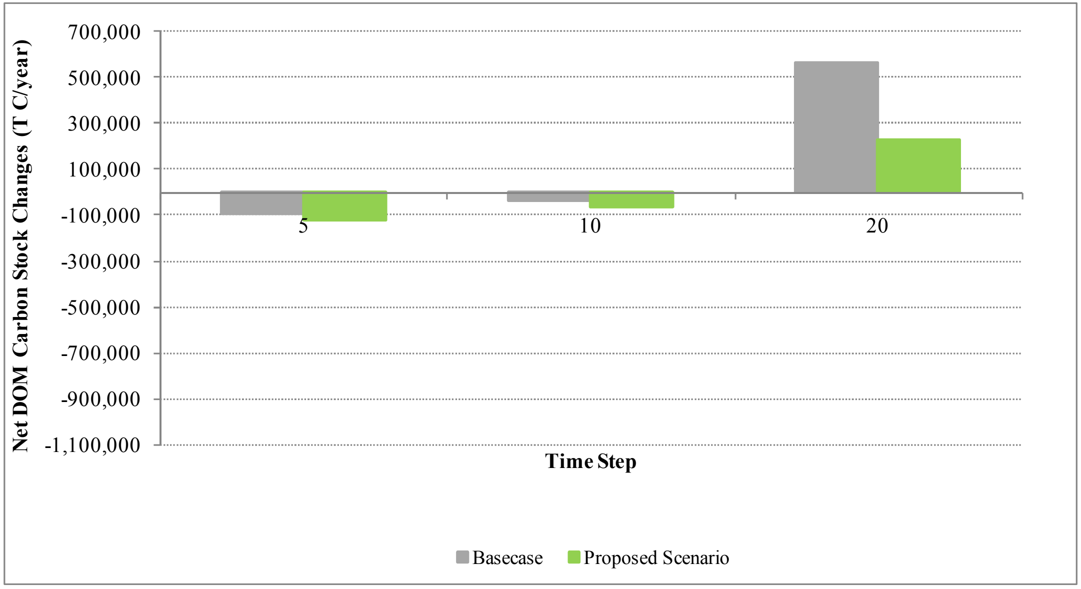

Figure 3.7 DOM Carbon Stocks Changes Over the First 20 years

Figure 3.8 shows the ecosystem changes in carbon stock over the first 20 years. Total changes in carbon stock - the sum of biomass and DOM are negative for the first ten years for both scenarios. However, the difference of net ecosystem carbon stock changes was apparent during the second ten year period (from year 10 to year 20). For example, the basecase is losing carbon at a rate of 344,000 T C/year, while the proposed scenario is gaining carbon at a rate of 66,000 T C/year. The carbon loss from the basecase is mainly from DOM decomposition, while the carbon gained in the proposed scenario is due primarily to aggressive reforestation.

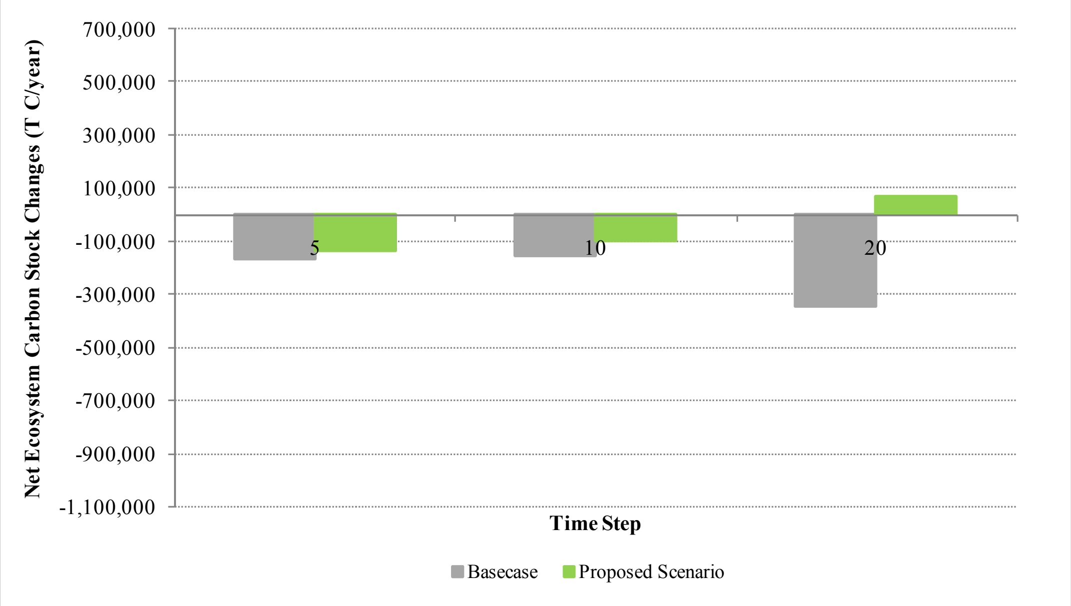

Figure 3.8 Net Ecosystem Carbon Stock Changes over the first 20 years

Figure 4.9 shows the cumulative net ecosystem carbon stocks for the first 20 years in the planning horizon. The polynomial fit (solid black and green lines) lines show the trends of the net carbon stocks. The cumulative net ecosystem carbon stocks are calculated by adding up yearly net ecosystem carbon stocks. The proposed scenario gains a significant amount of carbon (about 1.3 million tonnes (MT)) during the last four years (from year 16 to 20). The basecase scenario loses 3.1 MT of carbon during the first 20 years. The difference between the two scenarios is 4.4 MT of carbon for the first 20 years.

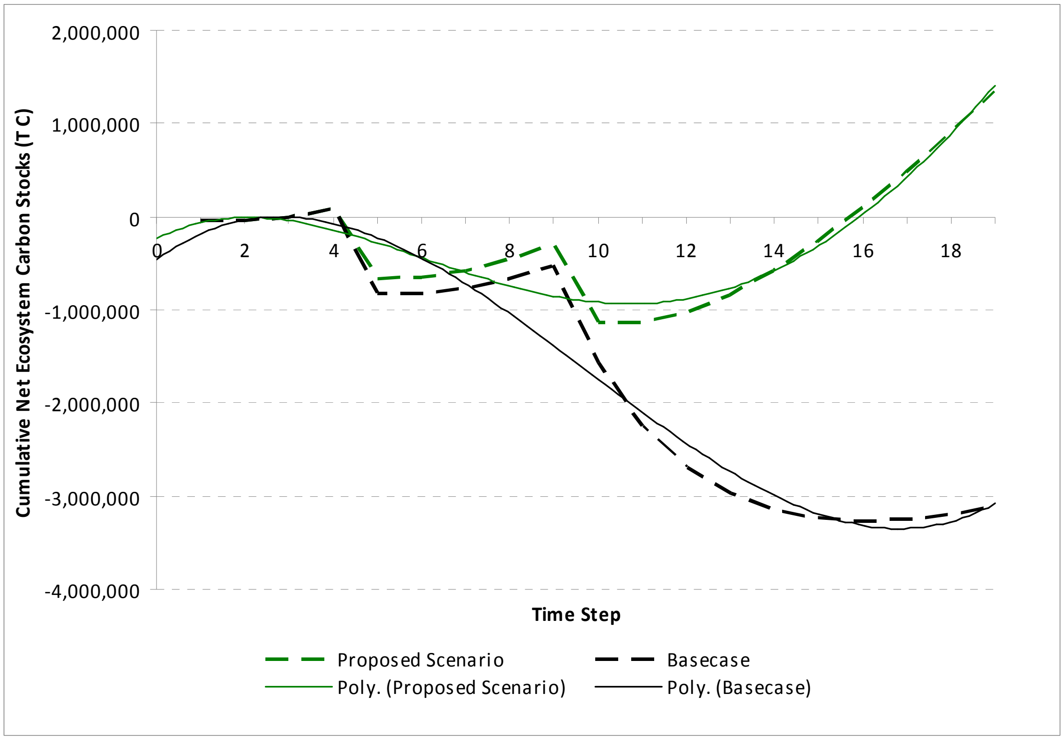

Figure 3.9 Cumulative net ecosystem carbon stocks for 20 years[5]

3.3 Carbon Stocks

This section is split into three sections:

1. Biomass stocks (below-ground, above-ground, and total);
2. DOM stocks (below-ground, above-ground, Total DOM, and snag); and
3. Total ecosystem carbon stocks.

3.3.1 Biomass Stocks

Figure 3.10 shows the biomass carbon stocks captured in above-ground, below-ground, and total biomass for the Boundary TSA over the modelling horizon. The initial carbon stocks are usually treated as baseline carbon stocks for the pools in interest. The baseline carbon stocks of above-ground, below-ground, and total biomass are 35.5, 7.9, and 43.4 MT C. The below-ground biomass has little effects by MPB catastrophic event at year 10 of the simulation and timber harvesting scheduling. The average below-ground biomass of carbon stocks is about 6.4 MT C/year, which is about 18% of the total biomass

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[5] the black and green solid lines are the polynomial fits of the raw data

of carbon stocks for both scenarios. The above-ground biomass, on the other hand, was significantly affected by MPB attack during the simulation. The aboveground carbon losses 4.8 and 7.1 MT C at MPB attack for the proposed and basecase scenario, respectively. For the long-term (after 70 years), both scenarios are similar in aboveground carbon stocks, and their variations are mainly caused by the timber harvest scheduling. The average above-ground carbon stocks is about 28.9 and 28.6 MT C/year for the proposed and basecase scenario, respectively. The average biomass carbon stock is about 34.9 and 35.3 MT C/year for basecase and proposed scenario, respectively.

Figure 3.10 Proposed Scenario Biomass Carbon Stocks

3.3.2 Dead Organic Matter Stocks

Figure 3.11 shows the above-ground, below-ground, and total DOM carbon stocks over the modelling horizon. The baseline carbon stocks are 18.3, 93.1, and 111.4 MT C for above-ground, below-ground, and total DOM. The basecase increases by 4.0 MT C due mainly to the effect of the MPB on the above-ground DOM carbon stocks, while the proposed scenario realizes little effect by MPB because of harvesting and aggressive reforestation. The below-ground DOM is relatively a stable pool, which consists of 85% of the total DOM carbon stocks in both basecase and proposed scenarios.

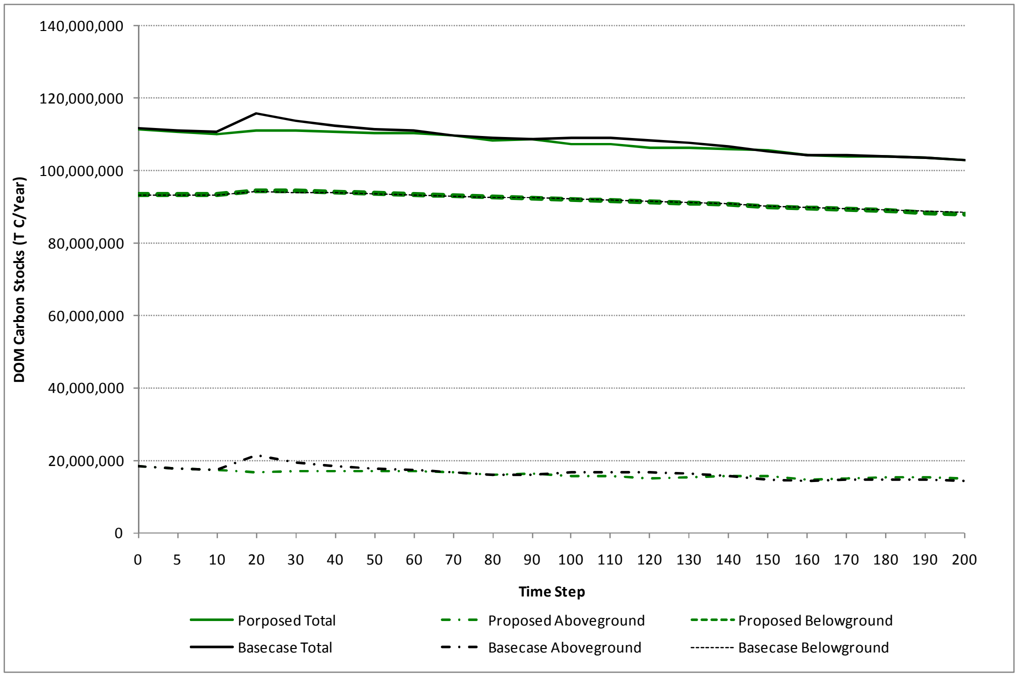

Figure 3.11 Carbon Stocks- Above Ground DOM (MPB Basecase and Proposed Scenario)

A snag for our purposes is simply a standing dead tree. Snags represent a sub-set of the above ground DOM pool and have been created in abundance from the MPB epidemic. It is for this reason that snags have been shown in a separate graph- Figure 3.12. In the MPB basecase scenario, the total snag stock increases about 4.2 MT C after the MPB epidemic.

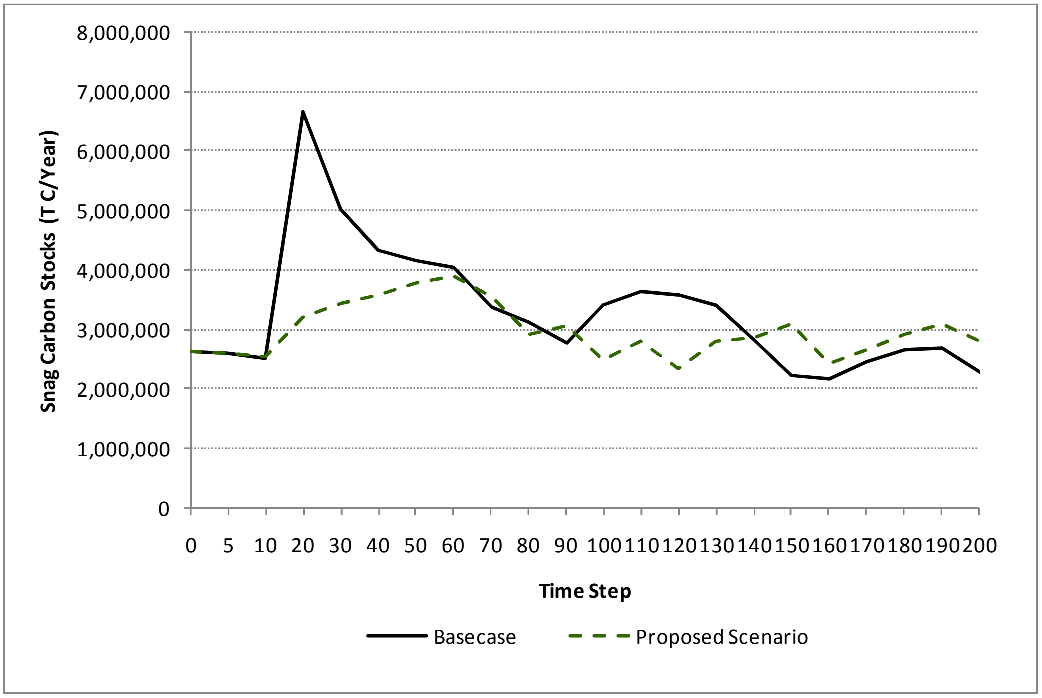

Figure 3.12 Carbon Stocks- Snags (Basecase-black line and Proposed Scenario-green line)

3.3.3 Total Ecosystem Carbon Stocks

Figure 3.13 shows the total ecosystem carbon stocks over the modelling horizon. The total carbon stocks are composed of DOM and biomass. The baseline carbon stock is about 154.8 MT C in Boundary TSA. While the average carbon stocks over the simulation period are 143.4 and 143.0 MT C/year for basecase and proposed scenario, respectively, the total ecosystem carbon stock for the project area decreases over the modelling time period.

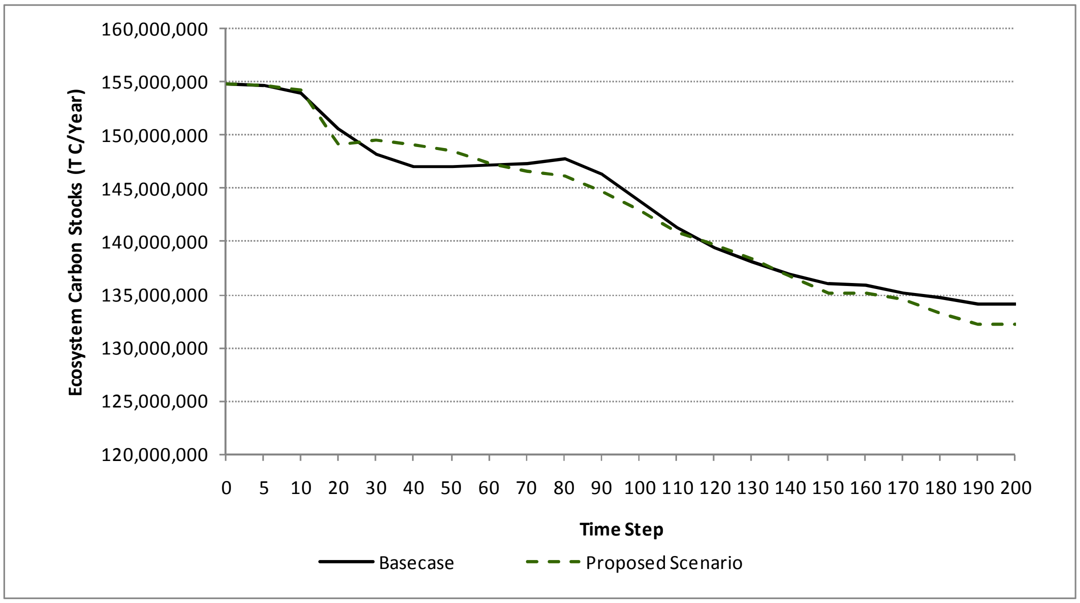

Figure 3.13 Carbon Stocks- Total Ecosystem (MPB Basecase and Proposed Scenario)

3.4 Carbon Emissions to Atmosphere

Figure 3.14 shows the GHG emissions from biomass to the atmosphere across the modelling horizon for the basecase and proposed scenarios. Two major green house gases, $C0_2$ and CH_4, are monitored in the model. Methane is a small component of the total biomass emission, with an average of 166 and 175 T C/year for basecase and proposed scenario during the modelling period. The $C0_2$ fluctuates according to harvest scheduling: the higher harvesting volumes, the lower the $C0_2$ emissions. The $C0_2$ accounts for over 90% of the biomass GHG emissions, with an average of 16,000 and 17,000 T C/year for basecase and proposed scenario, respectively.

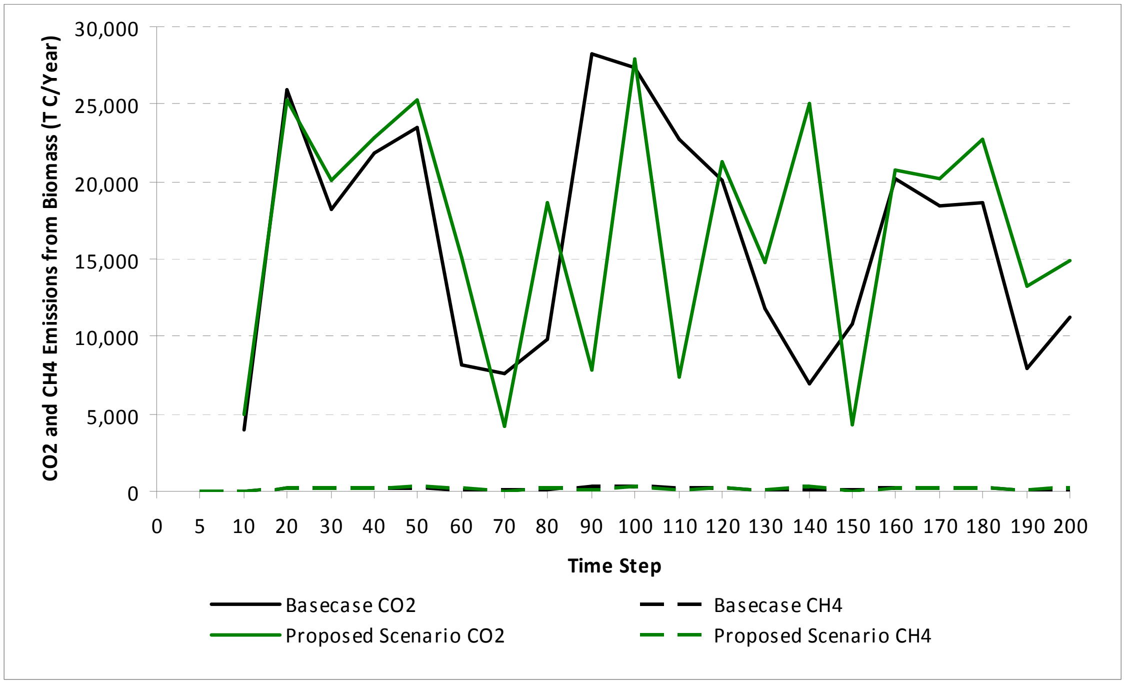

Figure 3.14 Green house gases emissions from biomass to atmosphere

Figure 3.14 shows the GHG emissions from DOM to atmosphere across the modelling horizon for both the basecase and proposed scenario. For the basecase scenario, $C0_2$ emissions pulse during the MPB attack reaching about 1.95 MT C. The average $C0_2$ emission is about 1.75 and 1.74 MT C/year for the basecase and proposed scenario, respectively. The CH_4 emission is a minor component compared to $C0_2$ emissions. The average CH_4 emission is about 293 and 175 T C/year for basecase and proposed scenario, respectively.

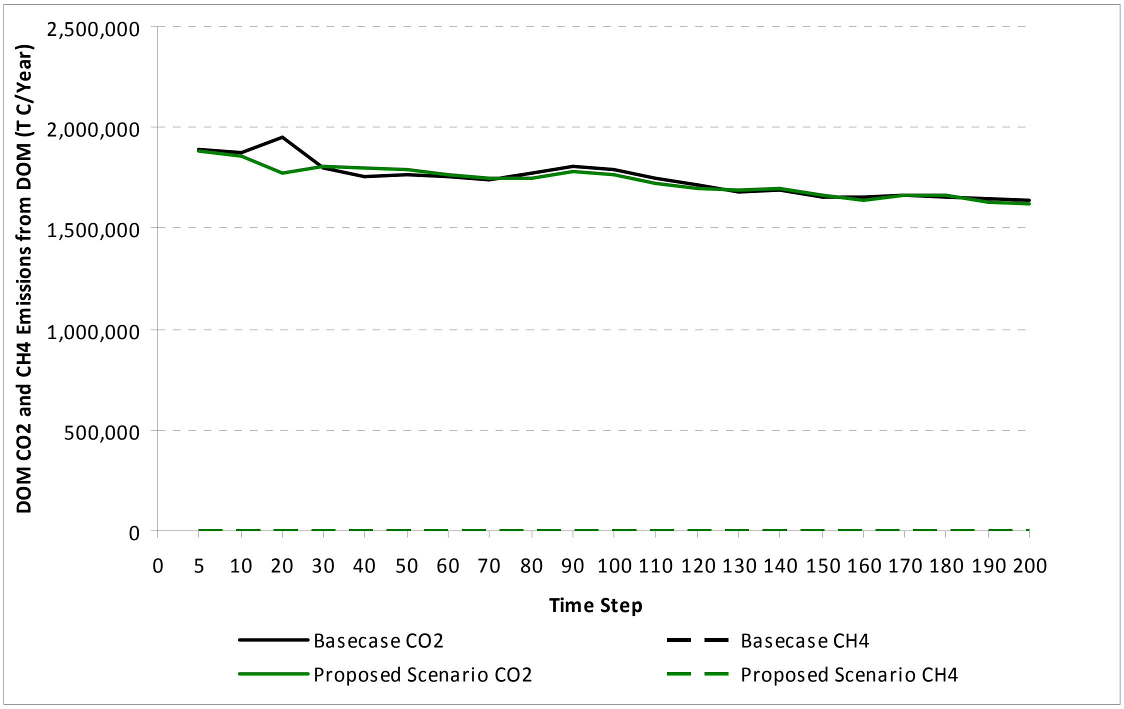

Figure 3.15 Green house gas emissions from DOM to atmosphere

In summary, the total GHG emissions from the Boundary TSA are about 1.76 MT C/year due mainly to ecosystem respiration, dead organic aerobic decomposition, and anaerobic decomposition. The GHG emission from the Boundary TSA is approximately 1% of the total carbon stocks (see above). However, the GHG emission determines whether the ecosystem is a net carbon source or a net sink for a given year.

4.0 DISCUSSION

The intentions of these analyses are to understand the impact forest management decision have on carbon stocks. Carbon stocks were not considered in making the management decisions, but the impact on carbon has been determined. In the analysis it was found that the changes in carbon stock for the proposed scenario are improved by over 400,000 tonnes of carbon per year in 20 years which is a result of:

- Lower harvest level in non-MPB affected stands.
- Fertilization effects over 10,000 ha of land, which directly prompt biomass production[6]; and
- Aggressive reforestation in some MPB affected areas speeds up regeneration and increases biomass production.

This is the equivalent of having 68,109 passenger vehicles off of the road per year according to the US Environmental protection agencies greenhouse gas equivalencies calculator (US EPA, 2008).

In time it is expected that the impact on carbon stocks will become one of the key values considered when making resource management decisions. As a next step it would be prudent to take the carbon curves from the CBM model and include them in the *Patchworks* optimization analysis. This would allow for carbon sequestration to be considered one of the landbase objectives and select harvest levels, silviculture regimes, and schedules accordingly. Currently the proposed scenario, which suggests to significantly improve carbon stocks, is focused mainly on improving the mid-term timber supply. It is likely that there are other solutions that include carbon in the analysis.

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[6] The carbon used for making and applying the fertilization was not considered, however this would be considered in full carbon accounting.

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