FORRx CONSULTING INC.

ECOSYSTEM MANAGEMENT SIMULATION

Knowledge, Experience, Innovation

Development of carbon curves for analysis units within the Fort St. John TSA

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1. **Introduction**

This project was undertaken to address the short-term needs around assessing the potential implications of forest management activities on ecosystem carbon (C) storage and sequestration rates within the context of the Fort St. John SFM plan. To properly evaluate the potential impact of forest management activities on global C cycles it is necessary to go beyond coarse estimates based on growing stock and MAI from standard yield curves and work toward developing appropriate C indicators. An initial step towards resolving this problem was the development ecosystem carbon storage curves for the discrete forest analysis units used for the timber supply analysis within the SFM plan. The incorporation of C curves facilitates an evaluation of the direct impacts of proposed forest management activities on long-term patterns of carbon storage and sequestration rates in the forest ecosystems within the Fort St. John TSA. It also provides a foundation upon which to build more detailed methodologies for evaluating C indicators in the context of other forest values.

The primary tasks involved in this project were the following:

1) *Dividing the NHLB into more specific analysis units*
2) *Clumping existing THLB and new NHLB analysis units into C analysis units*
3) *Use of the FORECAST model calibrated for forest types in northeastern BC to generate carbon curves for the C analysis units*
4) *Preparation of a database of ecosystem C storage and sequestration rate curves for each of the C analysis units*
5) *Preparation of a report describing the use of the curves to develop and assess C indicators within the context of the Ft. St. John TSA.*

2. Methods

2.1. Dividing the NHLB into representative forest types for analysis

For the purposes of the timber supply analysis in the Ft. St. John TSA, the NHLB was divided into only three general AUs. To meet the requirements of a C analysis, it was necessary to subdivide these units into more specific AUs based on forest cover types and site indices. After evaluating the range of site indices and forest types within the NHLM, a series of discrete analysis units were described that were consistent with the AUs used in the THLB. The areas and average SI for each of the new NHLB AUs is shown in (Table 1).

Table 1. Description of the new AUs created for the NHLB based on the forest cover data.

Old AU	New AU	Forest Area (% of Total TSA)	Sp1	Other Sp	Avg SI	Avg Sp1%
887	887	15.9%	Sb leading		9.2	
886 & 888	901	1.3%	S	Pl	16.1	68
886 & 888	902	7.6%	S	Pl	8.3	70.1
886 & 888	903	1.1%	S	At	17	69
886 & 888	904	0.6%	S	At	10	75
886 & 888	905	1.5%	P	S	16	69
886 & 888	906	7.2%	P	S	9.5	71
886 & 888	907	1.2%	P	At	16.8	65
886 & 888	908	0.8%	P	At	10.5	69
886 & 888	909	1.7%	At		10.6	80
886 & 888	910	4.7%	At		17.2	77
886 & 888	911	0.4%	At	S	10.7	59
886 & 888	912	0.9%	At	S	16.9	58
886 & 888	913	0.4%	At	Pl	10.8	57
886 & 888	914	0.6%	At	Pl	16.8	58
886 & 888	915	1.6%	Bl	S	6	74
All	**All**	**31.7%**				

2.2. Clumping the existing THLB and new NHLB AUs into carbon AUs

Since many of the existing AUs were similar in terms of species and average SI, they were clumped together to fit within a series of 49 carbon analysis units developed for simulation in FORECAST. The FORECAST carbon analysis units were designed to represent a range of a site quality classes and a range of species mixtures that was consistent with the existing AUs. The regeneration assumptions for each of the carbon AUs were based on those described for the existing managed-stand AUs. Each of the existing THLB and new NHLB AUs was subsequently assigned to one of the new carbon AUs based on species, site index, and regeneration assumptions. Details of the FORECAST carbon AUs is provided in Table 2.

Table 2. Description FORECAST carbon AUs including: a list of existing AUs to be assigned to each carbon AU, management status, stand type, represented species both naturally regenerated and planted, and the regeneration densities (stems ha^{-1}) for planted and naturally regenerated trees.

Forecast C AUs	Assigned TSA AUs	Status	Type	Lead Sp	Other Sp	Nat Sp	SI	Plant Density	Nat Density
1	13,16,511	natural	Con	Se 75%	Bl 25%	Se,Bl	9		1200
2	12,15	natural	Con	Se 75%	Bl 25%	Se,Bl	12		1200
3	11,14,514	natural	Con	Se 75%	Bl 25%	Se,Bl	17		1200
4	21,26,29,31,34,35	natural	Con	Pl		Pl	12		3000
5	25,28	natural	Con	Pl		Pl	16		3000
6	24	natural	Con	Pl		Pl	21		3000
7	53, 123,602,605,606,909,910	natural	Dec	At		At	12		3000
8	52, 122,604	natural	Dec	At		At	16		5000
9	51, 121,603	natural	Dec	At		At	21		7000
10	62, 66,904	natural	Con-Dec	Sw 65%	At 35%	Sw,At	12		2000
11	61,65, 903	natural	Con-Dec	Sw 65%	At 35%	Sw,At	16		2500
12	64	natural	Con-Dec	Sw 65%	At 35%	Sw,At	21		3000
13	73	natural	Con	Sx 75%	Pl 25%	Sx,Pl	9		1200
14	72, 561	natural	Con	Sw 75%	Pl 25%	Sw,Pl	12		1200
15	71, 901	natural	Con	Sw 75%	Pl 25%	Sw,Pl	16		1200
16	74	natural	Con	Sw 75%	Pl 25%	Sw,Pl	21		1200
17	76,93,96	natural	Con	Pl 75%	Sw 25%	Pl,Sw	12		2000
18	75,91,95,97,905	natural	Con	Pl 75%	Sw 25%	Pl,Sw	16		2000
19	94	natural	Con	Pl 75%	Sw 25%	Pl,Sw	21		2000
20	81,86,908	natural	Con-Dec	Pl 65%	At 35%	Pl,At	12		2000
21	521,907	natural	Con-Dec	Pl 65%	At 35%	Pl,At	16		2500
22	84,85	natural	Con-Dec	Pl 65%	At 35%	Pl,At	21		3000
23	103, 911	natural	Dec-Con	At 65%	Sw 35%	At,Sw	12		3000
24	102, 912	natural	Dec-Con	At 65%	Sw 35%	At,Sw	16		3500
25	101	natural	Dec-Con	At 65%	Sw 35%	At,Sw	21		4000
26	113, 913	natural	Dec-Con	At 65%	Pl 35%	At,Pl	12		3000
27	112,914	natural	Dec-Con	At 65%	Pl 35%	At,Pl	16		4000

Forecast C AUs	Assigned TSA AUs	Status	Type	Lead Sp	Other Sp	Nat Sp	SI	Plant Density	Nat Density
28	111	natural	Dec-Con	At 65%	Pl 35%	At,Pl	21		5000
29	915	natural	Con	Bl		Bl	6		2000
30	902, 887	natural	Con	Se 75%	Pl 25%	Se,Pl	9		1000
31	906	natural	Con	Pl 75%	Se 25%	Pl,Se	9		2000
32	2013, 2511, 2073	managed	Con	S 90%	Pl 10%	Bl	9	1400	400
33	2012	managed	Con	S 90%	Pl 10%	Bl	12	1400	400
34	2011, 2014, 2514,1001,2551,1551	managed	Con	S 90%	Pl 10%	Bl	17	1400	400
35	2021, 2026,2029,2031,2034,2035	managed	Con	Pl 90%	Sx 10%		12	1600	
36	2025, 1002	managed	Con	Pl 90%	Sx 10%		16	1600	
37	2024	managed	Con	Pl 90%	Sx 10%		21	1600	
38	2076	managed	Con-Dec	S 90%	Pl 10%	At	12	1040	2000
39	2061, 1056, 1006,1007,1556,2521	managed	Con-Dec	S 90%	Pl 10%	At	16	1040	2000
40	2064	managed	Con-Dec	S 90%	Pl 10%	At	21	1040	2000
41	2561, 2093,2081	managed	Con-Dec	Pl 90%	Sx 10%	At	12	1300	2000
42	1008, 1009, 2097	managed	Con-Dec	Pl 90%	Sx 10%	At	16	1300	2000
43	2084, 2085, 1552,2552	managed	Con-Dec	Pl 90%	Sx 10%	At	21	1300	2000
44	1053	managed	Dec			At	12		
45	1052	managed	Dec			At	16		
46	1051	managed	Dec			At	21		
47	2103	managed	Dec-Con	S 90%	Pl 10%	At	12	500	3000
48	2102	managed	Dec-Con	S 90%	Pl 10%	At	16	500	5000
49	2101	managed	Dec-Con	S 90%	Pl 10%	At	21	500	7000

2.3. Preparing a database of carbon curves using the FORECAST model

The FORECAST model, which has been calibrated for use in similar forest types in TFL48, works well for an analysis of ecosystem carbon storage as it is a biomass-based model that simulates patterns of carbon accumulation in both above and below-ground biomass components as well as in dead organic matter components including soil organic matter, litter and coarse woody debris. FORECAST was used to generate ecosystem C storage curves for each of the carbon AUs described in Table 2. Because ecosystem carbon storage is a continuous variable (i.e. it cannot easily be reset like merchantable volume following harvest) it was necessary to carefully consider transition pathways when preparing the carbon curves. The transition pathways described for the existing AUs were used to guide this process. The goal was to create a relatively smooth transition, in terms of ecosystem C storage, from a natural stand to a managed stand following harvest. This was achieved by estimating an average harvest age for each of the natural stand types and using this harvest age to generate the starting condition for each of the managed stand-curves. The starting condition of an ecosystem simulation in FORECAST is represented by a series of state variables described within the ECOSTATE file. The average harvest ages for each natural-stand AU and the particular natural-stand AU used to create the ECOSTATE file for each of the managed-stand AUs are presented in Table 3. Despite using this method, there will still be some errors generated during the transition process but they should be relatively small compared to total ecosystem C storage.

Table 3. Estimated average harvest ages for each of the natural-stand AUs used to create starting conditions for managed stands. The parent natural-stand AU is shown for each managed-stand AU.

Forecast C AUs	Status	Type	Estimated Avg. Harvest Age	SI	Nat-Stand AU for managed stand AU
1	natural	Con	200	9	
2	natural	Con	175	12	
3	natural	Con	140	17	
4	natural	Con	100	12	
5	natural	Con	90	16	
6	natural	Con	80	21	
7	natural	Dec	100	12	
8	natural	Dec	90	16	
9	natural	Dec	80	21	
10	natural	Con-Dec	140	12	
11	natural	Con-Dec	120	16	
12	natural	Con-Dec	100	21	
13	natural	Con	200	9	
14	natural	Con	130	12	
15	natural	Con	110	16	
16	natural	Con	90	21	
17	natural	Con	150	12	
18	natural	Con	130	16	
19	natural	Con	110	21	
20	natural	Con-Dec	110	12	

Forecast C AUs	Status	Type	Estimated Avg. Harvest Age	SI	Nat-Stand AU for managed stand AU
21	natural	Con-Dec	100	16	
22	natural	Con-Dec	90	21	
23	natural	Dec-Con	120	12	
24	natural	Dec-Con	100	16	
25	natural	Dec-Con	80	21	
26	natural	Dec-Con	120	12	
27	natural	Dec-Con	100	16	
28	natural	Dec-Con	80	21	
29	natural	Con		6	
30	natural	Con		9	
31	natural	Con		9	
32	managed	Con		9	AU 1
33	managed	Con		12	AU 2
34	managed	Con		17	AU 3
35	managed	Con		12	AU 4
36	managed	Con		16	AU 5
37	managed	Con		21	AU 6
38	managed	Con-Dec		12	AU 10
39	managed	Con-Dec		16	AU 11
40	managed	Con-Dec		21	AU 12
41	managed	Con-Dec		12	AU 17
42	managed	Con-Dec		16	AU 18
43	managed	Con-Dec		21	AU 22
44	managed	Dec		12	AU 7
45	managed	Dec		16	AU 8
46	managed	Dec		21	AU 9
47	managed	Dec-Con		12	AU 23
48	managed	Dec-Con		16	AU 24
49	managed	Dec-Con		21	AU 25

A carbon curve database was subsequently prepared by summarizing the results for total ecosystem C storage on 10-year time steps for each of the FORECAST carbon AUs. In addition, average rates of C sequestration were calculated for each time step based on the following equation:

$$\text{Avg. Sequestration Rate}_t = \frac{\text{Ecosystem C}_t - \text{Ecosystem C}_{t-10}}{10}$$

3. Results and Discussion

3.1. Ecosystem C storage and Average Sequestration Rates

Total Ecosystem C storage provides an estimate of the total amount of carbon stored in a given AU for a specific stand age. In contrast the calculated average sequestration rate represents an estimate of the rate of change in ecosystem C storage with time. It incorporates C losses via decomposition of dead organic matter and C gains via photosynthesis and biomass growth. As such it may be positive or negative.

The carbon curve database resulting from this work is included in the attached Excel file. An example of the carbon curves produced for a natural mixed conifer stand and its associated managed stand are shown in Figure 1. The relatively larger ecosystem C storage observed early in stand development for the natural stand is the result of the larger quantity of dead organic matter (primarily snags and CWD) following the fire which initiated the natural disturbance stand. In contrast, the managed stand has a smaller initial pool of C in dead organic matter resulting from the removal of harvested material. The differences in dead organic matter pools following disturbance also has an effect on the average sequestration rates of natural and managed stands (Fig. 2). There is a greater release of C to the atmosphere following the decomposition of the larger pool of dead organic matter in the natural stand which results in a lower sequestration rate during the first several decades of stand development. In the example provided, the average sequestration rate takes longer to return to positive values in the natural stand versus the managed stand. This is partly related to the fact that the harvested wood removed from the site during harvesting does not contribute to ecosystem C release to the atmosphere. Rather, it is assumed to be stored in wood products.

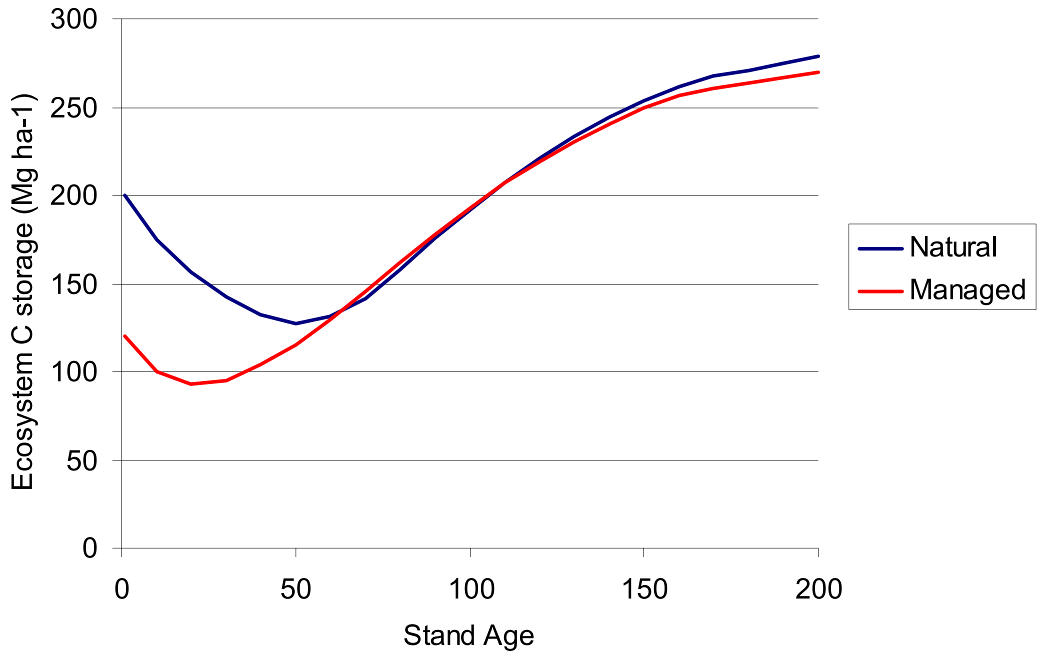

Figure 1. An example of total Ecosystem C storage for a natural stand (FORECAST AU 3) and an associated managed stand (FORECAST AU 34).

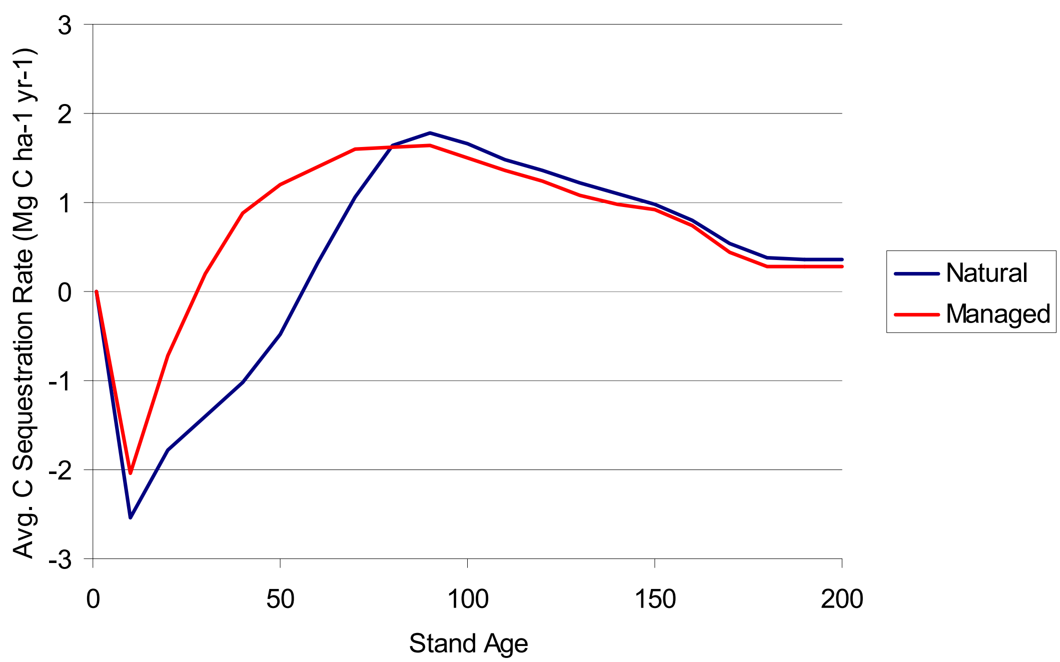

Figure 2. An example of average C sequestration rates for a natural stand (FORECAST AU 3) and an associated managed stand (FORECAST AU 34).

3.2 The Development of C indicators for landscape-scale analyses

The carbon curves generated using FORECAST can be used to provide a foundation for the development of landscape-level C indicators for use in support of SFM plans. By incorporating the stand-level C curves into a forest planning model such as FS-SIM, it is possible to estimate the effects of landscape-scale harvesting activities on the global C cycle. Thus, two separate landscape-scale indicators (ecosystem C storage and average C sequestration rates) could be defined and evaluated as described below:

1) Total Ecosystem C storage

Definition: The calculation of total ecosystem C storage within a timber supply area allows for a long-term evaluation of effects of management activities and/or natural disturbance on forest C stocks. Stock change is the current method accepted for C accounting under the Kyoto Protocol. It assumes that C stored in harvested materials is returned to the atmosphere immediately following harvesting.

Spatial Extent: Timber supply area

Units: Mg or Mt (10^6 Mg) C

Establishing Targets: An initial estimate of the target for ecosystem C storage could be based on a long-term (e.g. 300 years) simulation of historical natural disturbance rates in the absence of fire suppression. A target could then be defined as being within the range of variation that occurred during the natural baseline simulation.

2) Average C sequestration rates

Definition: The calculation of average C sequestration rates within a timber supply area allows for a long-term evaluation of effects of management activities and/or natural disturbance on the rate at which the forested landscape is sequestering C. Unlike the stock change method, average sequestration rates are based on changes in ecosystem carbon storage over time without accounting for C removed in harvested biomass. The rationale is that the carbon in harvested materials will be stored in wood products following harvest. An assessment of the sequestration rate provides a measure of the rate and direction of carbon exchange between the forest ecosystem and the atmosphere.

Spatial Extent: Timber supply area

Units: Mg C yr^{-1}

Establishing Targets: Using an approach similar to that used for ecosystem C storage, an initial estimate of the target for average C sequestration rates could be based on a long-term (e.g. 300 years) simulation of historical natural disturbance rates in the absence of fire suppression. A target could then be defined as being within the range of variation that occurred during the natural baseline simulation.