ECOSYSTEM MANAGEMENT SIMULATION

Knowledge, Experience, Innovation

Development of carbon curves for addressing CSA certification requirements in the Morice and Lakes Timber Supply Areas

Prepared by:

Brad Seely, Ph.D.

Feb. 22, 2005

For:

Jim Burbee

TWEEDSMUIR FOREST LTD.

FORRx Consulting Inc.
3960 Marine Avenue
Belcarra, BC
Canada V3H 4R9
T: 604. 538. 5173
F: 604. 538. 8175

Contents	**Page**

List of Tables

Description Page

List of Figures

Description Page

1. Introduction

With Canada's recent ratification of the Kyoto Protocol and the increasing global awareness of climate change issues, forest companies are under mounting pressure both nationally and internationally to account for the effects of their activities on terrestrial carbon (C) stocks and greenhouse gas emissions (GHGs). The capacity of forest ecosystems to sequester C has been increasingly recognized as an environmental value and thus a significant component of sustainable forest management plans. Moreover, several certification schemes, including the Canadian Standards Association (CSA), have identified the effects of management on global C cycles as a criterion for sustainable forest management. To successfully implement such a criterion within a certification system, it is necessary to utilize scientifically credible indicators and associated measures that can be evaluated as part of a sustainable forest management plan. Indicators based on correlations with volume and mean annual increment are insufficient.

This project was undertaken to provide support for the Morice and Lakes IFPA certification (CSA) initiative with respect to meeting the requirements around the measuring the impacts of forest management activities on global C cycles.

The primary tasks involved in this project were the following:

1) *Preparing FORECAST existing calibration datasets for representing forest types within the Morice and Lakes TSAs*

2) *Preparing carbon analysis units (CAUs) and transition pathways for the Base Case, Natural Disturbance and Forest Productivity scenarios for both the Morice and Lakes TSAs*

3) *Use of the FORECAST model to generate a database of carbon curves for the defined CAUs*

4) *Assigning CAUs to existing and future managed stands (GIS_Tags) in the Access database*

5) *Preparation of a report describing the development and use of the curves to assess C indicators as part of the landscape-scale Tesera modelling for the Morice and Lakes TSAs.*

1.1 Employing C indicators in the Morice and Lakes TSAs

Acceptable indicators for directly assessing the impacts of forest management on carbon cycles include:

1) Stock change: a measure of absolute changes in to ecosystem carbon storage within a defined forest management area over a specific period of time
2) Sequestration rate: a measure of the rate at which atmospheric CO_2 is converted into biomass through photosynthesis. A negative sequestration rate indicates that the forest is acting as a source of CO_2 rather than a sink.

The use of the C indicators described above in the context of the forest planning modelling being conducted by Tesera Systems for the Morice and Lakes Timber Supply Areas (TSAs) requires a calculation of total ecosystem C content for each forest cover polygon in each time period of the planning horizon. This, in turn, requires the capability to project the impacts of forest management and disturbance on C content.

2. Methods

2.1 Model description

FORECAST is a management-oriented, stand-level forest growth simulator that has been federally and provincially approved for use in forest carbon modelling. The model was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their effect upon forest productivity, stand dynamics and a series of biophysical indicators of selected non-timber values including ecosystem carbon dynamics. The model uses a hybrid approach whereby local growth and yield data (often from TASS/TIPSY) are utilized to derive estimates of the rates of key ecosystem processes related to the productivity and resource requirements of selected species. This information is combined with data describing rates of decomposition, nutrient cycling, light competition, and other ecosystem properties to simulate forest growth under changing management conditions as well as the storage of ecosystem carbon in above and below-ground biomass, dead organic matter and soil pools. Growth occurs in annual time steps. Depending upon the species, plant populations are initiated from seed and/or vegetatively, and stand development can occur with or without the presence of competition from non-target tree species and understory populations. Decomposition is simulated using a method in which specific biomass components are transferred at the time of litterfall, to one of a series of independent litter types. These litter types decompose at rates defined by empirical data. Further details of FORECAST calibration and its potential applications are provided in Kimmins et al. (1999), and Seely et al. (1999).

2.2 Preparing FORECAST calibration datasets for the Morice & Lakes TSAs

Existing forecast calibration data sets for SBS, CWH and ESSF forest types were used for the representation of the range of forest types occurring within the Morice and Lakes TSAs. For a description of the calibration process employed to create these datasets refer to Seely 2004. To prepare the datasets for use in modelling ecosystem carbon storage for the specific carbon analysis units (see section 2.3) it was necessary to run the model in set-up mode to establish initial site conditions. In this stage, the model is run with nutrient feedback turned off to allow it to accumulate vegetation, litter and soil organic matter representative of the site(s) to be modeled, and which reflects the historical patterns of accumulation. This is typically achieved by simulating the known or estimated natural disturbance and/or management history of the site (see Seely et al. 1999 for a detailed description). Once the initial conditions had been established for each analysis unit, the model was used to simulate changes in ecosystem carbon storage resulting from specific management and or disturbance regimes (see Section 2.4).

2.3. Development of Carbon Analysis Units for the Morice and Lakes TSAs

Given the fact that carbon accounting must be summarized at the landscape scale and the fact that the forest inventory data consists of hundreds of thousands of discrete polygons it was necessary to employ a modelling and accounting approach using carbon analysis units (CAUs) as the primary modelling unit. This method is consistent with that employed by the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) (see Kurz et al. (2002). A series of analysis units were defined for both the Morice and Lakes TSAs that would allow the landscape forest planning model used by Tesera to estimate the impacts of various modelled harvesting and disturbance scenarios on long-term patterns of ecosystem carbon storage and sequestration rates.

A set of CAUs were developed based on the Timber Supply Review (TSR) analysis units (for both the Morice and Lakes TSAs) to represent existing natural stands, existing managed and future managed stands based on species composition, site quality and regeneration assumptions. The final set of CAUs used to represent the Base Case, Natural Disturbance and Forest Productivity scenarios (see Tesera Systems 2003) for the Morice TSA are shown in Tables 1-5 and for the Lakes TSA in Tables 6-10. Improvements in growth rates from resulting from silviculture in the Forest Productivity scenario were not explicitly represented in the modelling of the CAUs. The reason for this omission was that the CAU approach could not accommodate the large number of treatment combinations applied to a wide variety of stand types.

CAUs were assigned to the forest inventory polygons based on the criteria outlined in Tables 1 & 2 for the Morice TSA and Tables 4 & 5 for the Lakes TSA. It should be noted that the forest inventory data used for Base Case and Natural Disturbance scenarios (based on the TSR2 inventory) was significantly different from that used for the Forest Productivity scenario in which the inventory was updated to reflect a whole series of changes including: site index adjustments, more recent inventory data, etc. (see Tesera Systems 2004). Thus, the assignment of CAUs to the time-zero landscape for the Forest Productivity scenario was different than that for the other two scenarios. This fundamental difference in starting inventories means that results for the **carbon stock change** indicator from the Base Case and Natural Disturbance scenarios **cannot** be directly compared to those from the Forest Productivity scenario. However differences in average carbon sequestration rate could be compared among all scenarios with the understanding that differences in curve assignments between the Forest Productivity and the other scenarios will influence sequestration rates.

Table 1. Carbon analysis units for existing natural stands within the Morice TSA. Relationships to TSR and Base Case AUs are indicated. These CAUs are applicable to all scenarios.

C AU	TSR Description	Base Case AU#	SQ	ITGs	Spp	SI Criteria
1	Balsam-good	11x	G	18,19,20	B,BH,BS	>14
2	Balsam-med	12x	M	18,19,20	B,BH,BS	11 to 14
3	Balsam-poor	13x	P	18,19,20	B,BH,BS	8 to 11
4	Spruce-good	21x	G	21,24,25,26	S,SB,SPl,SDec	>16
5	Spruce-med	22x	M	21,24,25,26	S,SB,SPl,SDec	12 to 16
6	Spruce-poor	23x	P	21,24,25,26	S,SB,SPl,SDec	8 to 12
7	Pine-good	31x	G	28,30,31	Pl,PlS,PlDec	>19
8	Pine-med	32x	M	28,30,31	Pl,PlS,PlDec	15 to 19
9	Pine-poor	33x	P	28,30,31	Pl,PlS,PlDec	8 to 15
10	Hemlock-med	42x	M	12,13,14,15,16,17	H leading	12 to 16
11	Hemlock-poor	43x	P	12,13,14,15,16,17	H leading	8 to 12

C AU	TSR Description	Base Case AU#	SQ	ITGs	Spp	SI Criteria
12	Dec- good	51x,61x,71x	G	35,36,40,41,42	Decid leading	>16
13	Dec- med	52x,62x,72x	M	35,36,40,41,43	Decid leading	12 to 16
14	Dec - por	53x,63x,73x	P	35,36,40,41,44	Decid leading	8 to 12
15	Conifer - low	NA	L	all but 35,36,40,41,43	Conifer leading	<8
16	Dec - low	NA	L	35,36,40,41,44	Decid leading	<8

Table 2. Carbon analysis units for existing and future managed stands within the Morice TSA. The scenario field refers to the landscape management scenarios for which each CAU was used.

C AU	Originating Nat stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M1	Balsam-good	BC, FP	Balsam-good	113	18,19,20	B,BH,BS	>14
M2	Balsam-med	BC, FP	Balsam-med	123,423	18,19,20	B,BH,BS	11 to 14
M3	Balsam-poor	BC, FP	Balsam-poor	133	18,19,20	B,BH,BS	8 to 11
M4	Dec-good	BC, FP	Dec-good	713	35,36,40,41,42	Decid leading	>16
M5	Dec-med	BC, FP	Dec-med	623, 723	35,36,40,41,43	Decid leading	12 to 16
M6	Dec-poor	BC, FP	Dec-poor	733, 833	35,36,40,41,44	Decid leading	8 to 12
M8	Balsam-good	BC, FP	S/Pl (S 80%,Pl20%)	114	18,19,20	B,BH,BS	>14
M9	Balsam-good	BC, FP	S/Pl (S 50%,Pl 50%)	114	18,19,20	B,BH,BS	>14
M10	Balsam-good	BC, FP	Pl/S (Pl 80%,S 20%)	114	18,19,20	B,BH,BS	>14
M11	Spruce-good	BC, FP	S/Pl (S 80%,Pl20%)	213, 214	21,24,25,26	S,SB,SPl,SDec	>16
M12	Spruce-good	BC, FP	S/Pl (S 50%,Pl 50%)	213, 214	21,24,25,26	S,SB,SPl,SDec	>16
M13	Spruce-good	BC, FP	Pl / S (Pl 80%,S 20%)	213, 214	21,24,25,26	S,SB,SPl,SDec	>16
M14	Pine-good	BC, FP	Pl/S (Pl 80%,S 20%)	313, 314	28,30,31	Pl,PlS,PlDec	>19
M15	Pine-good	BC, FP	Pl/S (Pl 50%,S 50%)	313, 314,513	28,30,31	Pl,PlS,PlDec	>19
M16	Dec -good	BC, FP	S/Pl (S 80%,Pl20%)	214	35,36,40,41,42	Decid leading	>16
M17	Dec -good	BC, FP	S/Pl (S 50%,Pl 50%)	214	35,36,40,41,43	Decid leading	>16
M18	Dec -good	BC, FP	Pl / S (Pl 80%,S 20%)	214	35,36,40,41,44	Decid leading	>16
M19	Balsam-med	BC, FP	S/Pl (S 80%,Pl20%)	124	18,19,20	B,BH,BS	11 to 14
M20	Balsam-med	BC, FP	S/Pl (S 50%,Pl 50%)	124	18,19,20	B,BH,BS	11 to 14
M21	Balsam-med	BC, FP	Pl/S (Pl 80%,S 20%)	124	18,19,20	B,BH,BS	11 to 14
M22	Spruce-med &Hw	BC, FP	S/Pl (S 80%,Pl20%)	223, 224,423	21-26,12-17	S,SB,SPl,Sdec & H leading	12 to 16
M23	Spruce-med &Hw	BC, FP	S/Pl (S 50%,Pl 50%)	223, 224,423	21-26,12-17	S,SB,SPl,Sdec & H leading	12 to 16
M24	Spruce-med &Hw	BC, FP	Pl / S (Pl 80%,S 20%)	223, 224,423	21-26,12-17	S,SB,SPl,Sdec & H leading	12 to 16

C AU	Originating Nat stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M25	Pine-med	BC, FP	Pl/S (Pl 80%,S 20%)	323, 324	28,30,31	Pl,PlS,PlDec	15 to 19
M26	Pine-med	BC, FP	Pl/S (Pl 50%,S 50%)	323, 324	28,30,31	Pl,PlS,PlDec	15 to 19
M27	Dec-med	BC, FP	S/Pl (S 80%,Pl20%)	224	35,36,40,41,42	Decid leading	12 to 16
M28	Dec-med	BC, FP	S/Pl (S 50%,Pl 50%)	224	35,36,40,41,43	Decid leading	12 to 16
M29	Dec-med	BC, FP	Pl / S (Pl 80%,S 20%)	224	35,36,40,41,44	Decid leading	12 to 16
M30	Balsam-poor	BC, FP	S/Pl (S 80%,Pl20%)	134	18,19,20	B,BH,BS	8 to 11
M31	Balsam-poor	BC, FP	S/Pl (S 50%,Pl 50%)	134	18,19,20	B,BH,BS	8 to 11
M32	Balsam-poor	BC, FP	Pl/S (Pl 80%,S 20%)	134	18,19,20	B,BH,BS	8 to 11
M33	Spruce-poor	BC, FP	S/Pl (S 80%,Pl20%)	233, 234	21,24,25,26	S,SB,SPl,SDec	8 to 12
M34	Spruce-poor	BC, FP	S/Pl (S 50%,Pl 50%)	233, 234	21,24,25,26	S,SB,SPl,SDec	8 to 12
M35	Spruce-poor	BC, FP	Pl / S (Pl 80%,S 20%)	233, 234	21,24,25,26	S,SB,SPl,SDec	8 to 12
M36	Pine-poor	BC, FP	Pl/S (Pl 80%,S 20%)	333, 334	28,30,31	Pl,PlS,PlDec	8 to 15
M37	Pine-poor	BC, FP	Pl/S (Pl 50%,S 50%)	333, 334	28,30,31	Pl,PlS,PlDec	8 to 15
M38	Dec-poor	BC, FP	S/Pl (S 80%,Pl20%)	234	35,36,40,41,42	Decid leading	8 to 12
M39	Dec-poor	BC, FP	S/Pl (S 50%,Pl 50%)	234	35,36,40,41,43	Decid leading	8 to 12
M40	Dec-poor	BC, FP	Pl / S (Pl 80%,S 20%)	234	35,36,40,41,44	Decid leading	8 to 12
M41	Spruce-good	ND	Same (Nat Regen)	21x	21,24,25,26	S,SB,SPl,SDec	>16
M42	Spruce-med	ND	Same (Nat Regen)	22x	21,24,25,26	S,SB,SPl,SDec	12 to 16
M43	Spruce-poor	ND	Same (Nat Regen)	23x	21,24,25,26	S,SB,SPl,SDec	8 to 12
M44	Pine-good	ND	Same (Nat Regen)	31x	28,30,31	Pl,PlS,PlDec	>19
M45	Pine-med	ND	Same (Nat Regen)	32x	28,30,31	Pl,PlS,PlDec	15 to 19
M46	Pine-poor	ND	Same (Nat Regen)	33x	28,30,31	Pl,PlS,PlDec	8 to 15
M47	Hemlock-med	ND	Same (Nat Regen)	42x	12,13,14,15,16,17	H leading	12 to 16
M48	Nat_Hemlock-med	FP	Balsam-med	na	12,13,14,15,16,17	H leading	12 to 16
M49	Nat_Hemlock-med	FP	S/Pl (S 80%,Pl20%)	na	12,13,14,15,16,17	H leading	12 to 16
M50	Nat_Hemlock-med	FP	Pl/S (Pl 80%,S 20%)	na	12,13,14,15,16,17	H leading	12 to 16
M51	Nat_Hemlock-med	FP	S/Pl (S 80%,Pl20%)	na	12,13,14,15,16,17	H leading	12 to 16
M52	Nat_Hemlock-med	FP	Pl/S (Pl 80%,S 20%)	na	12,13,14,15,16,17	H leading	12 to 16
M53	Nat_Hemlock-poor	FP	Balsam-good	na	12,13,14,15,16,17	H leading	<12
M54	Nat_Hemlock-poor	FP	S/Pl (S 80%,Pl20%)	na	12,13,14,15,16,17	H leading	<12

C AU	Originating Nat stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M55	Nat_Hemlock-poor	FP	Pl/S (Pl 80%,S 20%)	na	12,13,14,15,16,17	H leading	<12
M56	Nat_Dec-good	FP	Balsam-good	na	35,36,40,41,42	Decid leading	>16
M57	Nat_Dec-poor	FP	Balsam-med	na	35,36,40,41,43	Decid leading	12 to 16
M58	Nat_Dec-poor	FP	Balsam-poor	na	35,36,40,41,44	Decid leading	8 to 12
M59	Nat_Conifer-low	FP	Balsam-good	na	all but 35,36,40,41,41	Conifer leading	<8
M60	Nat_Conifer-low	FP	S/Pl (S 80%,Pl20%)	na	all but 35,36,40,41,42	Conifer leading	<8
M61	Nat_Conifer-low	FP	Pl/S (Pl 80%,S 20%)	na	all but 35,36,40,41,43	Conifer leading	<8
M62	Nat_Dec-low	FP	Pl/S (Pl 80%,S 20%)	na	35,36,40,41,44	Decid leading	<8
M63	Nat_Spruce-good	FP	Balsam-good	na	21,24,25,26	S,SB,SPl,SDec	>16
M64	Nat_Spruce-med	FP	Balsam-med	na	21,24,25,26	S,SB,SPl,SDec	>16
M65	Nat_Spruce-poor	FP	Balsam-poor	na	21,24,25,26	S,SB,SPl,SDec	>16
M66	Nat_Pine-good	FP	Balsam-good	na	28,30,31	Pl,PlS,PlDec	>19
M67	Nat_Pine-good	FP	S/Pl (S 80%,Pl20%)	na	28,30,31	Pl,PlS,PlDec	>19
M68	Nat_Pine-med	FP	Balsam-med	na	28,30,31	Pl,PlS,PlDec	15 to 19
M69	Nat_Pine-med	FP	S/Pl (S 80%,Pl20%)	na	28,30,31	Pl,PlS,PlDec	15 to 19
M70	Nat_Pine-poor	FP	Balsam-poor	na	28,30,31	Pl,PlS,PlDec	8 to 15
M71	Nat_Pine-poor	FP	S/Pl (S 80%,Pl20%)	na	28,30,31	Pl,PlS,PlDec	8 to 15
M72	Man_Balsam-good	FP	Pl/S (Pl 80%,S 20%)	na	18,19,20	B,BH,BS	>14
M73	Man_Balsam-good	FP	Pl/S (Pl 50%,S 50%)	na	18,19,20	B,BH,BS	>14
M74	Man_S80_Pl20-good	FP	Pl/S (Pl 80%,S 20%)	na	21,24,25,26	S,SB,SPl,SDec	>16
M75	Man_S50_Pl50-good	FP	Pl/S (Pl 50%,S 50%)	na	21,24,25,26	S,SB,SPl,SDec	>16
M76	Man_Pl80_S20-good	FP	S/Pl (S 80%,Pl20%)	na	28,30,31	Pl,PlS,PlDec	>19
M77	Man_Pl50_S50-good	FP	S/Pl (S 50%,Pl 50%)	na	28,30,31	Pl,PlS,PlDec	>19
M78	Man_Balsam-med	FP	S/Pl (S 80%,Pl20%)	na	18,19,20	B,BH,BS	11 to 14
M79	Man_Balsam-med	FP	Pl/S (Pl 80%,S 20%)	na	18,19,20	B,BH,BS	11 to 14
M80	Man_S80_Pl20-med	FP	Balsam-med	na	21,24,25,26	S,SB,SPl,SDec	12 to 16
M81	Man_S80_Pl20-med	FP	Pl/S (Pl 80%,S 20%)	na	21,24,25,26	S,SB,SPl,SDec	12 to 16
M82	Man_S80_Pl20-med	FP	Balsam-med	na	21,24,25,26	S,SB,SPl,SDec	12 to 16
M83	Man_S50_Pl50-med	FP	Pl/S (Pl 50%,S 50%)	na	21,24,25,26	S,SB,SPl,SDec	12 to 16
M84	Man_Pl80_S20-med	FP	Balsam-med	na	28,30,31	Pl,PlS,PlDec	15 to 19
M85	Man_Pl80_S20-med	FP	S/Pl (S 80%,Pl20%)	na	28,30,31	Pl,PlS,PlDec	15 to 19

C AU	Originating Nat stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M86	Man_Pl80_S20-med	FP	Pl/S (Pl 80%,S 20%)	na	28,30,31	Pl,PlS,PlDec	15 to 19
M87	Man_Pl80_S20-med	FP	Balsam-med	na	28,30,31	Pl,PlS,PlDec	15 to 19
M88	Man_Pl80_S20-med	FP	S/Pl (S 50%,Pl 50%)	na	28,30,31	Pl,PlS,PlDec	15 to 19
M89	Man_Balsam-poor	FP	S/Pl (S 80%,Pl20%)	na	18,19,20	B,BH,BS	8 to 11
M90	Man_Balsam-poor	FP	Pl/S (Pl 80%,S 20%)	na	18,19,20	B,BH,BS	8 to 11
M91	Man_S80_Pl20-poor	FP	Pl/S (Pl 80%,S 20%)	na	21,24,25,26	S,SB,SPl,SDec	8 to 12
M92	Man_S50_Pl50-poor	FP	S/Pl (S 50%,Pl 50%)	na	21,24,25,26	S,SB,SPl,SDec	8 to 12
M93	Man_Pl80_S20-poor	FP	S/Pl (S 80%,Pl20%)	na	21,24,25,26	S,SB,SPl,SDec	8 to 15
M94	Man_Pl50_S50-poor	FP	S/Pl (S 50%,Pl 50%)	na	21,24,25,26	S,SB,SPl,SDec	8 to 15
M95	Man_Dec-good	FP	S/Pl (S 80%,Pl20%)	na	35,36,40,41,42	Decid leading	>16
M96	Man_Dec-good	FP	Pl/S (Pl 80%,S 20%)	na	35,36,40,41,43	Decid leading	>16
M97	Man_Dec-med	FP	Pl/S (Pl 80%,S 20%)	na	35,36,40,41,42	Decid leading	12 to 16
M98	Man_Dec-poor	FP	Pl/S (Pl 80%,S 20%)	na	35,36,40,41,43	Decid leading	8 to 12

* BC = Base Case scenario; ND = Natural Disturbance scenario; FP = Forest Productivity scenario

Table 3. Regeneration assumptions for Morice TSA CAUs including regeneration delay, competition from understory vegetation, and total run length.

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
1	Natural	2000	Bl	70	S	20	Pl	10	3	med	300
2	Natural	1500	Bl	70	S	20	Pl	10	5	med	300
3	Natural	1500	Bl	70	S	20	Pl	10	5	low	300
4	Natural	1500	Sx	70	Pl	20	Bl	10	3	high	300
5	Natural	1500	Sx	70	Pl	20	Bl	10	3	med	300
6	Natural	1200	Sx	70	Pl	20	Bl	10	5	low	300
7	Natural	2500	Pl	80	S	20			2	med	200
8	Natural	2000	Pl	80	S	20			2	med	200
9	Natural	2000	Pl	80	S	20			4	low	200
10	Natural	1500	Fd	75	Bl	25			4	med	300
11	Natural	1500	Fd	75	Bl	25			4	med	300
12	Natural	4000	At	85	S	10	Pl	5	2	high	200
13	Natural	3000	At	85	S	10	Pl	5	2	med	200
14	Natural	2000	At	85	S	10	Pl	5	2	low	200

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
15	Natural	1500	Bl	100					5	low	300
16	Natural	1500	At	100					4	low	150
M1	Natural	2000	Bl	70	S	20	Pl	10	3	med	300
M2	Natural	1500	Bl	70	S	20	Pl	10	4	med	300
M3	Natural	1500	Bl	70	S	20	Pl	10	5	low	300
M4	Natural	4000	At	85	S	10	Pl	5	1	high	200
M5	Natural	3000	At	85	S	10	Pl	5	1	med	200
M6	Natural	2000	At	85	S	10	Pl	5	1	low	200
M8	Plant	1500	S	80	S	20			1	med	300
M9	Plant	1500	S	50	Pl	50			1	med	200
M10	Plant	1500	Pl	80	S	20			1	med	200
M11	Plant	1500	S	80	S	20			1	high	300
M12	Plant	1500	S	50	Pl	50			1	high	200
M13	Plant	1500	Pl	80	S	20			1	high	200
M14	Plant	1500	Pl	80	S	20			1	high	200
M15	Plant	1500	Pl	50	S	50			1	high	200
M16	Plant	1500	S	80	S	20			1	high	300
M17	Plant	1500	S	50	Pl	50			1	high	200
M18	Plant	1500	Pl	80	S	20			1	med	200
M19	Plant	1500	S	80	S	20			1	med	300
M20	Plant	1500	S	50	Pl	50			1	med	200
M21	Plant	1500	Pl	80	S	20			1	med	200
M22	Plant	1500	S	80	S	20			1	med	300
M23	Plant	1500	S	50	Pl	50			1	med	200
M24	Plant	1500	Pl	80	S	20			1	med	200
M25	Plant	1500	Pl	80	S	20			1	med	200
M26	Plant	1500	Pl	50	S	50			1	med	200
M27	Plant	1500	S	80	S	20			1	med	300
M28	Plant	1500	S	50	Pl	50			1	med	200
M29	Plant	1500	Pl	80	S	20			1	med	200
M30	Plant	1500	S	80	S	20			1	low	300
M31	Plant	1500	S	50	Pl	50			1	low	200
M32	Plant	1500	Pl	80	S	20			1	low	200
M33	Plant	1500	S	80	S	20			1	low	300
M34	Plant	1500	S	50	Pl	50			1	low	200
M35	Plant	1500	Pl	80	S	20			1	low	200
M36	Plant	1500	Pl	80	S	20			1	low	200
M37	Plant	1500	Pl	50	S	50			1	low	200
M38	Plant	1500	S	80	S	20			1	low	300
M39	Plant	1500	S	50	Pl	50			1	low	200
M40	Plant	1500	Pl	80	S	20			1	low	200

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
M41	Natural	1500	Sx	70	Pl	20	Bl	10	3	high	300
M42	Natural	1500	Sx	70	Pl	20	Bl	10	3	med	300
M43	Natural	1200	Sx	70	Pl	20	Bl	10	5	low	300
M44	Natural	2500	Pl	80	S	20			2	med	200
M45	Natural	2000	Pl	80	S	20			2	med	200
M46	Natural	2000	Pl	80	S	20			3	low	200
M47	Natural	1500	Fd	75	Bl	25			4	med	300
M48	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M49	Plant	1500	S	80	S	20			1	med	300
M50	Plant	1500	Pl	80	S	20			1	med	200
M51	Plant	1500	S	80	S	20			1	low	300
M52	Plant	1500	Pl	80	S	20			1	low	200
M53	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M54	Plant	1500	S	80	S	20			1	med	300
M55	Plant	1500	Pl	80	S	20			1	high	200
M56	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M57	Plant	1500	Bl	70	S	20	Pl	10	1	low	300
M58	Plant	1500	Bl	70	S	20	Pl	10	1	low	300
M59	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M60	Plant	1500	S	80	S	20			1	low	300
M61	Plant	1500	Pl	80	S	20			1	low	200
M62	Plant	1500	Pl	80	S	20			1	med	200
M63	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M64	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M65	Plant	2000	Bl	70	S	20	Pl	10	1	low	300
M66	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M67	Plant	1500	S	80	S	20			1	med	300
M68	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M69	Plant	1500	S	80	S	20			1	med	300
M70	Plant	2000	Bl	70	S	20	Pl	10	1	low	300
M71	Plant	1500	S	80	S	20			1	med	300
M72	Plant	1500	Pl	80	S	20			1	med	200
M73	Plant	1500	Pl	50	S	50			1	high	200
M74	Plant	1500	Pl	80	S	20			1	low	200
M75	Plant	1500	Pl	50	S	50			1	high	200
M76	Plant	1500	S	80	S	20			1	high	300
M77	Plant	1500	S	50	Pl	50			1	high	200
M78	Plant	1500	S	80	S	20			1	med	300
M79	Plant	1500	Pl	80	S	20			1	low	200
M80	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M81	Plant	1500	Pl	80	S	20			1	med	200

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
M82	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M83	Plant	1500	Pl	50	S	50			1	high	200
M84	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M85	Plant	1500	S	80	S	20			1	med	300
M86	Plant	1500	Pl	80	S	20			1	med	200
M87	Plant	2000	Bl	70	S	20	Pl	10	1	med	300
M88	Plant	1500	Pl	50	S	50			1	high	200
M89	Plant	1500	S	80	S	20			1	low	300
M90	Plant	1500	Pl	80	S	20			1	low	200
M91	Plant	1500	Pl	80	S	20			1	low	200
M92	Plant	1500	Pl	50	S	50			1	high	200
M93	Plant	1500	S	80	S	20			1	med	300
M94	Plant	1500	Pl	50	S	50			1	high	200
M95	Plant	1500	S	80	S	20			1	high	300
M96	Plant	1500	Pl	80	S	20			1	med	200
M97	Plant	1500	Pl	80	S	20			1	low	200
M98	Plant	1500	Pl	80	S	20			1	low	200

* Brush Potential refers to the degree of simulated competition from “brush” vegetation species including shrubs and herbs.

Table 4. Carbon analysis units (AUs) for existing natural stands within the Lakes TSA. Relationships to TSR and Base Case AUs are indicated. These CAUs are applicable to all scenarios.

C AU	TSR Description	TSR Base Case AU#	SQ	ITGs	Spp	SI Criteria
1	Fir / Balsam	1, 401	All	1,4,5,8,18-20	F,B	All
2	Spruce leading	2	G	21-26	S	>=18
3	Spruce leading	3 ,403	M	21-26	S	12 to 18
4	Spruce leading	4, 404	P	21-26	S	8 to 12
5	Pure Pine	5	G	28	Pl	>=18
6	Pure Pine	6	M	28	Pl	12 to 18
7	Pure Pine	7	P	28	Pl	8 to 12
8	Pine leading w F/S	8	G	29-31	Pl,F,S	>=18
9	Pine leading w F/S	9	M	29-31	Pl,F,S	12 to 18
10	Pine leading w F/S	10	P	29-31	Pl,F,S	8 to 12
11	H leading	11	G	12,13,14,15,16,17	H	>=18
12	H leading	12	M	12,13,14,15,16,17	H	12 to 18
13	H leading	13	P	12,13,14,15,16,17	H	8 to 12
14	Dec leading	14,17,21	G	35,36,40-42	Deciduos leading	>=18
15	Dec leading	15,18,22	M	35,36,40-42	Deciduos leading	12 to 18

C AU	TSR Description	TSR Base Case AU#	SQ	ITGs	Spp	SI Criteria
16	Dec leading	16,19	P	35,36,40-42	Deciduos leading	8 to 12
17	Conifer low	na	L	all but 35,36,40-42	Conifer leading	<8
18	Dec Low	na	L	35,36,40-42	Deciduos leading	<8

Table 5. Carbon analysis units for existing and future managed stands within the Lakes TSA. The scenario field refers to the landscape management scenarios for which each CAU was used.

C AU	Originating Nat or existing Man stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M1	Fir / Balsam	BC, FP	Fdi/Bl (50%/50%)	101	1,3,4,5,8,18-20	F,B	All
M2	Dec leading	BC, FP	Dec leading	311,315	35,36,40-42	Deciduous leading	>=18
M3	Dec leading	BC, FP	Dec leading	312	35,36,40-42	Deciduous leading	12 to 18
M4	Dec leading	BC, FP	Dec leading	313	35,36,40-42	Deciduous leading	8 to 12
M5	Spruce leading	BC, FP	S/Pl (60%/40%)	102	21-26	S ,Pl	>=18
M6	Spruce leading	BC, FP	S/Pl (60%/40%)	103	21-26	S ,Pl	12 to 18
M7	Spruce leading	BC, FP	S/Pl (60%/40%)	104	21-26	S ,Pl	8 to 12
M8	Pure Pine	BC, FP	Pl (100%)	105, 205, 305	28	Pl	>=18
M9	Pure Pine	BC, FP	Pl (100%)	106, 206, 306	28	Pl	12 to 18
M10	Pure Pine	BC, FP	Pl (100%)	107, 207, 307	28	Pl	8 to 12
M11	Pine leading w F/S	BC, FP	Pl/S (80%,20%)	108, 208, 308	29-31	Pl,F,S	>=18
M12	Pine leading w F/S	BC, FP	Pl/S (80%,20%)	109, 209, 309	29-31	Pl,F,S	12 to 18
M13	Pine leading w F/S	BC, FP	Pl/S (80%,20%)	110, 210, 310	29-31	Pl,F,S	8 to 12
M14	Dec leading	BC, FP	S/Pl (60%/40%)	na	35,36,40-42	Deciduous leading	>=18
M15	Dec leading	BC, FP	S/Pl (60%/40%)	na	35,36,40-42	Deciduous leading	12 to 18
M16	Dec leading	BC, FP	S/Pl (60%/40%)	na	35,36,40-42	Deciduous leading	8 to 12
M17	H leading	ND, BC, FP	H leading (Nat Regen)	11	12,13,14,15,16,17,9	H	>=18
M18	H leading	ND, BC, FP	H leading (Nat Regen)	12	12,13,14,15,16,17,9	H	12 to 18
M19	H leading	ND, BC, FP	H leading (Nat Regen)	13	12,13,14,15,16,17,9	H	8 to 12
M20	Spruce leading	ND	S leadinfg (Nat Regen)	2	21-26	S	>=18
M21	Spruce leading	ND	S leadinfg (Nat Regen)	3 ,403	21-26	S	12 to 18
M22	Spruce leading	ND	S leadinfg (Nat Regen)	4, 404	21-26	S	8 to 12
M23	Pure Pine	ND	Pure Pl (Nat Regen)	5	28	Pl	>=18

C AU	Originating Nat or existing Man stand	Scenario*	Man stand (Regen)	TSR Base Case AU#	ITGs	Spp	SI Criteria
M24	Pure Pine	ND	Pure Pl (Nat Regen)	6	28	Pl	12 to 18
M25	Pure Pine	ND	Pure Pl (Nat Regen)	7	28	Pl	8 to 12
M26	Pine leading w F/S	ND	Pl w F/S (Nat Regen)	8	29-31	Pl,F,S	>=18
M27	Pine leading w F/S	ND	Pl w F/S (Nat Regen)	9	29-31	Pl,F,S	12 to 18
M28	Pine leading w F/S	ND	Pl w F/S (Nat Regen)	10	29-31	Pl,F,S	8 to 12
M29	Fir / Balsam	ND	Fdi/Bl (50%/50%) (Nat Regen)	101	1,3,4,5,8,18-20	F,B	All
M30	Conifer low	FP	Fdi/Bl (50%/50%)	na	all but 35,36,40-42	Conifer leading	<8
M31	Conifer low	FP	Pl (100%)	na	all but 35,36,40-42	Conifer leading	<8
M32	Conifer low	FP	Pl/S (80%,20%)	na	all but 35,36,40-42	Conifer leading	<8
M33	Conifer low	FP	S/Pl (60%/40%)	na	all but 35,36,40-42	Conifer leading	<8
M34	Decid low	FP	Dec leading	na	35,36,40-42	Deciduos leading	<8

* BC = Base Case scenario; ND = Natural Disturbance scenario; FP = Forest Productivity scenario

Table 6. Regeneration assumptions for the Lakes TSA CAUs including regeneration delay, competition from understory vegetation, and total run length.

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
1	Natural	2000	Fd	70	S	20	Pl	10	3	med	300
2	Natural	2000	S	70	Pl	20	Bl	10	3	high	300
3	Natural	2000	S	70	Pl	20	Bl	10	3	med	300
4	Natural	1500	S	70	Pl	20	Bl	10	5	low	300
5	Natural	3000	Pl	100					3	high	200
6	Natural	2500	Pl	100					3	med	200
7	Natural	2000	Pl	100					4	low	200
8	Natural	2500	Pl	75	S	25			3	high	200
9	Natural	2000	Pl	75	S	25			3	med	200
10	Natural	1500	Pl	75	S	25			4	low	200
11	Natural	2500	Fd	75	Bl	25			4	high	300
12	Natural	2500	Fd	75	Bl	25			4	med	300
13	Natural	2000	Fd	75	Bl	25			4	low	300
14	Natural	4000	At	75	Sw	15	Pl	10	3	high	200
15	Natural	3000	At	75	Sw	15	Pl	10	3	med	200
16	Natural	2000	At	75	Sw	15	Pl	10	3	low	200
17	Natural	1000	Bl	100					4	low	300

C AU	Regen Type	Density	Sp1	Sp%	Sp2	Sp2%	Sp3	Sp3%	Regen Delay	Brush potential*	run length (y)
18	Natural	1500	At	100					3	low	150
M1	Plant	2,800	Fd	50	Bl	50			1	med	300
M2	Natural	4000	At	85	S	10	Pl	5	1	high	200
M3	Natural	3000	At	85	S	10	Pl	5	1	med	200
M4	Natural	2000	At	85	S	10	Pl	5	1	low	200
M5	Plant	2,800	S	60	Pl	40			1	high	200
M6	Plant	2,800	S	60	Pl	40			1	med	200
M7	Plant	2,800	S	60	Pl	40			1	low	200
M8	Plant	2,800	Pl	100					1	high	200
M9	Plant	2,800	Pl	100					1	med	200
M10	Plant	2,800	Pl	100					1	low	200
M11	Plant	2,800	Pl	80	S	20			1	high	200
M12	Plant	2,800	Pl	80	S	20			1	med	200
M13	Plant	2,800	Pl	80	S	20			1	low	200
M14	Plant	2,800	S	60	Pl	40			1	high	200
M15	Plant	2,800	S	60	Pl	40			1	med	200
M16	Plant	2,800	S	60	Pl	40			1	low	200
M17	Natural	2500	Fd	75	Bl	25			3	high	300
M18	Natural	2500	Fd	75	Bl	25			3	med	300
M19	Natural	2000	Fd	75	Bl	25			3	low	300
M20	Natural	2000	S	70	Pl	20	Bl	10	4	high	300
M21	Natural	2000	S	70	Pl	20	Bl	10	4	med	300
M22	Natural	1500	S	70	Pl	20	Bl	10	4	low	300
M23	Natural	3000	Pl	100					3	high	200
M24	Natural	2500	Pl	100					3	med	200
M25	Natural	2000	Pl	100					3	low	200
M26	Natural	2500	Pl	75	S	25			3	high	200
M27	Natural	2000	Pl	75	S	25			3	med	200
M28	Natural	1500	Pl	75	S	25			3	low	200
M29	Natural	2000	Fd	70	S	20	Pl	10	3	med	300
M30	Plant	2,800	Fd	50	Bl	50			1	low	300
M31	Plant	2,800	Pl	100					1	low	200
M32	Plant	2,800	Pl	80	S	20			1	low	200
M33	Plant	2,800	S	60	Pl	40			1	low	200
M34	Natural	4000	At	85	S	10	Pl	5	1	low	200

* Brush Potential refers to the degree of simulated competition from “brush” vegetation species including shrubs and herbs.

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

The FORECAST model 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 CAUs described in Tables 1-10. 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 stand management transition pathways determined for specific forest polygons within the forest planning scenarios prepared by Tesera were summarized and used to guide this process. The objective 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 existing stand types and using this harvest age to generate the starting condition for each of subsequent managed stand-curves. Using this approach each managed stand CAU was limited to a single predecessor. The starting condition of an ecosystem simulation in FORECAST is represented by a series of state variables described within the ECOSTATE file. The transition pathways including average harvest ages for all of the existing stand types (including natural and managed stands) are defined for the Morice and Lakes CAUs in Tables 11 and 12, respectively. Natural disturbance events (including mountain pine beetle mortality) were not explicitly modelled in FORECAST but were represented implicitly using the transition pathways provided by Tesera which assumed that all affected stands were salvaged harvested. Despite using this method, there will still be some errors generated during the transition process but they should be relatively small compared to changes in total ecosystem C storage due to growth and harvest.

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 CAUs. In addition, average annual rates of C sequestration were calculated for each CAU for each time step based on the following equation:

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

Table 7. Transition pathways and average harvest age for existing natural and managed stand C AUs for the Morice TSA at the time of harvest.

		Transition Pathway*			Avg. Harvest age		
C AU	Description	Base case	Ecosystem	Forest Productivity	Base case	Ecosystem	Forest Productivity
1	Balsam-good	M8-M10	M1	M1,M8-M10	120	120	120
2	Balsam-med	M19-M21	M2	M2,M19-M21	140	140	140
3	Balsam-poor	M30-M32	M3	15,M3,M30-M32	200	200	200
4	Spruce-good	M11-M13	M41	M11-13,M63	110	135	110
5	Spruce-med	M22-M24	M42	15,M22-M24,M64	140	175	140
6	Spruce-poor	M33-M35	M43	M33-M35,M65	200	250	200
7	Pine-good	M14,M15	M44	M14,M15,M66,M67	80	80	80
8	Pine-med	M25,M26	M45	M25,M26,M68,M69	100	100	100
9	Pine-poor	M36,M37	M46	M36,M37,M70,M71	120	120	120
10	Hemlock-med	M22-M24	M47	M48-M52	140	125	140
11	Hemlock-poor	11	11	M53,M54,M55	na	na	150
12	Dec- good	M16-M18	M4	M16-M18,M56	60	60	60
13	Dec- med	M27-M29	M5	M27-M29,M57	75	75	75
14	Dec - por	M38-M40	M6	M38-M40,M58	100	100	100
15	Conifer - low	15	15	15,M59-M61	na	na	200
16	Dec - low	16	16	15,M62	na	na	100
M1	Man_Balsam-good	M1	M1	M1,M72	na	na	110
M2	Man_Balsam-med	M2	M2	M2,M78,M79	na	na	130
M3	Man_Balsam-poor	M3	M3	M3,M89,M90	na	na	160
M4	Man_Dec-good	M4	M4	M4,M95,M96	na	na	60
M5	Man_Dec-med	M5	M5	M5,M97	na	na	75
M6	Man_Dec-poor	M6	M6	M6,M98	na	na	90
M11	Man_S80_Pl20-good	M11	M11	M11,M74	na	na	100
M12	Man_S50_Pl50-good	M12	M12	M12,M75	na	na	100
M14	Man_Pl80_S20-good	M14	M14	M14,M76	na	na	80
M15	Man_Pl50_S50-good	M15	M15	M15,M77	na	na	80
M22	Man_S80_Pl20-med	M22	M22	M22,M80,M81	na	na	100
M23	Man_S50_Pl50-med	M23	M23	M23,M83	na	na	100
M25	Man_Pl80_S20-med	M25	M25	M25,M84-M86	na	na	100

		Transition Pathway*			Avg. Harvest age		
C AU	Description	Base case	Ecosystem	Forest Productivity	Base case	Ecosystem	Forest Productivity
M26	Man_Pl50_S50-med	M26	M26	M26,M87,M88	na	na	100
M33	Man_S80_Pl20-poor	M33	M33	M33,M91	na	na	150
M34	Man_S50_Pl50-poor	M34	M34	M34,M92	na	na	150
M36	Man_Pl80_S20-poor	M36	M36	M36,M93	na	na	110
M37	Man_Pl50_S50-poor	M37	M37	M37,M94	na	na	110

* In the case where there are multiple transition pathways, assignments are based on the growth and yield transition pathways determined in the Tesera model.

Table 8. Transition pathways and average harvest age for natural-stand C AUs for the Lakes TSA at the time of harvest. Managed stand types are assumed to transition to themselves unless otherwise stated.

		Transition Pathway*			Avg. Harvest age		
C AU	Description	Base case	Ecosystem	Forest Productivity	Base case	Ecosystem	Forest Productivity
1	Fir / Balsam-all	M1	M29	M1	120	140	120
2	Spruce leading-good	M5	M20	M5	100	120	100
3	Spruce leading-med	M6	M21	M6	120	140	120
4	Spruce leading-poor	M7	M22	M7	160	180	160
5	Pure Pine-good	M8	M23	M8	80	80	80
6	Pure Pine-med	M9	M24	M9	100	100	100
7	Pure Pine-poor	M10	M25	M10	120	120	120
8	Pine leading w F/S-good	M11	M26	M11	90	90	90
9	Pine leading w F/S-med	M12	M27	M12	110	110	110
10	Pine leading w F/S-poor	M13	M28	M13	130	130	130
11	H leading-good	M14	M17	M17	70	90	70
12	H leading-med	M15	M18	M18	85	110	85
13	H leading-poor	M16	M19	M19	110	130	110
14	Dec leading-good	M14	M2	M2	70	70	70
15	Dec leading-med	M15	M3	M3	85	85	85
16	Dec	M16	M4	M4	110	110	110

		Transition Pathway*			Avg. Harvest age		
C AU	Description	Base case	Ecosystem	Forest Productivity	Base case	Ecosystem	Forest Productivity
	leading-poor						
17	Conifer low-low	17	17	17,18,M30,M31,M32,M33	na	na	200
18	Dec Low-low	18	18	18,M34	na	na	110

* In the case where there are multiple transition pathways, assignments are based on the growth and yield transition pathways determined in the Tesera model.

3. Results and Discussion

3.1. Ecosystem C storage and Average Sequestration Rates

Ecosystem C storage provides an estimate of the total amount of carbon stored in a given analysis unit for a specific stand age and is used to measure stock change (see Section 3.2). In contrast, the calculated average annual 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 provided in an Excel file on the included CD. Examples of the long-term dynamics of carbon storage within the major ecosystem pools are shown for a natural stand (CAU 4) (Fig. 1) and an associated managed stand type (CAU M11) (Fig. 2). A direct comparison total ecosystem C storage for the natural and managed stand examples is shown in Figure 3. 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 stand (see Figure 1). In contrast, the managed stand has a smaller initial pool of C in dead organic matter resulting from the removal of harvested material (see Figure 2). The pronounced increase in CWD around year 200 in both examples is the result of a simulated break-up of pine component of the stand at this age. The differences in dead organic matter pools following disturbance also has an effect on the average annual sequestration rates of natural and managed stands (e.g. Fig. 4). In both cases there is a negative carbon balance for several decades following the disturbance. This is the result of the release of C (as CO_2) to the atmosphere following the decomposition of the various pools of dead organic matter resulting from the disturbances. Since the managed stand type has much smaller residual pools of CWD and relatively fast growth rates, its average sequestration rate climbs much more quickly than that for the natural stand types. However, from the perspective of total ecosystem stock change and assuming that both stands started with a similar quantity of ecosystem C prior to disturbance, the managed stand represents the greatest loss of carbon until around 50 years following disturbance when its total carbon content recovers to the level observed for a similarly aged natural stand. If storage in wood products created from harvested materials were considered, total stock change for the managed stand would be significantly improved in the first few decades following harvest.

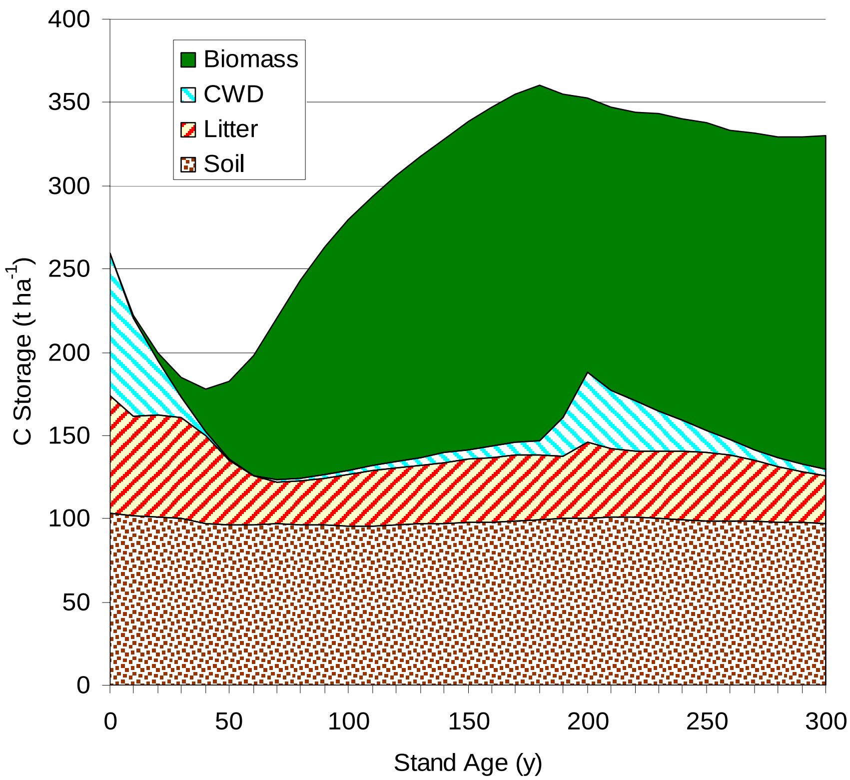

Figure 1. An example of the long-term changes in ecosystem carbon storage within the major ecosystem pools for a natural stand (CAU 4).

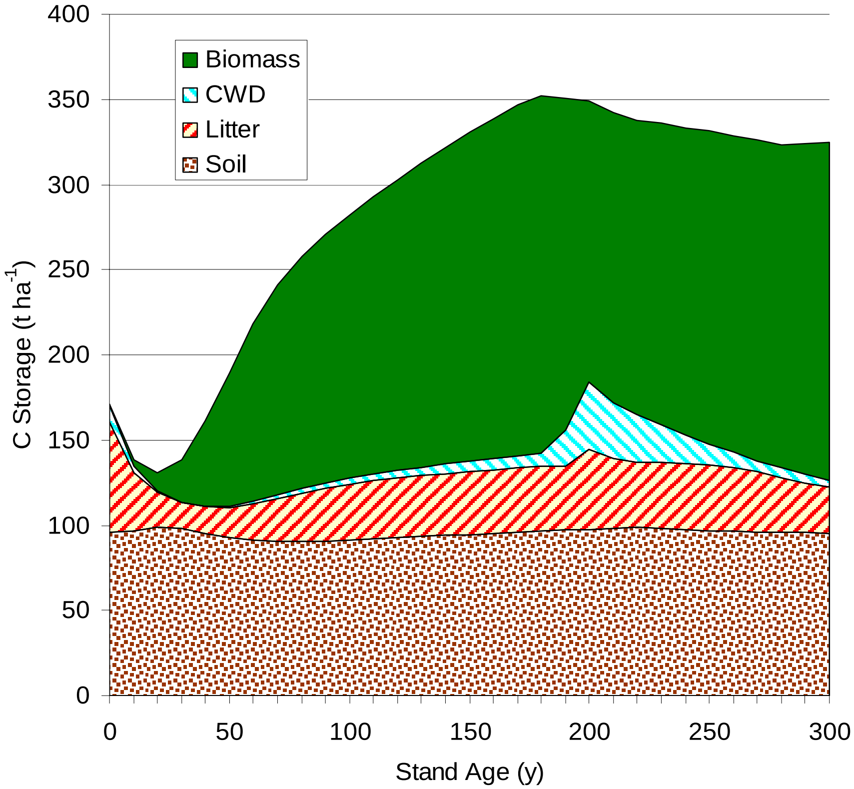

Figure 2. An example of the long-term changes in ecosystem carbon storage within the major ecosystem pools for a managed stand (CAU M11).

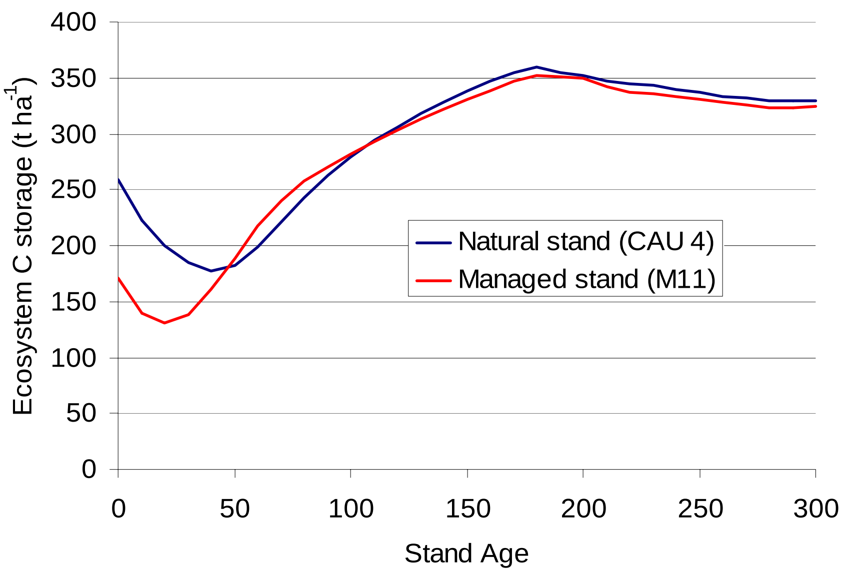

Figure 3. A comparison of total ecosystem C storage for a natural stand (Morice CAU 4) and an associated managed stand (Morice CAU M11).

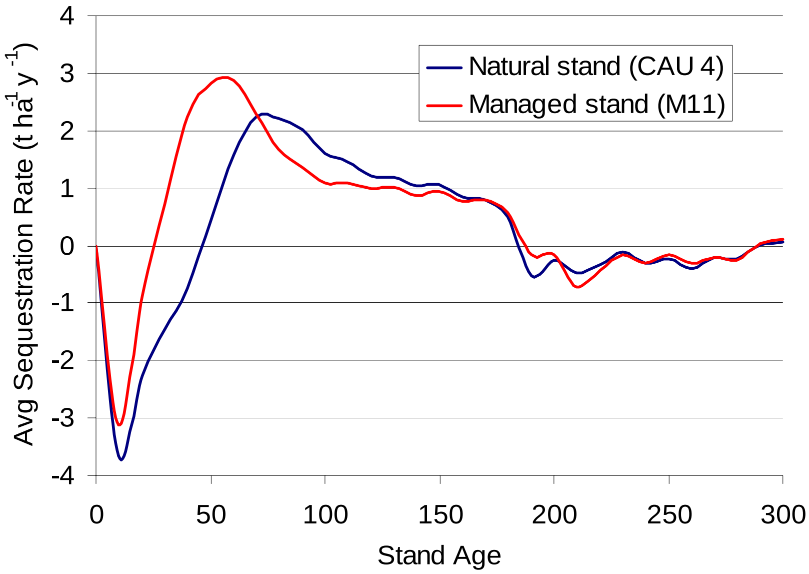

Figure 4. A comparison of average annual C sequestration rates for a natural stand (Morice CAU 4) and an associated managed stand (Morice CAU M11).

3.2 The application of C indicators for landscape-scale analyses

The carbon curves generated using FORECAST can be used to for the calculation 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 the Tesera model, 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:

A) 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: Mt (10^6 tonnes) 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.

B) 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 much of 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: Tonnes 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.

4. References

Kimmins, J.P., Mailly, D., Seely, B., 1999. Modelling forest ecosystem net primary production: the hybrid simulation approach used in FORECAST. Ecological. Modelling 122: 195-224.

Kurz. W.A, M.J. Apps, E. Banfield, and G. Stinson. (2002). Forest carbon accounting at the operational scale. Forestry Chronicle 78: 672-679.

Seely, B., Kimmins, J.P., Welham, C., Scoullar, K.A., 1999. Ecosystem management models: defining stand-level sustainability, exploring stand-level stewardship. Journal of Forestry 97(6):4-10.

Seely, B., C. Welham, and J.P Kimmins, (2002). Carbon Sequestration in a Boreal Forest Ecosystem: Results from the Ecosystem Simulation Model, FORECAST. Forest Ecology and Management 169:123-135.

Seely, B. (2004). Partial Calibration and Verification of FORECAST for CWH forest types (in support of the LLEMS Project) using output from TASS/TIPSY. Unpublished report prepared for International Forest Products Ltd.

Tesera Systems Inc. (2003). Scenario Planning Technical Report. Prepared for the Morice and Lakes Innovative Forest Practices Agreement.

Tesera Systems Inc. (2004). Forest Productivity Scenario Yield Curves. Report prepared for the Morice and Lakes Innovative Forest Practices Agreement.