Millar Western Forest Products Ltd.

Impacts of Climate Change at the Stand Level

2007-2016 Detailed Forest Management Plan

Prepared by the Climate Change Landscape Projection Group

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EXECUTIVE SUMMARY

This document describes the purpose, calibration, and results of a forest stand scale level computer simulation modeling project that is part of a much wider multi-scale, integrative, and hierarchical computer simulation modeling endeavour that was initiated to investigate the potential outcome of a forest landscape under the influence of global climate change (GCC) and natural and anthropogenic disturbances over a long time horizon. The purpose of the stand-level modeling is twofold: 1) to explore several key questions relating to the impact of climate change on a number of variables important for scientific and management purposes, and 2) to create a digital library of growth and yield computer simulation data output for the usage within the SELES landscape model.

We calibrated the FORECAST stand-level ecosystem model to determine the potential impacts of climate change on a set of above and below ground response variables related to several densities and mixtures of trembling aspen, lodgepole pine, white and black spruce growing on the forested Upper and Lower Foothills, Central and Dry Mixedwood ecosites of Millar Western Forest Products Ltd.'s boreal forest landbase. To achieve our objectives it was necessary to create two new sub-models do account for the influence of climate on the photosynthetic and soil decomposition responses. To initialise our sub-models and calibrate the FORECAST climate dependent variables we used the published temperature, precipitation, and carbon dioxide values given by the CCSR-NIEM GCM values in accordance with the SRES A-1 emission scenario, which represents an extreme case of climate change with twice the atmospheric CO_2 levels, an increase of seven degree Celsius, and a relative increase of approximately 8% in precipitation.

Our simulations suggest that under GCC conditions a white spruce monoculture stand can accumulate a surplus gain of approximately 25m^3/ha of merchantable volume, approximately 8% more than a stand growing under normal conditions. However, for dry sites with moisture deficits we found a slight decrease in biomass production. Both species growing in white spruce-trembling aspen communities benefited from GCC conditions. Our results also suggest

that white spruce growing in mixedwood communities may have a greater ability to benefit from climate change conditions than if grown by itself as a monoculture. In other words, climate change may have reduced the impact of trembling aspen competition on the production of white spruce aboveground biomass. Further investigation of our modeling output suggests that the possible cause of this observed relative surplus gain in productivity may be related to an increase of soil fertility along with an enhancement of white spruce's capacity to satisfy its total nitrogen demand under GCC conditions. Other species productivity increased or decreased according to stand and site nutrition conditions. Black spruce stands were the exception since they always showed a decrease of productivity under GCC conditions. This may be partly due to some difficulties encountered in the calibration phase, since we had noticeable less empirical data to work with to assure proper calibration. Another notable finding was how climate change seemed to alter succession. Indeed, we found that some two species mixedwoods could lose one species entirely and become a monoculture, very rapidly within the first 50 years of stand development.

Despite several noted shortcomings, we consider FORECAST, with its two new climate sensitive sub-models, to be an acceptable simulation model and a valuable heuristic tool as it helps the user-community to better understand the major issues involved in exploring complex questions such as dynamics of forest productivity under global climate change conditions.

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1. Introduction

This document describes the forest stand scale level computer simulation modeling portion of a much wider multi-scale, integrative, and hierarchical computer simulation modeling project that was initiated to investigate the outcome of a forest landscape under the influence of global climate change (GCC) and natural and anthropogenic disturbances over a long time horizon. The purpose of the stand-level modeling is twofold: 1) to explore several key questions relating to the impact of climate change on a number of variables important for scientific and management purposes, and 2) to create a digital library of growth and yield computer simulation data output for the usage within the SELES landscape model. From the latter scale, a number of indicators of sustainability will be evaluated: coarse and fine filter indicators of biodiversity, indicators of forest productivity and health, indicators of economic sustainability, and indicators for carbon sequestration in ecosystems.

1.1 Global Climate Change and Forest Ecosystems

According to the various scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) and the modeling results from the Canadian Centre for Climate Modeling and Analysis (CCCma), both the temperature and the atmospheric concentration of carbon dioxide (CO_2) are likely to significantly increase in Alberta's future, while precipitation may increase or decrease depending on which 'marker' scenario is used to guide the calibration of the Global Circulation Models (GCM) (IPCC 1996). The impact of changing climate on Alberta's forest ecosystems is far from being straightforward, since many biotic and abiotic factors coupled with ecological and geographical considerations need to be taken into account. For example, it is estimated that by 2080, drought could reduce forest productivity by up to 50%, particularly at the southern margin of the existing boreal forest and in locations where soil water-holding capacity is low. However, drought may improve growing conditions in locations where the water table is currently too high for forest growth. In areas where there is sufficient moisture, productivity

could increase up to 40% due to higher conditions (Johnston et al. 2001). Other impacts are expected, such as species migration and stand replacement due to coniferous regeneration failures (Hogg and Schwartz 1997), reductions in total ecosystem carbon storage due to greater soil decomposition rates (Price et al. 1999), increases in fire disturbance frequency and decreases in forest volumes, landscape fragmentation and diversity (Li et al. 2000), and negative impacts on biodiversity, and recreational and cultural values (Henderson et al. 2002), amongst others.

One of the challenges is to predict long-term and the large-scale responses of forests to a rapidly changing environment, and to transfer knowledge to forest mangers, policy makers, and other stakeholders. To make progress, computer simulation models, such as hybrid models that incorporate the advantages of both process-based and empirical models, may be used even though they cannot easily be verified at the temporal scales on which they are applied (Peng 2000).

1.2   Computer Simulation Modeling

In order to model long-term forest stand-level dynamics under various management and climate change scenarios, stand dynamic models should be capable of extrapolating ecosystem dynamics to a new set of environmental conditions, and produce useful products for the forest manager (Monserud 2003). Unfortunately, this precludes use of most forest growth and yield models since they are environmentally static (*i.e.*, future conditions are assumed to be identical to the past), and most gap models since their structural design are most often inappropriate. Indeed, many gap models: 1) assume that the realized niche of a species is identical to its fundamental niche, 2) fail to separate the effect of temperature on seedling establishment from the temperature effect on growth of established trees, 3) use arbitrary equations to predict the effect of changes in temperature, moisture, and nutrients on growth, 4) employ a convex-parabolic model for the effect of temperature on growth which contradicts the demonstrated fact that established trees can grow far outside their current range, and 5) are incapable of making accurate predictions of the consequences of increased CO_2 concentrations (Hinckley et al. 1996). Additionally, traditional gap models fail to account for key mechanisms in regeneration that could be strongly influenced by climate change (Price et al. 2001), and finally they lack connections with forest management needs (Monserud 2003).

Hybrid models that incorporate both empirically defined and mechanistic elements to simulate important physiological processes may provide a promising alternative for the projection of ecosystem behaviour, as long as the different aspects are well defined in the model (Schenk 1996). While modeling the effect of climate change on tree and stand development over long time periods is still in its infancy, some indication of the importance of causal factors has been recognized and classified as being of primary importance (increase in temperature, CO_2, and O3), of secondary importance (increase in soil temperature, microbial activity, and changes in precipitation patterns), and of tertiary importance (changes in tree phenology and photosynthesis) (Schwalm and Ek, 2001). It is therefore argued that a climate change model must strive to: 1) have detailed dependencies of metabolic processes on climate variables (e.g. temperature and precipitation), 2) couple above and belowground processes, 3) incorporate responses such as

flowering, seed production, and tree migration to climatic conditions, 4) recognize the multiple interactions of factors on stand development, and 5) possess a rigorous mechanistic treatment of natural regeneration of trees and other non-tree vegetation (Schwalm and Ek, 2001).

1.3   Stand-Level Modeling Objectives

This research project is a collaboration between the "Institut Québécois d'Aménagement de la Forêt Feuillue" (IQAFF) and Millar Western Forest Product Ltd., a privately owned forest products company that manages approximately 400,000 hectares of forestland in the Whitecourt region of Alberta, Canada. As previously mentioned the main purpose of the stand-level modeling is twofold: 1) to answer several key questions relating to the impact of climate change on a number of variables important for scientific and management purposes, and 2) to create a digital library of growth and yield simulation data output for the usage within the SELES landscape model. More precisely, the first purpose maybe broken down into two main objectives: 1) to present the important ecosystem responses for the main ecological processes involved at the forest stand level, for the normal and GCC conditions, and differences between, and 2) compare these responses to other similar simulation modeling efforts done in the boreal forest, and elsewhere if relevant. For the sake of clarity each main objective has been broken down into a subset of questions that aim to cover the main forest ecosystem responses for both above and below ground processes.

In order to explore such complex issues we chose the FORECAST model because it uses both empirical data and ecological processes to simulate forest growth and other stand-level dynamics. While, temperature and precipitation, two important climate drivers, are not explicitly dealt with in the model, it is possible to determine what effect these climate variables have on the forest ecological processes that are explicitly modeled. Here, an extensive literature review of the impacts of climate change variables (temperature, CO_2 concentration, and moisture) on forest ecological processes is necessary to ensure that the modeling exercise is based on a solid foundation of ecological research. Some key climate sensitive processes that are explicitly integrated into FORECAST are photosynthesis, decomposition of biomass (e.g., tree, soil litter, and humus), nutrient dynamics (e.g., precipitation input and internal cycling), and the partitioning of net primary production between aboveground and belowground biomass. Other impacts of climate change on forest dynamics can also be integrated and yet remain external to the FORECAST model (Figure 1). For example, the influence of climate change can be integrated in the regeneration sub-model by modifying the equations that relate CO_2 to tree seed fecundity (as suggested by LaDeau and Clark (2001)), the ability of vegetative reproduction (Price et al. 2001), and the probability that a seed will germinate on dryer/wetter and warmer/colder seedbeds. Other essential variables used by the regeneration sub-model (e.g. light at the forest floor, foliage and root biomass) will be provided by FORECAST.
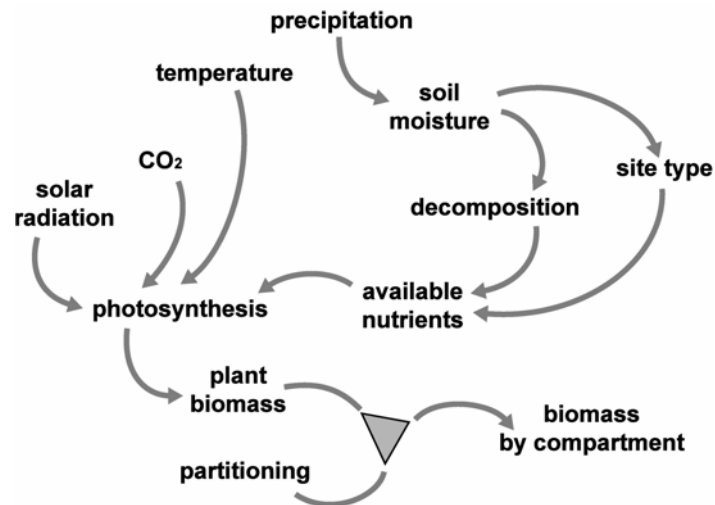
Figure 1. Conceptual model of the relationship between the environmental factors and ecological processes involved in the stand-level modeling context.

In order to adapt FORECAST to the study area, two separate model calibration schemes will be adopted. The first will consider the forest without climate change. Here, empirical data will be used from Millar Western's temporary and permanent sample plots, with help of The Forestry Corp. consultants, data found in the literature, and simulation output from a locally calibrated growth and yield model (the Mixedwood Growth Model (Titus, 1998)). A second calibration will then be performed to modify the climate dependent variables found in FORECAST. As previously mentioned, a literature review will be necessary to identify the state of knowledge, empirical data, and the relationship between climate variables and key forest ecological processes. Thus, important FORECAST climate sensitive variables (see above) will be modified to account for the climate change variables provided by regional climate models (RCM).

2. Model Description, Calibration, and Evaluation

2.1 The FORECAST Model

The FORECAST forest ecosystem management simulation model (Kimmins et al., 1999) is a stand-level ecosystem model that combines the traditional bioassay modeling approach with process-based simulation modeling to provide a method of projecting future forest biomass yield as well as a variety of other ecosystem variables under a range of management conditions. FORECAST, as a hybrid model, takes the yield (production) predictions from observed field data and modify these predictions according to the temporal variation in competition for light and the availability of one or more nutrients (e.g. nitrogen). As such, it was design to account for changes in future management regimes, human impacts on the environment (e.g. climate change), and/or changes in soil fertility that are anticipated to occur, which may differ from past conditions. From the observed empirical data FORECAST first calculates total net primary production (TNPP), then derives the production efficiency of foliar nitrogen (FNE) by dividing the annual TNPP for a particular species by the total quantity of foliar nitrogen present in a given time step. Annual potential growth (APG) of vegetation is driven by the photosynthetic production of the foliage biomass (given by photosynthetic light saturation curves), and is calculated as a function of shade-corrected foliar nitrogen efficiency (SCFNE), which represents the "driving function" of the model, and can be simply viewed as modification of the TNPP scaled to the amount of fully illuminated foliage N (in sun foliage) (Kimmins et al.1999)

The actual annual growth (AAG) depends upon whether the nutrient uptake demand created by the potential growth can be satisfied by the available nutrient resources. The quantity of available nutrient resource is a function of the: 1) simulated internal translocation of nutrients

within the plant, 2) simulated net canopy uptake/leaching losses, and 3) simulated level of available nutrients in that soil that are available to the plants. Nutrient cycling is based on a mass balance approach where nutrients can exist in three different pools: a) the plant biomass pool, b) the available soil nutrient pool, and 3) the soil organic matter/forest floor pool. Litter decomposition is driven by empirical input data describing the weight loss rates as a function of the type of decomposing material and its age, the concentrations of nutrients in litter and humus, and the temporal change in nutrient concentration between litter and humus. Finally, competition for nutrients among species is a function of the size of nutrient pools, and the relative occupancy of the soil by fine-roots of each species (Kimmins et al. 1999).

2.2 Classification of the Landbase

Millar Western's forest management area falls within the Foothills and Boreal Forest Natural Regions. Four natural subregions are found within the FMA: Upper Foothills, Lower Foothills, Central Mixedwoods, and Dry Mixedwoods. Each Subregion can be further divided into Ecosites that represent ecological units that develop under similar environmental influences (climate, moisture, and nutrient regime). The major tree species found in the Lower Foothills, the dominant Subregion found in the study area, are lodgepole pine (Pl), white spruce (Sw), and trembling aspen (Aw).

In order to account for the combined interaction of biophysical factors which together dictate the availability of moisture and nutrients for plant growth, it was decided that smallest modeling unit would be the ecosite level of the Alberta's ecosystem classification system (Beckingham and Archibald 1996). Since there are more than 20 forested ecosites in the landbase we sought to reduce the amount of units by grouping ecosites that displayed similar soil nutrient and moisture characteristics, along with similar tree productivity index (i.e. mean height of trees at year 50). This was accomplished by using the data from Beckingham and Archibald (1996) and performing a principal component analysis (PCA) in order to assign each ecosite found on the landbase to one of five groups.
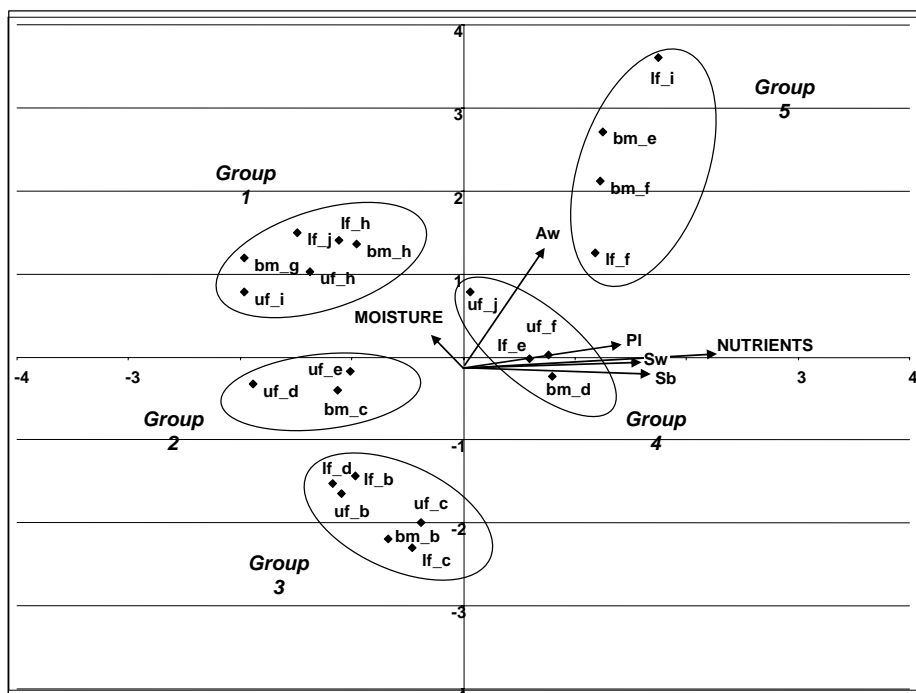
Figure 2. PCA grouping of ecosites according to tree specific site index as a function of site moisture and nutrient status found in the Alberta's ecosystem classification system.

Figure 2 shows the results of the PCA analysis and the five groups that were determined to represent relativity homogeneous groups, and Table 1 gives the summary statistics of the different groups. In general terms, group1 represents the productivity of trees growing on moist and nutrient poor sites, group 2 mesic and poor, group 3 dry and poor, group 4 mesic and medium, and group 5 moist and rich site. These five combinations cover all of the possible moisture and nutrient classes found on the forested landbase.

Table 1.   **Main statistics of the grouping of ecosites found on the Millar Western landbase according to site index, soil moisture and nutrients found in the Alberta's ecosystem classification system.**

Characteristics of Ecosite Groupings from the Alberta Field Guides						
PCA Groupings	**Species Specific Site Index[3]**				**Percent Land Area[1]**	**Moisture[2]**	**Nutrients[2]**
	Sw	**Sb**	**Pl**	**Aw**			
G1	14.26	10.85	14.46	18.50	7.44%	6.61	2.43
G2	11.21	11.09	13.91	17.80	13.89%	4.95	2.87
G3	13.17	12.60	15.37	15.81	12.04%	4.85	2.56
G4	18.93	14.64	17.39	17.76	55.28%	5.02	3.20
G5	17.74	14.07	18.51	20.62	3.32%	5.84	3.56

[1] Only forested ecosites where used

[2] Moisture code fall between 2 (xeric) to 9 (Hydric), and nutrients 1 (poor) to 5 (very rich)

[3] Site index is mean weighed height of trees at year 50 according to percent land area

2.3   Model Calibration

Because the FORECAST model requires large quantities of calibration data it is preferable to start the calibration phase by using a previously calibrated version containing similar tree species for relatively similar site conditions. Fortunately, the model had already been calibrated twice of boreal tree species, once in British Columbia (Seely 2002) and once for the boreal forest of Saskatchewan (Welham 2002). FORECAST also requires empirical data along a temporal scale, which can be collected either by gathering data from sample plots along a chronosequence, or from growth and yield output tables generated from government models especially calibrated for the purpose of producing acceptable yield curves. We opted for the second approach given the limited amount of permanent sample plots established in the Millar Western landbase, and to assure the congruence between the Alberta's government growth and yield estimates and our models' empirical calibration data. However, we will acknowledge the usefulness of Millar Western's temporary and permanent sample plot data in a subsequent section once it is required to evaluate (a.k.a. validate) some aspects of our modeling output.

We used the Mixedwood Growth Model (MGM version 2002A) (Titus 1998) to produce growth and yield tables for white spruce, trembling, aspen, and lodgepole pine, for the several productivity levels (i.e. site index). Black spruce was calibrated separately using Millar Western's growth and yield data because MGM version 2002A did not contain data for this species.

The remaining tree stand variables (e.g. fine root biomass) that needed calibration were parameterized using allometric equations (Ter-Mikaelian and Korzukin 1997; Li et al. 2000), and

data from other FORECAST datasets previously calibrated for similar boreal forest types. Finally, other important climate driven forest related ecosystem processes such as photosynthesis (Landhausser and Lieffers 2001; Cannell and Thornley 1998) and soil decomposition (Trofmymow et al. 2002) were identified, and parameter rates modified according to the relative anticipated differences in temperature, CO_2, and precipitation between normal and climate change conditions. As such, anticipated climate variables were given by the CCSR-NIEM GCM with the SRES scenario A1, which represents an extreme case of climate change with approximately twice the level atmospheric CO_2 and an increase of temperature of approximately seven degrees. Some FORECAST variables were therefore twice calibrated, once to express ecosystem processes under normal climate and once more to account for change in climatic conditions.
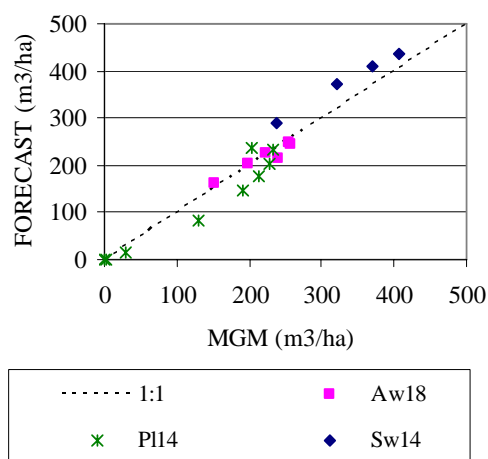
Figure 3. Example of the relationship between merchantable volume (m3/ha) from outputs of the MGM and FORECAST models for three species. Output from FORECAST are for species grown on ecosites represented by productivity Group 1 (moist and nutrient poor) and for MGM site index of Aw was 18, of Sw = 14, and for Pl 14.

Figure 3 shows an example of the fit in the calibration process between the MGM and FORECAST model, when the latter is used as a light only model. The purpose of this first calibration phase was to create empirical equivalence between both models, as to assure that FORECAST's output would be comparable to MGM, which is widely used by university, government and forest industry, and deemed an acceptable growth and yield model in Alberta. In the example given above we can see there is a close one-to-one relationship between both model outputs for merchantable volume. Other variables and productivity sites gave similar acceptable results, which is not surprising since concordance between models was the main calibration object.
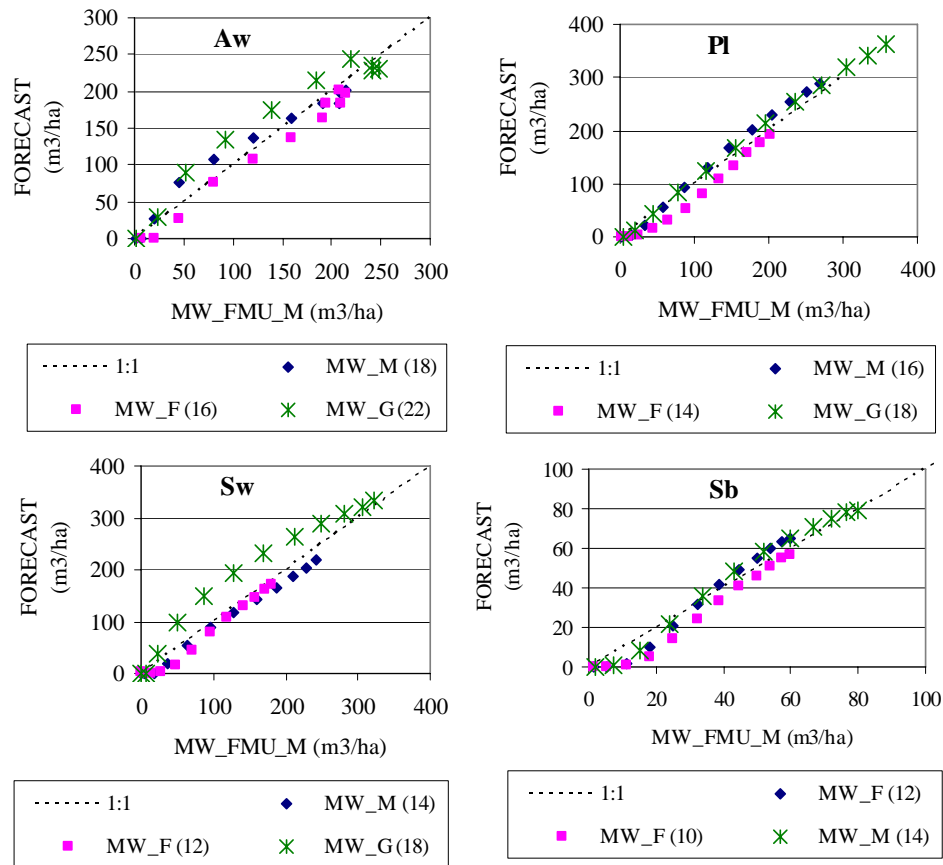
Figure 4. Example of the relationship between merchantable volume (m3/ha) from Millar Western's Forest Management Units growth and yield data for managed stands (MW_FMU_M) and output from the FORECAST model for four species. Tags in the legend are as follow: MW = Millar Western data; _F = fair sites, _M= medium sites; _G= good sites, and numbers in parentheses (e.g. 18)) represent the corresponding site index use for the FORECAST simulations.

We also sought to fine-tune the calibration of the growth and yield component of the model by comparing FORECAST output with empirical and modeling data gathered on the landbase and provided by the Millar Western Forest Products Ltd.. As such we compared the merchantable volume (m³/ha) produced by FORECAST to the Millar Western growth and yield data published in the Timber Supply documentation of the 1997-2006 Detailed Forest Management Plan (DFMP). Figure 4 shows the level of congruity between the modeled output data and that used for the timber supply growth and yield analysis of the forest company. Overall we found a relatively good fit (1:1 ratio) for all species growing on fair, medium and good sites. However, FORECAST tends to slightly overestimate merchantable volume for aspen and white spruce on good site.

2.4   Tree and stand biomass

This section describes the equations uses for the calibration of the various FORECAST tree and stand level biomass components. Extensive data was needed since FORECAST calibration requires biomass values for all components along a chronosequence of up to 400 years. Clearly such level of empirical detail is lacking, thus it is necessary to use simple available stand data (i.e. dbh and height of trees) coupled with allometric equations to determine the other unavailable biomass data. Below we give the equations as well as the parameters used to determent all levels of stand level biomass components needed to calibrate the empirical portion of the FORECAST model.

$$Bmass = aDBH^{\,b}$$ (equation 1.0)

where:

- Bmass = above ground tree component biomass (kg).

- a and b = species-specific scaling parameters (see Table 2)

- DBH = diameter at breast height (cm)

Table 2. **Parameter values for the allometric equation used to calibrate the above ground stand level biomass component of the four species in the FORECAST model.**

Parameter Values for the Allometric Equation[1]			
Tree Species	Tree Components	Parameter Values	
		a	b
AW	Total Above	0,1049	2,391
AW	Stemwood	0,0639	2,3938
AW	Bark	0,0139	2,4007
AW	Total Stem	0,0558	2,5046
AW	Foliage	0,0198	1,8031
AW	Branch	0,0192	2,4468
SW	Total Above	0,1077	2,3308
SW	Stemwood	0,0376	2,4883
SW	Bark	0,011	2,1547
SW	Total Stem	0,0445	2,4737
SW	Foliage	0,061	1,8465
SW	Branch	0,0435	2,149
PL	Total Above	0,2131	2,1283
PL	Stemwood	0,1172	2,2116
PL	Bark	0,0157	2,0701
PL	Total Stem	0,147	2,1673
PL	Foliage	0,0489	1,714
PL	Branch	0,0353	2,1113
SB	Total Above	0,1444	2,2604
SB	Stemwood	0,069	2,3387
SB	Bark	0,0124	2,1815
SB	Total Stem	0,0849	2,313
SB	Foliage	0,0495	1,8761
SB	Branch	0,0287	2,2679

[1]Parameter values from Ter-Mikaelien and Korzukhin 1997

$$SBmass = \frac{Bmass * density}{1000} * SCLP$$ (equation 2.0)

where:

- SBmass = Stand aboveground biomass (t/ha).

- a and b = species-specific scaling parameters (see Table 2).

- DBH = diameter at breast height (cm)

- SCLP = scaling parameter to adjust literature values to local empirical observations

And for belowground tree components

$$SBBmass = AvRp \text{ (equation 3.0)}$$

where:

- SBBmass = Stand belowground biomass (t/ha).

- Av = numerical values from a FORCAST allometric variable (see Table 3).

- Rp = species-specific scaling parameters (see Table 3).

Table 3. **Parameter values for the allometric equation used to calibrate the below ground stand level biomass component of the four species in the FORECAST model.**

Parameter Values for the Allometric Equation			
Tree Species	**Tree Components**	**Allometric Variable (Av)[1]**	**Parameter Values (Rp)**
AW	Large Roots	Stemwood	0,1588
AW	Medium Roots	Stemwood	0,1016
AW	Small Roots	Foliage	0,7
SW	Large Roots	Stemwood	0,2272
SW	Stemwood	Stemwood	0,1016
SW	Small Roots	Foliage	0,4
PL	Large Roots	Stemwood	0,2805
PL	Medium Roots	Stemwood	0,1016
PL	Small Roots	Foliage	0,98
SB	Large Roots	Stemwood	0,2272
SB	Medium Roots	Stemwood	0,1016
SB	Small Roots	Foliage	0,7

[1]Refers to the FORECAST variable used to calculate the tree component in the allometric equation

2.5 Forest Succession

Natural regeneration at the stand level occurs in two different manners: 1) mechanistically as a stand initiating process, and 2) as a user defined input variable to ensure succession. The first method of dealing with regeneration is very complex and necessitated a great number of variables to depict a more realistic representation of the recruitment process. It is also a means

for initiating a stand following a disturbance, and a method for scaling up to landscape, all within the context of climate change. In Appendix I, we describe the mechanisms involved at the stand level, but forward the reader to the landscape document here within the DFMP for more details. The second manner of treating natural regeneration occurs within the FORECAST model, and is comparable to seedling cohorts being added to a stand already on successional pathway, and letting the internal dynamics of the model determine the fate of the additional seedlings. While we acknowledge that adding a mechanistic natural sub-model within FORECAST would have been a more precise solution, time and other logistical constraints made it impossible and forced us to proceed with a user defined input procedure. As such, given our knowledge of the species life histories (e.g. age of reproduction, maximum age, and anticipated regeneration success, etc.), we added 1/2 of the initial stem densities found at stand origin, at strategic moments in the temporal evolution of stand (Table 4). It is also important to mention that the number of stems at stand initiation is intended to cover a wide range of possible recruitment abundance events, and reflect mostly the abundance of stems that are expect to be free to grow according to the managed crop plans of Millar Western (i.e. plantation seedlings established and pass the critical mortality stage of the recruitment process).

Table 4.   The temporal user defined species-specific seedling abundances within the FORECAST regeneration procedure

Seedling Densities Involved within the FORECAST Regeneration Procedure					
Tree Species	Time (years)				
	0	121	241	300	361
Sw; Sb	125	63	63	63	63
Aw; Sw	375	188	188	188	188
Aw; Sw; Sb; Pl	625	313	313	313	313
Aw	875	438	438	438	438
Aw;Sb; Pl	1125	563	563	563	563
Pl	1275	638	638	638	638
Sb	1625	813	813	813	813
Sw; Pl	1875	938	938	938	938
Pl	2125	1063	1063	1063	1063
Sw; Sb	2375	1188	1188	1188	1188
Aw; Pl	3125	1563	1563	1563	1563
Pl	3875	1938	1938	1938	1938

2.6   Photosynthesis and soil decomposition

2.6.1   Photosynthesis

Photosynthesis is an important ecological process to consider for modeling forest dynamic under climate change. In FORECAST, annual potential growth (APG) of vegetation in the ecosystem module is driven by photosynthetic production of foliage biomass, which is calculated as a

function of shade-corrected foliar nitrogen efficiency (SCFNE), and subsequently determined by the availability of nutrients. In essence, foliage biomass is distributed uniformly into quarter-meter canopy height increments between the top and bottom of the live canopy, and a light profile is determined. Species-specific photosynthetic light saturation curves (PLSC), based on the proportion of the maximum photosynthesis rate determined as a function of light levels, are used to define the extent of the photosynthetic activity associated with the foliage nitrogen content of each quarter-meter height increment in the canopy.

Since there has been no research that has experimentally manipulated all the factors that control photosynthesis (i.e. temperature, CO_2, light, moisture, nutrients), there are no comprehensive datasets that explicitly define the PLSC`s of all boreal tree species, for all current and future conditions under climate change. It is therefore essential to derive a mathematical function for which the photosynthetic light saturation curves can be determined for all the boreal tree species, under all possible environmental conditions.

There are two main approaches for modeling photosynthesis. The first is to model the photosynthetic process at the biochemical level, such as the Farquhar model (Farquhar 1989). These models are typically designed to describe the photosynthesis at the enzymatic, cellular, and leaf level, contain eight to ten parameters, five or six that are temperature dependent, and have an emergent behaviour that is not always transparent. Furthermore, parameter values for the boreal tree species growing *in-situ* are often lacking, and scaling from enzymatic reactions to forest canopy dynamics is problematic since the two scales are very far apart and often unrelated. The second approach to modeling photosynthesis is to simplify the procedure and rely on a mathematical function (i.e. non linear models) that describes the shape of the photosynthetic response, and that contains two or three parameters with high biological meaning. These models, such as the non-rectangular hyperbola Cannell and Thornley (1998) or the Mitscherlich function as describe by Potvin et al. (1990) and Peek et al. (2002) and used by Landhausser and Lieffers (2001), are easily fitted to field data through statistical procedures such as repeated-measures analysis of variance, are well suited to CO_2-response data for multiple scales (e.g. from leaf to canopies), and may be easily modified to account for the influence of climate variables on the shape of the curve. Due to the nature and scale of this modeling project, the Mitscherlich function has been selected as the main function for producing the species-foliage-specific PLSC`s, where both the predicted rate of CO_2 (Asat) and the apparent quantum yield parameters will be allowed to change as a function of temperature and CO_2, according to the suggestions of Cannell and Thornley (1998).

Since I found no single research study where all boreal tree species had been compared amongst each other in their photosynthetic response under various climatic influences, and failed to find a simple photosynthesis model to arrive at such requirements, it was necessary to create a computer simulation tool. This simulation tool is programmed in Visual Basic for Application and generated net photosynthetic light saturation curves (PLSC's) for the major boreal tree species for any combination of carbon dioxide concentrations and temperature levels. Additionally, these curves must be generated for both sun and shade foliage, with regards to the possibility of photosynthetic acclimation to elevated CO_2.

The basic of the photosyntesis model is the **Mitscherlich** function which is formulated as follow:

$$A = A_{sat}\left[1 - e^{-\phi(PPFD - \Gamma)}\right]$$ (equation 4.0)

where:

- A = Photosynthetic CO_2 assimilation (mmol m^{-}1.s^{-1}).

- A_{sat} = light-saturated photosynthesis (mmol m^{-}1.s^{-1}).

- ϕ = apparent quantum yield (mol$_{CO2}$m^{-2}.mol$_{photon}$m^{-2}).

- PPFD = a measure of light incidence at foliage level (mmol m^{-1}.s^{-1}).

- Γ = light compensation point (mmol m^{-}1.s^{-1}).

Since the objective is to model photosynthesis for boreal tree species for both sun and shade foliage, and given the need to reduce the amount of inferential problems that arise when having to deduce parameter estimates from a collection of unrelated research studies, it was deemed reasonable to use the study of Landhausser and Lieffers (2001) as a starting point. As such, since this study fitted the Mitscherlich function to six boreal tree species grown in the understory and open conditions, it best suited the selection criteria mentioned above.

The photosynthetic function having been selected it is essential to understand how carbon dioxide and temperature affect the biologically meaningful parameters. A possible solution for modeling temperature and CO_2 responses of leaf and canopy photosynthesis comes from Cannell and Thornley (1998). These authors argue that the responses of photosynthesis to increasing temperature and CO_2 can be readily understood in terms of the temperature dependencies of quantum yield and light-saturated photosynthesis, two parameters involved in most non-linear photosynthesis functions such as the Mitscherlich. Additionally, besides for the explicit description of the temperature and CO_2 dependencies of the apparent quantum yield and of light-saturated photosynthesis, the authors include a means to mathematically account for acclimation to temperature. In their dependency equation acclimation can shift the temperature optimum where light-saturated photosynthesis occurs. In their appendix Cannell and Thornley (1998) give a working example for modeling photosynthesis according to light, carbon dioxide concentrations, and temperature, however, they use typical generic values of the involved parameters for C$_3$ plants. It is therefore essential to work out a detailed method to calibrate their mathematical equations with published values for boreal tree species.

The first step in providing a means for parameterizing a photosynthesis model for boreal tree species under climate change is to describe how carbon dioxide and temperature affects the parameters in the non-linear function. Since we anticipate the responses to be species-specific it is essential to first express the dependencies described above in relative terms (i.e. as

percentages), and second to calibrate according to empirical data of boreal tree photosynthesis response. According to the Appendix of Cannell and Thornley (1998) the general equation used to describe:

The temperature and CO_2 dependence of the apparent quantum yield is:

$$\phi_i = \phi_{i15} f_{Ca,\phi i} f_{T\phi i} \quad \text{(equation 5.0)}$$

where:

- ϕ_i = the apparent quantum yield.

- ϕ_{i15} = a notational maximal value at 15°C .

- $f_{Ca,\phi i}$ = a function that accounts for the CO_2 concentration.

- $f_{T\phi i}$ = a function that accounts for temperature.

The temperature and CO_2 dependence of light-saturated photosynthetic rate is:

$$A_{sat} = A_{sat,20} f_{Ca,Asat} f_{T,Asat} \quad \text{(equation 6.0)}$$

where:

- A_{sat} = the light-saturated photosynthetic rate.

- $A_{sat,20}$ = a notational maximal value at 20°C.

- $f_{Ca,Asat}$ = a function that accounts for the CO_2 concentration.

- $f_{T\phi I,Asat}$ = a function that accounts for temperature.

The mathematical expressions of the functions found inside these fundamental equations can be found in Cannell and Thornely (1998). Finally, in FORECAST the photosynthetic light saturation curves (PLSC's) are expressed on a percentage scale, so the last step is to express the differences between the GCC and N curves (Figure 5) as a relative percent difference and to adjust the FORECAST curves accordingly. Both the sun and shade foliage curves are given the same relative percent difference.
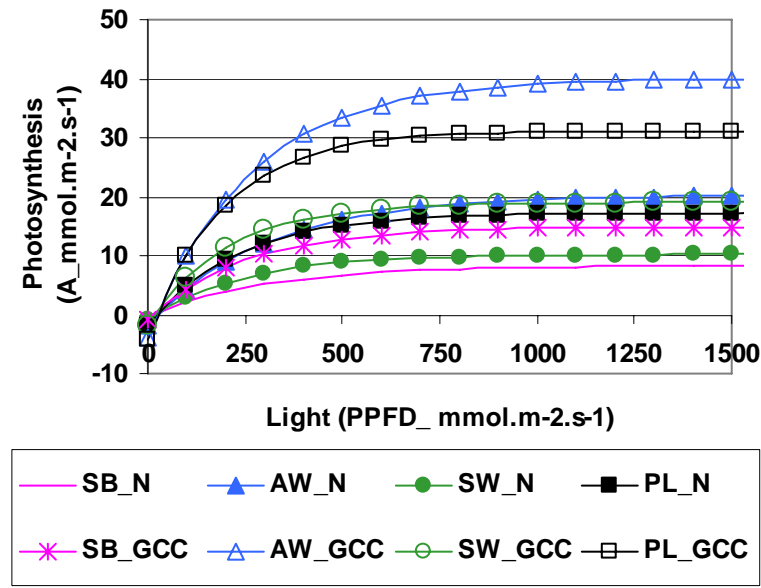
Figure 5. **Photosynthetic light saturation curves estimates produced from the FIXIT sub-model for AW, SW, SB, and PL.**

2.6.2 Soil decomposition

Under an alternate climate change scenario several FORECAST soil variables require a re-parameterization, such as the decomposition rates of the forest floor organic matter. It has been argued that the main factors controlling the stages of decomposition include climate (temperature and moisture), substrate quality (chemical and physical characteristics), and the composition and abundance of the soil biotic communities (Berg, 2000). While the theory of climate change driven impacts on soil decomposition processes may be increasing in the literature, the actual "in-situ" numerical quantification of process rates under alternate climate conditions remains lacking. As such, to determine parameter rates under climate change we must infer the impact from field experimental studies that have begun to examine decomposition processes over a broad range of site, climate, and litter qualities. The Canadian Intersite Decomposition Experiment (CIDET) represents the best alternative for gaining insight since it describes the decomposition of a range of litter types (tree leaves, needles, herbs and wood), over 6 years at forested sites ranging from the transitional grassland to the subartic (Trofymow et al. 2002). The premise for using data from the CIDET study is that space (geographical location of experimental sites) may be substituted for the temporal conditions of climate change. As such, we must infer that the observed decay rates of forest litter of a more southern site (e.g. higher *in-situ* soil temperature) may represent the future conditions of a more northern site. We acknowledge that this inference is most likely incorrect, but argue that, given the current lack of empirical evidence, it represents the most practical and logical method of proceeding for the calibration of FORECAST.

According to Trofymow *et al.* (2002) mean annual temperature and summer precipitation are two good climate predictors of litter mass remaining. They summarized their results by regressing the following two-variable model ($r^2 = 0.52$):

$$MRY6 = 49.39 - 2.82(T30) - 0.095(SP30) \quad \text{(equation 7.0)}$$

where:

- MRY6 = mass remaining at year 6 (%).

- T30 = 30-year mean annual temperature (ºC).

- SP30 = 30-year mean summer precipitation (mm)

Given equation x, with 1.44 ºC and 3.19 mm as normal climate variables, and 8.58ºC and 3.48mm to represent future climate change conditions, we find that the litter mass remaining at year-6 drops from 59.36 to 39.19%, a relative change of 20.17 percent. If we accept the premise and inference given above we may therefore re-calibrate the soil decomposition variables of FORECAST by adjusting the current rates by a factor of 0.2017. For example, we increased the percent mass loss rate of the litter components by a factor of 20.17% (Figure 6), as well as the rates of both humus types (i.e. slow and medium pools) (Figure 7).
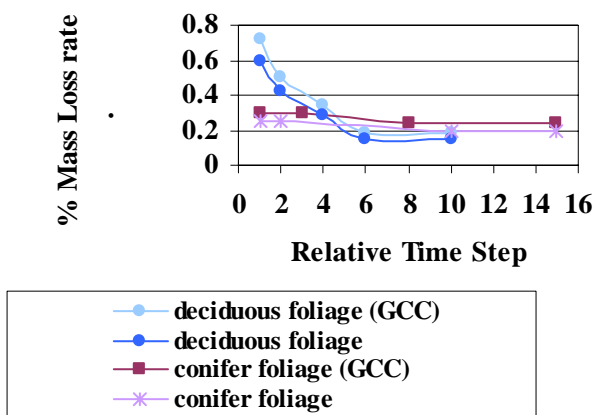
Figure 6. Decomposition example of how the 20.17% is applied to the mass loss rate of coniferous foliage.
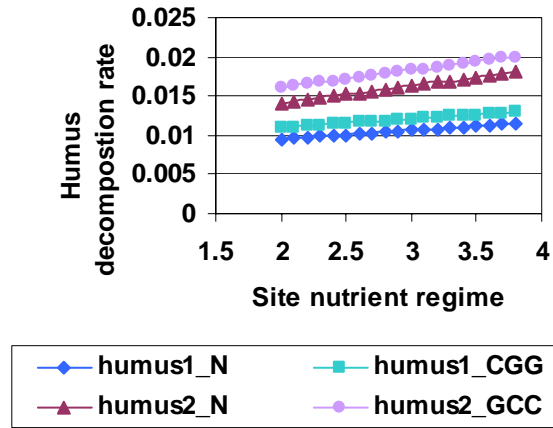
Figure 7. Decomposition rate of humus pools 1 and 2; example of how the 20.17% is applied. Note: Humus decomposition rates are dependant on both the nutrient and climatic conditions; humus1 and humus2 refers to the slow and medium decomposition types FORECAST humus pools, respectively.

3. Model Simulation Plan, Outputs and Results

3.1 Simulation Plan

We used the FORECAST model version 6.6.0 (Kimmins et al., 1999) and performed 400 simulations (Table 5) to document ecosystem change in terms of several key variables (e.g. above and below ground biomass, merchantable volume, soil nutrients, etc.), for various initial stem densities, species composition, and site productivity groups. For each five productivity group (Table 1) and two climatic conditions (normal and GCC) we simulated several strategic species combinations and initial stand stem densities. It should be noted that the initial stand stem densities represent the number of tree seedlings at year zero, but meant to represent the abundance of seedlings that have actually passed the critical early establishment phase where mortality is typically very high. In other words, the number of stems represent tree seedlings that are well established and part of the cohort of individuals that constitutes the initial stand, such as a plantation that has passed a typical regeneration stocking standard (e.g. free-to-grow).

Table 5. Simulation plan of the 400 FORECAST simulation runs. Table identifiers the five productivity groups (G1-G5), with two climatic conditions (normal = N; and global climate change GCC), and the species combinations (SP_1 and SP_2) along with the initial stand stem densities. The numbers within the table represent a TAG identifier of the specific run parameters (runs 1 to 400)

FORECAST Simulation Runs Grouped by Species and Species Combination Similarities													
G1_N	G2_N	G3_N	G4_N	G5_N	G1_GCC	G2_GCC	G3_GCC	G4_GCC	G5_GCC	SP_1	NbSP_1	SP_2	NbSP_2
5	45	85	125	165	205	245	285	325	365	AW	0	PL	2125
6	46	86	126	166	206	246	286	326	366	AW	0	PL	3875
7	47	87	127	167	207	247	287	327	367	AW	0	SB	1875
8	48	88	128	168	208	248	288	328	368	AW	0	SB	2375
2	42	82	122	162	202	242	282	322	362	AW	0	SW	375
1	41	81	121	161	201	241	281	321	361	AW	0	SW	1875
3	43	83	123	163	203	243	283	323	363	AW	1125	SW	0
4	44	84	124	164	204	244	284	324	364	AW	3125	SW	0
15	55	95	135	175	215	255	295	335	375	AW	375	SW	375
14	54	94	134	174	214	254	294	334	374	AW	1625	SW	625
25	65	105	145	185	225	265	305	345	385	AW	2375	SW	2375
31	71	111	151	191	231	271	311	351	391	AW	3125	SW	125
23	63	103	143	183	223	263	303	343	383	AW	3125	SW	1375
35	75	115	155	195	235	275	315	355	395	AW	3125	SW	2375
9	49	89	129	169	209	249	289	329	369	AW	875	SW	1875
18	58	98	138	178	218	258	298	338	378	AW	625	PL	625
40	80	120	160	200	240	280	320	360	400	AW	3125	PL	625
30	70	110	150	190	230	270	310	350	390	AW	3125	PL	2125
10	50	90	130	170	210	250	290	330	370	AW	875	PL	2125
26	66	106	146	186	226	266	306	346	386	AW	1375	PL	3125
36	76	116	156	196	236	276	316	356	396	AW	3125	PL	3875
20	60	100	140	180	220	260	300	340	380	PL	625	SW	625
32	72	112	152	192	232	272	312	352	392	PL	3875	SW	125
24	64	104	144	184	224	264	304	344	384	PL	3375	SW	1375
38	78	118	158	198	238	278	318	358	398	PL	3875	SW	2375
28	68	108	148	188	228	268	308	348	388	PL	1375	SW	2375
12	52	92	132	172	212	252	292	332	372	SW	375	SB	375
21	61	101	141	181	221	261	301	341	381	SW	1375	SB	1125
29	69	109	149	189	229	269	309	349	389	SW	2375	SB	2375
33	73	113	153	193	233	273	313	353	393	SW	125	SB	2375
13	53	93	133	173	213	253	293	333	373	AW	375	SB	375
16	56	96	136	176	216	256	296	336	376	AW	1625	SB	625
34	74	114	154	194	234	274	314	354	394	AW	3125	SB	125
39	79	119	159	199	239	279	319	359	399	AW	3125	SB	2375
11	51	91	131	171	211	251	291	331	371	AW	875	SB	1875
19	59	99	139	179	219	259	299	339	379	PL	625	SB	625
22	62	102	142	182	222	262	302	342	382	PL	3875	SB	625
37	77	117	157	197	237	277	317	357	397	PL	3875	SB	2375
17	57	97	137	177	217	257	297	337	377	PL	1125	SB	1625
27	67	107	147	187	227	267	307	347	387	PL	1875	SB	2375

3.2 Simulation Outputs and Results

In this section we summarize and present the yield (e.g. merchantable volume and various biomasses) of the four tree species and their combinations, for each groups and initial stand stem densities, for each climatic condition. First we give general descriptive statistics of the simulation output, and then we follow a question/answer format as a means of achieving the previously mentioned objectives. For the sake of making the text less encumbering we often refer to a simulation run ID rather then having to give all the background details for each simulation initial condition. For example, R50 refers to the initial simulation condition of a

stand growing in a normal climate, on a site type with characteristics of Group 2 (G2), with 872 stems of Aw and 2125 stems of Pl growing as a mixture (Appendix I). Moreover, we focus on the first 120 years of simulation output to tease apart the initial model simulation growth dynamics from the impacts of internal the successional rules, which we consider to be more difficult to interpret because of a greater number modeling assumptions, along with a different inferential context. In other words, the first few years of simulation output are more comparable to other conventional growth and yield model output, which remains the crux of the interpretation of the our growth and yield modeling at the stand level.

3.2.1 Summary statistics

Appendix II-VIII contains summary statistic output tables of average and standard deviation for the simulated stand basal area (m^2/ha), merchantable volume (m^3/ha), and total available nitrogen (kg/ha), for several stand compositions (i.e. initial species combination and stem densities), and for the normal and global climate change conditions. Statistics were calculated first by averaging the data from the five groups (G1-G5) given for a particular stand composition, then by determine the mean response for the simulation ages 70, 80 and 90 year, which together represent the variability at the site productivity level (i.e. site index, moisture and nutrient gradient), and the growth and yield data in the temporal window that represents the typical operational rotation age of Millar Western's crop plans. In order to facilitate the analysis of these output tables, the data was sorted and ordered to represent the increasing rank of impact of climate change on the three response variables (Table 6 and Table 7). Only the ten greatest and ten worst responses were kept, as they describe most of the variability in the dataset and indicate which stand composition contain the extremes.

Table 6. Percent change in simulated basal area between normal and global climate change condition. Only results for the stands (species combination and initial stem densities) showing the ten greatest increases (positive values) and ten worst decrease (negative value) are shown. Data used for calculations are given in Appendix (II-VIII).

Extremes Values of Descriptive Statistics of FORECAST Outputs					
Rank	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Species	(GCC-N) BA %
1	SW	2375	SB	2375	Sw	18,58
2	PL	3875	SB	2375	Pl	18,30
3	PL	3875	SW	2375	Pl	15,64
4	PL	3875	SB	625	Pl	14,95
5	AW	0	PL	3875	Pl	13,25
6	PL	3875	SW	125	Pl	13,13
7	PL	1875	SB	2375	Pl	11,40
8	PL	3375	SW	1375	Pl	11,10
9	AW	3125	SB	2375	Aw	10,89
10	PL	1375	SW	2375	Sw	10,04
63	AW	3125	SW	0	Aw	-0,47
64	PL	625	SB	625	Sb	-0,48
65	PL	3875	SB	625	Sb	-0,48
66	SW	375	SB	375	Sw	-0,54
67	SW	1375	SB	1125	Sb	-0,56
68	AW	0	SW	375	Sw	-0,58
69	PL	625	SW	625	Sw	-0,80
70	PL	3875	SB	2375	Sb	-0,80
71	AW	3125	SB	2375	Sb	-0,92
72	SW	2375	SB	2375	Sb	-4,32

Table 6 shows that stands growing under climate change conditions can increase in basal area up to 18.58% and also decrease up to 4.43%, depending on the species combination, and which species is regarded in the responses. It is often the case that when the basal area of a given species in a mixture of two species significantly increases, it impacts the second species in a negative fashion making its basal area decrease. Having said that, overall stands tend to grow more under climate change since the ten worst stands only showed slight decreases (near zero values).

Table 7. **Percent change in merchantable volume between normal and global climate change condition. Only results for the stands (species combination and initial stem densities) showing the ten greatest increases (positive values) and ten worst decrease (negative values) are shown. Data used for calculations are given in Appendix (II-VIII).**

Extremes Values of Descriptive Statistics of FORECAST Outputs						
Rank	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Species	(GCC-N) VoL %
1	SW	2375	SB	2375	Sw	21,98
2	PL	3875	SB	625	Pl	21,48
3	AW	0	PL	3875	Pl	19,86
4	PL	3875	SW	125	Pl	19,62
5	AW	3125	SB	2375	Aw	19,40
6	PL	3875	SB	2375	Pl	17,23
7	AW	3125	PL	3875	Aw	16,24
8	PL	3375	SW	1375	Pl	16,07
9	PL	1875	SB	2375	Pl	15,32
10	AW	1375	PL	3125	Pl	14,41
63	SW	1375	SB	1125	Sb	-0,41
64	SW	375	SB	375	Sw	-0,58
65	AW	0	SW	375	Sw	-0,62
66	PL	3875	SB	2375	Sb	-0,62
67	AW	3125	SW	125	Aw	-0,69
68	AW	3125	SB	125	Aw	-0,70
69	AW	3125	SW	0	Aw	-0,78
70	AW	3125	SB	2375	Sb	-0,79
71	PL	625	SW	625	Sw	-0,86
72	SW	2375	SB	2375	Sb	-3,58

For merchantable volume, stands mostly impacted by climate change tend to be the same ones that showed an impact on their basal area (Table 7). As such, the greatest increase in merchantable volume was for a mixedwood stand comprised of 2375 stems of white spruce with 2375 stems of black spruce, for a gain of 21.98%, merchantable volume increasing from 111.8 to 157.61 m^3/ha. Besides for this special case of SwSb mixture, it seems like lodgepole pine (Pl), either growing as monoculture or in mixtures with spruces, tends to show consistent increases in merchantable volume due to climate change, ranging from 14.41 to 21.48%. There are only two cases where the merchantable volume of trembling aspen (Aw) increased; stand comprised of 3125 stems of aspen growing with 2375 stems of black spruce, or growing with 3895 stems of pine. Besides for the case of SwSb, decreases in merchantable volume are very small (near zero values). Percent change in simulated total available nitrogen between normal and global climate change condition. Only results for the stands (species combination and initial stem densities) showing the ten greatest increases (positive values) and ten worst decrease (negative value) are shown. Data used for calculations are given in Appendix (II-VIII).

3.2.2 Above ground responses

Q.1.1: For typical monoculture plantations of Sw, Aw, Pl, and Sb growing on mesic sites, how does climate change impact the different tree biomass components?
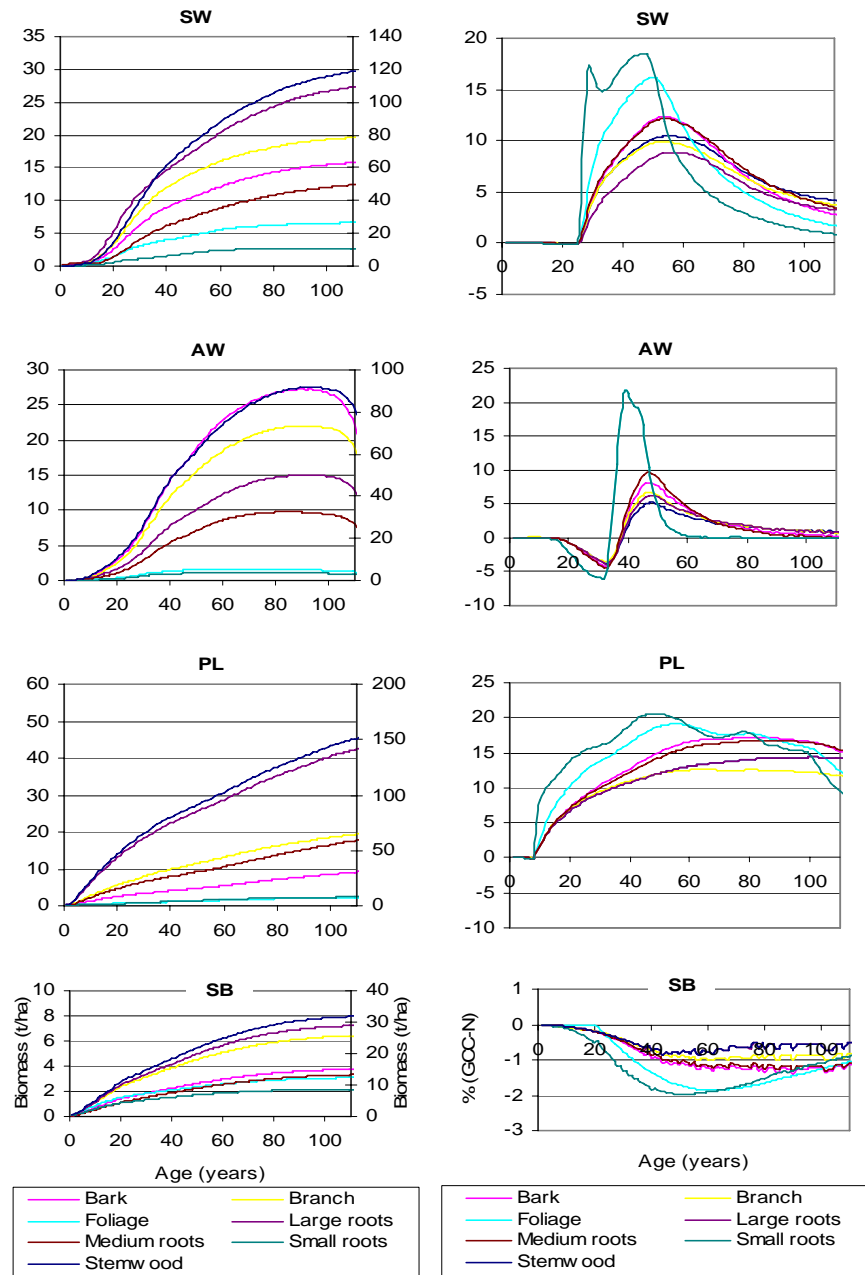
Figure 8. **Various tree biomass components for R121 (SW), R123 (AW), R125 (PL) and R127 (SB) for normal conditions (left panes) and the relative percent change due to the impact of global climate change (right panes). Note: stemwood biomass (t/ha) is on right y-axis.**

A.1.1: Stemwood biomass is by far the most abundant tree component biomass in the stands with maximal value of approximately 140 t/ha, 120 t/ha, 90 t/ha, and 30 t/ha, for Pl, Sw, Aw, and Sb, respectively. Foliage and small roots biomass always have the lowest values ranging from 1.6 to 7.3 t/ha for foliage, and 1.17 to 2.7 t/ha for small roots, with spruces and pines having the greatest amount of foliage and small roots, and aspen the lowest. Except for black spruce, foliage and small root showed the greatest relative gain in biomass for all stands, with maximal gains of approximately 20% for Pl and Aw, and 17% for Sw. Foliage and small root, and well as all other tree components slightly decreased in the black spruce stand. Finally, while the biomasses of the tree components in all the stands increased steadily to peak around and over 110 years of simulations, the relative percent gain most often reached it's maxima around 40 to 60 years and then declined (Figure 8).

Q1.2: *What is the variability in merchantable volume (m^3/ha) for the typical monoculture species managed plantation growing on a nutrient and moisture gradient?*

A1.2: Simulation results (Figure 9) suggest that under climate change:

- Trembling aspen (Aw) gained up to approximately 15m^3/ha at year 50 on ecosites falling in G5, 13m^3/ha at year 60 for G1, 5 m^3/ha for G4, and slight decreases in yield for G2 and G3.

- White spruce (Sw) gained up to approximately 25m^3/ha at year 60 on ecosites falling in G4 and G5, 20 m^3/ha for G1 at year 20, and slight decreases in yield for G2 and G3.

- Lodgepole pine (Pl) gain up to approximately 60m^3/ha at year 120 on ecosites falling in G4, 10 m^3/ha for G1 at year 80, 9 m^3/ha for G5 at year 40, and slight decreases in yield for G2 and G3.

- Black spruce (Sb) showed very slight decreased (i.e. barely 1m^3/ha over the rotation) in growth and yield for all ecosites.
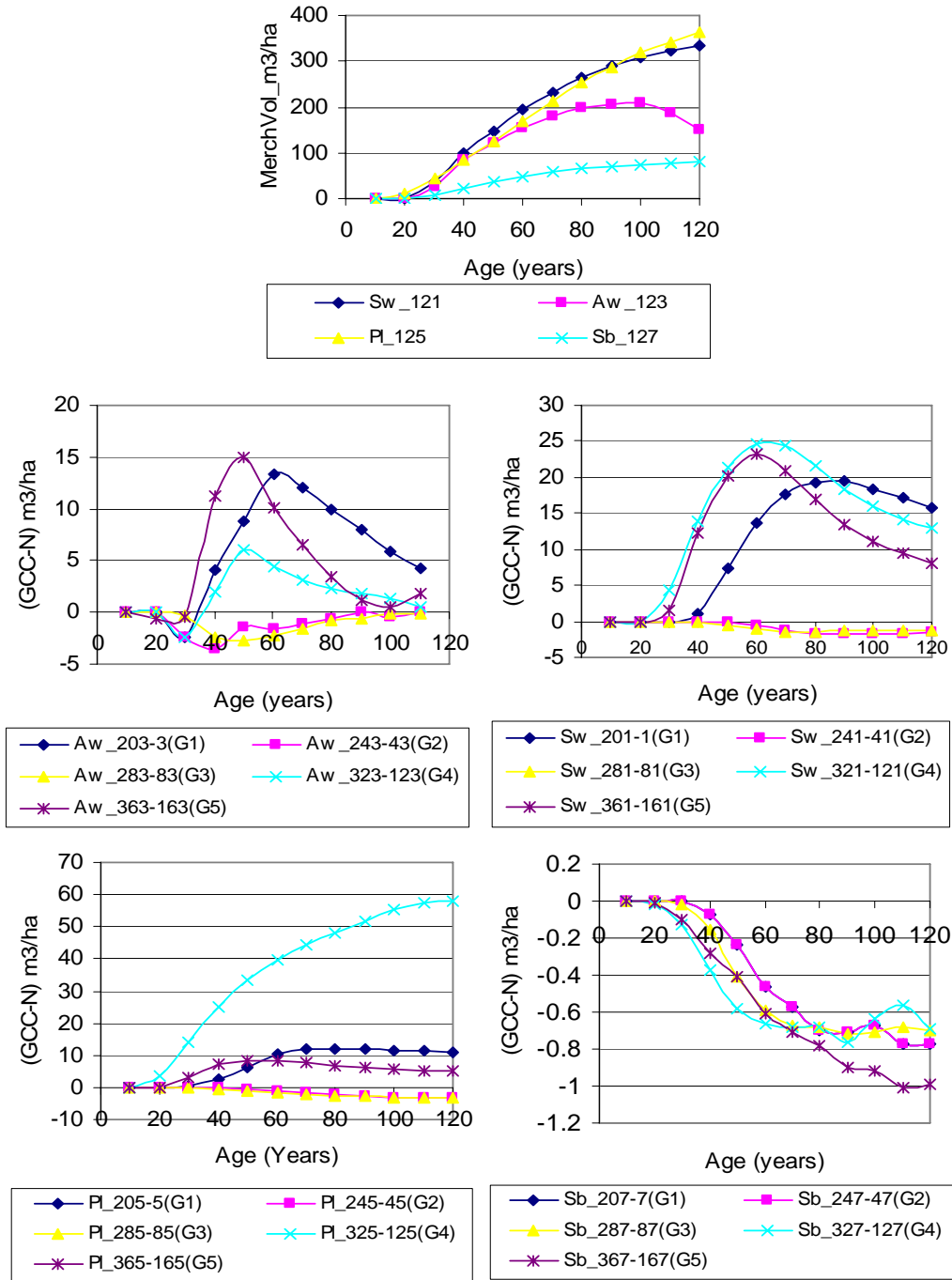
Figure 9. The impact of GCC on trembling aspen (Aw=1125 stems/ha), white spruce (Sw = 1875 stems/ha), lodgepole pine (Pl=2125 stems/ha), and black spruce (Sb=1785 stems/ha) monocultures, for the five ecosite groups. Y-axis is simulated merchantable volume (m^3/ha) under GCC minus (m^3/ha) under normal climatic conditions.

Q1.3: Under an extreme climate change scenario, what are the anticipated changes in merchantable volume (m³/ha) on white spruce (Sw) plantations growing on mesic site (G4) if other crop species are allowed to compete and create mixedwoods?
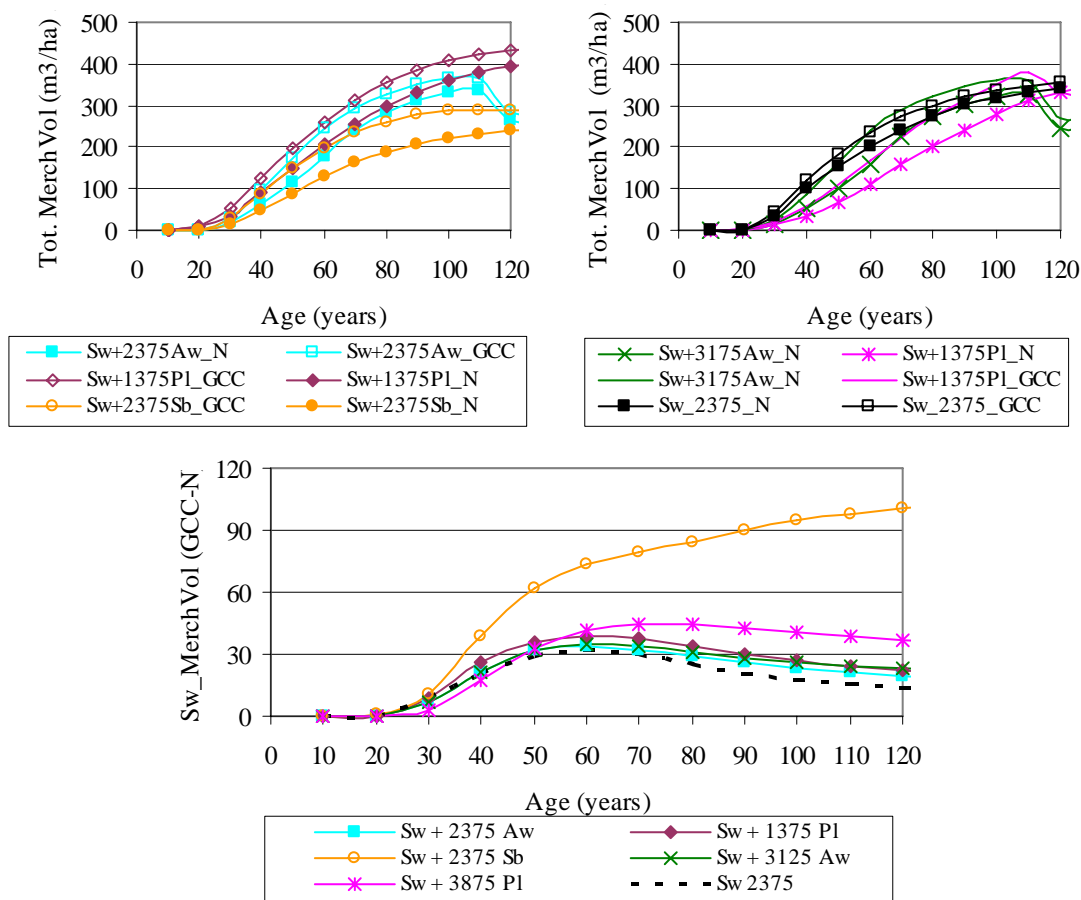
Figure 10. **The simulated impact of GCC after adding 2375 stems/ha of Aw, 1375 s/ha of Pl, 3125 s/ha of Aw, 3875 s/ha of Pl, and 2375 s/ha of Sb, to a monoculture of 2375 stems/ha of white spruce (dotted line). Y-Axis is the cumulative merchantable volume of both species, and the difference in merchantable volume between GCC and normal climatic conditions for the bottom pane.**

A.1.3: Simulation results suggest that under climate change (Figure 10):

- A white spruce (Sw) managed monoculture plantation may grow up to approximately 350m³/ha, with 25m³/ha of the volume owing to the increase of climate change.

- White spruce growing with 2375 stems of black spruce (Sb) was the most advantages mixedwood combination, with Sw showing a gain of up to $100m^3$/ha at year 120, for a total of $260m^3$/ha.

- The second best mixedwood combination was with 3875 stems of lodgepole pine, with Sw showing a gain of up to $150m^3$/ha at year 80, for a total of $275m^3$/ha.

3.2.3 Belowground soil responses

In this section we present results for the stands showing the ten greatest and ten least extreme departures in percent total available nitrogen (%GCC-N) Tot_N)) between stands growing under normal and global climate change conditions (Table 7). Then, for both climatic conditions, we show the temporal dynamics of nitrogen released from the litter (LI_REL) and the humus (HU_REL), the total available nitrogen (TOT_AV_N), and the humus mass (HUM_M) for the four typical tree species type of monoculture plantations (Sw, Aw, Pl, and Sb) (Figure 11). Finally, for these same four stands, we present curves that show the relationship between total available nitrogen and stemwood biomass across the first 120 years of stand development (Figure 12).

Table 8.   **Percent change in total available nitrogen between normal and global climate change condition. Only results for the stands (species combination and initial stem densities) showing the ten greatest increases (positive values) and ten worst decrease (negative values) are shown. Data used for calculations are given in Appendix (II-VIII).**

Extremes Values of Descriptive Statistics of FORECAST Outputs						
Rank	**Sp_1**	**Nb Sp1**	**Sp_2**	**Nb Sp2**	**Species**	**(GCC-N) Tot_N %**
1	PL	3875	SW	2375	Pl	21,24
2	PL	3875	SW	2375	Sw	21,24
3	PL	3375	SW	1375	Pl	19,15
4	PL	3375	SW	1375	Sw	19,15
5	AW	2375	SW	2375	Aw	18,72
6	AW	2375	SW	2375	Sw	18,72
7	AW	875	SW	1875	Aw	18,46
8	AW	875	SW	1875	Sw	18,46
9	PL	1375	SW	2375	Pl	18,19
10	PL	1375	SW	2375	Sw	18,19
63	AW	3125	SW	0	Aw	6,09
64	SW	125	SB	2375	Sb	3,42
65	SW	125	SB	2375	Sw	3,42
66	PL	625	SB	625	Pl	2,90
67	PL	625	SB	625	Sb	2,90
68	AW	0	SB	2375	Sb	2,81
69	AW	0	SB	1875	Sb	2,42
70	SW	375	SB	375	Sb	1,91
71	SW	375	SB	375	Sw	1,91
72	AW	0	SW	375	Sw	0,90

Responses in changes of the percent total available nitrogen follow the observed trends for increases and decreases in stand basal area and merchantable volume. In general, stands comprised of mixtures of white spruce (Sw) with pine (Pl), or aspen (Aw) showed greater increases in total available nitrogen, and stands with black spruce (Sb) were conservative in their nitrogen responses due to climate change. Values of total available nitrogen range between 78 to 111 kg/ha for normal climate and 96 to 119 kg/ha under climate change, with increases for the ten best stands ranging from 18.58 to 21.24%, and decreases being very small (6%) and near zero (Table 7).
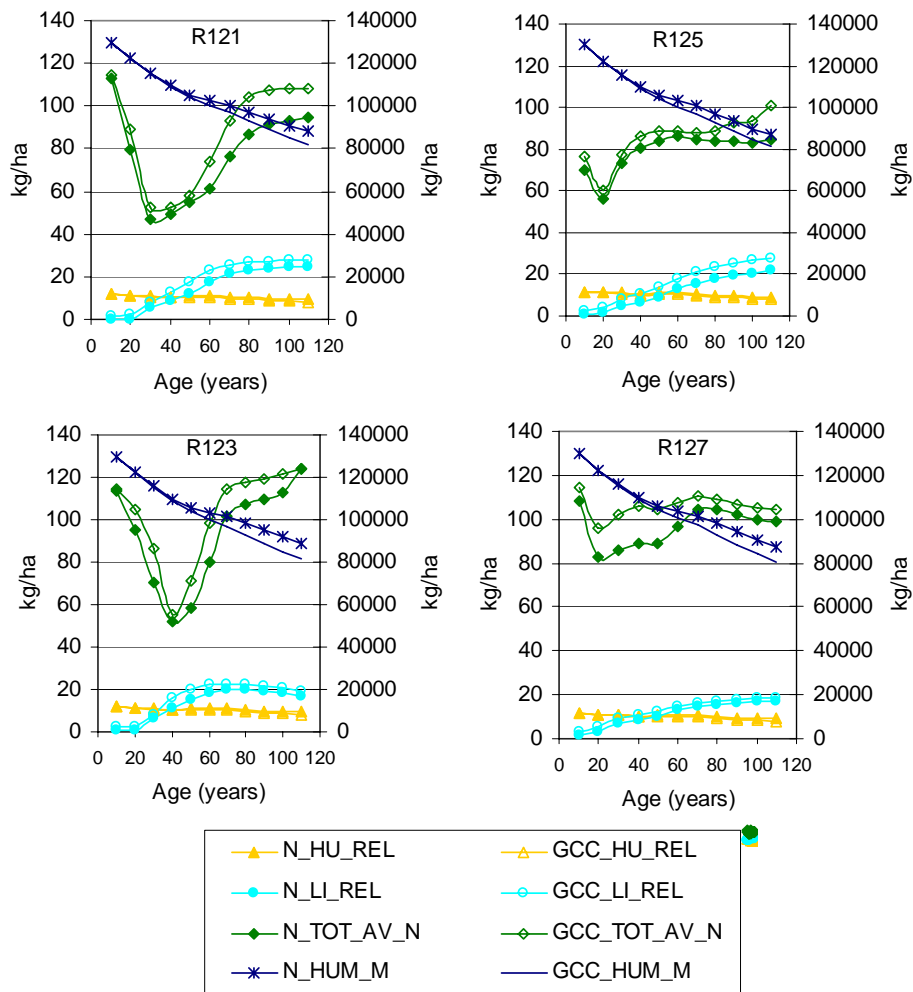
Figure 11. The impact of GCC (N_ or GCC_) on the temporal dynamics of nitrogen release from the litter (LI_REL) and humus (HU_REL), the total available nitrogen (TOT_AV_N), and the humus mass (HUM_M) for a typical monoculture stand of trembling aspen (R123;Aw=1125 stems/ha), white spruce (R121;Sw = 1875 stems/ha), lodgepole pine (R125;Pl=2125 stems/ha), and black spruce (R127;Sb=1785 stems/ha). Y-axis is simulated merchantable volume (m³/ha) under GCC minus (m³/ha) under normal climatic conditions.

In all four stands nitrogen release from the litter increased in time reaching approximately 24, 20, 21, and 17 kg/ha for Sw, Aw, Pl, and Sb stands respectively, with the impact of GCC slightly increasing the overall response with a maximum gain of 5 kg/ha for all stands, except Sb which only reached a maximum gain of 2 kg/ha (Figure 11). Nitrogen release from the humus decreased from approximately 12 to 9 kg/ha for all stands, with practically no differences owing to the impact of climate change. For all stands, the mass of the humus steadily declined from approximately 129000 to 85000 kg/ha, with climate change accentuating the decline from up to 6000 kg/ha by year 120. The most significant temporal variations occurred in the total available nitrogen variable with curves first rapidly declining in the first 20-40 years of stand development, and then increasing for the remaining years. Notable characteristics are as follow:

- White spruce and aspen stands have starting values of approximately 113 kg/ha, decline to 50 kg/ha near year 30 and increase to maximal values of 94 and 123 kg/ha, with maximum gains of 80 and 60 kg/ha owing to GCC, respectively.

- The lodgepole pine stand is unique in that it starting value of approximately 70 kg/ha is lower than its value of 84 kg/ha at year 120, showed only a slight decline of 10 kg/ha at year 20, with a small increase due to climate change along the growing period.

- Black spruce had a starting value of approximately 108 kg/ha, slightly declined to 82 kg/ha at year 20, ended with 99 kg/ha at year 120, with a maximal differential increase of 40 kg/ha at year 40 due to GCC.

Q.1.4: *For the typical monoculture stands of Sw, Aw, Pl, and Sb, what is the relationship across time between the total available soil nitrogen and the stemwood biomass, for the stands growing under normal and GCC conditions?*
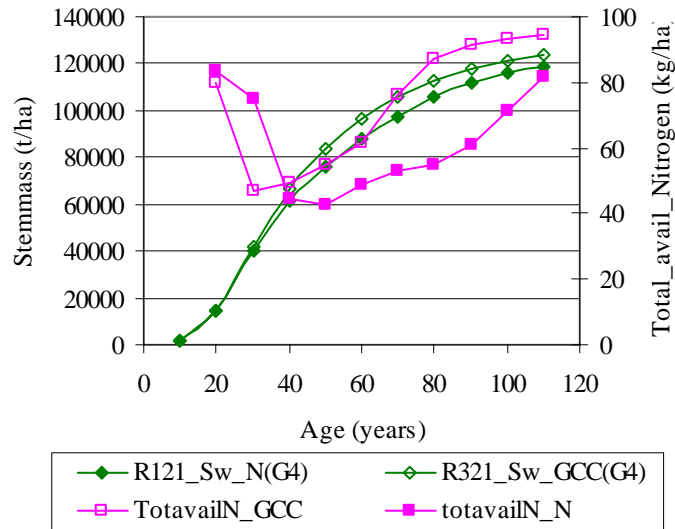
Figure 12. Total available nitrogen (kg/ha) and stemwood biomass (t/ha) for a typical monoculture stand of white spruce (R121;Sw = 1875 stems/ha), growing under normal and GCC conditions, on a G4 site (mesic moisture and medium nutrients).
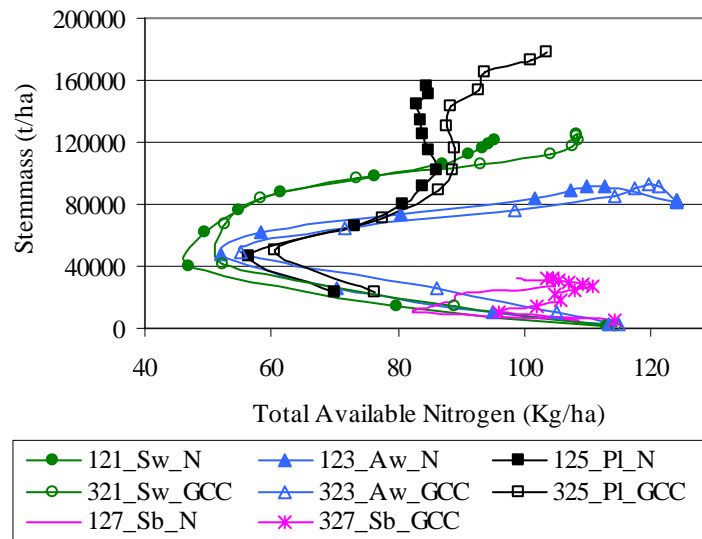
Figure 13. The relationship between total available nitrogen (kg/ha) and stemwood biomass (t/ha) for the typical monoculture stands of trembling aspen (R123;Aw=1125 stems/ha), white spruce (R121;Sw = 1875 stems/ha), lodgepole pine (R125;Pl=2125 stems/ha), and black spruce (R127;Sb=1785 stems/ha), growing under normal and GCC conditions. Note that each point along a curve

corresponds to a simulation year as indicated, for example, by the numbers above the solid green circles on the curve 121_Sw_N.

For a white spruce monoculture growing on a mesic site, stemwood biomass increases up to 10% under climate change. Total available nitrogen decreases faster for the first 30 years under climate change than normal conditions, but then increases up to 40% more than normal conditions, reaching up to approximately 90 kg/ha (Figure 12).

The general trends in the relationship across time between the total available soil nitrogen and the stemwood biomass for Sw, Aw, Pl, and Sb stands are as follow (Figure 13):

- In the first 20 years, for Sw, Aw, and Pl stands, total available nitrogen decreases while stemwood biomass increases, then throughout the remaining growth period biomass continues to increase while nitrogen increases,

- In the later periods of stand development the total available nitrogen in the Pl stand tends to stabilise without affecting the stands capacity to gain in stemwood biomass,

- The amount of total available nitrogen in Sb stands tends to be relatively stable around it starting conditions while stemwood biomass slightly increases in time,

- GCC does not seem to significantly affect the patterns of response of the relationship between total available nitrogen and stemwood biomass.

4. Discussion

4.1 Model Performance and limitations

The FORECAST model requires a lot of calibration data, but fortunately there are several existing pre-calibrated versions for many forest ecosystem types, including the boreal forest of Canada. For this project, we used as a baseline a calibrated version for the mixedwood boreal model and supplemented the calibration process using both simulation output from the MGM model, and empirical data from Millar Western's temporary and permanent sampling plots. Our evaluation showed that FORECAST proved to be empirically equivalent to MGM, and Millar Westerns growth and yield curves (e.g. merchantable volume) when simulations were preformed with the calibration version using normal climate variables. In other words, we are confident that FORECAST can be used to simulate growth and yield and its output is comparable to quantitative values normally accepted by the Alberta government, and forest industry. Moreover, experience to date suggests that FORECAST perform predictably and this it is able to address most of its design objectives (Apps et al., 1988; Sachs and Trofymow, 1991; Trofymow and Sachs, 1991; Wang et al, 1995; Morris et al. 1997).

For simulations under climatic change conditions, it was necessary to build two climate sensitive sub-models, namely for photosynthesis and soil decomposition. These sub-models were used to determine alternate parameter rates used by FORECAST from its calibration data sheets. As such, FORECAST was twice calibrated, once to represent process rates occurring under normal climatic conditions, and once more for global climate change. Whether these sub-models have accurately modified the process rates can only be surmised by analysing the logical conceptual framework and algorithm program of the sub-models. Moreover, we must assume that FORECAST responds accurately to the change of its internal process input variables. The first issue was addressed by developing a scientific collaboration with an independent expert in the field of the ecophysiology. Both the conceptual framework was submitted for evaluation, as well

as the program code. No logical discrepancies were found in the concepts and in the program code was validated. However, upon performing a sensitivity analysis to determine the impact of our climate change sub-models we noted that some species (e.g. white spruce) failed to show quantitative differences in several output variables (e.g. stemwood biomass) when simulations were performed with only the photosynthesis sub-model being activated. When we added the soil decomposition sub-model we found that these output variables showed difference between the two initial climate conditions. Upon further investigation (data not shown in this document) we determined that it was the photosynthetic light saturation curved for the sun foliage of certain species that did not respond to climate change. Conversely, these same species showed differences when their shade foliage was solicited. We do not believe that the failure of sun foliage to benefit from climate change (i.e. CO_2 enrichment with an increase in temperature) has any real physiological justification (although down-regulation may be possible in natural systems), but rather an artefact of the model. As a consequence, we believe that in some cases the dominate species in a stand (i.e. trees containing mostly sun foliage) may be underestimating the photosynthetic response of climate change, since only gains due to the soil decomposition processes are actively contributing to differences.

We also recognise the limits of using the approach of a two stage modeling calibration of FORECAST, since in reality climatic variables such as temperature, precipitation, and CO_2 will most likely increase gradually until they reach their projected values. Our method was necessary due to logistical calibration limitation since we did not have access to the FORECAST programming code. A better solution would have been to run the model for a single year at a time, while continually updating the models climate dependant process calibration rates using the sub-models. By failing to do so it is probable that we have over estimated the impact of climate change on the first few years of the stand development. Whether we have truly over estimated the impacts, and its consequences on stand dynamics, is hard to tell since we have no "real" empirical data to make a serious comparison.

FORECAST is a valuable heuristic tool as it helps the user-community to better understand the major issues involved in exploring complex questions such as forest stand dynamics under climate change. Because FORECAST is a hybrid model (i.e. merges empirical observations with processual realities), we believe it to be an acceptable tool for modeling the impact of climate change on forest ecosystems dynamics. However, the integration of more sub-models would improve the robustness of our conceptual understanding with the modeling objectives (e.g. adding soil hydrology sub-model), and a better coupling of these external sub-models with the main internal FORECAST model would resolved some other logistical details, as previously mentioned above. In other words, it would best to program the external sub-model within the FORECAST algorithm.

It is important to remember that this computer simulation modeling project constitutes a distinct and autonomous effort to explore the potential impacts of global climate change on the growth and yield dynamics of the boreal forest ecosystem in Alberta. As such, it does not aim to give an absolute and reliable response for such a complex question. Trustworthiness comes about once several independent computer modeling studies that strive to explore similar questions from comparable geographic locations and equivalent forest ecosystems have taken place, and once we have thoroughly confronted all methodologies and analysed their simulation output co-jointly. In other words, we believe our study to be akin to a single point in space, where several

points are needed to define a state space that could represent the impact of climate change on a particular forest ecosystem. This problem is rather unique and owing to the fact that we have no empirical dataset that represents the hypothetical future that we aim to explore. We therefore can only confront our simulation output with that of other comparable modeling output, without ever knowing the extent of realism, but trusting that the collective effort ought to be meaningful. Because we know of no other modeling project comparable to our own, we recognize the deficiencies in our interpretations. However, we also recognise the importance of our modeling output since it allows for our own interpretations and set a point of reference for other future studies, while achieving other objectives as previously mentioned in the overall description of the global purpose of the stand-level simulation modeling project.

4.2 Monoculture Responses

The relative values and partitioning of the different tree component biomass for typical monoculture plantation of Sw, Aw, and Pl are comparable to other datasets. Freeman et al. (1982) reported that the percentage of biomass in stem bark varied from 8 to 10% for softwoods and, from 8 to 11% for hardwoods. Ker (1980) found that stem bark comprised 8 and 12% of softwood and hardwood biomass respectively, and Jenkins et al. (2003) 8 to 14% for softwoods and 10 to 15% for hardwoods. These data fall roughly within the bounds reported in our simulation of 6% for softwoods and 15% for hardwoods. Similarly, for foliage, branch component biomasses our analysis fall roughly within the bounds of these studies, with 4% and 2% for foliage, 10% and 12% for branches, for softwoods and hardwoods, respectively. Root biomass is typically similar to foliage biomass in allometric terms.

Our simulation results show that the impact of climate change caused slight modifications in the relative amount of biomass partitioning between the different component biomasses. For example, results indicate that, while all component biomasses increased in absolute amounts compared to those observed in normal climate conditions, small roots and foliage biomass relatively increased more then the other components. The fact that root biomass increased under climate change is no surprise as pointed out in a review study by Rogers et al. (1994) that concludes that root biomass always increases in studies with elevated CO_2 atmospheric concentrations. The observed disproportionate gain in root biomass is also plausible, since a shift in whole-tree carbon allocation pattern towards below-ground parts has been associated with increased atmospheric CO_2 has been reported in many studies (Ceulmans et al. 1999).

Climate change caused increases in stand yield, but the gain in merchantable volume was species-specific and a function of the moisture and nutrient regime of the site, with maximum gains occurring at different times in the rotation. Our simulation results are in agreement with the general knowledge that tree growth enhancement is generally larger at high rates of nutrient supply; when nutrient supply rates do not meet growth rates, tree nutrient status declines and nutrients become limiting. Indeed, stands growing on dry to mesic sites with poor nutrients failed to respond positively to climate change, while moist sites with medium to rich nutrients

produced increases in stand merchantable volume. Given that groups G1, G4, and G5 are deemed the "best" sites for a potential gain in stand productivity, we may calculate that approximately 80% of Millar Westerns forested landbase may be subject to positive gains in merchantable volume, with increases of up to 5, 6, and 20% for trembling aspen, white spruce, and lodgepole pine respectively. Clearly, the best combination is lodgepole pine stands growing on ecosites LFi, LFf, BMe, and BMf, which occur on moist and nutrient rich edatopic grid of the Alberta ecosite classification system (Beckingham and Archibald 1996). Conversely, stands established on ecosites falling in the productivity groups of G2 and G3 may show little to no gain in merchantable volume.

The amount of total available soil nitrogen first decreases in time and then returns, more or less, to its original concentrations, depending on stand type and climatic conditions. The observed decrease in the first 20 years is due to the strong increase in vegetation biomass, where nutrient uptake is greater than nitrogen release from soil decomposition. As stand age increases, stand level processes such as density dependant tree mortality and litterfall may contribute additional substrate to the decomposition processes replenished the pool of available nitrogen. As the same time nutrient uptake decreases to due slower growth rates. Under climate change conditions the rate of the soil decomposition processes increase giving more available nitrogen for tree growth. The rate of decomposition increases more for moist site than dry sites, which may explain the faster growth rate of trees growing mesic and moist sites.

At the end of a growing cycle of 120 years the amount of total available nitrogen for stand growing under normal climatic conditions slightly decreases for white spruce and lodgepole pine, but slightly increases for trembling aspen. Under climatic change coniferous stands show a slight increase in total available nitrogen, while the nitrogen concentrations for aspen stands remains similar to that of stands growing under normal conditions. It would therefore seem like conifers tend to slightly reduce soil productivity throughout time (i.e. pine stands being the worse, followed by white spruce), while aspen increases soil productivity. At the same time, climate change lessens the negative impact of conifers on soil productivity, while soils under aspen stands show no difference between climatic conditions.

4.3   Mixedwood Responses

We focus our discussion on the productivity of mixedwoods in terms of the temporal patterns of biomass for stands growing on all five site productivity groups, and on the average yield of merchantable volume for the stand age period between 70 to 90 years, the typical age of harvest (i.e. rotation).   Overall, we found that for a given desired species (e.g. white spruce) merchantable volume is always greater in pure monocultures than in mixedwoods, but that its loss in productivity was reduced under climate change conditions. While it is not surprising that adding a certain quantity of stems of another species to a monoculture stand (i.e. competition) will negatively impact its productivity, the fact that climate change lessens the loss of merchantable volume in time is someone surprising. We further analysed our model outputs and found that the possible cause of the observed "reduced competition" was partly due to a joint effect of a change in the available light and nutrient temporal patterns, and well as in the stand

mortality. For example, under climate change conditions in a stand comprised of both white spruce and black spruce, we found that white spruce growth is enhanced due to climate change, more so than that of black spruce, thus significantly reducing the available light for the black spruce understory cohort which ultimately led to an increase in stem mortality. Inversely, we observed a decrease of mortality of white spruce stems. We noted an increase of total available nitrogen, which we suspect may have further enhanced the productivity of white spruce. Therefore, we argue that while competition may have a negative impact on the productivity (i.e. merchantable volume) of a target species growing in a mixture, climate change can minimize this loss by lessening impact of competition.

4.4   Management Interpretations

A discussion of how computer simulation modeling results may influence real world forest management issues must address important matters such as the state of current scientific knowledge, our capacity to develop multiple decision support tools that can assess alternative possible futures (Peng 2000, Kimmins 2005), and the willingness of provincial forest management agencies and forest product companies to incorporate uncertainty and risk in sustainable forest management (Johnston and Williamson 2005). As such, we recognize that, 1) forest science is a very young discipline, complex, and that there much that we don't yet understand, 2) models are only a representation of reality, not reality itself, and we can never predict the future with absolute confidence, and 3) uncertainty is a defining feature of climate change impact studies. In this computer simulation study we hold constant the uncertainty given by the variability of climate impacts due to the different combinations of the numerous emissions scenarios. Rather, we focus on how the results vary under different assumptions regarding stand-level above ground tree responses coupled with below ground soil dynamics.

In general, merchantable volume increased under climate change changes throughout the existence of the stand. In certain instances the impact of climate was long-lived and lasted for hundreds of year, and in other cases was more akin to a transient effect, only affecting the first few years of stand development. As such, for management purposes, it may be advisable to change the harvest rotation time to reach the optimal economic gain of climate impact. For example, the impact of climate on lodgepole pine lasted up to 120 years and merchantable yield increased up to 20 percent. While there are many other issues that determine the optimal harvest rotation age, managers may want to consider extending the current rotation to optimize the gains of climate impact. Conversely, it may be beneficial to shorten the rotation age for aspen and spruce on mesic to medium, and moist to nutrient rich sites, since climate impact was short-lived, making the optimal economic rotation age occur sooner in time. Another interesting result from this study that may interest forest management concerns the dynamic of mixedwoods under climate change. Our results suggest that white spruce grown in mixtures may have a greater ability to benefit from climate change than if grown by itself in a monoculture. Man and Lieffers (1999) have already reported that mixtures of aspen and white spruce may be more productive that single species stands. Our results also confirm this trend, but even more they show that the

impact of climate change is even more beneficial for white spruce growing in the type of mixedwood.

Not covered in this report, but of significant importance, is the issue that several major tree species currently present in the boreal forest fringe may retract to the north (Carr et al. 2004). In particular, interest should be paid to conifers occurring in the southern location of Millar Westerns landbase. Indeed, where a stand-replacing event occurs, it might be anticipated that the reduced viability of softwood seedlings would lead to a change in forest composition (Carr et al. 2004). Hogg and Schwarz (1997) studies the influence of dry climates on coniferous regeneration, and concluded that if increased in CO_2 levels lead to a drier climate in the southern boreal forest of western Canada, the ability of conifers to regenerate naturally may be significantly reduces, especially for white spruce.

4.5   Comparison with other Modeling Outputs

Comparing our result to other computer simulation output is both essential and difficult, since models are the only source capable of producing plausible external quantitative data for comparison purposes, but often have different objectives and are calibrated for dissimilar forest types or geographic locations. For these reasons, once reasonably comparable modeling projects have been found, we search not for quantitative equivalence, but rather for general trends that would add to our interpretations and inferences.

Price et al. (1999) carried out a modeling investigation to study the effect of climate change on ecosystem carbon pools in the Boreal Forest Transect Case Study (BFTCS), which is located in central Canada. The authors used CENTURY 4.0 and FORSKA2 with the Goddard Institute for Space Studies (GISS) 2x CO_2 GCM scenario. Several results from this study are in agreement with some of our projections. For example, both CENTURY 4.0 and FORSKA2 predicted small increases in aboveground biomass carbon density and decreases in soil and litter pools, with the first model showing greater variations. While we cannot quantitatively compare carbon biomass as a variable, we have also found that aboveground stand level tree biomass components (i.e. merchantable volume, branches, bark, etc.) increase under climate change, with variability owing to species and site type. Similarly, our simulation results indicate decreases in the quantity of biomass in humus pools.

Johnston and Williamson (2005) used the model Photosynthesis and Evapo-Transpiration (PnET) (Aber et al. 1997) to project white spruce stand yields under climate change in central Saskatchewan. On sites with adequate moisture and no drought they report that productivity (merchantable volume) increased by about 40% in the absence of increased water use efficiency (WUE), and by 60% where WUE is increased. These gains in productivity far exceed the impact of climate change on white spruce yields found in our simulation study. Indeed, for moist and

rich ecosites we found approximately 10% increases in white spruce merchantable yields. Such big differences are somewhat troublesome since their study concerns relatively similar forest types and sites, and relatively similar changes in the future climate conditions as in our own simulation study. As such, we surmise that the differences in projected productivity may be the result of differences in the internal mechanics of the two models, and how ecological processes relate to climate variables. Indeed, as our sensitivity analysis indicated we noted that white spruces sun foliage failed to benefit from climate change.

5. Conclusion

We calibrated the FORECAST stand-level ecosystem model to determine the potential impacts of climate change on a set of above and below ground response variables related to several densities and mixtures of trembling aspen, lodgepole pine, white and black spruce growing on the forested Upper and Lower Foothills, Central and Dry Mixedwood ecosites of Millar Western Forest Products Ltd.'s boreal forest landbase. To achieve our objectives it was necessary to create two new sub-models do account for the influence of climate on the photosynthetic and soil decomposition responses. To initialise our sub-models and calibrate the FORECAST climate dependent variables we used the published temperature, precipitation, and carbon dioxide values given by the CCSR-NIEM GCM values in accordance with the SRES emissions scenario A1, which represents an extreme case of climate change with twice the atmospheric CO_2 levels, an increase of seven degree Celsius, and a relative increase of approximately 8% in precipitation.

Our simulation results showed that the impact of climate change caused slight modifications in the relative amount of biomass partitioning between the different tree components. While stemwood biomass did increase, we were surprised to find that foliage and small root biomass showed the greatest relative gain of all tree component types, and for all species under investigation. Climate change caused increases in stand yield, but the gain in merchantable volume was species-specific and a function of the moisture and nutrient regime of the site, with maximum gains occurring at different times in the rotation. Results show that under GCC conditions a white spruce monoculture stand can accumulate a surplus gain of approximately $25m^3$/ha of merchantable volume, approximately 8% more than a stand growing under normal conditions. This species was the most positively impacted by climate. Conversely, for dry sites with moisture deficits we found a slight decrease in biomass production. Both species growing in white spruce-trembling aspen communities benefited from GCC conditions. We were astonished to find that white spruce growing in mixedwood communities may have a greater ability to benefit from climate change conditions than if grown by itself as a monoculture. If our simulation results are correct, we believe that climate change may "alleviate" some of the negative impact of competition on timber production of conifers. Other species above-ground

productivity also increased or decreased according to stand and site nutrition conditions. Black spruce stands were the exception since they always showed a decrease of productivity under GCC conditions.

We argued the importance to remember that this modeling project constitutes a single distinct effort to explore the potential impacts of global climate change, and it does not aim to give an absolute and reliable quantitative response for such a complex question. Trustworthiness can take place once several independent computer modeling studies that strive to explore similar questions, from comparable geographic locations and equivalent forest ecosystems have taken place, and once we have thoroughly confronted all methodologies and analyzed their simulation output co-jointly.

Finally, we consider that FORECAST, with its two new climate sensitive sub-models, to be a valuable heuristic tool as it ought to help the user-community to better understand the major issues involved in exploring complex questions such as forest stand dynamics under climate change. We also recognize that it would be of value to include more realism in how such a modeling exercise deals with moisture related issues by incorporating a climate sensitive hydrological soil sub-model, amongst others.

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Appendix I   Identifiers for the Planned Simulations

Table 9.   FORECAST simulation runs grouped by species and species combination

FORECAST Simulation Runs Grouped by Species and Species Combination Similarities

G1_N	G2_N	G3_N	G4_N	G5_N	G1_GCC	G2_GCC	G3_GCC	G4_GCC	G5_GCC	SP_1	NbSP_1	SP_2	NbSP_2
5	45	85	125	165	205	245	285	325	365	AW	0	PL	2125
6	46	86	126	166	206	246	286	326	366	AW	0	PL	3875
7	47	87	127	167	207	247	287	327	367	AW	0	SB	1875
8	48	88	128	168	208	248	288	328	368	AW	0	SB	2375
2	42	82	122	162	202	242	282	322	362	AW	0	SW	375
1	41	81	121	161	201	241	281	321	361	AW	0	SW	1875
3	43	83	123	163	203	243	283	323	363	AW	1125	SW	0
4	44	84	124	164	204	244	284	324	364	AW	3125	SW	0
15	55	95	135	175	215	255	295	335	375	AW	375	SW	375
14	54	94	134	174	214	254	294	334	374	AW	1625	SW	625
25	65	105	145	185	225	265	305	345	385	AW	2375	SW	2375
31	71	111	151	191	231	271	311	351	391	AW	3125	SW	125
23	63	103	143	183	223	263	303	343	383	AW	3125	SW	1375
35	75	115	155	195	235	275	315	355	395	AW	3125	SW	2375
9	49	89	129	169	209	249	289	329	369	AW	875	SW	1875
18	58	98	138	178	218	258	298	338	378	AW	625	PL	625
40	80	120	160	200	240	280	320	360	400	AW	3125	PL	625
30	70	110	150	190	230	270	310	350	390	AW	3125	PL	2125
10	50	90	130	170	210	250	290	330	370	AW	875	PL	2125
26	66	106	146	186	226	266	306	346	386	AW	1375	PL	3125
36	76	116	156	196	236	276	316	356	396	AW	3125	PL	3875
20	60	100	140	180	220	260	300	340	380	PL	625	SW	625
32	72	112	152	192	232	272	312	352	392	PL	3875	SW	125
24	64	104	144	184	224	264	304	344	384	PL	3375	SW	1375
38	78	118	158	198	238	278	318	358	398	PL	3875	SW	2375
28	68	108	148	188	228	268	308	348	388	PL	1375	SW	2375
12	52	92	132	172	212	252	292	332	372	SW	375	SB	375
21	61	101	141	181	221	261	301	341	381	SW	1375	SB	1125
29	69	109	149	189	229	269	309	349	389	SW	2375	SB	2375
33	73	113	153	193	233	273	313	353	393	SW	125	SB	2375
13	53	93	133	173	213	253	293	333	373	AW	375	SB	375
16	56	96	136	176	216	256	296	336	376	AW	1625	SB	625
34	74	114	154	194	234	274	314	354	394	AW	3125	SB	125
39	79	119	159	199	239	279	319	359	399	AW	3125	SB	2375
11	51	91	131	171	211	251	291	331	371	AW	875	SB	1875
19	59	99	139	179	219	259	299	339	379	PL	625	SB	625
22	62	102	142	182	222	262	302	342	382	PL	3875	SB	625
37	77	117	157	197	237	277	317	357	397	PL	3875	SB	2375
17	57	97	137	177	217	257	297	337	377	PL	1125	SB	1625
27	67	107	147	187	227	267	307	347	387	PL	1875	SB	2375

Appendix II   Summary Statistics

Table 10. Descriptive statistics of FORECAST outputs for monocultures

Descriptive Statistics of FORECAST Outputs for Monocultures (mean_stddev of yrs 70,80 and 90)											
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	AW	0	PL	2125	Pl	23,98	3,65	175,65	59,12	89,22	18,76
	AW	0	PL	3875	Pl	24,93	5,18	145,88	63,08	90,95	21,12
	AW	0	SB	1875	Sb	9,46	0,71	53,92	15,23	101,05	4,94
	AW	0	SB	2375	Sb	10,62	0,67	61,79	16,39	102,90	5,05
	AW	0	SW	375	Sw	7,08	1,51	50,35	20,21	97,10	6,55
	AW	0	SW	1875	Sw	27,46	4,56	193,38	71,80	80,01	17,04
	AW	1125	SW	0	Aw	21,71	1,83	191,08	26,29	108,08	15,42
	AW	3125	SW	0	Aw	22,40	2,47	207,65	29,58	111,12	14,21
GCC	AW	0	PL	2125	Pl	25,31	4,80	188,14	71,86	103,81	9,45
	AW	0	PL	3875	Pl	28,57	5,65	187,27	78,31	106,60	15,02
	AW	0	SB	1875	Sb	9,36	0,70	53,22	15,17	103,74	6,33
	AW	0	SB	2375	Sb	10,62	0,67	61,67	16,40	106,03	6,83
	AW	0	SW	375	Sw	6,92	1,47	49,06	19,82	98,10	7,94
	AW	0	SW	1875	Sw	28,77	5,12	204,23	78,03	96,72	15,62
	AW	1125	SW	0	Aw	22,09	1,76	193,98	27,34	115,19	8,25
	AW	3125	SW	0	Aw	22,27	2,60	206,02	27,05	117,88	9,43
GCC-N	AW	0	PL	2125	Pl	1,33	1,15	12,50	12,73	14,59	-9,31
	AW	0	PL	3875	Pl	3,64	0,47	41,39	15,23	15,65	-6,10
	AW	0	SB	1875	Sb	-0,10	0,00	-0,70	-0,06	2,69	1,40
	AW	0	SB	2375	Sb	0,00	0,00	-0,11	0,01	3,12	1,78
	AW	0	SW	375	Sw	-0,16	-0,04	-1,28	-0,39	1,00	1,39
	AW	0	SW	1875	Sw	1,31	0,56	10,85	6,23	16,71	-1,42
	AW	1125	SW	0	Aw	0,39	-0,08	2,90	1,05	7,11	-7,18
	AW	3125	SW	0	Aw	-0,13	0,13	-1,63	-2,53	6,76	-4,78

Appendix III Summary Statistics

Table 11. Descriptive statistics of FORECAST outputs for AW+SW mixedwoods

Descriptive Statistics of FORECAST Outputs for AW+SW Mixedwoods (mean_stddev of yrs 70,80 and 90)										
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	AW	375	SW	375	Aw	14,84	1,87	121,96	18,82	97,71	21,30
					Sw	6,33	1,74	45,13	20,89	97,71	21,30
	AW	1625	SW	625	Aw	19,01	2,99	173,68	31,67	101,78	22,46
					Sw	8,55	2,76	60,85	33,08	101,78	22,46
	AW	2375	SW	2375	Aw	14,56	4,73	123,93	51,73	91,06	22,85
					Sw	19,38	4,69	121,07	69,76	91,06	22,85
	AW	3125	SW	125	Aw	22,22	2,45	206,12	31,62	110,19	15,87
					Sw	1,53	0,49	10,54	5,92	110,19	15,87
	AW	3125	SW	1375	Aw	18,78	3,69	166,63	46,41	99,58	24,40
					Sw	12,71	3,56	83,31	48,75	99,58	24,40
	AW	3125	SW	2375	Aw	16,24	5,02	132,88	59,34	93,59	23,83
					Sw	17,72	4,44	106,62	66,23	93,59	23,83
	AW	875	SW	1875	Aw	10,12	3,89	91,10	32,01	85,44	20,42
					Sw	21,54	5,16	149,43	71,22	85,44	20,42
GCC	AW	375	SW	375	Aw	15,44	1,42	127,17	21,33	109,65	14,28
					Sw	6,30	1,64	44,83	20,05	109,65	14,28
	AW	1625	SW	625	Aw	20,01	2,88	182,71	35,65	116,01	13,08
					Sw	8,65	2,68	62,20	32,39	116,01	13,08
	AW	2375	SW	2375	Aw	16,00	4,88	143,91	52,34	111,87	22,98
					Sw	20,88	5,30	139,86	77,72	111,87	22,98
	AW	3125	SW	125	Aw	22,10	2,61	204,67	28,32	118,33	9,21
					Sw	1,62	0,53	11,29	6,28	118,33	9,21
	AW	3125	SW	1375	Aw	19,66	3,37	181,21	43,26	116,56	17,77
					Sw	13,81	4,19	95,77	54,40	116,56	17,77
	AW	3125	SW	2375	Aw	17,43	4,41	153,54	54,24	113,65	22,87
					Sw	19,31	5,11	126,58	74,67	113,65	22,87
	AW	875	SW	1875	Aw	11,47	4,21	103,72	36,04	105,95	21,66
					Sw	22,74	5,71	161,68	76,47	105,95	21,66
GCC-N	AW	375	SW	375	Aw	0,61	-0,45	5,21	2,51	11,94	-7,02
					Sw	-0,03	-0,10	-0,30	-0,84	11,94	-7,02
	AW	1625	SW	625	Aw	1,00	-0,11	9,03	3,98	14,23	-9,38
					Sw	0,10	-0,09	1,35	-0,69	14,23	-9,38
	AW	2375	SW	2375	Aw	1,44	0,15	19,98	0,60	20,81	0,13
					Sw	1,51	0,61	18,79	7,96	20,81	0,13
	AW	3125	SW	125	Aw	-0,12	0,17	-1,44	-3,30	8,14	-6,66
					Sw	0,09	0,04	0,75	0,37	8,14	-6,66
	AW	3125	SW	1375	Aw	0,88	-0,31	14,57	-3,15	16,98	-6,63
					Sw	1,10	0,63	12,46	5,65	16,98	-6,63
	AW	3125	SW	2375	Aw	1,19	-0,60	20,66	-5,10	20,07	-0,95
					Sw	1,58	0,67	19,96	8,45	20,07	-0,95
	AW	875	SW	1875	Aw	1,35	0,32	12,62	4,03	20,51	1,24
					Sw	1,20	0,55	12,25	5,25	20,51	1,24

Appendix IV Summary Statistics

Table 12. Descriptive statistics of FORECAST outputs for AW+PL mixedwoods

Descriptive Statistics of FORECAST Outputs for AW+PL Mixedwoods (mean_stddev of yrs 70,80 and 90)										
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	AW	625	PL	625	Aw	16,91	1,78	145,27	24,74	103,62	20,27
					Pl	6,79	1,81	50,36	23,55	103,62	20,27
	AW	3125	PL	625	Aw	21,42	2,19	198,68	39,23	109,56	18,20
					Pl	4,74	1,61	32,00	17,73	109,56	18,20
	AW	3125	PL	2125	Aw	18,13	3,47	155,63	59,24	105,01	23,84
					Pl	10,97	2,78	60,51	30,01	105,01	23,84
	AW	875	PL	2125	Aw	11,86	3,39	108,18	34,85	98,66	23,73
					Pl	16,32	3,34	107,96	41,05	98,66	23,73
	AW	1375	PL	3125	Aw	11,18	3,77	99,99	45,81	97,99	23,58
					Pl	16,58	3,69	89,51	38,99	97,99	23,58
	AW	3125	PL	3875	Aw	13,23	4,07	98,56	48,14	100,25	24,28
					Pl	13,65	3,67	54,73	26,97	100,25	24,28
GCC	AW	625	PL	625	Aw	17,65	1,65	151,70	29,14	114,60	10,85
					Pl	7,09	2,49	53,84	29,53	114,60	10,85
	AW	3125	PL	625	Aw	21,68	2,32	201,73	35,25	119,47	8,88
					Pl	5,17	1,80	36,65	20,56	119,47	8,88
	AW	3125	PL	2125	Aw	19,74	3,29	180,48	58,45	119,96	13,91
					Pl	12,50	3,33	79,57	40,59	119,96	13,91
	AW	875	PL	2125	Aw	13,16	3,45	120,60	39,13	114,35	19,39
					Pl	18,06	4,08	128,35	50,91	114,35	19,39
	AW	1375	PL	3125	Aw	12,80	4,03	119,30	48,59	114,54	20,56
					Pl	18,96	4,30	119,53	52,86	114,54	20,56
	AW	3125	PL	3875	Aw	15,62	4,31	132,40	59,75	117,38	19,71
					Pl	15,92	4,13	77,68	39,57	117,38	19,71
GCC-N	AW	625	PL	625	Aw	0,74	-0,13	6,43	4,40	10,99	-9,41
					Pl	0,30	0,68	3,48	5,98	10,99	-9,41
	AW	3125	PL	625	Aw	0,26	0,14	3,05	-3,98	9,91	-9,32
					Pl	0,43	0,20	4,65	2,83	9,91	-9,32
	AW	3125	PL	2125	Aw	1,61	-0,19	24,85	-0,79	14,95	-9,92
					Pl	1,54	0,55	19,06	10,58	14,95	-9,92
	AW	875	PL	2125	Aw	1,30	0,07	12,42	4,28	15,69	-4,34
					Pl	1,73	0,73	20,39	9,86	15,69	-4,34
	AW	1375	PL	3125	Aw	1,62	0,26	19,30	2,78	16,55	-3,02
					Pl	2,38	0,62	30,02	13,87	16,55	-3,02
	AW	3125	PL	3875	Aw	2,39	0,24	33,84	11,61	17,14	-4,57
					Pl	2,27	0,46	22,95	12,60	17,14	-4,57

Appendix V   Summary Statistics

Table 13. Descriptive statistics of FORECAST outputs for PL+SW mixedwoods

Descriptive Statistics of FORECAST Outputs for PL+SW Mixedwoods (mean_stddev of yrs 70,80 and 90)											
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	PL	625	SW	625	Pl	8,32	2,07	62,55	27,89	87,38	13,16
					Sw	11,56	2,44	82,46	33,14	87,38	13,16
	PL	3875	SW	125	Pl	24,13	5,09	137,99	59,56	90,38	21,27
					Sw	1,25	0,48	8,23	5,84	90,38	21,27
	PL	3375	SW	1375	Pl	17,92	4,25	88,21	38,57	82,42	19,26
					Sw	11,42	3,88	72,19	49,27	82,42	19,26
	PL	3875	SW	2375	Pl	13,83	3,70	58,20	25,10	80,09	18,41
					Sw	15,40	7,15	87,62	67,15	80,09	18,41
	PL	1375	SW	2375	Pl	9,73	2,01	58,29	23,09	78,73	18,70
					Sw	23,13	4,59	152,26	69,04	78,73	18,70
GCC	PL	625	SW	625	Pl	8,57	2,75	64,79	33,67	98,71	5,69
					Sw	11,34	2,38	80,66	32,53	98,71	5,69
	PL	3875	SW	125	Pl	27,73	5,47	178,89	74,38	106,35	15,65
					Sw	1,42	0,55	9,76	6,52	106,35	15,65
	PL	3375	SW	1375	Pl	20,97	4,58	121,71	50,61	103,70	20,21
					Sw	13,28	4,37	88,97	55,81	103,70	20,21
	PL	3875	SW	2375	Pl	18,13	4,76	87,33	40,35	103,70	21,33
					Sw	15,85	5,48	94,62	70,35	103,70	21,33
	PL	1375	SW	2375	Pl	10,83	2,23	71,54	27,59	98,94	19,85
					Sw	25,88	4,66	178,87	73,65	98,94	19,85
GCC-N	PL	625	SW	625	Pl	0,25	0,68	2,24	5,79	11,33	-7,47
					Sw	-0,22	-0,06	-1,80	-0,60	11,33	-7,47
	PL	3875	SW	125	Pl	3,60	0,38	40,90	14,82	15,97	-5,61
					Sw	0,18	0,07	1,53	0,68	15,97	-5,61
	PL	3375	SW	1375	Pl	3,05	0,33	33,49	12,03	21,27	0,95
					Sw	1,86	0,50	16,77	6,55	21,27	0,95
	PL	3875	SW	2375	Pl	4,30	1,05	29,12	15,25	23,61	2,92
					Sw	0,46	-1,67	6,99	3,20	23,61	2,92
	PL	1375	SW	2375	Pl	1,10	0,22	13,25	4,50	20,21	1,16
					Sw	2,76	0,06	26,61	4,61	20,21	1,16

Appendix VI Summary Statistics

Table 14. Descriptive statistics of FORECAST outputs for SW+SB mixedwoods

Descriptive Statistics of FORECAST Outputs for SW+SB Mixedwoods (mean_stddev of yrs 70,80 and 90)											
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	SW	375	SB	375	Sb	2,10	0,20	11,47	3,23	96,77	5,27
					Sw	7,05	1,50	50,15	20,09	96,77	5,27
	SW	1375	SB	1125	Sb	5,25	0,31	30,05	7,59	81,78	16,44
					Sw	20,58	3,65	145,39	54,92	81,78	16,44
	SW	2375	SB	2375	Sb	8,62	1,73	51,29	18,45	88,85	15,56
					Sw	18,04	4,14	111,80	47,34	88,85	15,56
	SW	125	SB	2375	Sb	10,40	0,62	60,60	15,88	102,66	4,90
					Sw	2,23	0,51	15,84	6,53	102,66	4,90
GCC	SW	375	SB	375	Sb	2,01	0,19	10,94	3,14	98,90	6,21
					Sw	6,90	1,46	48,93	19,71	98,90	6,21
	SW	1375	SB	1125	Sb	5,10	0,24	29,19	7,24	97,55	15,05
					Sw	22,31	4,42	159,07	62,73	97,55	15,05
	SW	2375	SB	2375	Sb	7,44	1,41	43,83	13,94	105,69	18,08
					Sw	23,14	4,01	157,61	62,61	105,69	18,08
	SW	125	SB	2375	Sb	10,41	0,63	60,60	15,90	106,46	5,86
					Sw	2,21	0,49	15,60	6,42	106,46	5,86
GCC-N	SW	375	SB	375	Sb	-0,09	-0,01	-0,53	-0,09	2,12	0,94
					Sw	-0,15	-0,04	-1,21	-0,38	2,12	0,94
	SW	1375	SB	1125	Sb	-0,15	-0,07	-0,86	-0,35	15,76	-1,39
					Sw	1,72	0,77	13,68	7,81	15,76	-1,39
	SW	2375	SB	2375	Sb	-1,19	-0,31	-7,47	-4,51	16,85	2,52
					Sw	5,10	-0,13	45,80	15,27	16,85	2,52
	SW	125	SB	2375	Sb	0,01	0,00	-0,01	0,02	3,80	0,97
					Sw	-0,03	-0,01	-0,24	-0,11	3,80	0,97

Appendix VII Summary Statistics

Table 15. Descriptive statistics of FORECAST outputs for AW+SB mixedwoods

Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	AW	375	SB	375	Aw	16,49	1,48	134,68	20,77	102,57	19,13
					Sb	1,81	0,18	10,02	2,80	102,57	19,13
	AW	1625	SB	625	Aw	21,51	1,76	195,79	30,34	107,79	19,34
					Sb	2,78	0,25	15,70	4,26	107,79	19,34
	AW	3125	SB	125	Aw	22,47	2,35	208,41	30,51	110,83	15,16
					Sb	0,57	0,05	3,14	0,85	110,83	15,16
	AW	3125	SB	2375	Aw	19,59	3,95	164,09	50,42	100,15	21,25
					Sb	8,58	1,08	50,60	15,96	100,15	21,25
	AW	875	SB	1875	Aw	16,73	2,46	147,87	24,15	97,30	21,06
					Sb	7,48	0,73	43,92	12,76	97,30	21,06
GCC	AW	375	SB	375	Aw	16,75	1,30	137,10	23,34	112,08	11,08
					Sb	1,77	0,16	9,82	2,72	112,08	11,08
	AW	1625	SB	625	Aw	21,99	1,62	198,71	28,75	118,12	9,42
					Sb	2,74	0,21	15,50	4,11	118,12	9,42
	AW	3125	SB	125	Aw	22,35	2,50	206,95	27,27	118,37	9,39
					Sb	0,57	0,05	3,12	0,83	118,37	9,39
	AW	3125	SB	2375	Aw	22,58	2,71	204,52	46,50	117,83	17,95
					Sb	8,33	0,90	48,94	14,91	117,83	17,95
	AW	875	SB	1875	Aw	18,80	1,77	165,59	30,78	113,64	18,29
					Sb	7,38	0,61	43,25	12,09	113,64	18,29
GCC-N	AW	375	SB	375	Aw	0,26	-0,18	2,42	2,57	9,51	-8,04
					Sb	-0,04	-0,02	-0,20	-0,08	9,51	-8,04
	AW	1625	SB	625	Aw	0,48	-0,14	2,92	-1,59	10,33	-9,91
					Sb	-0,04	-0,03	-0,21	-0,14	10,33	-9,91
	AW	3125	SB	125	Aw	-0,12	0,16	-1,46	-3,25	7,54	-5,77
					Sb	0,00	0,00	-0,02	-0,02	7,54	-5,77
	AW	3125	SB	2375	Aw	2,99	-1,24	40,43	-3,92	17,67	-3,30
					Sb	-0,25	-0,18	-1,65	-1,04	17,67	-3,30
	AW	875	SB	1875	Aw	2,07	-0,68	17,72	6,63	16,34	-2,77
					Sb	-0,10	-0,12	-0,67	-0,67	16,34	-2,77

Descriptive Statistics of FORECAST Outputs for AW+SB Mixedwoods (mean_stddev of yrs 70,80 and 90)

Appendix VIII   Summary Statistics

Table 16. Descriptive statistics of FORECAST outputs for PL+SB mixedwoods

Descriptive Statistics of FORECAST Outputs for PL+SB Mixedwoods (mean_stddev of yrs 70,80 and 90)											
Climate	Sp_1	Nb Sp1	Sp_2	Nb Sp2	Sp	Avg_Ba m²/ha	StDev_Ba m²/ha	Avg_VoL m³/ha	StDev_VoL m³/ha	Avg_Tot_N kg/ha	StDev_Tot_N kg/ha
N	PL	625	SB	625	Pl	8,84	2,83	67,18	34,49	96,85	6,85
					Sb	3,47	0,33	19,18	5,43	96,85	6,85
	PL	3875	SB	625	Pl	21,35	5,19	112,12	50,70	90,69	20,71
					Sb	2,97	0,54	16,74	5,48	90,69	20,71
	PL	3875	SB	2375	Pl	11,72	5,63	44,75	29,15	98,77	13,08
					Sb	9,08	1,47	53,74	17,86	98,77	13,08
	PL	1125	SB	1625	Pl	12,99	1,58	94,70	28,12	93,77	14,80
					Sb	7,81	0,65	45,05	12,33	93,77	14,80
	PL	1875	SB	2375	Pl	14,19	4,51	88,05	43,27	91,74	15,97
					Sb	9,42	1,12	55,55	16,85	91,74	15,97
GCC	PL	625	SB	625	Pl	8,83	3,02	67,07	36,00	100,07	6,32
					Sb	3,34	0,31	18,42	5,28	100,07	6,32
	PL	3875	SB	625	Pl	25,45	5,50	156,88	67,32	107,82	15,51
					Sb	2,83	0,46	16,03	5,05	107,82	15,51
	PL	3875	SB	2375	Pl	16,75	6,18	80,66	43,97	113,23	14,48
					Sb	8,86	1,55	52,46	18,29	113,23	14,48
	PL	1125	SB	1625	Pl	13,94	2,96	103,91	42,44	106,79	6,73
					Sb	7,75	0,55	44,65	11,94	106,79	6,73
	PL	1875	SB	2375	Pl	17,32	3,69	119,97	46,05	105,99	16,64
					Sb	9,31	1,22	54,88	16,83	105,99	16,64
GCC-N	PL	625	SB	625	Pl	-0,01	0,19	-0,11	1,51	3,22	-0,53
					Sb	-0,13	-0,02	-0,76	-0,15	3,22	-0,53
	PL	3875	SB	625	Pl	4,11	0,30	44,76	16,62	17,14	-5,20
					Sb	-0,13	-0,08	-0,71	-0,44	17,14	-5,20
	PL	3875	SB	2375	Pl	5,03	0,55	35,91	14,82	14,46	1,41
					Sb	-0,22	0,08	-1,29	0,42	14,46	1,41
	PL	1125	SB	1625	Pl	0,95	1,38	9,22	14,32	13,02	-8,07
					Sb	-0,06	-0,11	-0,40	-0,39	13,02	-8,07
	PL	1875	SB	2375	Pl	3,13	-0,82	31,92	2,78	14,26	0,67
					Sb	-0,11	0,10	-0,66	-0,02	14,26	0,67

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