PROGRESS REPORT

Climate Change Impacts on Saskatchewan's Wood Supply

for

Prince Albert Model Forest

by

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INTRODUCTION

In January 2002, a Prince Albert Model Forest project was established to investigate the impacts of climate change on wood supply in Saskatchewan. The need for this work was identified by Weyerhaeuser Saskatchewan at the PAMF Science and Technology workshop held in Prince Albert in August of 2001. The objectives of the project were to calibrate a climate-sensitive forest productivity model for commercial forest species in Saskatchewan, and to determine how climate change will affect the wood supply available to Weyerhaeuser. The original plan was to calibrate the StandLeap forest ecosystem simulation model currently under development by the Canadian Forest Service and use it for the climate change impacts analysis. However, preliminary testing indicated that the model requires further development before it can be used under Saskatchewan conditions. Therefore, two other forest ecosystems models (BIOME-BGC, Thornton et al. 2002 and PnET, Aber et al. 1997) were tested. PnET was found to provide forest productivity estimates that were close to independent yield data and was chosen for further analysis. To date, we have focused on white spruce productivity but will expand this analysis to aspen and jack pine during 2005-2006. The study area was the Prince Albert Model Forest (PAMF) area.

METHODS

In order to project forest productivity into the future, we used a forest ecosystem simulation model that is sensitive to climate and other environmental factors. The model is known as PnET (**P**hotosy**n**thesis and **E**vapo-**T**ranspiration, Aber et al. 1997) and has been widely tested across North America (see the PnET web site for extensive documentation of model applications (www.pnet.sr.unh.edu). The model provides estimates of net primary productivity (NPP, g biomass m^{-2} yr^{-1}) based on inputs of climate, species physiology and soil conditions. Climatic inputs for future scenarios were obtained from the Canadian Regional Climate Model (CRCM, Laprise et al. 2003). This model provides climatic variables (minimum and maximum temperature, precipitation) for three time periods: 1975-1984, 2040-2049 and 2080-2089. Climate data for the nine grid cells overlying the PAMF area were used in the productivity modelling. Most of the species physiological data were taken from PnET calibration data for the spruce-fir forest type in the northeastern US (Aber et al. 1997). However, the model is particularly sensitive to foliar nitrogen content so we used local data for white spruce from the BOREAS study carried out in the Prince Albert National Park area from 1994-1998 (Newcomer et al. 2000). Another key input is soil available water-holding capacity (AWC). For soils data, we used a recently collected data set from the Agriculture and Agrifood Canada Land Resources Centre at the University of Saskatchewan (G. Padbury, personal communication). These data comprise detailed soil survey information for a large portion of the forested area of Saskatchewan collected between 2002 and 2005. We found that 67% of white spruce-dominated stand types occur on soils with AWC values in the range of 110-200 mm, and chose the upper end of the range (200 mm) to represent the better sites.

Recent climate modeling indicates that drought events are likely to increase in the prairie region (McCarthy et al. 2001). To examine these effects, we included a drought scenario in the productivity analyses. We used the recent (2001-2003) drought in the Prince Albert area and developed a scenario in which that drought pattern persisted for 10 years. We examined the effects of drought on growth on sites with 200 mm AWC, and 50 AWC to simulate extreme conditions.

The model provides a number of options for considering the effects of CO_2 on growth and water-use efficiency. The user can fix the level of CO_2 for an individual model run, or let the model vary the CO_2 concentration according to the rate of change of CO_2 concentration measured in Mauana Loa Hawaii (data available from the Carbon Dioxide Information and Analysis Center, www.cdiac.ornl.gov). In addition, the effect of CO_2 on controlling stomatal opening and the associated increase in water use efficiency (WUE, Medlyn et al. 2001) can be turned on or off. This option is available to represent uncertainty in the current literature regarding the magnitude of this effect on tree growth under real field conditions (Ollinger et al. 2002)

In order to determine the validity of the model outputs, we tested the model estimates of NPP against the provincial yield curve for white spruce. In PnET, separate estimates of NPP are produced for foliage, wood and fine roots. Wood includes stem wood, branch wood and coarse roots. We converted total wood NPP estimates to stem wood NPP by subtracting the proportion of branch and coarse root biomass. The proportion of branch wood was taken from the recent CFS biomass inventory (Penner et al. 1997) using the data for white spruce in Saskatchewan. The proportion of coarse root biomass was determined from total biomass using the aboveground to belowground ratios for softwood species given in Li et al. (2003). We assumed the specific gravity of white spruce wood was 0.404 Mg m^{-3} (Gonzales 1990). We found that the peak CAI for white spruce from the yield curve was 4.2 m^3 ha^{-1} yr^{-1}, while that estimated by PnET was 3.8 m^3 ha^{-1} yr^{-1}.

While this agreement was strong, we used the relative change in productivity rather than the absolute change in comparing current with future productivity levels. This was accomplished by determining the ratio of future to current NPP values and multiplying the current yield curve by this ratio. In this fashion we developed yield curves for each of the future scenarios and used them in the subsequent analysis described below.

The productivity scenarios included the following variations:

- Baseline: White spruce on 200 mm AWC soils with CO_2 at current (1975-1984) levels (340 ppmv), no drought;
- Future productivity for white spruce on 200 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), no drought, stomatal response turned off;
- Future productivity for white spruce on 200 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), no drought, stomatal control turned on;
- Future productivity for white spruce on 200 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), with drought, stomatal response turned off;

- Future productivity for white spruce on 200 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), with drought, stomatal control turned on;

- Future productivity for white spruce on 50 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), with drought, stomatal response turned off;

- Future productivity for white spruce on 200 mm AWC soils with CO_2 levels according to the IS92a levels (642 ppmv), with drought, stomatal control turned on;

We were also interested in the effects of future changes in the fire regime in the PAMF area. Recent research suggests that fires in the future will be more intense and cover larger areas (Parisien et al. 2005, Flannigan et al. 2005). We used the estimates of future area burned from Flannigan et al. (2005) to indicate future changes in fire activity in the PAMF area.

RESULTS

Forest Productivity

Figure 1 shows the average productivity levels for the future scenarios for white spruce, relative to those under the current climate. On sites with adequate moisture and no drought, productivity goes up by about 40% with no increased water use efficiency (WUE), and by 60% where WUE is increased. Under drought conditions on 200 mm AWC soils, productivity only increased when the WUE effect was included. On 50 mm AWC soils without increased WUE, productivity declined by 20% relative to current levels, and remained about the same when the WUE effect was included.

The values for each scenario shown in Figure 1 were applied to the provincial white spruce D-density yield curve, resulting in a group of modified curves shown in Figure 2. These were then used in the Soil Expected Value (SEV) analysis shown below.

Soil Expectation Value

As noted, climate change will affect both yield and disturbance regime on forest lands. Both of these will affect the inherent value of land when that land is used for forestry production. Faustmann's formula is the basis for assessing the value of land in forest production (Buongiorno 2001). The Faustmann model measures the soil expectation value (SEV) of forestland. Soil expectation value represents the present value of net revenues obtained from a perpetual series of forest rotations. The value of T that maximizes SEV is the optimal economic rotation.

Table 1 provides the soil expectation values for northern Saskatchewan spruce stands under both current climate and climate conditions that may prevail in the 2080s. The data and analytical assumptions that underlie the results are as follows. First, fire burn rates (λ) and discount rates (δ) are assumed to be constant over time. Second, a constant real stumpage price is assumed. The stumpage price for white spruce in Saskatchewan is assumed to be $25 per cubic meter based on an assumed cash value of $15 per cubic meter plus $10 per cubic meter to account for costs incurred by leaseholders in return for harvesting rights. Reforestation costs are assumed to be $1,750 per ha and are assumed to be a current cost of harvesting. Therefore, reforestation costs are deducted from stumpage value at the time of harvesting as opposed to discounting future revenues and comparing these to current reforestation costs. In general, the decision to reforest a harvested stand is not based on economic criteria. Rather, companies operating on public lands are required to reforest all sites. The assumed discount rate for this analysis is 4 %.

There are five main findings that are evident from the results provided in Table 1. First, an increase in burn rates reduces soil expectation values. Second, the optimal economic rotation under future climatic conditions is generally lower than that under present conditions. Third, the results regarding the economic impact of climate change are ambiguous. It is clear that there is some potential for economic gains through higher productivity but these effects are offset by higher fire risk. Fourth, the impacts of climate change are very sensitive to site conditions. For example, if moisture becomes limiting under future climates then forestland values for sites with low water holding capacity could significantly decrease. Thus, climate change may be beneficial on some sites but decrease the value of other sites. Fifth, the assessment of net impacts depends on assumptions regarding adaptive response of both trees and land managers. For example, productivity gains are in some respects dependent on the ability of trees to take advantage of CO_2 fertilization and their ability to become more efficient in their use of water. Economic gains are dependent on the willingness of forest managers to adjust harvest ages.

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Table 1 **Soil expectation values under the scenarios shown in Figure 1. Values in bold indicate the highest SEV for a given scenario.**

Scenario →	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Drought			No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil WHC			200	200	200	200	200	200	200	200	50	50	50	50
WUE effect			No	No	Yes	Yes	No	No	Yes	Yes	No	No	Yes	Yes
Climate and CO_2	Current		2080		2080		2080		2080		2080		2080	
Lambda (fire rate)	0	0.0038	0.004	0.0131	0.004	0.0131	0.004	0.0131	0.004	0.0131	0.004	0.0131	0.004	0.0131
Age	Soil expectation values													
40	38.0	34.5	240.0	189.2	302.9	238.8	45.7	36.0	148.6	117.1	0.0	0.0	34.3	27.0
50	187.8	165.6	**353.0**	**258.4**	**414.6**	**303.5**	174.8	**127.9**	**270.7**	**198.2**	82.2	60.2	161.1	117.9
60	**212.0**	**181.1**	333.9	226.0	380.4	257.5	**188.1**	127.3	266.3	180.2	**114.1**	**77.2**	**177.5**	**120.2**
70	182.9	151.2	263.6	164.4	299.4	186.8	157.7	98.3	213.3	133.0	102.0	63.6	148.4	92.6
80	140.2	112.1	189.6	108.7	214.7	123.1	114.9	65.9	155.2	89.0	76.3	43.8	109.9	63.0
90	98.3	75.9	128.3	67.5	144.8	76.2	78.6	41.3	104.8	55.1	52.4	27.6	74.3	39.1
100	65.8	49.0	82.0	39.5	92.6	44.6	50.3	24.2	67.3	32.4	33.8	16.3	47.9	23.1
110	42.0	30.1	50.6	22.3	57.4	25.3	30.9	13.6	41.4	18.3	20.6	9.1	29.4	13.0
120	25.7	17.8	30.3	12.2	34.4	13.9	18.3	7.4	24.6	9.9	12.0	4.8	17.3	7.0

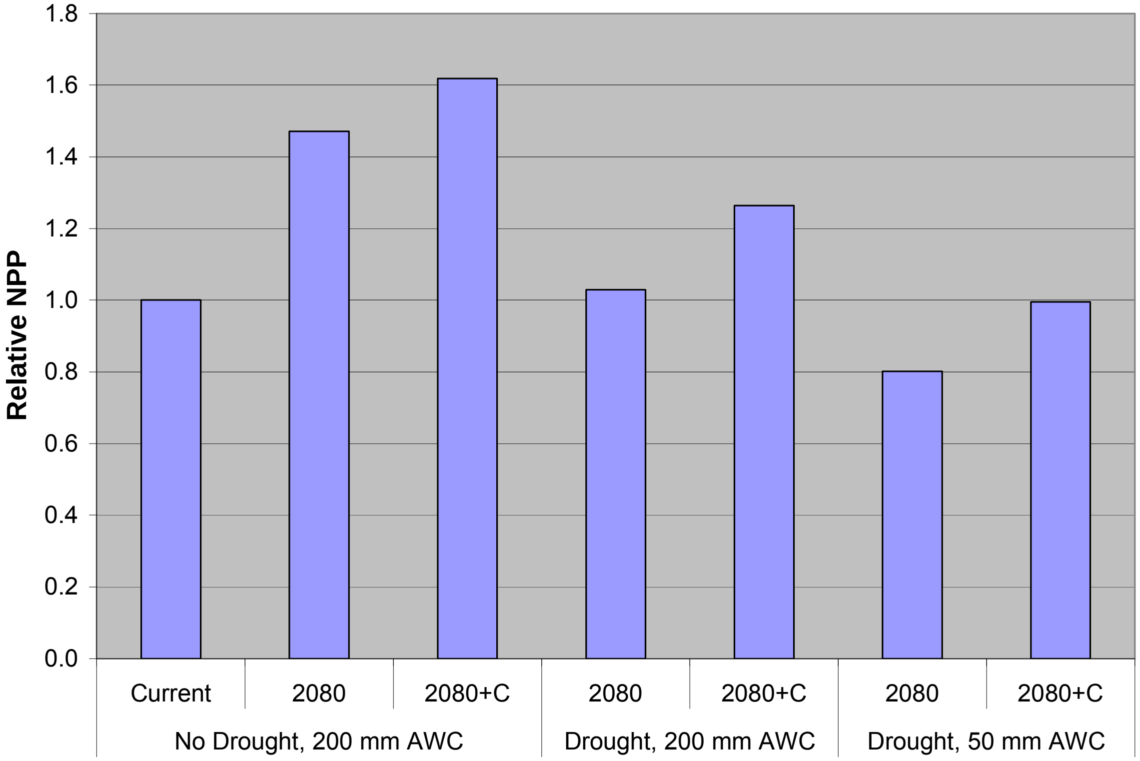

Figure 1. White spruce net primary productivity simulated by PnET for Prince Albert under various scenarios, shown as values relative to current NPP. "+C" indicates scenarios in which the effect of increased water use efficiency was included.

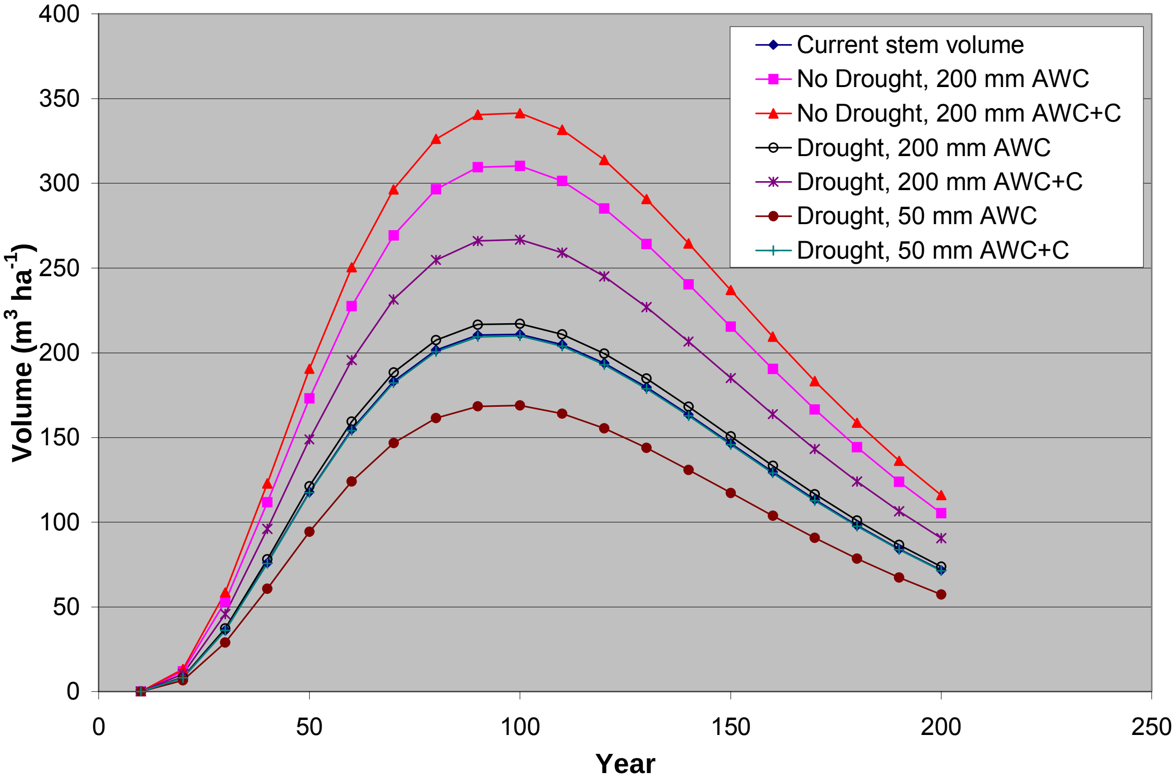

Figure 2. Current and modified and yield curves for D-density white spruce stands in the Prince Albert Model Forest area. Scenarios follow those shown in Figure 1.