Including Climate in the Mixedwood Growth Model

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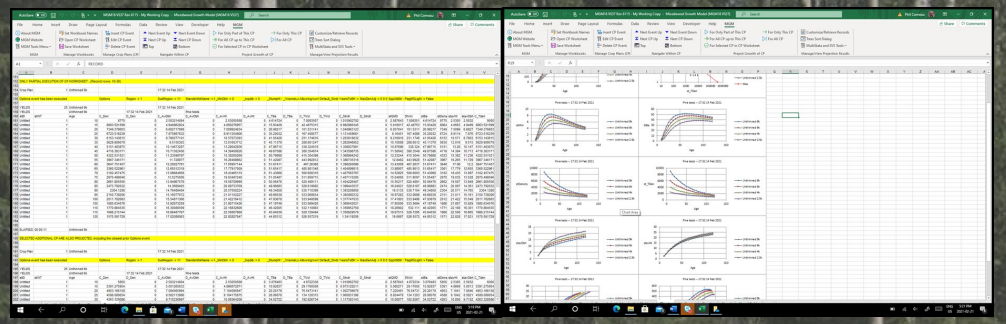
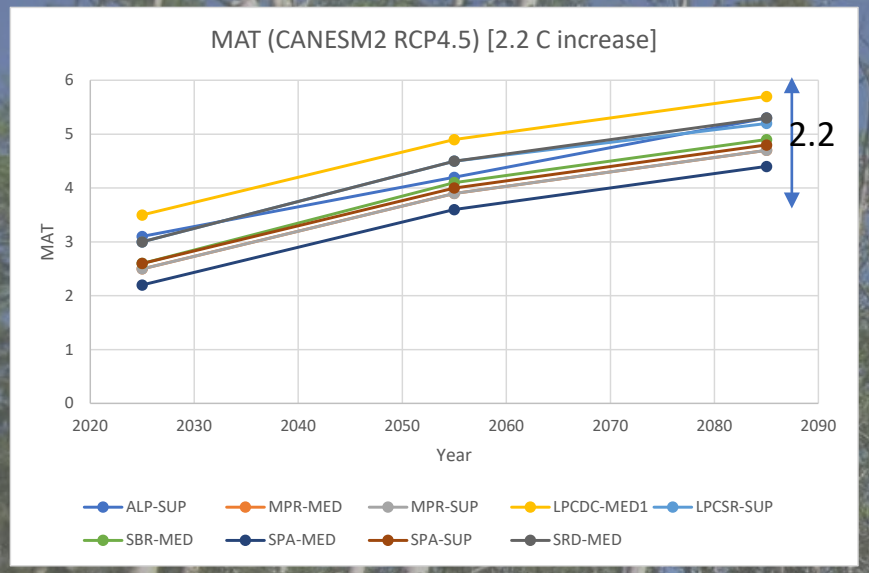
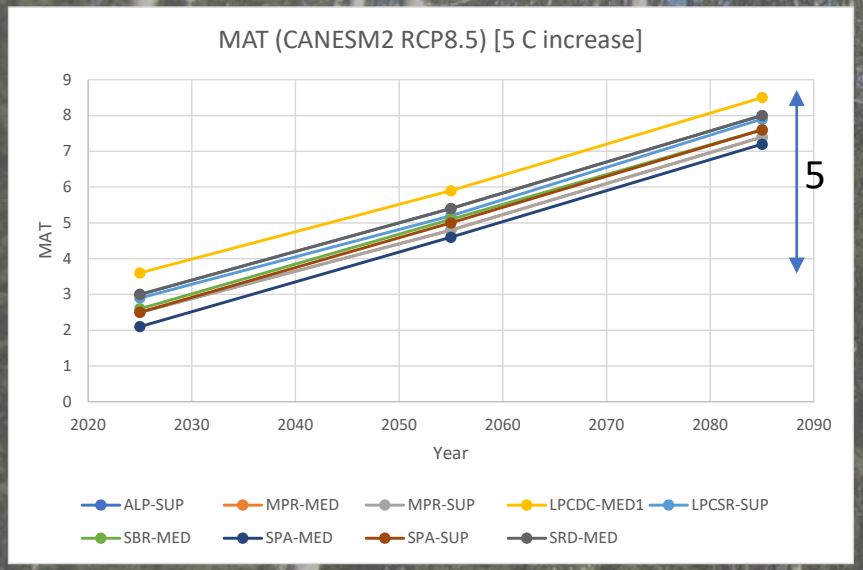
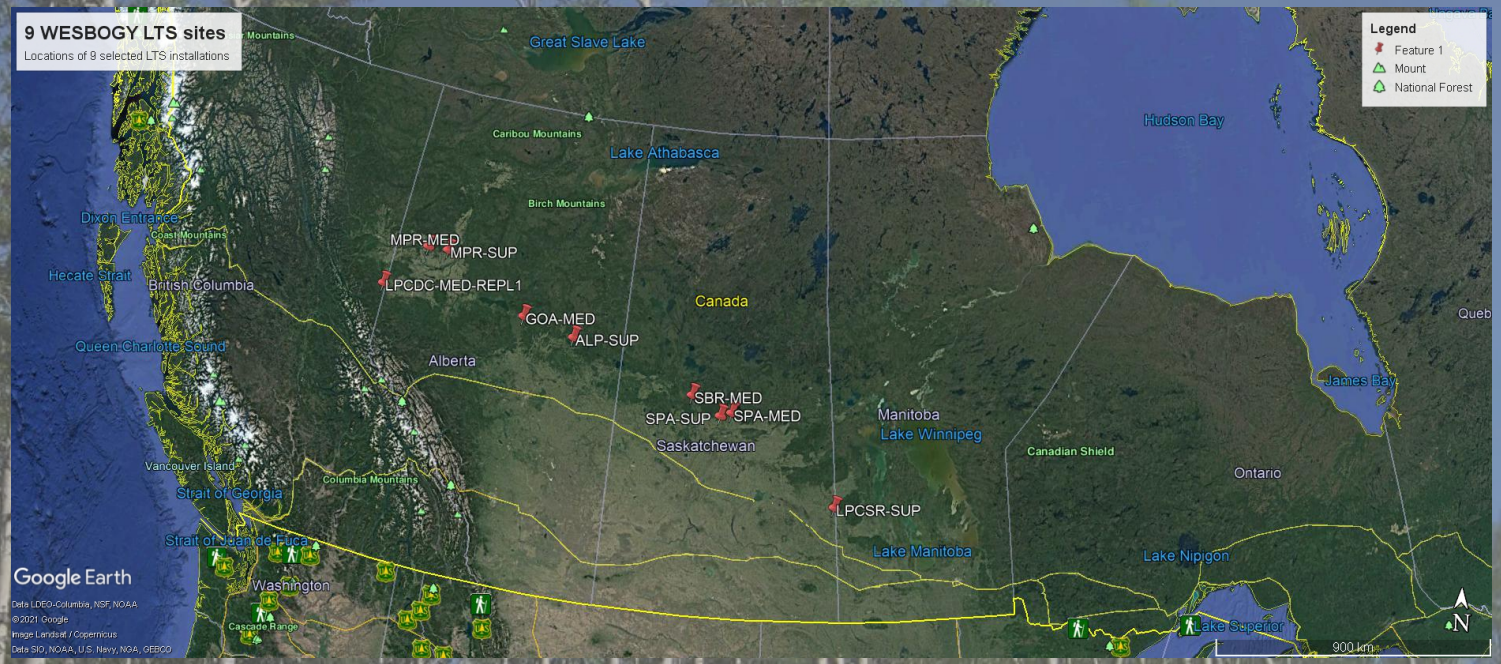


Projected changes in mean annual temperature (MAT) between 2010 and 2100 based on CANESM2



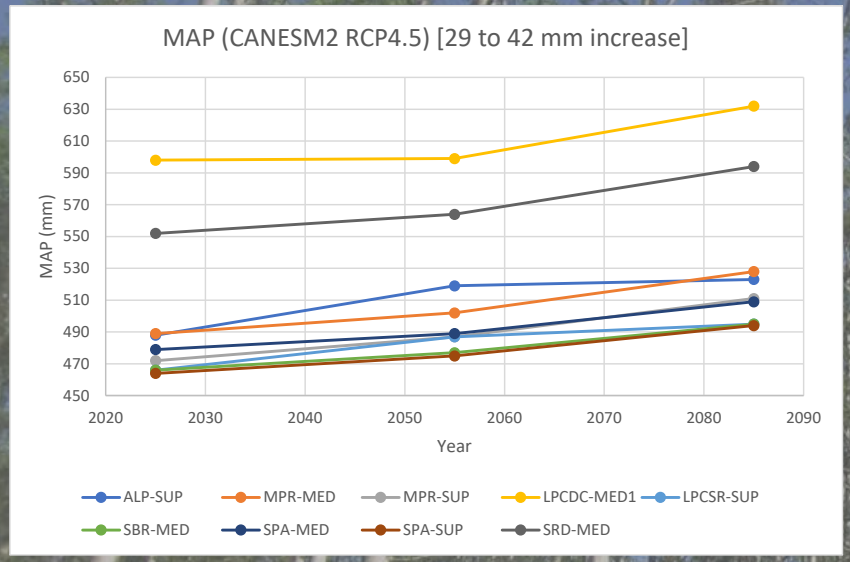


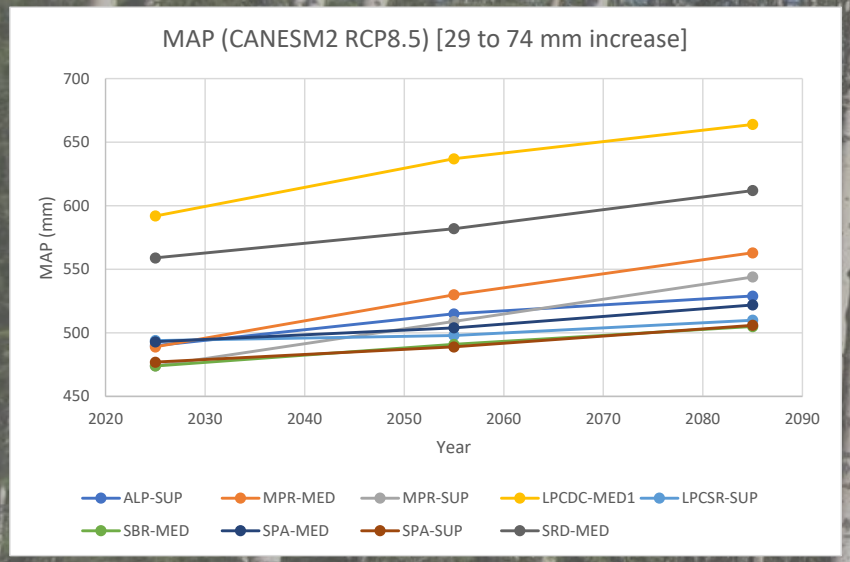


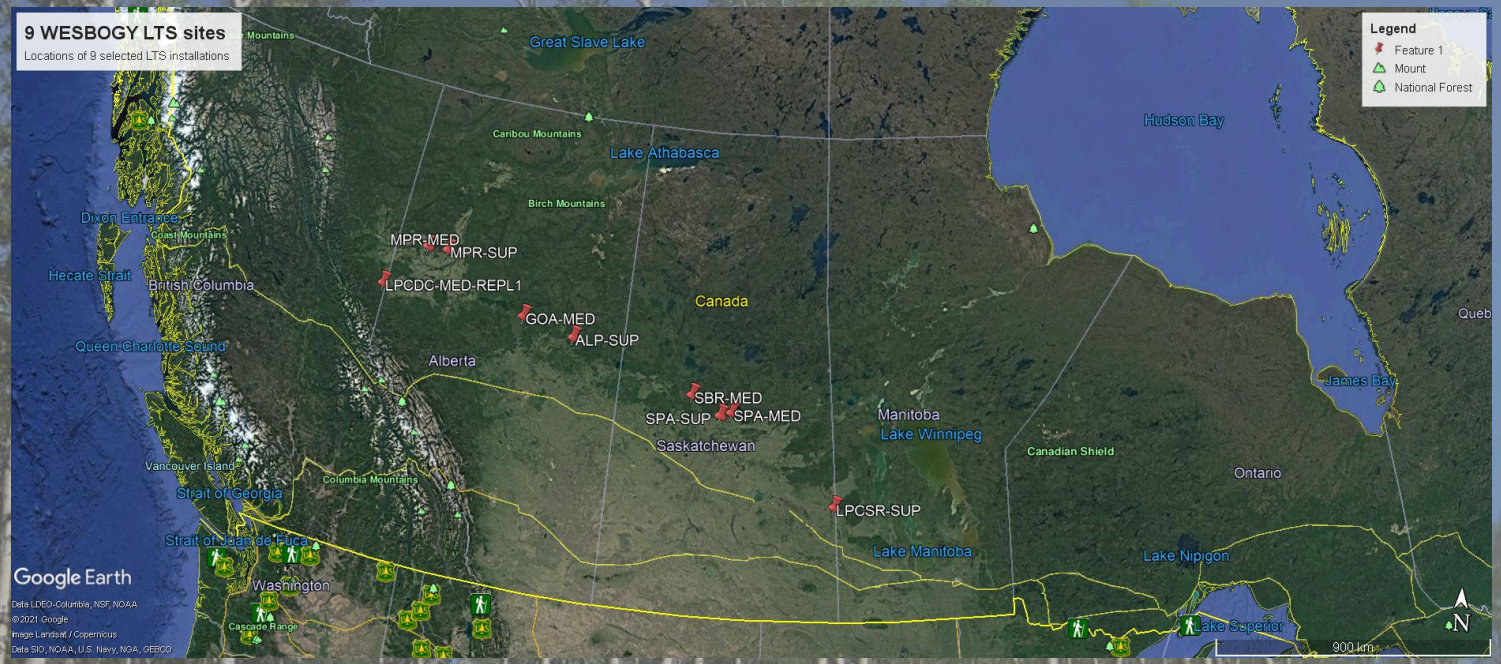
RCP4.5=Representative Concentration Pathway 4.5 is an **intermediate** emissions mitigation scenario that stabilizes radiative forcing at 4.5 Watts m^{-2} in the year 2100 without ever exceeding that value.

RCP8.5= Representative Concentration Pathway 8.5 is a scenario associated with **high GHG levels** that stabilizes radiative forcing at 8.5 Watts m^{-2} squared in the year 2100 without ever exceeding that value.

Projected changes in mean annual precipitation (MAP) between 2010 and 2100 based on CANESM2







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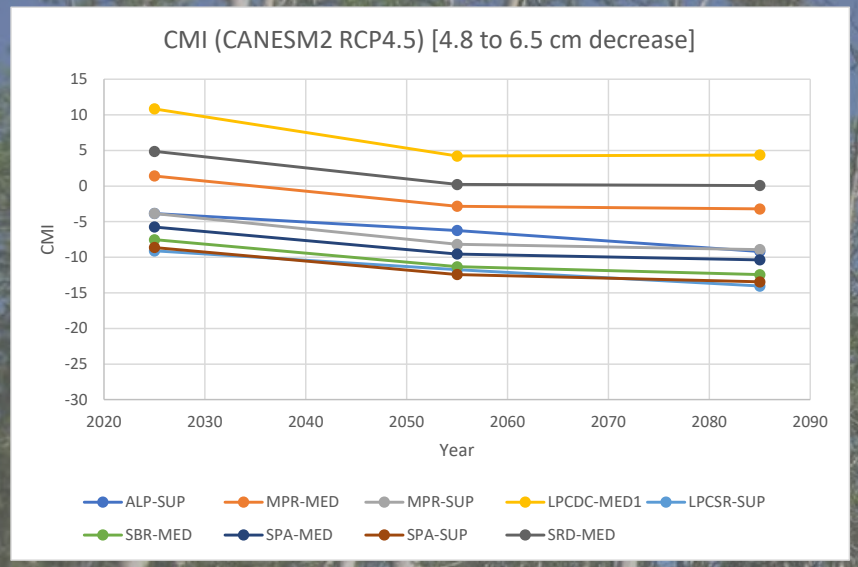
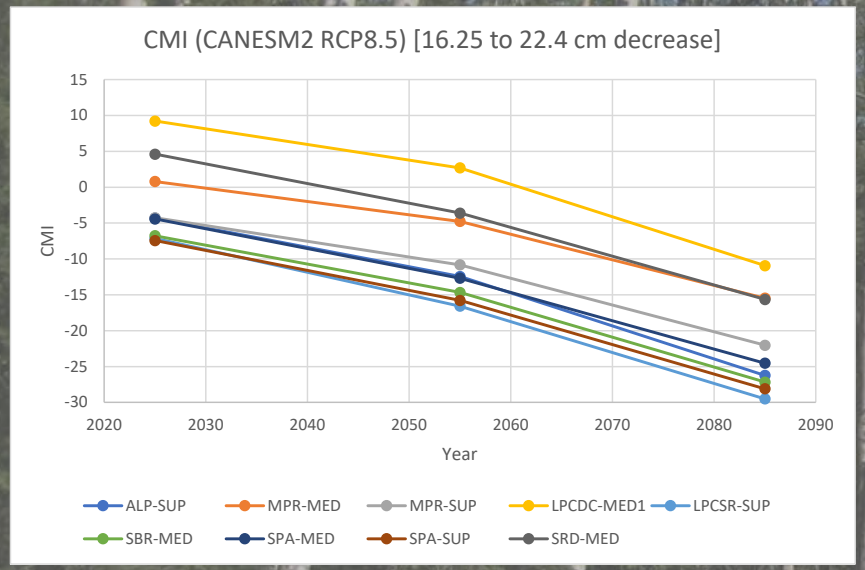
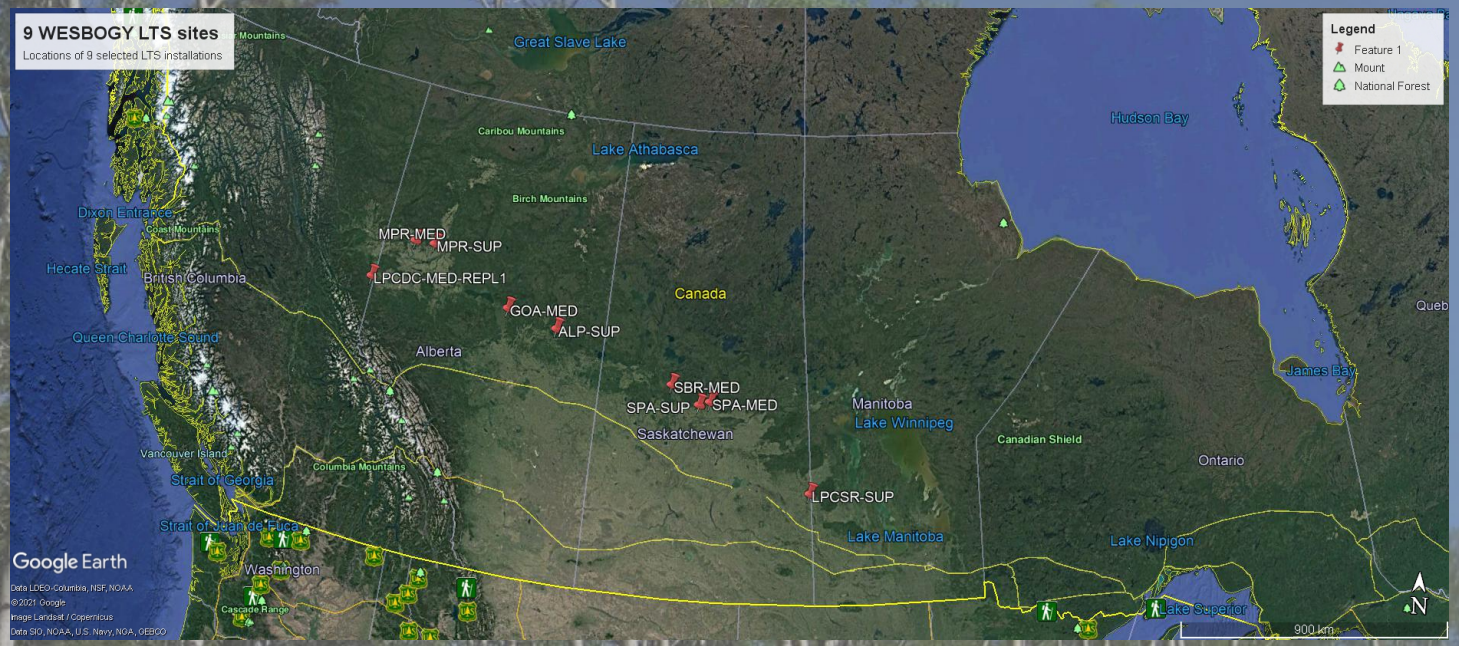
Projected changes in Climate Moisture Index (CMI) between 2010 and 2100







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Bioclimatic envelope modeling indicates the potential for dramatic shrinkage of boreal forests in over the next 70 years due to global warming

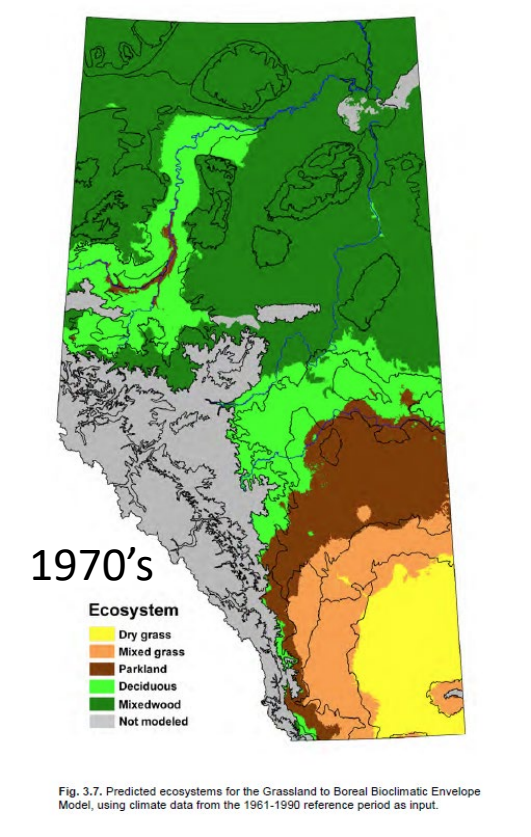
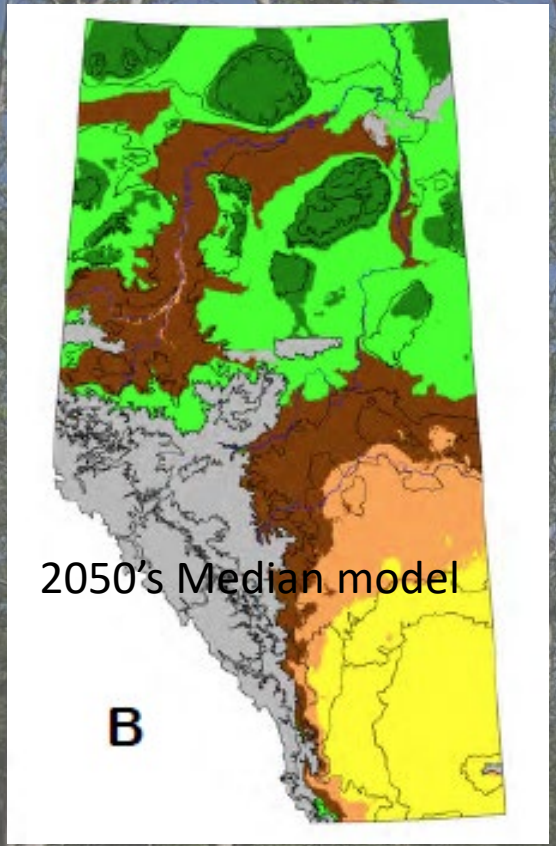
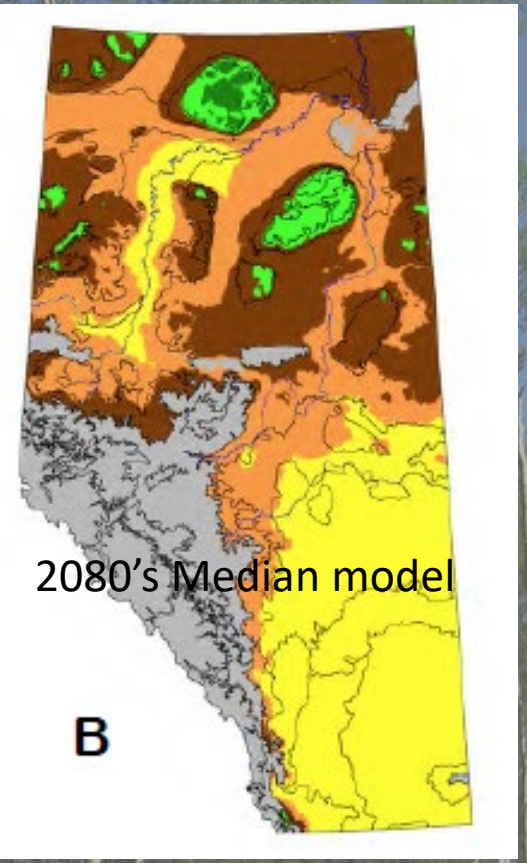


Fig. 3.7. Predicted ecosystems for the Grassland to Boreal Bioclimatic Envelope Model, using climate data from the 1961-1990 reference period as input.





From: Schneider, R.R. 2017. Alberta's natural subregions under a changing climate: past, present and future. Alberta Biodiversity Monitoring Network. url: Schneider_2013_AlbertaNaturalSubregionsUnderaChangingClimate.pdf (abmi.ca)

Climate Change and Sustainable Forest Management

- Drought could lead to increased mortality, reduced stocking, reduced growth of trees, loss of stands, and regeneration challenges
- Increasing temperatures and longer growing season may increase growth where drought is not an issue
- Increasing temperatures could increase insect and disease issues (MPB, spruce bark beetle, weevil, forest tent caterpillar)
- Increasing temperatures increase fire risk

- Management options for adaptation:
  - Thinning and partial cutting
  - Complex stands: species mixtures and multi-aged stands
  - Assisted migration (species and populations)
    - "Climate smart" deployment of provenances and seedlots, species transfers
  - Fire smart practices
  - others

Why include climate in a stand growth model?

- Improve model predictions through better localization
- Predict possible outcomes of climate change and use predictions to:
  - Assess risk
  - Assist in the development of adaptation strategies
  - Support policy changes (seed transfer and deployment, assisted migration etc.)

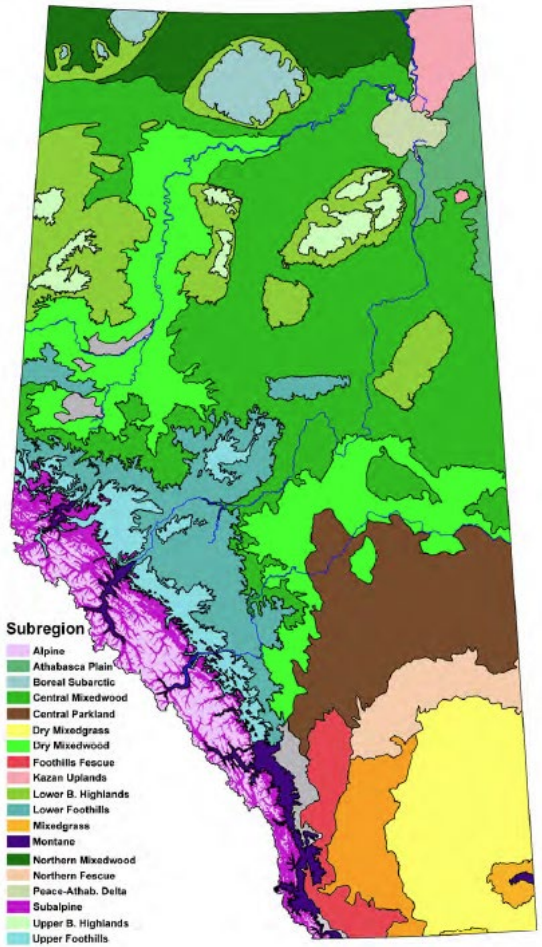


Fig. 1.1. The Natural Subregions of Alberta.

The Mixedwood Growth Model (MGM)

Background

- Deterministic
- Individual tree
- Distance independent
- Developed for Boreal and Foothills Forests in Alberta, Saskatchewan, MB and BC (northeast and central/northern interior)
- Models pure and mixed, even-aged and uneven-aged (structured) stands
  - trembling aspen, balsam poplar, white spruce, hybrid (Sw*Se) spruce, black spruce, balsam fir/subalpine fir, jack pine, lodgepole pine
- Can model partial cutting and thinning

Modeling Approach

- MGM is a "height-driven model" that uses provincial site index curves (i.e. height-age-site index models) to predict the maximum potential annual height increment for each tree.
- Then, each tree is ranked by social status, and competition-adjusted height increment, diameter increment, and survival are calculated.

Adding Climate Sensitivity to MGM

- MGM18 – new Survival Probability function included CMI
- MGM21 – added a Maximum Density – Size function which included CMI and stand composition
- MGM22 – adding climate sensitive height and diameter growth functions

MGM Functions
a) Potential Height Growth (MGM18, MGM21, MGM22)

$$MaxHI_{ijk} = SiteHeight_j(SiteIndex_{ij}, BHage_{ijk} + 1) - SiteHeight_j(SiteIndex_{ij}, BHage_{ijk})$$

Where:

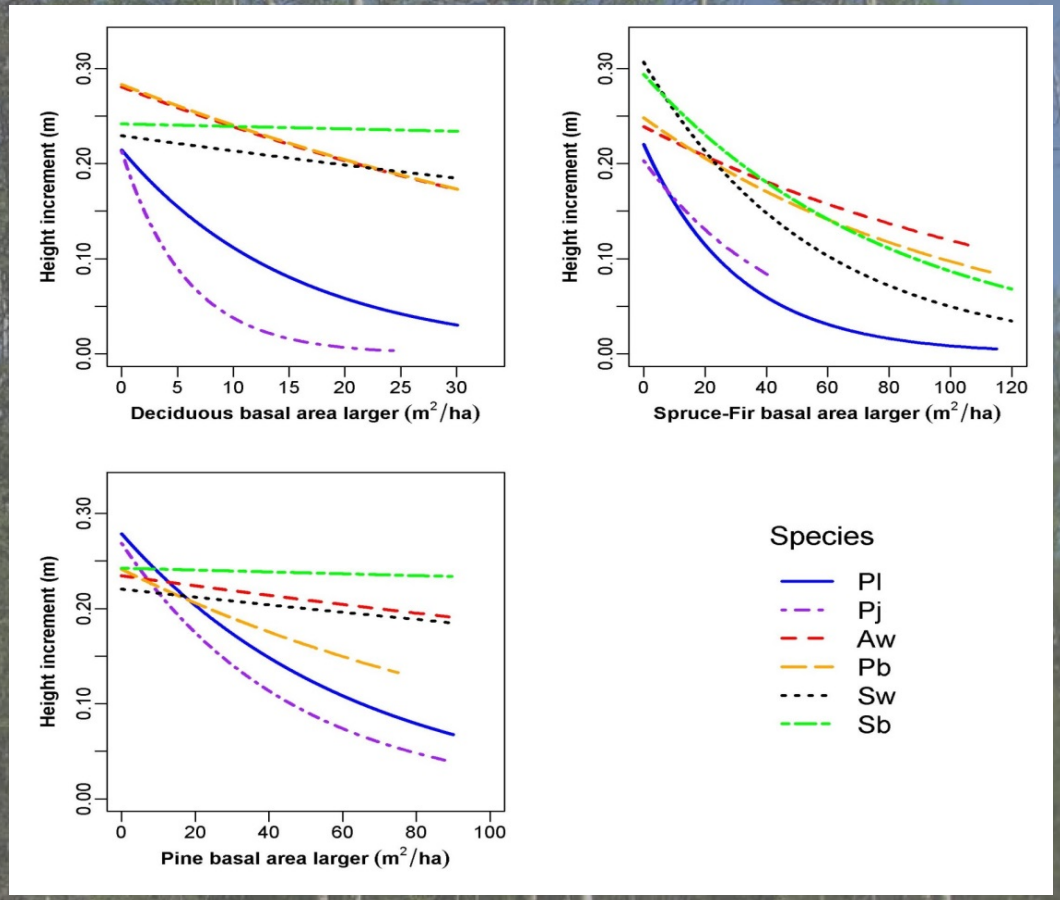
- $MaxHI_{ijk}$ = Maximum height increment (m/year) of tree k of species j in stand i
- $SiteHeight_j$ = Height (m) defined by the site index curve for species j, given $SiteIndex_{ij}$ and $BHage_{ijk}$.
- $SiteIndex_{ij}$ = Site index (m@50 years breast height age) of species j in stand i
- $BHage_{ijk}$ = Breast height age (years) of tree k of species j in stand i

MGM Functions
b) Height Growth (MGM22)

$$HI = MaxHI * exp^{(-(\partial_1 * DecBAL + \partial_2 * SfBAL + \partial_3 * PinBAL + \partial_4 * FFP + \partial_5 * MSP))}$$

where

- HI=height increment (m/y)
- MaxHI = potential maximum height increment (m/y))
- DecBAL=deciduous basal area larger (m^2/ha)
- SfBAL=spruce/fir basal area larger (m^2/ha)
- PinBAL=pine basal area larger (m^2/ha)
- FFP=frost free period (days)
- MSP=mean summer precipitation (mm/y)



Oboite and Comeau in prep

MGM Functions
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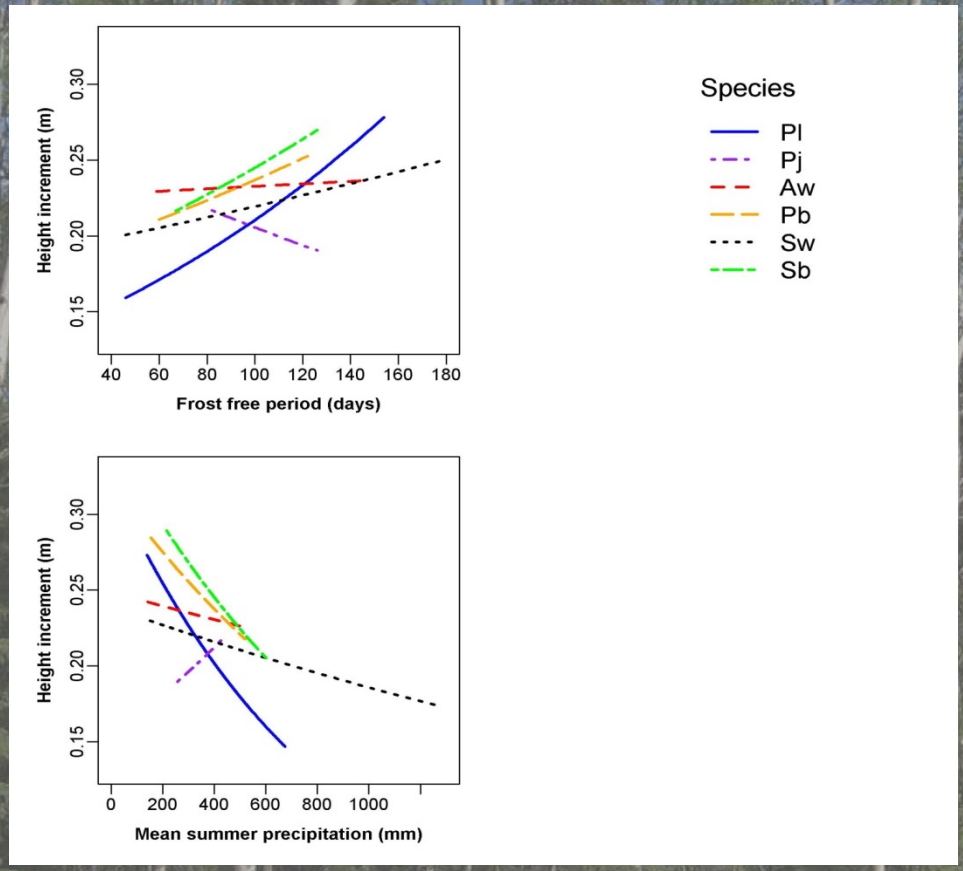
$$HI = MAXHI * exp^{(-(\partial_1 * DecBAL + \partial_2 * SfBAL + \partial_3 * PinBAL + \partial_4 * FFP + \partial_5 * MSP))}$$



Oboite and Comeau in prep

MGM Functions
c) Diameter Growth (MGM22)

$$DI = HI * \eta$$

For trembling aspen, white spruce and lodgepole pine:

$$\eta = \beta_{00} * exp\ (-((\beta_{10}) * DBH + (\beta_{20} * DecBAL) + (\beta_{21} * SfBAL) + (\beta_{22} * PinBAL) + (\beta_{30} * MAT) + (\beta_{31} * MSP) + (\beta_{40} * TotBAL * MSP))) + \varepsilon_{ijk}$$

Where:

- DI=diameter increment (cm/y)
- HI=height increment (m/y)
- DBH=Diameter at 1.3 m (cm)
- DecBAL=deciduous basal area larger, SfBAL=spruce/fir basal area larger, PinBAL=pine basal area larger, TotBAL=total basal area larger (m^2/ha)
- MAT=mean annual temperature (°C)
- MSP=mean summer precipitation (mm/y)

Oboite and Comeau in prep

MGM Functions
c) Diameter Growth (MGM22)

$$DI = HI * \eta$$

For jack pine and balsam poplar:

$$\eta = \beta_{00} + (\beta_{10}) * \mathrm{DBH} + (\beta_{20} * \mathrm{DecBAL}) + (\beta_{21} * \mathrm{SfBAL}) + (\beta_{22} * \mathrm{PinBAL}) + (\beta_{30} * \mathrm{MAT}) + (\beta_{31} * \mathrm{MSP}) + (\beta_{40} * \mathrm{TotBAL} * \mathrm{MAT}) + \varepsilon_{ijk}$$

For black spruce:

$$\eta = (\beta_{00}) + exp\left(\beta_{10} * \exp\left(\mathrm{DBH}^{\beta_{11}}\right)\right) * exp(-((\beta_{20} * \mathrm{DecBAL}) + (\beta_{21} * \mathrm{SfBAL}) + (\beta_{22} * \mathrm{PinBAL})) + (\beta_{30} * \mathrm{MAT}) + (\beta_{31} * \mathrm{MSP}) + (\beta_{40} * \mathrm{TotBAL} * \mathrm{MAT}))) + \varepsilon_{ijk}$$

Where:

- DI=diameter increment (cm/y)
- HI=height increment (m/y)
- DBH=Diameter at 1.3 m (cm)
- DecBAL=deciduous basal area larger, SfBAL=spruce/fir basal area larger, PinBAL=pine basal area larger, TotBAL=total basal area larger (m^2/ha)
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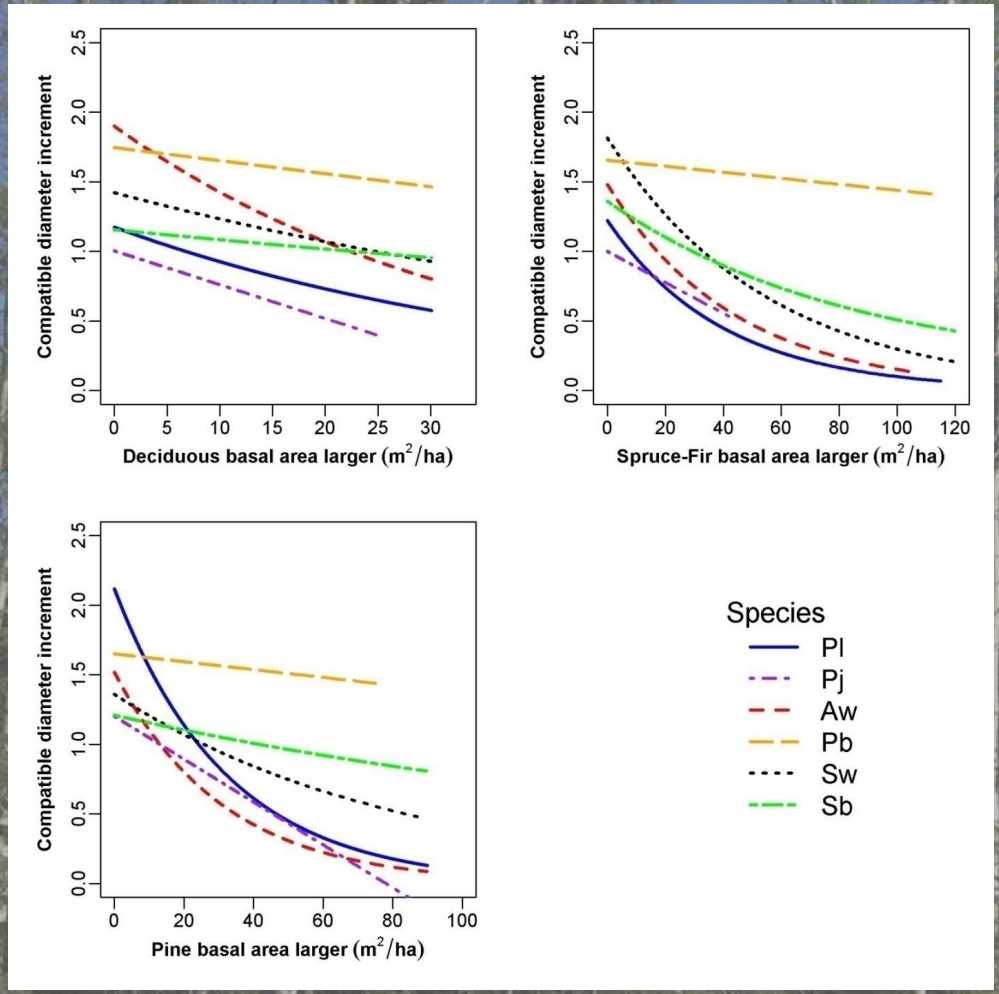

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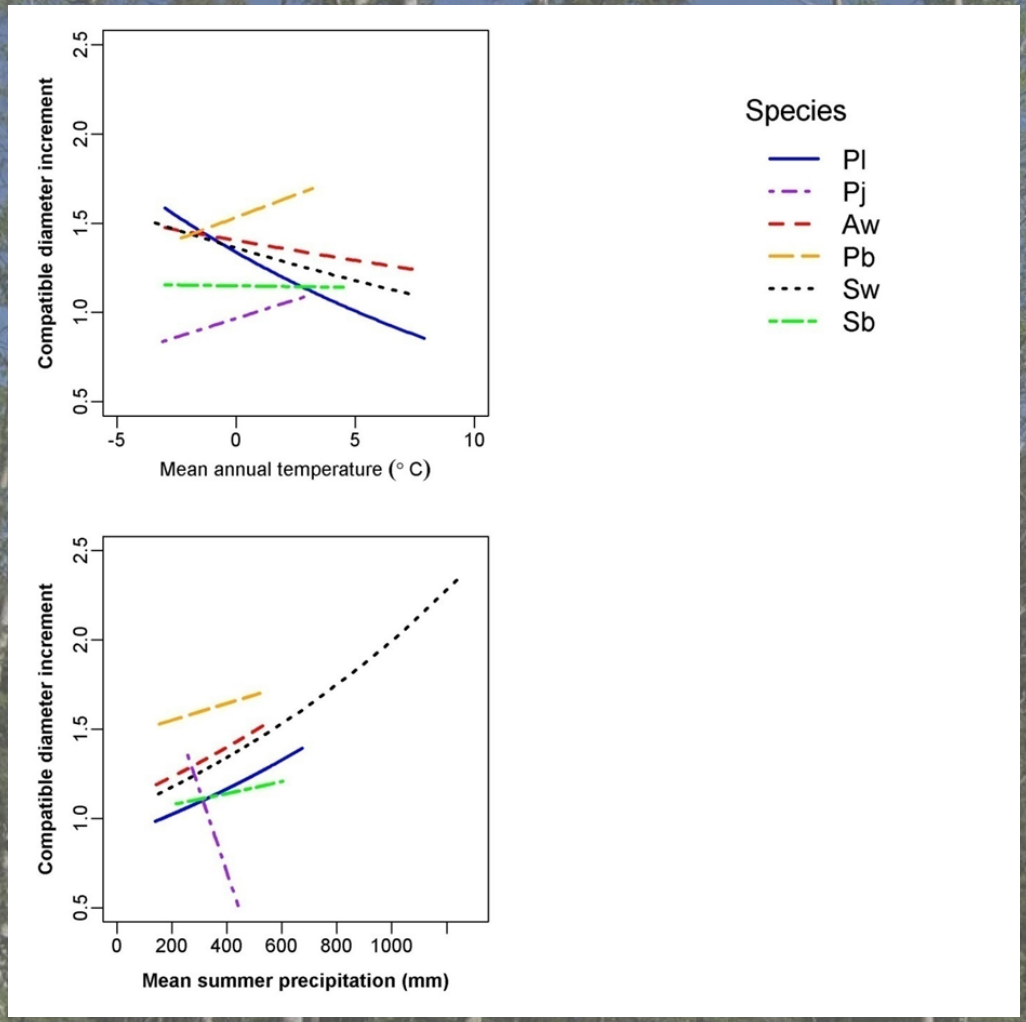
MGM Functions
c) Diameter Growth (MGM22)



Oboite and Comeau in prep

MGM Functions
d) Individual Tree Survival (MGM18, MGM21, MGM22)

$$P_{ijk} = \left(\frac{\exp(c)}{(1+\exp(c))} \right)^{L_{jk}} + \varepsilon_{ijk}$$

$$c = a_0 + a_1 * DBH_{ijk} + a_2 * DBH_{ijk}^2 + a_3 * DecBAL_{ijk} + a_4 * SfBAL_{ijk} + a_5 * PinBAL_{ijk} + a_6 * CMI_i$$

Where:

P_{ijk} = survival probability

DBH_{ijk} = DBH (cm);

$DecBAL_{ijk}$ = basal area of deciduous trees larger than the subject tree (m^2 ha^{-1}); $SfBAL_{ijk}$ = basal area of spruce and fir larger than the subject tree (m^2 ha^{-1}); $PinBAL_{ijk}$ = basal area of pine trees larger than the subject tree (m^2 ha^{-1});

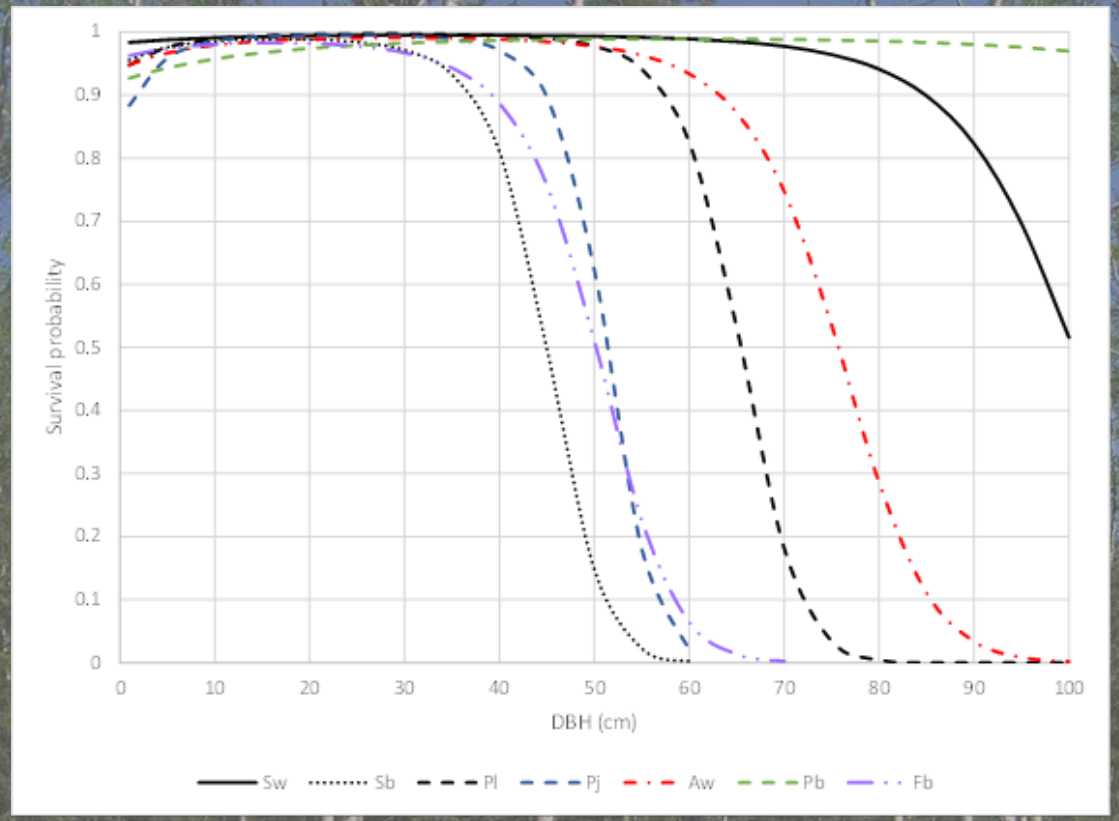
CMI_i = Climate Moisture Index (cm/y);

L_{jk} = time elapsed between consecutive measurements (years), set to 1 in MGM;

a_o–a_6 = fixed effects parameters;

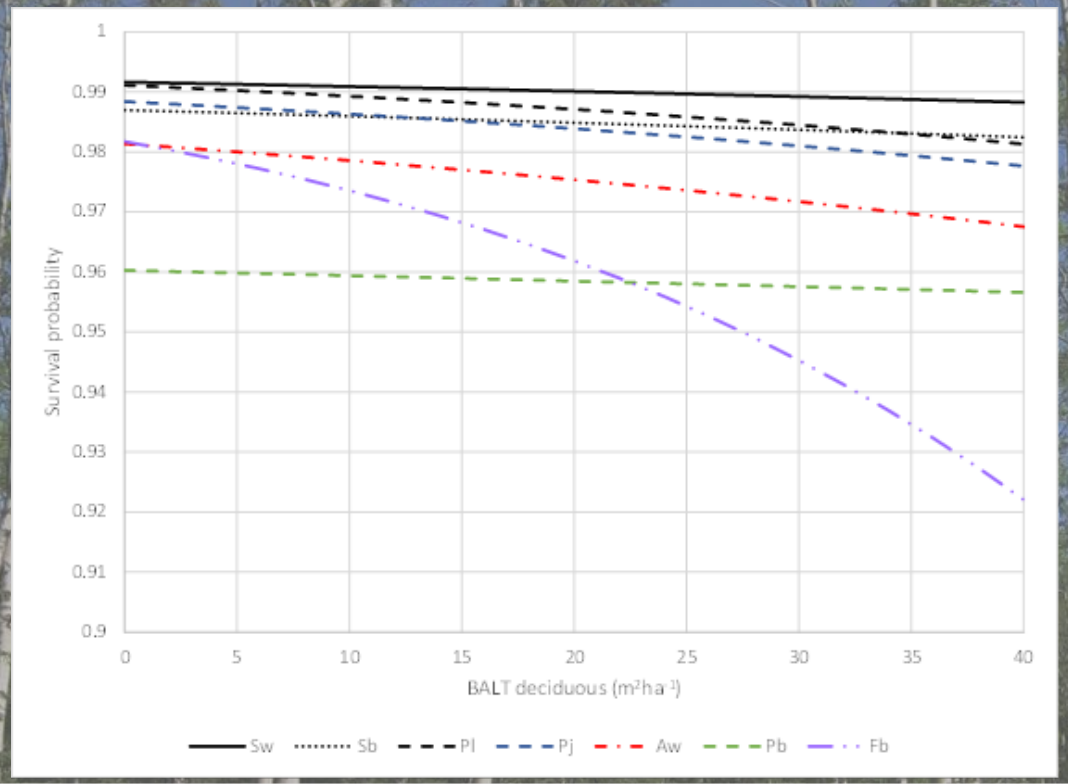
Cortini et al. 2017. For. Ecol. Manage. 402: 77-185

MGM Functions
d) Survival (MGM18, MGM21, MGM22)



Effect of DBH on survival probability of each species.
Species are: Sw=white spruce ; Sb= black spruce ; Pl= lodgepole pine ; Pj= jack pine; Aw= trembling aspen ; Pb= balsam poplar; and Fb= balsam fir/subalpine fir.

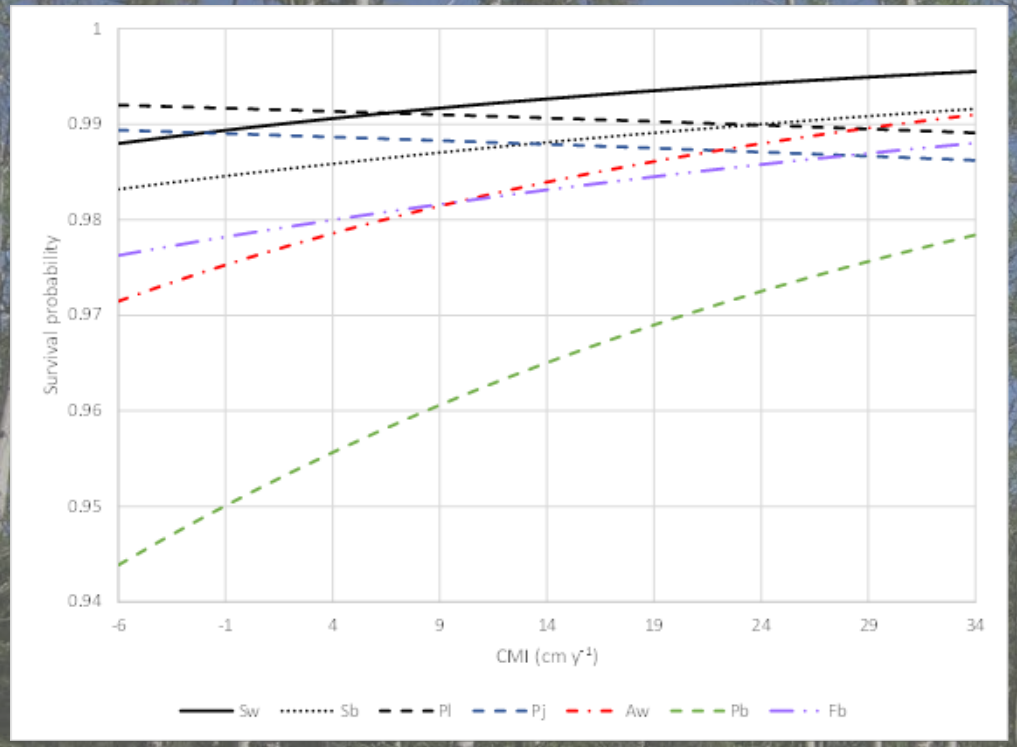
MGM Functions
d) Survival (MGM18, 21, 22)



Effect of DecBAL on survival probability

Species are: Sw=white spruce ; Sb= black spruce ; Pl= lodgepole pine ; Pj= jack pine; Aw= trembling aspen ; Pb= balsam poplar; and Fb= balsam fir/subalpine fir.

MGM Functions
d) Survival (MGM18, MGM21, MGM22)

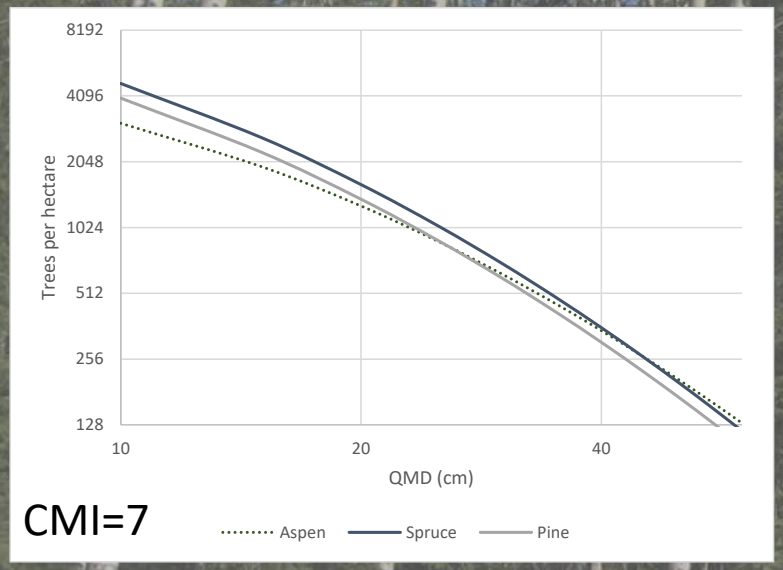


Effect of CMI on predicted survival probability for each species.
Species are: Sw=white spruce; Sb= black spruce; Pl= lodgepole pine; Pj= jack pine; Aw= trembling aspen; Pb= balsam poplar; and Fb= balsam fir/subalpine fir.

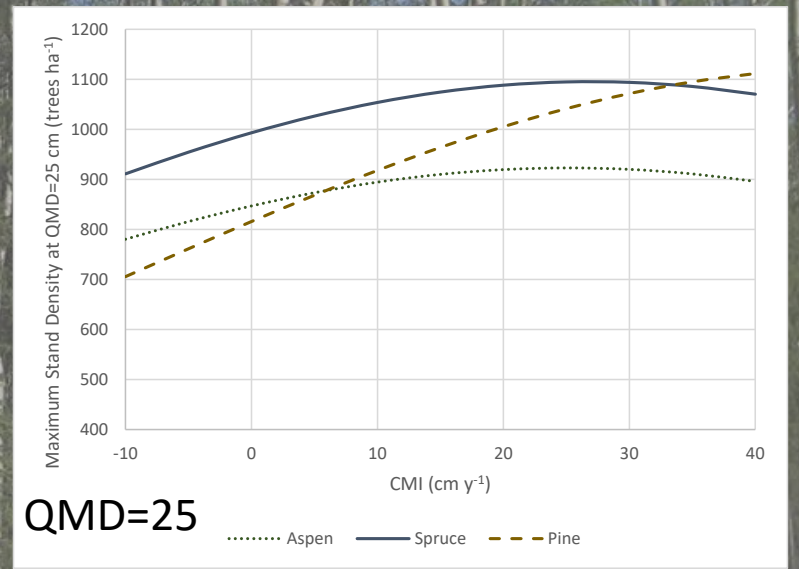
MGM Functions
e) Maximum Density (MGM21, MGM22)

$$ln(TPH)=8.5870+0.9013*ln(QMD)-0.4601*(((ln(QMD))^2) - 0.008596*Dec_pct + 0.001968*Sf_pct + 0.002786*ln(QMD)*Dec_pct + 0.01314*CMI - 0.00013532*CMI^2 - 0.00006326*CMI*Dec_pct - 0.00005859* CMI*sf_pct$$

where: QMD=quadratic mean diameter for the stand (cm); dec_pct=percent of stand basal area that is deciduous; sf_pct= percent of stand basal area that is spruce or fir; CMI=Climate Moisture Index (cm/*y*)



CMI=7



QMD=25

Implementation in MGM22

- Implementation of the new height and diameter growth functions will be completed in 2021.
- Behaviour of these functions in conjunction with other model functions (Site index functions, survival, maximum density, etc.) will be evaluated and compared against the functions used in MGM21
- Validation of the model under current climatic conditions (1981-2010 normal) will be completed
- Behavioural testing will include testing effects of ranges of all input variables
- Model projections under RCP2.6, RCP4.5 and RCP8.5 are planned

Conclusions

- Work so far shows substantial benefits to incorporating climate sensitivity in MGM
- MGM21 has undergone extensive validation and behavioural testing and will be available soon
- MGM22 is under development and will include climate in height and diameter growth functions
- Refinements (future development after MGM22)
  - Climate: Use averages for 5-10 year periods coinciding with PSP remeasurement intervals in place of 30 year (1981-2010) Climate Normals
  - Add explicit representation of Soil Moisture Regime and other site effects
  - Model potential seed/population transfers and assisted migration

Acknowledgements

- Special Thanks to:
  - FGrOW (Forest Growth Organization of Western Canada) – Western Boreal Growth and Yield Project Team and Mixedwoods Project Team and members for long-term funding and support
  - Forest Resource Improvement Association of Alberta (FRIAA) for funding
  - NSERC for funding (2005-2009)
  - MITACS, WestFraser, Weyerhaeuser and Canfor for funding to support development of climate sensitive growth functions by Felix Oboite (2018-2020)
  - ALPAC and Saskatchewan Environment for funding support for MGM22
  - Steve Titus and Bill Adams who began developing MGM in 1986
  - Ken Stadt who assisted with development of MGM from 2004 to 2010
  - Students who have contributed to development of MGM

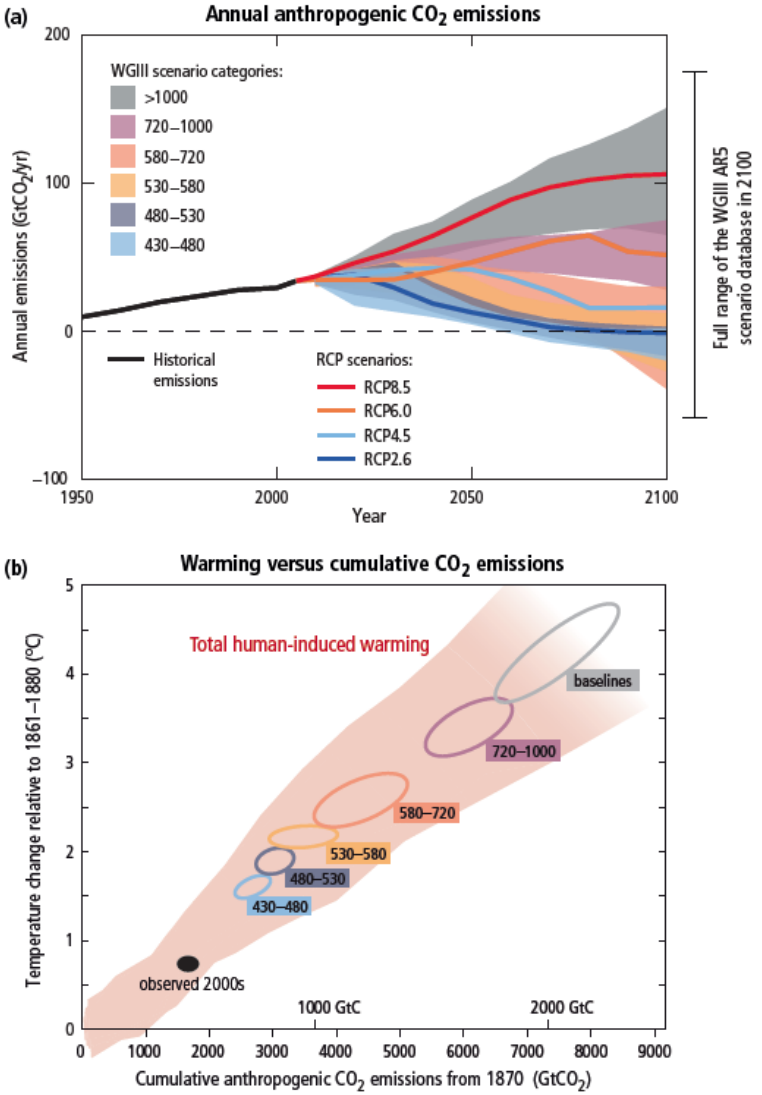


Figure SPM.5 | **(a)** Emissions of carbon dioxide (CO_2) alone in the Representative Concentration Pathways (RCPs) (lines) and the associated scenario categories used in WGIII (coloured areas show 5 to 95% range). The WGIII scenario categories summarize the wide range of emission scenarios published in the scientific literature and are defined on the basis of CO_2-eq concentration levels (in ppm) in 2100. The time series of other greenhouse gas emissions are shown in Box 2.2, Figure 1. **(b)** Global mean surface temperature increase at the time global CO_2 emissions reach a given net cumulative total, plotted as a function of that total, from various lines of evidence. Coloured plume shows the spread of past and future projections from a hierarchy of climate-carbon cycle models driven by historical emissions and the four RCPs over all times out to 2100, and fades with the decreasing number of available models. Ellipses show total anthropogenic warming in 2100 versus cumulative CO_2 emissions from 1870 to 2100 from a simple climate model (median climate response) under the scenario categories used in WGIII. The width of the ellipses in terms of temperature is caused by the impact of different scenarios for non-CO_2 climate drivers. The filled black ellipse shows observed emissions to 2005 and observed temperatures in the decade 2000–2009 with associated uncertainties. *{Box 2.2, Figure 1; Figure 2.3}*

From: IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 151 pp.