Climate change-associated trends in biomass dynamics are consistent across soil drainage classes in western boreal forests of Canada

Eric B. Searle and Dr. Han Y.H. Chen

Introduction

- Long-term consistent decline in net aboveground biomass reported in some boreal and tropical forests
  - Large increases in mortality with increases in growth insufficient to offset these losses (Brienen et al. 2015; Chen and Luo 2015; Chen et al. 2016).
- Major driver in some cases: global change type drought
  - Defined as increased evapotranspiration without increased precipitation leading to negative ecological water balances

Introduction

- Global change type drought linked to:
  - Increased mortality (van Mantgem et al. 2009; Michaelian et al. 2011; Luo and Chen 2013; Allen et al. 2015; Hember et al. 2017)
  - Decreased growth (Chen and Luo 2015; Hogg et al. 2017)
  - Declining net aboveground biomass change (Ma et al. 2012; Chen and Luo 2015; Chen et al. 2017; Hogg et al. 2017)

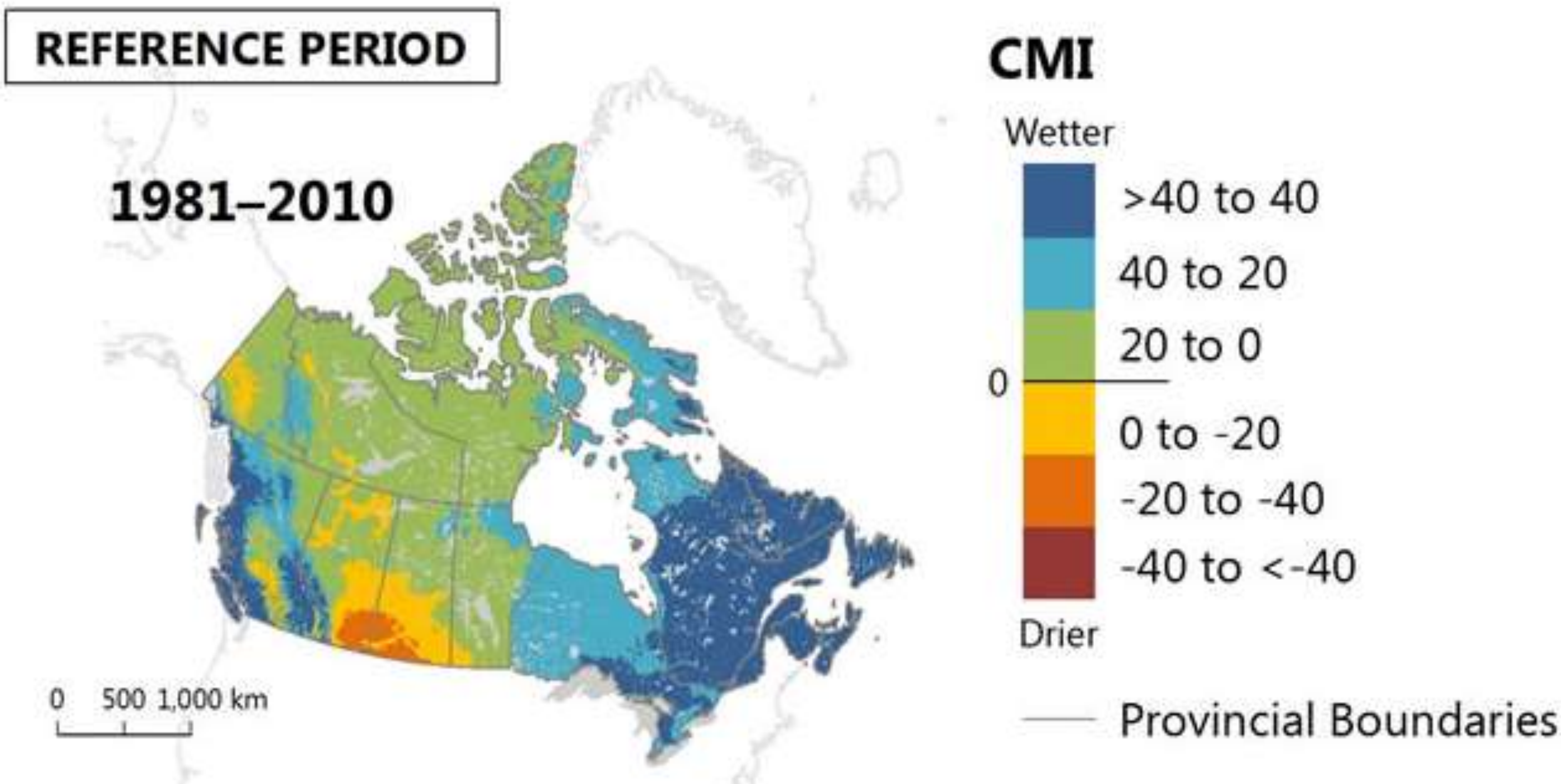
Local site buffering

- If global-change type drought is a major driver of effects of climate change, then sites with little water retention should be more negatively affected than sites with higher water retention

Boreal forests

- Disturbance driven system, endogenous stand development controls on biomass dynamics (Zhang et al. 2015)

Boreal forests and climate change

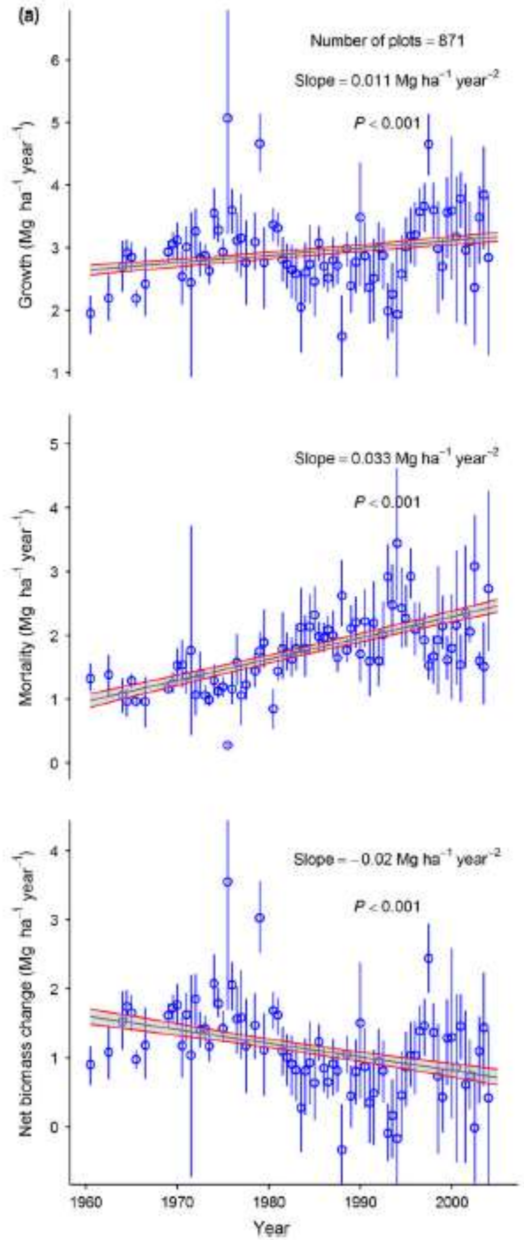


Natural Resources Canada

Chen et al. 2016

Boreal forests and climate change

- Growth trends uncertain (Chen and Luo 2015; Chen et al. 2016; Girardin et al. 2016)
  - Dependent on age, composition, location
- Mortality consistently increasing (Peng et al. 2011; Hember et al. 2017)
- Net biomass change consistently decreasing (Ma et al. 2012; Chen and Luo 2015; Chen et al. 2016)



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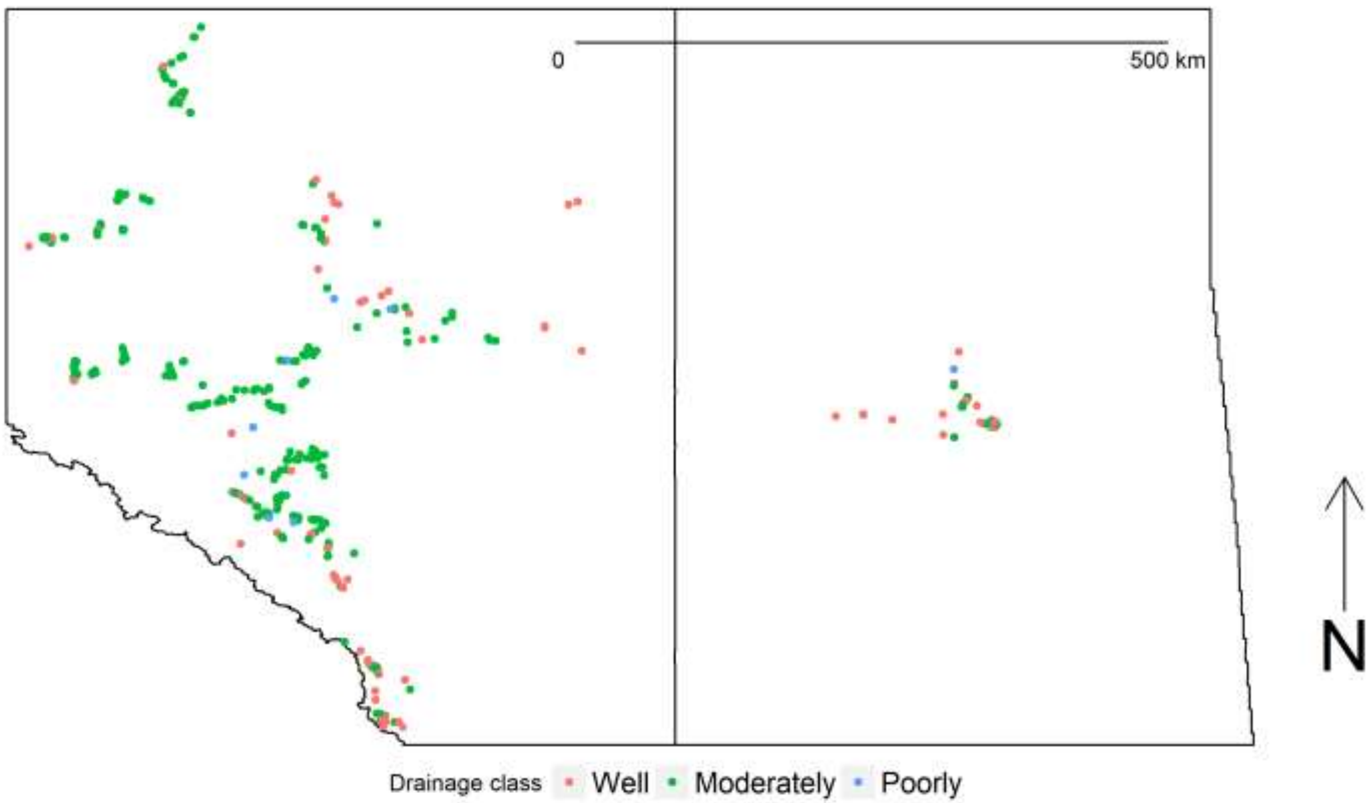
Well-drained sites will have less growth and higher biomass loss from mortality across the study period than sites with higher water retention

Study area

- Permanent sample plot (PSP) network across Saskatchewan and Alberta, Canada

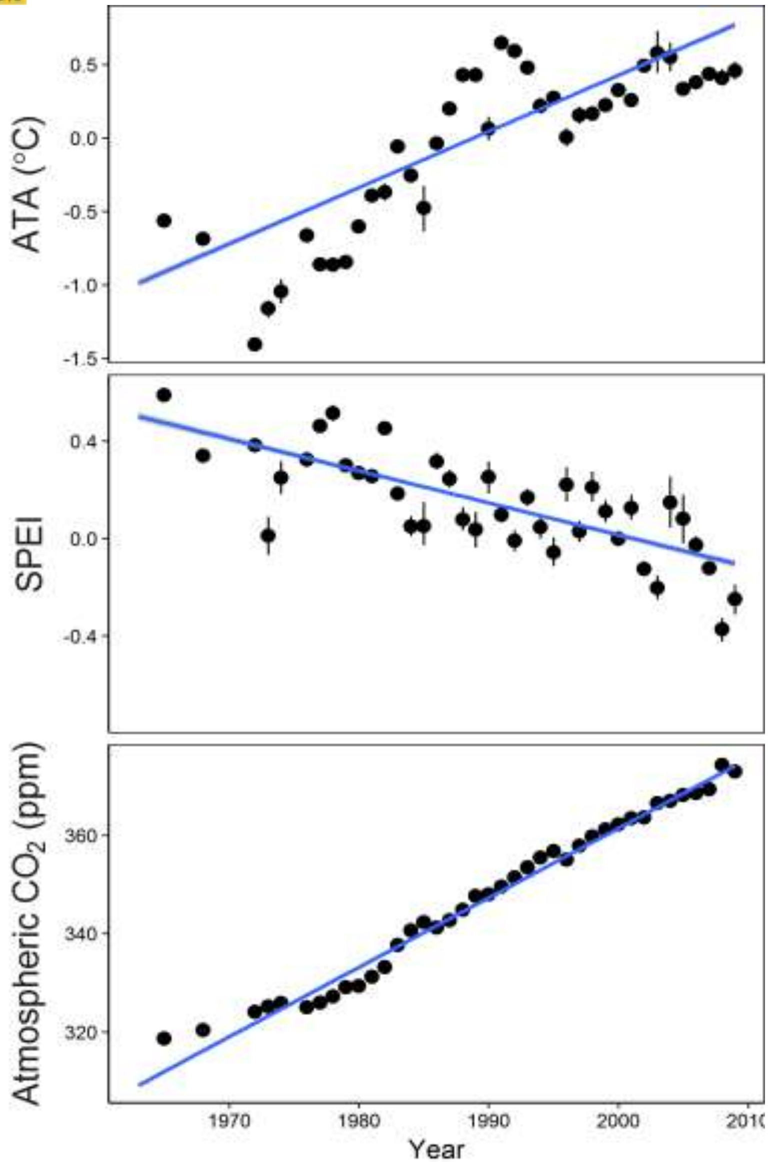
1. Known date of wildfire; unmanaged
2. All trees marked and measured accurately and repeatedly
3. Minimum of three censuses
4. Plot size, soil drainage class, and spatial information available

Study area



Biomass Calculations

- Species specific allometric equations (Lambert 2005)
- Growth: sum of increase in surviving stems and biomass added by recruits divided by census interval
- Mortality: sum of biomass lost due to dead stems divided by census interval
- Net change: Growth minus mortality, or final biomass of census period minus initial biomass divided by census interval
- Relative rates were absolute rates divided by mean standing biomass

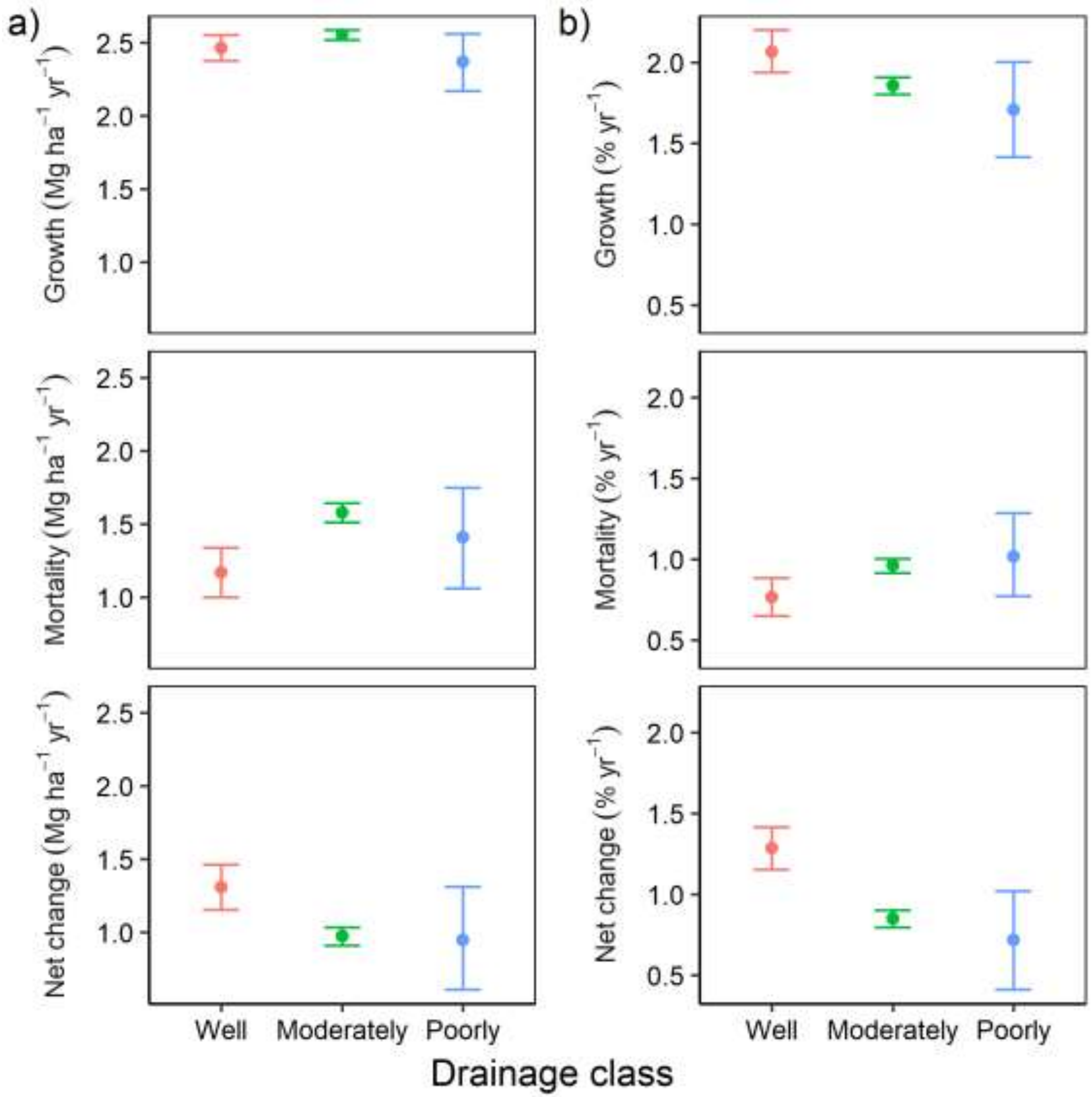


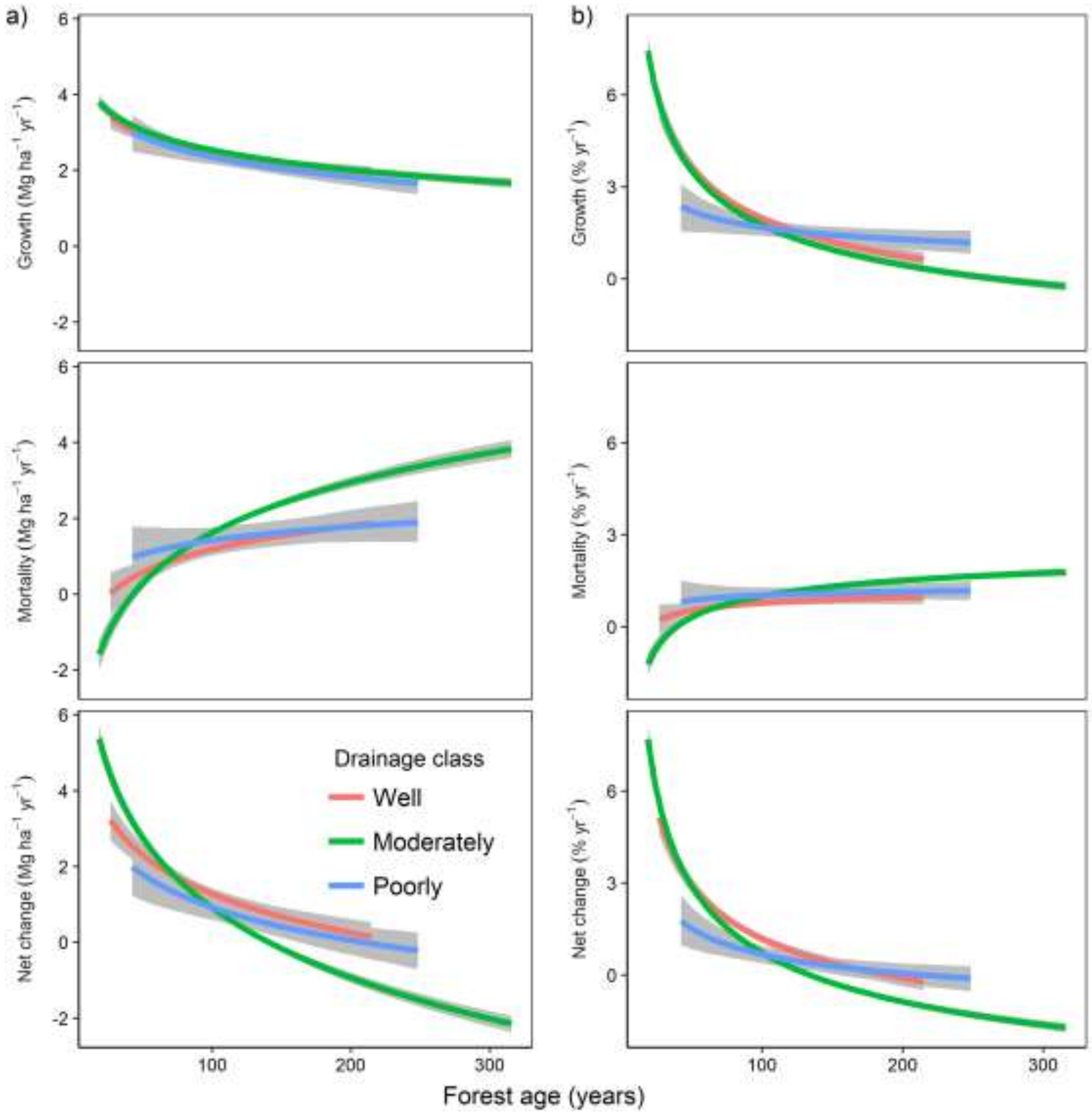
ATA (°C)
0.5
0.0
-0.5
-1.0
-1.5
SPEI
0.4
0.0
-0.4
Atmospheric CO_2 (ppm)
360
340
320
1970
1980
1990
2000
2010
Year

Statistical model

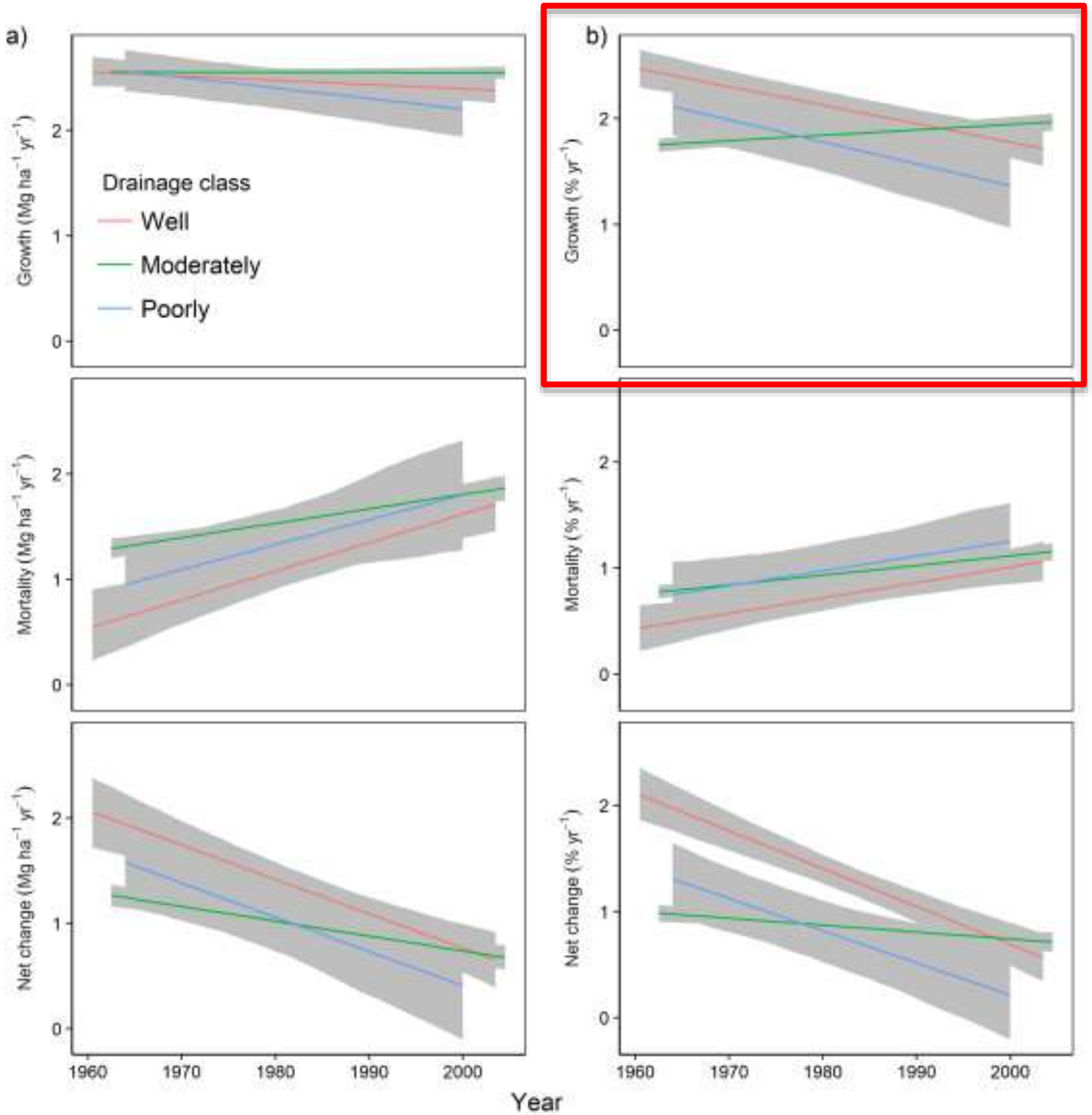
$$\Delta \mathrm{AGB}_{\mathrm{ij}} = \beta_0 + \beta_1 \cdot D_j + \beta_2 \cdot Y_{ij} + \beta_3 \cdot f(A_{ij}) + \beta_4 \cdot D_j \times Y_{ij} + \beta_5 \cdot D_j \times f(A_{ij}) + \beta_6 \cdot Y_{ij} \times f(A_{ij}) + \pi_j$$

- D is the soil drainage class of the plot
- Y is the mid-calendar year
- f(A) is natural logarithm of forest age for absolute ΔAGB models and is the inverse of the natural logarithm of forest age for relative ΔAGB
- π is the random plot error


a)
b)
Growth (Mg ha⁻¹ yr⁻¹)
Mortality (Mg ha⁻¹ yr⁻¹)
Net change (Mg ha⁻¹ yr⁻¹)
Growth (% yr⁻¹)
Mortality (% yr⁻¹)
Net change (% yr⁻¹)
2.5
2.0
1.5
1.0
0.5
Well
Moderately
Poorly
Drainage class



a)
b)
Growth (Mg ha⁻¹ yr⁻¹)
Growth (% yr⁻¹)
Mortality (Mg ha⁻¹ yr⁻¹)
Mortality (% yr⁻¹)
Net change (Mg ha⁻¹ yr⁻¹)
Net change (% yr⁻¹)
Drainage class
Well
Moderately
Poorly
100
200
300
Forest age (years)


a)
b)
Growth (Mg ha^{-1} yr^{-1})
Growth (% yr^{-1})
Mortality (Mg ha^{-1} yr^{-1})
Mortality (% yr^{-1})
Net change (Mg ha^{-1} yr^{-1})
Net change (% yr^{-1})
Drainage class
Well
Moderately
Poorly
0
1
2
1960
1970
1980
1990
2000
Year

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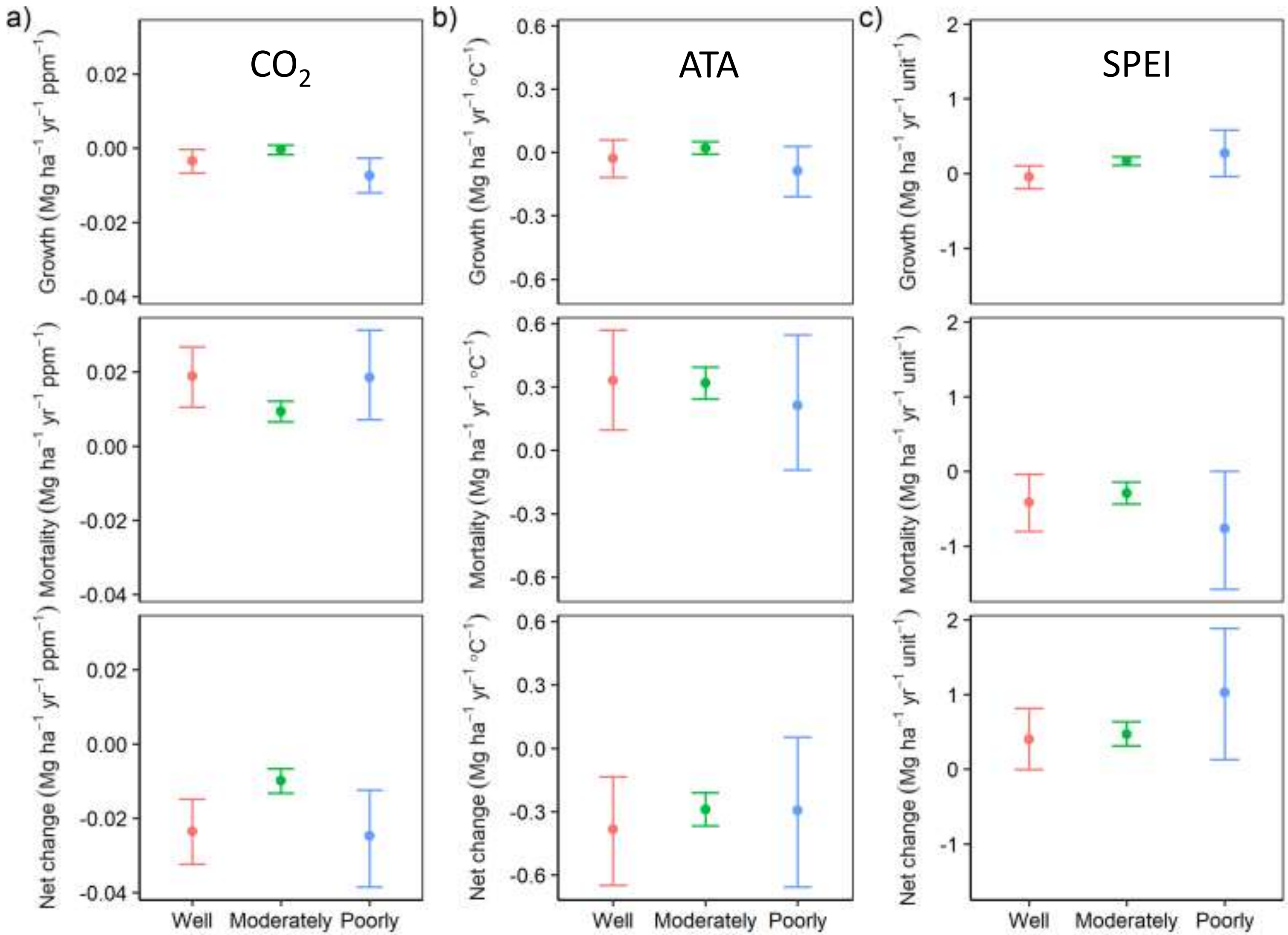

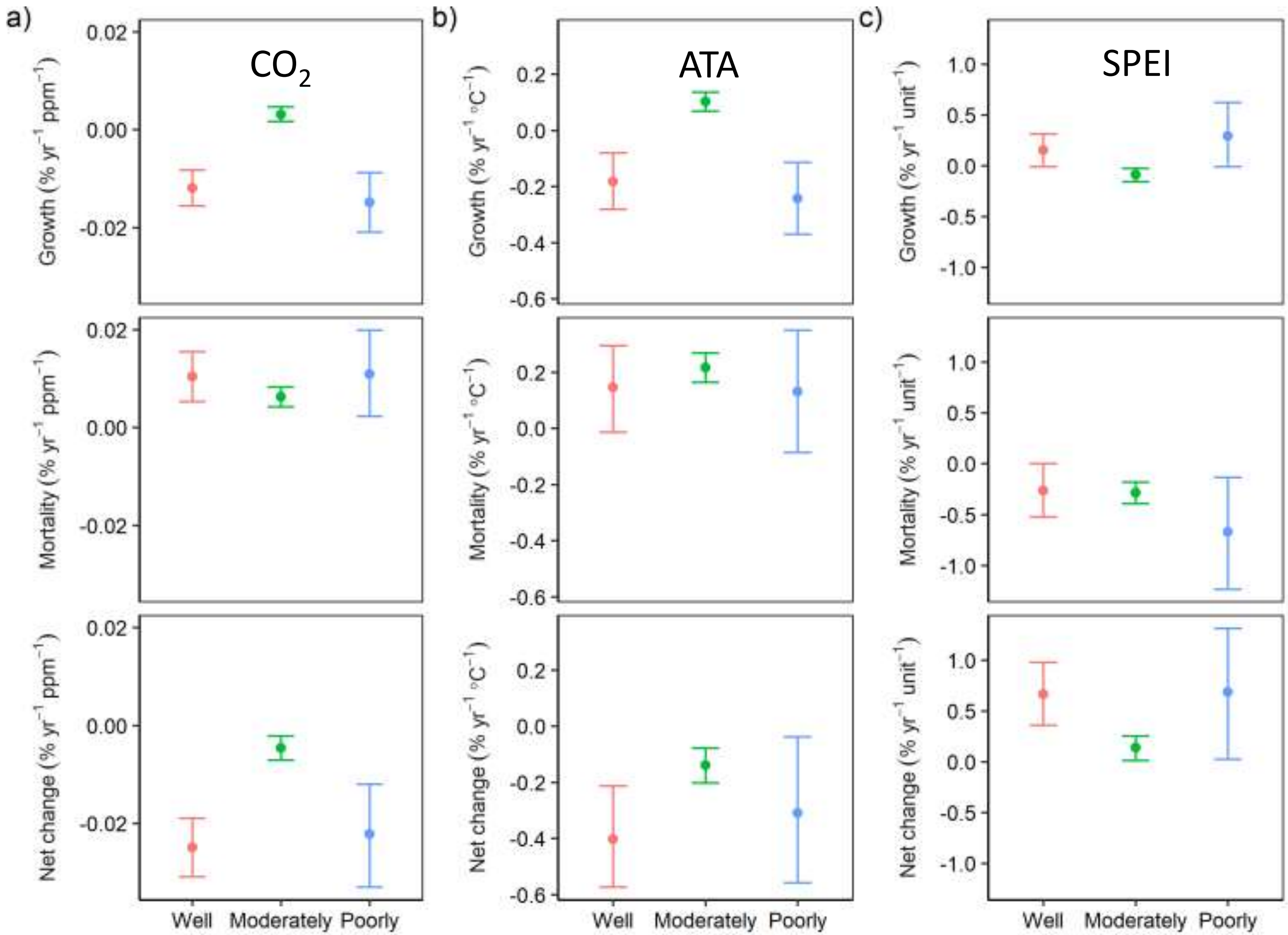
a)
CO_2
b)
ATA
c)
SPEI
Growth (% yr-1 ppm-1)
Mortality (% yr-1 ppm-1)
Net change (% yr-1 ppm-1)
Growth (% yr-1 °C-1)
Mortality (% yr-1 °C-1)
Net change (% yr-1 °C-1)
Growth (% yr-1 unit-1)
Mortality (% yr-1 unit-1)
Net change (% yr-1 unit-1)
Well
Moderately
Poorly

Conclusion

- Why would trends be consistent?
  1. Differences in species composition
  2. Adaptation to local site conditions (irrespective of community composition)
  3. Possibly less sensitive to long-term trends and more sensitive to discrete events (e.g., droughts)

- Differences in relative growth rates are interesting but difficult to discern ecological relevance

Conclusion

- Our results suggest that climate change serves as a top-down control on forest growth, mortality and net biomass change.

- Indicates that the current practise of pooling local drainage effects into a random effect is robust

References

- Allen, C.D., Breshears, D.D., McDowell, N.G., 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere 6, 1-55.
- Brienen, R.J., Phillips, O.L., Feldpausch, T.R., Gloor, E., Baker, T.R., Lloyd, J., Lopez-Gonzalez, G., Monteagudo-Mendoza, A., Malhi, Y., Lewis, S.L., Vasquez Martinez, R., Alexiades, M., Alvarez Davila, E., Alvarez-Loayza, P., Andrade, A., Aragao, L.E., Araujo-Murakami, A., Arets, E.J., Arroyo, L., Aymard, C.G., Banki, O.S., Baraloto, C., Barroso, J., Bonal, D., Boot, R.G., Camargo, J.L., Castilho, C.V., Chama, V., Chao, K.J., Chave, J., Comiskey, J.A., Cornejo Valverde, F., da Costa, L., de Oliveira, E.A., Di Fiore, A., Erwin, T.L., Fauset, S., Forsthofer, M., Galbraith, D.R., Grahame, E.S., Groot, N., Herault, B., Higuchi, N., Honorio Coronado, E.N., Keeling, H., Killeen, T.J., Laurance, W.F., Laurance, S., Licona, J., Magnussen, W.E., Marimon, B.S., Marimon-Junior, B.H., Mendoza, C., Neill, D.A., Nogueira, E.M., Nunez, P., Pallqui Camacho, N.C., Parada, A., Pardo-Molina, G., Peacock, J., Pena-Claros, M., Pickavance, G.C., Pitman, N.C., Poorter, L., Prieto, A., Quesada, C.A., Ramirez, F., Ramirez-Angulo, H., Restrepo, Z., Roopsind, A., Rudas, A., Salomao, R.P., Schwarz, M., Silva, N., Silva-Espejo, J.E., Silveira, M., Stropp, J., Talbot, J., ter Steege, H., Teran-Aguilar, J., Terborgh, J., Thomas-Caesar, R., Toledo, M., Torello-Raventos, M., Umetsu, R.K., van der Heijden, G.M., van der Hout, P., Guimaraes Vieira, I.C., Vieira, S.A., Vilanova, E., Vos, V.A., Zagt, R.J., 2015. Long-term decline of the Amazon carbon sink. Nature 519, 344-348.
- Chen, H.Y., Luo, Y., 2015. Net aboveground biomass declines of four major forest types with forest ageing and climate change in western Canada's boreal forests. Glob Chang Biol 21, 3675-3684.
- Chen, H.Y., Luo, Y., Reich, P.B., Searle, E.B., Biswas, S.R., 2016. Climate change-associated trends in net biomass change are age dependent in western boreal forests of Canada. Ecol Lett 19, 1150-1158.
- Girardin, M.P., Bouriaud, O., Hogg, E.H., Kurz, W., Zimmermann, N.E., Metsaranta, J.M., de Jong, R., Frank, D.C., Esper, J., Buntgen, U., Guo, X.J., Bhatti, J., 2016. No growth stimulation of Canada's boreal forest under half-century of combined warming and CO2 fertilization. Proc Natl Acad Sci U S A 113, E8406-E8414.
- Hember, R.A., Kurz, W.A., Coops, N.C., 2017. Relationships between individual-tree mortality and water-balance variables indicate positive trends in water stress-induced tree mortality across North America. Glob Chang Biol 23, 1691-1710.
- Lambert, M.C., Ung, C.H., Raulier, F., 2005. Canadian national tree aboveground biomass equations. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 35, 1996-2018.
- Luo, Y., Chen, H.Y., 2013. Observations from old forests underestimate climate change effects on tree mortality. Nat Commun 4, 1655.
- Ma, Z., Peng, C., Zhu, Q., Chen, H., Yu, G., Li, W., Zhou, X., Wang, W., Zhang, W., 2012. Regional drought-induced reduction in the biomass carbon sink of Canada's boreal forests. Proc Natl Acad Sci U S A 109, 2423-2427.
- Michaelian, M., Hogg, E.H., Hall, R.J., Arsenault, E., 2011. Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. Global Change Biology 17, 2084-2094.
- van Mantgem, P.J., Stephenson, N.L., Byrne, J.C., Daniels, L.D., Franklin, J.F., Fule, P.Z., Harmon, M.E., Larson, A.J., Smith, J.M., Taylor, A.H., Veblen, T.T., 2009. Widespread increase of tree mortality rates in the western United States. Science 323, 521-524.
- Zhang, J., Huang, S., He, F., 2015. Half-century evidence from western Canada shows forest dynamics are primarily driven by competition followed by climate. Proc Natl Acad Sci U S A 112, 4009-4014.

Questions?

Eric Searle
esearle@lakeheadu.ca