Interannual variation in estimated carbon uptake by western Canadian aspen forests

[1]E.H. (Ted) Hogg, [2]Alan G. Barr & [3]T. Andrew Black

[1]Natural Resources Canada, Canadian Forest Service, Edmonton AB
[2]Environment Canada, Science & Technology Branch, Saskatoon SK
[3]University of British Columbia, Vancouver BC

Background

Trembling (Quaking) Aspen

Populus tremuloides Michx.

- The most widespread tree in North America
- Especially abundant in the western Canadian boreal forest:
  - aspen forest area > 150,000 km^2 total for Canada's boreal plains & taiga plains ecozones
  - estimated 800 million tonnes of carbon stored in aboveground aspen biomass

  source: Canada's National Forest Inventory, https://nfi.nfis.org
- Recent concerns about aspen decline across North America (Worrall et al. 2013)

Poor aspen regeneration after fire & drought near Whitehorse, Yukon (see Hogg & Wein 2005)

Aspen decline caused by tent caterpillars & drought in Ontario & Minnesota (see Worrall et al. 2013)

"Sudden Aspen Decline" following severe drought in SW Colorado (Worrall et al. 2013)

Major causes of aspen decline

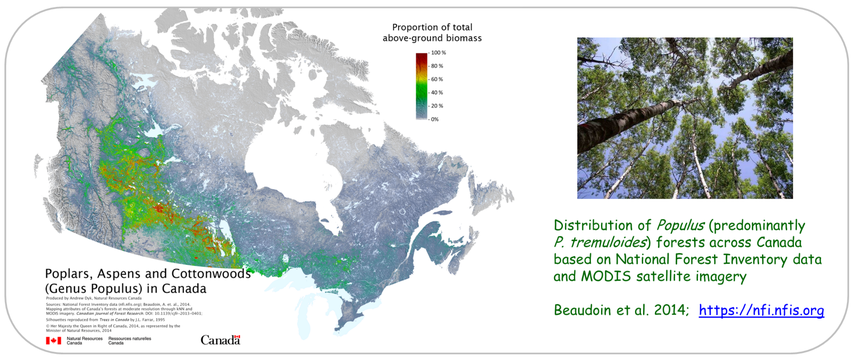
- Severe drought
- Tent caterpillar defoliation
- Spring thaw-freeze events
- Wood-boring insects
- Fungal pathogens

Massive mortality of aspen along the northern edge of the Canadian prairies following severe drought (Michaelian et al. 2011)

Objectives

- Estimate the magnitude of interannual variation in aspen forest NEP* at the regional scale across Canada's western boreal forest.
- Examine the role of drought as a factor driving this variation.

*Note: NEP is Net Ecosystem Production (= annual net carbon uptake)



Distribution of *Populus* (predominantly *P. tremuloides*) forests across Canada based on National Forest Inventory data and MODIS satellite imagery

Beaudoin et al. 2014; https://nfi.nfis.org

References

Barr, A.G., Black, T.A., Hogg, E.H., Kljun, N., Morgenstern, K., and Nesic, Z. 2004. Inter-annual variability in the leaf area index of a boreal aspen-hazelnut forest in relation to net ecosystem production. Agric. For. Meteorol. 126: 237-255.

Barr, A.G., Black, T.A., Hogg, E.H., Griffis, T.J., Morgenstern, K., Kljun, N., Theede, A., and Nesic, Z. 2007. Climatic controls on the carbon and water balances of a boreal aspen forest, 1994-2003. Global Change Biol. 13: 561-576.

Beaudoin, A., Bernier, P.Y., Guindon, L., Villemarie, P., Guo, X.J., Stinson, G., Bergeron, T., Magnussen, S., and Hall, R.J. 2014. Mapping attributes of Canada's forests at moderate resolution through kNN and MODIS imagery. Can. J. For. Res. 44: 1545-1554.

Hogg, E.H., and Michaelian, M. 2015. Factors affecting fall down rates of dead aspen (*Populus tremuloides*) biomass following severe drought in west-central Canada. Global Change Biol. (in press).

Hogg, E.H., and Wein, R.W.. 2005. Impacts of drought on forest growth and regeneration following fire in southwestern Yukon, Canada. Can. J. For. Res. 35: 2141-2150.

Hogg, E.H., Barr, A.G., Black, T.A. 2013. A simple soil moisture index for representing multi-year drought impacts on aspen productivity in the western Canadian Interior. Agric. For. Meteorol. 178-179: 173-182.

Hogg, E.H., Brandt, J.P., and Kochtubajda, B. 2005. Factors affecting interannual variation in growth of western Canadian aspen forests during 1951-2000. Can. J. For. Res. 35: 610-622.

Hogg, E.H., Brandt, J.P., and Michaelian, M. 2008. Impacts of a regional drought on the productivity, dieback and biomass of western Canadian aspen forests. Can. J. For. Res. 38: 1373-1384.

Lambert, M.-C., Ung, C.-H., and Raulier, F. 2005. Canadian national tree aboveground biomass equations. Can. J. For. Res. 35: 1996-2018.

Michaelian, M., Hogg, E.H., Hall, R.J. and Arsenault, E. 2011. Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest. Global Change Biol. 17: 2084-2094.

Worrall, J.J., Rehfeldt, G.E., Hamann, A., Hogg, E.H., Marchetti, S.B., Michaelian, M., and Gray, L.K. 2013. Recent declines of *Populus tremuloides* in North America linked to climate. For. Ecol. Manage. 299:35-51.

Methods

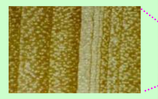
Regional monitoring (CIPHA)

- Collaborative study initiated in 1999
- One of 13 boreal CIPHA sites was co-located near BOREAS/BERMS Old Aspen flux tower
- Includes annual measurements of:
  - aspen stem diameter, height, dieback & mortality
  - defoliation and stem damage by insects & diseases
  - tree-ring widths from disks & cores (2000 & 2012)
- Estimated annual growth increment (g m^{-2} yr^{-1}) (AGI) of aboveground aspen biomass using allometric equations (Lambert et al. 2005)

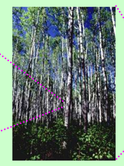
  Further details are given by Hogg et al. (2005, 2008)

CIPHA study: *Climate Impacts on Productivity & Health of Aspen*

Estimation of annual growth increment (AGI) through "scaling up" of tree-rings & plot-based measurements



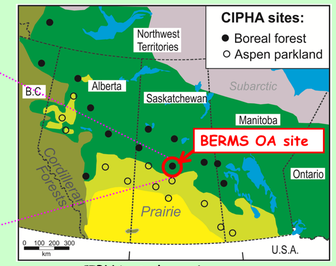
Aspen tree-rings



25-30 trees per plot

2 plots per stand

3 stands per site

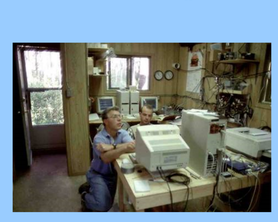


CIPHA study region including 13 boreal sites (78 plots)

Carbon flux measurements (BERMS)

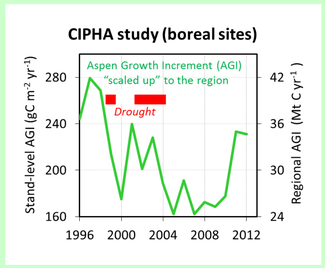
- Initiated during BOREAS & continued under Canadian programs including BERMS (Boreal Ecosystem Research & Monitoring Sites)
- Long, continuous record of above-canopy C fluxes 1996-present, methods given by Barr et al. (2004, 2007)
- Comprehensive environmental monitoring, including soil water content in the tree rooting zone (0 – 1.2 m depth, TDR probes)
- This enabled the calculation of on-site climate indicators including a scalable model of soil moisture (Hogg, Barr & Black 2013)

Tower-based monitoring of CO_2 fluxes (eddy covariance)

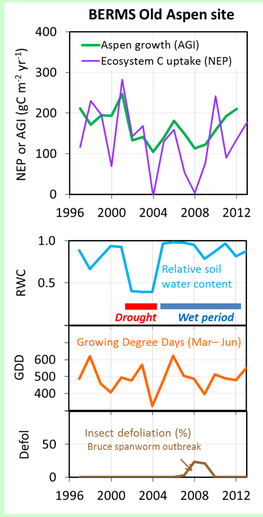


BOREAS/BERMS Old Aspen flux tower

Results & Discussion



- At the regional scale, AGI showed large interannual variation, ranging from 162-279 g C m^{-2} yr^{-1} during 1996-2012.
- Previous studies show that drought is the main climatic factor limiting aspen growth in this region (Hogg et al. 2005)
- Assuming these CIPHA sites represent the region's boreal aspen forests (150,000 km^2 area), an average of 31 Mt C yr^{-1} was sequestered within living aspen stemwood during 1997-2012.
- The total range of interannual variation in stem carbon uptake was 18 Mt C yr^{-1}



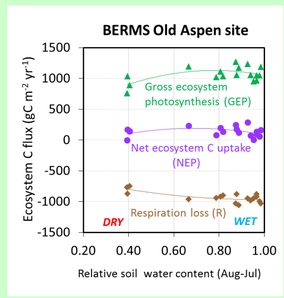
Bruce spanworm www.for.gov.bc.ca

Aspen leaf litter at BERMS OA, 2008

- Tree measurements at 6 CIPHA plots near the BERMS tower site gave mean (± SD) AGI of 166 ± 40 g C m^{-2} yr^{-1} (1997-2012).
- Eddy covariance measurements gave mean (± SD) NEP of 131 ± 82 g C m^{-2} yr^{-1} based on "tree water years" from 1 August – 31 July
- Thus, interannual variation in ecosystem C uptake was twice as large as that of AGI.
- Linear regression showed a significant positive relationship between NEP and AGI: NEP = 1.17 AGI – 64, r^2 = 0.33, P < 0.02
- This suggests that at the regional scale, interannual variation in ecosystem C uptake is greater than the estimated 18 Mt C yr^{-1} variation in aspen stem growth increment.
- Relative soil water content (RWC) was the most important factor affecting AGI whereas spring warmth (GDD) was the main factor affecting NEP.
- The main reason for this is that drought-induced reductions in photosynthesis (GEP) were largely offset by parallel reductions in respiration (R).
- Moderate defoliation (Defol) by bruce spanworm was accompanied by reductions in both NEP and AGI
- Regression analysis showed a significant non-linear response of NEP to relative soil water content, with a tendency for reduced NEP in the wettest years:

NEP = 1571 RWC – 1146 RWC^2 + 0.488 GDD – 4.56 Defol – 569

R^2 = 0.63, P < 0.05 for each of the four regression coefficients



Summary & Conclusions

- Aspen forests are abundant in the western Canadian boreal forest and show large (ca 18 Mt C yr^{-1}) interannual variation in annual growth increment (AGI) of aboveground biomass carbon.
- Recent, severe drought led to strong reductions in AGI but its effects on ecosystem C uptake (NEP) were less evident because 1) both photosynthesis (GEP) and respiration (R) were reduced during periods of low soil moisture; and 2) a tendency for reduced GEP & NEP in the wettest years.
- Further field-based research is needed to support modelling of longer-term drought impacts on forest carbon cycling, including the question of how rapidly carbon is lost following episodes of drought-induced tree mortality and subsequent snag fall down (Hogg & Michaelian 2015).

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Contact: Ted Hogg (ted.hogg@nrcan.gc.ca)