

PERSPECTIVE

Browning boreal forests of western North America

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The GIMMS NDVI dataset has been widely used to document a 'browning trend' in North American boreal forests (Goetz *et al* 2005, Bunn *et al* 2007, Beck and Goetz 2011). However, there has been speculation (Alcaraz-Segura *et al* 2010) that this trend may be an artifact due to processing algorithms rather than an actual decline in vegetation activity. This conclusion was based primarily on the fact that GIMMS NDVI did not capture NDVI recovery within most burned areas in boreal Canada, while another dataset consistently showed post-fire increasing NDVI. I believe that the results of Alcaraz-Segura *et al* (2010) were due simply to different pixel sizes of the two datasets (64 km² versus 1 km² pixels). Similar results have been obtained from tundra areas greening in Alaska, with the results simply due to these pixel size differences (Stow *et al* 2007). Furthermore, recent studies have documented boreal browning trends based on NDVI from other sensors. Beck and Goetz (2011) have shown the boreal browning trend derived from a different sensor (MODIS) to be very similar to the boreal browning trend derived from the GIMMS NDVI dataset for the circumpolar boreal region. Parent and Verbyla (2010) found similar declining NDVI patterns based on NDVI from Landsat sensors and GIMMS NDVI in boreal Alaska. Zhang *et al* (2008) found a similar 'browning trend' in boreal North America based on a production efficiency model using an integrated AVHRR and MODIS dataset.

The declining NDVI trend in areas of boreal North America is consistent with tree-ring studies (D'Arrigo *et al* 2004, McGuire *et al* 2010, Beck *et al* 2011). The decline in tree growth may be due to temperature-induced drought stress (Barber *et al* 2000) caused by higher evaporative demands in a warming climate (Lloyd and Fastie 2002). In a circumpolar boreal study, Lloyd and Bunn (2007) found that a negative relationship between temperature and tree-ring growth occurred more frequently in warmer parts of species' ranges, suggesting that direct temperature stress might be a factor in some species. Since warm growing seasons are also typically dry growing seasons, direct temperature stress and moisture stress could occur simultaneously. For example, 2004 was the warmest summer in over 200 years in boreal Alaska (Barber *et al* 2004) but it was also during a drought with less than 50 mm of summer precipitation recorded in Fairbanks. In Fairbanks, the length of the growing season, as defined as the period above freezing, has increased by 45 per cent over the past 100 years, with no significant increase in precipitation (Wendler and Shulski 2009). Regional winter runoff has increased, likely associated with permafrost thawing (Brabets and Walvoord 2009), while surface water has decreased, likely associated with increased evapotranspiration (Riordan *et al* 2006, Anderson *et al* 2007, Berg *et al* 2009). The mean annual air temperature in boreal Alaska has increased by over 1.5 °C during the past 50 years (Stafford *et al* 2000), and is projected to increase by 3–7 °C by end of this century (Walsh *et al* 2008). Thus, it would be surprising if a declining NDVI trend was not occurring in the western boreal region of North America as the climate continues to warm.

Insects and disease in the North American boreal forest may also affect the NDVI browning trends (Malmström and Raffa 2000), as the life histories of damaging insects may be linked to a warming boreal climate. For example, warmer temperatures contributed to the spruce beetle outbreaks in Alaska with a reduction in the beetle life cycle from two years to one year (Berg *et al* 2006).

Thus, as the boreal climate continues to warm, tree growth reduction and mortality from insects and diseases may become more substantial. In boreal Alaska, recent alder dieback and mortality is likely to be related to alder's susceptibility to a canker-causing fungus in drought years (Ruess *et al* 2009). Recent widespread and prolonged outbreaks of aspen leaf miner and a willow leaf blotch miner in boreal Alaska are likely to have resulted in decreased NDVI (Parent and Verbyla 2010).

The NDVI browning trend has expanded in area in boreal North America (Beck and Goetz 2011). If the trend towards a warmer and drier climate continues, these areas may represent a future tipping point where drought-induced mortality across a boreal region may occur. Such events have already occurred in the western United States (van Mantgem *et al* 2009) and the aspen parklands of the southern Canadian boreal forest (Michaelian *et al* 2010).

References

- Alcaraz-Segura D, Chuvieco E, Epstein H E, Kasischke E S and Trishchenko A 2010 Debating the greening vs. browning of the North American boreal forest: differences between satellite datasets *Glob. Change Biol.* **16** 760–70
- Anderson L, Abbott M B, Finney B P and Burns S J 2007 Late Holocene moisture balance variability in the southwest Yukon Territory, Canada *Quatern. Sci. Rev.* **26** 130–41
- Barber V A, Juday G P and Finney B P 2000 Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress *Nature* **405** 668–73
- Barber V A, Juday G P, Finney B P and Wilkening M 2004 Reconstruction of summer temperatures in interior Alaska from tree-ring proxies: evidence for changing synoptic climate regimes *Clim. Change* **63** 91–120
- Beck P S A and Goetz S J 2011 Satellite observations of high northern latitude vegetation productivity changes between 1982 and 2008: ecological variability and regional differences *Environ. Res. Lett.* **6** 045501
- Beck P S A, Juday G P, Alix C, Barber V A, Winslow S E, Sousa E E, Heiser P, Herriges J D and Goetz S J 2011 Changes in forest productivity across Alaska consistent with biome shift *Ecol. Lett.* **14** 373–9
- Berg E E, Henry J D, Fastie C L, De Volder A D and Matsuoka S M 2006 Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: relationship to summer temperatures and regional differences in disturbance regimes *Forest Ecol. Manag.* **227** 219–32
- Berg E E, Hillman K M, Dial R and DeRuwe A 2009 Recent woody invasion of wetlands on the Kenai Peninsula Lowlands, south-central Alaska: a major regime shift after 18 000 years of wet *Sphagnum*-sedge peat recruitment *Canadian J. Forest Res.* **39** 2033–46
- Brabets T P and Walvoord M A 2009 Trends in streamflow in the Yukon River Basin from 1944 to 2004 and the influence of the Pacific Decadal Oscillation *J. Hydrol.* **371** 108–19
- Bunn A G, Goetz S J, Kimball J S and Zhang K 2007 Northern high-latitude ecosystems respond to climate change *EOS Trans. Am. Geophys. Union* **88** 333–40
- D'Arrigo R, Kaufmann R K, Davi N, Jacoby G C, Laskowski C, Myneni R B and Cherubini P 2004 Thresholds for warming-induced growth decline at elevational tree line in the Yukon Territory, Canada *Glob. Biogeochem. Cycles* **18** GB3021
- Goetz S J, Bunn A G, Fiske G J and Houghton R A 2005 Satellite-observed photosynthetic trends across boreal North America associated with climate and fire disturbance *Proc. Natl Acad. Sci. USA* **102** 13521–5
- Lloyd A H and Bunn A G 2007 Responses of the circumpolar boreal forest to the 20th century climate variability *Environ. Res. Lett.* **2** 045013
- Lloyd A H and Fastie C L 2002 Spatial and temporal variability in the growth and climate response of treeline trees in Alaska *Clim. Change* **52** 481–509
- Malmström C and Raffa K R 2000 Biotic disturbance agents in the boreal forest: considerations for vegetation change models *Glob. Change Biol.* **6** (Suppl. 1) 35–48
- McGuire A D, Ruess R W, Lloyd A, Yarie J, Clein J S and Juday G P 2010 Vulnerability of white spruce tree growth in interior Alaska in response to climate variability: dendrochronological, demographic, and experimental perspectives *Canadian J. Forest Res.* **40** 1197–209
- Michaelian M, Hogg E H, Hall R J and Arseneault E 2011 Massive mortality of aspen following severe drought along the southern edge of the Canadian boreal forest *Glob. Change Biol.* **17** 2084–94
- Parent M B and Verbyla D 2010 The browning of Alaska's boreal forest *Remote Sens.* **2** 2729–47
- Riordan B, Verbyla D and McGuire A D 2006 Shrinking ponds in subarctic Alaska based on 1950–2002 remotely sensed images *J. Geophys. Res.* **111** G04002

- Ruess R W, McFarland J M, Trummer L M and Rohrs-Richey J K 2009 Disease-mediated declines in N-fixation inputs by *Alnus tenuifolia* to early-successional floodplains in interior and south-central Alaska *Ecosystems* **12** 489–502
- Stafford J M, Wendler G and Curtis J 2000 Temperature and precipitation of Alaska: 50 year trend analysis *Theor. Appl. Climatology* **67** 33–44
- Stow D, Peterson A, Hope A, Engstrom R and Coulter L 2007 Greenness trends of Arctic tundra vegetation in the 1990s: comparison of two NDVI data sets from NOAA AVHRR systems *Int. J. Remote Sens.* **28** 4807–22
- van Mantgem P J *et al* 2009 Widespread increase of tree mortality rates in the western United States *Science* **323** 521–4
- Walsh, J E, Chapman W L, Romanovsky V, Christensen J H and Stendel M 2008 Global climate model performance over Alaska and Greenland *J. Clim.* **21** 6156–74
- Wendler G and Shulski M 2009 A century of climate change for Fairbanks, Alaska *Arctic* **62** 295–300
- Zhang K, Kimball J S, Hogg E H, Zhao M, Oechel W C, Cassano J J and Running S W 2008 Satellite-based model detection of recent climate-driven changes in northern high-latitude vegetation productivity *J. Geophys. Res.* **113** G03033