Does forest age and disturbance history affect tree growth, carbon storage, and water usage?

Carbon-water tradeoffs in old-growth and young forests of the Pacific Northwest

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Is there a tradeoff between water usage and carbon storage in Pacific Northwest forests? Do tradeoffs differ between young and mature forests? Forests are important for climate change adaptation and mitigation because of their carbon storage capacities. Land use history and forest age impact productivity, water and nutrient usage, and carbon storage potential. The authors attempt to develop landscape-scale reconstructions and predictions by combining tree growth data with long-term climate and streamflow data. They asked whether tree growth rates and forest variables differ among watersheds in a forest, and how forest history impacts both water use efficiency and which factors predict carbon-water tradeoffs.

How did basal area growth change over time?

- The average basal growth for trees in the old-growth watershed increased steadily from the 1850s to the 1900s and again to the 2010s and into the present, while in the planted watersheds the average basal area growth decreased after the 2010s.
- However, during the period 2005-2015 trees grew slightly more in the young thinned forest than in the old growth forest while the young unthinned forest had the least growth per year.

How did environmental variables change over time? Was basal area growth related to environmental variables?

- Over the study period air temperature increased, especially during midwinter and summer. Summer precipitation decreased, but annual precipitation showed no significant trends.
- In general, the annual basal area and ring width indices were not related to annual temperature or annual precipitation. There was a weak relationship between basal area and precipitation in WS06.
- Basal area growth rate was not related to streamflow or evapotranspiration during summer. However, since 2010 young forests had lower summer streamflow and ~2 times higher evapotranspiration than the old-growth forest and basal area growth declined in the unthinned young forest.

Was tree growth associated with water use? Did this differ between young and mature forests?

- At the tree level, higher basal area growth was associated with higher water use. At the stand level, basal area growth was positively related to evapotranspiration in the young forests, but not in the old-growth forest.
- The mature forest had greater water use efficiency than the young forests. Stand-level basal area growth per unit of evapotranspiration was nearly 5 times higher in the old-growth forest than in the young forests.

Did remotely sensed data capture carbon storage differences among watersheds with different forest ages and disturbance histories?

- Greenness and wetness indices were not related to basal area growth, summer moisture, precipitation, temperature, or streamflow.
- Both greenness and wetness were lower in young forests than in mature forest before canopy closure. After canopy closure greenness and wetness were higher in young forests than in mature forest.
- Remotely sensed analyses did not capture the differences in carbon uptake among forests with different land use histories. Field measurements are needed to complement estimates of carbon stocks from remotely-sensed data.

Which factors affected streamflow?

- Precipitation was strongly positively related to streamflow. Forest history and basal area growth also helped explain variation in streamflow among years. Greenness and wetness indices from remotely sensed data did not explain variation in streamflow.

Did soil chemistry differ among forests? What is the significance of this?

- Soil C, N, and C:N were not significantly different among watersheds at any of the 3 depths sampled, indicating that soil chemistry is resilient to the infrequent forest disturbances related to both wildfire and logging.

Research Approach/Methods

- The researchers sampled in three small watersheds in the western Oregon cascades. Two were previously logged; WS06 had 45-year-old planted forest and WS07 had 35 to 45-year-old planted and thinned forest. The third, WS08, was old growth with most trees ~170 years old and some aged ~500 years.
- They collected daily air temperature and precipitation from a nearby meteorological station and assembled mean daily streamflow for 1963 to 2017. They then calculated monthly and annual unit area streamflow and evapotranspiration for each watershed.
- The researchers sampled individual trees in each watershed. In WS08 they sampled in 1000 m^2 plots at ~5-year intervals since 1979 and in WS06 and WS07 they sampled in 250 m^2 plots at 6-year intervals since 2002.
- They sampled five healthy dominant living trees along each of three 100-m transects in each watershed for a total of 45 trees. They collected an increment core and measured diameter at 1.5m above ground. The researchers processed, digitally scanned the cores, and measured ring widths.
- The authors calculated an annual ring width index and basal area increment for each tree each year. They also used basal area and canopy height to calculate standing biomass when lidar-derived canopy height data was available.
- The researchers sampled soil carbon and nitrogen in three depth bins at three locations on each transect. They also estimated stand level ecosystem structure and leaf area index for each location on each sample date.

- The authors calculated canopy height profiles for each watershed using lidar data from 2008. They calculated a greenness index for forest productivity and a wetness index for canopy water status for years 1984 to 2017 by processing surface reflectance imagery through Google Earth Engine.
- They used bivariate correlations to investigate relationships between the forest variables: tree basal area, greenness, wetness, soil C, and soil N and the environmental variables: evapotranspiration, streamflow, air temperature, and precipitation.
- They authors used least-squares regressions to investigate trends in tree growth and climate. They used mixed-effects models to relate water yield to precipitation, mean temperature, basal area growth, canopy wetness and greenness, and forest history. They used two-way ANOVA to investigate differences in C, N, and C:N by watershed and soil depth.

Keywords Carbon-water tradeoffs, carbon storage, water use efficiency, basal area index, forest productivity, evapotranspiration, dry-season streamflow

Images

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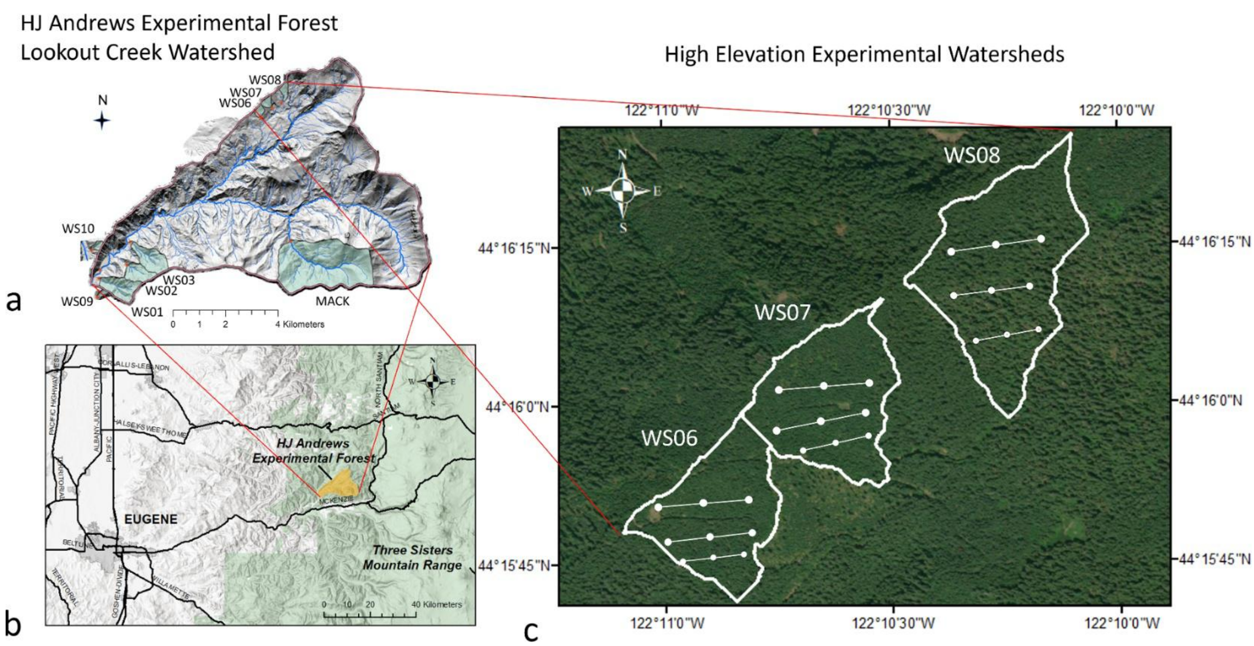

Figure 1 in Farinacci et al. 2024. Location of (a) the H.J. Andrews Experimental Forest, (b) relative to Eugene, Oregon, and (c) sampling transects in WS06, WS07, and WS08. Source of map in Panel (a): Adapted from *andrewsforest.oregonstate.edu*.

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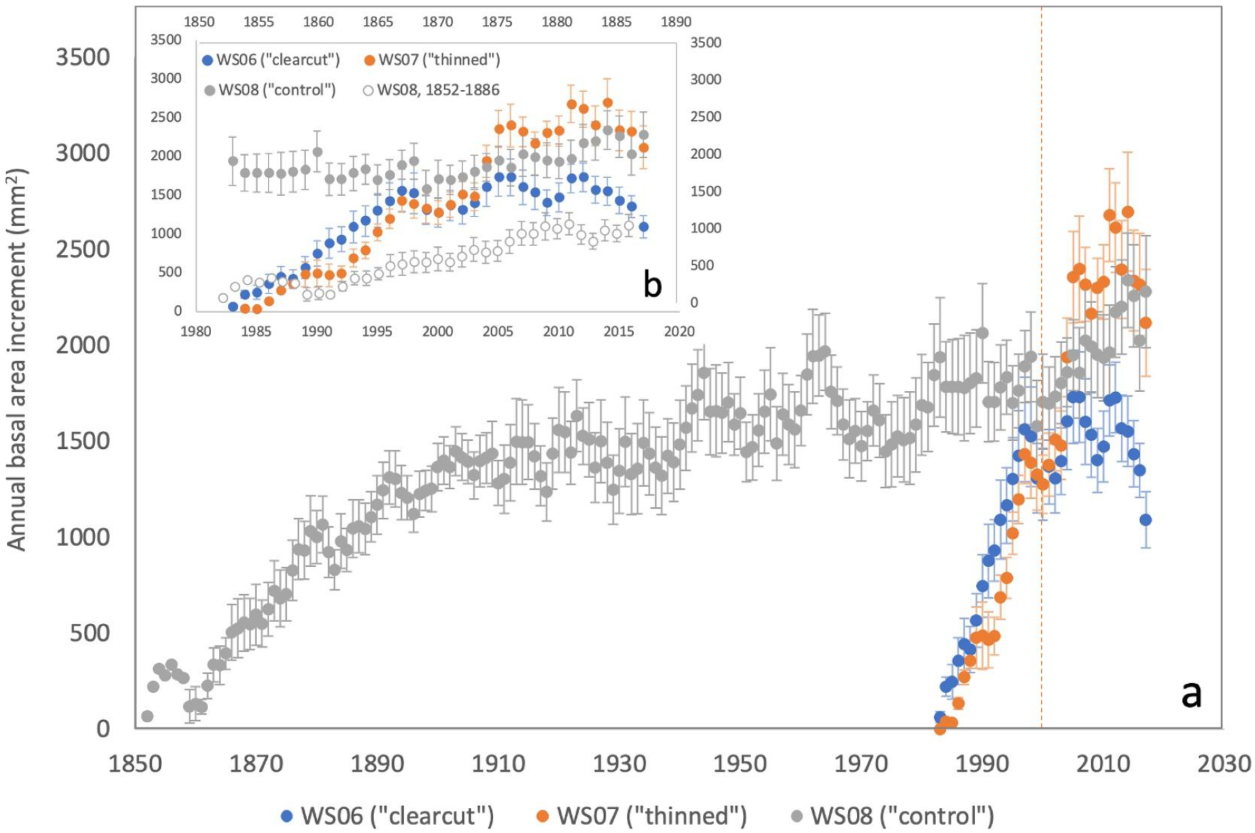

Figure 3 in Farinacci et al. 2024. Average and standard error of annual basal area increment (BAI) of dominant Douglas‐fir trees (*n* = 15 per watershed) for (a) 1852 to 2017 in WS06 (100% clear‐cut in 1974 and planted), WS07 (50% shelterwood cut in 1974, partly planted, remaining overstory removed 1984, thinned in 2001), and WS08 (mature and old‐growth forest regenerated after fires in the early 1800s). Inset (b) annual BAI for the first 25 years after the earliest tree establishment date, 1980 to 2017 in WS06, WS07, and WS08, compared to 1850 to 1887 in WS08. Earliest tree establishment dates were 1983 for WS06, 1984 for WS07, and 1852 for WS08.

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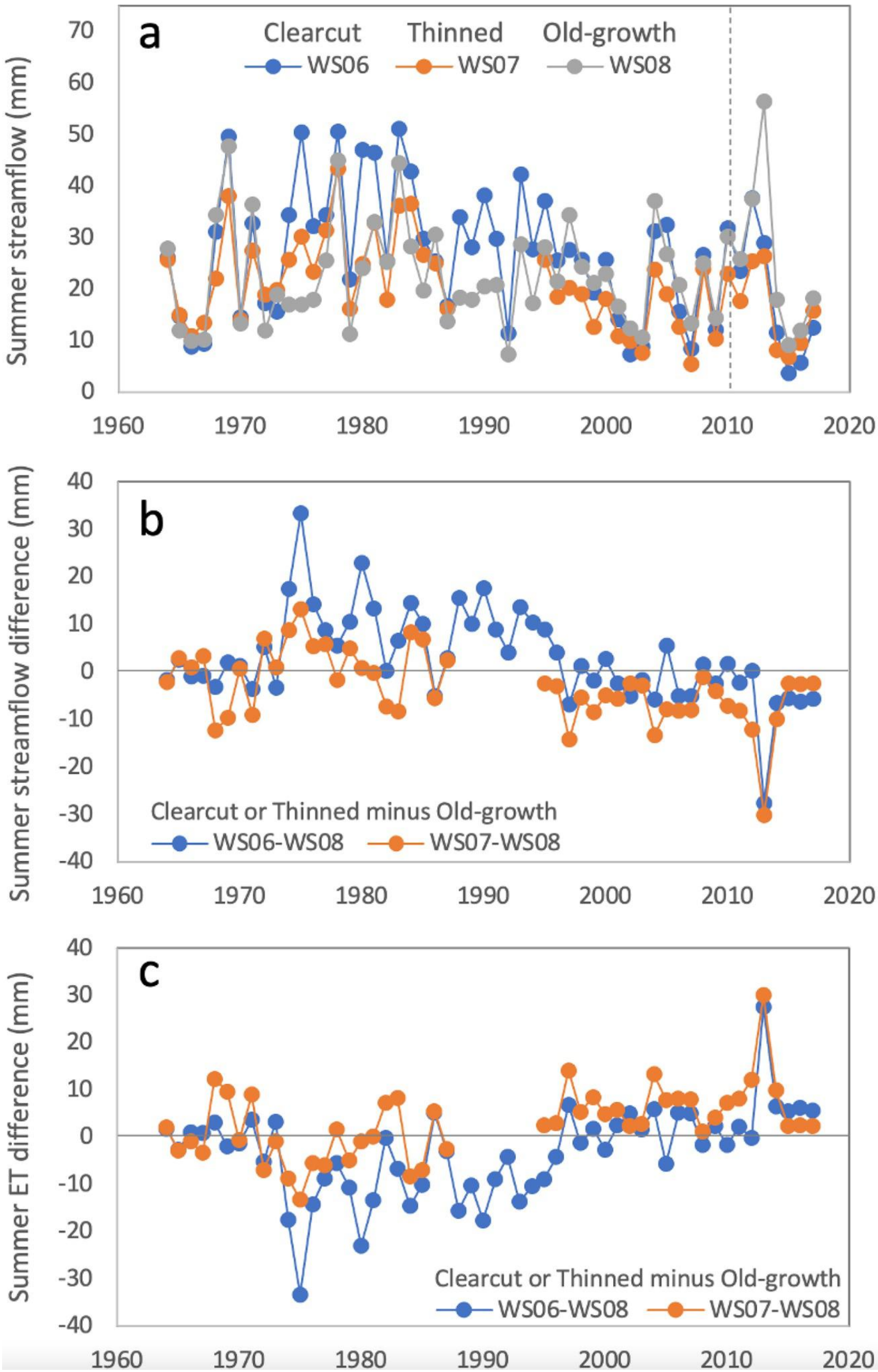

a
Clearcut
Thinned
Old-growth
WS06
WS07
WS08
Summer streamflow (mm)
70
60
50
40
30
20
10
0
1960
1970
1980
1990
2000
2010
2020
b
Summer streamflow difference (mm)
40
30
20
10
0
-10
-20
-30
-40
Clearcut or Thinned minus Old-growth
WS06-WS08
WS07-WS08
c
Summer ET difference (mm)
Clearcut or Thinned minus Old-growth
WS06-WS08
WS07-WS08

Figure 4 in Farinacci et al. 2024. Watershed scale hydrological measurements: (a) summer streamflow, July ‐ September, showing higher streamflow in the young forest watersheds (WS06, WS07) compared to the mature/old ‐ growth forest watershed (WS08) in the mid ‐ 1970s to mid 1990s, when trees in WS06 and WS07 were aged 0‐20 years, followed by lower streamflow in WS06 and WS08 than in WS08, especially after 2010; (b) summer streamflow differences (treated minus control) showing a major decline in ecosystem water supply over time in young forest (WS06, WS07) relative to old forest (WS08); and (c) summer evapotranspiration differences (treated minus control) showing a major increase in ecosystem water use over time in young forest (WS06, WS07) relative to old forest (WS08).

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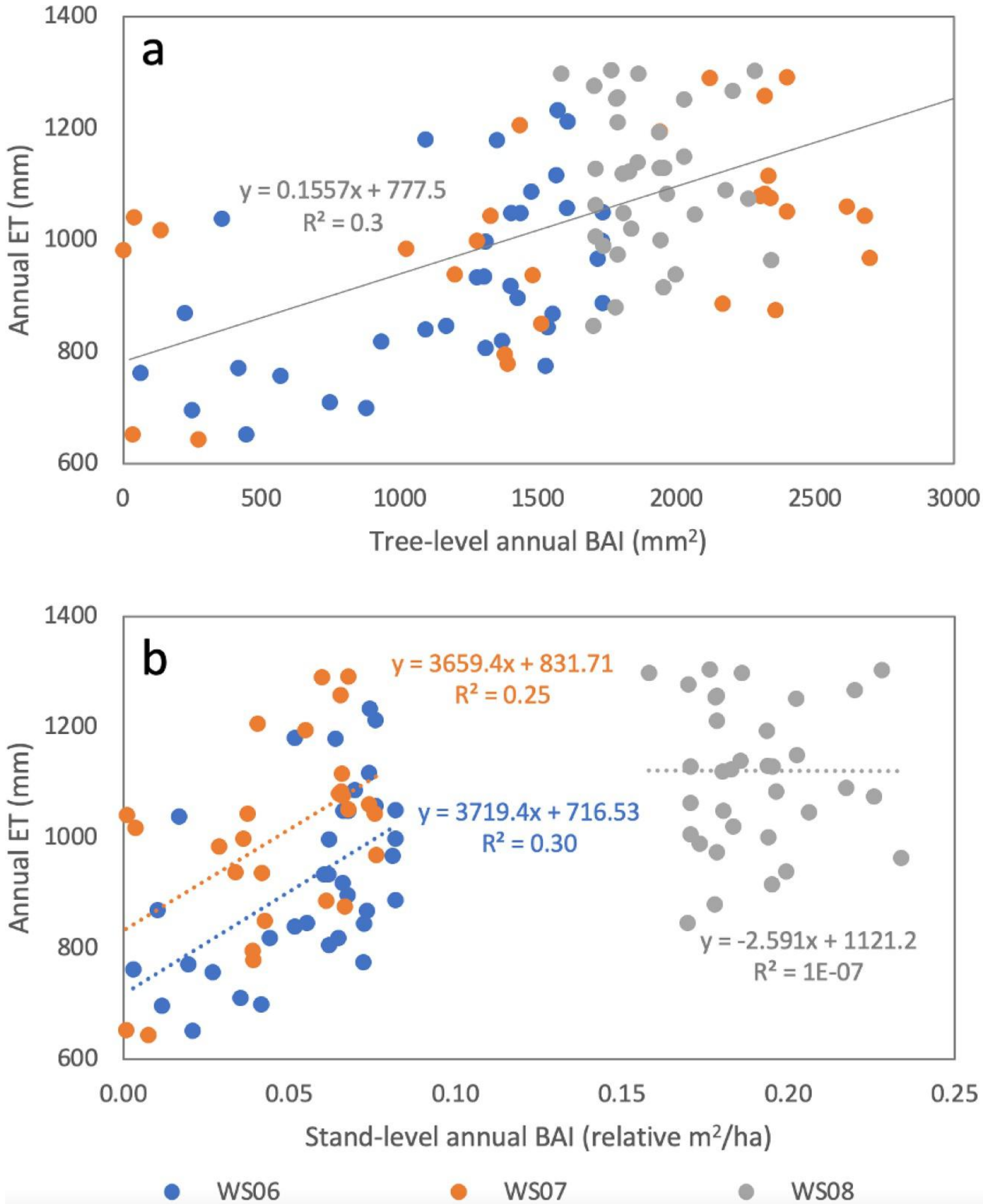

Figure 5 in Farinacci et al. 2024. Relationship between annual evapotranspiration and tree basal area increment (BAI) of dominant Douglas‐fir trees, 1983‐2017. (a) Average annual tree‐level BAI (*n* = 15 trees per watershed, Figure 3) versus annual evapotranspiration and (b) average annual stand‐level BAI versus annual evapotranspiration. Relative BAI per hectare is determined by rescaling average annual tree‐level values based on 2008 relative basal area (Table 1), WS08 = 1, WS06 = 0.47, WS07 = 0.28 (Figure 1).