Can forest primary productivity be predicted from leaf area and topography?

Thirty years of forest productivity in a mountainous landscape: The Yin and Yang of topography

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Can local-scale data be used to improve models of forest carbon storage, as measured by primary production? Do later-stage variables impact the amount of carbon stored in a forest? Forests are carbon sinks and regulate global climate. Understanding changes in carbon cycles after forest disturbance and recovery will improve predictive carbon sink models. The authors tested whether aboveground net primary productivity can be predicted by initial leaf area and topography and whether including later mortality and foliar nutrients measurements improved models. They also determined whether mortality impacted productivity in stands with different planting densities and whether light use efficiency and foliar nitrogen were related.

What was the primary productivity measured? Which variables impacted forest productivity? Did impacts extend over the entire course of the study?

- Above ground net primary productivity averaged 8.29 Mg ha^{-1} yr^{-1} and ranged from 2.9 to 13.5 Mg ha^{-1} yr^{-1}. It was positively associated with irradiation, aspect, and initial post-thinning leaf area and negatively associated with soil nitrogen.
- Above ground net primary productivity over the 30-year study was positively related to the initial leaf area for leaf areas up to about 4 m^2 m^{-2} and plateaued at higher initial leaf areas.
- Biomass increased over the 30 years of the study, with a nearly linear relationship between biomass and time. Leaf area increased over the first 20 years and plateaued for the final 10 years of the study period.

Did initial stand density impact forest productivity? What about pruning or fertilization treatments?

- Above ground net primary productivity varied significantly with thinning level, but not with subtreatment. However, high density plots may not have higher long-term productivity, especially if system resilience cannot balance mortality.

How did the amount of light available impact primary productivity?

- Plots in sunlit and shaded areas had different levels of 30-year above ground primary productivity. The authors split plots into high and low irradiation groups using bootstrapping to identify the boundary level as 3434 MJ m^{-2}.
- High irradiation plots averaged 40% higher primary productivity than low irradiation plots over the 30 years, a highly significant difference. Two foliar nutrients differed significantly between plot types: calcium was higher and potassium lower in low irradiation sites. Soil potassium was elevated slightly at high irradiation sites.

Where the models significant? Which variables produced the strongest models? What additional information was gained from residual analysis?

- The four general linear models of 30-year primary productivity versus initial leaf area and either irradiation or aspect all produced statistically significant results with little difference in predictive ability or Akaike information criterion. In all models, initial leaf area was highly significant and the strongest models included an irradiation step function or aspect.
- Analysis of residuals showed that above ground primary productivity on sunlit plots was negatively correlated with the foliar N/Ca and slope steepness. Foliar N/Ca was negatively correlated with shrub and fern cover. On shaded plots, productivity was positively correlated with foliar magnesium and medium height understory, and negatively correlated with the interaction between thinning level and tree mortality.

Were there differences in light use efficiency among plot types? Was light use efficiency associated with foliar nutrient levels?

- Within a light group, there was not much difference among thinning levels in light use efficiency of a given area. Between light groups, the light use efficiency of a given area differed only for moderately thinned plots.
- Light used efficiency was significantly positively correlated with foliar nitrogen to potassium, but not with foliar nitrogen.

Did light availability and thinning level impact the effects of mortality on productivity or the accumulation of biomass?

- Irradiation and thinning level impacted the effect of mortality on primary productivity. In unthinned sunlit plots, productivity decreased markedly above 40% mortality. In unthinned shaded plots productivity increased with mortality up to 75% but at higher mortality levels productivity dropped sharply.
- Mean tree biomass was lower in shady plots than in sunlit plots at any given stocking density with all thinning levels included. Trees on thinned shaded plots did not build enough leaf area to compensate for low light.

Research Approach/Methods

- The study was located on four plantations in a Cascade Range experimental forest. Researchers used a split-plot design with randomly located main plots with heavy, moderate, or no thinning. They randomly located subplots of four treatments within each main plot: pruning, fertilization, fertilization and pruning, and control.
- Within each subtreatment, the researchers placed a measurement plot for data collection, which were buffered from adjacent treatments. Plot size was determined by tree number, with a goal of 50 trees.
- The authors periodically measured tree diameter and calculated aboveground biomass, foliar biomass, and gross primary productivity. They also calculated absorbed photosynthetic irradiation (APAR) using leaf area index and used mean APAR to calculate light use efficiency.
- In each measurement plot the researchers also determined aspect, analyzed soils for macronutrients, pH, rockiness, and anaerobic mineralizable N (AN), used AN to estimate microbial biomass, analyzed midcrown branches to sample foliage nutrients, and estimated understory vegetation cover.

- The authors calculated solar radiation over the April 1 to October 31 growing season for each subplot using a LiDAR-derived ground surface elevation model and a hemispherical viewshed algorithm. They then calculated direct and indirect radiation with the ESRI ArcMap Solar Radiation tool, with 62% cloud cover, and assuming 50% photosynthetically active radiation.
- To analyze main plot and subplot effects on aboveground net primary productivity, the authors used a general linear model excluding covariates, which had highly nonlinear relationships with primary production. To identify explanatory variables, the authors used R packages and to quantify values of important explanatory variables they used bootstrapped regression trees.

Keywords carbon, irradiation, light-use efficiency, LTER, mortality, mountains, plantations, thinning, thresholds, topography

Images

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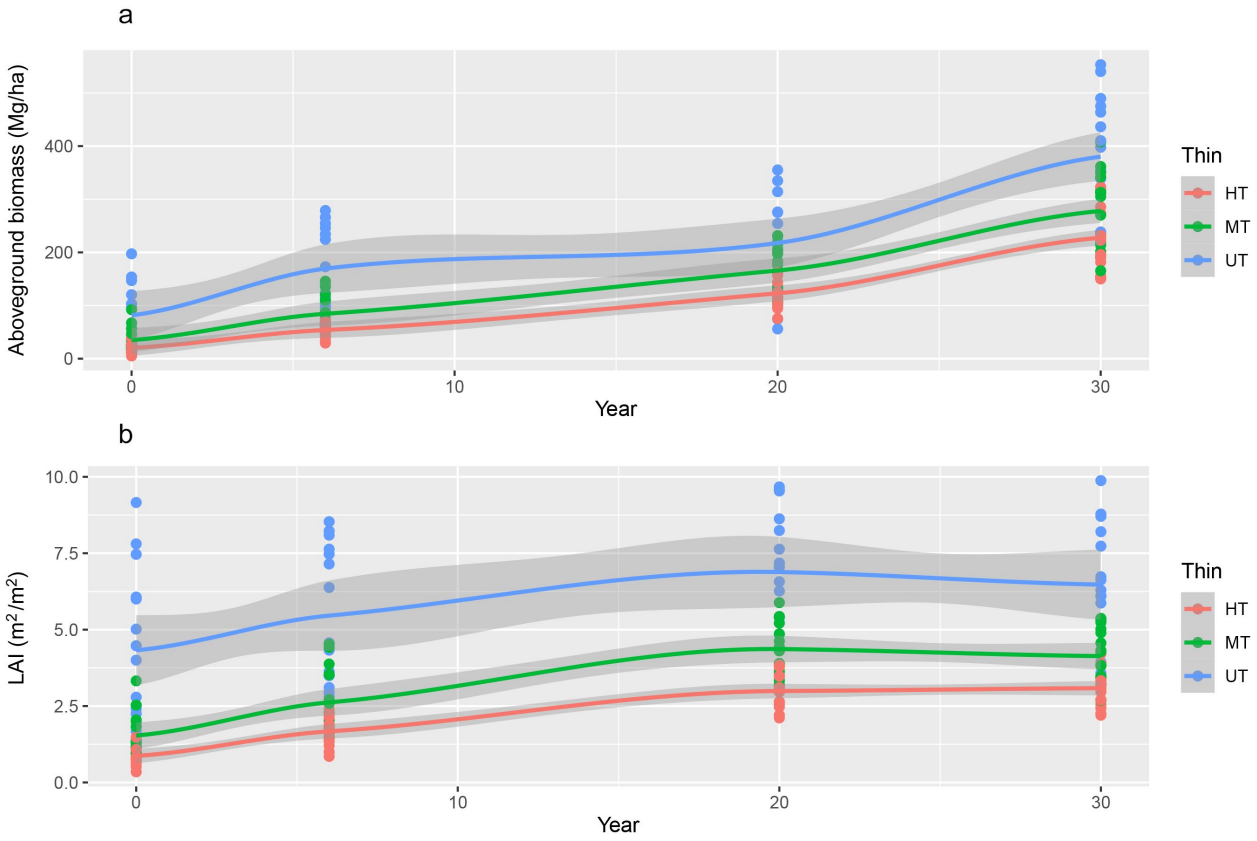

Figure 3 in Perry and Oetter 2024. (a) Change over time in aboveground biomass and (b) change over time in LAI, by thinning level (HT, heavy thinning; MT, moderate thinning; UT, no thinning). Shaded areas represent 95% CIs. Year 0 = 1981 post thinning. See text for 1981 post-thinning densities.

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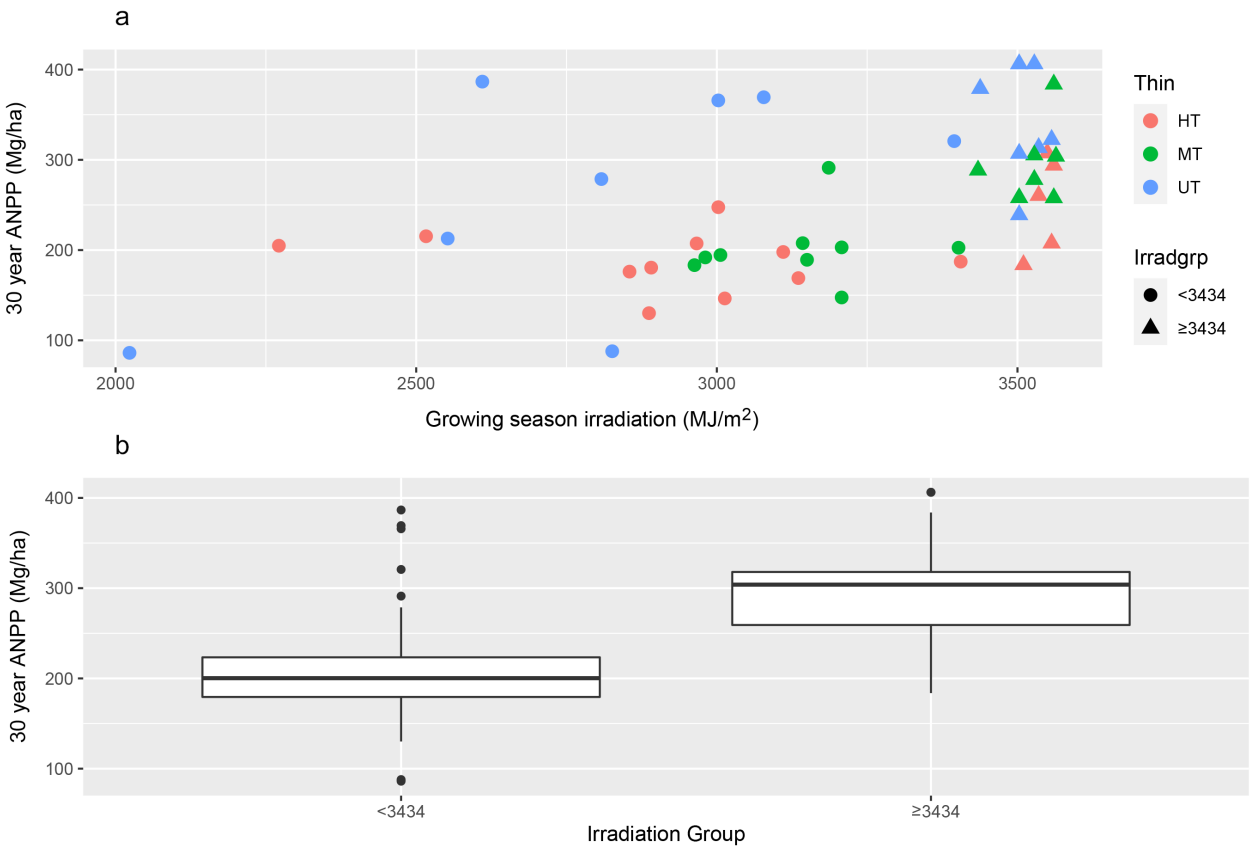

Figure 4 in Perry and Oetter 2024. (a) The relation between growing season irradiation and 30-year aboveground net primary productivity (ANPP), by thinning level (HT, heavy thinning; MT, moderate thinning; UT, unthinned). (b) Boxplot comparing 30-year ANPP between irradiation groups. The height of the box shows the interquartile range (IQR), which is the middle 50% of the data. The midline is the median, where the position of the median line shows skewness; if in the middle of the box there is no skew, while above (below) the middle denotes a left (right) skew. The whiskers show the range of plots 1.5 above or below the IQR. Points outside the whiskers are outliers. Comparing the upper and lower graphs, note that outliers are unthinned plots. The irradiation groups differ at p = 0.000 (t test). See text for 1981 post-thinning densities.

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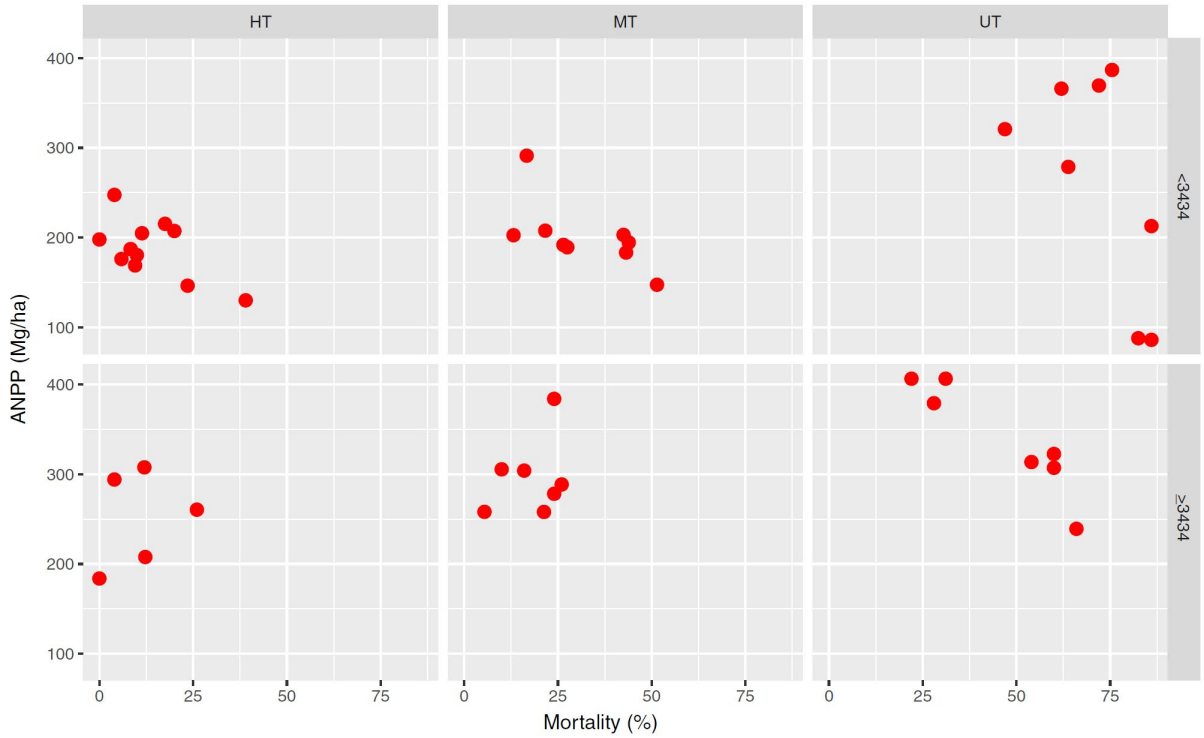

Figure 9 in Perry and Oetter 2024. The relation between 30-year mortality and 30-year aboveground net primary productivity (ANPP), by irradiation and thinning level (HT, heavy thinning; MT, moderate thinning; UT, unthinned).

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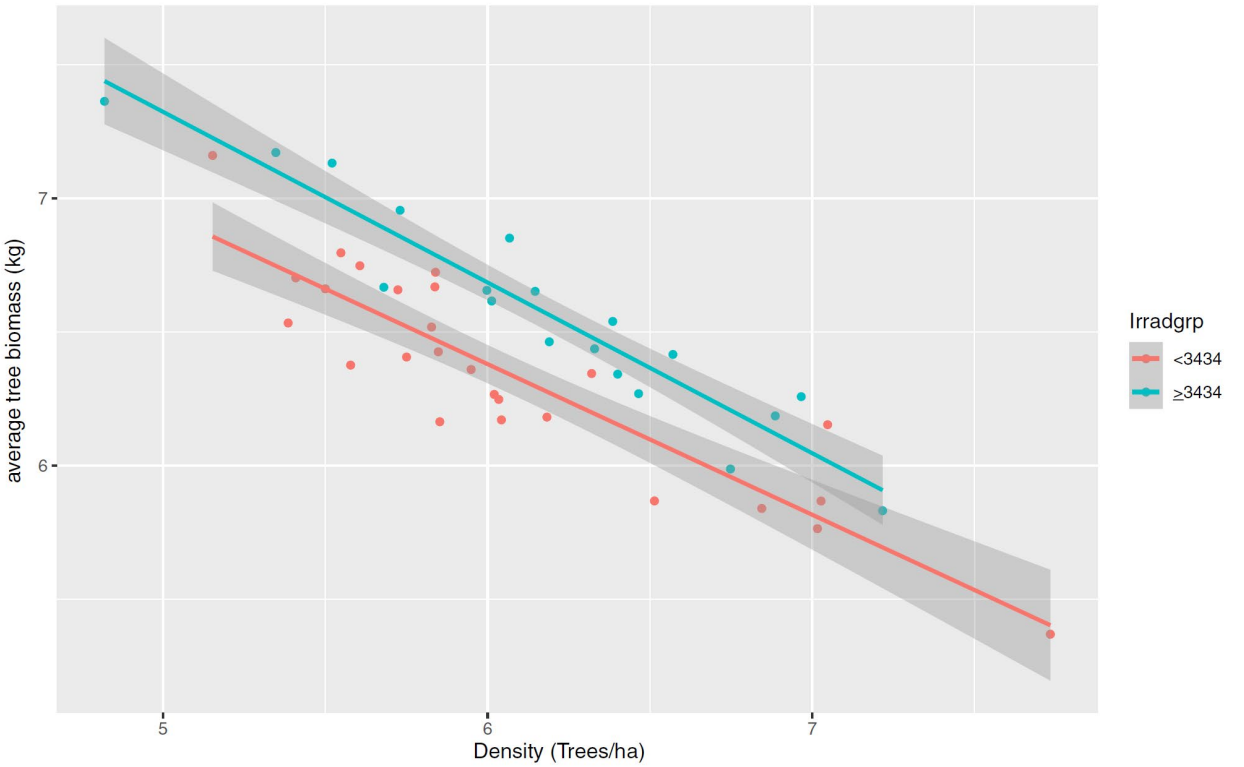

Figure 10 in Perry and Oetter 2024. Log–log plot of mean tree biomass (aboveground) versus stocking density in 2010, by irradiation level. All thinning levels are included, excluding two plots with catastrophic mortality. Gray bands are 95% confidence intervals. High irradiation: adjusted r 2 = 0.89, SE = 0.13, F = 193.0; low irradiation: r 2 = 0.80, SE = 0.17, F = 99.8. From the Chow test, the null hypothesis that the two curves describe the same population is rejected (F = 13.9, p = 0.002).