Critique of Laufenberg Paper

Stat 512: Rough Draft of Final Project

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Friday, April 14, 2023

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0.1 Introduction

Whitebark pine (*Pinus albicaulis* Engelm.) is a conifer tree native to the mountains of the western United States and Canada. It inhabits subalpine areas where it can be found growing up to the tree line, at a higher elevation than other tree species found with it.

Whitebark pine ~~(WBP)~~ is an early successional species that is often the first to establish after disturbance such as wildfire. WPB is a keystone species of subalpine environments where it plays important ecological roles such as providing food for wildlife such as Clark's Nutcracker and the threatened Grizzly Bear.

Due to threats from climate change, mountain pine beetle, and the invasive white pine blister rust, Whitebark pine has undergone a rapid and widespread decline. It was recently estimated that over half of all standing WBP in the United States are dead. This decline has lead to its recent listing as Threatened under the Endangered Species Act. Future climate projections indicate further deterioration of WBP's habitat.

Strategies to conserve this species involve planting WBP seedlings for restoration of high-elevation forests. Successful plantings in the face of climate change require an understanding of the relationship between climate and seedling establishment and growth in this species. Competition from other tree species also plays a role in seedling establishment and was investigated here.

This study investigated USFS plantings of WBP seedlings in the Greater Yellowstone Ecosystem (GYE) to ~~answer~~ two research questions:

1) What is the relationship between climate/competition and WBP seedling establishment, measured by individual growth rate?

2) What is the relationship between climate/competition and WBP seedling survival, measured by density change?

We are interested here in the first question relating to seedling growth rate.

0.2 Methods

0.2.1 Field Methods/Study design

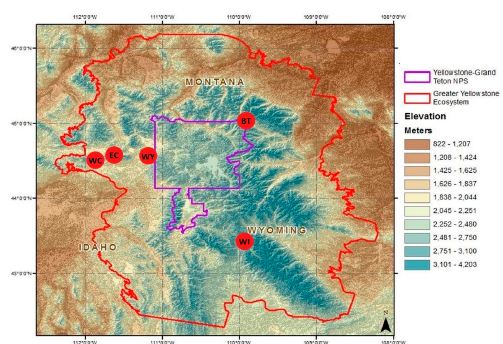


Figure 1: Map of planting units included in study in the Greater Yellowstone Ecosystem

Over the past 40 years, the US Forest Service and National Park Service has planted more than 1500 acres of WBP in the GYE. This study investigated five planting units (figure

1) that each contained between two and eight planting sites.

This study used a hierarchical sampling design including 5 planting units, with a total of 29 planting sites across units, and thousands of white bark pine seedlings per planting site. (See figure 2 for model design.)

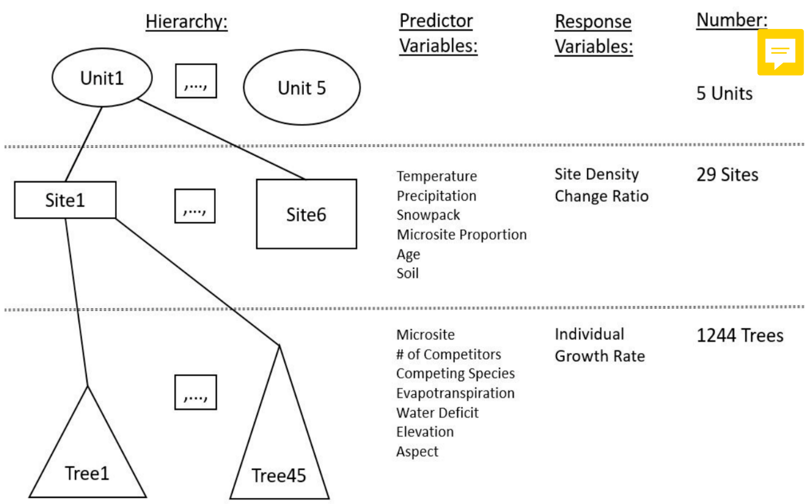


Figure 2. Hierarchical study design, predictor variables, and sample sizes.

Figure 2: Visualization of study design

Sampling took place from May 2018 to October 2018. A grid cell matrix of 10m x 10m was overlaid on the study site or unit. A random starting point was decided and then every 20th grid cell from that was sampled, equating to sampling between 2-15% of each site. Each seedling within that grid cell was digitally tagged, and Survey123 was used to collect field data.

There are only 5 units and only 29 sites within each of those units, resulting in a somewhat small sample size. However, with over 1000 seedlings within each site/unit combination, there is a of replication within each unit.

Researchers were most interested in the annual growth rate. Seedlings were too small to measure growth rings via coring, so height was used as a proxy for growth rate. Specifically, growth rate was calculated as the change in height between the study year (2018) to the relative planted height when the seedling was first planted. This was divided by the number of years since planting minus 2.5 years to account for the period of time when seedlings sequester carbon instead of focusing on their own growth.

From examination of the raw data, there appears to be unequal variance in growth rate by planting unit. This suggests that a log transformation be applied, and the variances look better after transformation (Figure 3).

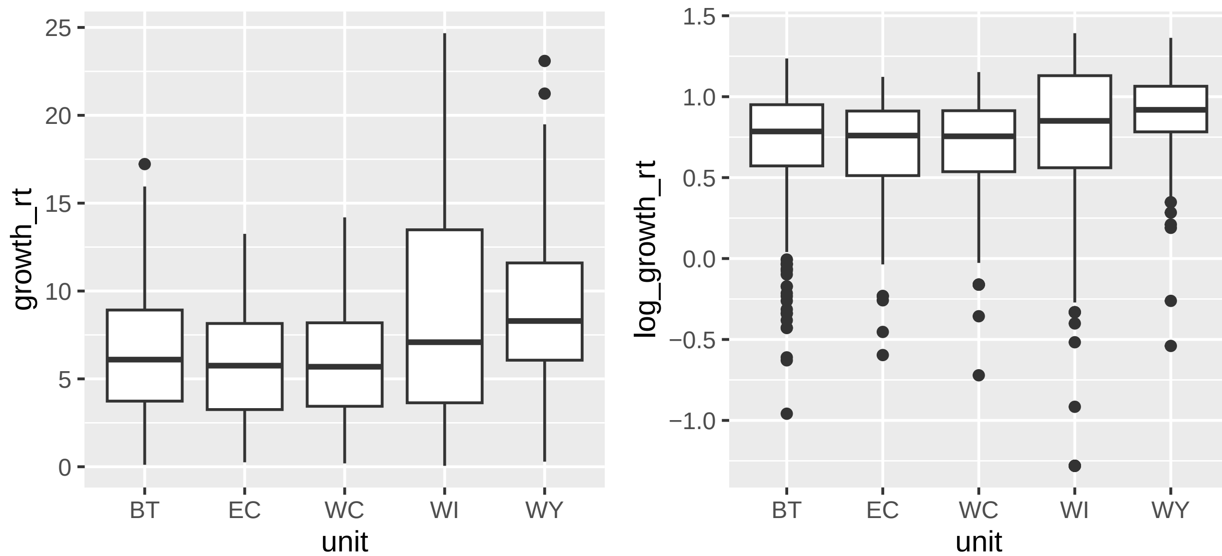


Figure 3: Growth rate by unit, before and after log transformation

At each site, data on seedling heights (used to estimate growth rate) and competing plant species was recorded. Water balance variables were estimated using Daymet devices as inputs for temperature and precipitation.

Our reponse variable is `log_growth_rt`. This is the log of the annual growth rate, determined by measuring seedlings and dividing by the number years since planting.

The following predictor variables were evaluated:

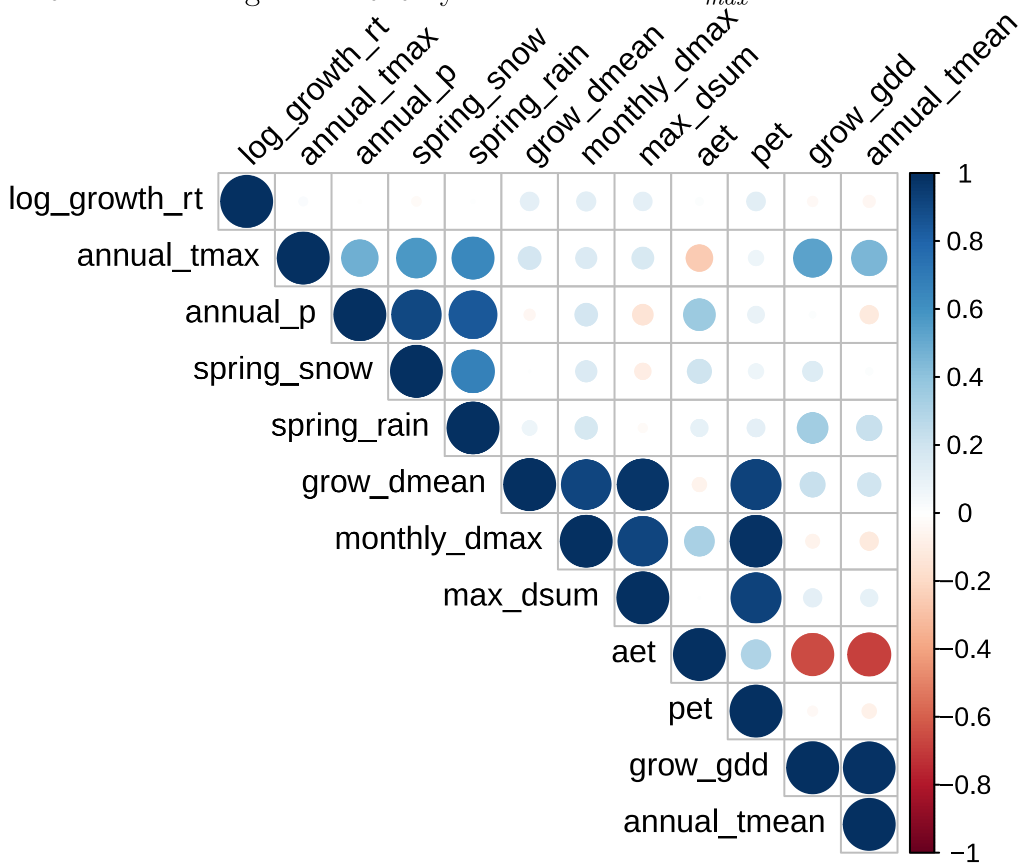
- Predictor variables are as follows:
  - Age - Years since planting
  - T_{mean} - Mean annual temperature (°C)
  - T_{max} - Max monthly temperature (°C)
  - PPT (mm) - Mean annual precipitation.
  - Snowpack (mm) - Mean spring (March-May) snowpack
  - WD_{annual_mean} (mm)
  - WD_{annual_max} (mm)

– WD_{month_max} (mm)
– AET - Mean actual evapotranspiration (mm) during growing season (April–October)
– PET - Mean potential evapotranspiration (mm) during growing season (April–October)
– GDD - Mean annual growing degree days (April-October)
– Micro - This was a binary variable indicating presence of favorable microsite conditions. 1 if there was a rock or other topographical feature that changed the environmental conditions where the seedling lived.
– $Micro_{prop}$ - Proportion of WBP with a microsite at the site-level
– Comp_number - number of competitors within a 3.59m radius
– PICO - Presence of Lodgepole pine (*Pinus contorta*) within 3.59m radius of WBP. 1 if PICO is present, 0 otherwise.
– PIEN - Presence of Apache pine (*Pinus engelmannii*) within 3.59m radius of WBP. 1 if PIEN is present, 0 otherwise.
– ABLA - Presence of subalpine fir (*Abies lasiocarpa*) within 3.59m radius of WBP. 1 if ABLA is present, 0 otherwise.

Data were provided by Laufenberg, but the process of cleaning and structuring the data were not explicit in the paper. As such, we had to experiment to figure out how data were cleaned. We did this by modifying data in an ecologically reasonable way while comparing raw data plots to the paper. A few examples of data cleaning are:

- creating AET which is the total annual evapotranspiration. To get this, we multiplied the average monthly evapotranspiration by 7 for the 7 months of the growing season. The same was done for PET or potential evapotranspiration.
- multiplying p by 12 to get the total "annual precipitation".

Climate and water balance predictor variables were tested for colinearity with a cutoff of r >= +/- 0.6 (**??**. A parsimonious list of water balance variables was selected by choosing the more biologically relevant variable from pairs that exceeded this threshold. This list of variables was then combined with the variables pertinent to the research question, which were for the number of competitors, age of the planting site, and microsite presence/absence to create a list of candidate variables to evaluate in model selection. Following this process, our list of candidate variables to evaluate in model selection is T_{max}, PPT, PET, AET, comp_number, micro, PICO, PIEN, ABLA. This differs from the "full model" evaluated in Table 6 of Laufenberg et al. 2020 by the inclusion of T_{max} and the exclusion of T_{mean}.



Fix correlation plot with ggplot. In general, Correlation matrix of predictor variables. Larger circles and darker colors indicate a higher degree of correlation.

After data were selected based on their correlation, we looked at linearity and potential other polynomial forms (Figure 4).

0.2.2 Statistical Procedures Used

Mixed effects models were used to study what covariates were correlated with white bark pine performance. Random effects were always used for the unit. A variety of linear and polynomial functions, and fixed effects were explore. Cubic forms were explored due to the biological idea that WBP seedling establishment may vary drastically depending on the conditions. In below average conditions, we expect low growth rate. We expect there to be an average growth rate in average conditions, and then for high quality conditins, we expect

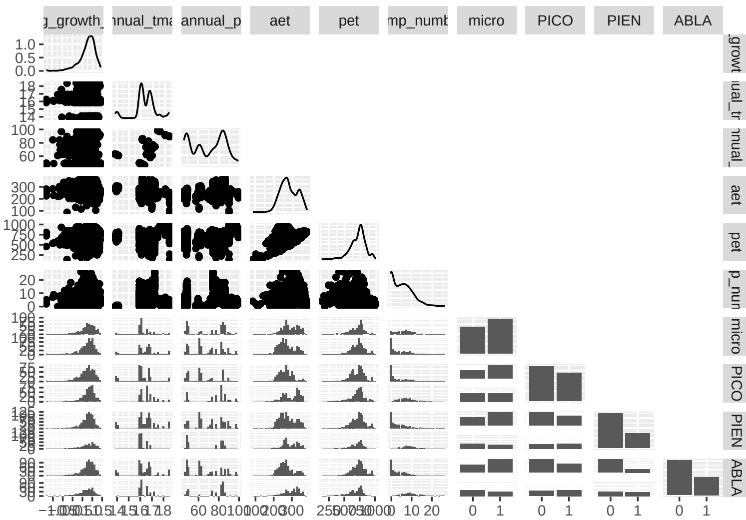


Figure 4: Raw data visualization of variables of interest

a much higher growth rate - therefore following a cubic form. A corrected AIC was used to compare models. We attempted to find the most parsimonious set of water balance variables while still incorporating the biologically relevant variables and incorporating environmental variables related to the research questions (including number of competitors, age of planting, and microsite status).

We ran the saturated cubic model without interactions (**??**), and then refined it using backwards selection from the *step*() function and a AIC cutoff of AIC<2. All analysis was done use R statistical software.

For simplicity sake, lower-order terms were not explicitly written out here but were included in model. The theoretical model for our full model analyzed is as follows:

$$
\begin{aligned}
log(growth\_rate)_{ij} &= \hat{\mu}_{ij} + Unit_i + \epsilon_{ij} \\
Unit_i &\overset{iid}{\sim} \mathcal{N}(0, \sigma^2_{unit}) \\
\epsilon_{ij} &\overset{iid}{\sim} \mathcal{N}(0, \sigma^2_{error}) \\
\hat{\mu}_{ij} &= \beta_0 + \beta_1 AET + \beta_2 T_{max} + \beta_3 PPT + \beta_4 PET \\
&\quad + \beta_5 Comp\_number + \beta_6 Micro + \beta_7 PICO \\
&\quad + \beta_8 PIEN + \beta_9 ABLA
\end{aligned}
$$

0.3 Results/Summary of Statistical Findings

Using backwards selection, the most parsimonious model is below, where $annual\_Tmax$ took on a quadratic form, and PIEN and Micro were removed. This model has an AIC score of 1111.89.

$$
\begin{aligned}
log(growth\_rate)_{ij} &= \hat{\mu}_{ij} + Unit_i + \epsilon_{ij} \\
Unit_i &\overset{iid}{\sim} \mathcal{N}(0, \sigma^2_{unit}) \\
\epsilon_{ij} &\overset{iid}{\sim} \mathcal{N}(0, \sigma^2_{error}) \\
\hat{\mu}_{ij} &= \beta_0 + \beta_1 AET^3 + \beta_2 AET^2 + \beta_3 AET \\
&\quad + \beta_4 PET^3 + \beta_5 PET^2 + \beta_6 PET \\
&\quad + \beta_7 Comp\_number^3 + \beta_8 Comp\_number^2 + \beta_9 Comp\_number \\
&\quad + \beta_{10} PPT^3 + \beta_{11} PPT^2 + \beta_{12} PPT \\
&\quad + \beta_{13} T^2_{max} + \beta_{14} T_{max} + \beta_{15} PICO + \beta_{16} ABLA
\end{aligned}
$$

The initial full model, with all variables of interest, had an AICc of 1126.5. This was a 14.62 reduction in AICc value.

The final model suggests the WBP seedling growth is most correlated with the annual evapotranspiration, the potential evapotranspirtaion, the number of competitors around the seedling, annual precipitation, and max temperature while accounting for the random effect of planting unit.

Going forward, we would like to look into the following things: - We get the error "fixed-effect model matrix is rank deficient so dropping 14 columns / coefficients" and need to look at what that means.
- Better understand the variable selection process and why certain variables were included.
- Look for a more parsimonious model, perhaps dropping cubic forms.
- Creating diagnostic plots for mixed models - Interpreting the coefficients and the 95% CI in the context of WPB restoration
- Insert model table - Effects plot/model estimate - Random effect for sample site? - Better define initial model and which betas are important

0.4 Scope of Inference

- Random sampling of WPB = inferences to large population
- No random treatment (because nature) = correlation/association but not causation.

0.5 Critique

- paper had no clear model selection criteria or process
- difficult data cleaning and processing without instruction
- unfamiliar with drop1() technique for model selection, so hard to critique that with what we are used to, but struggled using step selection with random effects
- reason for cubic form is unclear
- no mention of what made something more biologically relevant during variable selection looking at correlation
- paper fishing for explanation

0.6 Group Work Statement

Steve spearheaded the data wrangling and analysis, while Parker took lead on the write-up and formatting. Both people contributed to the interpretation, discussion, and critique.

0.7 References

- Laufenberg, David, et al. "Biophysical gradients and performance of whitebark pine plantings in the Greater Yellowstone Ecosystem." Forests 11.1 (2020): 119.

0.8 Appendix

- Must include a compiled RMarkdown with all of our results
- All code is in currently in an R script, will attach for final paper