A Climate-water balance model for whitebark pine distribution modeling within the GYE

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Introduction

Methods

Results

Conclusion
The Greater Yellowstone Ecosystem encompasses Yellowstone National Park, Grand Teton National Park, and 10 wilderness area.
Introduction
Climate change in the Greater Yellowstone Ecosystem

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1. The mean temperature of the GYE has seen a $0.6^\circ C$ increase in the last 30 years
2. Warming is effecting alpine regions (> 2250m* 7500ft) elevations, the habitat of Whitebark Pine (aka WBP)
3. Projected warming in the next century to exceed $3^\circ C$ across the region
Methods

1. Summarize PRISM climate dataset for the GYE spatial domain at 30 arc-second resolution (Daly et al 2002)
2. Construct water balance model for predictor variable dataset
3. Calibrate Random Forest model given Forest Inventory Analysis (FIA) and Whitebark Limber Pine Information System (WLIS) presence and absence dataset
4. Generate prediction probability across all cells within GYE spatial domain (Breiman 2001)
**Water balance model**

**Thornthwaite method for calculating AET and deficit (Thornthwaite 1948, Dingman 2002)**

We calculate the melt factor $F_m$

\[
T_a \leq 0^\circ C : F_m = 0 \\
0^\circ C < T_a < 6^\circ C : F_m = 0.167T_a \\
T_a \leq 6^\circ C : F_m = 1
\]  

where $T_a$ is the mean monthly temperature, we then estimate the amount of rain and snow from the known $P_m$ precipitation values:

\[
\text{RAIN}_m = F_m P_m \\
\text{SNOW}_m = (1 - F_m) P_m
\]
Water balance model

We then determine the monthly total accumulated snow pack $PACK_m$ and snow melt $MELT_m$

$$PACK_m = (1 - F_m)^2P_{m+} = (1 - F_m)PACK_{m-1}$$
$$MELT_m = F_m(SNOW_m + PACK_{m-1})$$

The monthly water input $W_m$ to the system (or individual cell) is:

$$W_m = RAIN_m + MELT_m$$
Water balance model

The point is that we want to find out the soil moisture & ET

$$\text{SOIL}_m = \min\{\text{SOIL}_{\text{max}} \cdot [(W_m - \text{PET}_m) + \text{SOIL}_{m-1}]\}$$  \hspace{1cm} (5)

But soil moisture evaporates so we need that rate $\text{PET}_m$:

$$\text{PET}_m = 29.8 \cdot n\text{Days} \cdot \text{Daylength} \cdot \frac{e_a(T_a)}{T_a + 273.2}$$  \hspace{1cm} (6)

e_a is the saturation vapour pressure at $T_a$:

$$e_a = 0.611 \exp\left(\frac{17.3T_a}{T_a + 237.3}\right)$$
Results

Random Forest model of WBP distribution
Results

Projection scenario 1: RCP 4.5 650 ppm CO₂
Results

Projection scenario 2: RCP 8.5 1464 ppm CO$_2$
Conclusion

1. 80% mortality of WBP already in GYE (MacFarlane et al 2013)
2. Whitebark pine climate envelope projected to reduce significantly over the next century
3. Active management should be considered for conservation of species