Mapping Climate and Disturbance Refugia for Conservation of Whitebark Pine

MS Thesis Defense

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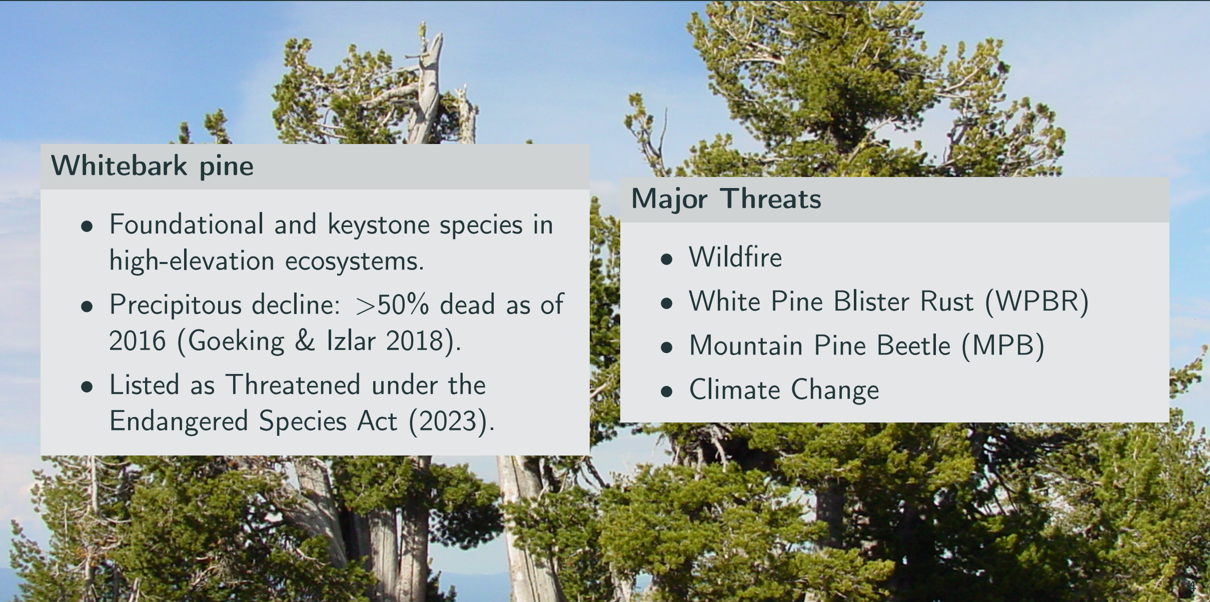
Outline

1. Context: Whitebark pine
2. Wildfire refugia in the GYE
3. Climatic drivers of white pine blister rust infection in WBP
4. Planting microsite selection using a high-resolution water balance model

Whitebark Pine (*Pinus albicaulis* Engelm.)



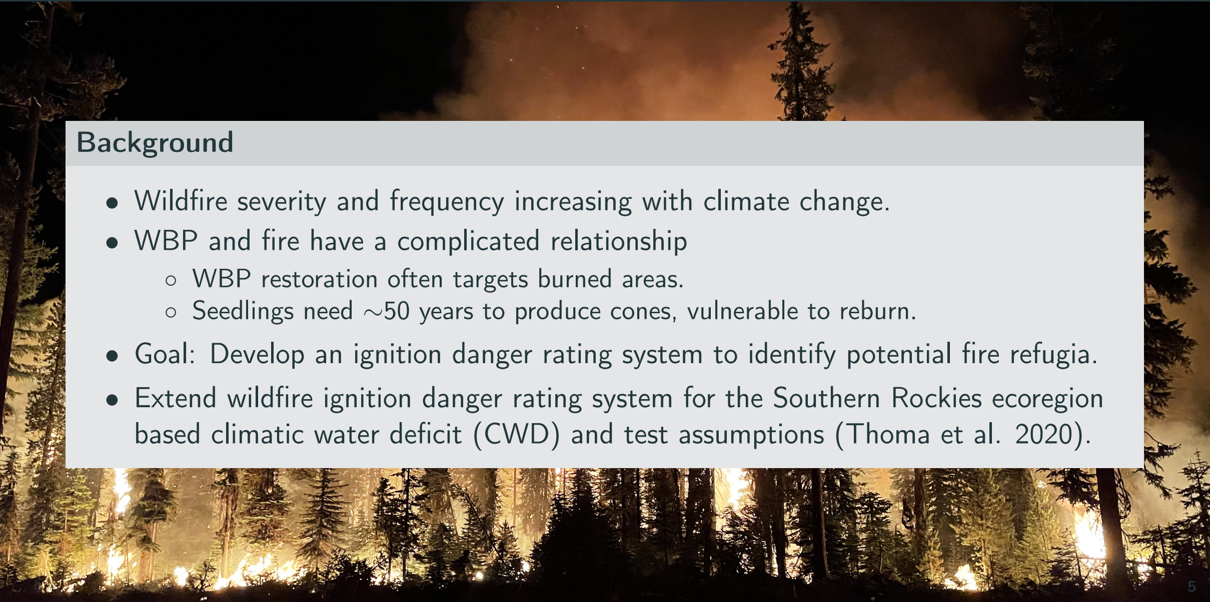
Whitebark pine

- Foundational and keystone species in high-elevation ecosystems.
- Precipitous decline: >50% dead as of 2016 (Goeking & Izlar 2018).
- Listed as Threatened under the Endangered Species Act (2023).

Major Threats

- Wildfire
- White Pine Blister Rust (WPBR)
- Mountain Pine Beetle (MPB)
- Climate Change

Chapter 1: Wildfire refugia in the Middle Rockies ecoregion



Background

- Wildfire severity and frequency increasing with climate change.
- WBP and fire have a complicated relationship
  - WBP restoration often targets burned areas.
  - Seedlings need ∼50 years to produce cones, vulnerable to reburn.
- Goal: Develop an ignition danger rating system to identify potential fire refugia.
- Extend wildfire ignition danger rating system for the Southern Rockies ecoregion based climatic water deficit (CWD) and test assumptions (Thoma et al. 2020).

Wildfire ignition danger rating — Methods

Indicators of Dryness

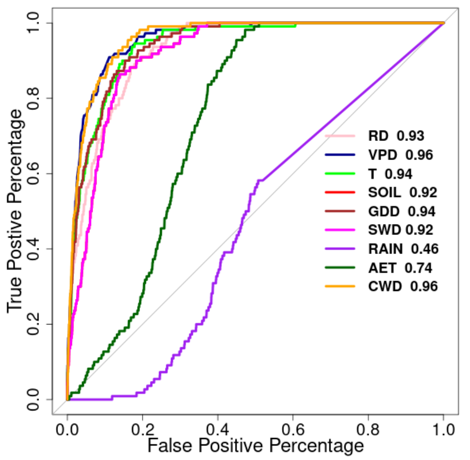
Variable	Abbrev.	Units	Note
Average temperature	T	°C	
Average relative dryness	RD	%	RD = 1 − RH
Vapor pressure deficit	VPD	kPa	
Actual evapotranspiration	AET	mm	Water use/favorable growing conditions
Climatic water deficit	CWD	mm	Drought stress
Soil moisture	SOIL	mm	
Soil water deficit	SWD	mm	SWD = WHC − SOIL
Rain	RAIN	mm	
Growing degree days	GDD	°C	Base temperature of 5.5 °C

Steps:

- Identify best predictors of wildfire ignition:
  1. Calculate 1-31 day rolling sums/means of dryness indicators.
  2. Normalize using percentile ranks.
  3. Use the Area Under the Receiver Operating Characteristic Curve (AUC-ROC) to find best classifiers of ignition and optimal rolling window width.
- Wildfire ignition danger rating: Identify conditions that are dry enough to burn.

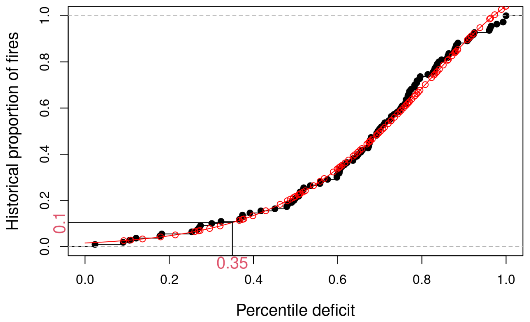
Best performing dryness indicators

- Percentiles of **3-day rolling sums of CWD and VPD** were best classifiers of ignition.
- CWD/VPD also the best classifiers of ignition in Thoma et al. 2020, but only 14-day rolling sums were tested.



ROC for 3-day rolling values

Identifying conditions that are dry enough to burn

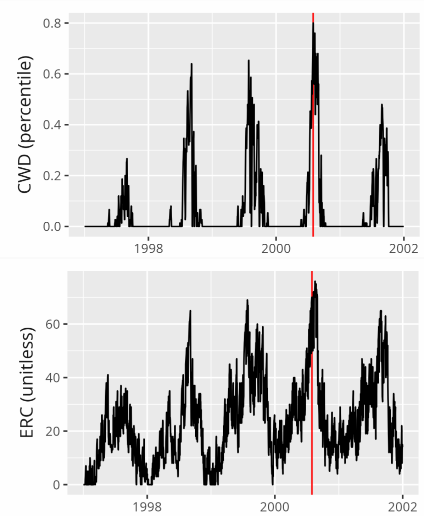


Cumulative distribution of wildfires that burned at a percentile of 3-day sum of CWD or wetter

Select risk threshold based on management objectives:

- WBP planting requires conservative estimates of risk — percentile of dryness at or below which 10% of historical fires burned.
- Maximize opportunities to conduct prescribed burns — accepting conditions at or below which 30-40% of historical ignitions occurred could highlight more days as potentially viable.

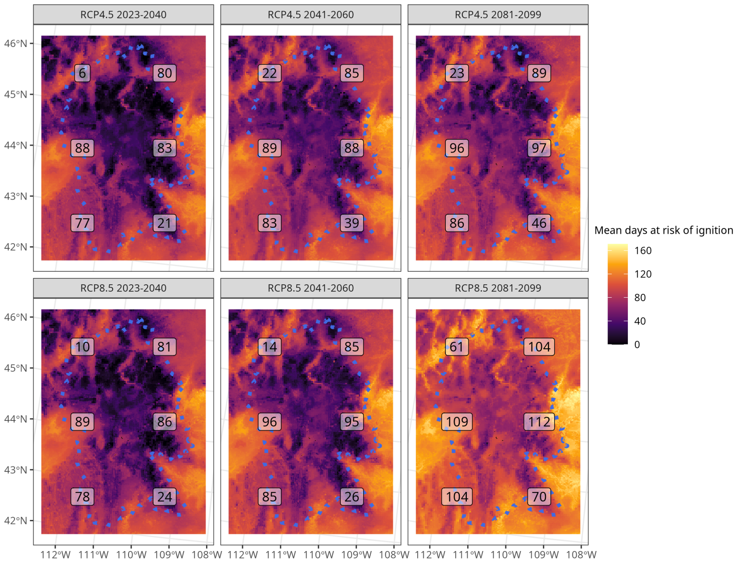
Ours versus Theirs



Strengths of this approach

- Simplicity - based on one measure of climate.
- Calibrated to local conditions at each pixel/location.
- Can be tuned for specific management objectives.
- Appears to perform favorably compared to other fire danger indices, such as NFDRS, but further analysis needed.

Projected Ignition Risk (GYE Forests)



- Increased fire risk across GYE by end-century.
- Larger increases under RCP8.5.
- Persistence of refugia only apparent under RCP4.5.

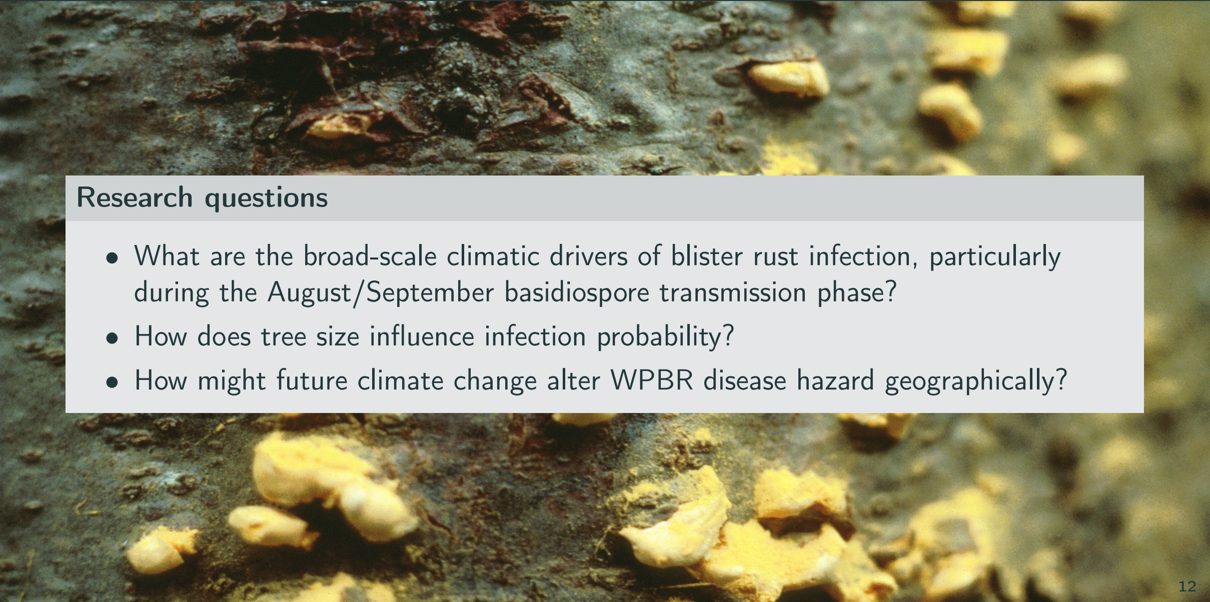
Wildfire refugia: Conclusions and Future Work

Conclusions

- Percentiles of 3-day rolling sums of CWD/VPD were the best classifiers of wildfire ignition in the Middle Rockies ecoregion.
- Increases in fire risk are projected, varying with emissions scenarios.

Future Work

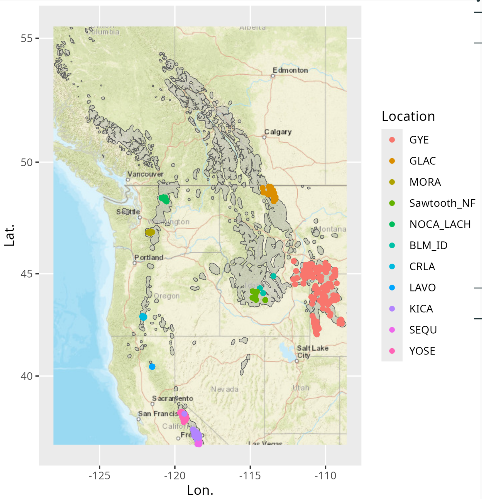
- Test model in other ecoregions.
- Develop automated near-term forecast system (www.climateanalyzer.us/grsa_dash).
- Evaluate performance compared with other fire danger indices.



Research questions

- What are the broad-scale climatic drivers of blister rust infection, particularly during the August/September basidiospore transmission phase?
- How does tree size influence infection probability?
- How might future climate change alter WPBR disease hazard geographically?

Monitoring data



Mean Aug/Sep climate and infection rates

Monitoring Area	asP (mm)	asT (°C)	asVPD (kPa)	asRH (%)	Inf. rate (%)
GYE	90.27	10.51	0.88	46.33	45.80
GLAC	**119.66**	**10.51**	**0.75**	**54.55**	**75.06**
MORA	104.58	10.54	0.60	62.41	46.71
Sawtooth_NF	60.25	11.52	0.99	43.09	11.57
NOCA_LACH	89.55	10.83	0.76	50.35	54.89
BLM_ID	69.12	11.44	0.89	49.05	46.84
CRLA	49.74	12.15	0.83	55.14	43.24
LAVO	41.15	12.00	1.05	42.79	51.82
KICA	13.42	9.62	0.82	38.97	5.94
SEQU	**6.08**	**10.46**	**1.00**	**34.08**	**1.51**
YOSE	24.28	11.15	0.96	36.67	3.82
Western U.S.	60.74	10.98	0.87	46.68	35.2

- 22,292 trees between 490 transects, monitored between 2000 and 2022.
- Thank you Erin Shanahan, EJ, and data contributors!

Spatially explicit logistic regression models

Response

WPBR status: Whether or not a tree was infected between 2000 and 2022

Predictors

- 2000-2022 August and September climate averages (Basidiospore transmission season)
  - **Temperature** (asT)
  - **Precipitation** (asP)
  - **Relative humidity** (asRH)
  - **Vapor pressure deficit** (asVPD)

  ↪ Second order effects — parabolic relationships?
- **Tree size** (log DBH)

Random Effects

Spatial random field — other spatially varying processes, spatial autocorrelation.

Model selection and performance

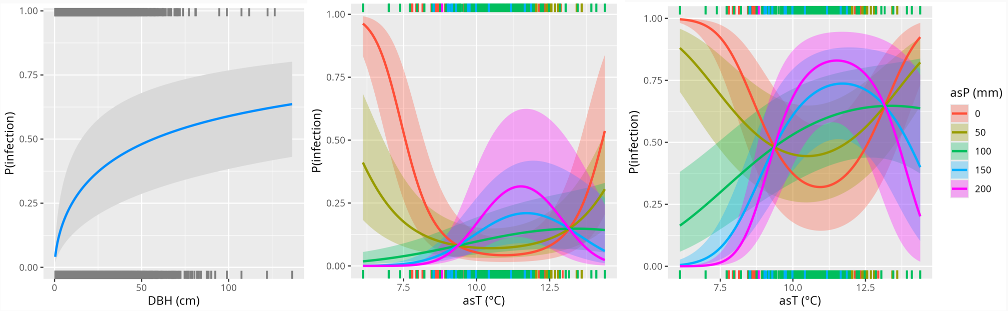
Model	AICc	ΔAICc
$asT^2 \times asP + \log DBH$	17266.4	0.0
$asT^2 \times asRH + \log DBH$	17292.7	26.3
$asT \times asP + \log DBH$	17323.9	57.6
$asT \times asRH + \log DBH$	17343.1	76.7
$asT^2 + \log DBH$	17345.0	78.6
$asT + asP + \log DBH$	17346.2	79.8
$asVPD^2 + \log DBH$	17346.9	80.6
$asP + \log DBH$	17350.6	84.2
$asT + \log DBH$	17351.4	85.0
$asT + asRH + \log DBH$	17353.0	86.6
$asVPD + \log DBH$	17358.3	92.0
$\log DBH$	17367.2	100.9
$asRH + \log DBH$	17367.5	101.1
$asRH^2 + \log DBH$	17367.9	101.5

- 8-fold CV shows strong model performance for top model
  - 88.2% Specificity (True Negatives)
  - 63.3% Sensitivity (True Positives)
  - 80.9% Overall Accuracy
- Model predictions at lower levels of Aug/Sep precipitation should be viewed with caution!

Effect of Climate and Tree Size on Disease Hazard

$$\text{WPBR infection status} \sim \text{asT}^2 \times \text{asP} + \log \text{DBH} + \omega_s$$

Spatial random field



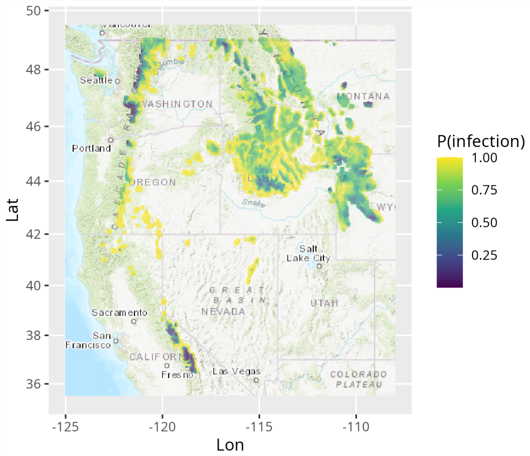
DBH (cm)

Seedlings (1 cm DBH)

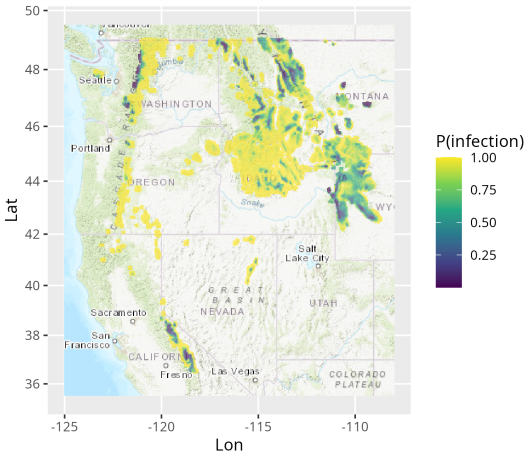
Mature Trees (40 cm DBH)

$\text{asT}^2 \times \text{asP}$ (Interaction)

Projections of WPBR disease hazard in the GYE



RCP4.5



RCP8.5

Ensemble end-of-century probability of WPBR infection (Mature trees).

WPBR: Conclusions and future work

Conclusions

- WPBR infection across CONUS is driven by August/September Temperature and Precipitation.
- Projections show potential WPBR refugia; are they suitable climates for WBP?

Future Work

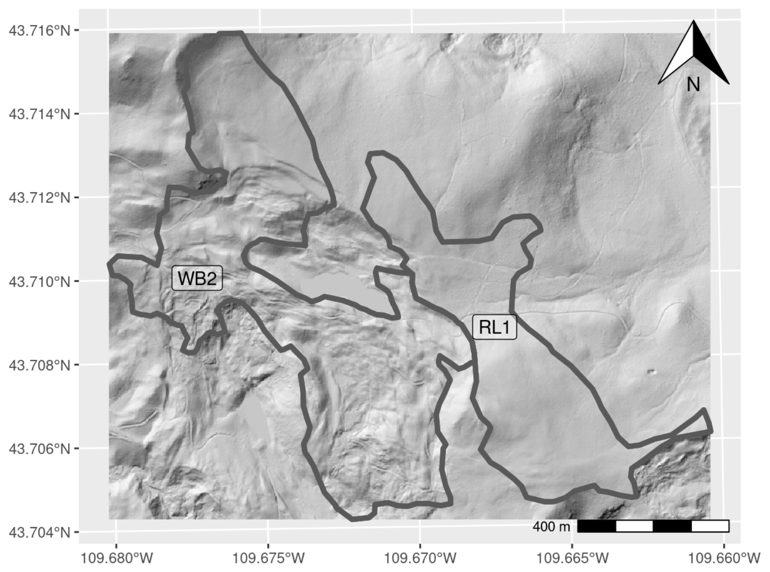
- Extend analysis to Canada.
- Investigate biologically implausible temperature effect at low precipitation.

High-resolution water balance model

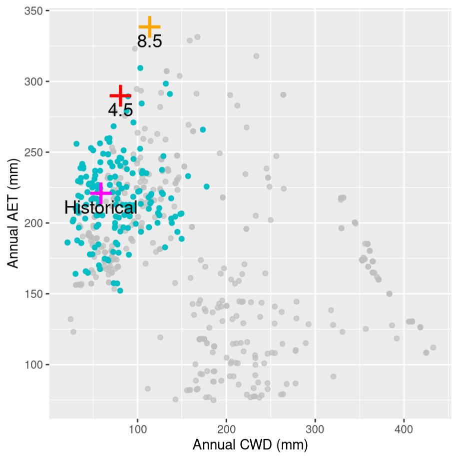
- Microsites are intuitively understood and used by tree planters.
- Gridded climate data (800m-4km) too coarse for individual seedling scale.
- Microclimates influenced by local topography and soils can buffer regional climate.
- Goal: Leverage high-resolution LiDAR terrain data to develop a 1 m water balance model to identify suitable microclimates for planting.
- Case study: Burroughs Creek, Shoshone NF, Wyoming, USA. Macro- and microclimate analysis

Seedling microsite created by snag
Photo credit: Erin Shanahan (NPS)

Case Study: Burroughs Creek, Shoshone NF, Wyoming, USA



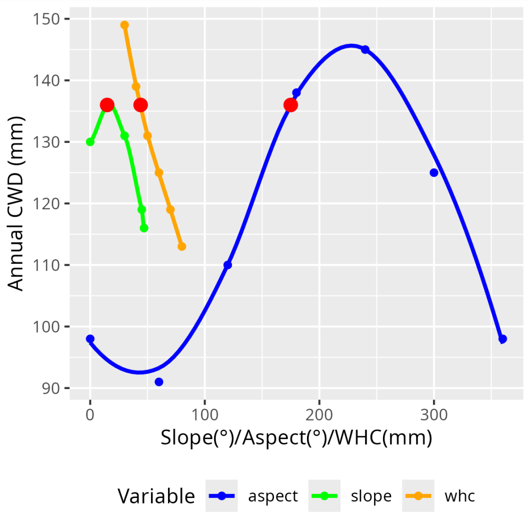
Burroughs Creek Macroclimate



1 km scale historical AET/CWD (2000-2019) for WPBR monitoring points (grey) and GYE (blue), with historical and projected data for Burroughs Ck (crosses).

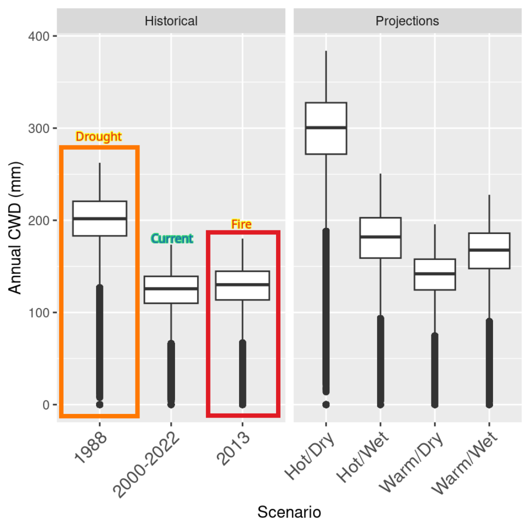
- 1 °C maximum mean annual temperature recommendation for planting WBP in the Northern Rockies (Bower & Aitken 2008).
  - Burroughs Ck *barely* exceeds this (4 km MACA).
- Water balance **AET** (water use) and **CWD** (drought stress) more effectively characterize the biophysical environment of plants than temperature and precipitation (Stephenson 1998).
- Macroclimate (1 km) water balance projections for Burroughs Ck are marginal to unfavorable.

Microclimate Sensitivity Analysis



- **Soil WHC** is the strongest control on Actual Evapotranspiration (AET).
- **Aspect** is the strongest control on Climatic Water Deficit (CWD).
- Slope plays a smaller role for both.
- Highlights importance of local topoedaphic features.

Microclimatic Variability

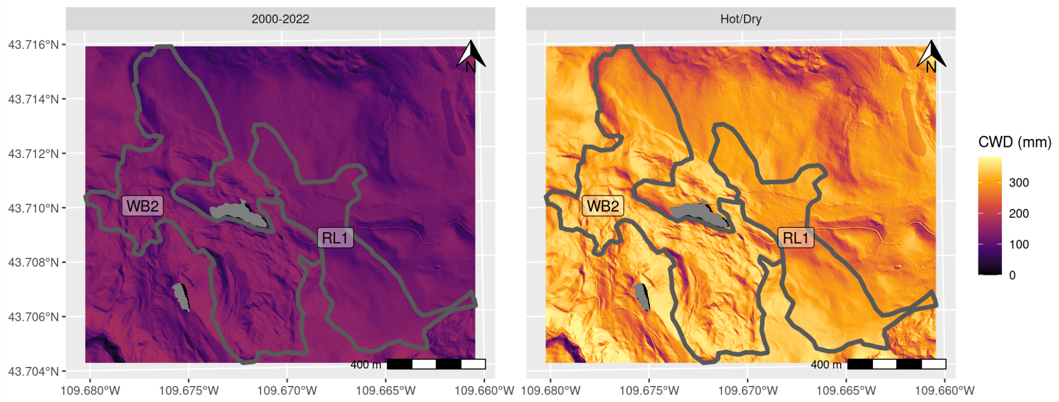


- **Increases in AET and CWD in all projections.**
- Higher AET is associated with increased growth rates in WBP seedlings (Laufenberg 2020)
- High CWD is bad!

→ Drought stress, fire risk.

→ Several projections of 2075-2099 average annual CWD are similar or higher than CWD in 1988 (drought year).

Microsites: Modeled CWD



- Model identifies fine-scale patterns in drought stress (CWD).
- North-facing slopes and high WHC areas show lower CWD.
- These patterns persist under future climate scenarios, identifying potential microrefugia.

Surprise & Amphitheater Lakes, GTNP
Average annual CWD 2002-2022

Overall Conclusions

- Wildfire: Disturbance refugia are likely to persist in the GYE under lower emissions scenarios.
- WPBR: Geographic patterns of disease hazard are likely to shift in the future.
- Uncertainty in above projections due to uncertainty about future climate!
- Our high-resolution water balance model can help identify suitable planting microsites even in unfavorably macroclimates.

Questions?

Appendices

AET Sensitivity