Creating a Hydraulic Vulnerability Curve for Two-Year Old Ponderosa Pine Seedlings

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Background

Recent assessments have indicated ponderosa pine (*Pinus ponderosa*) have experienced increasing tree mortality and widespread forest die-off events due to drought and heat stress conditions caused by climate change. Hydraulic failure in trees occurs during water-stress conditions when tensions in the xylem become too high and an air pocket, or embolism, is formed, blocking the transport of water, and resulting in the loss of conductivity of the xylem. Resistance to hydraulic failure has also been found to correlate with reduced mortality rates during drought conditions. It is unlikely that complete hydraulic failure is necessary for tree mortality and may act in conjunction with other mechanisms; therefore, quantifying xylem percent loss of conductivity at different levels of stress is important for understanding the relative contribution of hydraulic failure to ultimate mortality. Hydraulic vulnerability curves can be used to quantify xylem conductivity at a given water potential, which can then be utilized to predict percent loss of conductivity (PLC) across stress levels.

Our work seeks to establish a hydraulic vulnerability curve for for ponderosa pine seedlings to better understand factors contributing to mortality. By generating improved understanding of the relationship between PLC and mortality, we hope to inform predictions of landscape scale mortality events of ponderosa pine colonies due to ongoing water stress, and ultimately help to conserve and protect these species from future drought conditions.

Figure 1: Two-year old ponderosa pine seedlings in the greenhouse.

Experimental Design

To create the hydraulic vulnerability curve, we measured the water potential and xylem conductivity of 30 two-year old ponderosa pine seedlings from three treatment groups:, well-watered (n = 10), moderate drought (n = 10) and severe drought (n = 10)

The water potential of the ponderosa pine seedlings was measured on full fascicles from the upper canopy using a pressure chamber equipped with a digital pressure gauge. The percent loss of conductivity was found for each seedling with the equation $K_{leaf} = C log_e(\psi_0/\psi_f)/t$, where K_{leaf} is the conductivity of the leaf xylem, C is the capacitance, ψ_0 is the leaf water potential before partial rehydration, ψ_f is the leaf water potential after partial rehydration, and t is the duration of rehydration in seconds. C, capacitance, was obtained from PV curves of the seedlings, which was calculated as the slope of relative water content versus leaf water potential.

A hydraulic vulnerability curve was fit to the data with PLC on the y-axis and leaf water potential on the x-axis.

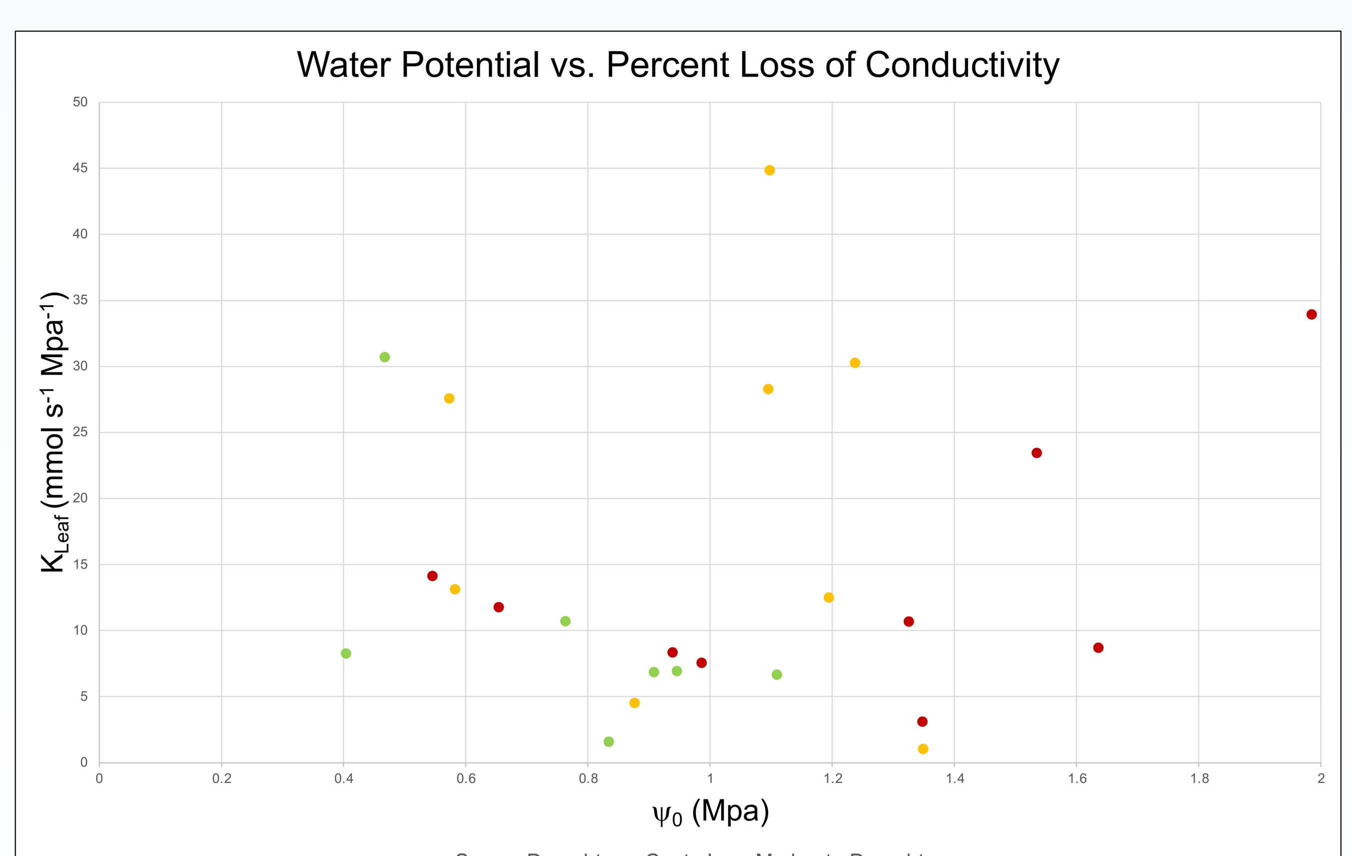

Figure 2: Osmotic potential (ψ_0) in Mpa vs. the conductivity (K_{leaf}) of two-year old Ponderosa Pine seedlings across well-watered, moderate drought, and severe drought treatments.

Results and Discussion

Median capacitance across treatments was found to be 21.9196. The average relative water content in living cells at the turgor loss point for the control treatment was 89.95%, 82.78% for the moderate drought treatment, and 72.08% for the severe drought treatment. The average turgor loss point, or the point at which the turgor pressure in cells is zero, was found to be -0.648 Mpa for the well-watered group, -0.975 Mpa for the moderate drought treatment, and -1.678 Mpa for the severe drought treatment. The average osmotic potential at the turgor loss point for the control treatment was found to be -1.021 Mpa, -0.807 Mpa for the moderate drought treatment, and -0.731 Mpa for the severe drought treatment. The average value for epsilon, or the bulk modulus of elasticity, was found to be 0.038 Mpa for the control treatment, 1.359 for the moderate drought treatment, and 0.009 for the severe drought treatment. ANOVA tests determined that none of the PV curve parameters (RWC at TLP, TLP, osmotic potential at TLP, or the bulk modulus of elasticity) were significantly different between treatments.

Figure 2 indicates no correlation was found between water potential and conductivity in the ponderosas between the different treatments. This could be due to a multitude of reasons related to errors in the methods used to obtain the data and/or physiological properties of the ponderosa pines that prevented the methods from working properly. Some of the possible reasons are that cutting the stems may have induced embolism due to the sudden air exposure, and this would have affected conductivity, the water potential values did not have an adequate range for differences in conductivity to be noticeable, the time of rehydration was not long enough due to the slow conductivity of pine shoots, and the methods were developed using Costa Rican based tree species, and not conifer shoots. The physiological differences between the xylem conduits of the tropical tree species used to create the methods and ponderosa pine we used could be enough for the methods to not work effectively on ponderosa pines.

Conclusion

Further research is needed to understand why no correlation was found between water potential and PLC in the two-year old ponderosa seedlings, and whether new methods need to be developed specifically for conifers and/or ponderosas or if the current methods only need to be altered to obtain a viable hydraulic vulnerability curve.

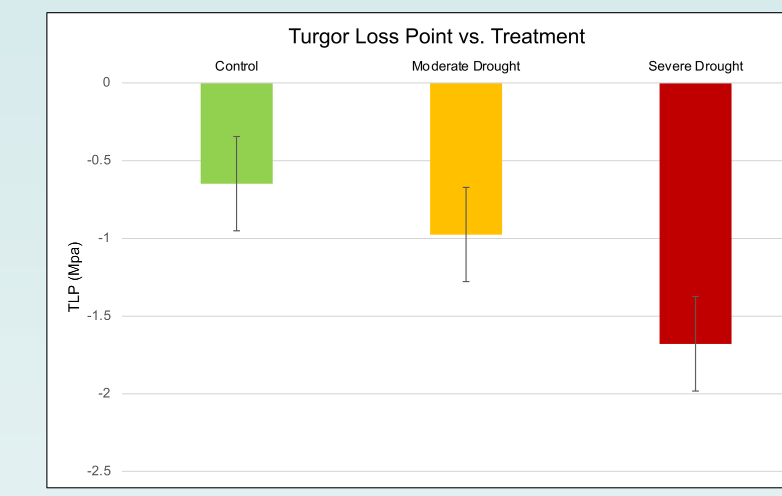

Figure 3: Turgor loss point (in Mpa), also known as when leaf water potential is equal to osmotic water potential, in two-year old ponderosa pine seedlings across well-watered, moderate drought, and severe drought treatments.

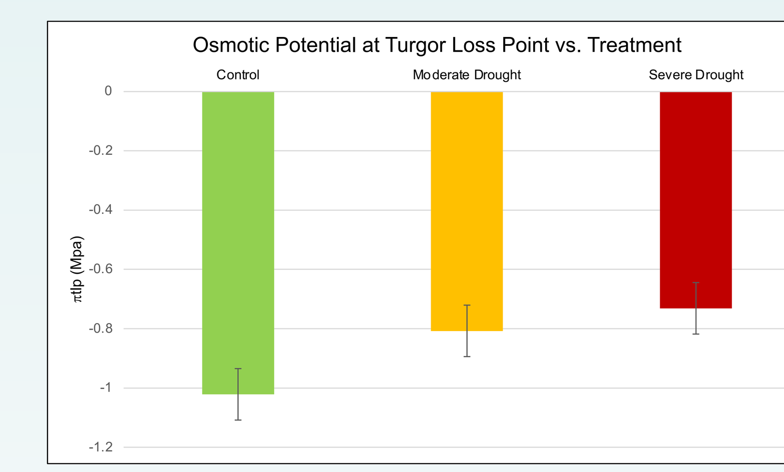

Figure 4: Osmotic water potential at the turgor loss point (π_{tlp}) in Mpa in two-year old Ponderosa Pine seedlings across well-watered, moderate drought, and severe drought treatments.

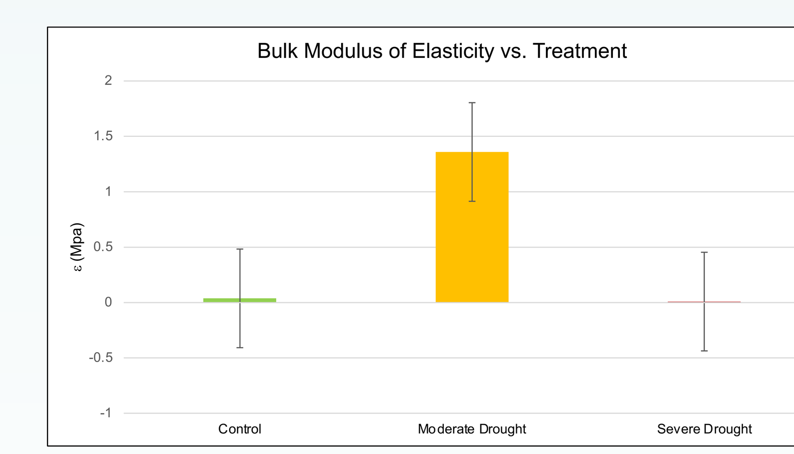

Figure 5: Bulk modulus of elasticity in Mpa of two-year old Ponderosa Pine seedlings across well-watered, moderate drought, and severe drought treatments.

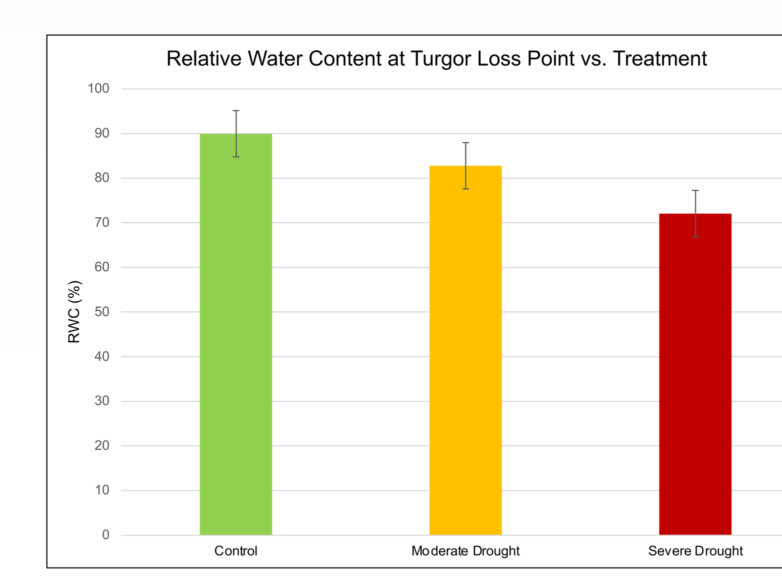

Figure 6: Relative water content in live cells at the turgor loss point (%) of two-year old Ponderosa Pine seedlings across well-watered, moderate drought, and severe drought treatments.