Driving Seedling Morpho-Physiology Towards Drought Tolerance With Drought Conditioning in the Nursery

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Overview:

- Experiment 1: A late season drought of 10 weeks was applied to potted ponderosa pine and western redcedar seedlings, then followed by 1 month of recovery. Measurements of growth, photosynthesis, water status, wood anatomy, and biochemistry in droughted seedlings were compared to a well-watered control.
    - For ponderosa pine, living parenchyma cells occupied a smaller fraction of wood in droughted seedlings than in control seedlings, which may indicate a drought acclimation available to ponderosa pine. Incoming carbon is often limited by drought, but if less sugar (less carbon) is distributed over equivalently lower cell volume, the osmotic strength required for water retention (and so cell turgor) may be maintained.
    - Droughted western redcedar seedlings demonstrated less variability (no significant differences) in the wood fraction occupied by living parenchyma cells relative to control seedlings. Comparatively, these cells occupied significantly lower fractions of wood relative to ponderosa pine regardless of treatment. This may help to explain western redcedar's consistently low stem vulnerability to embolism (high stem resistance to drought).
- Experiment 2: Greenhouse irrigation treatments were used to drought condition ponderosa pine and western redcedar seedlings prior to outplanting.
    - For ponderosa pine, a nursery culturing treatment that reduced irrigation starting 10 weeks after radical emergence, then returned to well-watered conditions at around budset, led to no significant difference from consistently well-watered control seedlings in new root tip counts prior to outplanting; however, the same treatment had significantly deeper tap roots and 0% mortality after the first outplanting season (relative to 4.2% for the control).
- Western redcedar seedlings responded poorly to any drought-conditioning in terms of root growth and performed no better than the control or worse at outplanting.

Summary:

Hot, dry climates are a menace to seedling establishment in naturally and artificially regenerated forests alike. These tough outplanting conditions are problematic because a seedling's limited mass dictates reserves of energy (sugars or starch), water, and nutrients. Furthermore, in order to establish itself, risky investments in growth must precede any leap in a seedling's ability to acquire new resources (i.e., increases in light interception for photosynthesis or soil exploration for water and nutrient uptake). With new climate normals indicating hotter and dryer growing seasons combined with more frequent stand replacing (and seedbank-incinerating) fires, as well as initiatives from governments across the world to plant more trees, it is critical to advance our understanding of how nursery interventions may prepare seedlings for dry environments. In two studies, we examine some of the ways that seedling morphophysiological characteristics may be modified by nursery culture to increase seedling survival under dry outplanting conditions.

Silvicultural Concepts:

- This research aligns with the target plant concept in tailoring seedling fitness for purpose. Targets for conventionally grown seedlings, set to maximize productivity at high productivity sites, may lead to traits that decrease fitness (survival and subsequent growth) at sites subject to tough outplanting conditions or low productivity. Just as treatments like thinning, prescribed burning, or vegetation control can be used to manage growth and composition in a standing forest, cultural controls in the nursery such as irrigation, fertilization, temperature, or light may be used to enhance a seedling's fitness for purpose—in this case, at dry outplanting sites.

Management Applications:

- Our preliminary findings indicate that stems (living cells in the wood) and roots (early season tap root length) of ponderosa pine seedlings may vary significantly with the moisture conditions imposed at outplanting and/or with the moisture conditions imposed in the nursery. These observations may make ponderosa pine an ideal model plant for additional drought conditioning research in conifers, and the traits observed may be candidates for wide scale nursery conditioning for drought tolerance in similar species.

- The root morphology and stem anatomy of western redcedar appear relatively unresponsive to moisture conditions. This species does not form a taproot and its stems are relatively resistant to embolism even under well-watered conditions (50% loss of conductivity occurs in western redcedar at around -5 MPa relative to -3 MPa in ponderosa pine). It may be that because the stem anatomy of this species is always comparatively primed for drought tolerance with lower parenchyma fractions as well as narrower tracheids, it has less morphological leeway for adjustment.

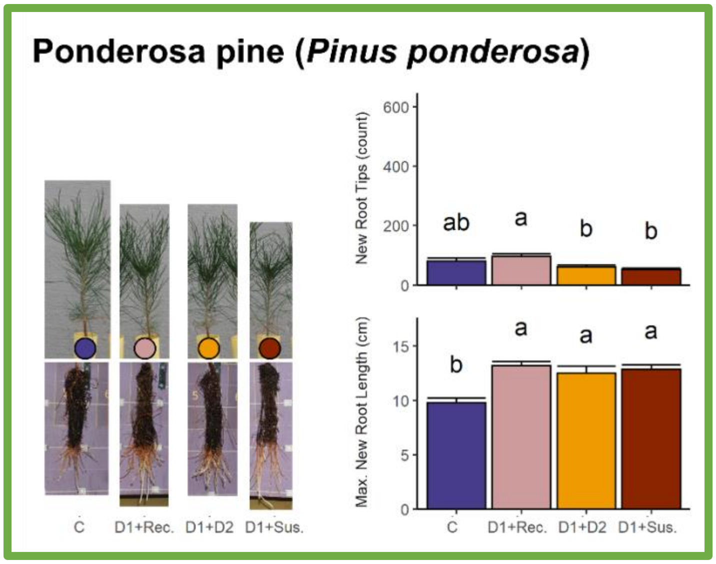

Figure 1—Ponderosa pine seedling characteristics after the greenhouse-imposed drought culture treatments in Experiment 2. Treatments were a well-watered control (C, blue) as well as three drought-conditioning treatments (D1+Recovery in pink, D1+D2 in orange, and D1+Sustained in red). See treatment details in the table description below. Data represent means and standard error; letters indicate significance groupings (Tukey's HSD, $P < 0.05$).

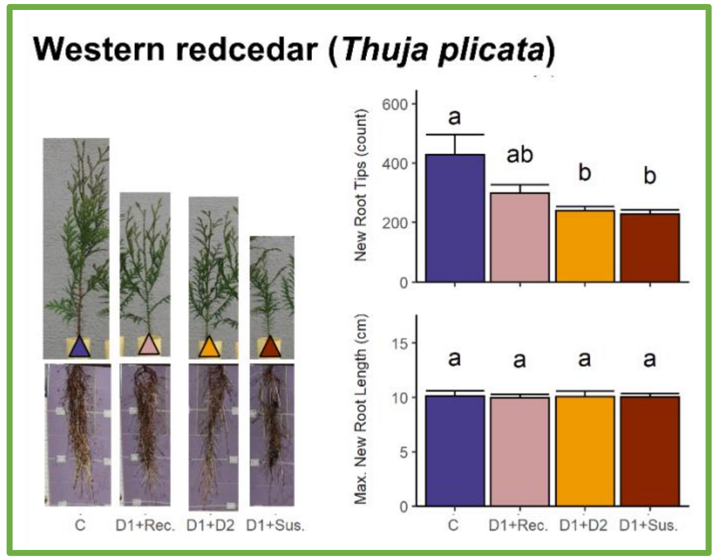

Figure 2—Western redcedar seedling characteristics after the greenhouse-imposed drought culture treatments in Experiment 2. Treatments were a well-watered control (C, blue) as well as three drought-conditioning treatments (D1+Recovery in pink, D1+D2 in orange, and D1+Sustained in red). See treatment details in the table description below. Data represent means and standard error; letters indicate significance groupings (Tukey's HSD, $P < 0.05$).

Table 1—Ponderosa pine and western redcedar seedling characteristics (averages ± standard error, n = 6) prior to outplanting for the greenhouse-imposed drought culture treatments in Experiment 2. These treatments included (1) a well-watered control (C); (2) an early season reduced irrigation period, followed by recovery to well-watered conditions (D1+Recovery); (3) an early season reduced irrigation period, followed by some recovery then a late season irrigation period and a final recovery (D1+D2); and (4) an early season reduced irrigation period, sustained to the end of the season and a final recovery (D1+Sustained). Letters in parentheses indicate significance groupings (Tukey's HSD, $P < 0.05$). Asterisk (*) in the Survival column indicates that no statistical analysis was performed.

Species	Treatment	Height (cm)	Diameter (mm)	Survival (%)*
Ponderosa pine	C	16.71 ± 0.60 (a)	4.02 ± 0.10 (a)	95.8 ± 4.17
	D1+Recovery	13.42 ± 0.49 (b)	3.74 ± 0.18 (bc)	100 ± 0.00
	D1+D2	12.78 ± 0.50 (b)	3.48 ± 0.14 (bc)	95.8 ± 4.17
	D1+Sustained	12.71 ± 0.54 (b)	3.13 ± 0.09 (c)	95.8 ± 4.17
Western redcedar	C	36.63 ± 1.63 (a)	3.55 ± 0.17 (a)	66.7 ± 10.54
	D1+Recovery	25.81 ± 1.16 (b)	2.93 ± 0.10 (ab)	66.7 ± 16.67
	D1+D2	22.53 ± 0.83 (b)	2.57 ± 0.07 (bc)	41.7 ± 15.37
	D1+Sustained	18.67 ± 0.31 (b)	2.13 ± 0.07 (c)	45.8 ± 15.02