Circadian Regulation of Stomatal Conductance in Albino and Green Redwoods and Other Gymnosperms

[1]Mo, Jennifer, [1]Simonin, Kevin, [1]Parker, V. Thomas, [2] Geary, Michelle

1. Biology Department, San Francisco State University, San Francisco, CA; 2. Biology Department, West Valley College, Saratoga, CA

Background

Plants have closable pores (stomata) that open during the day and take in carbon dioxide for photosynthesis. Water vapor is simultaneously lost in a process called transpiration. Surprisingly, many plants also transpire at night when photosynthesis is not possible. One explanation is that predawn transpiration is part of a circadian rhythm that enables a plant to anticipate daylight and photosynthesize more effectively. While correlations between circadian regulation of stomatal conductance (flow rate of gas exchange, g_s) and photosynthetic efficiency have been demonstrated in angiosperms, gymnosperms have not been investigated.

Albino and green redwood sprouts at SF Botanical Garden

In this project, nighttime water use was measured in the green and albino sprouts of *Sequoia sempervirens*, and in two other gymnosperm species found in California (*Pinus ponderosa, Pseudotsuga menziesii*).

Primary research questions:

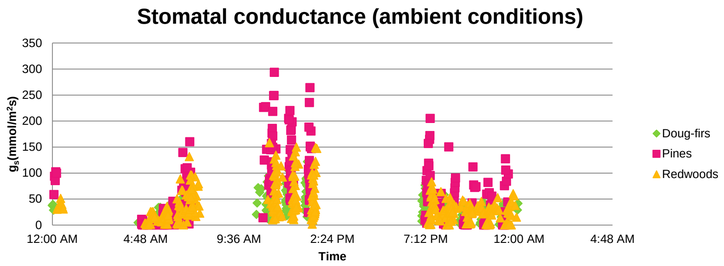
- Is stomatal conductance in gymnosperms under circadian regulation? Is there evidence for predawn (anticipatory) stomatal conductance?
- What happens to nighttime water use when photosynthetic ability is removed, as with albino redwood shoots?
- How is physiology affected when photosynthesis is removed from a system?

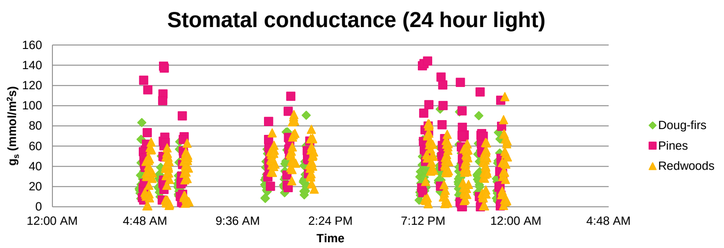
Materials and Methods

Field measurements of stomatal conductance, transpiration, water potential, and VPD of green and albino redwood shoots were taken at the San Francisco Botanical Garden. Greenhouse measurements were made on 40 redwood, douglas-fir, and ponderosa pine seedlings at the SFSU experimental greenhouse. The seedlings were entrained to 13 hour days, with lights on between 6 am and 7pm. A shade reduced ambient daylight. Stomatal conductance and transpiration measurements were conducted hourly between 7pm and 12 am, 4:30 am and 7:30 am, and 10am and 1pm for two consecutive days at a time. On the second night, grow lights were kept on to maintain 24 hour light conditions. Stomatal conductance and transpiration were measured with a Li-1600 steady state porometer, water potential was measured using a SoilMoisture pressure bomb. VPD curves were generated using a Walz GFS-3000 system. Area of leaves was evaluated using Image-J.

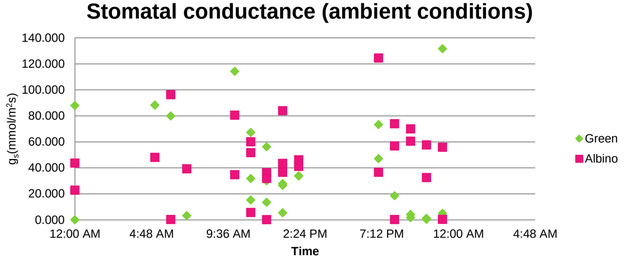
Preliminary Results

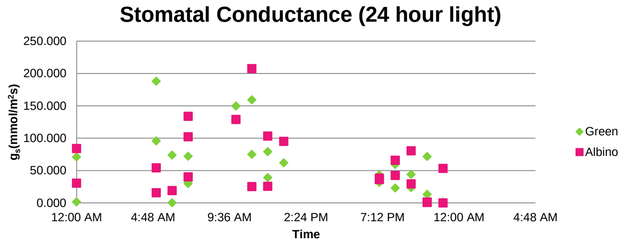
Greenhouse Experiments on Douglas-firs, Ponderosa Pines, and Redwoods





Field Experiments on Albino & Green Redwoods





Conclusions

Daily patterns of stomatal conductance are evident for all three species in the greenhouse experiments. As expected, conductance rises in the morning, peaks around noon, and drops off at night. However, all three species reached their lowest levels of conductance at or shortly before dawn (6am). In contrast, angiosperms begin to open their stomata several hours before daylight (Resco de Dios 2013, 2016). The lack of predawn stomatal conductance suggests that gymnosperms are not able to anticipate daylight, but does not obviate the presence of a circadian clock. Measurements made under 24 hour light show a weaker version of the same pattern, but further analysis is needed to determine whether the pattern is internally regulated or affected by changes in temperature and humidity within the greenhouse's set parameters.

The field experiments done on the albino and green redwood sprouts are inconclusive. If gymnosperms do not anticipate light, it is likely differences in stomatal conduction between albino and green sprouts are due to other anatomical and physiological characteristics.

Selected References

1. Burgess, S.S.O. and Dawson, T.E., 2004. The contribution of fog to the water relations of Sequoia sempervirens (D. Don): foliar uptake and prevention of dehydration. Plant, Cell & Environment, 27(8), pp.1023-1034.
2. Caird, M.A., Richards, J.H. and Donovan, L.A., 2007. Nighttime stomatal conductance and transpiration in C3 and C4 plants. Plant Physiology, 143(1), pp.4-10.
3. Dawson, T.E., Burgess, S.S., Tu, K.P., Oliveira, R.S., Santiago, L.S., Fisher, J.B., Simonin, K.A. and Ambrose, A.R., 2007. Nighttime transpiration in woody plants from contrasting ecosystems. Tree Physiology, 27(4), pp.561-575.
4. Gyllenstrand, Niclas, Anna Karlgren, David Clapham, Karl Holm, Anthony Hall, Peter D. Gould, Thomas Källman, "No time for spruce: rapid dampening of circadian rhythms in Picea abies (L. Karst)."*Plant and Cell Physiology* 55, no. 3 (2014): 535-550.
5. Hennessey, T.L., and Freeden, A.L., 1993. Environmental effects on circadian rhythms in photosynthesis and stomatal opening. Planta,189(3), pp.369-376.
6. Johnson, C.H. and Kyriacou, C.P., 2005. Clock evolution and adaptation: Whence and whither?. Annual Plant Reviews Volume 21: Endogenous Plant Rhythms, pp.237-260.
7. Johnstone, J.A. and Dawson, T.E., 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences, 107(10), pp.4533-4538.
8. Lombardozzi, D.L., Zeppel, M.J.B., Fisher, R.A. and Tawfik, A., 2015. Observed nighttime conductance alters modeled global hydrology and carbon budgets. Geoscientific Model Development Discussions, 8(12), pp.10339-10363.
9. McClung, C.R., 2006. Plant circadian rhythms. The Plant Cell, 18(4), pp.792-803.
10. Ogle, K., Lucas, R.W., Bentley, L.P., Cable, J.M., Barron-Gafford, G.A., Griffith, A., Ignace, D., 2012. Differential daytime and night-time stomatal behavior in plants from North American deserts. New Phytologist, 194(2), pp.464-476.
11. Resco, de Dios, V., Hartwell, J. and Hall, A., 2009. Ecological implications of plants' ability to tell the time. Ecology letters, 12(6), pp.583-592.
12. Resco de Dios, V., Díaz-Sierra, R., Goulden, M.L., 2013. Woody clockworks: circadian regulation of night-time water use in Eucalyptus globulus. New Phytologist, 200(3), pp.743-752.
13. Resco de Dios, V., Loik, M.E., Smith, R., Aspinwall, M.J. and Tissue, D.T., 2016. Genetic variation in circadian regulation of nocturnal stomatal conductance enhances carbon assimilation and growth. Plant, cell & environment, 39(1), pp.3-11.

Acknowledgments

Thanks to Tyler Taunton and Mona Bourell for expediting my overnight data collection campaigns at the San Francisco Botanical Garden, Martin Grantham for greenhouse troubleshooting and plant care at SFSU, and Tasha Kayatsky, Ariane Kinnear, Ian Mounts, and Kevin Shlosberg for helping with various parts of data collection and analysis -- and for putting up with me while I was grumpy and sleep-deprived.

Future Directions

While stomatal conductance may not be under circadian regulation in gymnosperms, measurements of overnight water use suggest that gymnosperms continue to transpire long past nightfall, with a slight but intriguing rise around midnight. Relatively little is known about how gymnosperms use water at night. Because water is one of the most important physiological limitations plants face, understanding what controls water use in these plants is essential to predicting how they will respond to climate change – and how global hydrology will shift in response to changes in plant transpiration.