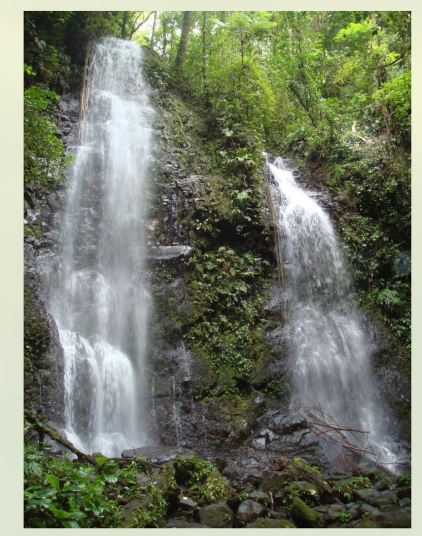
The contribution of large trees to total transpiration rates in a pre-montane tropical forest and its implications for selective logging practices

Graciela L. Orozco[1], Georgianne W. Moore[2], Gretchen R. Miller[2]

[1]Kansas State University; [2]Texas A&M University

Introduction & Objective

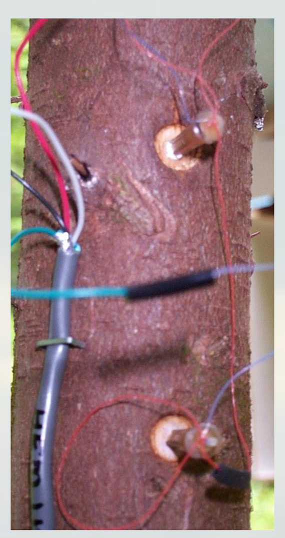
In the humid tropics, selective logging practices are common where large valuable timber is removed while the remaining forest is left relatively undisturbed. However, little is known about the impact of selective logging on site water balance. Because large trees have very deep sapwood and exposed canopies, they tend to have high transpiration. Removing these large trees has the potential to greatly affect hydrologic cycles as well as ecosystem dynamics. Previous studies suggest local hydrology is greatly affected by aboveground energy partitioning (Loescher 2005) with solar radiation and vapor pressure deficit being the primary drivers of transpiration. The first objective was to evaluate the methods used for scaling sap flow measurements to the watershed with particular emphasis on large trees. The second objective of this study was to determine the relative contribution of large trees to site water balance. Understanding the degree to which transpiration of tropical forests is impacted by logging of large trees will aid in predicting alterations in site ecohydrology.

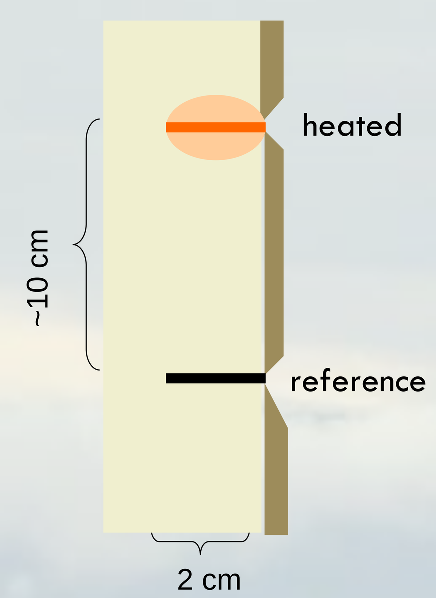


Methods

The study site is a pre-montane transitional forest located at the 96-ha Texas A&M University Soltis Center located in North Central San Ramón, Costa Rica. The site is comprised of primary and secondary forest due to selective logging. Transpiration was monitored in a 10-ha sub-watershed within a 30-m diameter plot using 20 mm heat dissipation sensors (Granier 1987) in 15 trees that were grouped by size. Two sets of probes were placed in each tree. The top probe was heated at a constant voltage. Temperature differences were recorded by a copper-constantan thermocouple in the center of the heating coil. The lower probe was unheated and served as the reference probe (**Figure 1**). In six of the largest trees, depth profiles were recorded at 10 mm intervals to a depth of 60 mm using compensation heat pulse sensors. Measurements were recorded every 10 min. To estimate sapwood basal area of the watershed, stand surveys were conducted in three 30-m-diameter plots. In each plot, we measured basal area of all trees and estimated sapwood basal area from sapwood depth measured in nearly half of the trees. Climate data was measured every 5 min at a weather station near the study site. Transpiration was estimated from the scaled sap flux measurements and estimated sapwood basal area. Resulting, transpiration rates were adjusted for velocity at varying depths.

Figure 1. *Granier heat dissipation sensors were installed into 15 trees. Sap flux velocities from the sensors were used to calculate transpiration rates.*





At night, sap flow is assumed to be zero. This yields our max ΔT. During the day, as water travels up the stem, temperature (ΔT) varies with flow rate.

Granier Equation

Sap Flux velocity (v)

$$V = 0.119\left(\frac{\Delta T_{max} - \Delta T}{\Delta T}\right)^{1.231}$$

Figure . *Trees 9 and 15 were chosen to represent typical trees with deep sapwood. Flow velocities are greatest in outer 2 cm of sapwood, with declines of 17% and 25% in 2-4 cm and 4-6 cm ranges, respectively.*

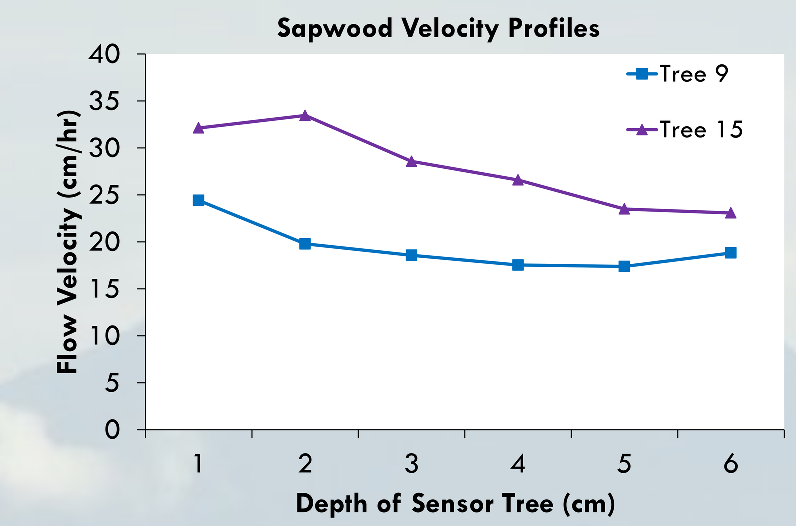
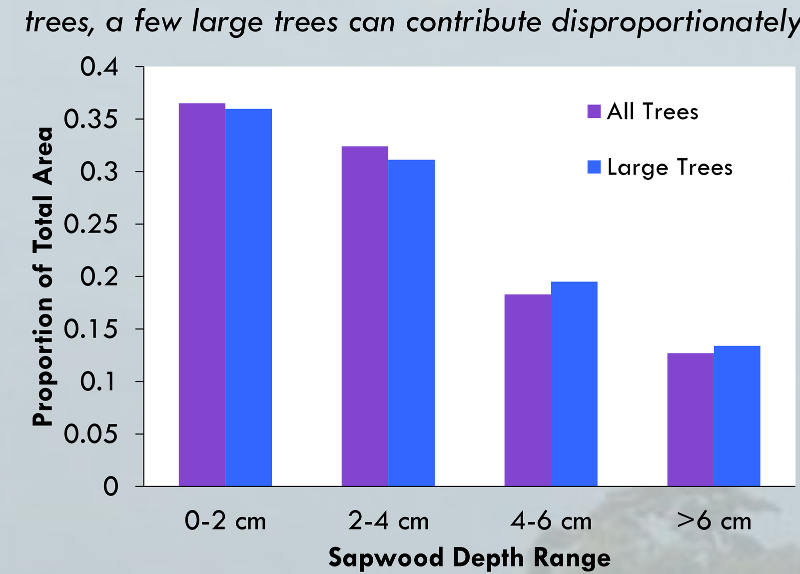


Figure 3. *Most of the sapwood in the forest is at depths less than 2 cm. Because of deeper sapwood, large trees hold a greater proportion of their total sapwood at depths greater than 4 cm. With more total sapwood than smaller trees, a few large trees can contribute disproportionately to total transpiration.*



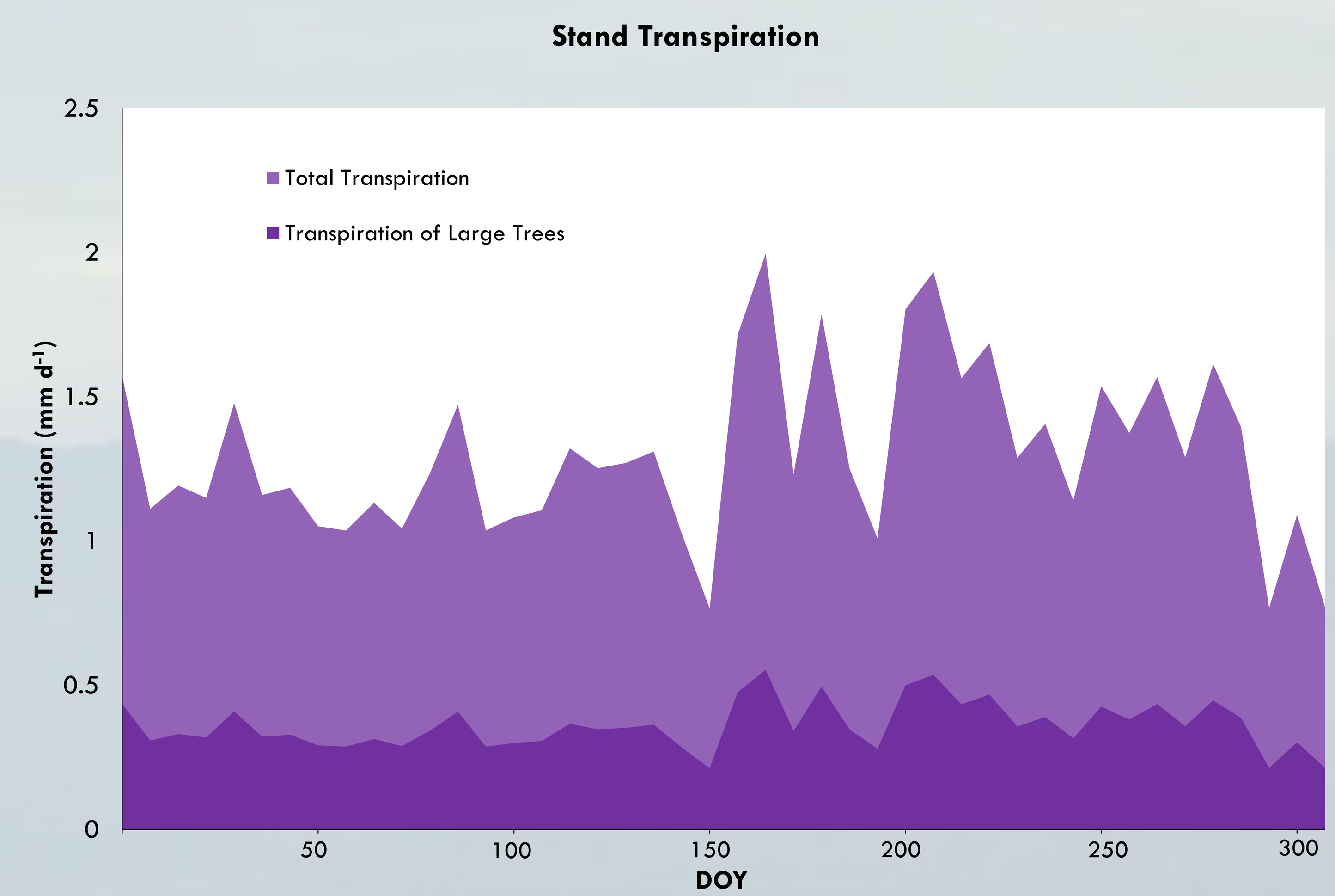


Figure 4. *7-day running mean of stand transpiration from DOY 16-319. Large trees contribute significantly (27.7%) to total stand transpiration. Selective logging of large tropical trees will greatly impact site ecohydrology. We estimate that removal of the large trees would cause a 3.62% increase in streamflow, which would significantly affect ecosystem dynamics. The system would also show an immediate decrease in transpiration rates until additional vegetative growth was able to compensate for the removal of large trees.*

Figure 5. *Daily transpiration correlates significantly with variations in solar radiation (I_s). System is highly energy dependent; transpiration would increase if light was non-limiting.*

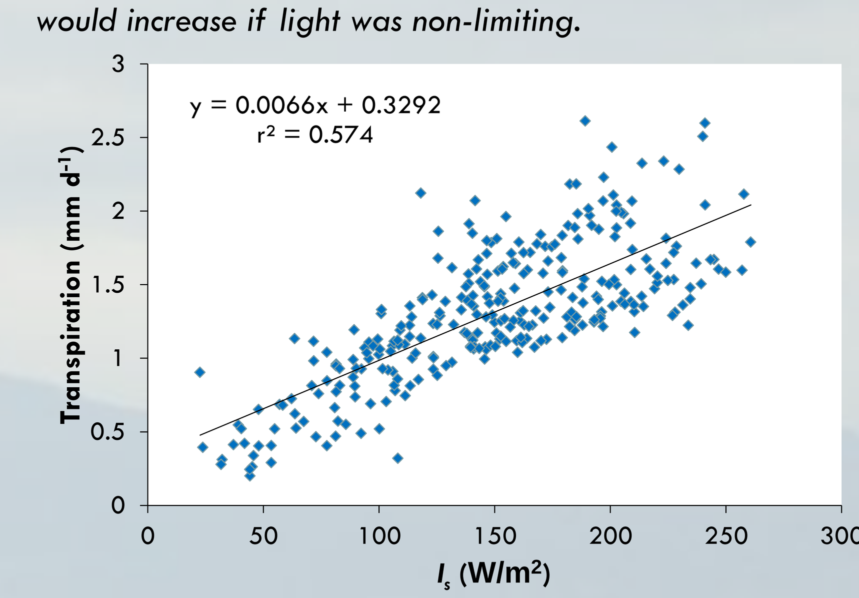
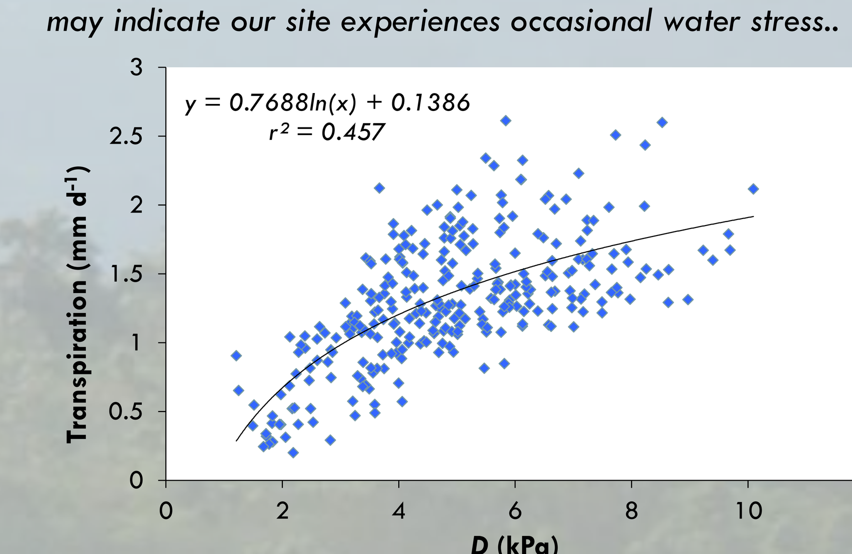


Figure 6. *Daily transpiration is also a function of variation in vapor pressure deficit (**D**). System experiences saturation when **D** is high, and transpiration levels off likely as a result of stomatal closure. This may indicate our site experiences occasional water stress..*



Results & Discussion

Xylem exhibited decreased conductance as depth of sapwood increased (**Figure 2**). An estimated 35% of total sapwood in this watershed is contained in the outer 2 cm of sapwood. The remaining 63.5% of sapwood is from depths greater than 2 cm, with nearly 13% of sapwood from depths beyond 6 cm (**Figure 3**). Total transpiration estimated solely from 0-2 cm averaged 1.72 mm d^{-1} (± 0.53 mm d^{-1}) while transpiration estimates based on velocity profiles averaged 1.49 mm d^{-1} (± 0.45 mm d^{-1}). Transpiration would have been overestimated by at least 15% without adjustments for velocity profiles. The largest 10% of trees disproportionately contributed to total transpiration. Trees with diameters greater than 110 cm represent over half of total basal area and 32% of total sapwood area. Trees with deep sapwood contributed over 27% to total stand transpiration (**Figure 4**). Transpiration is not only highly impacted by large trees but also by the energy demands of the system (**Figures 5 & 6**). Solar radiation (I_s) and vapor pressure deficit (**D**) accounted for 57% and 46% of the variability in transpiration, respectively. I_s is the primary driver of transpiration in tropical forests while ***D*** is a secondary predictor, which is consistent with other tropical regions (JB Fisher 2009).

Conclusion

The results of this study illustrate the importance of large trees in watershed-scale transpiration. Monitoring sap velocity profiles of large trees is imperative in avoiding overestimations of total transpiration. The importance of large trees to total transpiration is significant from a forest management perspective. Selectively logging only the very largest trees, which is a common practice among tropical forests of Costa Rica, will likely disproportionately impact site water balance unless water use of smaller trees can fully compensate. With fewer numbers of large trees, aboveground energy partitioning as driven by solar radiation and vapor pressure deficit also has the ability to greatly affect local hydrology. Large trees are significant contributors to both the total watershed-scale transpiration in tropical forests as well as system energy dynamics. This co-dependent relationship is important in predicting transpiration and possible alterations in water and energy budgeting. Further investigation into the significance of large trees in ecosystem dynamics will become increasingly important in understanding site level ecohydrology.

References

Granier, A. (1987). "Evaluation of transpiration in a Douglas-fir stand by means of sap flow measurements." Tree Physiology **3**(4): 309-320.

Fisher JB, Malhi Y, Bonal D, Da Rocha HR, De Araujo AC, Gamo M, Goulden ML, Hirano T, Huete AR, Kondo H, Kumagai T, Loescher HW, Miller S, Nobre AD, Nouvellon Y, Oberbauer SF, Panuthai S, Roupsard O, Saleska S, Tanaka K, Tanaka N, Tu KP. (2009) "The land-atmosphere water flux in the tropics." Global Change Biology **15**(11): 2694-2714.

Loescher, H.w., H.I. Gholz, J.m. Jacobs, and S.f. Oberbauer. "Energy Dynamics and Modeled Evapotranspiration from a Wet Tropical Forest in Costa Rica." Journal of Hydrology 315 (2005): 274-94.

Moore, G.W. (2003). "Drivers and Variability in Transpiration and Implications for Stream Flow on Forests of Western Oregon." PhD Defense, Oregon State University.

Acknowledgments

This study took place as part of the 2012 Texas A&M Research Experience for Undergraduates in Costa Rica, which was funded by the National Science Foundation (NSF). I greatly appreciate the support of NSF in this research and a special thanks to Olivia Dodge, Esther Buckwalter, Nathan Tourtellotte, Kelly Brumbelow, Tony Cahill, and Robert Washington-Allen for all their logistical and technical support.