Are allometric relationships for mixed-conifer species generalizable? Implications for up scaling in sap flow applications

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1.0 Background

Plant transpiration strongly modulates water balance (**Equation 1**) in mountain ecosystems across the southwestern USA by influencing the fraction of precipitation that ultimately reaches streams and aquifers. Precise measures of transpiration in montane vegetation (**Figure 1**)is therefore critical for improved water balance closure estimates across catchment and landscape level (**Figure 2**). An inexpensive and robust method to quantify the water use strategy of vegetation is to measure their sap flux. Sap flux density measurements obtained at the point level by sap sensors are scaled to sap flow rate at the tree level and further high level by sapwood cross-sectional area **(Figure 2).**

Allometric relationships are established to primary size measures **[diameter at breast height (*DBH*), canopy diameter (*CD*) and tree height (*H*)]** with sapwood cross sectional area **(A_s)**] because direct observation of sapwood is impossible without damaging the tree .Allometric relationships vary by tree species thereby requiring unique correlation coefficients and scaling exponents. While species-specific allometric relationships have been established in the literature, it is unclear whether these relationships are influenced by first order effects such as aspect, elevation or soil texture.

The goal of this research is to determine whether allometric relationships are generalizable across sites with similar species but different parent materials, slopes, and aspects. To do this, we analyzed the allometric relationship of co-occurring deciduous and evergreen vegetation across two high and mid elevation mixed forest ecosystem in New Mexico and Arizona.

Water Balance

$\Delta S = P - ET - R$ ……(Equation 1)

ΔS = Change in water storage; P = Precipitation; ET = Evapotranspiration; R = Surface Runoff

ET = Plant Transpiration (T) + Soil Evaporation (E)

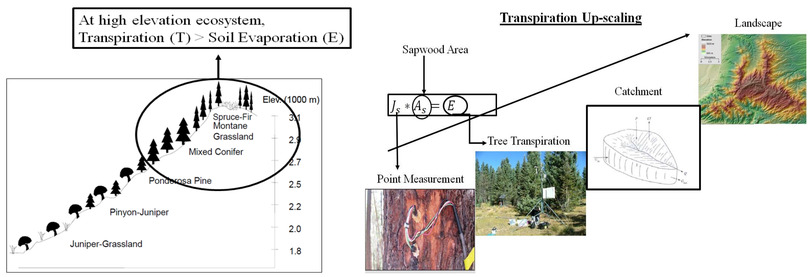

Figure 1: Plant transpiration strongly modulates water balance across high elevation ecosystem.

Figure 2: Point measurement of plant transpiration (*Js*) is scaled up by sapwood cross sectional area (*As*) to obtain tree transpiration (*E*).

2.0 Objective

- Establish the allometric relationship between sapwood area and easily measured tree variable like diameter at breast height (DBH), Tree Height (H) and Canopy Diameter (CD) .
- Analyze whether this relationship (for similar evergreen and deciduous trees) is a function of tree age, soil texture , elevation and aspect.

3.0 Study Site

- Our study sites were located in the Valles Caldera National Preserve (*VCNP*), located in Sandoval County in northern New Mexico and in the Santa Catalina Mountains of the Coronado National Forest, located northeast of Tucson, Arizona **(Figure 3)**.
- At *VCNP*, approximately **65% of the precipitation fall as snow** between October and April and the remaining **35 % as rain** between July and September. In the Santa Catalina Mountains, nearly **25 %** of that precipitation originates from North American Monsoon while **75 %** fall in the form of snow and rain between December and March.
- Of the four study sites at *VCNP*, vegetation at the ponderosa pine eddycovariance tower site was dominated by ponderosa pine (*Pinus ponderosa*) while the vegetation at higher site was dominated by spruce (*Picea engelmanii*). The other two sites, located less than two miles from the spruce site and at a similar elevation was part of the Jemez River Basin High-Elevation Zero Order Basin (*JRB ZOB*).
- Our two high elevation study sites (**Granite and Schist**) were located in Marshall Gulch, a 1.54 Km^2 catchment within the Upper Sabino Canyon watershed. Dominant vegetation within the catchment include Douglas-fir, fir, ponderosa pine and Douglas maple . Our third field site at Santa Catalina mountain was located at **Oracle Ridge** . The dominant vegetation at this site was ponderosa pine. Summary of the study sites has been provided in **Table 1.**

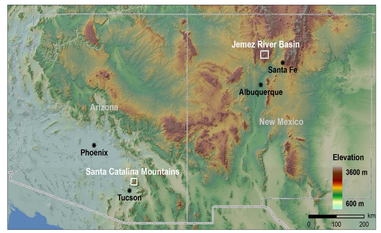

Figure 3: Map our study site at Jemez River Basin and Santa Catalina Mountains .

Site	MAT (oC)	MAP (mm)	Elevation (m)
Jemez River Basin, New Mexico			
Mixed Conifer	6.4	646	2500
Ponderosa Pine	9.8	550	2200
Jemez SE ZOB	6.4	646	3014
Jemez SW ZOB	6.4	646	3000
Santa Catalina Mountain, Arizona			
Schist	10.4	940	2349
Granite	10.4	940	2396
Oracle Ridge	11.9	840	2388

Table 1: Mean annual temperature (MAT), mean annual precipitation (MAP) and elevation of the 7 study sites

4.0 Method

Summary of the data collection at each of the 7 field site and statistical analysis has been provide in Figure 4. Table 2 provides a summary of the descriptive statistics of the trees that were sampled from each of the field sites.

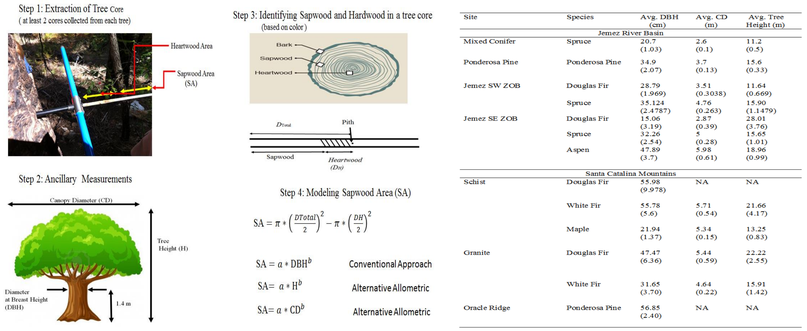

Figure 4: Establishment of allometric relationship involved collection of tree cores, measurement of tree dimensions, calculating sapwood area from tree cores and statistical analysis.

Site	Species	Avg. DBH (cm)	Avg. CD (m)	Avg. Tree Height (m)
Jemez River Basin				
Mixed Conifer	Spruce	20.7 (1.03)	2.6 (0.1)	11.2 (0.5)
Ponderosa Pine	Ponderosa Pine	34.9 (2.07)	3.7 (0.13)	15.6 (0.33)
Jemez SW ZOB	Douglas Fir	28.79 (1.969)	3.51 (0.3038)	11.64 (0.669)
	Spruce	35.124 (2.4787)	4.76 (0.263)	15.90 (1.1479)
Jemez SE ZOB	Douglas Fir	15.06 (3.19)	2.87 (0.39)	28.01 (3.76)
	Spruce	32.26 (2.54)	5 (0.28)	15.65 (1.01)
	Aspen	47.89 (3.7)	5.98 (0.61)	18.96 (0.99)
Santa Catalina Mountains				
Schist	Douglas Fir	55.98 (9.978)	NA	NA
	White Fir	55.78 (5.6)	5.71 (0.54)	21.66 (4.17)
	Maple	21.04 (1.37)	5.34 (0.15)	13.25 (0.83)
Granite	Douglas Fir	47.47 (6.36)	5.44 (0.59)	22.22 (2.55)
	White Fir	31.65 (3.70)	4.64 (0.22)	15.91 (1.42)
Oracle Ridge	Ponderosa Pine	56.85 (2.40)	NA	NA

Table 2: Descriptive statistics (Mean and SE) of the trees that were analyzed at each of the 7 sites.

- Tree core samples and tree survey were conducted in summer, 2012.
- Exponential Equation was used to reflect the growth process. The coefficients (*a, b*) are species specific.
- Statistical Modeling: We used the non linear regression approach. The reduced model was compared to the full model. In the reduced model, only the independent variable was included (DBH, H, CD). In the full model, we included the categorical model (texture, aspect, elevation).
- The 95% confidence interval was used to determine whether the categorical variables influenced the allometric relationship.

5.0 Preliminary Results:

Figures 5 and 6 highlights allometric relationship for Spruce and Ponderosa Pine. Preliminary results do not suggest any influence of aspect and elevation on the allometric relationship for spruce and ponderosa pine respectively.

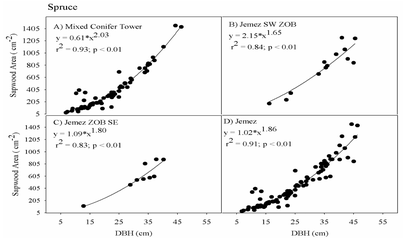

Figure 5 : Allometric relationship for Spruce was established for each of the 3 sites (Mixed Conifer (Fig. 5A), Jemez SW ZOB (Fig. 5B) and Jemez SE ZOB (Fig. 5C). In Figure 5D, we have established allometric relationship for spruce by combining dataset from all the 3 sites.

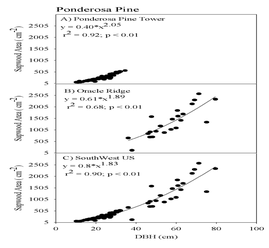

Figure 6 : Allometric relationship for Ponderosa Pine was established for each of the 2 sites (Ponderosa Pine (Fig. 6A)and Oracle Ridge (Figure 6B). In Figure 6C, we have established allometric relationship for South West USA by combining dataset from AZ and NM.

5.1 Influence of Aspect

- Figure 7 highlights the preliminary results of the allometric relationship for douglas fir from the Jemez and Santa Catalina mountain study site.
- The parameter coefficients for Douglas fir are significantly different between the Jemez SW (Fig 7A) and Jemez SE (Fig 7B) aspect, thereby suggesting that aspect (Figure 8) may play a role in modulating the relationship between sapwood area and DBH.

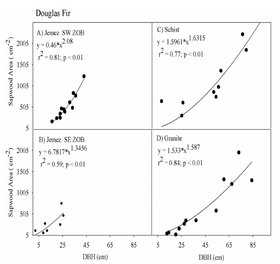

Figure7: Allometric relationship for douglas fir from the Jemez and Santa Catalina Mountain study site.

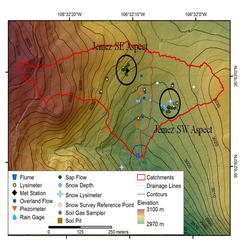

Figure 8: Analysis of the allometric relationship for similar vegetation as a function of aspect in Jemez, NM

5.2 Influence of Soil Texture

- White fir have a higher transpiration rate at the schist catchment compared to the granite catchment on account of the difference in the texture (Figure 10).
- Average soil depth range between 0.7 to 1.2 m in the schist catchment compared to 0.6 – 0.9m in the granite catchment.
- However that did not significantly modulate the allometric relationship between sapwood area and DBH at the two sites (Figure 9).

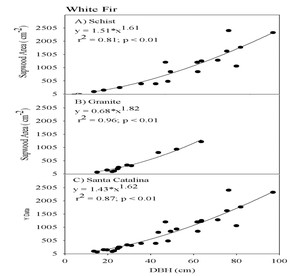

Figure 9: Allometric relationship for White Fir at the Schist and Granite catchment. Figure 10C is the allometric relationship established for White Fir by combining the schist an granite catchment data.

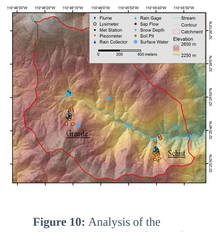

Figure 10: Analysis of the allometric relationship for similar evergreen trees in Marshall Gulch, AZ as a function of soil texture..

5.3 Alternative Approach to Model Sapwood Area

- Neither canopy diameter nor tree height were strongly correlated with sapwood area for all the vegetation at Jemez as evident from the weak R2 values (Table 3).
- The correlation was weaker for deciduous vegetation (Aspen) compared to evergreen trees.
- Use of alternative model structure (example – linear) did not significantly improve model performance (Results not shown)
- Similar weak correlation was obtained for the Santa Catalina Mountain Study site (Result not shown).

Location	Specie	Parameter	a	b	R^2	p - value
Jemez SW ZOB	Spruce	Canopy Dia.	68.37	1.554	0.5659	< 0.01
		Tree Height	14.21	1.442	0.7688	<0.01
	Douglas Fir	Canopy Dia.	86.96	1.44	0.768	<0.01
		Tree Height	6.078	1.822	0.543	<0.01
Jemez SE ZOB	Spruce	Canopy Dia.	33.17	1.792	0.5344	<0.01
		Tree Height	4.027	1.813	0.78669	<0.01
	Douglas Fir	Canopy Dia.	25.4	2.18	0.726	<0.01
		Tree Height	0.1687	2.194	0.7263	<0.01
	Aspen	Canopy Dia.	191.2161	0.6963	0.242	<0.01
		Tree Height	1.408	2.083	0.4294	<0.01
Mixed Conifer Tower	Spruce	Canopy Dia.	64	1.773	0.633	<0.01
		Tree Height	7.269	1.569	0.4397	<0.01
Ponderosa Pine Tower	Ponderosa Pine	Canopy Dia.	136.256	0.5232	0.187	<0.01
		Tree Height	1.764	1.781	0.33	<0.01

Table 3: Summary of the correlation of tree height and iameter with sapwood area for evergreen and deciduous species at Jemez River Basin.

6.0 Conclusions

- The allometric relationship can be generalized for some species (white fir and spruce) while site specific equations may be required for douglas fir.
- Mountain topography can create heterogeneity in transpiration trends on account of variation in precipitation, soil moisture and atmospheric conditions.
- However, a generalized allometric equation eliminates logistical challenge in obtaining allometric equations across an elevation gradient and thereby simplifies transpiration estimate across space and time.

7.0 Work in Progress

- Analysis of the model (SA vs DBH) residue for each specie for heteroscedasticity
- Analysis of the role of categorical variables in modulating the allometric relationship between sapwood area and tree height (or canopy diameter)
- Analysis of the influence of tree age on the allometric relationship

Acknowledgements

This project was funded by the NSF National Critical Zone Observatories Program (EAR-0724958). A very special note of thanks to Dr Valerie Trouet, Dr David Moore, Emily Dynes, Ian Shiach , Dr Julia N.Perdrial , Michael Pohlmann and Lori Lovell during the collection of tree core samples and tree survey.