Comparisons of Sap Flux and Transpiration between an Old Growth and Second Growth Forest

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Abstract

Northern Wisconsin was heavily logged in the past. As a result much of the old growth forest has been removed and new forest has regrown. Effects of land use legacies on transpiration have not been investigated in Northern Wisconsin forests. This experiment examined sap flux and transpiration using Granier sensors. Eight trees in sites at the Notre Dame Environmental Research Center and of eight trees in the Sylvania Wilderness old growth forest were selected for comparison. Three sugar maples *(Acer saccharum)*, three eastern hemlocks *(Tsuga canadensis)*, and two yellow birches *(Betula alleghaniensis)* were chosen and compared. No difference was found between transpiration at old growth and transpiration at the second growth forest. A significant difference was found for sap flux between sugar maple (*Acer saccharum)* and eastern hemlock (*Tsuga canadensis)* at the Notre Dame sight. No significant difference was found among trees at the Sylvania Wilderness.

Introduction

Landscape legacies and past management practices can influence ecosystems well into the future. Knowing the effects of past management is important for maintaining forests, understanding their responses to disturbances, and managing for old growth characteristics (White and Lloyd 1994). In forests, legacies of agricultural use and logging can decrease understory plant diversity, decrease amount of stored carbon stored in forest ecosystems, and encourage species homogenization (Dupouey et al, 2002, Foster et al 1998, Foster et al 2003). Human interaction with ecosystems can also influence the type of species present in different ecosystems, which in turn may affect the ability of an ecosystem to respond to other disturbances such as fire or wind (Foster et al 2003). Many of these effects are visible in forests in eastern North America. In many parts of the eastern forests, past settlement by European immigrants was accompanied by logging for timber and the creation of space for agriculture (Rhemtulla et al, 2009). Consequently much of the old growth in the eastern forests is gone and has regrown as second and third growth forests.

Wisconsin forests are no exception these trends. Wisconsin was heavily forested until about 1870-1920, when much of the forest was clear cut and burned for timber and agriculture (Rhemtulla et al, 2009). In the past, the landscape was mainly dominated by white pine *(Pinus strobus)*, which was a valuable timber crop. Most of the pine was harvested along with other conifers such as red pine *(Pinus rensinosa)* and eastern hemlock *(Tsuga canadensis)*. The removal of forest through clear cutting and burning favored early successional species such as aspen *(Populus spp)* and birch *(Betula spp)*, which began to dominate the forest landscape as other trees were removed (Rhemtulla et al, 2009, Steen-Adams et al, 2011).

When forests are cleared reforestation is often classified into specific stages. One way of understanding forest regeneration is through phases of regrowth. Chadwick Oliver describes this in his model of forest regrowth after major disturbances. Immediately after a forest is cleared, new pioneer species move into a forest and a new stand will begin in a phase called stand initiation. The phases of stem exclusions, where new trees do not reach the canopy, and understory regrowth follow. Eventually the forest will reach a state of old-growth, where understory plants gradually come to dominate the canopy. (Oliver, 1980). Another way to understand forest regrowth is through the biomass accumulation model described by Bormann and Likens. Forests first lose biomass as the stand begins to regenerate, in the reorganization phase, then the forest gains biomass over a century or more, which is referred to as the aggradation phase, then the forest goes through transition phase of biomass loss, and finally reaches a steady state phases where biomass fluctuates (Bormann and Likens 1979). The steady state phase is similar to old-growth phase of forest regrowth.

Northern Wisconsin forests are mainly second growth forests in the aggradation phase of forest succession. In normal forest development, this is the phase where pioneer species and shade intolerant species such as aspen and birch would begin to die and be replaced by more shade tolerant species. Forest succession in Wisconsin is incomplete and ongoing and this is evident in the fact that much of the forests in Wisconsin have seen a decline in many shade tolerant species, such as most conifers (Rhemtulla et al). However, there is some evidence of the redevelopment of forests in the presence of mid- successional species such as sugar maple *(Acer saccharum*) and red maple *(Acer rubrum)* in northern Wisconsin.

Many aspects of a forest change as it ages. One aspect of interest is how forest transpiration changes as a forest ages. Transpiration is an important part of the hydrologic cycle and can contribute to local climate. Transpiration can be affected by many different factors such as vapor pressure deficit, weather, wood anatomy, and leaf anatomy. In upland oak forests in Tennessee trees with diffuse porous wood were found to have higher sapwood area and found to contribute more to transpiration compared to ring porous trees (Wullschleger et al 2001). A study on mixed temperate forests in New England found that broadleaved oak species had higher rates of sap flux and transpiration compared to coniferous species (Catovsky et al 2002). In forests in western Oregon, sap flux was found to be greater in younger mature forests compared to old growth forests (Moore et al 2004). This experiment will examine how past forest management has impacted transpiration in a second growth stand in northern Wisconsin. Transpiration and sap flux data from both the second growth forest and the old growth stand in the Sylvania Wilderness, which has never been logged, were collected. The two sites will be compared to see if there is a difference in transpiration. Since previous studies indicate that that sap flux tended to be higher in younger stands, I predict that the second growth forest will have higher rates of sap flux and transpiration compared to the old growth. Additionally, since sap flux was found to be higher in diffuse porous trees and in broadleaved trees, I predict that these types of trees will have higher rates of sap flux.

Materials and Methods

Site description:

This study was conducted at the University Of Notre Dame Environmental Research Center (UNDERC) in Northern Wisconsin, near the border of Michigan. UNDERC consists of a mix of landscape types including wetlands, lakes, and forests. This site was first owned by lumber companies and then by the US Forest Reserve. It had been logged until the University of Notre Dame was given part the property by Martin J Gillen, a donor. Other parts were acquired in a land swap with the US Forest Reserve in 1943 (UNDERC Program Review). After Notre Dame acquired the property, logging activities ceased and the forest was allowed to regrow for use by university staff. The logging and subsequent regrowth made the forests at UNDERC ideal for understanding how land use legacies affect a forest and for making comparisons between a second growth and an old growth forest.

The study site is located near Plum Lake on the southeastern portion of the property. The stand consists of eastern hemlock *(Tsuga canadensis)*, sugar maple *(Acer saccharum*), and birch *(Betula spp.)*. Other species such as cedar *(Cedrus spp)* and balsam fir *(Abies balsamea)* were present in the stand but excluded due to low prevalence. Eight trees were measured: three eastern hemlocks, three sugar maples, and two yellow birches (*Betula alleghaniensis)*. These were chosen in order to represent the species composition within the stand. Measurements from this stand will be compared to previous measurements already taken as a part of the ChEAS effort at the Sylvania Wilderness in 2003. The Sylvania Wilderness site is dominated by eastern hemlock or sugar maple, with yellow birch *(Betula alleghaniesis),* basswood *(Tilia americana),* and ironwood *(Ostrya viginiana)* (Tang et al, 2006).

Sap flux measurements

Sap flux measurements were taken using homemade Granier sensors. The sensors were connected to a 12 volt battery and a datalogger through a four stranded interference shielding cable. The Granier sensors consisted of two probes. The first probe was a heating probe, which distributes constant heat into the tree. The heating probe contains a copper-constantan thermojunction and a heating coil (Figure 1). The other is a reference probe containing only a thermojunction which acts as a reference for the heating probed. Any temperature difference between both probes generates a voltage difference which is read by the datalogger. In order to keep the heat sent to the tree constant, voltage supplied from a battery is moderated by voltage regulators. Specific voltages were calculated for each sensor by measuring the resistance of individual sensors and applying it to the equation for electrical power:

$$P = I^2 \cdot R$$

Where *P* is the electrical power in watts, *I* is the current in amps, and *R* is the resistance in ohms. From this equation, current required for each sensor to work at 0.2 watts was calculated. The calculations were then applied to ohms law:

$$V = I \cdot R$$

Where *V* is the voltage measured in volts, *I* is the current in amps, and *R* is the resistance in ohms. The resistance of each sensor was measured such that the correct voltage was supplied by its voltage regulator. The heating probe was placed above the reference probe in the tree. The heating coil generated a difference in temperature which was measured as a voltage difference though the Seebeck effect from the thermocouple. The difference was modified through the sap flux flowing up the tree cooling the sensors. The voltages differences were recorded in the CR3000 Campbell Scientific datalogger (Davis et al, 2012).

Sap flux was measured constantly for two weeks. From those two weeks the same four days were randomly chosen from both the Plum Lake and Sylvania Wilderness site for comparison. Sap flux was calculated using the equation presented in Granier et al 1987:

$$J_s = 0.000119\left(\frac{\Delta T_0 - \Delta T}{\Delta T}\right)^{1.231}$$

Where J_s is sap flux density ($m \cdot s^{-1}$), ΔT_0 is the maximum temperature difference at zero sap flux (°C), and ΔT is the difference in temperature between the heating and reference probes (°C). Sapwood area was measured using tree cores taken from the trees at the site. Transpiration was calculated by multiplying cross sectional sapwood area by sap flux density.

Statistical Analysis:

Statistics were conducted using R. A two sample t-test was used to compare average sap flux between each site, and a one way ANOVA was used to compare sap flux and transpiration among species within each site.

Results

Typical sap flux for a single sensor (Figure 2), and for all sensors in trees on July twelfth for both Plum Lake and the Sylvania Wilderness are shown (Figure 3, Figure 4). Sap flux and transpiration at Plum Lake tended to peak around mid-day, between 11:00 and 15:00 (Figure 3). Sap flux and transpiration at the Sylvania Wilderness also tended to peak around mid-day, from 11:00 to 16:00 (Figure 4).

For the four days measured, there was no significant difference in transpiration between the Sylvania Wilderness and the study site (p=0.295, Table 2, Table 3). No significant difference was found in sap flux density between the two sites (p=0.683). Among species at Plum Lake, sugar maple (*Acer saccharum)* had the highest sap flux density, followed by yellow birch *(Betula alleghaniensis)*, and eastern hemlock *(Tsuga canadensis)*. Yellow birch had the highest transpiration, followed by sugar maple, and eastern hemlock (Table 4). The difference in sap flux density among species at Plum Lake was significant (p=0.0227), but the difference in transpiration between species not significant (p=0.107). In order to determine which species relationship was responsible for the significant difference found among species, a Tukey's HDS post hoc test was performed. The significant difference between sap flux density in species was found between sugar maple and eastern hemlock (p=0.0209). For species at the Sylvania Wilderness site, yellow birch had the highest sap flux density, followed by sugar maple, and eastern hemlock had the lowest sap flux density. Yellow birch also had the highest transpiration, followed by sugar maple, and eastern hemlock had the lowest. The differences among species sap flux and transpiration were not significant (p=0.492, p=0.341).

Discussion

This experiment was performed to examine whether land use legacies affect forest transpiration. In this experiment, the second growth forest was no different than the old growth forest in terms of transpiration. This is inconsistent with what was predicted and what was previously found in other forests (Moore et al, 2004). It is likely that this forest has had adequate time to regenerate after logging and is nearing the final stages of succession, as most of the logging occurred several decades ago. There is also evidence of the recovery of the forest in the species composition. Forest composition after logging in northern Wisconsin was said to favor early successional species such as aspen and birch (Rhemtulla et al 2009, Steen-Adams et al 2011). Mid-successional eastern hemlock and sugar maple, which would typically not be present in a new forest, are both common in both stands that were measured.

The significant difference between sugar maple and hemlock is most likely explained by tree anatomy. Previous studies suggested that wood type could be important in determining levels of sap flux and transpiration (Wullschleger et al 2001). Our results are consistent with these findings as sugar maple is a diffuse porous tree and eastern hemlock is not. Hemlocks had smaller sapwood areas compared to the sugar maples at the Plum Lake site, which is also a factor in differences in sap flux between these two species. Additionally, eastern hemlock is a needleleaf tree with less surface area for water to evaporate off of compared to the broadleaved sugar maple, a fact which could have contributed to a difference in sap flux. These differences in sap flux due to leaf type would reflect results found in other forests (Catovsky et al 2002).

The Sylvania Wilderness site did not show the same relationship found at the Plum Lake. This may be due to the large sapwood area of the hemlocks selected for this experiment. A significant relationship would most likely be present if a larger sample size was used.

This experiment indicates that, with respect to transpiration, UNDERC seems to have recovered for past landscape management. It is important to understand how past management practices affect current landscape ecology for both resource management and landscape restoration. Past management techniques for harvesting timber and creating agricultural land have been a cause of major disturbance in the northern Wisconsin forests. Forests are an important source of resources and important for regulating the climate. Understanding how to manage forests without damaging them is important for their preservation. Additionally, knowing the effects of management practices on transpiration can lead to greater understanding on how those practices affect the climate. If transpiration in old growth and second growth forests does not differ, then land managers can consider these forest types more equally when addressing questions about climate.

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Works Cited

1) Bormann, F. H, and Likens, G.E. "Development of Vegetation After Clear Cutting: Species Strategies and Plant Community Dynamics." *Pattern and Process in a Forested Ecosystem*. New York: Springer-Verlag, 1979. N. pag. Print.
2) Catovsky, S., N.M. Holbrook, and F.A. Bazzaz. "Coupling Whole-tree Transpiration and Canopy Photosynthesis in Coniferous and Broad-leaved Tree Species."*Canadian Journal of Forest Resources* 32 (2002): 295-309.
3) Davis, T. W., Kuo C.M, Liang X, and Yu P.S. "Sap flux Sensors: Construction, Quality Control and Comparison." *Sensors* 12 (2012): 954-71.
4) Dupouey JL, Dambrine E, Laffite JD, and Moares C. "Irreversible Impact of Past Land Use on Forest Soils and Biodiversity." *Ecology* 83 (2002): 2978-984.
5) Foster DR, Swanson F, Aber J, Burke I, Brokaw N, Tilman D, and Knapp A. "The Importance of Land-Use Legacies to Ecology and Conservation." *Bioscience* 53 (2003): 77-88.
6) Foster DR, Motzkin G, and Slater B. "Land-Use History as Long-Term Broad-Scale Disturbance: Regional Forest Dynamics in Central New England." *Ecosystems* 1 (1998): 96-119.

7) Granier, A., P. Biron, N. Breda, J. Y. Pontailler, and B. Saugier. "Transpiration of Trees and Forest Stands: Short and Long-term Monitoring Using Sapflow Methods." *Global Change Biology* 2 (1996): 265-74.
8) Granier, A. "Evaluation of Transpiration in a Douglas-fir Stand by Means of Sap Flow Measurements." *Tree Physiology* 3 (1987): 309-20.
9) Mackay, D.S, Ahl D.E, Ewers B.E, Gower S.T, S.N Burrows S.N, Samanta S., and Davis K.J. "Effects of Aggregated Classification of Forest Composition on Estimates of Evapotranspiration in a Northern Wisconsin Forest." *Global Change Biology* 8 (2002): 1253-265
10) Moore, G W., Bond B J, Jones J A, Nathan Phillips, and Meinzer FC. "Structural and Compositional Controls on Transpiration in 40- and 450-year-old Riparian Forests in Western Oregon, USA." *Tree Physiology* 24 (2004): 481-91.
11) Oliver, Chadwick. "Forest Development in North American following Major Disturbances." *Forest Ecology and Management* 3 (1980): 153-68.
12) Rhemtulla, JM., Mladenoff DJ, and Clayton MK. "Legacies of Historical Land Use on Regional Forest Composition and Structure in Wisconsin, USA (mid-1800s-1930s-2000s)." *Ecological Applications* 19.4 (2009): 1061-078.
13) Steen-Adams MM, Mladenoff DJ, Langston NE, Liu F, and Zhu J. "Influence of Biophysical Factors and Differences in Ojibwe Reservation versus Euro-American Social Histories on Forest Landscape Change in Northern Wisconsin, USA." *Landscape Ecology* 26 (2011): 1165-178.
14) Tang, Bolstad, Ewers, Desai, Davis, and Carey. "Sap Flux–upscaled Canopy Transpiration, Stomatal Conductance, and Water Use Efficiency in an Old Growth Forest in the Great Lakes Region of the United States." *Journal of Geophysical Research* 111 (2006)
15) "UNDERC Program Review." 1999. MS. University Of Notre Dame
16) Wullschleger, S D., Hanson PJ, and Todd DE. "Transpiration from a Multi-species Deciduous Forest as Estimated by Xylem Sap flux Techniques." *Forest Ecology and Management* 143 (2001): 205-13.
17) White, David, and F. Thomas Lloyd. "Defining Old Growth: Implications for Management." (1994)

Tables

Table 1: List of supplies required to build Granier sensors and voltage regulators

For Sap Flux Sensor:
Hypodermic needle
Constantan-copper thermocouple wire
Heating coil wire
Four stranded interference shielding cable
Heat Shrink tubing
Crimp connects
Hookup wire
For Adjustable Voltage Regulators (For one regulator):
Breadboards
2.5 ohm Potentiometer
240 ohm Resistor
LM317 Voltage Regulator
0.1 µF Capacitor
For Data Collection:
Terminal Strips
CR3000 datalogger

Species	Sap Flux Density (m/s)	Transpiration (m^3/s)	Transpiration (L/hr)
Tsuga canadensis (1)	1.9872 x10^{-5}	3.81 x10^{-6}	1.5803
Tsuga canadensis (2)	2.8078 x10^{-5}	1.72 x10^{-6}	3.7881
Tsuga canadensis (3)	1.8576 x10^{-5}	1.76 x10^{-6}	1.6992
Acer saccharum (1)	7.2800 x10^{-5}	2.00 x10^{-6}	13.70329
Acer saccharum (2)	6.8988 x10^{-5}	3.99 x10^{-6}	6.3501
Acer saccharum (3)	4.1763 x10^{-5}	1.05 x10^{-6}	7.1846
Betula alleghaniensis (1)	4.5167 x10^{-5}	4.39 x10^{-7}	6.2045
Betula alleghaniensis (2)	5.4817 x10^{-5}	4.72 x10^{-7}	14.3635

Table 2: Sap flux density and transpiration for all trees sampled at Plum Lake.

Table 3: Sap Flux Density and transpiration for all trees sampled from the Sylvania Wilderness

Species	Sap Flux Density (m/s)	Transpiration (m^3/s)	Transpiration (L/hr)
Tsuga canadensis (1)	2.5116 x10^{-5}	2.40 x10^{-6}	8.6253
Tsuga canadensis (2)	2.4859 x10^{-5}	1.42 x10^{-6}	5.0947
Tsuga canadensis (3)	2.8644 x10^{-5}	4.34 x10^{-7}	1.5633
Acer saccharum (1)	5.0697 x10^{-5}	6.78 x10^{-6}	24.4199
Acer saccharum (2)	5.1892 x10^{-5}	1.58 x10^{-7}	0.5702
Acer saccharum (3)	3.0076 x10^{-5}	3.12 x10^{-6}	11.2492
Betula alleghaniensis (1)	1.6965 x10^{-5}	2.20 x10^{-6}	7.9181
Betula alleghaniensis (2)	8.5692 x10^{-5}	1.18 x10^{-5}	42.6172

Table 4: Average sap flux density and transpiration for each species at Plum Lake and the Sylvania Wilderness

Site	Species	Sap Flux Density (m/s)	Transpiration m^3/s	Transpiration (L/hr)
Plum Lake	*Acer saccharum*	6.12 x10^{-5}	2.52 x10^{-6}	9.08
	Betula alleghaniensis	4.99 x10^{-5}	2.86 x10^{-6}	10.28
	Tsuga canadensis	2.22 x10^{-5}	6.54 x10^{-7}	2.36
Sylvania Wilderness	*Acer saccharum*	4.42 x10^{-5}	3.36 x10^{-6}	12.10
	Betula alleghaniensis	5.13 x10^{-5}	7.02 x10^{-6}	25.30
	Tsuga canadensis	2.62 x10^{-5}	1.42 x10^{-6}	5.09

Figures

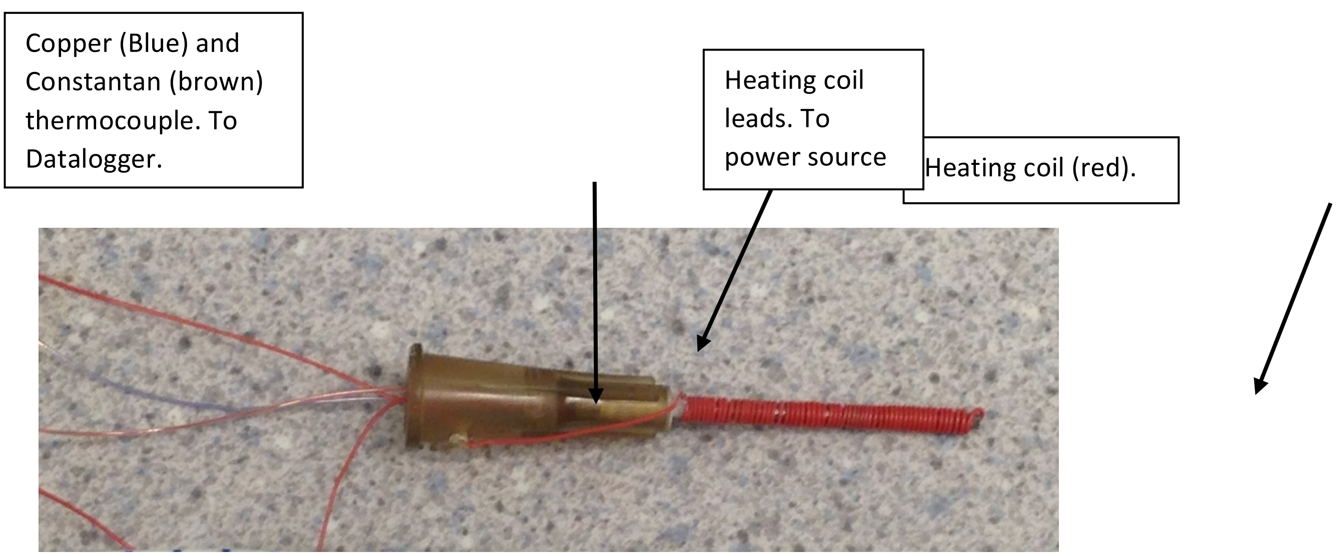


Figure 1: The heating probe of the sap flux sensor. Contains a heating coil and thermocouple.

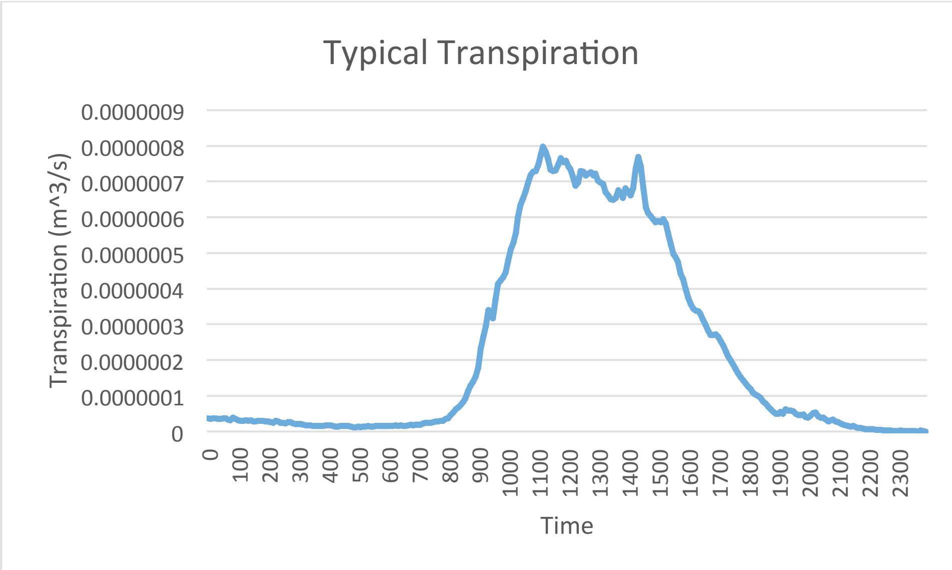


Figure 2: Typical transpiration over a period of twenty-four hours for a single sensor. Transpiration is highest mid-day and lowest at night.

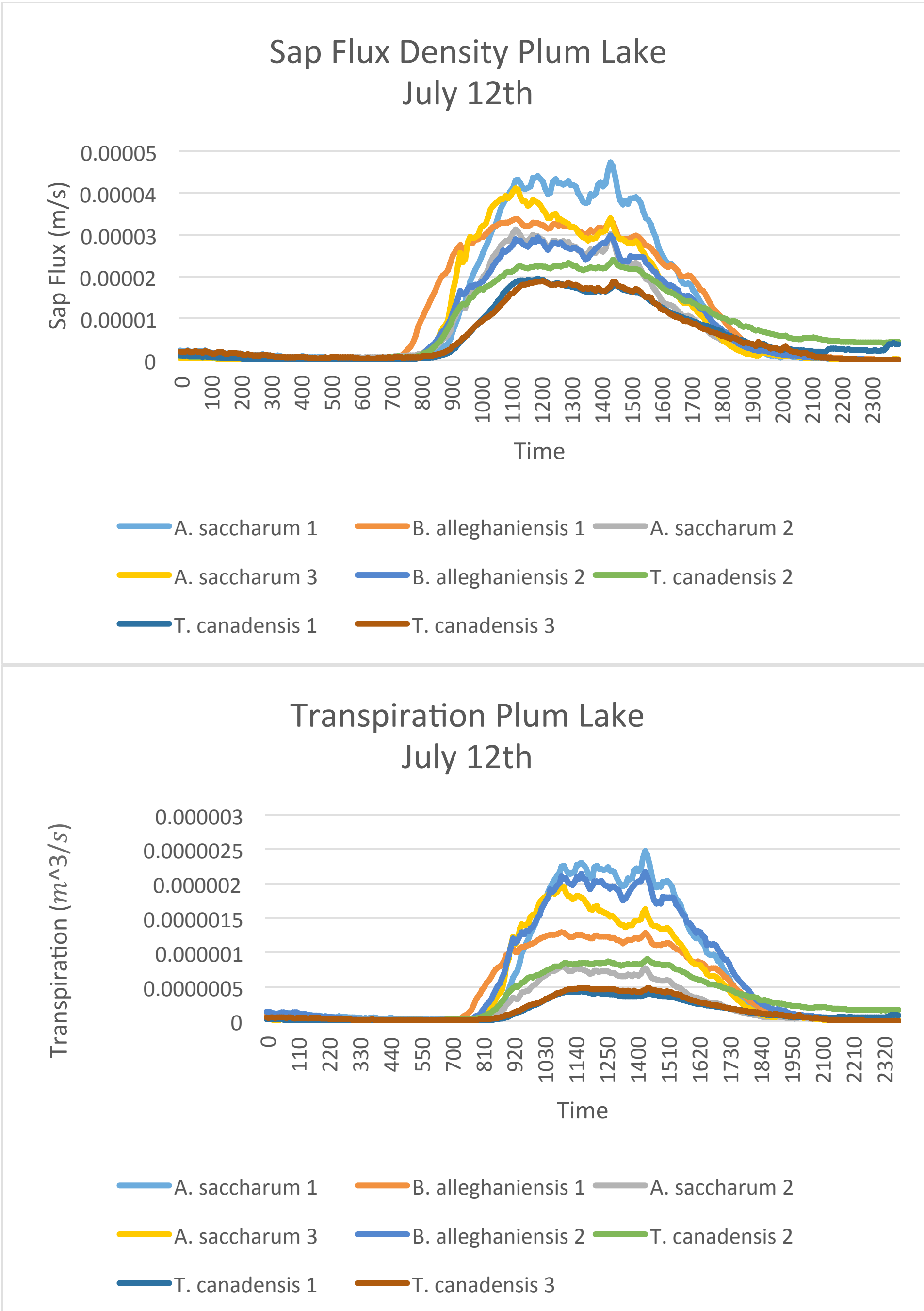
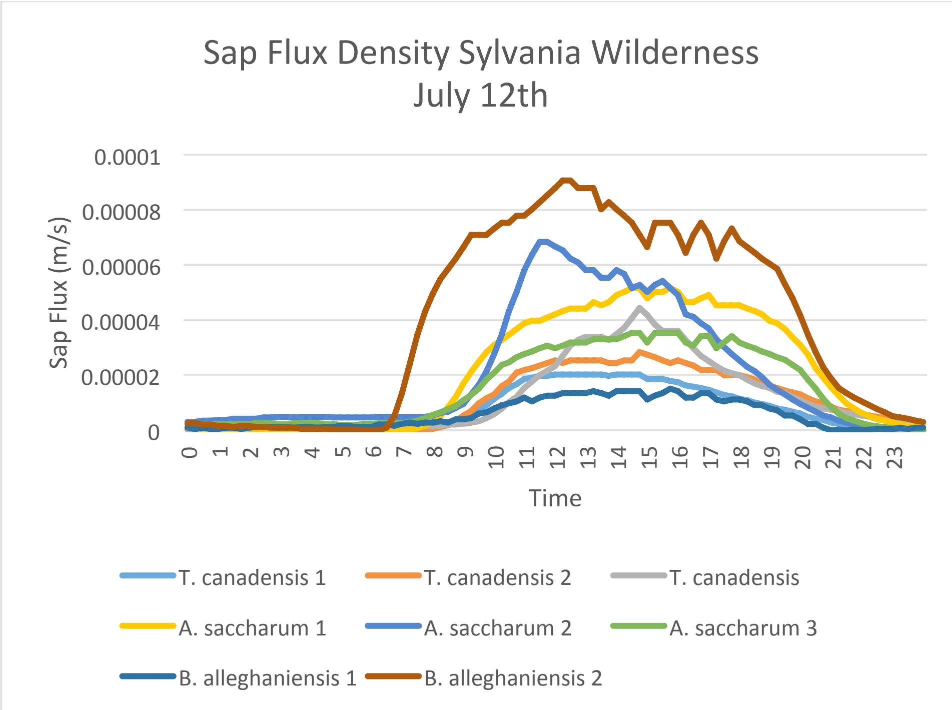


Figure 3: Sap Flux Density and Transpiration for all trees at Plum Lake on July 12th over a twenty-four hour period.



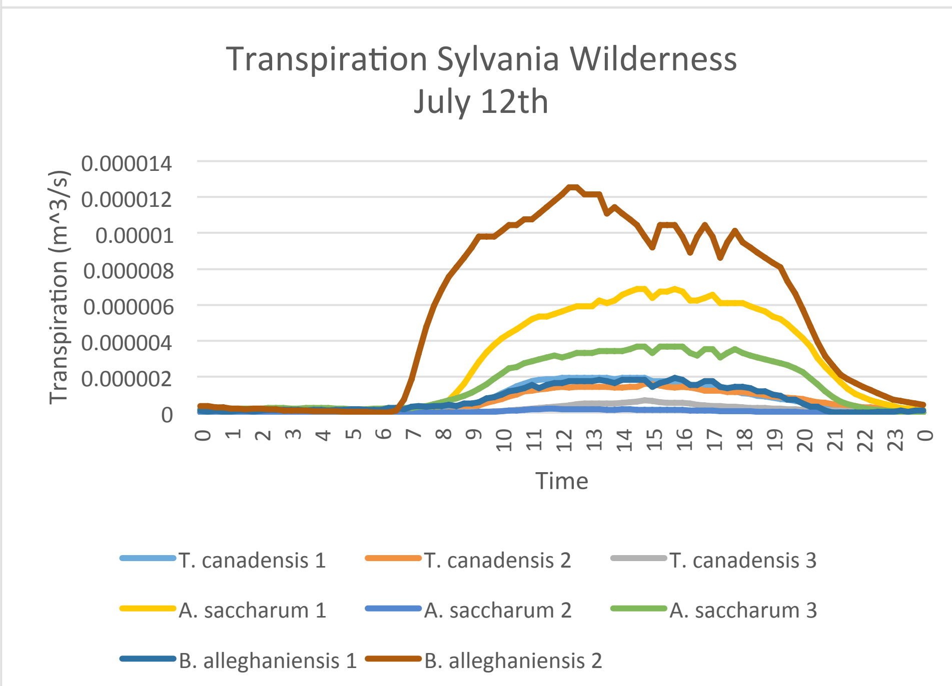


Figure 4: Sap flux density and transpiration over a twenty-four hour period for all trees sampled from the Sylvania Wilderness on July 12th.