Potential Climatic Impacts Due to Transpiration Differences between Red Pine and Sugar Maple

BIOS 35502-01: Practicum in Field Biology

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2015

Abstract:

Through the transpiration of trees, evaporative cooling can have a large impact on the temperature of canopy surfaces within forests, which can impact the amount of heat energy and the overall temperature of the area. Deciduous trees are thought to have higher rates of transpiration than coniferous trees, which suggests a higher rate of cooling at the canopy surface. This cooling of the surface can allow for more long wave radiation to be absorbed into the canopy and less long wave radiation to be reemitted back into the atmosphere. Through the use of Granier style sap flux sensors, the rates and volumes of transpiration were measured between two species, red pine, *Pinus resinosa*, and sugar maple, *Acer saccharum*. A comparison in the rates of the two species showed a significant difference, while a comparison in volume transpired did not show a significant difference. However, canopy heterogeneity amongst pines proved to have an effect on the volume transpired per tree. These results suggest that although the rate of transpiration is higher within the deciduous sugar maple than the coniferous red pine, evaporative cooling is also a result of volume transpired. This proposes that sugar maples may not have a higher affect on evaporative cooling because their daily volume transpired was lower than that of red pines. The rates and volumes of transpiration between these trees are important in regards to predicting the climatic impacts of new deciduous growth forests replacing old coniferous growth forests.

Introduction:

Through the process of transpiration, trees release water vapor into the surrounding environment which causes evaporative cooling. When a change in the rate of transpiration is large enough it can impact climate over a long period of time. One way for a large-scale change in transpiration rates to occur involves a large change in the tree species composition of a given area. Trees of different species have differing rates of sap flux as well as amount of daily sap flow. Within the Midwest, deforestation occurred for agriculture, logging, and construction purposes. After this impact to the environment, trees began to re-grow, but the forests were not only much younger than the previous forests, but also composed of different tree species (Rhemtulla et al. 2009). Over time, the trees of the Midwest have become more strongly dominated by deciduous species compared to being dominated by conifers in the past. This change in tree species leads to a change in the rate and amount of transpiration released into the area surrounding the canopy (Ewers et al. 2002), which is directly related to the amount of heat energy that resides there.

The amount of heat energy in an area is affected by long wave radiation. Long wave radiation is emitted by the atmosphere to the surface of the earth. The surface of the earth absorbs and reemits long wave radiation back into the atmosphere. The amount of energy that is reemitted is directly correlated to the temperature of the surface. If the surface is cooler less long wave radiation is reemitted, but if the surface is hotter more long wave radiation is reemitted. The temperature of the surface is impacted by the rate of transpiration of the surrounding trees. If the transpiration rate of an area is high, then the temperature of the canopy surface tends to decrease due to evaporative cooling. By calculating the rate of transpiration within certain species of trees, one is able to determine which trees can increase or decrease the cooling of the earth's surface and therefore the amount of long wave radiation that is reemitted into the atmosphere. An increase in transpiration also affects the humidity of the canopy surface, which affects latent and sensible heat. Sensible heat is affected by the cooling of the surface and therefore fluctuates depending upon transpiration rates. Latent heat is the energy that evaporates water in transpiration; this fluctuates as well depending upon how much transpiration is occurring in an area. As transpiration occurs, the amount of energy dissipated through latent heat increases, leaving less to be dissipated by sensible heat.

This study examines the rates of transpiration within red pines, *Pinus resinosa*, and sugar maples, *Acer saccharum*. A comparison of these sap flux rates can be used for further analysis and predictions to be made on the climatic impacts of coniferous forests transforming into deciduously dominated forests. Within the University of Notre Dame Environmental Research Center's (UNDERC) property in northern Wisconsin, there are many mixed forests which allows for multiple tree species in one area to be surveyed and compared. One patch of forest in particular is composed primarily of red pines, with occasional stands of sugar maples, and balsam fir saplings. The forest floor has a noticeable downward slope towards an adjacent body of water; upon this slope is where all of the ten monitored trees of this experiment reside, seven red pines and three sugar maples. The red pines displayed a large variation in canopy dominance which allowed for a second variable, sunlight exposure within red pines, to be tested for its affect on transpiration rates in addition to species.

We test the hypothesis that the rate of transpiration is higher within sugar maple trees than within red pine trees. Studies have supported higher transpiration rates within deciduous trees rather than coniferous (Tang et al. 2005). The second hypothesis being tested is that trees of the same species exposed to higher levels of sunlight have larger transpiration rates than trees of the same species receiving lower amounts of sunlight. Sunlight exposure is rated categorically based upon canopy dominance. The difference in sap density in relation to dominance has had support in Douglas-firs by Granier (Granier 1987).

Methods:

From a single site within the north woods property of UNDERC, the sap flux rates of ten trees, seven red pines and three sugar maples, were monitored over the course of two weeks. All ten trees were within a twenty meter radius from the center of the self designated study plot. Within each of the species tested, canopy dominance was also recorded. The seven red pines were categorized by crown class as either dominant, codominant, intermediate, or suppressed, with dominant meaning the tree largely resided above the canopy with maximum sunlight exposure, codominant meaning the tree resided at the general level of the main canopy, intermediate meaning the crown of the tree resided within the lower areas of the main canopy, and suppressed meaning that the tree completely resided below the canopy with a limited amount of sun exposure. Within the limiting selection of sugar maples, codominant and intermediate trees were selected.

Two patches of bark at breast height facing the northern direction were removed from each tree using a scraping tool. These patches allowed access to the sapwood of the trees for later placement of sap flux sensors. The sap flux sensors used were handmade Granier style sensors made following the paper by Davis et al (2012) with slight modifications. The sensors consist of a heated probe and a reference probe which were able to measure the temperature difference due to sap flow and a resulting difference in voltage. The sensors from each tree were connected to a data logger which was able to automatically retrieve and store voltage measurements. Heated sensors were powered by a regulated current from a 12V battery which was guided through four voltage regulators. The voltage regulators were made following the procedure as listed in Davis et al (2012).To position the sensors, two holes were drilled into the exposed sapwood of the tree, one above the other. The sensors were inserted into the holes after being coated in heat conducting past. To protect the sensors from the weather and surrounding environment, they were wrapped in a reflective bubble wrap and sealed with duct-tape.

After the two week period of data collection was completed, a core of each tree was taken using an increment borer in order to determine the area of the sapwood within the tree. This information along with the diameter at breast height (DBH) and the differences in voltages was used to calculate the rate and volume of sap flux within each tree. Sap flux was calculated using a set of empirical relationships derived from Granier (1987). To calculate the rate of sap flow, *K* was calculated by with the equation below:

$$K = \frac{\Delta Vm - \Delta V}{\Delta V}$$

where ΔV_m is the maximum voltage difference which was read between the sensors at night when the sapflux rate was zero and ΔV is the difference in voltage between the two sensors. *K* was then used to calculate *u* which is the rate of sap flux in meters per second, using the equation:

$$u = 119 \times 10^{-6} K^{1.23t}$$

The volume of sap flow was then calculated with the following equation:

$$F = u\, S_A$$

where S_A is the cross sectional area of the sapwood.

With this information, the average rate and volume of sap flow per hour was calculated for each of the ten trees. A two sample t-test was used to compare the average sap flux rate between species. A second two sample t-test was used to compare the average daily volume transpired between species. An ANOVA was used to assess differences in the average rates of sap flux between the different crown classes within the red pine species. A second ANOVA was performed to compare differences in the average volumes transpired according to crown class within the red pines species. A Tukey's post hoc test was then used to compare the volume differences between each crown class.

Results:

When looking at the average hourly sap flux rates (Figure 1), there appears to be differences and similarities between individuals of each tree species and crown classes. Sugar maples appeared to have a generally higher rate of transpiration than the red pines. Intermediate red pines had a lower average rate of sap flux than dominant, codominant, and suppressed red pines. Differences in the average daily rate of sap flux between species were found ($p = 0.05$; Figure 2). There are no differences in the average daily rate of sap flux within pines of varying crown classes ($p = 0.19$; Figure 3).

The average hourly volume each tree transpired showed great variance, with all red pines excluding the two suppressed red pines, showing a higher amount of volume transpired on average than the three sugar maples surveyed (Figure 4). Crown class appeared to show distinct differences in volume transpired of red pines as well. The difference in the average volume transpired between red pine and sugar maples (Figure 5) was shown not to be significant ($p = 0.17$). Volume transpired differed among crown classes of red pines ($p = 0.01$; Figure 6). We found differences in the volume transpired of codominant red pines compared to intermediate red pines ($p = 0.045$) and of codominant red pines in comparison to suppressed red pines ($p = 0.01$). However, there were no differences in the volume transpired between intermediate pines and suppressed pines ($p = 0.11$).

Discussion:

Our hypothesis that sugar maples have a higher rate of sap flux than that of red pines was supported. The second hypothesis tested, that sunlight exposure had a positive effect on the rate of transpiration within the red pine species, was not supported. This suggests that species composition does affect the rate of transpiration, while sunlight exposure does not.

It was expected that the deciduous sugar maple would have a higher rate of transpiration than the coniferous red pine due to the fact that transpiration rates are thought to have a positive relationship with the leaf area index (LAI) of a species (Ewers et al. 2002). The broad leaves of the sugar maple have a much larger LAI than the narrow needles of the red pines, which can explain the distinct difference in transpiration rates between the species. However, when considering the volume transpired daily amongst the two species, red pines transpired more on average than sugar maples. Although not supported, this relationship between species and volume transpired suggests that sap flux rate may not be the only factor to monitor for impacts on climate from forest succession. Increasing the number of trees of each species surveyed would improve the strength of this finding and allow for a more in depth examination of species affects on transpiration rates.

The increase in the volume of red pines despite its lower rate of sap flux than the sugar maples, suggests that the area of sapwood was greater within the selected pines than within the sugar maples. This increase in sapwood area allows for more transpiration even at a slower rate because of the larger area of sap moved. A past study found that sapwood volume in coniferous species increases with leaf area (Ryan 1989); however, this has not been examined in deciduous species. Red pines and sugar maples monitored in our study were not similar in DBH, making it difficult to determine differences in sapwood volume across species. Further studies examining the sapwood differences in species by surveying trees with similar DBH could reveal how sapwood areas change across species as well as with volume and rate of transpiration

Although sun light exposure did not have a positive effect on the sap flux rates of pines, there was a difference in the rates between intermediate pines and both codominant and suppressed pines, which both had similar rates. Suppressed pines showed similar rates to codominant pines, suggesting that rates are higher in saplings. This could be a strategy for competing and surviving with the surrounding established trees. The volume of transpiration was different across crown classes for red pines despite the lack of a relationship to rate. This was not surprising because as dominance increases, typically DBH increases, which leads to an increase in sapwood area and causes higher volumes to move at once throughout the tree. For example, total daily sap flow has been found to correlate positively to the basal area of a tree (Martin et al. 1996). This difference may be more attributed to the size of the trees than to the effect of sunlight exposure. When comparing crown classes, it would also be beneficial to have more trees within each class, having only two per class in this experiment did not allow for a wide population to be surveyed and therefore any outliers or abnormalities may have gone unrecognized.

It was initially believed that due to the higher rates of sap flux within the sugar maple species, the amount of evaporative cooling at the canopy surface of the sugar maples would be significantly higher than that of the red pines. This difference in canopy temperature would have a result on the amount of heat energy and heat partitioning within the surrounding area. However, due to the high volume transpired by the red pine species, it is hard to be certain which tree species would have a higher cooling impact at the canopy. Yet, it is possible to conclude that red pines ranked highly in dominance with larger DBH's have a higher contribution to the evaporative cooling of the canopy surface than any of the other sugar maples or red pines surveyed due to them having the highest volume transpired daily within the plot. Comparing rates and volumes within red pines and sugar maples of similar DBH's and dominances would be beneficial in further studies.

Acknowledgments:

I would like to thank my mentor, Bethany Blakely, for all of the guidance and assistance she provided me throughout this experiment. A special thanks to my classmates Amanda Keyes, Olivia Macek, Annika Kohler, Lorena Cortés, and Kamden Glade for giving me an extra hand when needed. Thank you to Dr. Gary Belovsky, Dr. Michael Cramer, Hannah Madson, Julia Hart, and Sarah Small for all the time they dedicated to making UNDERC a memorable and educational experience. Lastly, I'd like to thank the Bernard J. Hank Family Endowment which allows this wonderful opportunity to exist.

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Tables and Figures:

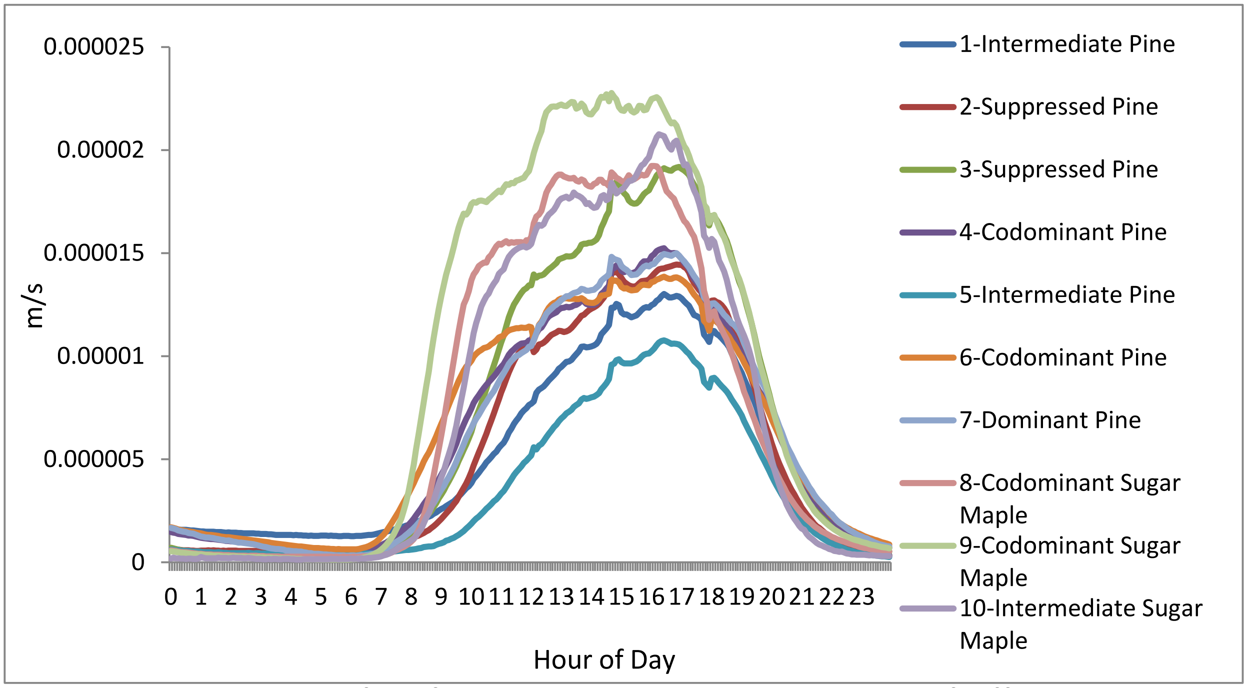

Figure 1. The hourly rates of sap flux across red pines and sugar maples of different crown classes.

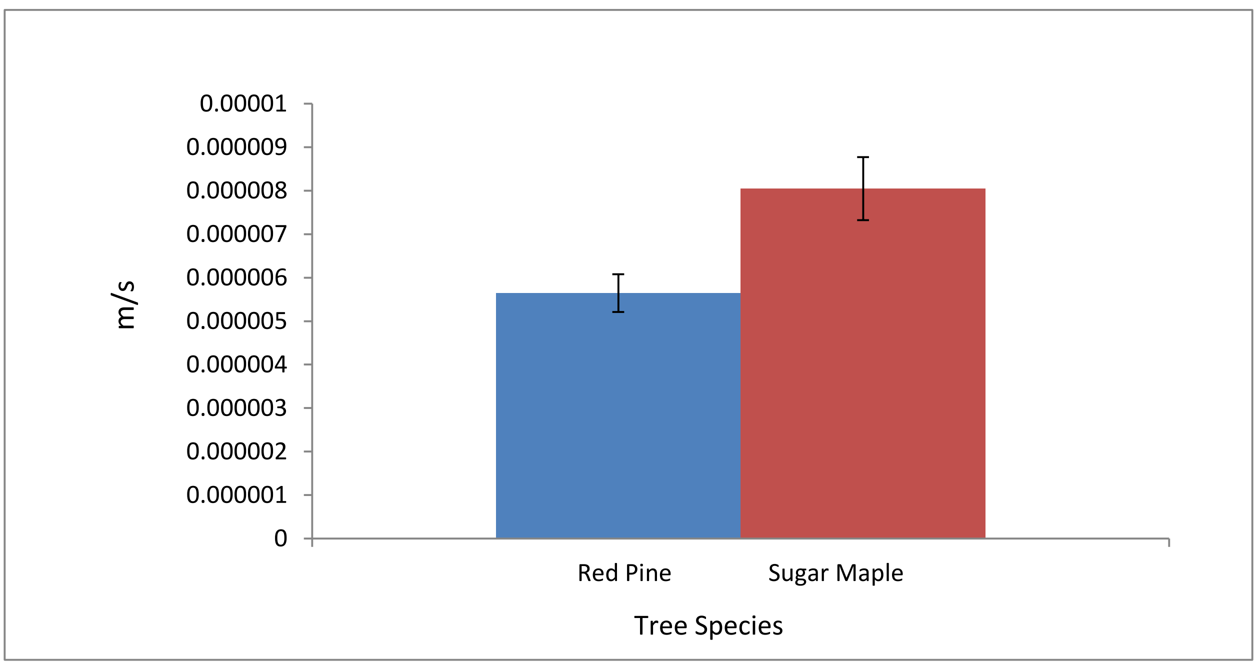

Figure 2. The daily average rate of sap flux per species. Error bars represent standard error. *=p<0.05.

Figure 3. The relationship of sap flux rates on average between codominant, intermediate, and suppressed red pines. Error bars represent standard error. *p=0.19.

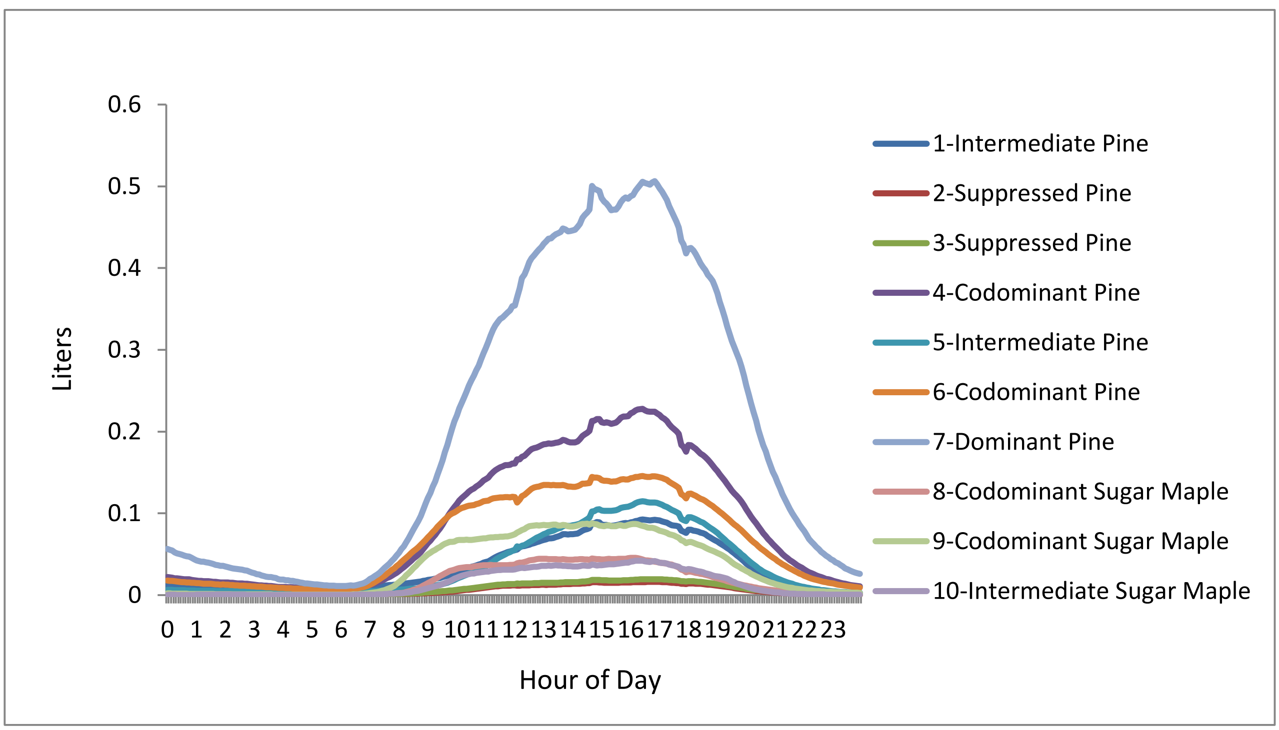

Figure 4. The volume of water transpired hourly in different crown classes of red pine and sugar maple.

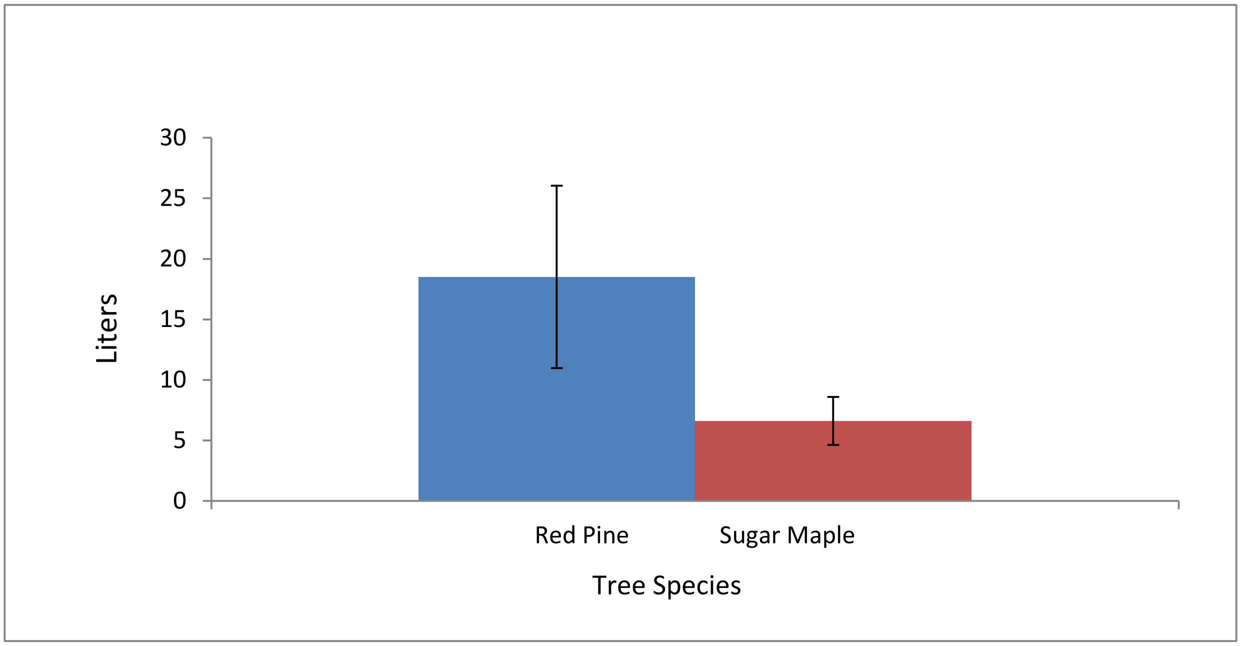

Figure 5. The average total daily volume of water transpired by red pines in comparison to sugar maples. Error bars represent standard error. *p=0.17.

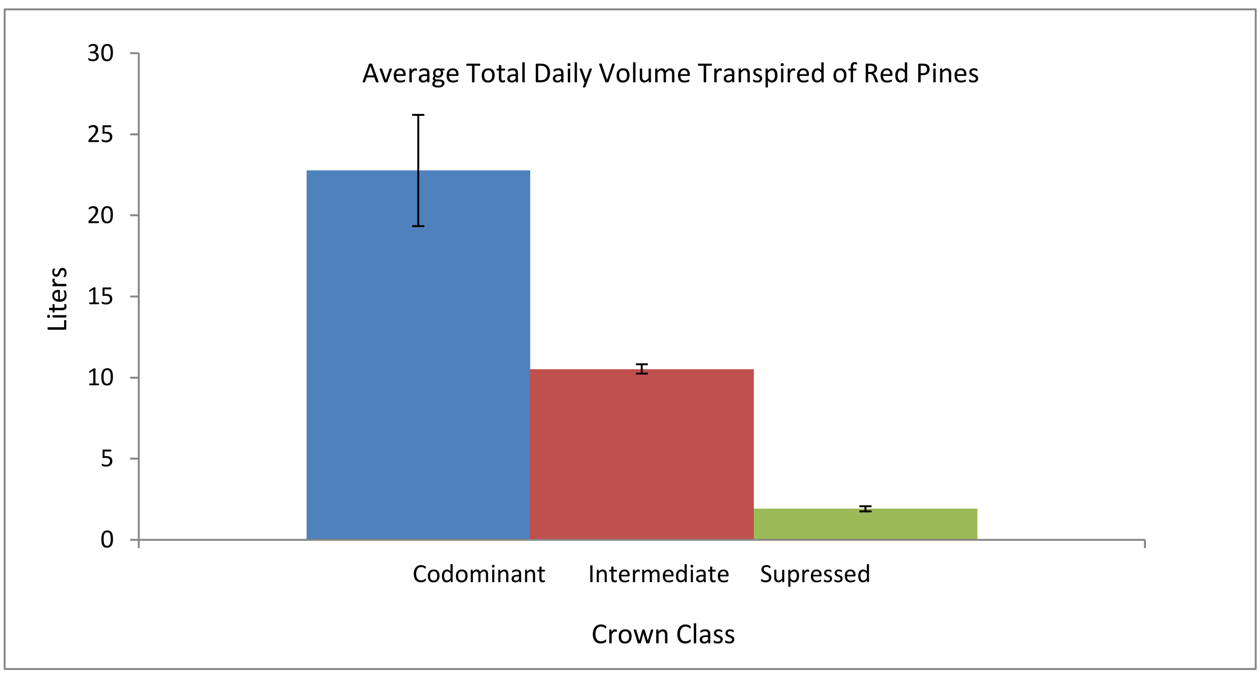

Figure 6. The relationship between the average volume transpired daily between red pines of crown classes: codominant, intermediate, and suppressed. *p<0.01. Codominant compared to intermediate *p<0.045. Codominant compared to suppressed *p<0.01. Intermediate compared to suppressed *p=0.11. Error bars represent standard error.