UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Carbon Sequestering Ability of Six Common Urban Trees of Vancouver British Columbia

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Directed Studies in Biology (BIOL 448)

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BIOL 448 – DIRECTED STUDIES IN BIOLOGY

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Abstract

The main objectives of this experiment were to provide information about the relative carbon sequestration rates and transpiration rates of six common tree species in Vancouver BC throughout autumn months. Results from these experiments shed light as to possibilities for future urban planning to aid in counteracting Earth's global warming crisis. The six species were the Japanese Flowering Cherry (*Prunus serrulata* L.), Ponderosa Pine (*Pinus ponderosa*), Lawson Cypress (*Chamaecyparis lawsoniana),* Western Red Cedar (*Thuja plicata*), Red maple (*Acer rubrum*) and Red Oak (*Quercus rubra).* A portable LiCor-6200 Photosynthesis system was used to measure photosynthesis and transpiration rates of these tree species. It was found that the Japanese Flowering Cherry had the highest overall rate of photosynthesis at 3.3 μmol CO_2 fixed/m^2/s and highest transpiration rate at 2.4 μmol H_20 given off/m^2/s. Red Oak however, showed the greatest water use efficiency (ratio of photosynthesis to transpiration).

1.0 Introduction

Being the fifth-best city in the world, Vancouver is known for its amazing health care system, low crime rates, political and social stability, and most of all, the beautiful natural environment that surrounds and is immersed within the city (24H Vancouver, 2011). There are over 138,000 trees on Vancouver streets alone, consisting of almost 600 species (Vancouver Parks Board, 2011). Urban forests aren't just for aesthetics, but play important ecological, environmental and economical roles. Urban trees aid in energy conservation by providing shade and wind reduction, noise buffering, wildlife habitat, increased property value, psychological well being and the sequestering of carbon dioxide (Tree Canada, 2010).

Plants use carbon dioxide (sequestration) for the purpose of making stored energy in the form of carbohydrates, with help from the sun. This process of photosynthesis is divided into two parts, the "light reactions" and "dark reactions". In the light reactions, light excites photosystems I and II to ultimately produce ATP and NADPH. This ATP and NADPH are then used in the dark reactions to power the reduction of atmospheric carbon dioxide into carbohydrates and other molecules. The reactions that transform CO_2 into organic compounds are together referred to as the Calvin Cycle. In the first of three steps, carbon dioxide and water is catalyzed by the enzyme Rubisco to form the three carbon molecule 3-phosphoglycerate. These molecules are then converted to other 3-carbon carbohydrates by ATP and NADPH driven enzymatic reactions (Taiz & Zeiger, 2010).

Respiration is the process by which the previously made carbohydrates are broken down to use for energy in cellular development and repair. Respiration also gives off CO_2 and water. Photosynthesis and respiration can occur at the same time. This can be confusing when trying to decipher the exact rates of each. For example, if respiration is occurring at a faster rate, photosynthesis may appear to have a negative value depending on the measuring devices used.

Transpiration is another important process in plants that must be considered. It is the loss of water from plant parts into the atmosphere. Water can be lost through stems, leaves, flowers and roots but mostly through stomatal pores of leaves. The amount of water lost is dependent on a number of factors, such as the number of stomata per leaf area, temperature, humidity, amount of sun, wind, and water supply to the plant.

The amount of carbon that a tree can take in depends on factors such as what species it is, its age, its location, and what type of soil that it's rooted in (Tufts University, 2009). It can also depend on if the stomata are open, there is enough light, and the temperature isn't too hot or too cold. An example of how much carbon can actually be taken in by trees was estimated by an Illinois tree CO_2 sequestering experiment. It was estimated that if 10 million trees were planted over a 10 year period, an approximately 363 million tonnes of carbon can be compensated for over the next 50 years (Nowak, 1993).

Adequate light is required for the assimilation of carbon dioxide. It's not just the light reactions need the energy source, but Rubisco needs light as well. Rubisco must first be activated before its catalytic effects can commence. Light causes an increase in stromal pH and mg^{2+}, which promotes the activation of Rubisco (Taiz & Zeiger, 2010).

Temperature also plays a large role in optimal photosynthesis. If it gets too warm for example, enzymes can denature and stop functioning. To reduce the amount of water loss, stomata will also close. This will limit the amount of gas exchange with the inside of leaves. Also, the affinity of Rubisco for CO_2 decreases as temperatures rise. Instead, Rubisco will bind with oxygen and produce 2C and 3C sugars instead (Taiz & Zeiger, 2010).

To help counteract the 4.6 tonnes of CO_2 emitted per person per year in Vancouver (Pander, 2007), the planting of specific trees best suited to Vancouver's environment could aid in the global carbon emissions crisis. This sustainability-related project examined carbon dioxide uptake rates and transpiration rates of six tree species located in and around the UBC campus. These trees include the Japanese Flowering Cherry, Ponderosa Pine, Lawson Cypress, Western Red Cedar, Red maple and Red Oak. The three deciduous trees are the cherry, maple, and oak. The coniferous trees are the pine, cedar, and cypress.

Japanese Flowering Cherry trees (*Prunus serrulata*) originated in Japan. They flower from February to May in a normal season. Since the climate in the Pacific Northwest is very similar to that of Japan, cherry tree grows fantastically in Vancouver. Both locations have the same winters that are very rainy, but not too cold. Vancouver's late summers are also like Japans warm Octobers, which are good for the next year's flowers. Cherry trees however, need good aeration and soil drainage to prevent pathogenic infections (Hall & Hall, 2008). Currently the Japanese flowering cherry makes up about 36% of all planted trees in Vancouver (Acrt, Inc., Urban Forestry Consultants, 1990).

Maple species constitute about 17% of all planted trees in Vancouver (Acrt, Inc., Urban Forestry Consultants, 1990). The Red Maple (*Acer rubrum)* has beautiful red to yellow leaves in the fall, can grow up to 75ft tall and can tolerate Vancouver's damp soils. They are however, sensitive to high salt concentrations (Wiley, 1996).

The Red Oak (*Quercus rubra)* can usually grow up to 90ft tall. It can even get up to 140ft if grown in an optimal environment. Its trunk can also grow to a diameter of 6ft. It is a fast grower and can tolerate a wide variety of soil types and environments (Keeler, 1900).

The Lawson Cypress (*Chamaecyparis lawsoniana)* is native to the Oregon coast. They have blue-green flat scale like foliage and can grow up to a remarkable 200ft. They grow the best in moist but well drained soil (Mobile Reference, 2008).

Western Red Cedars (T*huja plicata*) are the provincial trees of British Columbia. This native plant is widespread in the Pacific Northwest and grows up to 60m tall and 3m wide. Its wood is widely used for outdoor construction, since it is resistant to decay (Mobile Reference, 2008).

The Ponderosa Pine (*Pinus ponderosa*) is a large tree with very long, sharp needles that come out of in bunches from branch ends. In cities, they can reach up to 100 ft tall and 30ft wide. Their trunks can be up to 4ft as well. In North America, the ponderosa pine is the most common and widespread pine species (Plotnik & Arboretum, 2000).

This investigation took place in the early fall/early winter months, when the climate changed from bright and warm to having rainy, dark and cold weather. These two seasons allowed for time-course observations of physiological changes when temperature, light, and rain amounts change and differences that occur between deciduous and coniferous trees. The objective of this experiment was to provide information about the relative carbon sequestration rates and water use efficiencies of these six tree species. Since this experiment was in the time that trees loose their leaves, data was collected before and after leaf senescence and an average overall carbon sequestering ability of each tree species was evaluated. Carbon uptake was estimated with photosynthesis rates and water use efficiencies were estimated in terms of transpiration rate. This will hopefully give light as to which trees would be best for sustainability purposes in urban planning, especially suited for Vancouver. In addition, the major photosynthesis protein Rubisco was analyzed to observe any species/time difference.

2.0 Materials and Methods

The following six tree species were used in this project:

- Japanese Flowering Cherry (*Prunus serrulata*)
- Ponderosa Pine (*Pinus ponderosa*)
- Lawson Cypress (*Chamaecyparis lawsoniana)*
- Western Red Cedar (*Thuja plicata*)
- Red maple (*Acer rubrum*)
- Red Oak (*Quercus rubra)*

For specific LiCor instructions on system usage please refer to http://www.licor.com under the Li-6200 Support Page. Instructions for making and running SDS-PAGE gels, please refer to the UBC Plant Physiology Lab Manual. Trees are located on UBC campus in Vancouver BC. The cherry tree is located on the north east corner of Main

Mall and Agromony Rd, across from the Forestry Building main entrance. The pine tree is located in front of the Ponderosa Center on West Mall and University Blvd. The other four trees are located on Sustainability Road. Figures 1 & 2 show specific individuals that samples were collected from.

Data collection started in mid-September and occurred every week (except the first week in November) until mid-November. Data collection was taken whenever a tree had leaves. The deciduous trees however, started to loose their leaves late in the experiment. There were a total of nine data collection weeks. Every week, the morphology, leaf colour, and leaf presence of each tree were documented. Light readings were also taken. Each week, each tree had two leaf samples taken. They were then placed in a beaker of water, so that photosynthesis and respiration could still occur while other samples were being collected. The photosynthesis and transpiration rates of tree laves were analyzed by a LiCor Photosynthesis system. This was to ensure no air bubbles were present. The leaf chamber and light were set so that the light reading was kept constant at 400μmol. Water use efficiencies were also calculated (Table 1) by taking the ratio of photosynthesis rate to transpiration rate, (WUE=photosynthesis/transpiration). After data were obtained, pictures of the leaves themselves were documented. The leaves were then finely cut up, put into aluminum foil packets, put into liquid nitrogen for one minute to flash freeze, then placed in a freezer for further analysis.

In late November, SDS-PAGE gel electrophoresis was completed on all samples to determine which proteins were present. In total, 6 gels were run. Each gel contained one tree species samples with lanes 2 to 9 containing weekly samples.

3.0 Results

All trees at the start of the experiment were full of leaves and very green. Once more autumn like days approached in late October/early November, the leaves of the deciduous trees became yellow and fell off, where the evergreens didn't have this loss.

3.1 Photosynthesis Rates:

Average photosynthesis rates for all trees are diagrammed in figure 1. A confidence interval was calculated with an α =0.05. The tree with the highest rate of photosynthesis was the Japanese Flowering Cherry. Between mid-September and mid-November, it averaged at 3.3 μmol CO_2 fixed/m^2/s. The lowest average rate of photosynthesis was observed in the Lawson Cypress. It was a negative value, at -0.690 μmol CO_2 /m^2/s. This is not actually a negative photosynthesis, just that the rate of respiration was faster at giving off carbon dioxide than the tree was taking it up. The Lawson cypress had positive values in the first five weeks, however were below zero for the last four. The remaining four trees that were in the midrange of photosynthesis rates were Red Oak, Red Cedar, Red Maple, and the Ponderosa Pine. Their average values were 1.7, 1.5, 0.9, and 0.7 μmol CO_2 fixed/m^2/s, respectively. For a more clear view of photosynthesis in the deciduous trees, figure 2 shows the Oak, Maple, and Cherry tree data. All photosynthesis values are about zero. For the evergreen trees, figure 3 shows a clear view of the cypress, cedar and pine data. In October, photosynthesis rates decreased dramatically in all three of these species. Comparing the cherry with the second highest tree, the Oak, the cherry was about 52% better at carbon sequestering. Comparing the cherry to the best evergreen species, the cedar, it was 55% better.

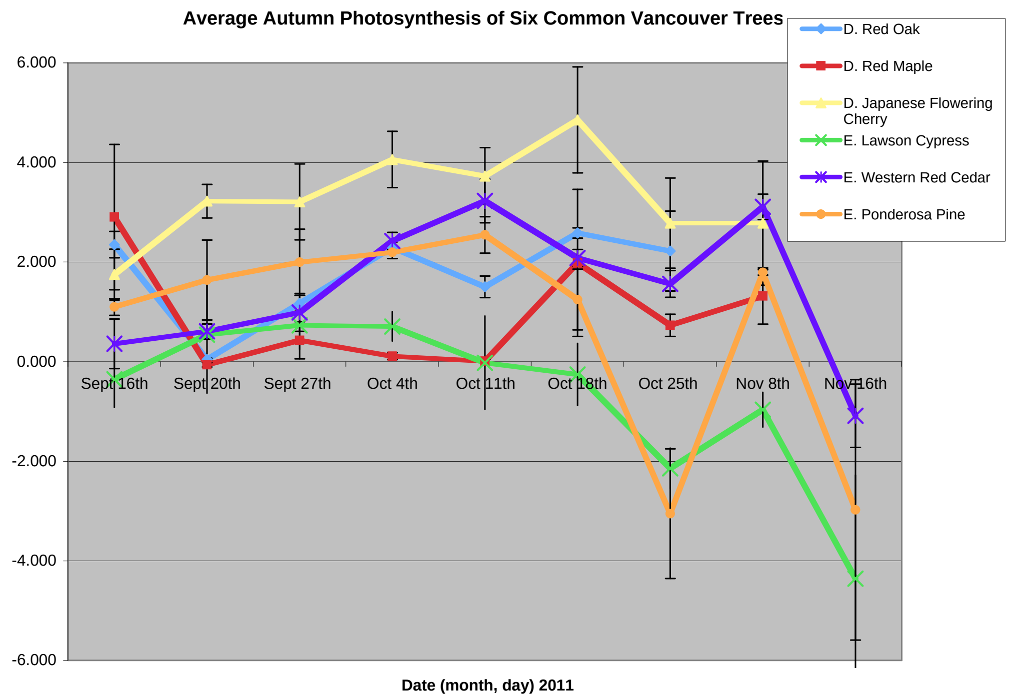

Figure 1: Average autumn photosynthesis rates from September 16th to Nov. 16th 2011 of the six tree species Red Oak, Red Maple, Japanese Flowering Cherry, Lawson Cypress, Western Red Cedar, and Ponderosa Pine. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

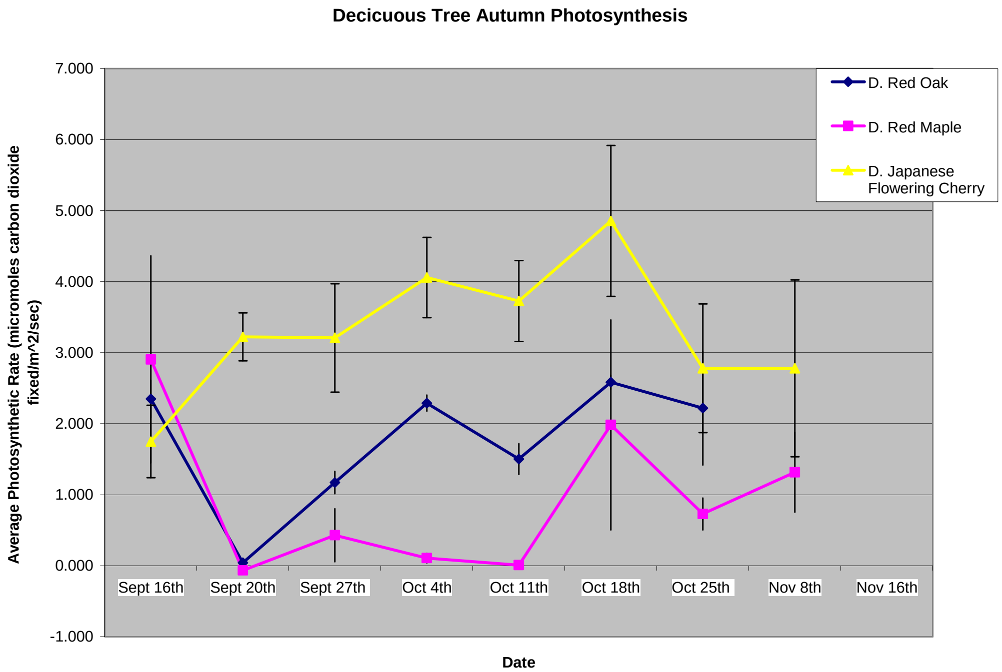

Figure 2: Average autumn photosynthesis rates from September 16th to Nov. 16th 2011 of the three deciduous tree species Red Oak, Red Maple and Japanese Flowering Cherry. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

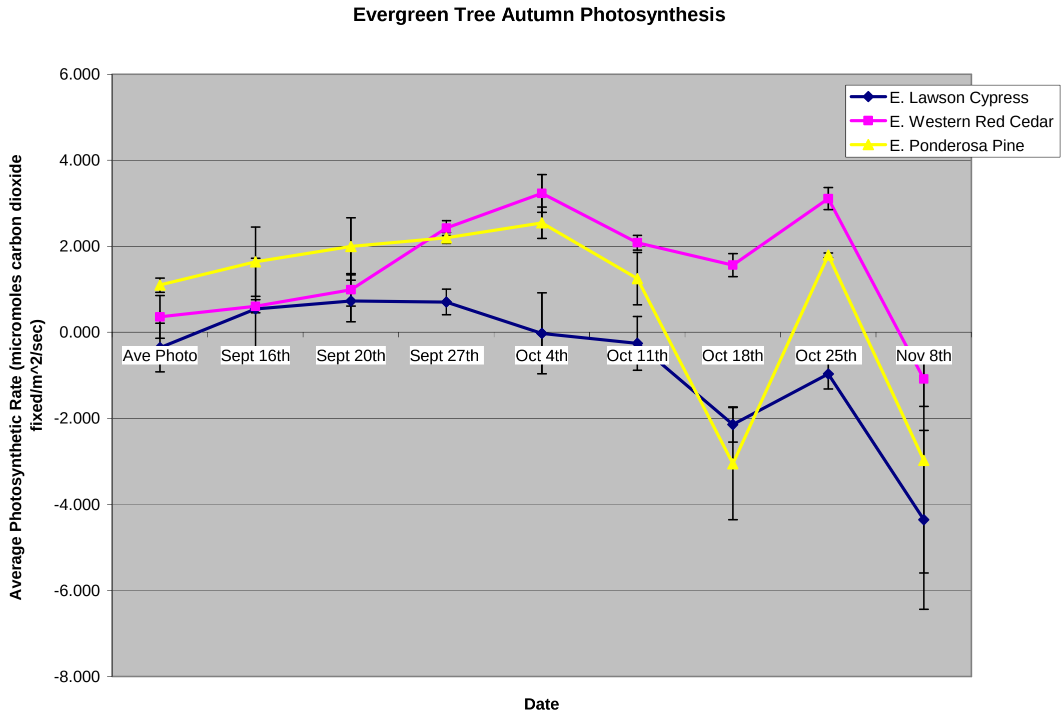

Figure 3: Average autumn photosynthesis rates from September 16th to Nov. 16th 2011 of the three evergreen tree species Lawson Cypress, Western Red Cedar, and Ponderosa Pine. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

3.2 Transpiration Rates:

Average transpiration rates for all trees are diagrammed in figure 4. A confidence interval was calculated with an α =0.05 as well. The tree with the highest rate of transpiration was the Japanese Flowering Cherry, with 2.4 μmol H_20 given off/m^2/s. The tree with the lowest was the Red Oak. Its average transpiration rate came to be 0.8 μmol H_20 given off/m^2/s. The remaining four trees that were in the midrange of transpiration rates were the Ponderosa Pine, Lawson Cypress, Western Red Cedar, and the Red Maple. Their transpiration rates were 2.1, 1.4, 1.2, and 0.9 μmol H_20 given off/m^2/s, respectively. For a more clear view of transpiration in the deciduous trees, figure 5 shows the Oak, Maple, and Cherry tree data. All values are about zero, with cherry values at least 60% higher than both the oak and maple. For the evergreen trees, figure 6 shows a clear view of the cypress, cedar and pine data. The pine and cedar show an even gradual increase in transpiration in September and early October, reaching the highest in mid October. After that, rates decrease again. The cypress trees, however, fluctuated between 1 and 2.1 μmol H_20 given off/m^2/s.

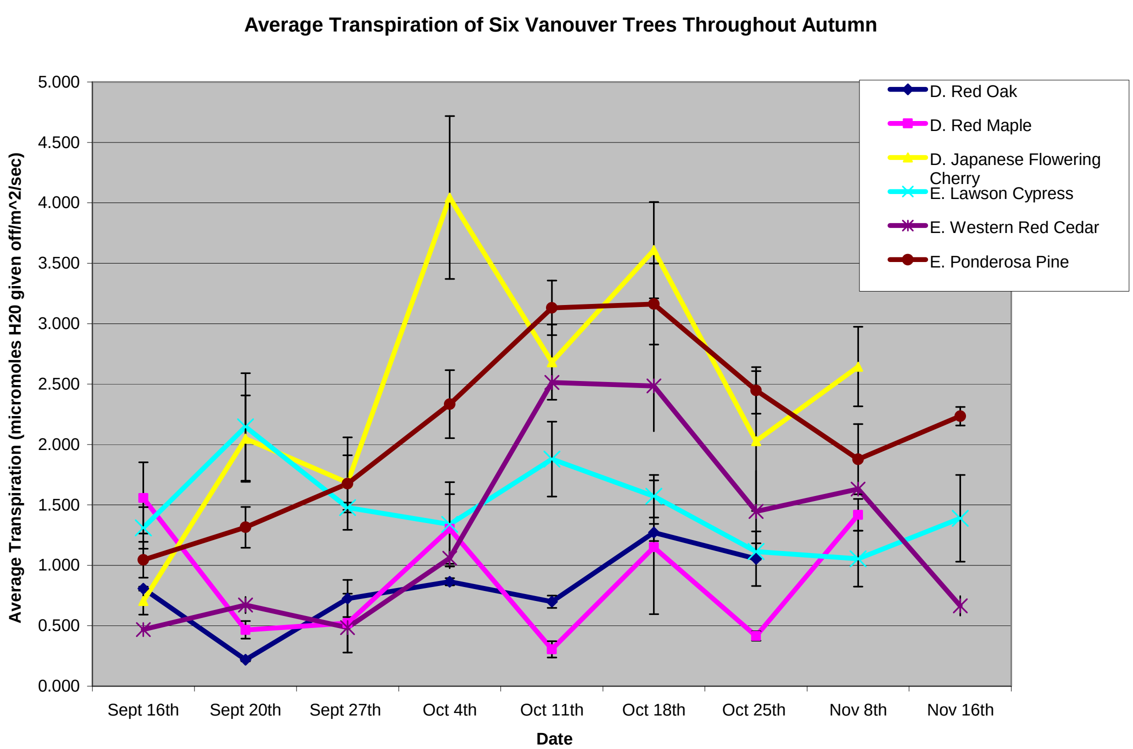

Figure 4: Average autumn transpiration rates from September 16th to Nov. 16th 2011 of the six tree species Red Oak, Red Maple, Japanese Flowering Cherry, Lawson Cypress, Western Red Cedar, and Ponderosa Pine. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

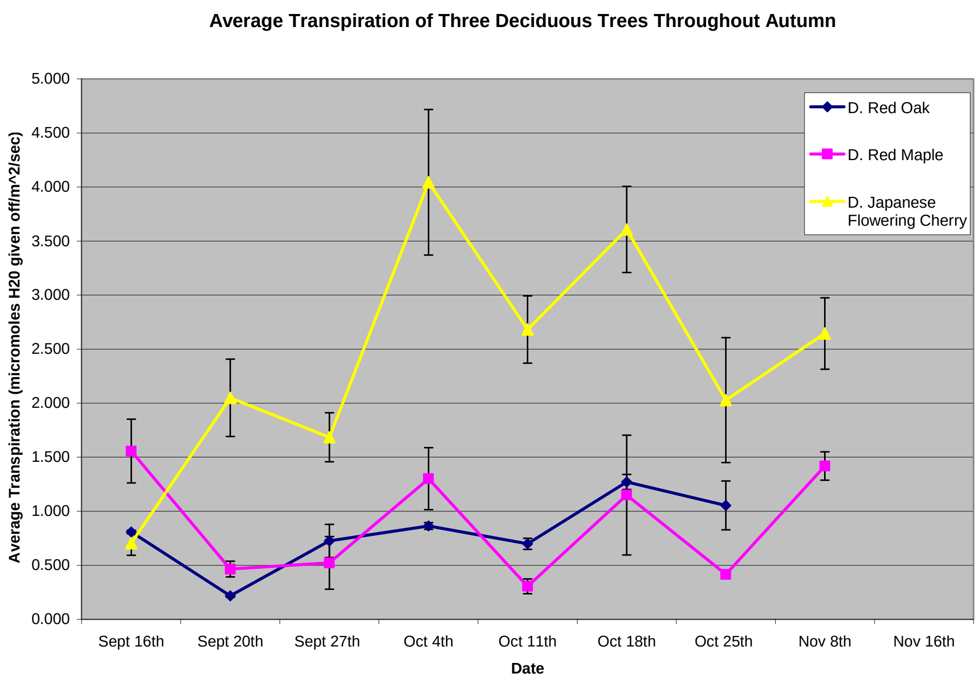

Figure 5: Average autumn respiration rates from September 16th to Nov. 16th 2011 of the three deciduous tree species Red Oak, Red Maple and Japanese Flowering Cherry. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

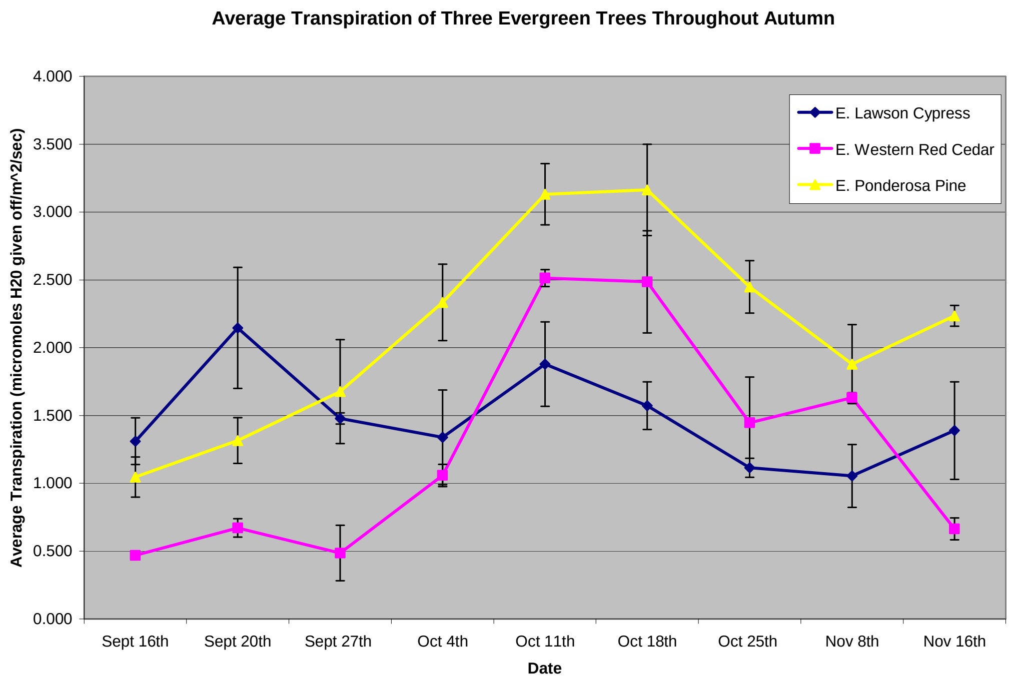

Figure 6: Average autumn respiration rates from September 16th to Nov. 16th 2011 of the three evergreen tree species Lawson Cypress, Western Red Cedar, and Ponderosa Pine. Confidence intervals (a=0.05) are shown as with black lines. Any data with lines that cross are considered to be insignificant.

3.3 Water Use Efficiencies:

Taking the ratios of photosynthesis to transpiration, water use efficiencies (WUEs) were calculated (Table 1). Deciduous Red Oak had the highest WUE at 2.16 μmol CO_2fixed/ μmol H_2O given off.

Table 1: Average water use efficiencies for six tree species. D indicates deciduous species, E indicates evergreen species.

WUE	Photosynthesis/Transpiration
D. Red Oak	2.16
D. Red Maple	1.04
D. Cherry	1.36
E. Lawson Cypress	-0.46
E. Western Red Cedar	1.16
E. Ponderosa Pine	0.34

3.4 Protein Data:

SDS-PAGE gel electrophoresis was done for each tree. Six gels were done in total, with one species per gel, and each gel lane indicating one week. A summary of the average band intensities for the six gels is shown in Table 2. As the weeks went on, band intensities decreased slightly. For each gel, the protein band for the large and small subunit of Rubisco had a very strong intensity. The only exception was that maple did not have a band for the small subunit (Table 2). CP43, a subunit of photosystem II, had moderately intense bands in the pine, cedar, maple, and oak gels. Light harvesting complex –Ia was also moderately intense in these four. There were also light bands in all the pine for D1, a subunit of photosystem II. The D2 subunit was also present, however in all but the pine and cypress.

Table 2: Summary of average band intensities of proteins for each of the six tree samples in SDS-PAGE gels

Protein	Pine	Cedar	Cypress	Cherry	Maple	Oak
Rubisco (large subunit)	++++	++++	++	+++	+++	+++
Rubisco (small subunit)	+++	+++	+	++		++
CP47 (a protein subunit of PSII complex)						
CP43 (a protein subunit of PSII complex)	++	++			+	+
NADPH: (PORA) or D2 (a protein subunit of PSII complex)		++				
LHC-Ia (LHC-I 680)	++	++			++	+
LHC-Ib (LHC-/730)		+				
LHC-IIa (CP29)	+					
LHC-IIb		++		+	+	
LHC-IIc (CP26)		++		+		
LHC-IId (CP24)	++					
D1 (a protein subunit of PSII complex)		+	+	+	+	+
D2 (a protein subunit of PSII complex)		++		++	+	+
PsaA (a protein subunit of PSI complex)	+			+		
Cyt f		+	+	+		

4.0 Discussion

Photosynthesis rates were highest in the Japanese flowering cherry tree, with an average of 3.3 μmol CO_2 fixed/m^2/s (Figure 3 & 4). This tree however, had the highest transpiration rate out of all the trees as well, at 2.4 μmol H_20 given off/m^2/s (Fig 6 & 7). As noted previously, the amount of carbon that a tree can take in depends on factors such as species, age, location, soil type, if stomata are open, light amount, and the temperature. Since there is lots of transpiration going on within the cherry, their leaves probably have many open stomata to let adequate gas exchange occur. This indicates that the Cherry tree has high water requirements. Since fall months are much more damp than in the summer, the trees susceptibility to water loss probably lessened. In observing the increase of photosynthesis within the cherry, it actually increases from September to a peak in mid-October. This might be because there is still adequate amounts of light for photosynthesis but conditions aren't as bad for water loss. Also for the cherry, the one that was used for this study was relatively young, as compared with the other larger trees. Net photosynthesis has been shown to not only decrease with tree age, but needle age as well for evergreen species (Teskey, et al., 1984). In another example of how age differences influence carbon uptake, Tufts University looked at the Northeast white and red pine. 25 year old forests averaged at 15 lbs of CO_2 per year per tree, whereas the 120 year forests of the same species took in about 12 lbs (Tufts University, 2009).

The other two deciduous trees, the oak and maple, did not have this gradual increase in photosynthesis (Fig. 3 & 4). Their transpiration rates did not fluctuate as much as well (Fig 6 & 7). This may be because they are larger, older trees. Red maple is also known to be more of a shade plant, with a lower net photosynthesis (Abrams, 1998). Shade plants have lower light compensation points – the amount of light where photosynthetic carbon dioxide uptake equals carbon dioxide release from respiration (Taiz & Zeiger, 2010). Once mid-October came, days started to get much shorter and colder. A study by Teskey, et al. (1995) had shown that for their species, an average temperature of 15°C was optimal for photosynthesis. Between September 16th and October 11th, temperatures in Vancouver fluctuated from between 23.1°C and 9.3°C (The Weather Network, 2011). This is when all trees had their highest photosynthesis rates, just as Teskey's study had predicted. On Oct 16th, temperatures dropped to 4.3°C, and a decrease in all species can be observed (Figure 3).

Photosynthesis rates in the trees were, from highest to lowest, cherry, red oak, red cedar, red maple, ponderosa pine and finally the lawson cypress. By taking the ratio of photosynthesis to transpiration, the trees water use efficiencies were calculated (Table 1). Even though the Cherry had the highest photosynthesis rate, it also had the highest transpiration rate. Its water use efficiency was only moderate, indicating a high water requirement. Red Oak had the best water use efficiency; a moderate photosynthesis rate with a low transpiration rate.

Protein analysis using SDS-PAGE gel electrophoresis gave very intense bands for both the large and small subunits of Rubisco in each species (Table 2). The only exception was for maple, without the small subunit. There was however a very dark band that seemed like it could have been it, but the molecular weight was slightly too high. This may have just been from improper electrophoresis techniques. Rubisco is one of the most abundant plant proteins in the world and is found in all plants, which is why these bands make sense. There were no conclusive differences in protein type between the evergreen and deciduous trees. The cherry, oak, cedar and maple all had moderate bands of D1 and D2 subunits of the photosystem II complex, whereas the other two did not. This may have accounted for a higher ability to capture light energy. A western blot was also attempted for Rubisco amounts in the cherry and cedar samples (Fig 10). There were only two light bands in the 5 minute cherry sample and none in the other samples. This doesn't give any substantial evidence of differences between species or change throughout the season. Data may have not shown up for a couple of reasons. The samples may have been diluted too much, or not enough antibodies were used. For future experiments, an optimal dilution factor should be obtained prior to running the final samples.

Other experimental errors and considerations include the size of the trees. Even though one tree may be better than the other at carbon sequestering, how big and how many leaves are on each tree should be taken into consideration as well. For purposes of sustainability, how old it will get, as well as what will happened to it when it dies, should also be looked at. If a tree can later be used for timber, that would be better than using it for firewood and putting all that carbon back into the atmosphere.

Taking everything into consideration, Japanese Flowering Cherry trees are the most optimal at sequestering atmospheric carbon within the autumn months. Deciduous trees however, only have leaves from spring to fall. They have high photosynthesis rates in these periods. Evergreens however, maintain their leaves and photosynthesis throughout the year, although at a lesser rate. This study only observed photosynthesis and transpiration rates in the autumn months. A more complete year round study should be carried out to obtain a broader knowledge of these six species, as well as other species that are common in the Vancouver area.

5.0 Acknowledgments

Special thanks to Mr. Jarnail Mahroke and Dr. Santokh Singh for the abundance of advice and support throughout this project, as well as the use of the laboratory and equipment. Thanks to Harleen for initial procedural advice, Divjot for helping take Licor readings and the other volunteers that were more than happy to help. Thanks also to my fellow lab mates, Midy, Doug and Rosy for being great friends in the lab.

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