Significance of Allocthonous Inputs to Carbon Profile of Douglas Lake and Little Carp Creek

Ashley Clark, Kyle Rorah, Michael White

University of Michigan Biological Station

EEB 381: General Ecology

11 June 2009

Prof. Glenna M. Malcolm

Abstract: Different sources of carbon are differentially utilized by aquatic species, and thus, understanding how much different sources of carbon contribute to aquatic ecosystems can be useful in understanding the community composition of aquatic food webs. One objective of this study was to determine whether or not allochthonous carbon, carbon from outside of the system, contributes significantly to Douglas Lake and Little Carp Creek. Another objective was to determine whether a gradient in contribution from allochthonous sources might be detected from shore to center and with depth in Douglas Lake and with distance from headwaters for Little Carp Creek. We determined the contribution from allochthonous sources by determining carbon isotopic ratios in samples procured from both aquatic systems. On average, the percent of organic carbon that comes from leaf input is 32% for Douglas Lake and 40% for the Little Carp Creek. The relationship between the distance from shore and carbon enrichment for Douglas Lake was found to be insignificant. The same was true for the comparison of lake depth and carbon enrichment. The data for Little Carp Creek also had an insignificant relationship between distance from headwaters and carbon enrichment. Our lake results might be explained by the spring turn over taking place, resulting in a lack of horizontal and vertical variation in isotopic carbon ratios. The lack of a positive correlation in our creek results might be related to stream length. Short distance streams may be physically limited in their ability to accumulate enough allochthonous carbon to alter the carbon isotopic ratio found at the headwaters. Nonetheless, knowing the percent contribution of allochthonous carbon to an aquatic system can be used to explain trophic interactions.

security, backup, preservation and access, and may migrate the Paper to any medium or format for the purpose of preservation and access in the future.

Introduction:

Carbon availability in aquatic ecosystems shapes the biotic community. There are two forms of Carbon that a lake or stream contains to sustain its resident organisms, autochthonous carbon, which is produced within the system by primary producers, and allochthonous carbon, which is produced outside the system and delivered largely via fallen plant matter (Kritzberg et al, 2004). Understanding the biological processes, especially the forms, sources and dynamics of organic material in freshwater systems is important because they influence dynamics of litter decomposition and communities associated with litter processing, fish and invertebrate community structure and production, water quality, and the global carbon budget (Balakrishna and Probst, 2005, Delong and Brusven, 1994).

Douglas Lake and Little Carp Creek, in Pellston, MI represent excellent study sites to examine the contributions of autochthonous and allochthonous carbon because they both have heavily wooded shore lines and are relatively undeveloped. These wooded shorelines may add significant amounts of leaf litter, which affects the amount of carbon available in both ecosystems.

By using stable carbon isotopic ratios we might be able to determine the composition allochthonous and autochthonous carbon inputs into Douglas Lake and Little Carp Creek. Carbon exists in two stable isotopic forms, ^{12}C and ^{13}C, which are both used by aquatic organisms but not in equal amounts. During photosynthesis plants discriminate against ^{13}C in favor of ^{12}C, and as a result the $^{13}C/^{12}C$ ratios of biogenic materials are lower than those of atmospheric CO_2 (Potter, 2005). This is true for both allochthonous and autochthonous plants. This preferential uptake is a result of the difference in atomic mass and bond strength between ^{12}C and ^{13}C. ^{12}C has weaker bonds and is the lighter isotope, thus making it easier for organisms to use and convert it into biomass.

An environment is considered enriched if it contains a high amount of ^{13}C relative to ^{12}C and depleted if it contains low relative amounts. In lakes, shifts toward more enriched $\delta^{13}C$ values in the surface waters, result from biological activity, and more depleted $\delta^{13}C$ values in deeper waters, results from the oxidation of sinking organic material (Stumm and Morgan, 1981). In rivers and streams, addition of leaf inputs as water flows from headwaters, tends to change the $^{13}C/ ^{12}C$ ratios to more depleted values. In other terrestrial systems, $\delta^{13}C$ values of the various carbon sources have been determined (Figure 1).

In our study we plan to assess the relative importance of plant litter carbon sources to these aquatic systems as compared with other carbon sources. We will assess this by looking for existing carbon isotopic gradients from shore to center and surface to deep water in Douglas Lake and from headwaters to Burt Lake in Little Carp Creep. For Douglas Lake we hypothesize that distance from shore and water enrichment is positively related (Figure 2A) as a result of distances from leaf inputs. We hypothesize that lake depth and water enrichment are negatively related (Figure 2B) because of the differing biological processes that take place on the surfaces versus those that take place on the bottom. Finally, for Little Carp Creek we hypothesize that the distance from headwater and enrichment are negatively related (Figure 2C) due to the carbon that is picked up by the steam as it flows over leaf litter.

Materials and Methods:

The systems of study are Douglas Lake and Little Carp Creek, in Pellston, Michigan. Located in the northern tip of the Lower Peninsula of Michigan, this area experiences a temperate climate with annual precipitation of 83cm and average temperatures ranging from -6° to 18° in winter and summer, respectively (NOAA, 2009). Douglas Lake is a medium-sized kettle lake, of area 15.27 km^2, whose benthic profile is dominated by seven unique depressions ranging from 16m to 27m (UMBS, 1972). The densely forested shores are dominated by a mixture of coniferous and deciduous trees. Little Carp Creek was observed to also be densely forested throughout its 2.5 km length. It begins at a width of roughly half of a meter and grows to four meters at the widest point. Depth is fairly constant throughout the river, reaching a maximum depth of about one meter. The average flow rate for the river is 368 liters per second (Vandekopple, 2009). We suspect that the carbon signature at the bottom of Douglas Lake, where lake water enters the aquifer and flows out the side of the moraine creating Little Carp Creek, would match that of the Little Carp Creek headwaters

Twenty water samples were obtained for this experiment. For the lake depth samples, Sedge Point Depression (SPD) was used for its relatively gradual increase in depth and its proximity to shore. Two perpendicular transects were roughly determined using a bathymetric map, depth chart (Figure 2). Fourteen were from Douglas Lake at varying depths and distances from shore with focus around a deep depression. Ten samples were from the surface: four at shore, four between shore and SPD, and two at SPD. In addition, four depth samples were taken in the depression. A handheld GPS devise (Garmin GPS12) was used to increase accuracy of actual sampling location with predetermined coordinates. Samples from Little Carp Creek were taken at four points along the river: headwaters, middle of river: before and after Hogsback Road, and mouth (where Little Carp Creek enters Burt Lake). Two samples were taken at each river site to increase result accuracy. At each sampling site, water was collected in 250mL bottles. Water samples from different depths were obtained using a Van Dorn apparatus. At each site geographic location and depth were recorded. The samples were collected in a two-day period with similar weather. All samples were analyzed for ^{13}C:^{12}C ratios at the University of

Michigan Biological Station (UMBS) Wet Lab using a Mass Spectrometer (Finnigan Delta Plus XP with Isodat 2.0) (Equation 1). The standard used is VPDB, limestone (Grant, 2009). Because this experiment is an observational study, controls were not needed. Three regressions were run comparing $\delta^{13}C$ value and distance from shore, depth, and distance from headwaters for Douglas Lake and Little Carp Creek. The two source mixing equation was also used to determine percent composition of carbon inputs for both systems (Equation 2).

Results:

The calculated allochthonous carbon inputs for Douglas Lake and Little Carp Creek are 32% and 40% respectively. The carbon isotopic values ranged from –23.14‰ to -24.60‰ from shore toward the center of SDP (Figure 4) with an average value of -24.30‰ (stdev=0.46). The relationship between distance from lake shore and carbon isotope ratios, however, was insignificant (r^2=0.048). The range of carbon isotopic values was from -23.01‰ to -24.53‰ for the depth profile of SPD (Figure 5) with an average of -23.91‰ (stdev=0.663). The relationship between water depth and carbon isotope ratios, however, had a weak trend (r^2=0.328). The range of carbon values were from -19.58‰ to -21.02‰ from the head waters of Little Carp Creek to the mouth of the stream (Figure 6) with an average of -20.52‰ (stdev=0.467). This relationship between carbon isotope ratios and distance from headwaters is weak but there is a slight trend (r^2=0.305).

Discussion:

Allochthonous carbon comprised 32% of the total organic carbon in Douglas Lake and 40% of the total organic carbon in the Little Carp Creek system, compared with autochthonous carbon inputs. This increase in proportional contribution of allochthonous carbon in the creek compared with the lake was expected. A system with low surface area to shoreline ratio is likely to have less primary production from within the system and instead be comprised of more terrestrially derived carbon sources to sustain the aquatic community (Finlay, 2001).

The rest of our results imply a lack of a relationship between carbon enrichment and all of our treatment variables: distance from lakeshore, lake depth, and distance from creek headwaters. All of our hypotheses can be rejected. When examining the Douglas Lake results, the lack of a relationship with carbon isotope ratios and lake depth may be due to the overturn of the lake. Lake water undergoes a cycling during spring, where the lack of stratification in water temperatures causes mixing across the thermocline. During these periods of overturn, carbon enrichment could be uniform throughout the water. Our samples were collected in late May, turnover begins in late March and the lake is thermally stratified by early July (Vandekopple, 2009). One factor that may have caused a lack of a relationship between carbon isotope ratios and the distance from the lake shore is the potential for an insignificant allochthonous input from leaf litter and aquatic plant matter. During the spring season, the lack of consistent and strong solar radiation may have prevented plant species from reaching photosynthetic and respiratory saturation.

Examining the Little Carp Creek results, the weak relationship between carbon isotopic ratios and distance from creek headwaters may be explained by stream retention time, which is the duration that water spends in the system. Retention time is a physical property of streams that is determined by flow rate and length. On average, the residence time of water in Little Carp Creek is 3.18 hours (Straw, 1990), which may provide a small window for leaf litter and other inorganic matter to become a significant allochthonous input into the creek.

The observed isotopic carbon ratios for the two sites cannot be explained by any of our initial hypotheses. Looking deeper into some of the biologic, geologic, and hyrdologic processes in Douglas Lake and Little Carp Creek offered some potential explanations. Carbon was identified and measured in two forms, dissolved inorganic (DIC) and dissolved organic (DOC). The primary sources of DIC in both Douglas Lake and Carp Creek are CO_3^{-2} from bedrock, CO_2 from the atmosphere, and CO_2 from respiration (Grant, 2007). The respiration delta value is based on the assumption that photosynthesis rates are low due to the spring cold-water temperatures (Wetzel, 2001). These three sources contribute different amounts to both systems, creating a discrepancy between the average DIC of the lake (-5.77‰) and the DIC of the creek (-9.26‰). The DIC of both systems is important to know and understand because when added to the photosynthetic fractionation factor of 22-23‰ (Wetzel, 2001), a delta value is obtained that represents the expected isotopic ratio of the water if all DOC originated from photosynthesis of DIC. This number can then be compared to the observed sample value and inferences can be made regarding the influencing organic carbon sources acting on the system.

Organic carbon in both systems comes primarily from terrestrial leaf litter, emergent aquatic vegetation, algae, and macrophytes (Grant, 2009). The latter three sources represent the autochthonous carbon and leaf litter represents the allochthonous carbon that we are interested in measuring. A carbon signature was calculated for both the autochthonous and allochthonous carbon sources by averaging delta values for a group of prominent tree species as well as a group of prominent aquatic primary producers that characterize both aquatic ecosystems. The calculated values for allochthonous and autochthonous carbon are -27.64‰ and -22.56‰ respectively (Grant, 2007).

We initially thought the carbon signature at the bottom of Douglas Lake, where lake water enters the aquifer and flows out the side of the moraine creating Little Carp Creek, would match that of the Little Carp Creek headwaters. Instead, the water is 3.71‰ more enriched coming out of the moraine at Three Rivers Gorge (Grant, 2009). We have come up with three possible explanations for the observed change. Bacterial catabolism may be taking place, in which carbon undergoes fractionation and the heavy isotopes are left in solution (Hickman et al, 2008). Another process that takes place in streams that are located in forests is soil leaching. Water that travels through the soil picks up old organic carbon that has been decomposing beneath the forest floor for long periods of time. This old carbon is highly enriched and contributes ^{13}C to the through flow water that ultimately ends up in the stream (Smemo et al, 2007).

The dense forest canopy drastically reduces available sunlight to the primary producers in the stream ecosystem, which lowers the rate of photosynthesis and thus decreases the levels of DIC that is converted to DOC by the autotrophs. An effect of this is less ^{12}C comprised biomass in the system and consequently a higher ^{13}C to ^{12}C ratio.

The water also runs through an aquifer on its way to Little Carp Creek. Below the surface of UMBS lies a limestone hard pan at a depth of 46.9m (Michigan dept of health, 1986). Once in the aquifer, the water remains underground for approximately two months where it could become more enriched with inorganic carbon molecules from the carbonate rock (Vandekopple, 1986).

Our experimental design could be improved in a number of ways. Avoidance of seasonal variation in carbon allocation associated with lake overturn and low photosynthesis can be done by taking samples periodically throughout the year. Lake samples could be taken later in the season, when Douglas lake has become stratified and surrounding vegetation is in full bloom. Also, samples taken in the fall may exhibit greater influence from deciduous leaf-fall.

Although our results did not support our original predictions, we have realized that there are many areas of future study regarding the topic of carbon signatures in aquatic ecosystems. Quantity of allochthonous inputs from riparian and other terrestrial vegetation has far-reaching implications (Delong and Brusven, 1994). This knowledge is beneficial to many areas of research and resource management and conservation. The understanding of aquatic systems and their carbon dynamics through the use of carbon isotopes can prove to be a vital tool in the research areas of trophic relationships, system quality, and carbon budgeting.

Acknowledgements:

We would like to thank University of Michigan Biological Station Wet Lab chemist, Mike Grant, for imparting his knowledge and love for science on us as we enriched our project and for the extra time spent contemplating our data.

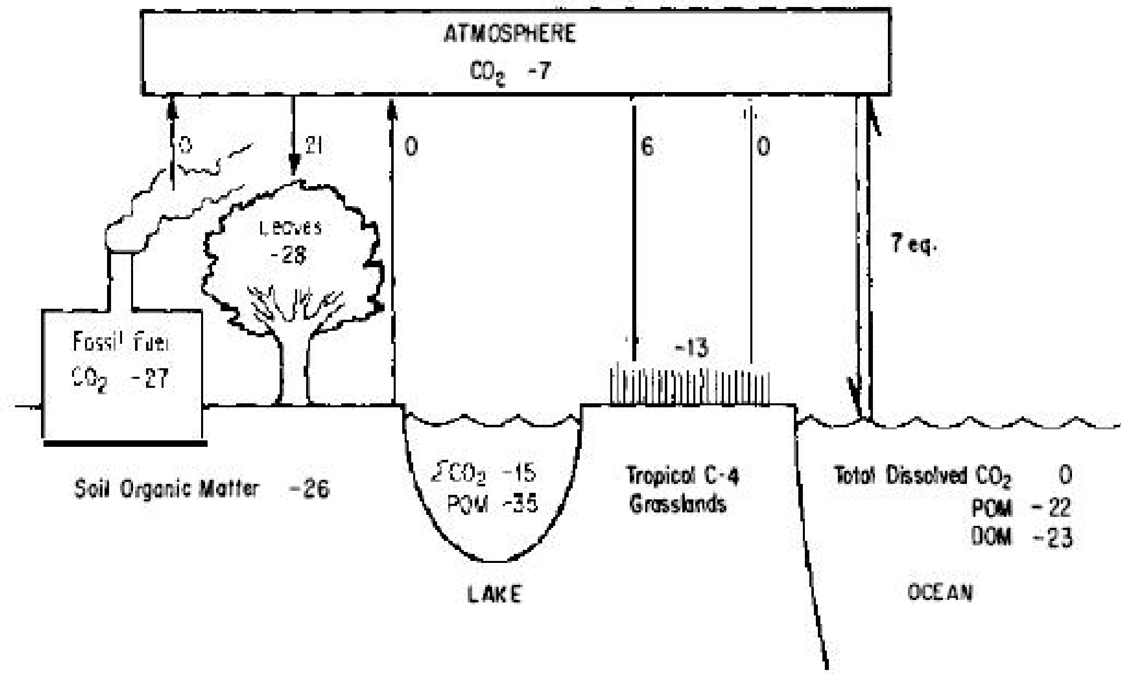

Figure 1: Diagram of Carbon Cycle

(Peterson and Fry 293-320)

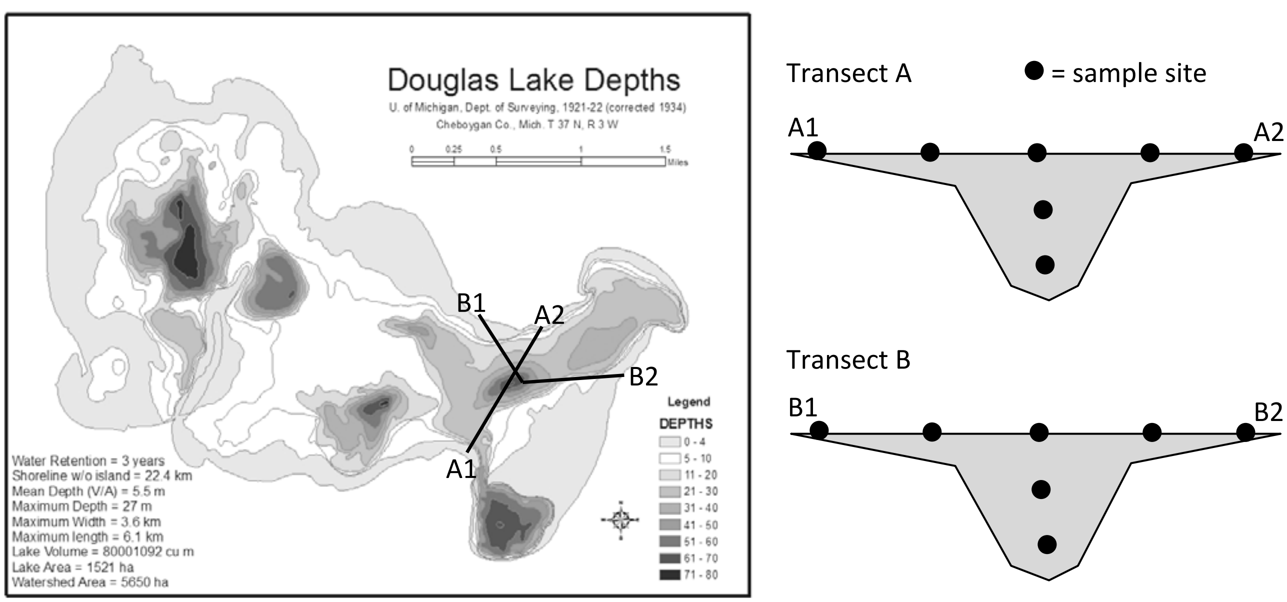

Figure 2. Douglas Lake Bathymetric Map with Sample Transects and Sample Sites. Map courtesy of UMBS: http://sitemaker.umich.edu/umbs/files/dougmap.jpg.

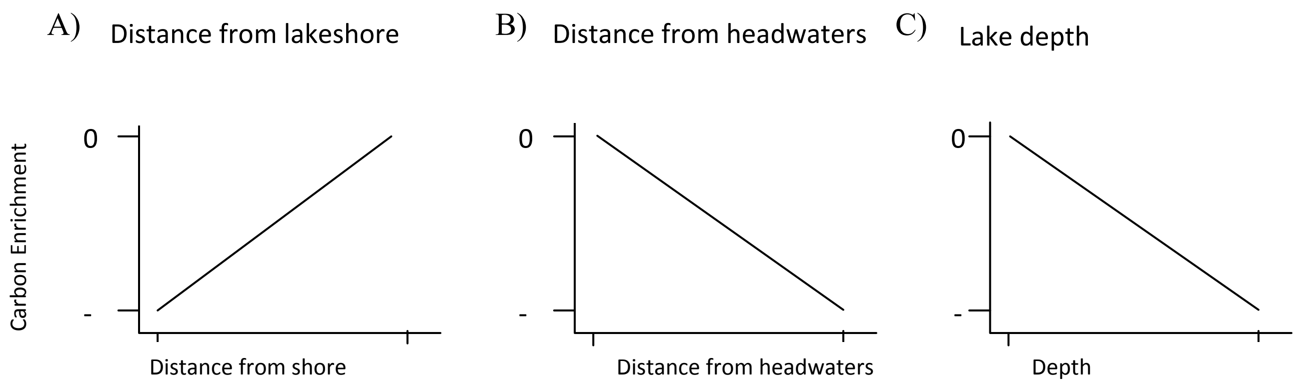

Figure 3. Hypothesized relationships between Carbon Enrichment and A) Distance from Lakeshore, B) Lake depth, and C) Distance from Little Carp Creek headwaters.

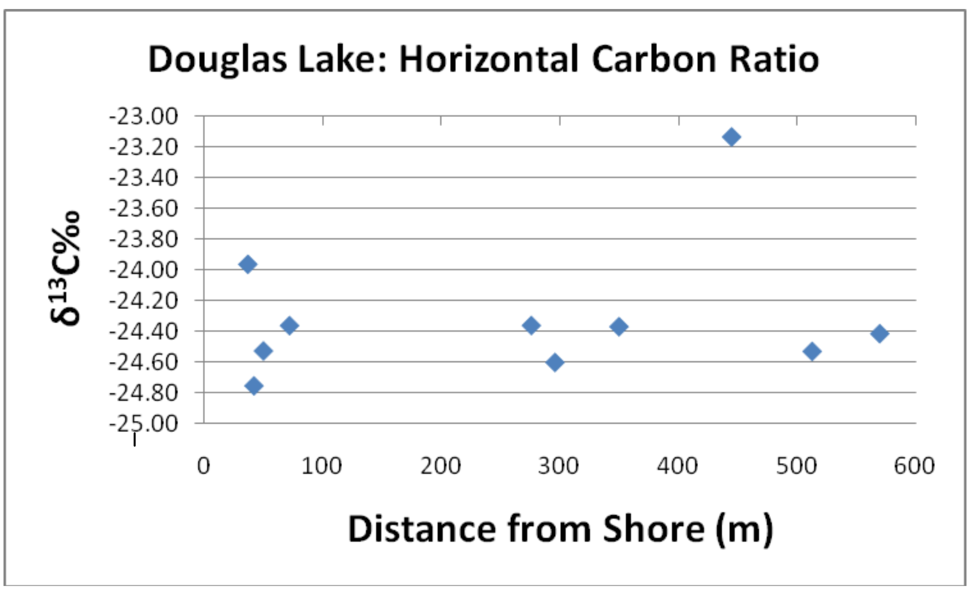

Figure 4: Douglas Lake Horizontal Carbon Gradient

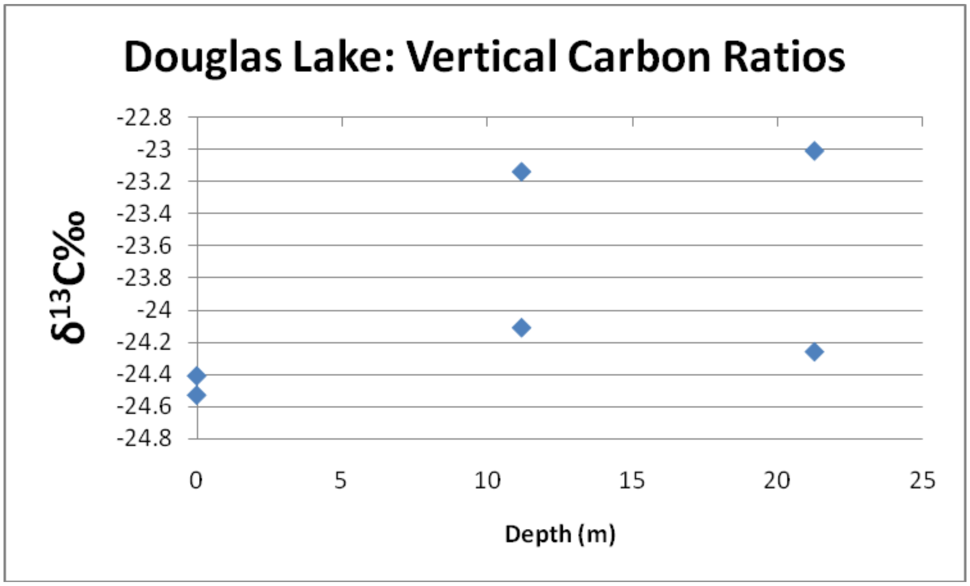

Figure 5: Douglas Lake Vertical Carbon Gradient

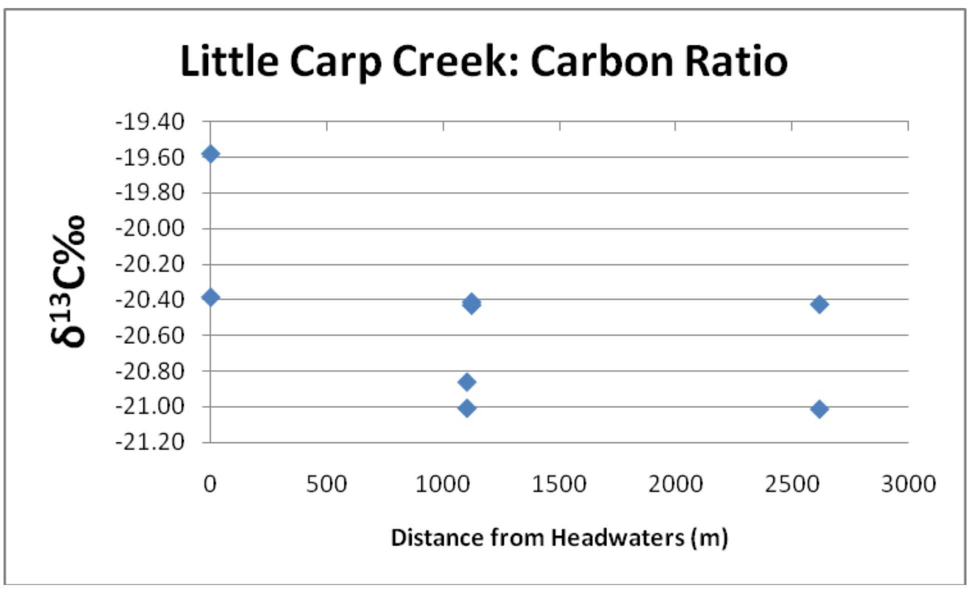

Figure 6: Little Carp Creek Carbon Gradient

Equation 1: $\delta(‰)=\dfrac{(^{13}C/^{12}C)_{sample}-(^{13}C/^{12}C)_{standard}}{(^{13}C/^{12}C)_{standard}} \times 1000$ (Stumm and Morgan, 1981)

Equation 2: $f_1=\dfrac{(\delta Sample-\delta Source_2)}{(\delta Source_1-\delta Source_2)}$ (Fry, 2006)

Literature Cited:

Balakrishna, K., and Probst, J.L.. (2005). Organic carbon transport and C/N ratio variations in. *Biochemistry*. 73: 457-473.

Cummins, K. W., (1974). Structure and Function of Stream Ecosystems. *Bioscience*. 11:631-641.

Delong, M.D. and Brusven, M.A.. (1994). Allochthonous Input of Carbon Matter from Different Riparian Habitats of an Agriculturally Impacted Stream. *Environmental Management*. 18:59-71.

Finlay, Jacques C.. (2001).Stable-Carbon-Isotope Ratios of River Biota: Implications for Energy Flow in Lotic Food Webs. *Ecology*. 82: 1052-1064.

Fry, Brian. (2006). Stable Isotope Ecology. Springer. New York City, NY. 288

Grant, Mike. (2007). Personal cataloging of $\delta^{13}C$ values of local flora. Resident Chemist. UMBS.

Grant, Mike. May, 2009. Personal interview. Resident Chemist. UMBS.

Hickman, Zachary A., B.J. Reid. (2008). Increased Microbial Catabolic Activity in Diesel Contaminated Soil Following Addition of Earthworms and Compost. *Soil Biology and Biochemistry*. 40: 2970-2976.

Kritzberg et al. (2004). Autochthonous versus allochthonous carbon sources of bacteria: Results from whole-lake 13C addition experiments. *Limnology and Oceanography*. 49:588-596.

Kritzberg, Emma S., et. al. (2005) "Does autochthonous primary production drive variability in bacterial metabolism and growth efficiency inlakes dominated by terrestrial C inputs?" *Aquatic Microbial Ecology*. Vol. 38: 103-111.

"National Weather Service Weathet Forcast office."(2009) NOAA. United States Department of Commerce. <http://www.crh.noaa.gov/apx/climate/climateGraphSSMSummer.php>.

Peterson, Bruce J, and Fry, Brian.(1987). Stable Isotopes in Ecosystem studies. *Ann. Rev. Ecol. Sl'st.* 18: 293-320.

Potter, P. E., Maynard, B.J., Depetris, P.J.(2005) *Mud and Mudstones: Introduction and Overview*. Springer.

Smemo, K.A., D.R. Zak, K.S. Pregitzer, A.J. Burton. (2007). Characteristics of DOC Exported from Norhern Hardwood Forests Receiving Chronic Experimental NO_3^- Deposition. *Ecosystems.* 369-379.

Stumm, W. and Morgan, J. J., (1981). Aquatic Chemistry: An introduction Emphasizing Chemical Equilibria in Natural Waters. New York City, NY. 214-218.

Straw, John R. (1990) "The Relationship of Current and the Amount of Detritus to the Invertebrate populations of Little Carp Creek." UMBS.

UMBS. (1972). Douglas Lake Profile.

Vandekopple, Robert. June, 2009. Personal Interview.

Wetzel, Robert G. (2001). Limnology. 3rd Edition. Elsevier Academic Press. San Diego, CA. 731-783.