Overview of stable isotope results from a comprehensive Savannah River study

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Abstract. Stable isotopes have proven to be a highly useful tool for gaining insight into the complex hydrological and ecological processes within rivers where isotopic signatures of source endmembers remain relatively constant. This consistency allows for endmember tracking as various sources mix and undergo processing along a river study reach. Insight from such analysis is only improved when a Lagrangian sampling approach (following a parcel of water as it flows downstream) is used to collect consecutive samples. We analyzed seston monthly for $\delta^{13}C$, $\delta^{15}N$, and C:N values in order to determine particulate organic matter (POM) dynamics and food web connectivity at nine mainstem and three creek locations within the middle and lower Savannah River watersheds. For three months, we analyzed $\delta^{18}O$ and $\delta^{2}H$ values on filtered water from each station as well in order to achieve a better understanding of the complex hydrology of the highly regulated and impounded middle and lower Savannah River basins. Both seston and water samples (for $\delta^{18}O$ and $\delta^{2}H$) were collected with a Lagrangian approach. The presumed dominant endmember sources of POM to the river study reach were: Lake Thurmond (provided ~60% of the flow to the middle and lower basins), a municipal wastewater treatment plant, a pulp and paper mill, a bottomland hardwood swamp, and the sampled creeks.

Results showed that $\delta^{13}C$, $\delta^{15}N$, and C:N values, along with a Lagrangian sampling scheme, proved to be quite powerful in helping to determine the ecological processing and contribution of presumed dominant endmember sources of POM to the river. For most of the POM data, C:N was high entering the Augusta/North Augusta area (CSRA), decreased through the CSRA (an urban corridor), and increased within the floodplain reach. $\delta^{13}C$ for mainstem stations were fairly consistent and trended toward the bottomland hardwood swamp endmember below the CSRA. $\delta^{15}N$ signature was high above the CSRA, decreased within the CSRA, and increased within the floodplain reach. Trends within mainstem Lagrangian samples were consistent with stimulation of algal growth and concomitant bacterial processing of that carbon source and were much less influenced by the presumed endmembers. These results indicate the necessity for further studies in order to achieve better resolution of carbon dynamics and should include $^{13}CO_2$ dynamics as well.

Many of the $\delta^{18}O$ and $\delta^{2}H$ values were consistent with the Global Meteoric Water Line (GMWL), however samples during the December 2007 sampling event had a slope << GMWL which may have indicated evaporative enrichment. Lagrangian samples indicated slight changes in $\delta^{18}O$ and $\delta^{2}H$ values along the study reach which may have resulted from groundwater and rain event contributions.

INTRODUCTION

Stable isotopes have been used extensively over the past 30 years as a tool to increase knowledge of food web connectivity in aquatic systems. Stable isotopes allow for determination of connectivity because organisms *nearly* take on the isotope values of those foods upon which an organism feeds, hence the origination of the phrase, “You are what you eat” (Peterson and Fry, 1987). *Nearly* in the previous sentence refers to slight shifts in isotope values as predator-prey relationships move up the food chain. For example, carbon isotopes shift by ~1‰ in the more positive direction, and nitrogen isotopes shift by ~3.5‰ in the more positive direction as successive trophic level jumps are made (Peterson and Fry, 1987). Another reliable trend that stable isotopes adhere to pertain to small scale processes such as respiration, photosynthesis, and chemical reactions; lighter isotopes are favored over heavier isotopes (Fry, 2006). For instance, if POM is processed within a river by bacteria, the bacteria will preferentially choose $\delta\,^{12}C$ over $\delta\,^{13}C$ and the overall remaining POM in the river water will be mostly $\delta\,^{13}C$ and will appear as a “heavier” signature (more negative) in successive downstream samples. General trends for $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ are shown in Figure 1.

Another method for understanding food web relationships and biological effects on organic material in aquatic systems is to use $\delta^{13}C$-vs-C:N plots. The same trends apply for $\delta^{13}C$ as above, but the C:N of organic material changes with sources and processing as well. In general, as bacteria process organic material they selectively utilize the nitrogen and labile carbon components of the POM complex, leaving highly refractory carbon and a high C:N.

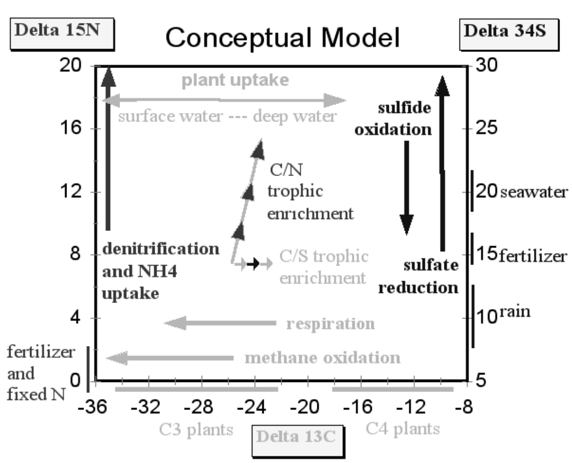

Figure 1. Conceptual model of $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ stable isotope dynamics in food web studies (from, Kendall et al., http://sofia.usgs.gov/publications/posters/atl-mtg/print.html).

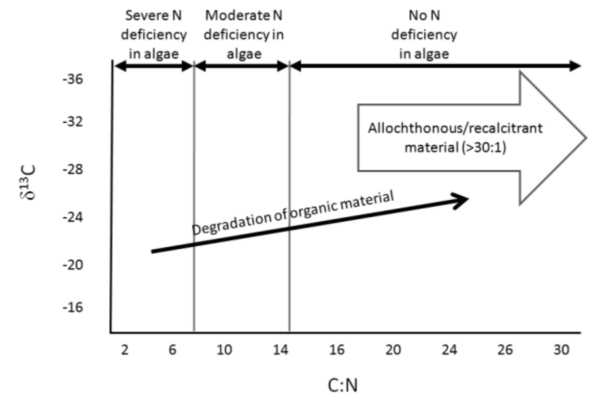

Figure 2. General trends of carbon degradation in aquatic systems as shown in $\delta^{13}C$-vs- C:N plots.

Although C:N vary widely according to individual sources, a few examples of C:N in nature are as follows: humic substances (recalcitrant organic material) >30:1, algae ~6.6:1, allochthonous material >45:1, autochthonous material ~12:1 (Wetzel, 2001); 5:1-8:1 for riverine plankton, 10:1-30:1 for periphyton and macrophytes (Kendall et al., 2001). Figure 2 shows general trends for $\delta^{13}C$-vs- C:N plots.

When viewed together, these plots provide powerful data analysis tools for source tracking and ecological studies of the fate and transport of POM in aquatic systems. The source tracking approach usually starts with an understanding of the major sources of material to the system. In this study we used the source tracking approach to determine the fate and transport of POM within the Savannah River by using a Lagrangian sampling approach and by considering the major sources of POM to be: discharge from the dam of a regulated river, a municipal wastewater treatment facility, a pulp and paper mill, major tributaries, and a bottomland hardwood forest.

METHODS

This study was conducted within the middle and lower Savannah Basin, from RM 215 (~7 miles below Thurmond Dam) to RM 61 (near Clyo, GA). We collected water samples monthly at 9 mainstem river stations (shown as designated river mile) and 3 tributaries

(Stevens Creek (SC), Horse Creek (HC), and Butler Creek (BC)) with a collapsible bag, volume and depth integrated sampler (where flows permitted) and with a hose and pump during low flows. Most of the mainstem samples were collected according to a Lagrangian scheme. Travel times were determined using trends within continuous discharge, temperature, dissolved oxygen, and specific conductance data.

Characterization of source samples was accomplished by sampling the nappe at the final outfall of the wastewater treatment plant (WWTP) and the pulp and paper mill (PPM) effluents. Discharge from the dam was sampled within the mainstem river, ~ 7 river miles below the dam (RM 215), and the bottomland hardwood swamp (BHS) samples were collected within the flowing portions of Phinizy Swamp which is a bottomland hardwood forest.

δ^{18}O and δ^{2}H samples were filtered in the field with a 0.2um syringe filter and were stored in 5 mL, Teflon sealed vials. POM samples were filtered in the lab on a pre-combusted GF/F filter. All samples were stored on ice in the field; δ^{18}O and δ^{2}H samples were stored at 4°C and filtered POM samples were stored in the freezer until analysis. Filters were sent to the University of Georgia's Analytical Chemistry Laboratory for analysis of δ^{13}C, δ^{15}N, and C:N and water samples were sent to the University of Georgia's Center for Applied Isotope Studies.

RESULTS

δ^{13}C, δ^{15}N, and C:N of POM

Designated sources had distinct enough signatures to elucidate POM dynamics, however seasonal trends were apparent at each site, especially RM215 which was influenced by seasonal stratification within the lake. In general, δ^{15}N of POM was highest at RM 215 (~12) and at WWTP (~12.5) and lowest at PPM (~ -2.7) with all other sources and river samples in between those values. The δ^{13}C values typically fell between the highest at PPM (~ -25.9) and lowest within SC (~34.5). C:N ratio values ranged from the lowest at WWTP (~6) and did not have a consistently high location but the highest value was ~14 which was in HC.

Mainstem Lagrangian sample results typically showed steady δ^{13}C values but a slight decrease in C:N below the dam followed by a steady increase in C:N. δ^{15}N values decreased steadily from the dam to RM179 then increased to RM61. All three parameters typically trended toward the BHS value (Fig. 3).

Water δ^{18}O and δ^{2}H results

δ^{18}O and δ^{2}H values were determined from November 2007 through January 2008 only. Most samples did not vary statistically for nearly all samples within a monthly sampling event. For each sampling event, HC was typically different from most other samples during each event. Nearly all samples fell approximately on or near the Global Meteoric Water Line (Craig, 1961) during the November sampling event, were nearly identical during the December event, and fell to the right of the North American Meteoric Water Line (Yurtsever, and Gat, 1981) during the January sampling event (Fig. 4).

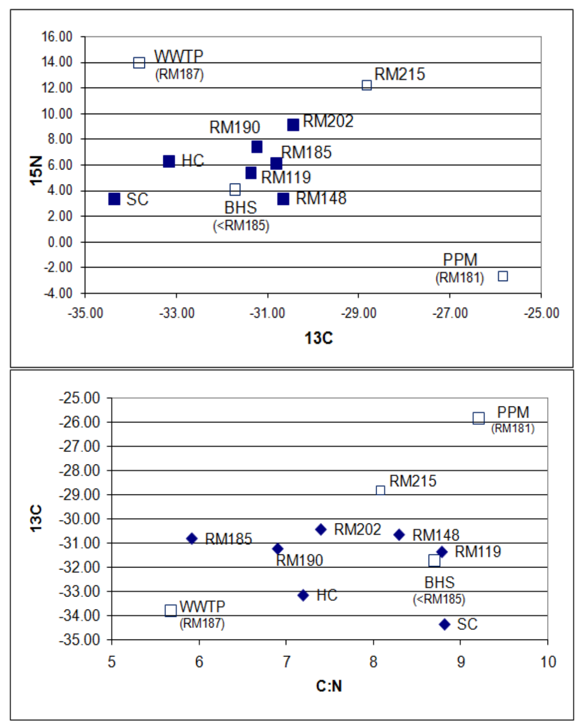

Figure 3. POM δ^{13}C-vs-C:N and POM δ^{13}C-vs- δ^{15}N values for mainstem Lagrangian samples and tributaries (solid symbols) and sources (hollow symbols) from the August 2006 sampling event. River miles in parentheses indicate approximate location of discharges to river. WWTP= wastewater effluent after constructed wetlands; RM215= 7 miles below dam-assumed to be signature for lake water; BHS= Phinizy swamp- assumed to be signature for bottomland hardwood swamp; PPM= pulp and paper mill effluent).

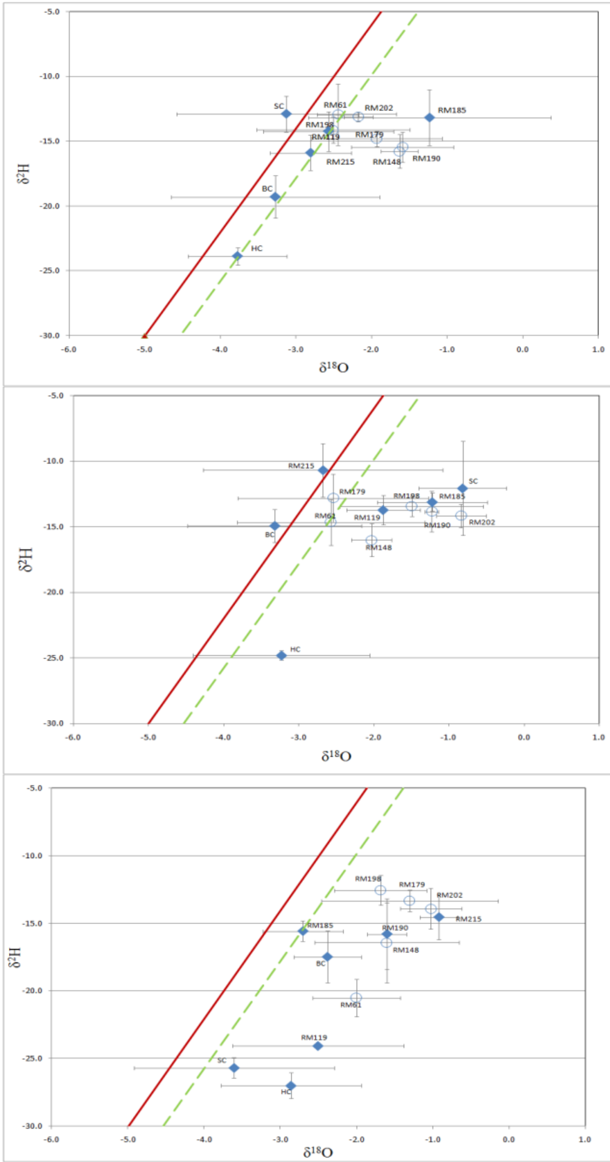

Figure 4. δ^{18}O and δ^{2}H values for Savannah River water for November 2007 (top), December 2007 (center), and January 2008 (bottom).. Solid line = GMWL, dotted line = NAMWL, empty circles indicate Lagrangian samples.

DISCUSSION

δ^{13}C, δ^{15}N, and C:N of POM

The trend among the Lagrangian samples shown in the δ^{13}C-vs-C:N plot, indicated that POM initially shifted from the dominant lake water source (RM215) to a more enriched carbon source with a smaller C:N to RM185. Since the mainstem river trended toward WWTP (RM187) with respect to C:N but not δ^{13}C, this trend most likely was not influenced by POM from WWTP but resulted from the stimulation of algae within that stretch of river where the decrease in C:N indicated stimulation of additional biomass. The decrease in δ^{13}C most likely resulted from the incorporation of a depleted CO_2 source. That source may have been the hypolimnetic water released during power generation. The concomitant depletion of the POM δ^{15}N signal was consistent with biomass generation as well. The δ^{13}C-vs-C:N trend after RM185 remained constant with regard to δ^{13}C but showed a significant increase in C:N. In addition, the δ^{15}N signal showed additional depletion as well. This trend was consistent with mixing of an additional source, most likely PPM effluent. Slight decreases in POM δ^{13}C, δ^{15}N, and C:N from RM148 to RM119 indicated that the bacterial respiration of the available POM was ongoing.

Since the mainstem Lagrangian samples steadily trended toward BHS from RM 185 to RM119, an alternative hypothesis could have been that the exchange of water through the floodplain section was influenced by the addition of POM from the floodplain. The data collected within the two year study were not enough to make definitive determinations between the two hypotheses but it was quite clear that the mainstem stations did not wholly trend toward either WWTP or PPM.

Water δ^{18}O and δ^{2}H

Most samples fell along the NAMWL which indicated that the hydrology was driven by surface water. Significant precipitation prior to and during the January 2008 sampling date indicated that the Local Meteoric Water Line may lie parallel and to the right of the NAMWL.

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