Progress Report to the Jordan River Farmington Bay Water Quality Council

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Nitrogen sources and transformations within the Jordan River, Utah

and

Microbial community response to energy and nutrient availability in the Jordan River, Utah

Prepared by

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Table of Contents

Executive Summary

The Jordan River is a 4th order river that runs through the Salt Lake Valley of north-central Utah, USA. The river suffers impairment in the form of low dissolved oxygen in some of parts of its flowpath. Low dissolved oxygen is likely due to excess organic matter and nutrients fueling microbial respiration.

We obtained funding[1] from the Jordan River Farmington Bay Water Quality Council, the innovative Urban Transitions and Arid-region Hydro-sustainability (iUTAH) Program, and the University of Utah Undergraduate Research Opportunties Program (UROP) to answer the following six research questions:

1. *What proportion of N entering the river is sourced from WRF effluent?*
2. *Is N being transformed along the Jordan River flowpath via dissimilatory N uptake?*
3. *Is wastewater effluent a source of N for in-stream biota?*
4. *Are substrates supporting microbial community metabolism in the Jordan River primarily of terrestrial or aquatic origin?*
5. *What is the quality of the organic matter within the Jordan River?*
6. *Are microbial communities in the Jordan River limited by C, N, and/or P?*

We collected data in spring, summer, and fall of 2016 from 18 sites along the Jordan River, 2 sites along the oil drain canal, 1 wetland of the Great Salt Lake, and 4 water reclamation facility (WRF) effluent discharge sites. This spatial and temporal design was selected to assess broad scale effects of WRF inputs to the system and fine scale dynamics of nutrient transformations at times when the river varied with respect to hydrology and temperature.

Main findings include the following:

- TDN inputs from WRF effluent discharge represented between 46-92% of total dissolved nitrogen (TDN) loads in Jordan River locations immediately downstream of WRF sites, with the majority of the load generally occurring as NO_3-N.
- We find evidence of mass nitrogen and phosphorus removal from the water column between water reclamation facilities, suggesting that biotic uptake is occurring and influences downstream nutrient loads.
- ^{15}N-NO_3 becomes less enriched along an intensively studied flowpath, suggesting either that N fixation is occurring or novel inputs of less enriched in ^{15}N-NO_3 are entering the system.
- Origination of fine particulate organic matter (POM) is difficult to discern due to likely contamination by entrained sediment, which confounded distinction in ^{2}H values between biofilm and riparian leaf end members.
- ^{15}N of POM and dissolved organic matter (DOM) become enriched downstream of the Central Valley WRF, but the effects of effluent on POM are less clear and we lack data on DOM ^{15}N in relation to other WRFs.

[1] Funding from the Jordan River Farmington Bay Water Quality Council supported, in part or in full, data collection and analysis for research questions 3-6.

- Fluorescence Index (FI) values, derived from emission-excitation matrices (EEMs), are very high for the Jordan River relative to other aquatic systems. High FI values are typically associated with microbially sourced organic matter. Elevated FI values downstream of WRFs relative to upstream sites in all seasons indicate that WRF inputs influence organic matter composition in the Jordan River.
- Ecoenzyme activities indicate that most of the organic matter in the river supporting microbial metabolism is labile.
- Microbial communities in the water column and sediment differ with respect to C, which is in adequate supply in the water column but appears to be limiting in the sediment in some seasons. Microbial communities in the water column and sediment are similar because N appears to be in adequate supply and both communities are limited with respect to P at some times of the year.

This research has contributed to the professional training of three undergraduate students, one graduate student, and two postdoctoral scholars. To date, we have presented our work at 8 conferences and have one manuscript in preparation for submission to the Journal of the American Water Resources Association in late January 2018.

Introduction

The Jordan River is a 4th order river that runs through the Salt Lake Valley of north-central Utah, USA. The river originates at the outlet of Utah Lake and drains into wetlands of the Great Salt Lake. Roughly 44% of the surface area of the 805 mi^2 Jordan River watershed is urban.

The Jordan River suffers impairment related to water temperature and concentrations of total dissolved and suspended solids (TDS and TSS, respectively), dissolved oxygen (DO), and pathogens (e.g., e coli) at levels to the detriment of human health and wildlife (Jensen and Rees 2005). DO concentrations are < 4 mg/L at some locations along the river's 58-mile course (Arens and Adams 2012).

Excess nutrient loading to streams and rivers also is an issue in many urban watersheds (Bernhardt et al. 2009; Kaushal et al. 2011). Eutrophication can promote blooms of nuisance algae, including taxa that produce toxins. Nutrient loading from water reclamation facilities (WRFs) are of concern within the Jordan River due to the number of WRFs and their contribution towards river flow via effluent. Twelve WRFs discharge into Utah Lake, the Jordan River itself, one of the major tributaries of the Jordan River, or a canal draining directly into the Great Salt Lake (Fig. 1). The three WRFs discharging directly into the Jordan River or the Mill Creek tributary contribute between 13 and 29% of the river's flow directly downstream of a given effluent outfall. These three direct WRF contributions constitute 20% of the river's flow above the surplus canal in spring and 43% in summer.

WRFs treat highly concentrated wastewater through a series of settling and mixing processes and vary widely in nitrogen (N) removal efficiency depending on which technologies are used (Townsend-Small et al. 2011; Schmidt et al. 2016). However, the contribution of WRFs to the overall load of N to the Jordan River and the extent to which the river can transform N inputs from organic to inorganic forms or remove N from the system via N_2 gas efflux is not clear. It also is not known whether biota assimilate N inputs from WRFs into biomass.

Microbial communities are responsible for the majority of organic matter and nutrient transformations in streams and rivers (Mallin et al. 2011, Sinsabaugh and Follstad Shah 2012). Microbial community metabolism is heterotrophic. This process can deplete oxygen within aquatic ecosystems, particularly in the presence of high supply of organic matter and nutrients. Debate exists whether organic matter supply in the Jordan River is largely due to in-stream production by autotrophs (i.e., algae, macrophytes) or inputs from terrestrial sources (i.e., plant litter, sediment in run-off, solids in waste water effluent). Furthermore, the quality of organic matter within the system has not been well characterized. It also is unclear whether microbial communities in the Jordan River are limited by an imbalance in organic matter, nitrogen and/or phosphorus at various times or locations, despite generally high supply of these resources.

Research Questions

We have asked the following research questions, in two complementary studies, in an effort to better understand the biogeochemistry and ecology of the Jordan River:

<u>'Intensive' study: Tracking nitrogen sources and transformations within the Jordan River</u>

1. *What proportion of N entering the river is sourced from WRF effluent?*
2. *Is N being transformed along the Jordan River flowpath via dissimilatory N uptake?*
3. *Is wastewater effluent a source of N for in-stream biota?*

Note: The innovative Urban Transitions and Aridregion Hydrosustainability (iUTAH) Program funded this study.

'Extensive' study: Microbial communities response to energy and nutrient supply within the Jordan River

7. *Are substrates supporting microbial community metabolism in the Jordan River (suspended solids and benthic organic matter) primarily of terrestrial or aquatic origin?*
8. *What is the quality of the organic matter within the Jordan River?*
9. *Are microbial communities in the Jordan River limited by C, N, and/or P?*

Methods

Study Design

For the intensive study, we established ten study sites, at 1 km intervals, within a 10 km stretch of the Jordan River beginning just downstream of the Central Valley Water Reclamation Facility (Figure 1, Table 1). These sites were sampled synoptically (i.e., within a single day) during each sampling campaign. We deemed the proximity of sites and synoptic sampling necessary to monitor change in N inputs from the WRF, given that processing of these inputs could occur rapidly and over small spatial scales.

For the extensive study, we established ten study sites along the Jordan River flowpath (Figure 1, Table 1), including a site just downstream of the Utah Lake outlet, sites above and below each WRF, one site within the oil drain canal just upstream of the Farmington Bay inlet and one wetland site. The last two 'river' sites were located within the oil drain canal because this is where the Salt Lake City WRF discharges effluent. The wetland site was included as a point of comparison for the riverine and canal sites.

Effluent from the four WRFs along the Jordan River flowpath was sampled in conjunction with field site sampling.

Samples were collected from the intensive and extensive sites in spring (late May and early June), summer (mid August), and fall (late October) of 2016. These dates were selected because they represent times that differ in terms of hydrology (high flow in spring and summer, low flow in fall) and dominant sources of organic matter inputs (i.e., autotrophic vs. terrestrial).

Analytical Techniques

Chemistry and stable isotopes of water

Wastewater effluent is often nutrient rich and enriched in $\delta^{15}N$ compared with other sources such

as precipitation, fertilizer and soil N, due to mass-dependent fractionation during waste production (Kendall et al. 2007). Denitrification within aquatic habitats can further enrich $\delta^{15}N$ within the water column as microbes preferentially use ^{14}N (Kendall et al. 2007). Hence, we are using measures of riverine nutrient concentrations, hydrologic flow volume, and stable isotope analyses (natural abundance) to quantify the contribution of effluent to N loading to the river, compared with other sources (Research Question 1), the degree to which N is transformed downstream via biotic processes (Research Question 2), and the extent to which biota assimilate N from WRF inputs (Research Question 3). We are using a mass balance approach to quantify WRF contributions of nutrients and water to the river, based on nutrient concentrations within the river and effluent sources combined with flow volumes for the river and effluent discharge (Research Question 1). We are quantifying changes in the natural abundance of $_{15}N\text{-}NO_3$ in the water column downstream of the Central Valley WRF to determine if denitrification is occurring along the Jordan River flowpath, which would result in a loss of N gas to the atmosphere (Research Question 2). We are measuring the natural abundance of ^{15}N in particulate organic matter within the water column, biofilms, and sediments to infer whether N inputs from WRFs are being assimilated by biota within the Jordan River (Research Question 3).

Elemental content and stable isotopes of biofilms, organic matter, and sediment

We are quantifying the natural abundance of a suite of stable isotopes (^2H, ^{13}C, and ^{15}N) and the C:N ratios of biofilms, fine particulate organic matter (FPOM) in the water column and sediments (^{13}C and ^{15}N only), and senesced leaves of riparian plants to infer whether organic matter within Jordan River is primarily of aquatic or terrestrial origin (Research Question 4). This suite of stable isotopes was chosen for several reasons. First, the natural abundance of deuterium (^2H) produced in aquatic (-250 $^0/_{00}$) vs. terrestrial (-150 $^0/_{00}$) habitats generally differs by ~ 100 dell units ($^0/_{00}$; Doucett et al. 2007). Second, measurement of ^{13}C and ^{15}N combined with C:N ratios also can distinguish between organic matter derived from algal vs. terrestrial production (Finlay and Kendall 2007). Third, measurement of ^{13}C and ^{15}N may help to determine if organic matter has an anthropogenic signature. Human diets are now rich in products derived from corn, a C4 plant that is more enriched (-13 $^0/_{00}$) in ^{13}C relative to C3 plants (-27 $^0/_{00}$), such as riparian shrubs and trees, and freshwater autotrophs (-18 to -35 $^0/_{00}$; Finlay and Kendall 2007). In addition, fecal matter is typically enriched in ^{15}N (+15-20 $^0/_{00}$) relative to the atmosphere or N fixed by biota (0 $^0/_{00}$; Kendall et al. 2007).

Ecoenzyme expression and excitation-emission matrices

We are inferring the quality of organic C fueling microbial community metabolism (Research Question 5) using two complementary approaches: measurement of ecoenzyme activity rates associated with the hydrolysis of labile and recalcitrant organic matter (Table 2) and quantification of dissolved organic C (DOC) concentrations combined with multi-wave fluorescence spectroscopy to create excitation-emission matrices (EEMs). Microbes generally express more POX relative to BG when available organic matter is recalcitrant (Sinsabaugh and Follstad Shah 2011). EEMs represent a simple index used to identify the types of organic matter present in samples and distinguish between likely sources of organic matter to rivers (McKnight et al. 2001).

Microbes generally produce and release enzymes proportional to energy or nutrient requirements (Sinsabaugh and Follstad Shah 2012; Table 2). When the availability of energy and nutrient resources meet microbial maintenance and growth demands, the ratios of ecoenzymes related to C, N, and P resources is approximately 1:1:1 (Sinsabaugh et al. 2009). Deviations from these ratios indicate whether microbial communities are energy or nutrient limited (Sinsabaugh and Follstad Shah 2012). We have measured the activity rates of five ecoenzymes associated with microbial acquisition of C, N, and P using high throughput fluorescence spectroscopy to address whether these resources are balanced or imbalanced relative to microbial stoichiometric requirements (Research Question 6).

Results

What proportion of N entering the river is sourced from WRF effluent?

Total dissolved nitrogen (TDN) loads (kg day^{-1}) within the Jordan River ranged from 150-4734 kg N day^{-1}in spring and 512-6847 kg N day^{-1} in summer, with the greatest increase in loads for both seasons occurring downstream of the Mill Creek tributary (Fig. 2). This tributary carries the effluent from the Central Valley WRF. TDN inputs from WRF effluent discharge represented between 46-92% of total dissolved nitrogen (TDN) loads (kg day^{-1}) in Jordan River locations immediately downstream of WRF sites in spring and summer (Fig. 3). The majority of the load from all WRFs occurred as NO_3-N in all seasons, with the exception of the Salt Lake City WRF. Loads from this WRF were dominated by NH_4-N in summer and were split almost equally between NH_4-N and dissolved organic N (DON) in fall (Fig. 4). NO_3-N also was the predominant form of N within the intensively studied reach of the river in spring and summer, while DON loads were generally greater than NH_4-N in this area (Fig. 5). DON and NH_4-N loads were similar, while NO_3-N loads remained higher (Fig. 5). NO_3-N loads ranged between approximately 1000-2500 kg day^{-1}, but loads as high as 4000-5000 kg day^{-1} were observed in fall (Fig. 5)

Is N being transformed along the Jordan River flowpath via dissimilatory N uptake?

We found a positive correlation between $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ for water samples collected in spring along the intensively sampled reach ($r^2 = 0.67$; Fig. 6). The slope for this relationship was 0.45, which is close to the value (0.50) expected if N is being transformed via denitrification along the downstream flowpath. However, we found that samples became less enriched in $^{15}N\text{-}NO_3$ along the flowpath, suggesting either that N fixation is occurring or novel inputs of less enriched in $^{15}N\text{-}NO_3$ are entering the system (e.g., leaf litter from N_2-fixing species, such as Russian olive [*Elaeagnus angustifolia*], groundwater recharge). Analyses of $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ for water samples collected in summer and fall do not show this trend, however. When combined with longitudinal trends in $\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$ our results suggest that denitrification does not have a strong impact on nitrate removal in the water column. Instead, nitrification may be favored.

Is wastewater effluent a source of N for in-stream biota?

$\delta^{15}N$ of fine particulate organic matter (POM) measured in our study was quite variable, ranging from 3-12 ‰ (Fig. 7). $\delta^{15}N$ of POM derived from effluent discharged from the Jordan Valley

WRF consistently had lower (depleted) values than the river, while effluent discharged from the Central Valley WRF consistently had higher (enriched) values than the river. Effluent from the South Valley WRF had $\delta^{15}N$ of POM values lower than the river in spring and fall, but higher values in summer. $\delta^{15}N$ of POM values just downstream of WRFs sometimes declined in response to lower effluent inputs (e.g., downstream of Jordan Valley WRF in fall), but sometimes increased (e.g., downstream of Jordan Valley WRF in summer) relative to upstream river $\delta^{15}N$ of POM signatures. These data indicate we cannot correlate $\delta^{15}N$ of POM signatures to effluent discharge. However, downstream of the Central Valley WRF, $\delta^{15}N$ of POM values were always enriched, suggesting a consistent influence of effluent inputs on POM signatures at this location. It is possible these differences are due to differences in technology used at the various WRFs along the river.

Because dissolved N in the river is not isotopically distinct from N in wastewater effluent, we were not able to quantify the proportion of N in POM sourced from effluent. The broader question here, however, relates to the potential for uptake of wastewater-derived nutrients within the stream channel. To that end, we do find evidence of mass nitrogen and phosphorus removal from the water column between water reclamation facilities (Fig. 3), suggesting that biotic uptake is occurring and influences downstream nutrient loads.

$\delta^{15}N$ of POM values measured in 2013 (Kelso and Baker 2017) and 2016 were of a similar range but values in 2016 were usually more enriched relative to values in 2013 (Fig. 7). $\delta^{15}N$ of POM values for both 2013 and 2016 were much more depleted relative to $\delta^{15}N$ of DOM measured in 2013 (Kelso and Baker 2017). $\delta^{15}N$ of DOM was 6 ‰ greater downstream of the Central Valley WRF relative to upstream in summer of 2013. These data suggest that the N signature of effluent discharge is more evident in the river's DOM pool as compared to the POM pool. However, we do not have data on the $\delta^{15}N$ of DOM within effluent, so this conclusion is uncertain.

We have not reported $\delta^{13}C$ values of POM or C:N ratio of POM because many of our samples had highly enriched $\delta^{13}C$ values, suggesting contamination of carbonates within the POM matrix presumably due to suspended solids in the river. We could not correct for these carbonates through acid digestion given the small quantity of POM collected on filters.

Are substrates supporting microbial community metabolism in the Jordan River primarily of terrestrial or aquatic origin?

We did not find distinction between the $\delta^{2}H$ values of biofilms and riparian vegetation, as expected (Figs. 8-9). Contamination of biofilms by entrained sediment enriched in ^{2}H is one possible reason for this outcome. However, we found that FPOM $\delta^{2}H$ values were similar in both 2013 (measured by J. Kelso) and 2016 (our study) (Fig. 9). FPOM from both years of sample collection and DOM (measured in 2013 by J. Kelso) also had similar $\delta^{2}H$ values (Fig. 9). Mean annual flow in the Jordan River at 1700 S. was 20.6 $ft^3\ s^{-1}$ for 2013 and 34.6 $ft^3\ s^{-1}$ for 2016 (USGS 2017). Differences in flow in these years may have altered the relative contribution of terrestrial vs. aquatic sources to dissolved and particulate organic matter pools, but it is not possible to distinguish between contributions from various sources without isotopic distinction in biofilm and riparian vegetation end-members.

Fluorescence Index (FI) is one type of index that can be calculated from excitation-emission matrices (EEMs). FI values from Antarctica (a purely microbial source) are approximately 1.8-2.0. FI values from the Suwannee River (with intact wetland) are approximately 1.1-1.2. Hence, lower FI values are associated with plant material and higher FI values are associated with microbial biomass or material sourced from microbes. The Jordan River has very high FI values – as high or higher than values observed from microbe dominated communities of Antarctica (Fig. 10). These results suggest that microbes may constitute a significant fraction of dissolved organic carbon (DOC) in the water column. However, EEMs have not been commonly used in urban river systems. Such systems may contain constituents that augment FI values relative to systems without large human populations. That said, our results spurred us to examine the methods used to generate FI values, which may lead to a modification of the analysis used to measure FI. We will re-analyze our data, should this modification be deemed appropriate. Regardless of the actual value of FI, our data suggest that WRFs influence FI values, given that FI values were generally elevated downstream of WRFs relative to upstream sites. Lowest FI values in the Jordan River were observed just downstream of Utah Lake, upstream of the Jordan Basin WRF, and in the Unit 1 wetland. Higher rates of primary production in all of these areas relative to other parts of the Jordan River may be one mechanism leading to similarity in FI values. FI values were lowest in the Jordan River in spring, during high hydrologic flow, and generally increased through summer and fall. Highest FI values in fall as compared to other seasons suggest terrestrial sources do not contribute significantly to dissolved organic matter loads, contrary to previous reports (UDWQ 2015).

What is the quality of the organic matter within the Jordan River?

High FI values (Fig. 10), as discussed previously, suggest that DOC in the Jordan River water column is very labile. BG:POX ratios (Fig. 11) also show much greater rates of ecoenzyme expression related acquisition of C from labile sources (i.e., glucose) relative to more recalcitrant sources (i.e., lignin). Ecoenzyme expression was measured on unfiltered water samples, so these data are reflective of both dissolved and particulate forms of organic matter.

Are microbial communities in the Jordan River limited by C, N, and/or P?

Ecoenzyme activities in water derived from the river, effluent, oil drain, and wetland were highly variable both spatially and temporally (Fig. 11). Activities of ecoenzymes associated with C and N acquisition (BG, NAG+LAP) were high in effluent, resulting in elevated activities downstream. This pattern was not evident with respect to activities of ecoenzymes associated with P acquisition (AP). AP activities along the river's flow path in summer were the mirror opposite of activities in spring and fall, while longitudinal patterns of BG and NAG+LAP were generally similar through time. Regression analyses of ecoenzyme activities (Fig. 12) showed consistent positive relationships between C and N acquisition, explaining between 54-85% of the variation. Slopes had values less than 1, suggesting the river is more limited with respect to N relative to C. Relationships between C and P acquisition and N and P acquisition were positive in summer, but explained less variation (27% for C:P, 11% for N:P). These positive relationships in summer may result from higher temperatures driving higher metabolic rates, and thus higher growth rates (Sinsabaugh and Follstad Shah 2011). High growth rate requires greater P uptake given that ribosomes are rich in P. In contrast, negative relationships were evident in spring and

fall, explaining between 15-26% of the variation. Negative relationships in spring and fall are indicative of greater allocation to P relative to C and N, which typically occurs when P is limiting growth. Hence, ecoenzyme expression in the water column of the Jordan River shows that microbial communities perceive differences in resource supply relative to metabolic needs and are responding most to P availability.

Ecoenzyme activities in sediment derived from the river, oil drain, and wetland were highly variable both spatially and temporally (Fig. 13). However, longitudinal variation in patterns of BG, NAG+LAP, and AP showed greater concordance as compared to patterns in the water column. Correlation in longitudinal patterns were supported by consistent positive relationships in relationships between BG vs. NAG+LAP, BG vs. AP, and NAG+LAP vs. AP, which explained between 11-51% of the variation (data not shown). BG vs. NAG+LAP and BG vs. AP slopes were close to or greater than 1, indicating either matched allocation of energy to C and N acquisition or greater allocation of energy towards C acquisition. NAG+LAP vs. AP slopes were approximately 1 in spring and fall, indicating matched allocation of energy to N and P acquisition, but 0.74 in summer indicative of greater allocation to P when growth rate demands are highest.

In summary, microbial communities in the water column and sediment differ with respect to C, which is in adequate supply in the water column but appears to be limiting in the sediment in some seasons. Microbial communities in the water column and sediment are similar because N appears to be in adequate supply and both communities are limited with respect to P at some times of the year.

Project Presentations

Oral Presentations

Smith, R.M., Follstad Shah, J.J., Weintraub, S., Gabor, R., Jameel, Y., Navidomskis, M. Seasonal variation in organic matter quality and microbial ecology along the Jordan River, Utah. Salt Lake County Watershed Symposium, November 16, 2017, Salt Lake City, Utah.

Follstad Shah, J.J., Gabor, R., Jameel, Y., Smith, R.M., M., Weintraub, S. Evidence of groundwater connectivity in the Jordan River despite flow regulation and effluent inputs. Salt Lake County Watershed Symposium, November 15, 2017, Salt Lake City, Utah.

Smith, R.M. Biogeochemical cycling of carbon and nutrients in an effluent-dominated river. University of Utah Department of Biology Annual Retreat August 26, 2016, Salt Lake City, Utah.

Follstad Shah, J.J., Smith, R.M., Gabor, R., Jameel, Y., Navidomskis, M., Weintraub, S. Do microbes of the Jordan River yo-yo diet? Salt Lake County Watershed Symposium, November 15, 2016, Salt Lake City, Utah.

Gabor, R. Relationships between microbial activity, nutrients, and organic matter chemistry in urban-impacted rivers. 253rd American Chemical Society National Meeting & Exposition, April 3, 2017, San Francisco, California.

Follstad Shah, J.J., Smith, R.M., Gabor, R., Jameel, Y., Navidomskis, M., Weintraub, S. Microbial community response to energy and nutrient flows within a semi-arid, effluent dominated urban river system. 2017 Spring American Water Resources Association Meeting – Connecting the dots: the emerging science of aquatic system connectivity, April 30-May 3, 2017, Snowbird, Utah.

Poster Presentations

Smith, R.M., Follstad Shah, J.J., Gabor, R., Navidomskis, M. Sources and cycling of nitrogen in the Jordan River, Annual Global Change & Sustainability Science Center Research Symposium, February 8, 2017, Salt Lake City, Utah.

Navidomskis, M , Follstad Shah, J.J., Smith, R.M., Gabor, R. Sources and cycling of nitrogen in the Jordan River. Salt Lake County Watershed Symposium, November 15, 2016, Salt Lake City, Utah.

Smith, R.M., Follstad Shah, J.J., Gabor, R., Navidomskis, M. Sources and processing of nitrogen in an effluent-dominated river. Association for the Sciences of Limnology & Oceanography 2017 meeting: Mountains to the Sea, Feb 26-Mar 3, 2017, Honolulu Hawaii.

Follstad Shah, J.J., Smith, R.M., Gabor, R., Jameel, Y., Navidomskis, M., Weintraub, S. Microbial community response to energy and nutrient flows within a semi-arid, effluent dominated urban river system. 2017 Spring Run-off Conference, Utah State University, March 28, 2017, Logan, Utah.

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Tables

Table 1. List of study sites and their locations.

Site Name	River Kilometer (starting at Utah lake outlet)	Intensive Site	Extensive Site	WRF
Willow Park (Lehi, UT)	5.6		x	
Bangeter Highway (13900 S)	21		x	
Jordan Basin Effluent	22			x
Jordan River Rotary Park	23		x	
Garner Village (7800 S)	36		x	
South Valley Effluent	37			x
Zagg foot bridge (7200 S)	38		x	
3300 S	49		x	
Central Valley Effluent	50			x
Cesar Chaves Drive	51		x	
1700 S	53	x		
California Avenue	54	x		
Indiana Avenue	56	x		
Poplar Grove Road (400 S)	57	x		
200 S	58	x		
North Temple	59	x		
Cottonwood Park (400 N)	60	x		
Redwood Road (700 N)	61	x		
Rose Park Library (1000 N)	62	x	x	
Joust Court Golf Course	63	x		
Northwest Middle School	64	x		
Salt Lake City Effluent	65			x
Oil Drain at Cudahey Lane	70		x	
Oil Drain in Great Salt Lake Wetlands	79.4		x	
Great Salt Lake Unit 1 Wetland	NA		x	

Table 2. Microbial ecoenzymes and their ecological roles.

Ecoenzyme	**Code**	**Ecological Role**
β-1,4-glucosidase	BG	Carbon acquisition via cellulose degradation; hydrolyzes glucose from cellobiose
β-1,4-N-acetylglucosaminidase	NAG	Carbon and nitrogen acquisition via chitin and peptidoglycan degradation; hydrolyzes glucosamine from chitobiose
Leucine aminopeptidase	LAP	Nitrogen acquisition via proteolysis; hydrolyzes leucine and other hydrophobic amino acids from the N terminus of polypeptides
Acid (alkaline) phosphatase	AP	Phosphorus acquisition via hydrolysis of phosphate from phosphosaccharides or phospholipids
Phenol oxidase	POX	C acquisition via the oxidative degradation of lignin

Figures

Cover Figure: Jordan Valley Water Reclamation Facility effluent discharge into the Jordan River.

Figure 1. Map of study area.

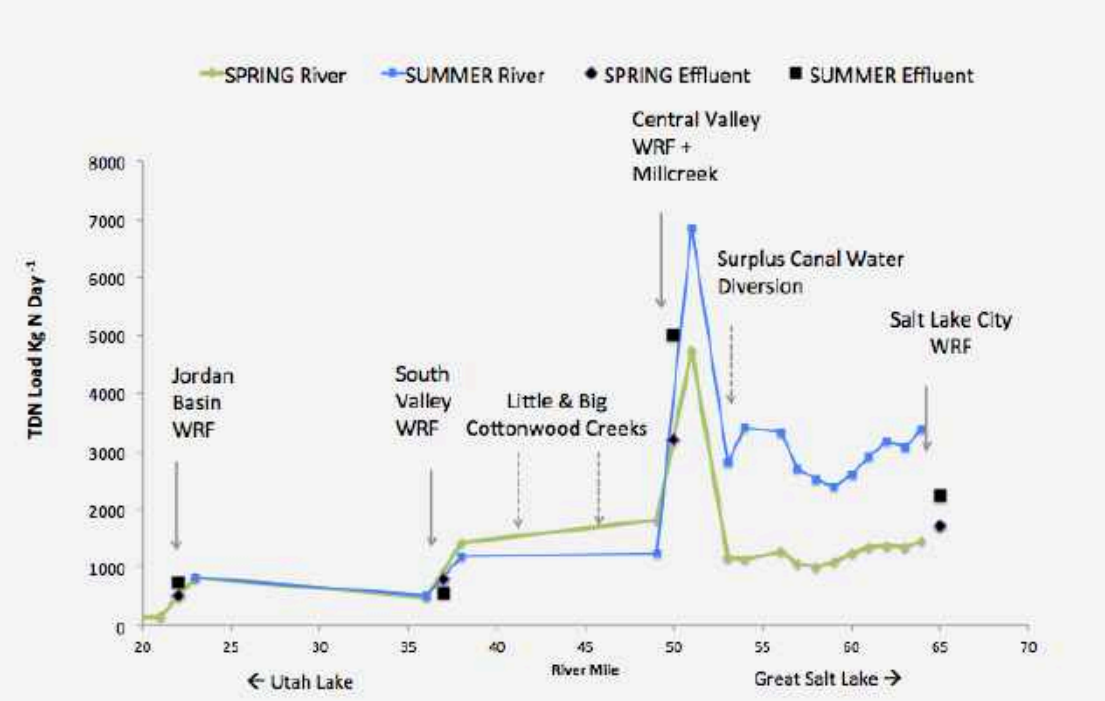

Figure 2. Total dissolved nitrogen (TDN) load of the Jordan River in spring (green line) and summer (blue line) of 2016. TDN loads from water reclamation facilities are shown as triangles (spring) and squares (summer). Data for fall are not available due to failure of equipment used to measure river discharge.

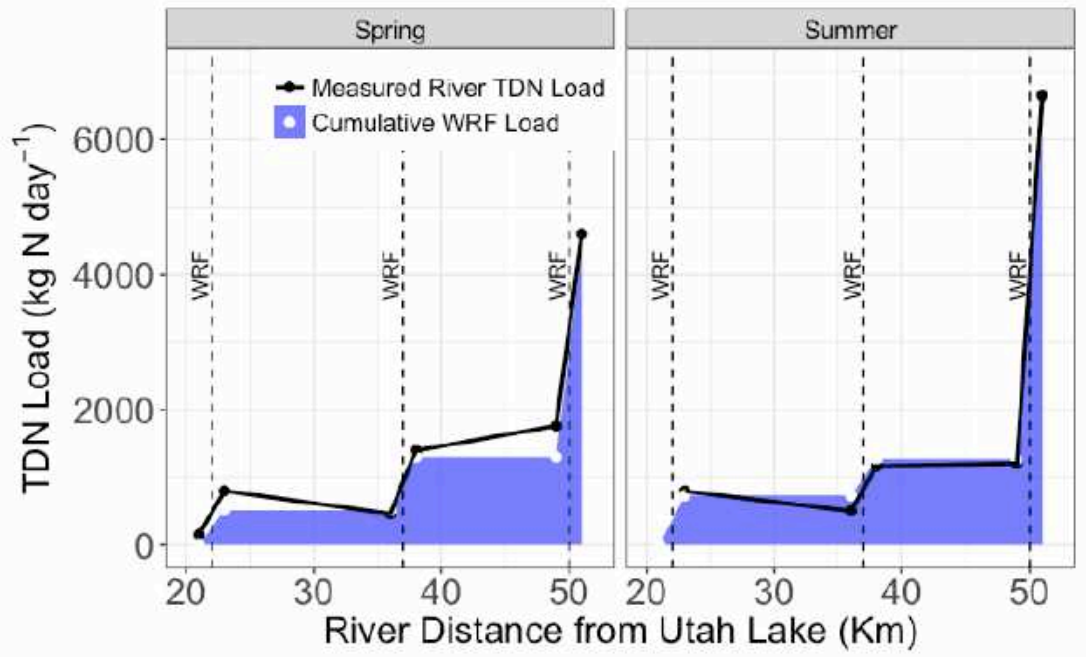

Figure 3. Measured river (TDN) load plotted alongside cumulative loads from three water reclamation facilities between Utah Lake and 1700 S in spring and summer of 2016. Load data for fall is not available due to lack of flow data.

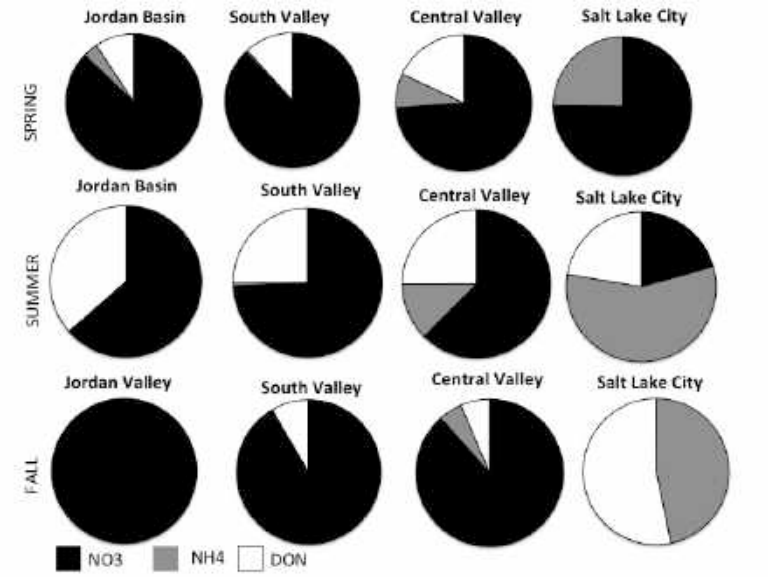

Figure 4. Composition of N inputs to the Jordan River from four water reclamation facilities in spring, summer, and fall of 2016.

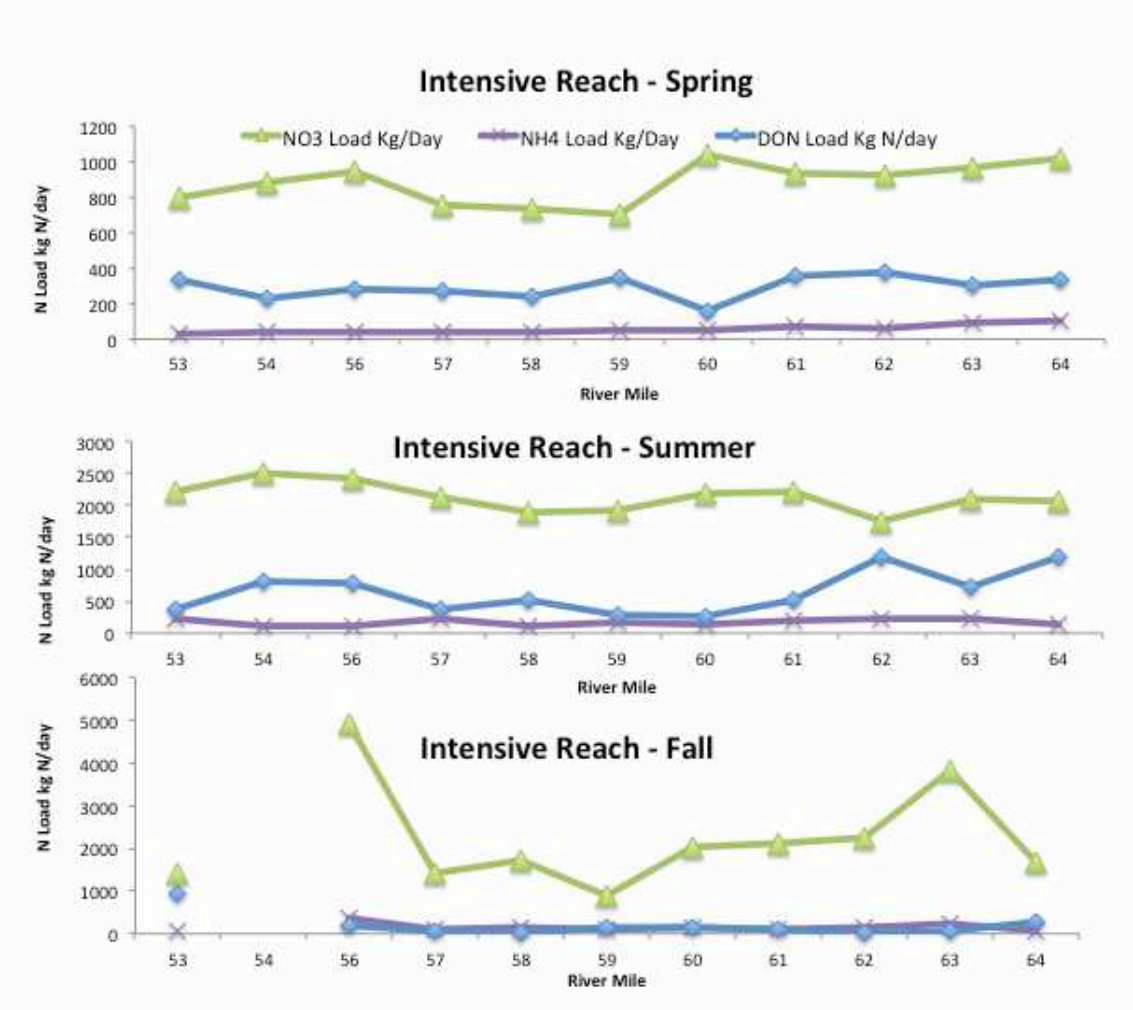

Figure 5. Loads of NO_3-N, NH_4-N, and dissolved organic N (DON) at the ten sites within the intensively studied reach in spring, summer, and fall 2016.

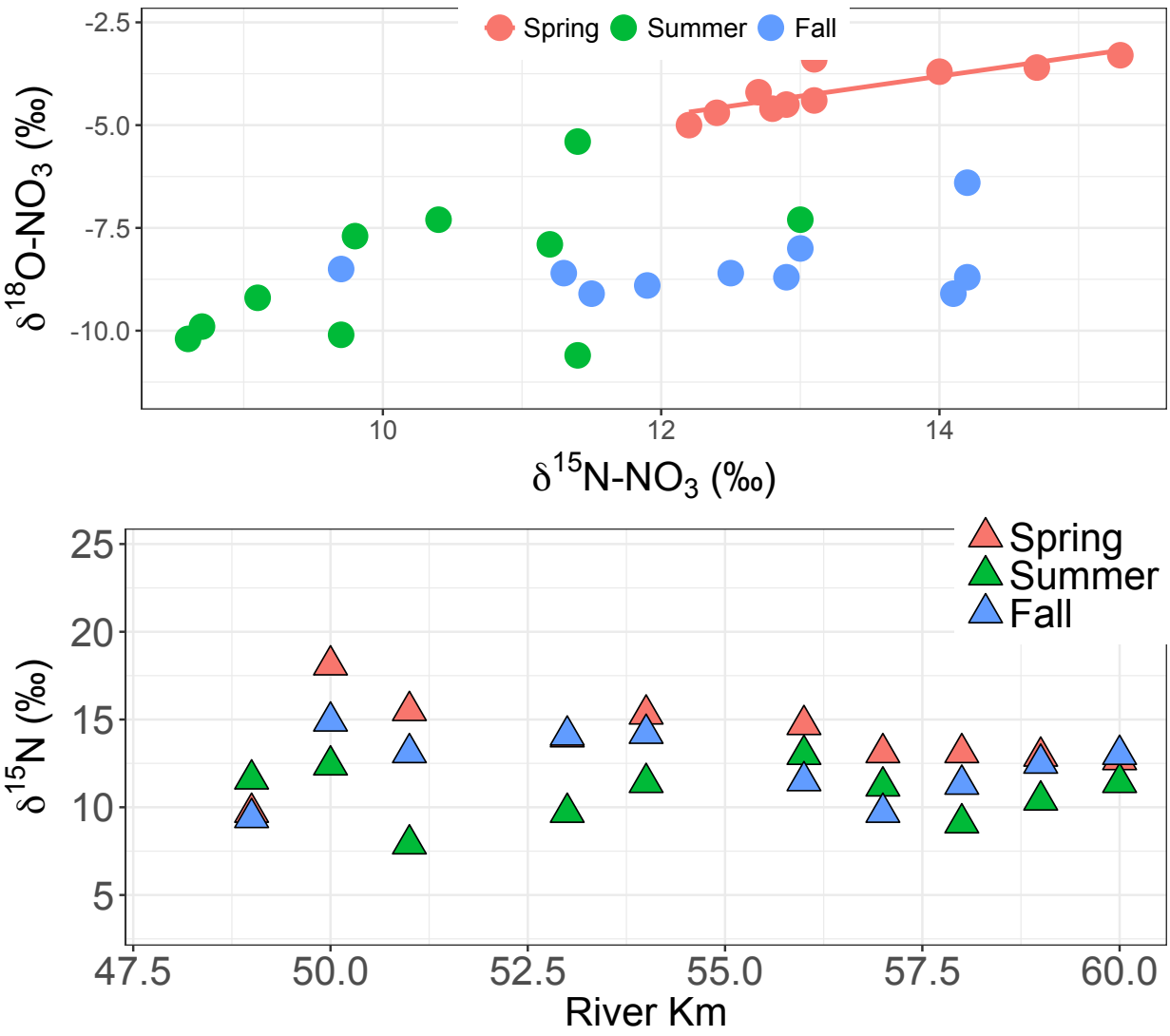

Figure 6. δ^{15}N-NO_3^- vs. δ^{18}O-NO_3 for the ten study sites within the intensively sampled reach of the Jordan River for spring, summer and fall (upper graph). Dual enrichment of δ^{15}N-NO_3 and δ^{18}O-NO_3 in spring (r^2=0.45, $p<0.05$) theoretically signifies potential removal from the water column, as denitrifying microbes preferentially convert isotopically lighter forms of NO_3^- to N_2O. This trend is initially apparent in spring, however this relationship is not present in fall or summer seasons. Additionally, for this relationship to truly signify NO_3^- removal, dual enrichment would need to occur in the downstream direction. Instead, we see a decreasing trend of δ^{15}N-NO_3^- downstream, net NO_3^- production in this reach (lower graph).

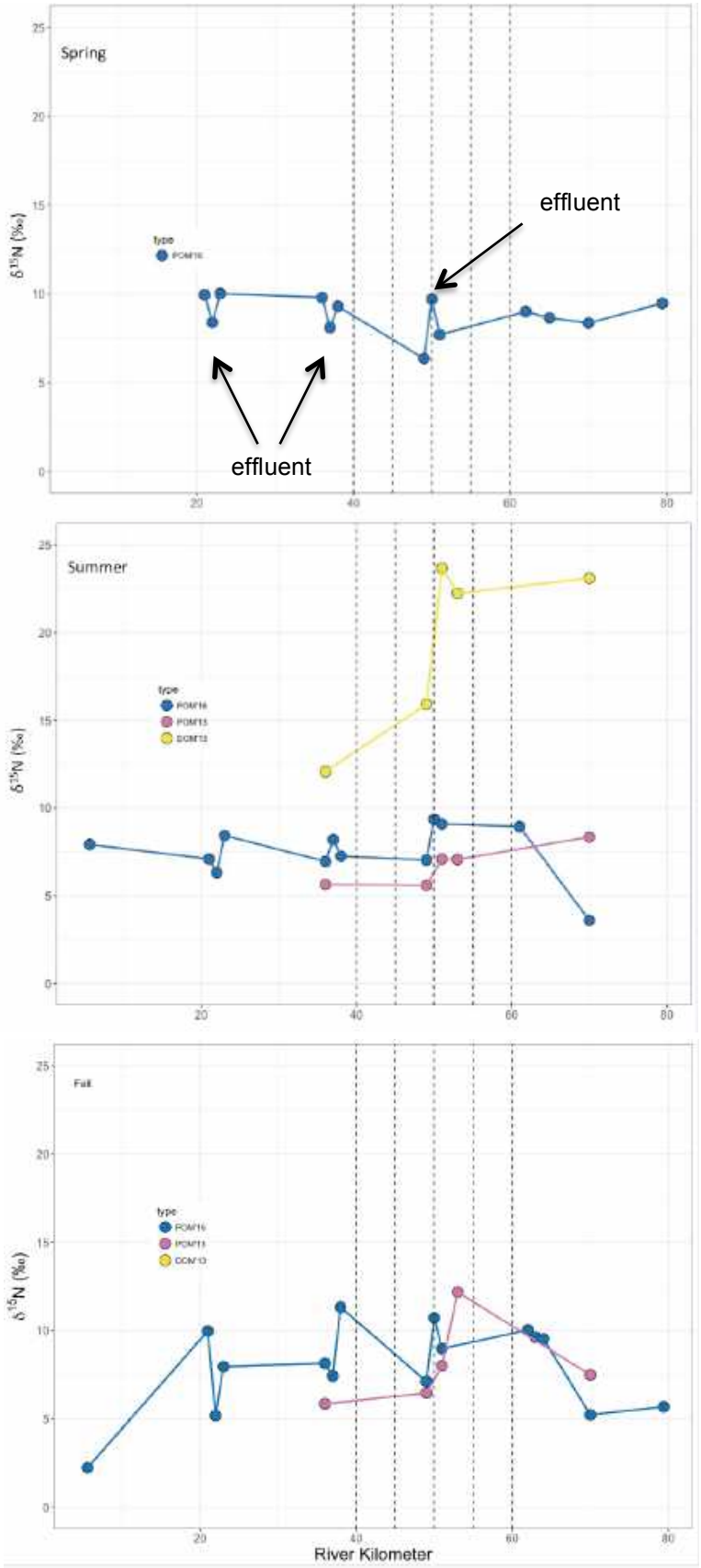

Figure 7. $\delta^{15}N$ of fine particulate organic matter (POM) in spring, summer, and fall of 2016 (blue symbols and line). These data are compared to $\delta^{15}N$ of POM (pink symbols and line) and dissolved organic matter (DOM; yellow symbols and line) measured in 2013 (Kelso & Baker 2017). Locations of effluent discharge measures are identified for spring, but corresponding measures are shown for summer and fall as well.

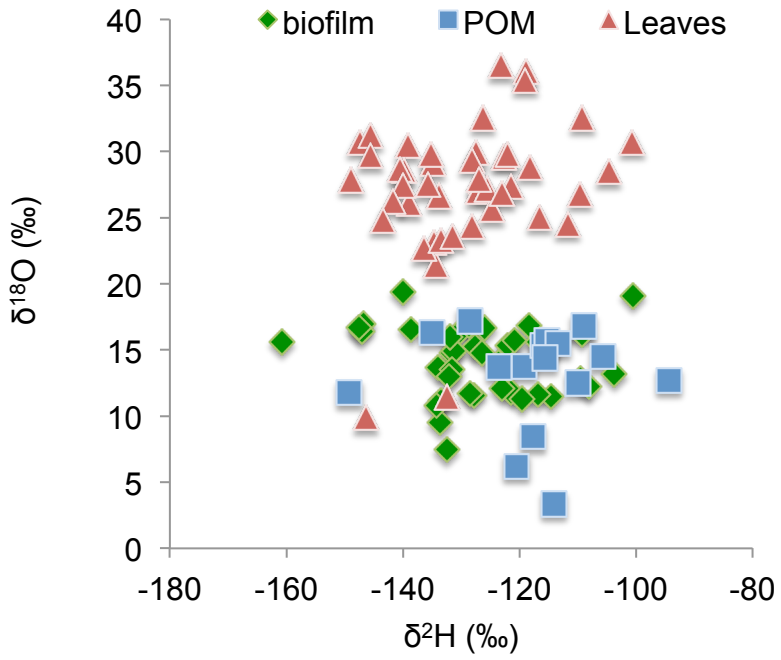

Figure 8. Values of δ^2H and $\delta^{18}O$ for biofilms (green diamonds), riparian leaves (red triangles), and fine particulate organic matter (POM; blue squares) from the water column of the Jordan River.

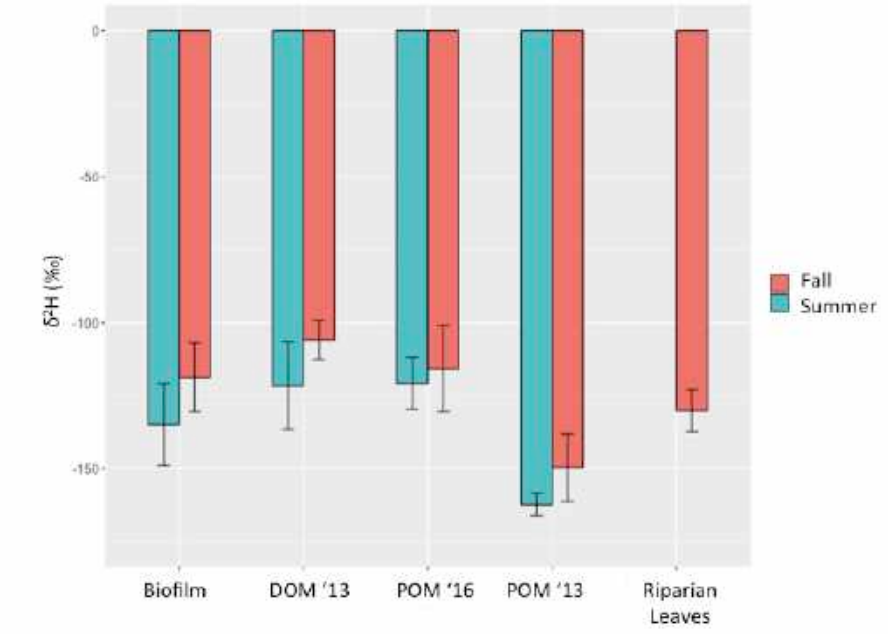

Figure 9. Similarity in δ^2H values in summer (green) and fall (orange) for biofilms, dissolved organic matter (DOM, measured in 2013), fine particulate organic matter (measured in both 2013 and 2016), and riparian leaves. Measurements from 2013 are from Kelso and Baker (2017).

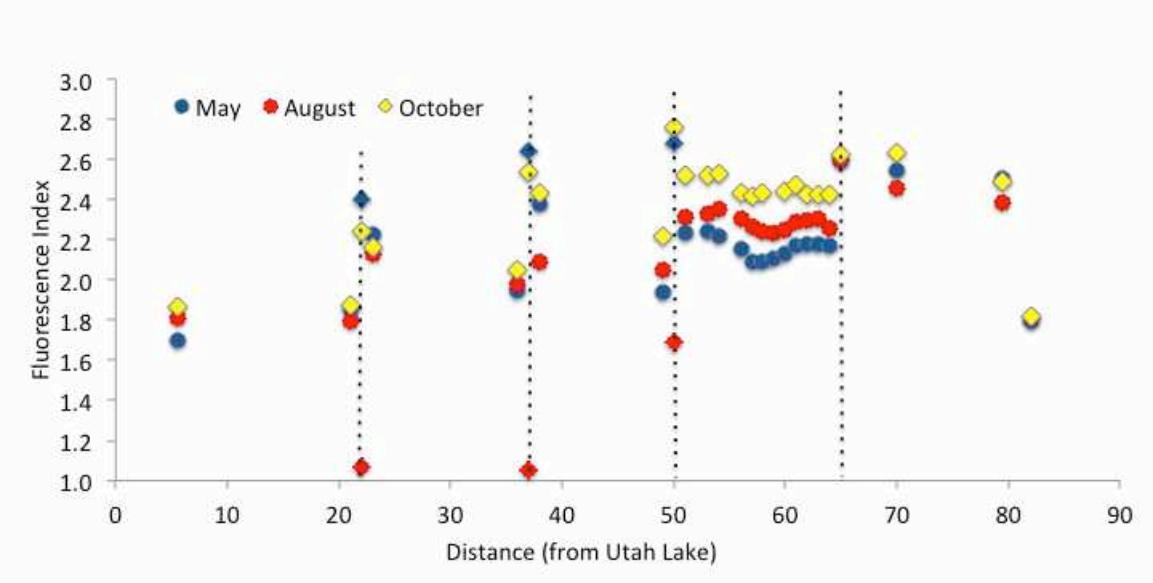

Figure 10. Fluorescence Index (FI) of dissolved organic carbon (DOC) collected from the Jordan River (circles) and water reclamation facilities (diamonds along dashed vertical lines) in spring (blue), summer (red), and fall (yellow). FI values were derived from excitation-emission matrix (EEM) analyses.

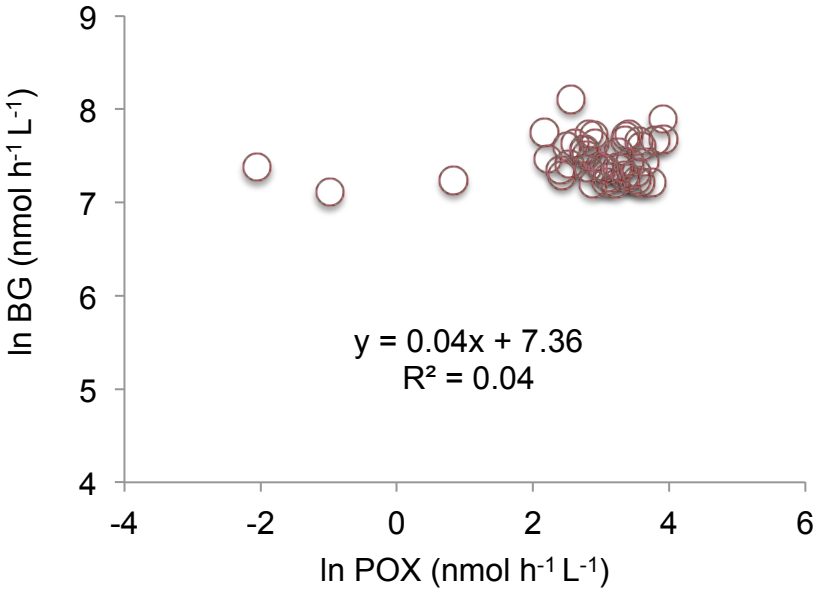

Figure 11. Microbial expression of β-1,4-glucosidase (BG) is greater than expression of phenol oxidase (POX) by a magnitude of ~100 times, but shows less variation in activity rates.

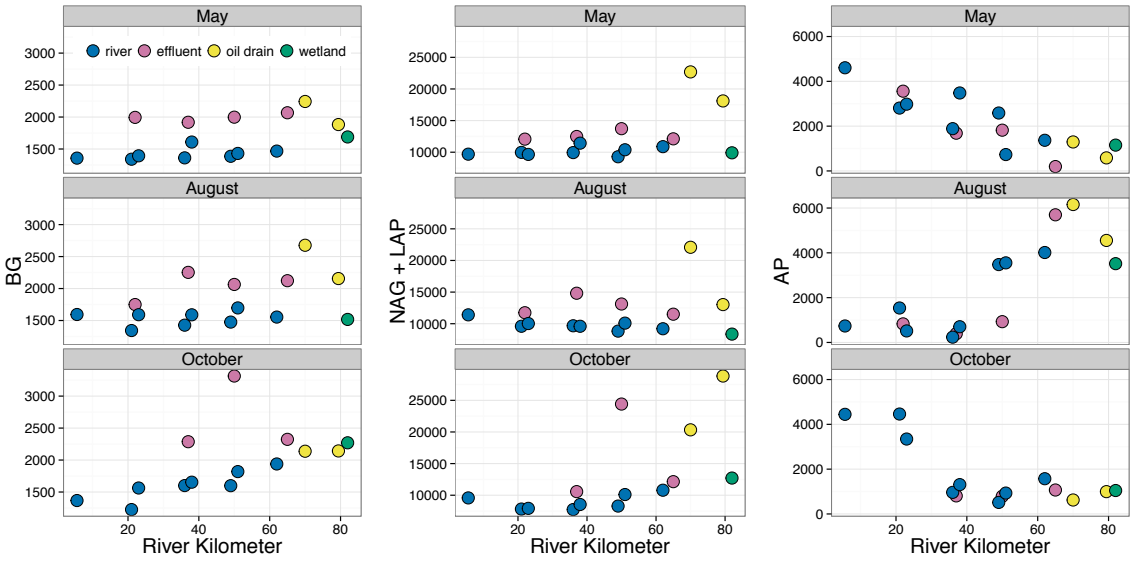

Figure 11. Activities (nmol L^{-1} h^{-1}) of ecoenzymes associated with acquisition of C (β-1,4-glucosidase, BG), N (β-1,4-N-acetylglucosaminidase, NAG; leucine aminopeptidase, LAP), and P (alkaline phosphatase, AP) are variable both spatially and temporally in water derived from the river (blue circles), effluent (pink circles), oil drain (yellow circles), and wetland (green circles).

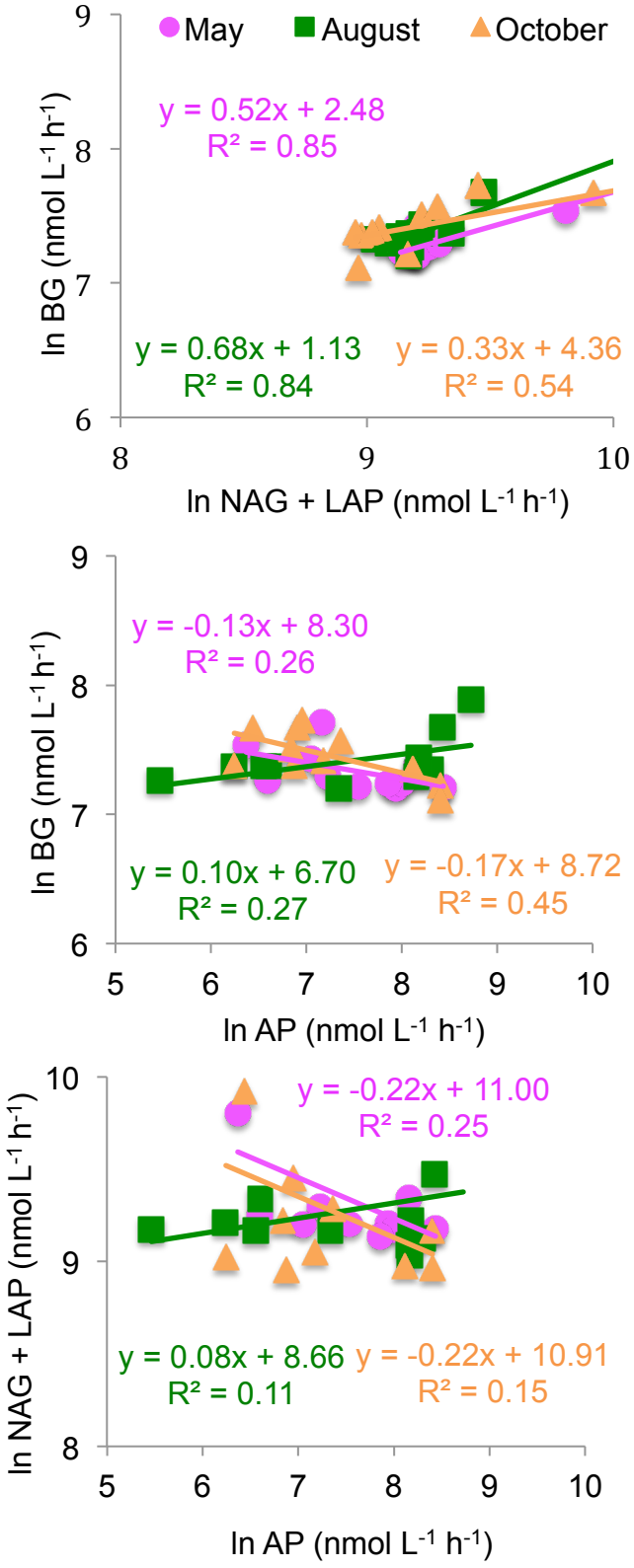

Figure 12. Ecoenzyme ratios of Jordan River water column samples in spring, summer, and fall. BG refers to β-1,4-glucosidase, which is associated with labile C acquisition. , NAG+LAP refers to β-1,4-N-acetylglucosaminidase and leucine aminopeptidase, which are associated with acquisition of N. AP refers to alkaline phosphatase, which is associated with acquisition of P. The graph show C:N (upper), C:P (middle), and N:P (lower) relationships.

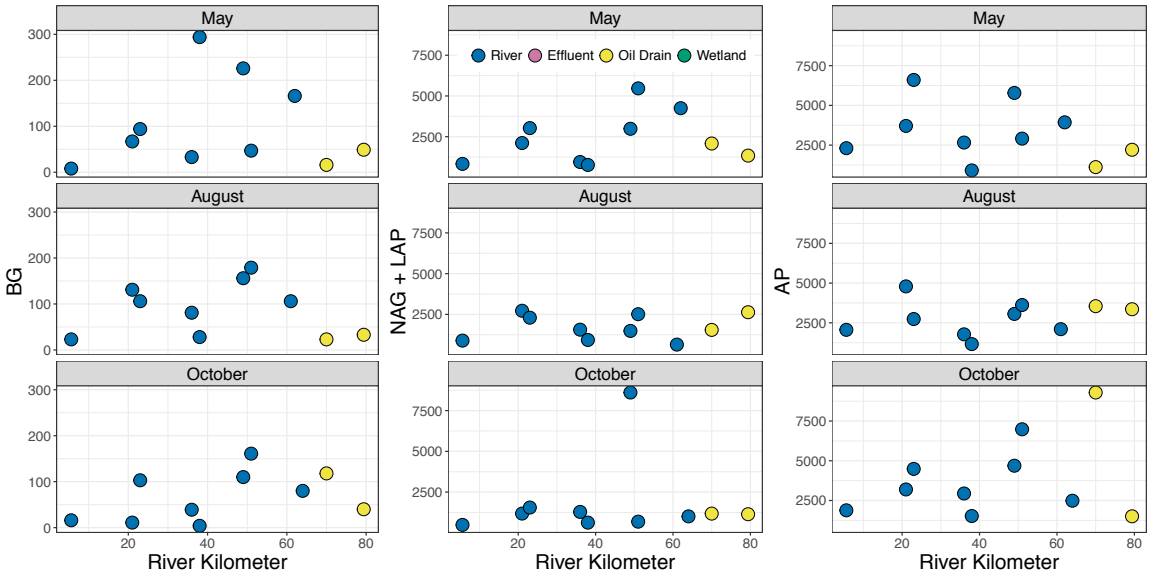

Figure 13. Activities (nmol L^{-1} h^{-1}) of ecoenzymes associated with acquisition of C (β-1,4-glucosidase, BG), N (β-1,4-N-acetylglucosaminidase, NAG; leucine aminopeptidase, LAP), and P (alkaline phosphatase, AP) are variable both spatially and temporally in sediment from the river (blue circles), oil drain (yellow circles), and wetland (green circles).