Dissolved organic carbon (DOC)

Differences in reactivity amongst water sources to boreal streams in Sweden

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Abstract

The importance of dissolved organic carbon (DOC) to aquatic environments is well established in the scientific community. In boreal landscapes, small streams receive water from headwater lakes, mires, and discrete flow paths that drain riparian soils. The goal of this study was to investigate the importance of these discrete riparian inputs (DRIPs) as sources of DOC and to explore whether quantity and quality of DOC from DRIPs differs from other sources in the landscape, including groundwaters that are not as hydrologically connected to streams. To do this, I collected water from already established riparian groundwater wells installed at the Krycklan Catchment Study (KCS) in northern Sweden, as well as from an adjacent lake, stream, and mire. Microbial activity (respiration) was analyzed in 24-hour laboratory incubations using a metabolically active dye, resazurin (Raz) which in the presence of aerobic respiration transforms into resorufin (Rru). Rru is easily measured in the lab, and its production can serve as a proxy for rates of microbial respiration. DOC concentration was also measured at each location, along with specific absorbance at 254 nm ($SUVA_{254}$) and the absorbance ratio (254/365 nm) as indices of DOC quality. The results show a large variation in DOC concentration among potential water sources to the stream. Furthermore, there was a strong correlation (R^2=0.96) between Rru production and DOC concentration among these sources, but no significant difference (p=0.067) in median Rru production between DRIPs and non-DRIPs. Overall, these results highlight important spatial variability in DOC from different water sources in the landscape, which likely have important consequences for patterns of microbial respiration in streams.

Key words: Dissolved organic carbon, DOC, Discrete riparian inputs, Resazurin, Resorufin

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1. Introduction

Dissolved organic carbon (DOC) is a term that describes all the forms of carbon (C) that are small enough to pass through a 0.45 or 0.22mm filter. Dissolved organic matter (DOM) is another related term, also present in many of the articles regarding DOC, but this includes all other dissolved components, such as nitrogen (N) and phosphorus (P), that make up organic compounds. So why is it important to study DOC? DOC is important to study for three major reasons:

1. DOC is an important energy source to aquatic microorganisms (i.e. bacteria) and, thus, is important in terms of food webs and energy flow through ecosystems (Berggren et al. 2007, 2010a, 2010b.).
2. While the vertical flux of C from soils to the atmosphere in the form of CO_2 is well studied due to its effect on climate change, the lateral fluxes of DOC at land surface (e.g. from land to aquatic environments) are increasingly thought to be vital for the understanding of the terrestrial C balance (Tank et al. 2018).
3. DOC can act as a carrier and transporter of other substances like mercury (Hg) and persistent organic pollutants (POPs) (e.g., Eklöf et al. 2014). Thus, by knowing what drives the C cycle related to DOC formation and transport, we can better understand how to prevent hazardous material from entering aquatic environments.

My paper addresses the first reason, i.e. the role of terrestrial DOC as an energy source to aquatic food webs.

The importance of DOC as an energy source to aquatic organisms is also dependent on the quality or 'bioavailability' of the DOC (Berggren et al. 2010b). In this context, quality depends on the compounds that make up DOC and can be divided into two broad groups: (1) low molecular weight compounds (LMWC) and (2) high molecular weight compounds (HMWC). LMWC consists mainly of amino acids, simple carbohydrates (e.g. glucose, fructose) and carboxylic acids (Berggren et al. 2010 b), which are more labile and easier for bacteria to consume. HMWC consists of, among others, fulvic and humic acids which are more resistant to degradation and, thus, harder for bacteria to consume. There are three general ways of measuring the DOC quality; by (1) directly measuring the actual compounds and how much each compound makes up the total DOC (e.g., Berggren et al. 2010b), (2) by using absorbance/fluorescence indicators ('optical properties') that are thought to be diagnostic for quality (e.g., Berggren et al. 2007, Ågren et al. 2008, Kothawala et al. 2015), or through (3) bioassays that directly assess how well bacteria grow on DOC (Soares et al. 2017). This study is based on the second and third of these approaches.

A vital part in studying DOC is knowing what regulates both the quality and quantity of DOC delivered from soils to streams or lakes. It is widely acknowledged that the amount of DOC supplied to aquatic ecosystems varies globally with the amount of organic matter stored in soils, i.e. a lot of soil C equals more DOC (Aitkenhead and McDowell 2000), and that DOC concentration often varies among streams with the amount of wetland/peatland cover in the catchment (Laudon et al. 2011). But it is not only geographical location or peatland cover that influences DOC transports from soil to stream. For example, studies from Ågren et al. (2007, 2008) shows that DOC supply to streams can change both interannually and seasonally due to fluctuation in discharge/hydrological flow. Thus, the physical structure of landscapes, and in particular the riparian zone, that governs the flow of water through soils can also influence the timing and supply of DOC to streams and lakes (Ledesma et al. 2018).

Recent research in boreal landscapes has focused on these details of the hydrological control. For example, it is known that changes in topography within catchments creates localized riparian (i.e., streamside) areas that contribute the bulk of the water to small streams ('discrete riparian inputs' or DRIPs), as well as other patches that are more hydrologically

disconnected (Kuglerova et al. 2014). Leach et al. (2017) showed that these locations along a stream can be identified both through digital elevation models and by using temperature and water isotope tracers. While the scientific community is just learning about the significance of DRIPs for landscape hydrology in boreal regions, how this landscape configuration influences the quantity and quality of DOC supplied to streams is largely untested. Thus, the objective of this study is to identify if and how these "groundwater hotspots" (the DRIPs) differ from each other and from non-DRIP locations in terms of the quality of DOC they contribute to streams. I tested this by measuring microbial activity, bulk DOC concentration, and common indices of DOC quality based on the absorbance spectrum from samples collected at DRIP and non-DRIP locations along two small boreal streams in northern Sweden

1.1 Purpose and research question

The purpose of this study is to evaluate catchment sources of DOC to boreal streams. The research question answered in the study is (1) how does DOC from the major sources of water feeding boreal streams differ in reactivity?

2. Materials and methods

I collected water from already established groundwater wells installed at the Krycklan Catchment Study (KCS). Specifically, I sampled a well located in a headwater mire (1 m depth), as well those installed in DRIP (n=9) and non-DRIP (n=6) locations in the riparian zone of two headwater streams (C4 and C6 in the KCS). On average, DRIP wells were installed to 0.8 m depth and non-DRIP wells to 1.2 m. For comparison, I also collected a water sample from the headwater lake that feeds one of these streams. Additionally, samples were collected from the stream (C6) itself after traveling 1.4 km from the lake and receiving water from the DRIPs. I analyzed the microbial activity (respiration) on DOC from these different locations using metabolically active dye, resazurin (Raz), in 24-hour laboratory incubations. Raz itself is not fluorescent, but when in the presence of aerobic respiration, e.g. from bacteria and other microorganisms, the oxygen removal transforms Raz into resorufin (Rru), which is highly fluorescent. Rru is easily measured in the lab, and its production can thus serve as a surrogate for rates of microbial respiration. Previous studies (e.g. González-Pinzón, Haggerty and Myrold 2012) have shown that the transformation of Raz to Rru in stream ecosystems is very well correlated to aerobic microbial respiration. For this assay I filtered samples in the field and then used a standard microbial inoculum for lab incubations. Thus, the production of Rru should reflect reactivity of DOC, rather than differences in microbial abundance at the start of the experiment. In addition, to assess 'quality' across sites, Rru production was corrected for the bulk DOC concentration, since more DOC, but of lower quality, could (in theory) have the same Rru production as less DOC but of higher quality.

2.1 Study site

The KCS is a 6790 ha catchment located in the boreal region of northern Sweden approximately 50 km northwest of the city of Umeå. It consists of a mosaic of coniferous forests, lakes, and mires characteristic of the boreal forest landscape. KCS is also an essential part of Svartberget research site which is practically centered within the catchment. The primary purpose of KCS is to provide an advanced field research infrastructure that encompasses all different aspects of the boreal landscape, such as forests, soils, mires and different water sources (Laudon et al. 2013).

The wells sampled for this experiment (Figure 1) are installed along two headwater streams (C4 and C6) as part of ongoing research projects in the KCS (Leach et al. 2017). Each DRIP or non-DRIP location consist of a transect of three groundwater wells extending from the

riparian zone to the uplands. For the purpose of this study, I only used riparian wells located directly adjacent to the stream.

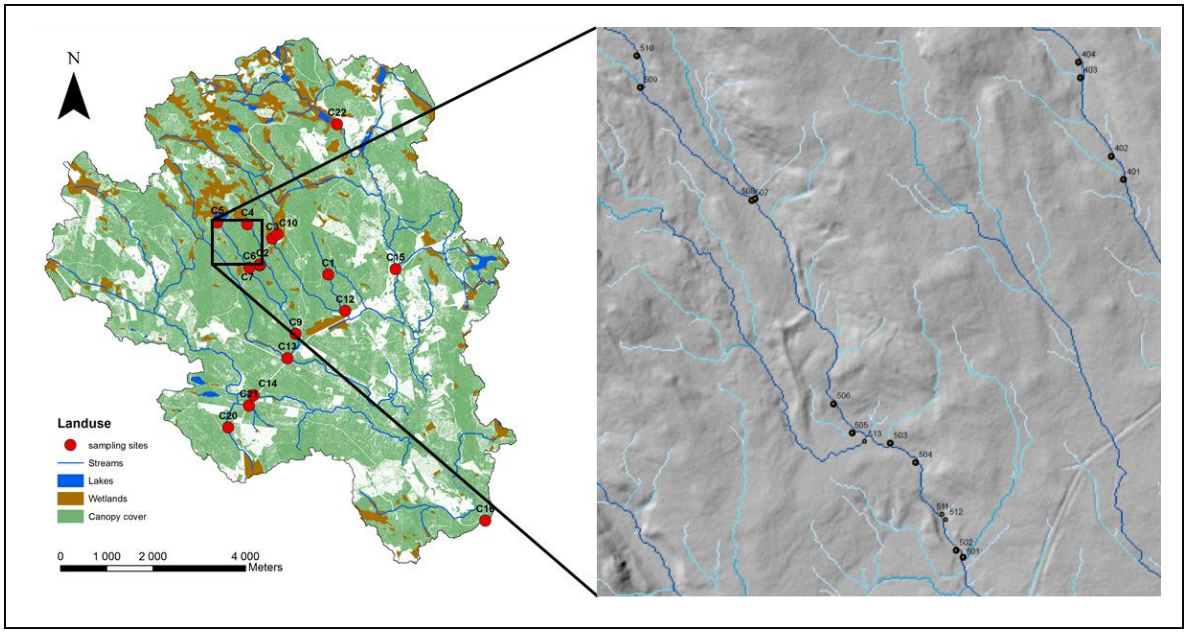

Figure 1. Map over KCS. The enlarged figure shows sampled wells in the two streams (C4 and C5). Other marked sampling sites (red dots) were not sampled in this study.

2.2 Field methods

Water was sampled using a pump constructed from a hand-held drill connected to a housing consisting of a rubber hose and three wheels enabling the pump to extract water from the well. A total number of 19 wells/water sources were targeted and 18 of these were successfully sampled (one non-DRIP well was dry). 15 of the samples came from riparian groundwater wells while the mire, lake and stream where sampled for reference. Before water was sampled from a well, the well was drained in order to remove the top layer of water, ensuring that the groundwater collected was "new". The water was sampled in a plastic 250-ml bottle that was rinsed with unfiltered water from the well three times before collecting the sample. A pre-rinsed 60-ml syringe was used to extract water from the sample vessel. The water was then filtered through a 0.2-mm filter. In the event (2 wells) that the water was unable to be filtered, a larger (0.45 mm) filter was used in the field and the water was filtered through a 0.2-mm filter back in the lab. The sampled water was collected in pre-rinsed 250-ml plastic bottle. Every bottle was marked with a label with the name of the well (e.g. 401R2). The samples were then kept in a cooler until refrigerated in the lab. Finally, from each well/water source, approx. 20 ml of unfiltered water was collected and mixed in a 250-ml plastic bottle to be used as a "microbial slurry" (i.e., the inoculum) for the 24-h incubations in the lab.

In the lab, each sample was subsampled into three 250-ml plastic bottles (marked with the well number and A, B or C) with 20 ml water in each bottle, using a 5-ml pipette, and refrigerated overnight. An additional bottle containing 15 ml of filtered water was sent to the lab for testing of DOC concentration. The testing of DOC concentration was performed by analysis of non-purgeable organic carbon ((NPOC) using Shimadzu TOC-V) by acidifying and bubbling each sample and thereafter introducing it into a heated combustion tube, which was filled with a catalyst driving oxidation of carbon to CO_2. Another subsample of filtered water from each location was immediately analyzed for the full absorbance spectrum on an Aqualog spectrofluorometer.

2.3 Measuring reactivity of DOC using Resazurin

A standard curve was created using a RAZ-solution with known concentrations (0, 25, 50, 100, 150 and 200 ppb) with R^2=0.99. A standard curve for Resorufin (RRU) could not be done so a previous used standard curve from 2017-08-16 was used instead with R^2=1.

Before starting the incubations, 500 ml of resazurin solution with a concentration of 200µg/l was prepared in a glass bottle and covered in paper to protect it from light degradation. In each subsample containing 20 ml of filtered groundwater, 40µl of microbial slurry and 4 ml of Raz solution was added. The bottle was stirred, and 3 ml of the solution was added to the cuvette along with 3 µl (1/10 of the volume of solution in the cuvette) buffer solution at pH≈8 (1M $NaH_2PO_4 \cdot H_2O$ + 1M NaOH, relation 1:1). The cuvette was cleaned with a paper cloth and rubber gloves were used in order to avoid contamination. After being filled with sample water+buffer, the cuvette was immediately placed in the spectrofluorometer and analyzed for the 'time-zero' Rru production. Between every sample, the cuvette was rinsed once with Milli-Q water and once with approx. 1.5 ml of water from the next sample and the pipette tip was replaced between every sample. The incubation bottles were placed in a plastic case and covered with a lid directly after starting the incubation to protect it from light and stored in room temperature for 24 h.

After 24 h, the incubations were tested again using the spectrofluorometer. This time, 3 ml of incubation solution together with 3 µl buffer solution was added to the cuvette and an identical measurement as the previous day was performed. The samples were tested in the same order as the first time to ensure that all were incubated for the same amount of time (testing all samples on day 2 took approx. 3.5 hours). The excitation/emission wavelengths investigated for Raz and Rru was 602/632 nm and 571/584 nm, respectively, as these are the wavelengths where these specific compounds fluoresce.

2.4 Calculations

The Rru production (in µg) was calculated by subtracting the initial Rru concentration at time 0 from the final concentration+background corrections at time 24. The Rru production divided by DOC concentration (further referred to as DOC-corrected Rru production) was also calculated in order to evaluate whether there were differences in microbial activity among sites after correcting for the total amount of DOC. Again, high amounts of DOC could generate high Rru production even if DOC quality is low, and low concentrations of DOC might generate the same, high Rru production due to high quality DOC. Thus, correcting for DOC concentration allowed me to assess the relative importance of DOC concentration *vs.* composition across sampling locations.

I used two different absorbance metrics as additional proxies of DOC quality. These included the ratio between absorbance at 254 nm and 365 nm ($ABS_{254/365}$) (as described in Berggren et al. 2007) and the specific ultraviolet absorbance at 254 nm ($SUVA_{254}$). $SUVA_{254}$ is a widely used method that has been shown to correlate to the percent aromaticity (Weishaar et al. 2003), meaning that aromaticity increases with $SUVA_{254}$ and arguably lowers the accessibility to microorganisms.

2.5. Statistics

Because the response variables were not normally distributed, I used non-parametric tests to compare median DOC concentration, Rru production, and DOC-corrected Rru production between DRIP and non-DRIP locations. In addition, I used simple linear regression to ask whether Rru production and DOC-corrected Rru production increased across all sites with DOC concentration or with estimates of DOC quality based on absorbance. Statistics were completed in Sigma Plot (version 14) using a critical p-value of 0.05.

3. Results

In Table 1 (appendix 1) all results from the measurements are presented.

The survey showed large differences in DOC concentrations across the potential water sources to streams, ranging from 1.39 mg/l up to 76 mg/l (Figure 2). The lowest DOC concentration was found at site 502R2 (non-DRIP) and the highest was found at site 402R2 (non-DRIP). The mean DOC concentration was 26.33 mg/l for DRIPs and 16.33 mg/l for non-DRIPs. However, a non-parametric test (Mann-Whitney U test) comparing DRIPs and non-DRIPs showed no statistically significant differences (p=0.068) between the two when including all sites. When site 402R2 (a potential outlier) was excluded, median DOC concentration was significantly higher in DRIP compared to non-DRIP wells (p=0.008).

As with the DOC concentrations, indices of DOC quality based on absorbance were variable across the landscape. The $ABS_{254/365}$ ranged from 3.0 to 6.4 and the site showing the lowest ratio was 502R2 (same DRIP that had the lowest DOC concentration) and the highest was observed at site 512R2 (non-DRIP). $SUVA_{254}$ was highest at 502R2 (8.58) and lowest at 512R2 (1.6). Overall, there were no significant differences in the median value of $ABS_{254/365}$ or $SUVA_{254}$ between DRIPs vs. non-DRIPs (p>0.6 following non-parametric t-test).

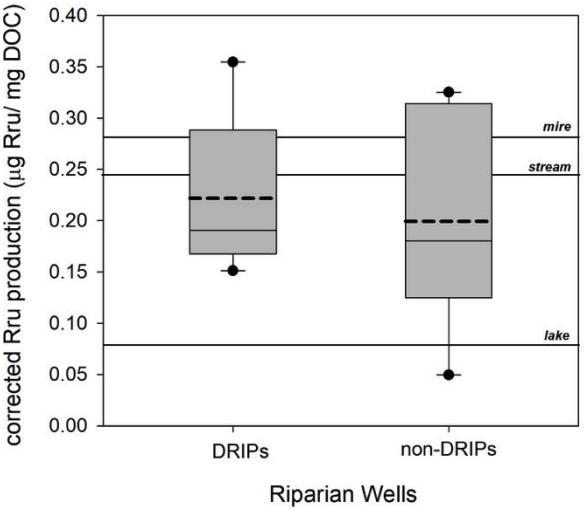

Figure 4. Rru production corrected for DOC in DRIPs and non-DRIPs with values for mire, stream and lake for reference. Dashed line is mean value and full line are median value.

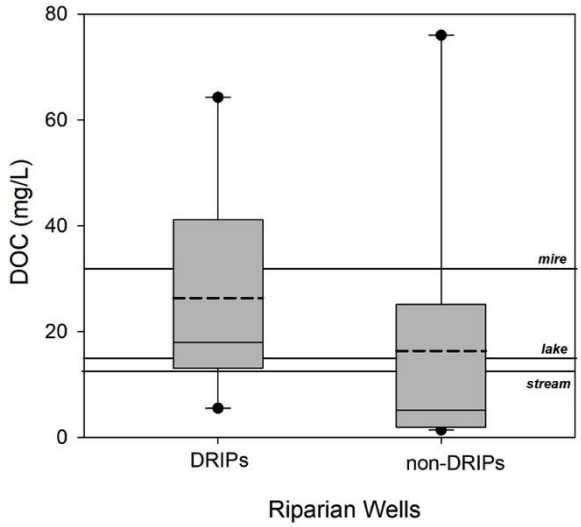

Figure 2. DOC in DRIPs and non-DRIPs with values for mire, lake, and stream waters for reference. Dashed line is mean and full line is median value.

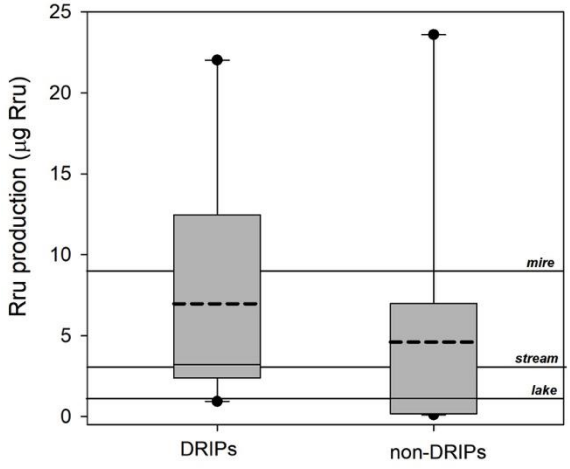

Figure 3. Total Rru production following 24 h laboratory incubations in water from DRIPs and non-DRIPs, with mire, stream, and lake values for reference. Dashed line is mean value and full line is median value.

Total Rru production in the laboratory displayed a wide variation across locations, ranging from an average of 0.11 µg Rru/l at site 512R2 up to an average of 23.59 µg/l at site 402R2 (Figure 3). The mean Rru production for all DRIPs was 6.97 µg and 4.60 µg for all non-DRIPs.

Non-parametric Mann-Whitney U test showed no significant difference (p=0.068) in median Rru production between DRIPs and non-DRIPs when including all sites. When excluding the possible outlier (402R2), the non-parametric test showed a significantly higher (p=0.008) median Rru production in the DRIPs.

When corrected for DOC (mean Rru production/DOC), Rru production also varied among the different sites with a range from 0.0496 µg Rru/mg DOC at site 512R2 up to 0.3546 µg Rru/mg DOC (Figure 4). However, A non-parametric test showed that DOC-corrected Rru production did not differ between DRIP and non-DRIP locations (p=0.51). Removing the outlying non-DRIP site (402) did not change the results of this test (p = 0.29).

The variation in Rru production mentioned above was most strongly correlated to the total amount of DOC across locations (R^2= 0.96, p< 0.001) and production increased approximately 7-fold between the lowest and highest DOC concentration (Figure 5a). Similarly, DOC-corrected Rru production also increased with DOC, but this relationship was not as statistically strong (R^2=0.42, p=0.004: Figure 5b). In contrast to the above-mentioned results, no correlations were found between Rru production and indices of DOC quality ($ABS_{254/365}$ and $SUVA_{254}$) (Figure 6a, 6b).

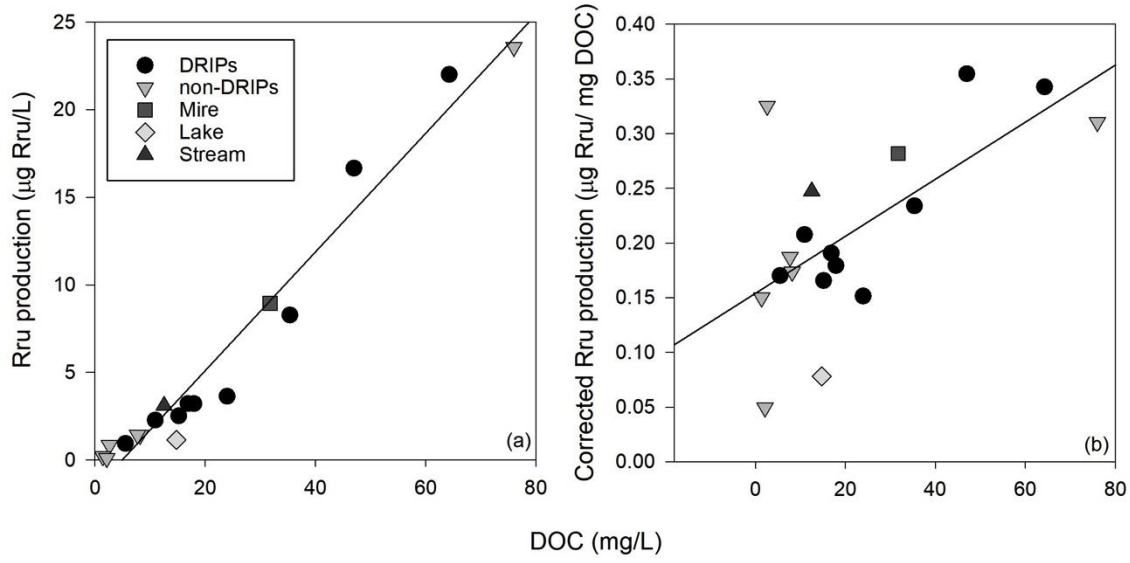

Figure 5. Correlations between DOC (mg/l) and Rru production (a) and corrected Rru production (b) in all sites. Line represent significant linear regression slope.

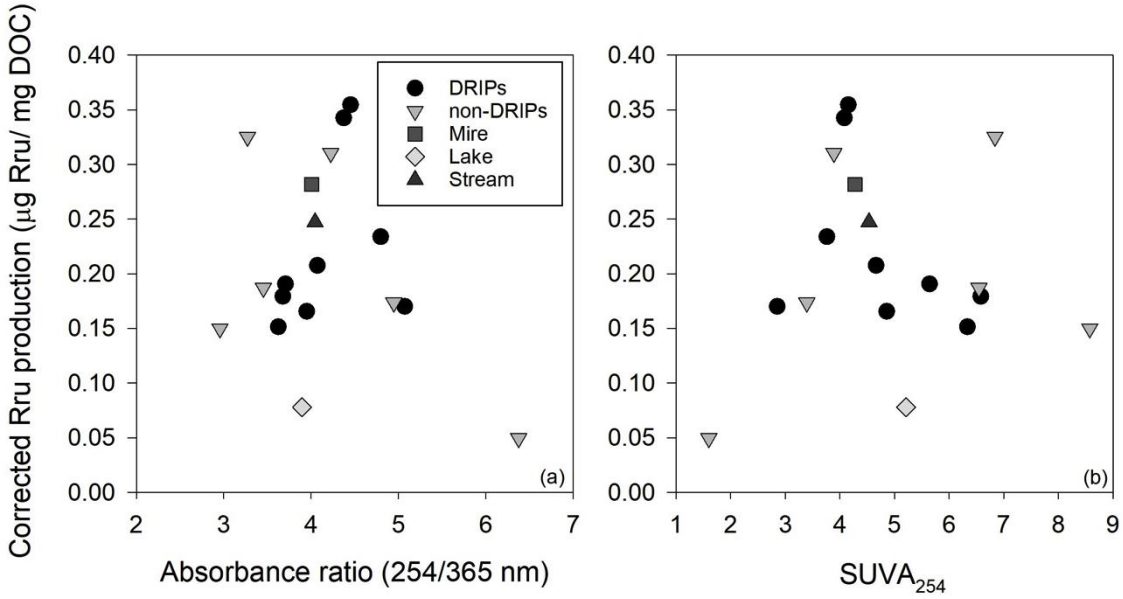

Figure 6. Correlations between corrected Rru production and $ABS_{254/365}$ (a) and $SUVA_{254}$ (b) in all sites.

4. Discussion

In this study, I wanted to evaluate DOC from different catchment sources to boreal streams and see if, and how, it would differ in terms of microbial reactivity. Overall, I found that variation in DOC concentration among these water sources is the driving force behind microbial respiration, measured as Rru production, even when correcting that Rru production for DOC concentration. This means that relatively large sources of DOC to streams are most important to stream bacteria, at least in terms of respiration. By comparison, traditional indices of DOC composition and quality ($ABS_{254/365}$ and $SUVA_{254}$) were not correlated with Rru production across the different habitats and study sites sampled here.

The results from this survey suggested that there are not clear differences between DRIPs and non-DRIPs with respect to DOC concentration or DOC quality. DRIPs tended to have higher DOC concentrations than non-DRIPs, but this was not statistically significant when all sampling sites were included. Importantly, both DRIPs and non-DRIPs showed high variability in DOC concentrations, and this likely reflects the overriding importance of local soil properties, such as organic matter content that could drive variation in DOC concentrations (Bishop et al. 2004). For example, Grabs et al. (2012) showed that, depending on soil characteristics, such as parent material, wetness, and organic matter content, riparian zones displayed great variability in total organic carbon (TOC), even showing high variability in TOC concentrations among sites that shared local topographic conditions.

Although I did not find any significant results to support a difference in DOC concentration between DRIPs and non-DRIPs, testing this in a robust way would require more sampling in space and time. My results did point to the potential for DRIPs to have higher DOC concentrations, which might reflect the higher (and more dynamic) ground water table that would benefit a more anaerobic environment and the build-up of organic matter (like peat) due to less decomposition. This hypothesis is supported by Grabs et al. (2012) who found higher TOC concentrations in soils with more superficial ground water tables. If that would be the case here as well, we would also have higher DOC content in soil waters associated with DRIPs. As groundwaters are a product of the soil environment in terms of the compounds mobilized, it is clearly important if the sampling wells drain organic-rich or mineral horizons, since this will influence how much DOC is available to mobilize locally (Bishop et al. 2004).

Lateral fluxes of hydrology such as those connecting DRIPs to streams are vital in order to transport C and nutrients to the stream. This groundwater-to-stream-connection was highlighted by Leach et al. (2017), who showed that there are several distinct locations of lateral groundwater inflow to this stream (C6). Others have identified similar topographic control over groundwater movement (Kuglerova et al. 2014). Thus, in the context of my study, and from the standpoint of stream ecosystem processes, the amount and reactivity of DOC in the groundwater is unimportant if that water never connects to the stream (i.e., in non-DRIPs). At the same time, not all DRIPs were identical, and the high variability in my results suggests that local topography and soil structure influence the way the DRIPs "behave". More research is needed in order to fully understand the complexity of DRIPs and their role in influencing river chemistry.

However, when the DRIPs are compared with the headwater lake that feeds this stream, they clearly play a more vital role in contributing 'usable' DOC, even though the lake had a relatively high DOC concentration. The low Rru production (both mean and corrected) suggests that the DOC coming from this lake is of very low quality. This result is consistent with the findings of Berggren et al. (2010 b), who reported that the LMW DOM content in a boreal forest stream was 2.6 times higher than in this same lake outlet stream during late spring. One explanation for the low Rru production in the lake sample could be the residence

time of the water. During summer and autumn, the lake holds its water for a long period of time (i.e., it has a long residence time), and therefore one could argue that most of bioavailable DOC compounds are consumed by bacterioplankton before the water reaches the outlet stream. Lake residence time as a factor of DOC degradation is well described by Catalan et al. (2016) and Evans et al. (2017) whom both describe a negative correlation between DOC decay rates and water residence time. Moreover, Catalan et al. (2016) explained this by the change in DOC composition, due to prolonged exposure of DOC to mineralization, leaving behind only those compounds that degrade more slowly.

While the lake revealed large differences when compared to the DRIPs, the mire showed some surprising similarities/overlap. The average Rru production, corrected Rru production, and DOC concentration for the DRIPs and the mire were all in similar ranges. However, these results do not automatically mean that there are no differences between these different water sources in terms of DOC. For example, Berggren et al. (2007) performed a study on bacterial production (BP) and bacterial growth efficiency (BGE) in the KCS and showed that both measures increased with the percentage of forest cover and decreased with mire cover. In line with these findings, Ågren et al. (2008) found that DOC draining from KCS mires is of higher aromaticity (i.e., lower quality) than that draining from forests. These findings, in some ways, contradict the results reported here. Specifically, I found no distinction in microbial activity between samples from the DRIPs/non-DRIPs and the mire. However, it should be emphasized that Rru production (as used in this paper) is not a measurement of either BP or BGE but is only a proxy for respiration. In fact, in Berggren et al. (2007), they report no relationship between land cover and bacterial respiration (BR), which is a better comparison to the Rru production reported. Thus, Rru production may not provide insight into whether microbes are efficiently converting DOC in to biomass.

Papers like Berggren et al. (2007) and Ågren et al. (2008) used optical measures (e.g., $ABS_{254/365}$/$SUVA_{254}$ respectively) to address patterns of DOC quality and BGE across boreal streams with different land cover. These same measurements were used in my study but did not help in understanding patterns of Rru production. However, the DOC-corrected Rru production does provide another way of addressing quality. In this context, my results suggest that as the bulk DOC pool increased, the amount or diversity of 'usable' DOC compounds increased with it. Therefore, larger pools of DOC had a greater ability to sustain microbial respiration, even if some large fraction of that DOC was of low quality. Whatever the case, these differences among sampling location were not captured by the optical indices of quality that I used here.

Overall, my findings suggest that Rru production may fall short as a method for assessing DOC quality where optical measures have successfully done so in the past. The fact that I did not find any relationships between Rru production and indices of DOC quality is probably because they measure different things. However, when the effect of DOC concentration was neutralized (i.e. Rru/[DOC]) the differences in DOC quality should have been visible with the absorbance indices. So why did I not see a relationship between Rru production and absorbance measurements? The simplest answer might be that the influence of the DOC concentration range was so overwhelming (ranged from 1-76 mg/l), when it comes to microbial respiration, that it obscured more subtle effects arising from differences in DOC composition. Another explanation is simply that there are no systematic differences between DRIPs and non-DRIPs when it comes to DOC quality. With all facts on hand, there are perhaps more informative methods to use (e.g. BP or BGE) when analyzing DOC quality through biological assays.

Regardless of whether mires supply streams with good or bad quality DOC, they deliver high concentrations to outlet streams, and are important simply because there are many of them in the landscape and they thereby constitute great contributors of DOC. Just over 51 km^2 (13%) of Sweden's area is covered by mires according to official forest statistics (Fransson

2018), and my results show that they are likely to support high rates of aquatic respiration. Based on comparing my results with previous work at this site (e.g., Berggren et al. 2007), this respiration is likely not very efficient from the standpoint of microbial growth. Thus, respiration from mire-derived DOC likely contributes more to CO_2 production and evasion from streams than it does to building microbial biomass and supporting food webs.

There are limitations to this study that are worth mentioning. First, I only did one sampling campaign. Both Berggren et al. (2010b) and Ågren et al. (2007, 2008) have shown important temporal dynamics in DOC concentrations and microbial activity in KCS streams. Second, the fact that only 18 wells were sampled might not be enough to capture the full range of variability or perceive the differences between DRIP and non-DRIP locations. Third, I also did not study soil properties (e.g. organic layer depth) linked to each well, something that might give more insight into the "behavior" of the DRIPs in relation to non-DRIPS. Further, 2018 also was a strong drought year in Sweden with only 60-80% of the normal precipitation (Jan.1st-Oct. 24th) (Swedish Meteorological and Hydrological Institute [SMHI] n.d. a) with notably warmer summer than usual by 2-2.5 °C (SMHI n.d. b). The effects of this drought period on groundwater levels, plant and root processes in DRIPs, and lake-water residence could have all influenced my results. Finally, while there are strengths to the Raz-Rru method (it is very easy to do many samples) there are also weaknesses. As shown in this study, Rru production can be a very precise proxy of microbial respiration, but potentially lacks the ability to securely ascertain other attributes of DOC quality.

4.1 Conclusion

This study set out to answer whether DOC reactivity differed among sources of water feeding boreal streams. The results suggested that there are no significant differences between DRIPs and non-DRIPs when it comes to Rru production. Importantly, I found that microbial respiration is significantly related to DOC concentrations and since the DRIPs are the 'hub' that connects groundwater to streams, they are vital for the supply of DOC in terms of microbial respiration, regardless DOC source. However, in order to fully appreciate the function of DRIPs in the riparian landscape, further research is needed where factors such as soil structure, implications for microbial BP and/or BGE, and temporal changes in groundwaters are also considered.

5. Acknowledgements

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7. Appendix

7.1 Appendix 1: Overview table

Table 1. Overview table of all analytical outputs: site names, habitats (D= DRIP, ND= non-DRIP), well depth in mm, mean Rru production (in µg), DOC concentration (in mg/l), corrected Rru production (mean Rru production/DOC), ABS 254/365 and SUVA 254. No measurements from "Lake" and "Stream" exists for well depth since they sampled surface water.

Site	Habitat	Depth (mm)	Mean Rru production (µg)	DOC (mg/l)	Corrected Rru prod. (µg Rru/DOC)	Abs. Ratio (254/365)	SUVA (254)
501 R1	D	1003	0.94	5.50	0.17	5.07	2.85
511 R2	D	979	2.27	10.92	0.21	4.07	4.67
513 R2	D	1113	2.51	15.18	0.17	3.95	4.86
401 R2	D	969	3.21	17.93	0.18	3.68	6.58
505 R2	D	599	3.22	16.88	0.19	3.71	5.64
507 R1	D	683	3.63	23.95	0.15	3.62	6.34
509 R1	D	623	8.27	35.36	0.23	4.80	3.76
403 R2	D	509	16.66	46.98	0.35	4.45	4.16
503 R2	D	823	22.01	64.26	0.34	4.37	4.08
512 R2	ND	937	0.11	2.13	0.05	6.37	1.60
502 R2	ND	1304	0.21	1.39	0.15	2.96	8.58
404 R1	ND	1808	0.84	2.61	0.33	3.27	6.84
504 R1	ND	1195	1.42	8.18	0.17	4.95	3.40
508 R2	ND	754	1.44	7.70	0.19	3.45	6.55
402 R2	ND	1246	23.59	75.99	0.31	4.22	3.89
Lake	Lake	-	1.15	14.74	0.08	3.90	5.21
Stream	Stream	-	3.10	12.53	0.25	4.04	4.53
Mire	Mire	1000	8.94	31.74	0.28	4.00	4.27

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