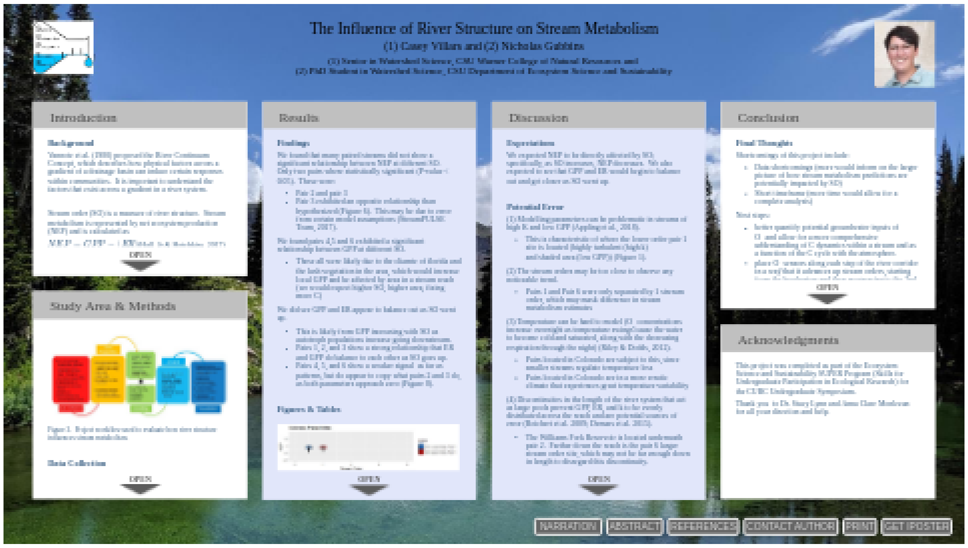
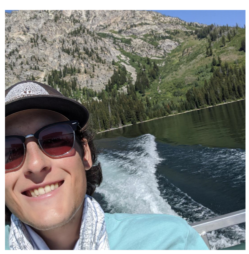
The Influence of River Structure on Stream Metabolism



(1) Casey Villars and (2) Nicholas Gubbins

(1) Senior in Watershed Science, CSU Warner College of Natural Resources and
(2) PhD Student in Watershed Science, CSU Department of Ecosystem Science and Sustainability




PRESENTED AT:

COLORADO STATE UNIVERSITY | CURC 2021 CELEBRATE UNDERGRADUATE RESEARCH AND CREATIVITY

INTRODUCTION

Background

Vannote et al. (1980) proposed the River Continuum Concept, which describes how physical factors across a gradient of a drainage basin can induce certain responses within communities. It is important to understand the factors that exist across a gradient in a river system.

Stream order (SO) is a measure of river structure. Stream metabolism is represented by net ecosystem production (NEP) and is calculated as

$NEP = GPP - |ER|$(Hall, Jr & Hotchkiss, 2017)

- GPP is gross primary production.
- ER is ecosystem respiration.

High NEP is productive. This indicates stream is autotrophic and is fixing more carbon (C) than is being respired.

Negative NEP is unproductive. This indicates stream is heterotrophic and is mineralizing more inorganic C (Hall, Jr & Hotchkiss, 2017).

Stream metabolism is also affected by the gas exchange rate coefficient (k600):

- This is k, the gas transfer velocity, but normalized and converted to a common Schmidt number (Raymond et al, 2012).
- This simply translates into the rate of gas movement between the stream surface and the atmosphere over length of stream (Raymond et al., 2012).

Utilizing publicly hosted data, this research aims to answer one primary question:

How does river structure influences stream metabolism in continuous river systems located in both Colorado and Florida?

At the conclusion of the research, we expect to see NEP go down as the order of streams increase. As stream order increases, we also expect to see the rates of ER and GPP become more similar.

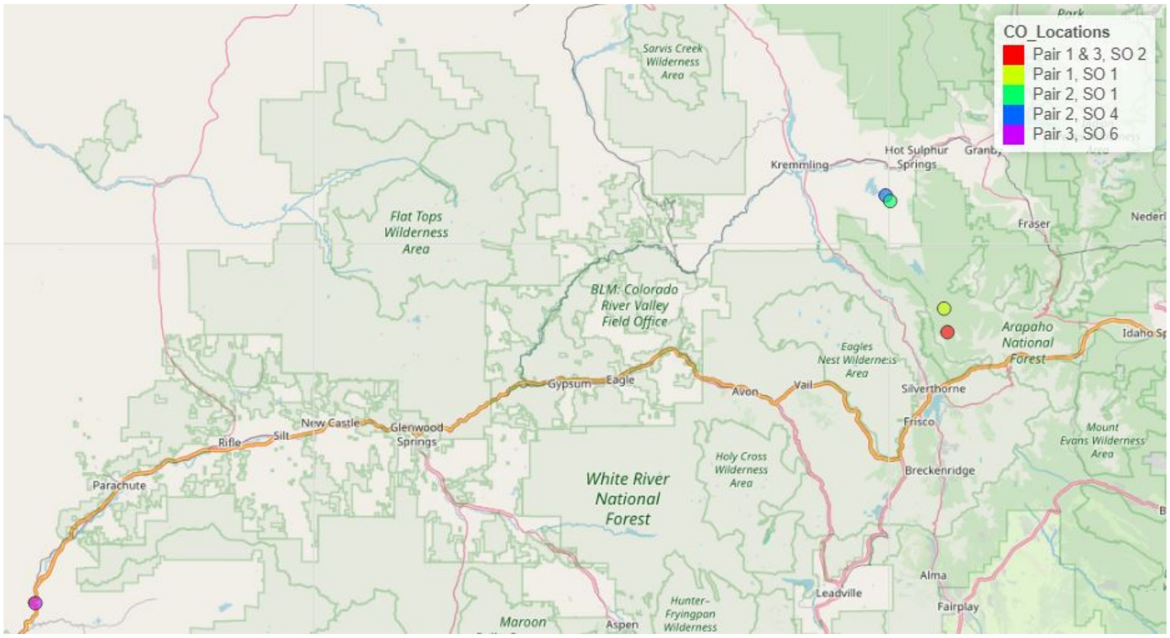


Figure 1. Colorado paired site locations. Shows spatial distribution of 5 distinct sites that make up three pairs of sites used in analysis of stream metabolism. Legend contains information on what pair each site belongs to and its stream order.

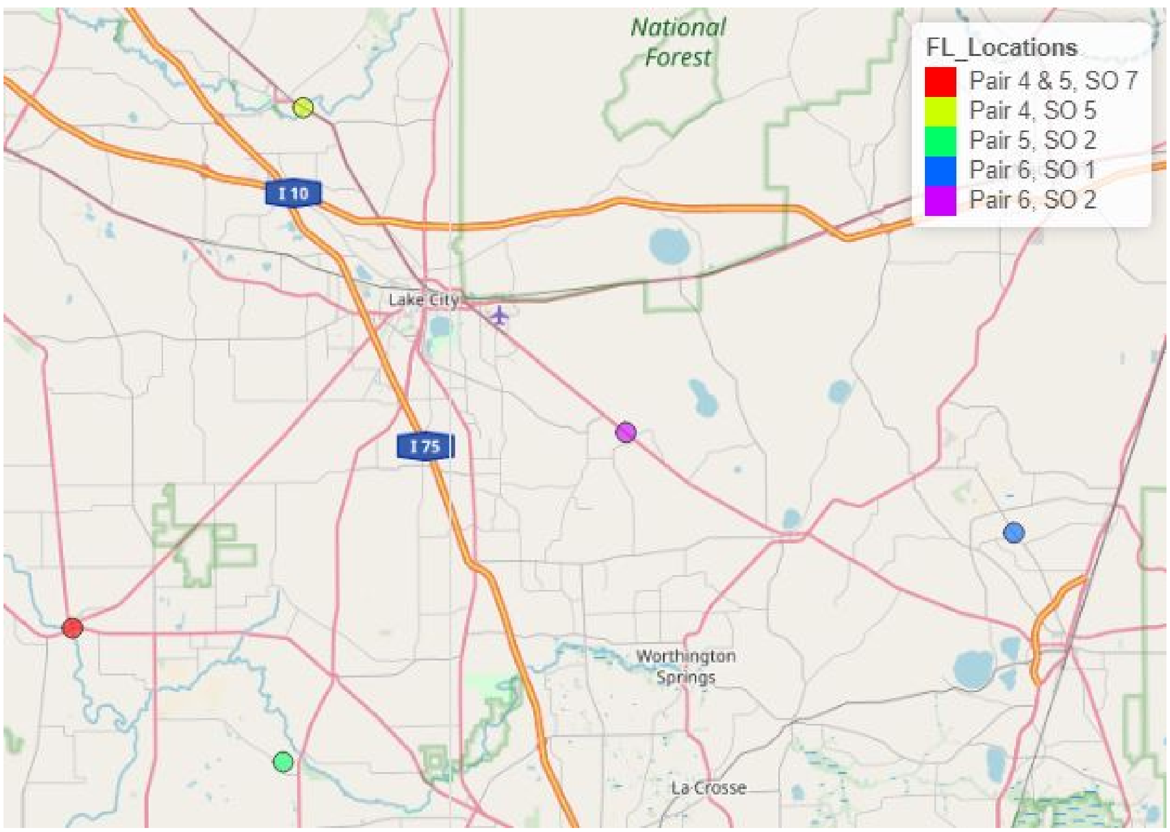


Figure 2. Florida paired site locations. Shows spatial distribution of 5 distinct sites that make up three pairs of sites used in analysis of stream metabolism. Legend contains information on what pair each site belongs to and its stream order.

Study Area

We collected necessary parameter and time-series data over ~3 months for sites during summer on the same river system. We choose studying sites on a specific system in order to help control ecosystem characteristics and not throw off estimates.

- Ecosystem characteristics include climate, soils, hydraulic regime, landcover, geology, etc.

We chose our temporal patterns over the summer in order to capture:

1. Highest productivity rates in autotrophs.
2. Most available data.
3. Multiday datasets gave additional accuracy benefits to modelling stream metabolism (Appling et al., 2018).

We paired gages that are located in the same river systems.

STUDY AREA & METHODS

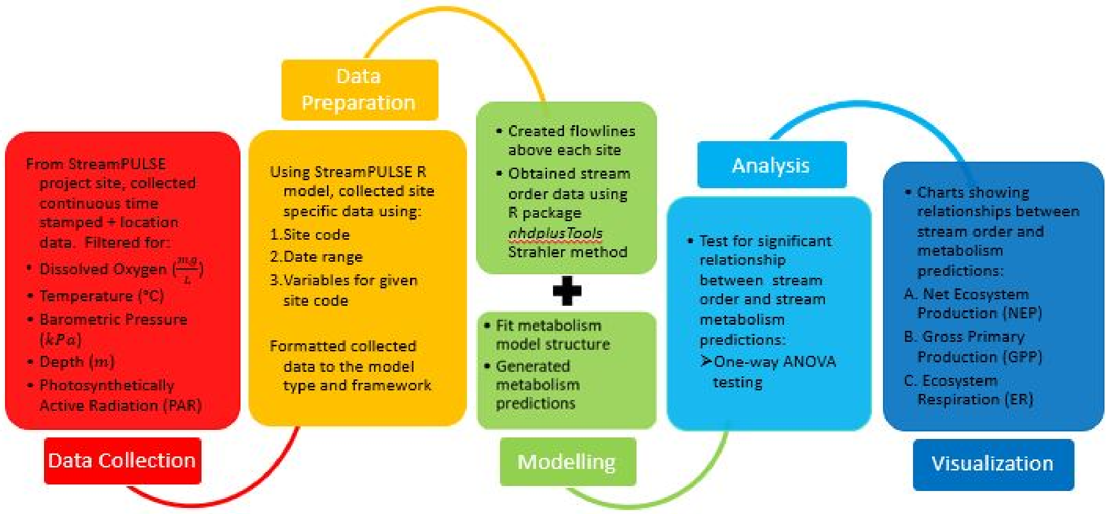


Figure 3. Project workflow used to evaluate how river structure influences stream metabolism.

Data Collection

We accessed the *StreamPULSE* project server to determined which sites to use by querying for specific parameters, logged with high frequency (15-min time step) data.

Data is also computed using supporting functions in the *StreamPULSE* and *streamMetabolizer* packages (Figure 3) (Vlah and Berdanier, 2020; Appling et al., 2018).

Data Preparation

We loaded data into R with the *StreamPULSE* package (Vlah and Berdanier, 2020). We used the model workflow developed by the StreamPULSE team which preparred the data and fit it to a Bayesian model from the *streamMetabolizer* package (Vlah, 2020; Appling et al., 2018).

Modelling

We fit the metabolism model and generated predictions, using the *streamMetabolizer* package (Appling et al., 2018). The model itself is anchored in O_2 dynamics and generated stream metabolism estimate of NEP, GPP, and ER within each stream reach.

We used the Strahler method from the *nhdplusTools* R package to calculate stream order (Blodgett, 2019). This package uses the National Hydrography Dataset (NHD) to calculate SO by sub-setting the full flowline model managed in the NHD (Blodgett, 2019).

Analysis

We ran one way ANOVA tests for NEP, GPP, and ER against SO to determine if the variance between the means was statistically significant.

We used resulting P-values to determine what site-specific parameter relationships to further investigate.

Visualization

Scatterplots were created for sites that had indicated high P-values, which indicate we reject the null hypothesis. We plotted the following graphs in order to make more potential inferences:

- NEP vs NEP at higher and lower stream orders for Pair 2 and Pair 3.
- GPP vs GPP at higher and lower stream orders for Pairs 4,5 and 6.
- GPP vs ER at higher and lower stream orders for all site pairs.

RESULTS

Findings

We found that many paired streams did not show a significant relationship between NEP at different SO. Only two pairs where statistically significant (P-value < 0.05).

- The two pairs were pair 2 and pair 3.
- Pair 3 exhibited an opposite relationship than hypothesized (Figure 6). This may be due to error from certain model assumptions (StreamPULSE Team, 2017).

We found pairs 4,5 and 6 exhibited a significant relationship between GPP at different SO.

- These all were likely due to the cliamte of florida and the lush vegetation in the area, which would increase local GPP and be affected by area in a stream reach (we would expect higher SO, higher area, fixing more C)

We did see GPP and ER appear to balance out as SO went up.

- This is likely from GPP increasing with SO as autotroph populations increase going downstream.
- Pairs 1, 2, and 3 show a strong relationship that ER and GPP do balance to each other as SO goes up.
- Pairs 4, 5, and 6 show a weaker signal as far as patterns, but do appear to copy what pairs 2 and 3 do, as both parameters approach zero (Figure 8).

Figures & Tables

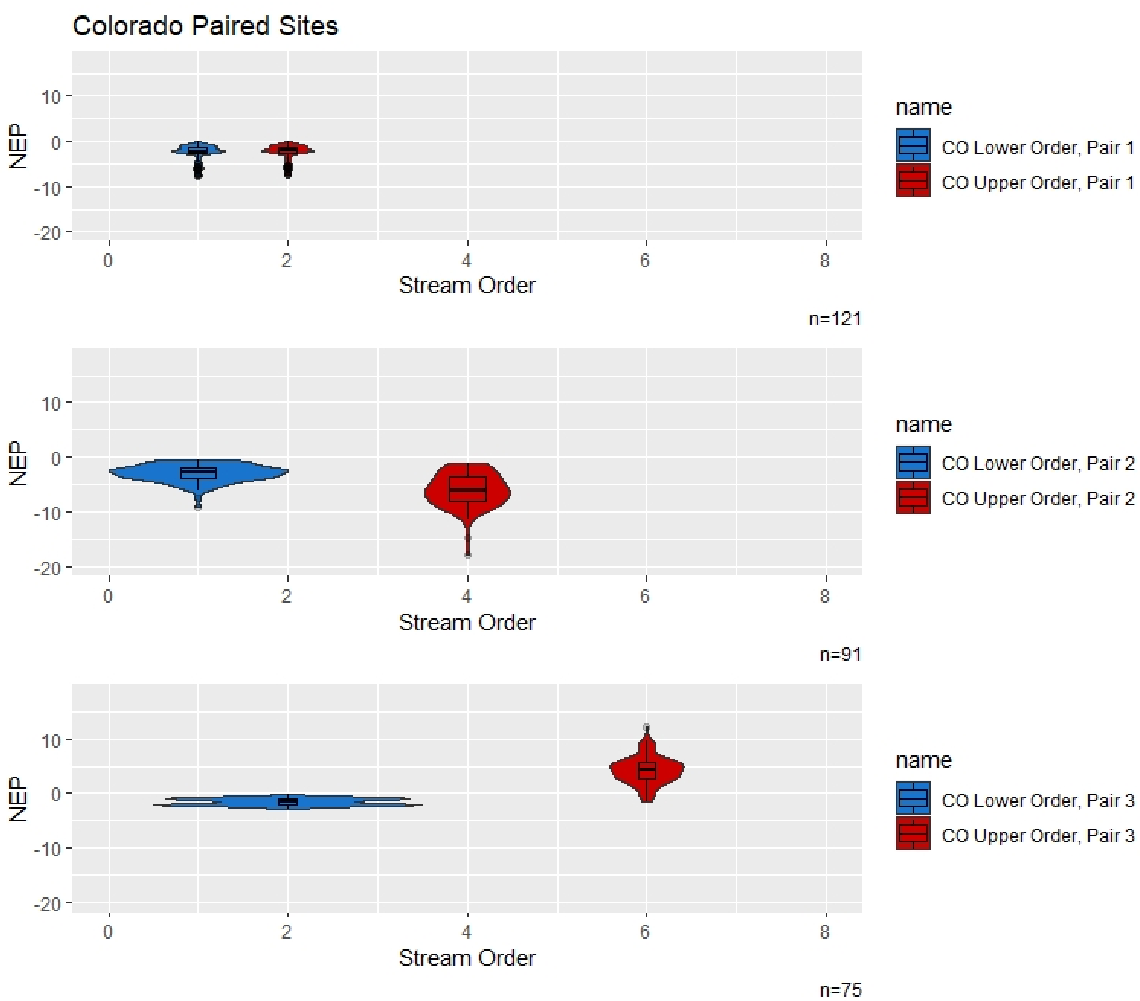


Figure 4. Violin plots of the Colorado sites comparing SO to NEP. Sample size for each pair displayed in bottom right of each graph.

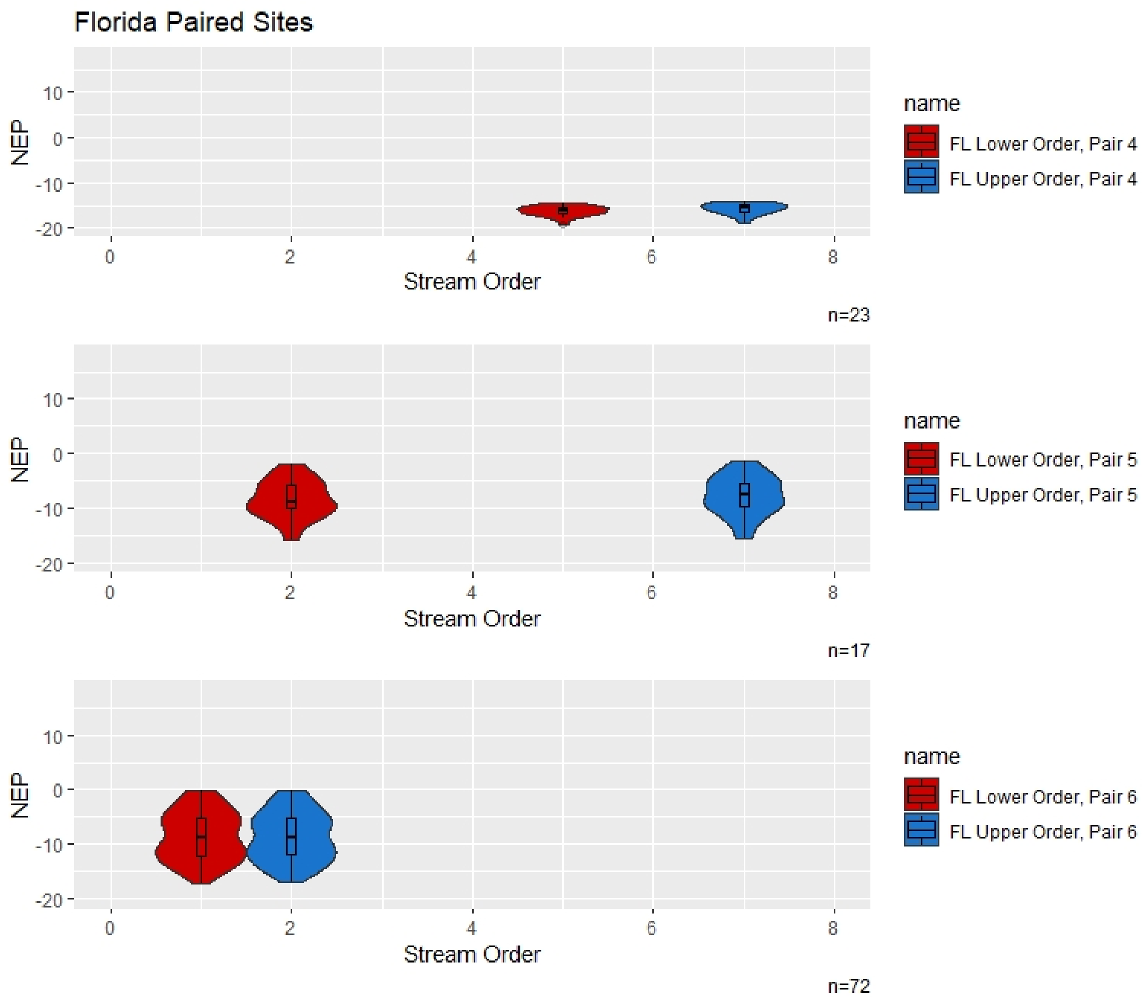


Figure 5. Violin plots of the Colorado sites comparing SO to NEP. Sample size for each pair displayed in bottom right of each graph.

Table 1. Table of resulting P values for all pairs in Colorado and Florida.

Pair Significance Values

Pair	NEP.Pvalue	GPP.Pvalue	ER.Pvalue
1	0.7247	2.2e-16	1
2	1.085e-14	2.2e-16	1
3	2.2e-16	2.2e-16	1
4	0.2178	0.0002928	1
5	0.6073	5.033e-05	1
6	0.8411	1.666e-07	1

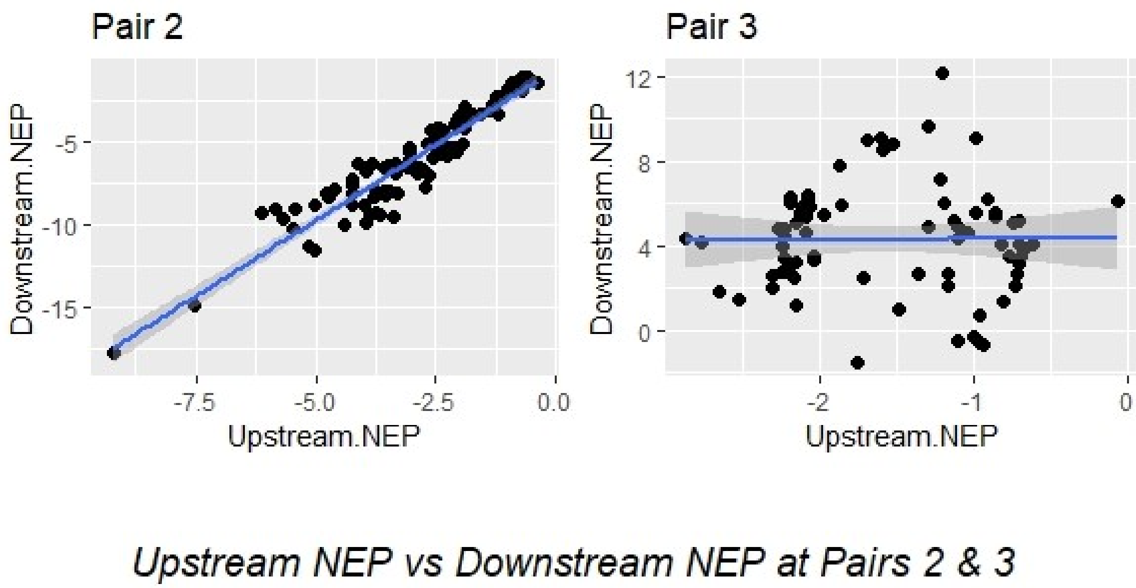


Figure 6. Scatterplots of pairs 2 & 3 (significant p-values from ANOVA test) with downstream NEP (y-axis) versus upstream NEP (x-axis). Pairs 2 & 3 are located north of Silverthorne, CO.

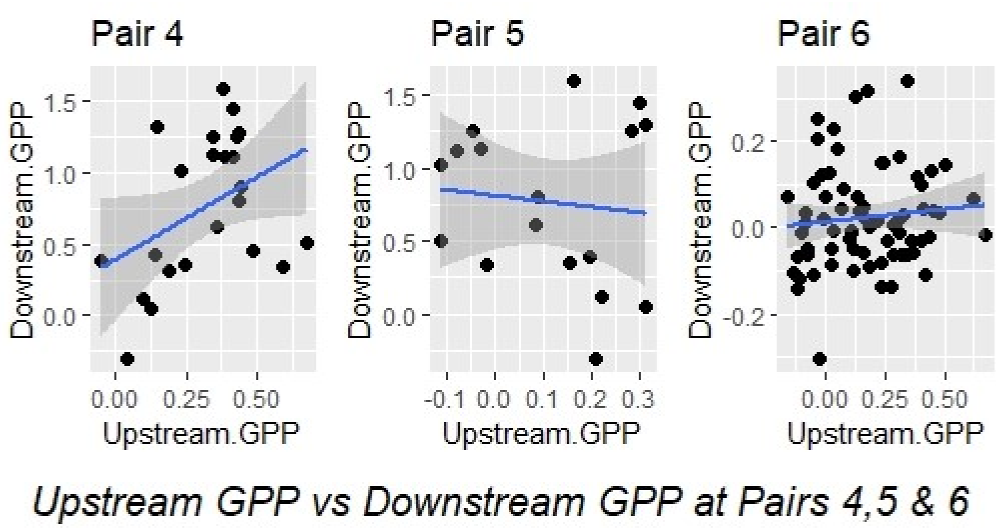


Figure 7. Scatterplots of pairs 4, 5 & 6 (significant p-values from ANOVA test) with downstream GPP (y-axis) versus upstream GPP (x-axis). Pairs 4, 5 & 6 are located in and around north/central Florida.

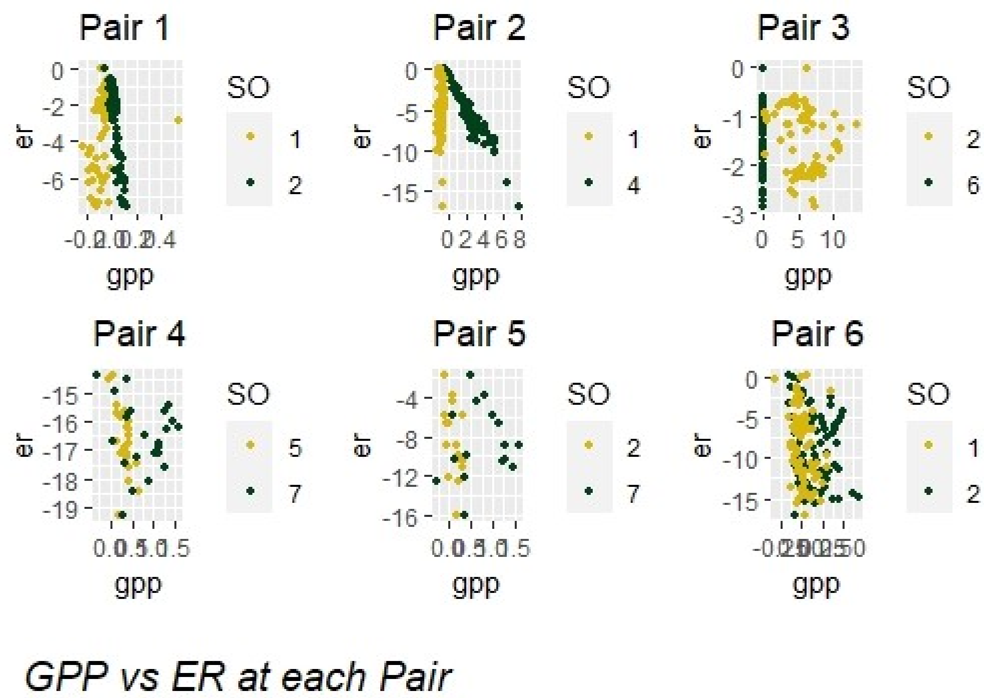


Figure 8. Scatterplots of all 6 pairs visualizing scatter of GPP versus ER values for different order streams within each pair. Yellow points are lower order streams while green points are upper order streams.

DISCUSSION

Expectations

We expected NEP to be directly affected by SO; specifically, as SO increases, NEP decreases. We also expected to see that GPP and ER would begin to balance out and get closer as SO went up.

Potential Error

(1) Modelling parameters can be problematic in streams of high K and low GPP (Appling et al., 2018).

- This is characteristic of where the lower order pair 1 site is located (highly turbulent (high k) and shaded area (low GPP)) (Figure 1).

(2) The stream orders may be too close to observe any noticeable trend.

- Pairs 1 and Pair 6 were only separated by 1 stream order, which may mask difference in stream metabolism estimates.

(3) Temperature can be hard to model (O_2 concentrations increase overnight as temperature swings cause the water to become cold and saturated, along with the decreasing respiration through the night) (Riley & Dodds, 2012).

- Pairs located in Colorado are subject to this, since smaller streams regulate temperature less.
- Pairs located in Colorado are in a more erratic climate that experirnces great temperature variability.

(4) Discontinuites in the length of the river system that act as large pools prevent GPP, ER, and k to be evenly distributed across the reach and are potential sources of error (Reichert et al. 2009; Demars et al. 2015).

- The Williams Fork Reservoir is located underneath pair 2. Farther down the reach is the pair 6 larger stream order site, which may not be far enough down in length to disregard this discontinuity.

(5) Reaches with undersaturated deep groundwater would cause ER to be inflated and throw off our analyses (Hall & Tank 2005).

- All florida pairs are prone to this. Florida is made up of largely carbonate rock, which goes through lots of dissoulution, creating underground cave systems that connect with groundwater.

CONCLUSION

Final Thoughts

Shortcomings of this project include:

- Sample sizes were small, as data was hard to find in certain cases (more data would inform on the larger picture of how stream metabolism predictions are potentially impacted by SO).
- Time was short which inhibited my ability to research more (more time would allow for a complete analysis).

Next steps:

- Better quantify potential groundwater inputs of O_2 and allow for a more comprehensive understanding of C dynamics within a stream and as a function of the C cycle with the atmosphere.
- Place O_2 sensors along each step of the river corridor in a way that it advances up stream orders, starting from the headwaters and then progressing to the 2nd, 3rd, 4th, and so on.

For sites paired in both the geographical regions of Colorado and Florida, there was not a noticeable effect that SO had has stream metabolism estimates.

Only for two out of six sites can we reject the null hypothesis that SO has no effect on NEP.

We cannot make a final decision on how GPP and ER behaved over increasing SO, but we can see that in several of the sites there appeared to be trends that showed GPP an ER balancing out as SO increases.

ACKNOWLEDGMENTS

This project was completed as part of the Ecosystem Science and Sustainability SUPER Program (Skills for Undergraduate Participation in Ecological Research) for the CURC Undergraduate Symposium.

Thank you to Dr. Stacy Lynn and Anna Clare Monlezun for all your direction and help.

ABSTRACT

The River Continuum Concept describes rivers as a continuous system, with a structure and gradient of conditions that influence its characteristics (Vannote et al., 1980). Stream order is one measurement of the river structure that contributes to the ecology and chemistry of the river system. Stream metabolism is an important biochemical process that measures net ecosystem production (NEP), which is calculated using ecosystem respiration (ER) and gross primary production (GPP). These quantify how efficient a system is in fixing or mineralizing carbon (C). The linkage between stream structure and metabolism is complicated and not well understood. Using improved three-parameter inverse modelling provided by the streamMetabolizer package (Appling et al., 2018), we aim to provide metabolism estimates for pairs of sites located in Colorado (CO) and Florida (FL) over photosynthetically active periods with open data hosted by the StreamPULSE project. We will determine the influence of river structure on stream metabolism by comparing estimates for these systems. We expect as stream order increases, relative ER will increase, lowering NEP. By quantifying stream metabolism, we can better estimate C flux and more accurately estimate climate change.

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