The Effect of Spawning Salmon Presence on Riverbank Soil Organic Matter Content

Maya Bird, Ruwanya Pujitha Gunawardana, Alexandra McDonald, Gabrielle Vaillancourt-Ehling

Abstract

The decomposition of salmon along riverbanks releases an abundance of nutrients, such as nitrogen and phosphorus, into the surrounding soil. This leads to higher amounts of organic matter absorbed into the soil which greatly benefits river ecosystems (Bilby et al., 2003). We examined how the presence of spawning salmon affects the organic matter in soil found along the riverbanks of three salmon spawning streams (Clayburn Creek, Capilano River, and Serpentine River) in comparison to the soil organic matter content of three creeks that do not support salmon (Poignant Creek, Coho Loop creek, and an unnamed creek in Meyer Glade, UBC Botanical Gardens). We measured the mass of organic matter in the soil (%) obtained from appropriate sampling locations, and predicted that the soil organic matter would be significantly greater when spawning salmon are present compared to the soil organic matter present in creeks that do not support salmon. Our statistical analysis showed that although on average the rivers containing salmon had a higher percentage of organic material in the soil, the results were not statistically significant and did not support our hypothesis that rivers that support spawning salmon will have more organic matter (%) in the soil along the riverbank compared to rivers that do not support spawning salmon.

Introduction

The Pacific coast of Canada is home to a portion of the largest temperate rainforest in the world. British Columbia's (BC) lush ecosystem supports an incredible amount of diversity, as it is home to over 50,000 species and has the greatest biodiversity of any Canadian province (Austin et al., 2008; Cannings et al., 2005). Within this plethora of species, salmon hold a historically and environmentally crucial role, as they greatly impact both the freshwater systems they use as spawning grounds and the adjacent terrestrial environment. For example, a large run of sockeye salmon can provide up to 5.4×10^5 kg of biomass to British Columbia's temperate rainforests when they return from the ocean to their hatching streams inland (Gende et al., 2002). When comparing otherwise similar habitats within this nutrient-rich temperate rainforest ecosystem, a question comes to mind: is there a significant difference in the percentage of organic matter in soil from salmon versus non-salmon streams?

Previous literature has explored the effect of salmon on the freshwater systems in which they spawn and the surrounding terrestrial environment. Salmon spawning streams supply ocean-derived carbon, nitrogen, and phosphorus-containing nutrients into both the water and adjacent terrestrial habitats (Gende et al., 2002). These nutrients are either directly excreted by the salmon (e.g. nitrogen) into freshwater streams or are released through the decomposition of carcasses both in water and on land. Certain nutrients, namely nitrogen and phosphorus , are associated with increased stream productivity and biomass (Levi et al., 2013; Ruegg et al., 2012).

Additionally, research has shown that fish carcasses deposited on adjacent river banks, which occurs when salmon are caught and transported by predators, are linked to increased terrestrial productivity (Ben-David et al., 1998; Helfield & Naiman, 2001; Bilby et al., 2003). For example, Tongass National Forest, which encompasses most of the south-east region of Alaska, contains almost 5000 salmon-supporting streams. 47% of this forested area is within 0.5km of a salmon stream and more than 90% is within 5km (Halupka et al., 2000). Nutrients from salmon runs enrich landscapes by supporting diversity (Mathewson et al., 2003) and play an important role in both shaping and maintaining the ecosystems within which they thrive.

This study is important to the topic of environmental conservation since policy makers often require motivation and political relevance to motion forward regulations. Understanding the importance of salmon returning inland each year, and how this affects the organic matter in soil, can inform policy-making proceedings and the implementation of such regulations. Pacific coast salmon are a species worthy of protection, as the nutrients from salmon decomposition are integral to maintaining soil health and nutrient supply to plants. Organic content in soil contributes to maintaining soil integrity by increasing resistance to wind/water erosion and its capacity to hold water. As a result, this increases capacity to both retain and release nutrients for plant growth and supports populations of soil biota (Sullivan et al., 2019).

In addition, the presence of soil organic matter indirectly affects salmon growth. The protection from erosion creates a clean body of water that supports salmon survival and growth (Post, 2008). High levels of organic matter in soil also help stabilize ecosystems by supporting the vegetative growth adjacent to salmon spawning rivers and streams. The growth of large trees provides shade and a cool environment for the salmon eggs to develop (Post, 2008). If our study and future replications can determine that salmon streams have a higher percentage of organic matter, and therefore represent a more healthy ecosystem benefitting multiple categories of ecosystem services, it would provide evidence to support the push for increasing conservation-based regulations of these habitats.

Although similar research has been done in the past regarding the impact of spawning salmon on freshwater systems and adjacent terrestrial systems, we did not find any research that has specifically explored the difference in organic content in soil along the riverbanks of streams supporting salmon versus streams without salmon. Our study aims to answer this question by collecting samples, weighing the difference between dry soil and soil with organic material removed, and using statistical analysis to determine if the results are significant. We hypothesize that if spawning salmon bodies break down and release nutrients to the nearby soil, then rivers that support spawning salmon will have more organic matter (%) in the soil along the riverbanks compared to rivers without spawning salmon.

Methods

Field methods and data collection

We collected soil samples from three salmon spawning rivers and three non-salmon rivers. The rivers where spawning salmon were present were Capilano River, Clayburn River, and Serpentine River. The non-salmon rivers were Poignant Creek, the Coho Loop (a creek just off of the Capilano River) and an unnamed creek in Meyer Glade within UBC Botanical Gardens. At all but one river, three samples of soil (approximately 1 cup each) were collected in three separate containers. A decision was made in the field to collect a total of 6 samples from Clayburn Creek (3 from upper and 3 from lower). A salmon carcass was spotted at lower Clayburn Creek, prompting the collection of additional samples since salmon carcasses were not observed at the upper Clayburn Creek sampling location. Each sample was obtained 1 m from the water's edge and 10 m apart along the water body (see Figure 1). We labelled each individual soil sample with the sample number, the location, date, and if the stream supported salmon or not (e.g. 1, Capilano River, 01/11/2020, Salmon Spawning). In total, 21 samples were collected.

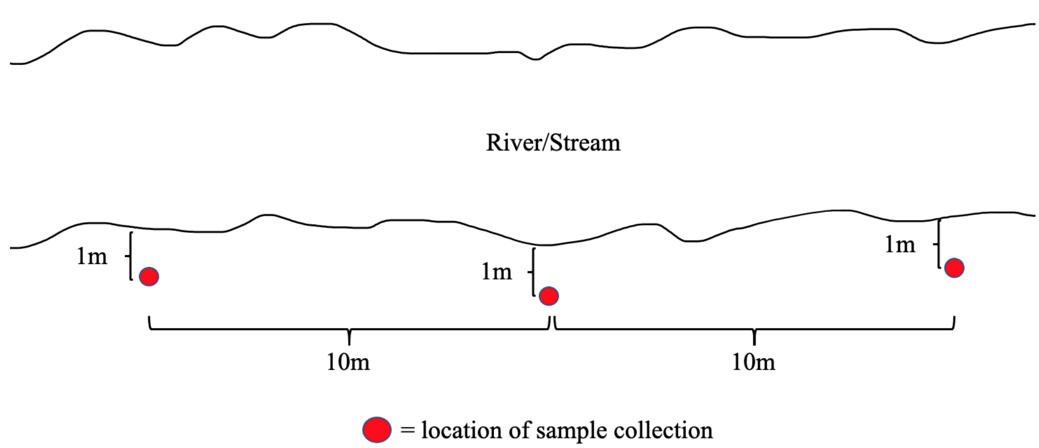

Figure 1. Method of soil sample collection along the edge of each river/stream. Red dots represent the location of sample collection. Each sample was taken 1m from the river's edge and 10m apart from each other.

After collection, we placed the samples on tin foil boats and dried them completely in an oven at 175°C. During the drying process, each sample was initially dried for 1 hour. If the sample still appeared wet, we returned it to the oven and checked periodically until it appeared dry. At this point, we took each sample out of the oven every 10 minutes and weighed it using a kitchen scale. Once two consecutive weight readings were the same, we removed the sample from the oven and recorded the mass as M_1.

Next, we soaked each soil sample in hydrogen peroxide (H_2O_2) to remove organic matter from the soil. The amount of H_2O_2 added depended on the mass of soil sample (M_1) after initial drying. For every 10g of soil, 4 teaspoons of H_2O_2 were added (Mikutta et al., 2005). We conducted the same drying process as mentioned above until the H_2O_2-treated soil samples were completely dried and this final mass was recorded as M_2. Lastly, we calculated the percentage organic matter content of the original soil sample using the following equation:

$$\frac{M1 - M2}{M1} * 100\%.$$

Statistical Analyses

We conducted statistical analyses of our data using *Graph Pad*. We divided the soil samples into two groups (salmon spawning rivers and non-salmon rivers) in order to calculate respective mean percentages of organic matter in soil. After obtaining the means, we performed a Mann Whitney U test to determine whether mean percentages for each group were statistically significant. We used a 95% confidence interval and alpha value of 0.05. The means for each data set along with the 95% error bars are represented in Figure 2.

Results

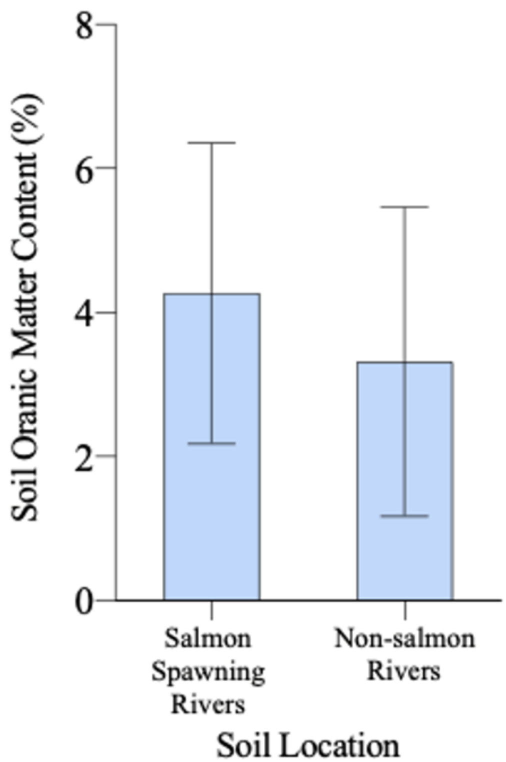

Figure 2. A comparison of mean soil organic matter content (%) in salmon spawning rivers versus non-salmon rivers. Data for both the salmon spawning (N=12) and non-salmon (N=9) rivers are presented as means within a 95% confidence interval. Error bars represent standard deviation. The organic content in salmon spawning soils and non-salmon soils was calculated, with means of 4.267 ± 1.862% and 3.318 ± 1.403, respectively. P-value was calculated to be 0.958 (> alpha of 0.05).

The mean organic matter content of soil collected from the salmon spawning rivers was calculated to be 4.267 ± 1.862 (%) and the mean organic matter content of soil collected from the non-salmon rivers was calculated to be 3.318 ± 1.403 (%). The results of the Mann-Whitney U test calculated a P-value of 0.958 within a 95% confidence interval. Since the calculated P-value is greater than our alpha value of 0.05, we fail to reject the null hypothesis. In addition, the U value for the statistical analysis was calculated to be 53 which is greater than the critical U value of 26.

Discussion

In this study, we aimed to determine whether there was a statistically significant amount of organic matter in British Columbia streams supporting spawning salmon versus streams where spawning salmon were not present. We collected a total of 21 samples from streams and removed organic matter from them to determine each sample locations' soil organic matter content. We failed to reject our null hypothesis given that our P-value was greater than alpha (0.05) and our U-value was greater than the critical U-value, and thus concluded that there is no significant difference in the percentage of organic matter content in the soil bordering rivers with salmon spawning in them compared to the soil alongside rivers without salmon in them. Therefore, any differences in organic matter content between the sampled streams are likely due to random chance.

A reason we may not have seen a significantly higher percentage of organic matter along salmon-spawning streams could be due to predatory or scavenger organisms, such as bears, influencing how nutrients are transferred in river ecosystems (Holtgrieve et al., 2009). Salmon supply a large amount of organic matter to inland ecosystems as bears carry salmon into the forest away from the river's edge to eat, thus avoiding interactions with other bears (Holtgrieve et al., 2009; Gende & Quinn, 2004) and affecting where elevated organic matter levels may be present in relation to streams. Since samples at non-salmon rivers (the Coho Loop and Poignant

Creek) were located within 1 km of salmon rivers, bears or other predators that catch salmon in those rivers may transport the salmon further than 1 m from the riverbank for consumption. It must also be considered that scavengers such as eagles and ravens who feed on salmon carcasses typically transport the salmon to a distance no longer within the stream's borders and our sampling area. These organisms only eat a small portion of the salmon (Van Daele et al., 2013) and the leftover salmon carcass is available to other animals, like small insects. The carcasses are broken down further by microbial activity and leaching by rain, making the nutrients that were present in salmon available to soil, increasing the soil's organic matter content.

Moreover, the rivers from which we obtained our soil samples may not be an accurate representation of the true organic matter content in soil within all salmon rivers in the Lower Mainland of British Columbia. Our samples were taken from locations accessible to humans which are visited regularly for recreational activities, and two of the salmon spawning streams were close to, or within, a salmon hatchery with regular human presence and security measures. This likely deters wildlife from feeding at these locations. For example, bears may be less likely to catch and consume salmon on the riverbanks of the rivers with higher rates of human activity. Therefore, we believe that the organic material in soil along rivers without human presence may have a higher organic material content than those sampled in this study.

Due to the current COVID-19 outbreak, data collection from each river in Metro Vancouver and the Lower Mainland was done independently and on different days. Consequently, it is plausible that inconsistencies occurred and contributed towards procedural sources of error that significantly affected our results. First of all, using different amounts of soil for our initial mass (M_1) is likely to have led to inconsistencies in the precision of values for soil mass after H_2O_2 treatment (M_2). This is due to the fact that the kitchen scales used in our experiment gave readings to the nearest gram. For smaller soil sample sizes (e.g. 30 g), if the loss of organic matter is less than one gram, the scale reading would not capture the difference and it would appear that the sample contained no organic matter. On the other hand, in soil samples over 100g (Capilano River and Coho Loop Creek), the loss of a greater amount of organic content (in grams) in a larger sample would be captured in the scale readings limited to the ones/units place. Thus, a larger sample, which is likely to contain a greater amount of organic carbon, is more likely to report an accurate percent organic content.

In addition, it is highly likely that there were deviations between true and reported percentages of organic matter for each treated sample due to variations in soil composition, which can affect the relative organic matter present and subsequent reaction with H_2O_2. According to Mikutta et al. (2005), soils with a large portion of organic matter bound to a mineral matrix, such as clay, have little carbon removed regardless of which oxidative reagent is used. Out of the 21 samples collected in this experiment, 2 were predominantly composed of clay. Therefore, it is likely that our use of H_2O_2 at any length of treatment failed to dissolve any significant amounts of organic matter in these samples. This would have led to a lower calculated organic matter content for those samples.

An assumption made during this experiment was that each sample's treatment with H_2O_2 went to completion. Upon further research, we determined that drying temperature affects reaction time of H_2O_2 with soil leading to varying efficiencies in degradation of organic matter. As explained by Mikutta et al. (2005), increasing oven temperature during drying shortens the reaction time needed to oxidize organic matter, yet also accelerates the rate of decomposition of

H_2O_2 into water and dioxygen ($2H_2O_2 \rightarrow 2H_2O + O_2$). Above 70°C, H_2O_2 is rapidly consumed and additional H_2O_2 is needed to continue degrading organic matter. At lower temperatures, the time of exposure to H_2O_2 needs to be extended to substantially degrade organic matter. This can be done by either adding more H_2O_2 periodically during oven drying or leaving the H_2O_2-treated samples at room temperature for a prolonged period of time. Often, using H_2O_2 as a reagent for removing organic matter from soil requires several days. Additionally, there is no reliable indication to signify the completion of the decomposition reaction, making the decision to measure final mass and determine percent organic matter difficult.

This experiment can be improved in future studies by having a more consistent amount of H_2O_2 added, higher accuracy scales to get a more precise weight measurement, and increasing the contact time for H_2O_2 treatment. Additionally, more accurate results would be obtained if the all measurements were simultaneously performed by a team in a controlled lab setting using a singular or identical model of oven and analytical scale. Ideally, future research teams should take samples on the same day, therefore reducing the variable impact that weather and rainfall could have on the results. Lastly, sample size should be increased to provide more accurate mean values and to identify possible outliers, if present.

Conclusion

Overall, our findings did not support our hypothesis that if spawning salmon bodies break down and release nutrients to the nearby soil, then rivers supporting spawning salmon will have more organic matter (%) in the soil along the riverbank compared to rivers without salmon. Since salmon are widely considered keystone species in BC's ecosystem, further research directly comparing the organic content of soil between salmon supporting and non-salmon supporting streams would highlight the benefits salmon bring to freshwater systems and the surrounding terrestrial environments they occupy. Such a comparison will be beneficial in order to provide policy makers with the evidence needed to strengthen conservation efforts. The lack of research comparing salmon supporting streams to streams that do not support salmon, along with the disparity between our results and the findings of previous studies, indicates a need for further investigation.

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Appendix

Table 1: Soil sample weights before and after hydrogen peroxide treatment, calculated percent organic matter, and amount of hydrogen peroxide used per sample.

Sample		**M_1 (g)**	**M_2 (g)**	**% Organic Matter**	**Hydrogen Peroxide (mL)**
Salmon Supporting					
Capilano River 49°21'14.1"N 123°06'56.2"W	1	277	273	1.444043321	100
	2	416	414	0.4807692308	100
	3	153	148	3.267973856	100
Clayburn Creek Upper 49°04'43.0"N 122°13'57.5"W	1	30	29	3.333333333	60
	2	30	27	10	60
	3	30	28	6.666666667	60
Clayburn Creek Lower 49°04'56.6"N 122°14'59.2"W	1	30	29	3.333333333	60
	2	30	27	10	60
	3	30	28	6.666666667	60
Serpentine River 49°10'41.7"N 122°45'47.4"W	1	197	195	1.015228426	120
	2	40	39	2.5	80
	3	40	39	2.5	80
Non-Salmon Supporting					
Coho Loop Creek 49°21'18.8"N 123°06'37.0"W	1	212	202	4.716981132	100
	2	124	119	4.032258065	100
	3	243	233	4.115226337	100
Poignant Creek 49°05'02.9"N 122°13'36.5"W	1	30	29	3.333333333	60
	2	30	30	0	60
	3	30	28	6.666666667	60
Meyers Glade Creek, UBC 49°15'05.4"N 123°14'53.7"W	1	100	96	4	180
	2	100	97	3	180
	3	105	105	0	180