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Spatial variability in surface sediment organic carbon structure in Barkley Sound, Vancouver Island, Canada

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NONTECHNICAL SUMMARY

This study investigates where carbon in marine surface sediments originates from, as well as how seafloor peaks and valleys influence the distribution of carbon in Barkley Sound, Vancouver Island, Canada. Samples were collected for an analysis to investigate how much carbon and nitrogen are present in the sediment. The C:N ratio allows for the identification of marine and terrestrial carbon. Bathymetric surveys enable the creation of a map of the seafloor that was used to determine areas of higher and lower elevation from the seafloor elevation mean. There was a wide distribution of marine and terrestrial carbon signatures. Results indicated that there was a negative correlation between weight percent of terrestrial carbon with distance from freshwater sources within Barkley Sound. The lack of the number of stations that were sampled for both carbon and bathymetry, lead to inconclusive evidence of whether bathymetric highs or lows gathered the most carbon.

ABSTRACT

The objectives of this study were to investigate how particulate organic carbon (POC) is distributed within fjords in Barkley Sound, Vancouver Is., Canada. The origin (marine or terrestrial) of the POC was determined as well as how bathymetric highs and lows influence the distribution. Sampling was conducted with an Ocean Instruments MC200 multicorer. These samples were analyzed by an element analysis isotope ratio mass spectrometer (EA-IRMS) for isotope ratio analysis that allowed for interpretation of the origin of the sediment through $\delta^{13}C$ and $\delta^{15}N$ signatures. Bathymetric surfaces were created in CARIS from surveys taken with an EM302 multibeam echosounder. The bathymetric position index of these surfaces made in ArcGIS enabled the identification of areas of bathymetric highs and lows. Highest carbon concentrations were found in the Inner Effingham Inlet and Uchucklesit Inlet, where organic carbon weight percentages ranged from 4.68 to 8.09 in these stations. The weight percent of terrestrial carbon was also high at these stations with values ranging from 44.9 % to 75.5 %. The strong terrestrial signatures are likely due to logging in these regions and poor circulation of bottom waters in Effingham Inlet.

The carbon cycle plays a key role in climate change (Sarmiento et al. 1998; Cox et al. 2000) by determining the CO_2 concentration in Earth's atmosphere through chemical, physical, and biological processes (Post et al. 1990). Particulate organic carbon (POC) acts as a major food source for zooplankton (Honjo et al. 2008) and benthic communities (Snelgrove 1997). As the largest reservoir of carbon on Earth (Post et al. 1990), oceans incorporate the majority of preserved carbon within marine sediments along continental margins (Hedges and Keil 1995).

Determining the variation and distribution of carbon storage in fjords is important because continental margin sediments are essential for balancing the global carbon budget (Berner 1989; Hedges and Keil 1995). The terrestrial and marine sources of sedimentary organic carbon can be identified using the C:N ratio (Nuwer and Keil 2005). The C:N isotope ratio allows identification of the POC source which also enables for the interpretation of the circulation patterns of the inlets within the sound.

The Bathymetric Position Index (BPI) is the measure of the elevation of a georeferenced location relative to the overall landscape called the focal area (Lundblad et al. 2006). In a study by Kehrl et al. (2011) it was found that maximum sediment loss occurred at bathymetric highs and maximum gain were found downslope of those losses. Assuming that carbon is carried along with the sediment, areas of carbon pooling should also be in the bathymetric lows.

Effingham Inlet is a fjord located on the southwestern coast of Vancouver Island bordered by coniferous forests (Kumar and Patterson 2002). The inlet is approximately 17 km long and 1 km wide along its entire length (Ingall et al. 2005). The maximum depth within the inlet is 210 m in the outer basin; the inner basin has a maximum depth of approximately 120 m (Ingall et al. 2005). There are two sills that separate the outer basin from the entrance and the inner basin from the outer basin (Dallimore 2005). Effingham Inlet is classified as a low freshwater runoff fjord (Pickard 1963). The fjord experiences a maximum river input during the winter where there is a peak in rain fall in the region (Pickard 1963; Nuwer and Keil 2005). Freshwater inputs include Effingham River which feeds into the head of the inlet (Kumar and Patterson 2002). The estimated mean flow of the Effingham River is 6 to 8 m^3s^{-1} (Stronach et al. 1993; Hay et al. 2007). The combination of sills, low freshwater input, low wind mixing, and cool dense saline waters of the deep waters of the inner and outer basins inhibit the circulation of subsurface waters (Patterson et al. 2000; Ingall et al. 2005). The long deep-water residence times of the subsurface waters corresponds with the basins frequent anoxic events (Ingall et al. 2005). The inlet faces the open ocean and an area of important upwelling which preserves a distinct offshore oceanographic signal within the sediment record of the inlet (McFarlane et al. 1997; Hay et al. 2007). The forest bordering the western part of the outer basin has been exposed to logging activity within the past 15 years (Kumar and Patterson 2002). Effingham Inlet has steep-sided basins with a relatively complex depositional setting (Hay et al. 2007). Uchucklesit Inlet also is off of the Barkley Sound next to Admiralty Inlet. The main freshwater inputs into the inlet are from Henderson Lake and Uchuck Lake (May 13, https://maps.google.com, Province of British Columbia). At this point in time Uchucklesit Inlet has been a region that remains unstudied. Imperial Eagle Channel in at the entrance of Barkley Sound and has direct contact with the Pacific Ocean.

The objective of this study was to observe the variation of POC source and distribution at different scales within the basins of Effingham Inlet, Uchucklesit Inlet, and Imperial Eagle Channel using sediment cores and seafloor bathymetry. This study has a three part hypothesis: 1) In stations where the bathymetric position index is lower than the focal area then the POC content will be higher due to sediment pooling. 2) It is hypothesized that the sediment samples with the highest POC content would be located near the riverine end of the inlet as riverine inputs will likely account for a large portion of the POC input to the system. 3) It is also predicted that the C:N ratio would reflect more terrestrial origin of carbon in the inner basin because the inlet is not well mixed.

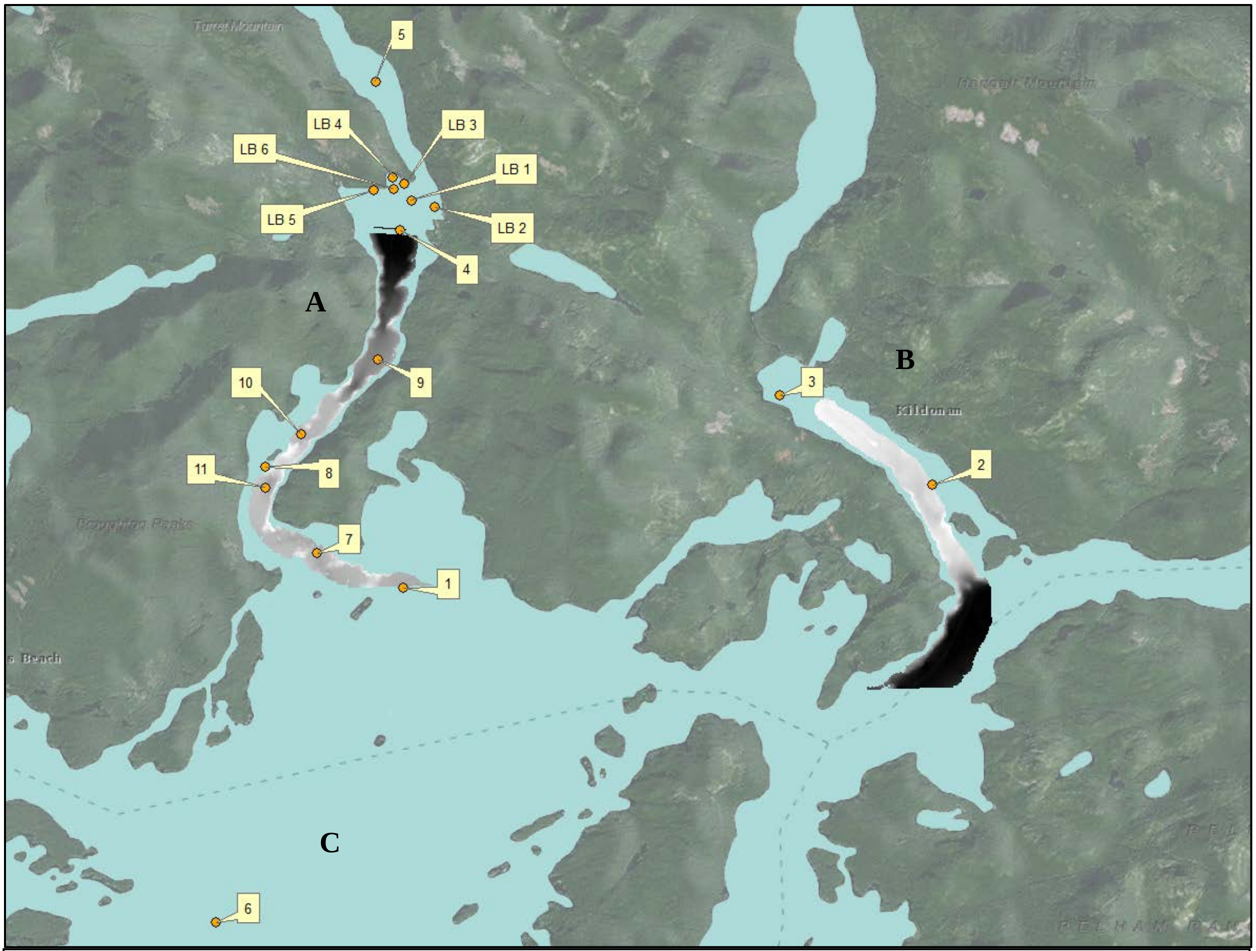

Figure 1: Map of 16 stations within Effingham Inlet (A), Uchucklesit Inlet (B), and Barkley Sound (C). Bathymetric surveys of Uchucklesit Inlet and Effingham Inlet are indicated in grayscale. Image from ArcGIS.

METHODS

Bathymetric profiles and sediment coring were conducted from 29 January to 1 February 2013 in Effingham Inlet and Uchucklesit Inlet, Barkley Sound, Vancouver Island, Canada. Samples and surveys were conducted on the *R/V Thomas G. Thompson* during the 2013 Senior Thesis Cruise.

Bathymetry

Aboard the *R/V Thompson*, the bathymetry of Uchucklesit Inlet and the outer basin of Effingham Inlet were surveyed with a Kongsberg EM302 multibeam echosounder using the Seafloor Information System (SIS) survey acquisition software. Before the surveys a CTD was used to acquire sound velocity profiles, which were then imported into the SIS for correction of changes in acoustic properties of the water column.

Post-processing of raw depth soundings to correct for tidal changes and ships motion were performed in CARIS HIPS ver. 7.1. Base surfaces using the CUBE (Combine Uncertainty Bathymetric Estimator) algorithm were made at 5 m and 15 m spatial resolution. The completed base surfaces were exported from CARIS HIPS to ArcGIS in the form of raster data layers for further surface analysis. The seafloor BPI was derived for each raster data grid cell by determining the difference in seafloor depth from the mean of the focal region adjacent to each grid cell. This results in areas identified as peaks and valleys positioned on the seafloor. Sampling stations were geo-referenced on a World_Imagery basemap using a WGS 1984 Web Mercator (auxiliary sphere) and proximity to freshwater and seawater sources were derived.

Sediment Collection and Analysis

Sediment samples were taken from 16 stations (Fig. 1). Ten sediment samples were collected with an Ocean Instruments MC200 multicorer. In the inner basin of Effingham Inlet, samples were collected at six stations with a Van Veen Grab aboard a zodiac. The top five centimeters of the cores were split in half and stored in Ziploc bags and frozen for transportation to the University of Washington. Methods described by Anderson (2012) were used to desalt, dry, and prepare the sediment samples for C:N analysis in the Keil Lab. Thawed samples were centrifuged in a TS-5.1-500 at 5,000 rpm for 35 minutes to desalt the samples and separate the sediments from excess water (Anderson 2012). The samples were refrozen for over 24 hours at -18 °C before freeze drying for over 48 hours. Dried samples were homogenized to a fine particle size with a spatula. Sediments were weighed into 46 combusted silver capsules for organic and inorganic carbon isotope analysis. Half of the combusted silver capsules were acid fumed with hydrochloric acid for $\delta^{13}C$ and $\delta^{15}N$ isotope analysis (Komada et al, 2008). The samples were sent to the UC Davis Stable Isotope Facility for isotope analysis. The weight percent of carbon and weight percent of carbon from terrestrial and marine sources were calculated from the C:N isotope data.

RESULTS

Bathymetry

The Effingham Inlet bathymetric depth at 5 m resolution ranged from -28.4873 m to -411.543 m. At 15 m resolution the bathymetry ranged from -33.713 m to -433.269 m. The Uchucklesit Inlet bathymetry at both 5 m and 15 m resolution ranged from -39.32 m to -191.299 m.

There were nine stations that were covered by surveys at 5 m, 15m, or 250m resolution. At the 250 m resolution the stations that were surveyed in the inner Effingham Inlet (Station 4, Little Boat Stations 1 and 6) ranged from -1.67 to 10.57 (Table 1). The stations of the entrance of Effingham Inlet (Stations 1 and 7) that were covered at this resolution ranged from 1.56 to 5.25 respectively (Table 1). Imperial Eagle Channel station (Station 6) had a slope of -0.06. The stations surveyed at 15 m resolution in the entrance to Effingham Inlet (Stations 7, 9-11) had slopes ranging from -0.13 to 0.49 (Table 1). These stations at 5 m resolution had slopes ranging from 0.01 to 0.35 (Table 1).

Carbon

There were 46 samples processed with an EA-IRMS for carbon and nitrogen isotopes. Organic carbon weights varied between the four main regions of the stations (Table 1). The Inner Effingham Inlet stations (Little Boat Stations 1-6, Stations 4 and 5) had a peak of weight percent of organic carbon (wt%C) at Station 5 where the amount of carbon was too high to be processed by the EA-IRMS. The other stations had percentages ranging from 0.99 wt%C to 8.10 wt%C. The carbon 13 ($\boldsymbol{\delta}^{13}C$) values of these stations ranged from -23.04 ‰ to -25.53 ‰. The nitrogen 15 ($\boldsymbol{\delta}^{15}N$) values ranged from 2.92 ‰ to 6.38 ‰. Weight percent nitrogen (wt%N) ranged from 0.06 wt%N to 0.47 wt%N. The Effingham Inlet entrance stations (Stations 1, 7-11) had weight percent of carbon ranging from 2.44 wt%C to 4.25 wt%C. The $\boldsymbol{\delta}^{13}C$ values of these stations ranged from -21.90 ‰ to -23.17 ‰. The $\boldsymbol{\delta}^{15}N$ values ranged from 5.95 ‰ to 6.72 ‰. Weight percent nitrogen ranged from 0.21 wt%N to 0.46 wt%N. The Imperial Eagle Channel station had weight percent of carbon of 2.32 wt%C. The $\boldsymbol{\delta}^{13}C$ values of these stations ranged from -22.21 ‰ to -22.28 ‰. The $\boldsymbol{\delta}^{15}N$ values ranged from 6.16 ‰ to 6.39 ‰. The channel had a nitrogen weight percent of 0.29 wt%N. The stations at Uchucklesit Inlet (Stations 2 and 3) had weight percent of carbon

Table 1. Carbon and nitrogen isotope analysis data and bathymetric data of all stations.

Station Name	Latitude	Longitude	Depth (m)	Distance (m) from river	Slope index 250m res	Slope index 15m res	Slope index 5m res	wt%C	C:N	δ^{13}C	%ter
1	48 58.65	125 08.96	94.3	16,558.35	1.56			3.70	9.41	-22.17	19.47
1	48 58.65	125 08.96	94.3	16,558.35	1.56			2.98	9.36	-22.14	18.97
2	48 59.80	125 00.24	77	1,155.70				2.92	20.51	-24.91	65.25
2	48 59.80	125 00.24	77	1,155.70				1.33	15.18	-23.69	44.91
3	49 00.79	125 02.59	59	600.33				8.09	15.27	-24.01	50.10
3	50 00.79	126 02.59	59	600.33				7.59	13.84	-23.68	44.66
4	49 02.6255	125 09.0156	202	2,333.87	1.88			4.68	11.78	-23.04	34.01
5	49 04.27	125 09.43	121.6	6,263.12				5.55	13.75	-24.05	50.89
5	49 04.27	125 09.43	121.6	6,263.12				5.57	13.84	-24.13	52.23
6	48 54.93	125°12.14'	101	24,714.18	-0.06			2.32	9.41	-22.21	20.16
6	48°54.93'	125°12.14'	101	24,714.18	-0.06			2.32	9.38	-22.28	21.26
7	48°59.04'	125°10.43'	95	13,655.31	5.25	0.47	0.35	3.17	9.99	-22.08	17.93
8	48 59.03	125 10.42	93.6	10,429.20				4.21	10.90	-22.25	20.83
9	49 01.19	125 09.4	117	5,729.32		0.49	0.27	4.26	10.76	-22.30	21.71
10	49 00.36	125 10.70	85.9	8,890.73		0.11	0.01	3.00	12.17	-22.67	27.87
10	49 00.36	125 10.70	85.9	8,890.73		0.11	0.01	2.45	13.36	-23.17	36.09
11	48 59.76	125 11.31	88.9	10,907.99		-0.13	0.04	3.38	9.84	-21.90	15.03
LB 1	49N 02 57.23	125 08 49.86	101	2,284.98	10.57			8.10	21.25	-25.53	75.51
LB 2	49N 02 52.74	125 08 26.27	52	3,037.90				0.99	18.18	-24.97	66.12
LB 3	49N 03 15.90	125 08 56.60	105	2,078.75				6.89	22.74	-25.46	74.30
LB 4	49N 03 12.56	125 09 08.32	60	226.23				5.68	18.90	-24.61	60.16
LB 5	49N 03 05.49	125 09 27.94	26	751.49							
LB 6	49N 03 05.06	125 09 07.48	194	1,716.50	-0.83			7.54	22.28	-25.45	74.16

ranging from 1.33 wt%C to 8.08 wt%C. The δ^{13}C values of these stations ranged from -23.68 ‰ to -24.91 ‰. The δ^{15}N values ranged from 6.02 ‰ to 6.61 ‰. Weight percent nitrogen ranged from 0.10 wt%N to 0.64 wt%N.

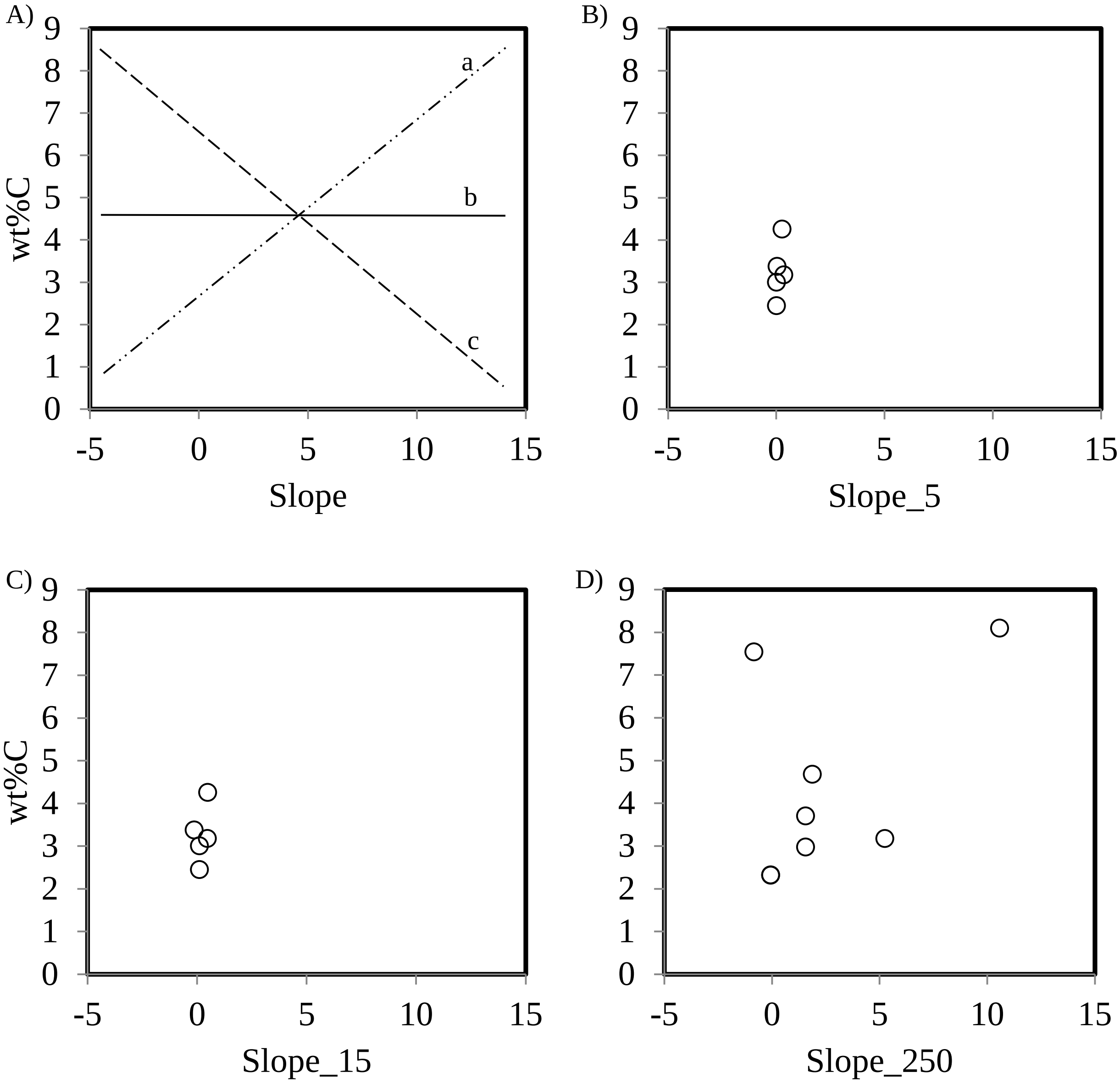

Figure 2. Comparison of bathymetric slopes with the weight percent of carbon in Effingham Inlet, Uchucklesit Inlet, and Imperial Eagle Channel. The ideal distribution (panel A) depicts the slope where carbon is distributed evenly and sediment pools in bathymetric lows (line a), where carbon and sediment are distributed together (line b), and where carbon flows downhill better than sediment (line c). The results of the slope with the weight percent of carbon at 5 m (panel B), 15 m (panel C), and 250 m resolution (panel D).

DISCUSSION

Bathymetric Positioning Index

The data related to the prediction that bathymetric lows would contain higher concentrations of POC due to sediment pooling was inconclusive. There was not sufficient coverage from the bathymetric surveys to accurately correlate carbon and BPI. This was due to a lack of stations covered by the bathymetric surveys to accurately correlate carbon and BPI. In a study done by Kehrl et al. (2011) it was found that sediment minimums were located on bathymetric highs and downslope from those highs were regions of sediment maximums. The majority of the stations surveyed had indications of bathymetric highs (Fig. 2); the lack of bathymetric lows made drawing a comparison between this study and the Kehrl et al. study difficult. Station 7 was the only station covered at all resolutions and showed highly variable slopes depending on the resolution (Table 1). Station 11 also showed different BPI values depending on the resolution. At the 5 m resolution Station 11 showed a bathymetric high and the 15 m resolution showed a bathymetric low (Fig. 2). Reasons for this variability could be attributed to human error, resolution, and relative bathymetric high and low versus the global high or low of the basin. The mean was calculated by eight pixels surrounding the location of the station, although this did not guarantee that the location of those eight points were consistent in proximity to the station. Since the pixel dimensions increased in size with lower resolution, the mean from the pixels would have been calculated from a greater range of the values (Table 1). The finer resolution may have picked up to a relative bathymetric high within a bathymetric low. Different resolutions resulted in different bathymetric slopes. If I were to do this differently, I would have made sure that all of my stations were covered by the bathymetric survey lines to create a fuller picture of the correlation between these two variables

Carbon

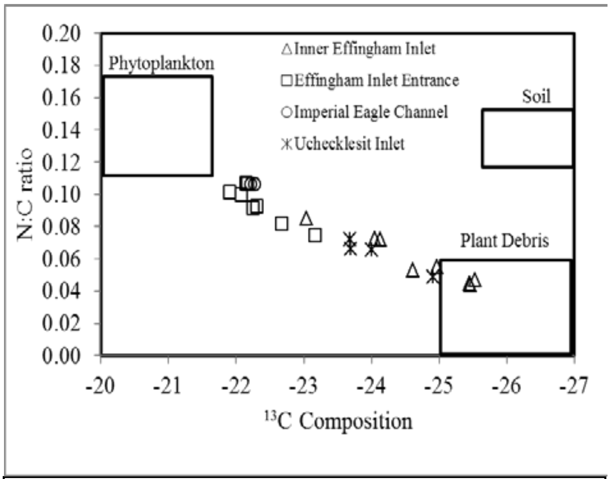

Figure 3. A N:C ratio vs. ^{13}C Composition mixing diagram of the stations within Barkley Sound. Boxes indicate regions of phytoplankton, soil, and plant debris signatures.

Carbon 13 (^{13}C) can be used for the identification of the carbon source. Generally the ^{13}C signature of plankton is roughly -21 ‰ (Keil et al. 1994) and plant debris (C3) has a ^{13}C signature of roughly -29 ‰ (Kramer and Gleixner 2008). The stations show a wide distribution between plankton organic matter and plant organic matter. Carbon appears to be well mixed between phytoplankton and plant debris sources (Fig. 3). This relationship is similar to previous findings in fjord environments (Walsh et al. 2008). Soil signatures were not present likely due to the fact that Effingham Inlet is a low runoff fjord and the forests along the periphery of the basins grow on very little soil. In a study by Nuwer and Keil (2005), soil signatures in Clayoquot Sound were related to a high degree of soil organic matter replacement, despite low sedimentation rates. It is reasonable to hypothesize that Effingham Inlet does not have a similar degree of soil organic matter replacement due to the lack of soil in all samples.

Five of the stations with the highest carbon content and strong plant debris signal were found in the upper portion of the inner Effingham Inlet (Fig. 4). Reasons for the strong conifer signals would be because there are conifer forests bordering the entire region, and 15 years ago the western portion bordering the inner Effingham

Inlet was logged (Kumar and Patterson 2002). The debris from the logging would have been carried off by the river that feeds the northwestern portion of the outer basin. Despite the length of time since the logging it is likely that the carbon has yet to be flushed out very far from the source. In Effingham Inlet the circulation of bottom waters are inhibited from mixing with the open ocean (Kumar and Patterson 2002). Essentially Effingham Inlet is a large sediment trap with relatively high sedimentation rates (Kumar and Patterson 2002). Similar findings were made in an inlet north of Barkley Sound by Nuwer and Keil (2005) that the greatest amount of terrestrial organic carbon preservation occurs in close proximity to the fjord heads where fluvial sediment is rapidly buried, resulting in the preservation of debris.

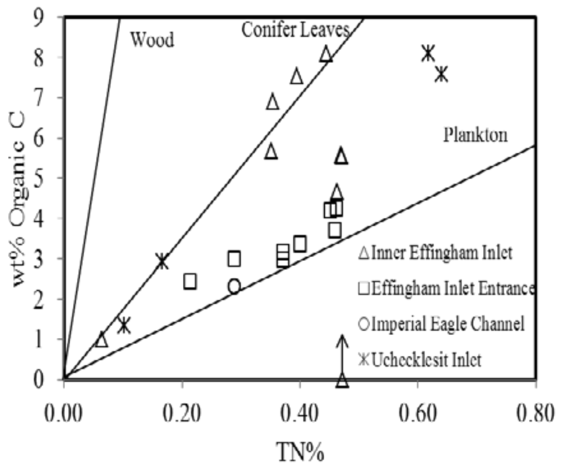

Figure 4. The weight percentage of organic carbon vs. the weight percentage of nitrogen. Lines of comparison from C:N ratio show wood, conifer leaves, and plankton signaling.

Effingham Inlet entrance stations showed a mix of marine and terrestrial source; though it appears that there was a slightly higher marine origin than terrestrial compared to the inner inlet (Fig. 4). The stations in the inlet entrance are further away from river inputs and closer to the ocean. The Imperial Eagle Channel station had strong marine plankton signaling likely due to the close proximity to the ocean and its distance away from any freshwater input (Fig. 4). In Uchucklesit Inlet, Station 3 was very high in carbon and showed a combination of terrestrial and marine input (Fig. 4). It appears that area has experienced logging recently this year (May 13, https://maps.google.com, Province of British Columbia). Station 2 had less carbon weight percentage but a stronger signaling from conifer leaves (Fig. 4).

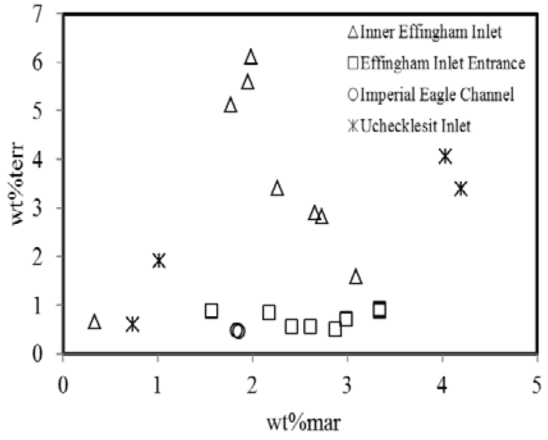

Figure 5. Comparison of weight percent of marine and terrestrial content in carbon.

There appeared to be multiple factors that controlled the weight percentages of both nitrogen and carbon (Fig. 5). In previous study by Keil et al. (1994), it was found that oxygen was a primary factor to increased organic carbon preservation. My findings do not support findings from the 1994 study. Out of the 16 stations, only Station 5 was in anoxic waters. Despite the anoxic sediment at this location the carbon and nitrogen percentages were not necessarily higher than the other stations in Effingham Inlet (Fig. 5). The findings of this study suggests that the terrestrial input is higher in stations closer to rivers such as the stations within the inner Effingham Inlet than stations further from river sources like Station 6 at Imperial Eagle Channel (Fig. 5). Although this is true in a qualitative sense, it has not been consistently true quantitatively.

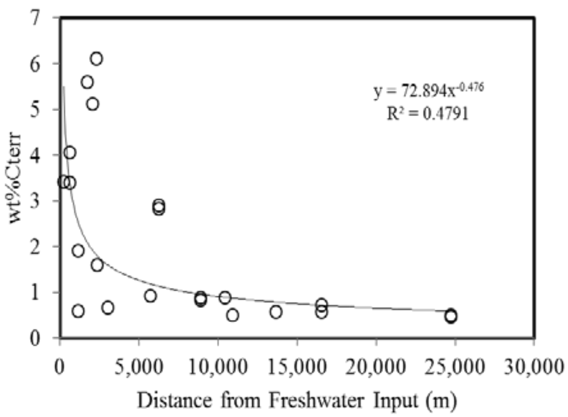

Figure 6. The weight percent of organic carbon from terrestrial source with distance (m) from freshwater inputs.

There is a positive correlation between the terrestrial weight percentage of carbon and distance from a freshwater source (Fig. 6). This supports the observation that circulation of the bottom waters in the inlets are weak and that carbon does not move too far away from source. The R^2 value of 0.48 indicates a weak correlation. The station that appears not to follow this trend may be closer to a freshwater input than was previously measured. Station 5 was measured by its proximity to the Effingham River which may not be the closest freshwater input for the station. If this is the case there should be a stronger correlation indicated by the R^2 value. Additionally Station 5 is in an anoxic region. Past studies have found that anoxic bottom water enhances organic matter preservation in marine sediments (Hartnet et al. 1998; Keil and Cowie 1999; Nuwer and Keil 2005). Although the concentrations of organic carbon were not higher than regions where the water was oxic; Station 5 does have higher carbon content than the trend followed by the other stations when comparing with distance from freshwater inputs.

CONCLUSIONS

Barkley Sound is a complex environment for carbon distribution. The comparison of carbon abundance with bathymetry was inconclusive in identifying regions of carbon pooling. The poor circulation of bottom waters in the basins is evident from the correlation between weight percent terrestrial carbon and distance from freshwater inputs. Stations with the highest amount of carbon were in the Inner Effingham Inlet and Uchucklesit Inlet, which both had strong ^{13}C signaling of conifer leaves source.

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REFERENCE LIST

Anderson, C. 2012. Reconstructing paleoceanographic oxygen conditions in the Soledad Basin, Mexico. http://hdl.handle.net/1773/20472.

Berner, R. A. 1989. Biogeochemical cycles of carbon and sulfur and their effect on atmospheric oxygen over Phanerozoic time. Palaeogeogr. Palaeclimatol. Palaeoccol. **73**: 97-122.

Cox, P. M., R. A. Betts, C. D. Jones, S. A. Spall, and I. J. Totterdell. 2000. Acceleration of global warming due to carbon-cycle feedbacks in a coupled climate model. Oceanogr. **408**: 184-187.

Dallimore, A., R. E. Thomson, and M. A. Bertram, 2005. Modern to late Holocene deposition in an anoxic fjord on the west coast of Canada: Implications for regional oceanography, climate and paleoseismic history. Mar. Geol. **219**: 47-69.

Hartnett, H. E., R. G. Keil, J. I. Hedges, and A. H. Devol. 1998. Influence of oxygen exposure time on organic carbon preservation in continental margin sediments. Nature. **391:** 572-574.

Hay, M. B., S. E. Calvert, R. Pienitz, A. Dallimore, R. E. Thomson, and T. R. Baumgartner. 2008. Geochemical and diatom signatures of bottom water renewal events in Effingham Inlet, British Columbia. Mar. Geol. **262**: 50-61.

Hedges, J. I., and R. G. Keil. 1995. Sedimentary organic matter preservation: an assessment and speculative synthesis. Mar. Chem. **49**: 81-115.

Honjo, S., S. J. Manganini, R. A. Krishfield, and R. Francois. 2008. Particulate organic carbon fluxes to the ocean interior and factors controlling the biological pump a synthesis of global sediment trap programs since 1983. Oceanogr. **76**: 217-285.

Ingall, E., L. Kolowith, T. Lyons, and M. Hurtgen. 2005. Sediment carbon, nitrogen and phosphorus cycling in an anoxic fjord, Effingham inlet, British Columbia. Science. **305**: 240-258.

Kehrl, L. M., R. L. Hawley, R. D. Powell, and J. Brigham-Grette. 2011. Glacimarine sedimentation processes at Kronebreen and Kongsvegen, Svalbard. Glaciol. **57**: 841-846.

Keil, R. G., E. Tsamakis, C. B. Fuh, J. C. Giddings, and J. I. Hedges. 1994. Mineralogical and textural controls on the organic composition of coastal marine sediments: Hydrodynamic separation using SPLITT- fractionation. Geochim. Cosmochim. **58**: 879-893.

Keil, R. G., and G. L. Cowie. 1999. Organic matter preservation through the oxygen-deficient zone of the NE Arabian Sea as discerned by organic carbon: mineral surface area ratios. Mar. Geol. **161:** 13-22.

Komada, T., M. R. Anderson, and C. L. Dorfmeier. 2008. Carbonate removal from coastal sediments for the determination of organic carbon and its isotopic signatures, delta C-13 and Delta C-14: comparison of fumigation and direct acidification by hydrochloric acid. Limnol. Oceanogr. **6**: 254-262.

Kramer, C., and G. Gleixner. 2008. Soil organic matter in soil depth profiles: distinct carbon preferences of microbial groups during carbon transformation. Soil Bio. Biochem. **40**: 425-433.

Kumar, A., R. T. Patterson. 2002. Dinoflagellate cyst assemblages from Effingham Inlet, Vancouver Island, British Columbia, Canada. Palaeogeogr. Palaeclimatol. Palaeoccol. **180**: 187-206.

Lundblad, E. R., D. J. Wright, J. Miller, E. M. Larkin, R. Rinehart, D. F. Naar, T. Battista, D.F. Naar, B. T. Donahue, and S. M. Anderson. 2006. Classifying benthic terrains with multibeam bathymetry, bathymetric position and rugosity: Tutuila, American Samoa. Mar. Geol. 2-20.

Lundblad, E. R., D. J. Wright, J. Miller, E. M. Larkin, R. Rinehart, D. F. Naar, B. T. Banahue, S. M. Anderson, and T. Battista. 2006. A benthic terrain classification scheme for American Samoa. Mar. Geol. **29**: 89-111.

McFarlane, G.A., D.M. Ware, R.E. Thomson, D.L. Mackas, and C.L.K. Robinson. 1997. Physical, biological and fisheries oceanography of a large ecosystem (west coast of Vancouver Island) and implications for management. Oceanol. Acta. **20**: 191-200.

Nuwer, J. M., and R. G. Keil. 2005. Sedimentary organic matter geochemistry of Clayoquot Sound, Vancouver Island, British Columbia. Limno. Oceanogr. **50**: 119-1128.

Patterson, R. T., J. P. Guilbault, and R. E. Thomson. 2000. Oxygen level control on foraminiferal distribution in Effingham Inlet, Vancouver Island, British Columbia. J. Foraminiferal Res. **30**: 321-335.

Pickard, G. L. 1963. Oceanographic characteristics of inlets of Vancouver Island, British Columbia. J. Fish. Res. Board Can. **20**: 1109-1144.

Post, W. M., T. Peng, W. R. Emanuel, A. W. King, V. H. Dale, and D. L. DeAngelis. 1990. The Global Carbon Cycle. Am. J. Sci. **78**: 310-324.

Sarmiento, J., T. Hughes, R. Stouffer, and S. Manabe. 1998. Simulated response of the ocean carbon cycle to anthropogenic climate warming. Nature. **393**: 245-249.

Snelgrove, P. V. R. 1997. The importance of marine sediment biodiversity in ecosystem processes. Ambio. **26**: 578-583.