2021 Particle Grain-Size and Total Organic Content Analyses of Surface Sediments from Puget Sound and Elliott Bay near Seattle, WA

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Abstract:	Seattle's Elliott Bay has been a particularly intriguing area in regards to anthropological activities and their effects on the surrounding environment. The construction of the city brought about the displacement of sediment around the bay, resulting in lower quality sediments that negatively impact the nutrient cycles in the benthic zone. This project's examination of total organic carbon and particle size in sediment serves as a baseline to which scientists can refer in monitoring future sediment health. To determine this baseline, UW Tacoma obtained sediment samples from Washington State Department of Ecology's Puget Sound Ecosystem Monitoring Program. The samples were analyzed in the lab with a Beckman-Coulter Particle Size Analyzer for sediment grain size, while the total organic content was found by the loss on ignition technique. Overall, the larger TOCs were found to correlate with smaller particle sizes. The particle size data from Elliott Bay indicates that the site ranges from sand to sandy silt. A few of the sites also had clayey silt sediments. Follow-up studies should be completed periodically to provide continuous monitoring of this bay. Any disturbances should be considered and provided to interested stakeholders.
Key Words:	Total organic content, particle size, Elliott Bay, sediment health, Puget Sound
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This research paper used data collected by the PSEMP Project from the Washington State Department of Ecology at the 37 sampling sites around Seattle's Elliott Bay. In addition to the particle sizes and total organic contents analyzed in this paper, other student researchers were able to collect and analyze data on microplastics and *Alexandrium* cysts. Combined, these projects will establish baseline sediment data for these specific sites that should reflect future transitions in the environment of Elliott Bay. I would like to thank Julie Masura for allowing me to take on this project and for providing guidance for these efforts. I would also like to thank my classmates Zoe Manuel and Gary Livingston for their support during this research project.

Introduction

Following the increasing population in the Puget Sound, various forms of pollution have been on the rise, from carbon dioxide levels in the air to nitrogen deposition in soil (Tilman and Lehman 2001). Sediment quality has decreased from its historic levels, sparking concern about the heath of the various ecosystems (Tilman and Lehman 2001). The analysis of sediment characteristics around the Puget Sound reveals health of the environments through detecting patterns indicative of anthropogenic interference. Doing so allows for the creation of policy changes that are able to better prevent environmental damage. These sediments are crucial for the nutrient cycles that occur in the benthic zone. In 2018, the Puget Sound Ecosystem Monitoring Program recognized total organic carbon (TOC) counts as a significant measurement standard because of its "determination of organic composition and quality in sediments" and "lability and availability of nutrients to benthos" (Dutch et al. 2018). Particle size analysis (PSA) in sediment represents a physical characteristic of the sediment instead of serving as an indicator of a sediment's biochemical health. A ternary plot indicating the relative grain sizes of each sample site is included in the results. These findings will be compared to the ternary plot produced from Dick Sternberg's Puget Sound sediment data from 1988 to 2004. This may indicate new habitat changes brought on by recent developments. Seattle's Elliott Bay in particular has experienced a marked change in its environment through industries such as shipbuilding, lumbering, and trade (Frantilla c1995-2021). The city even recognized a historic habit of dumping garbage into the Puget Sound in the beginning of the 19th century (Long 2001). To monitor the progression of ecological impact, this study focused on acquiring and analyzing Elliott Bay's physical sediment characteristics.

One of the earliest studies that analyzed TOC and PSA within the Central Basin of the Puget Sound was conducted in 1991 by the NOAA's National Status and Trends Program (fig. 1). In its quest to "continue monitoring historical trends in the concentrations of contaminants in Puget Sound sediments", NOAA's study focused on the chemical composition of sediments. Various concentrations of contaminants including lead and DDT were analyzed and found to be on a "trend toward recovery" (Lefkovitz et al. 1997). The particle sizes of the stations were found to have a range from 42-51% silt and 45-49% clay. Sand concentrations were much lower, ranging from 4% to 18%. TOC found by combustion method ranged from 1.37% to 2.26%, for which the total organic content was taken as a percentage of dry weight. The authors concluded that "no natural or other disturbances that would affect sediment type occurred within the 200-year time frame". However, only three of the six sampling locations were investigated for TOC and PSA (fig. 1). Similarly, only one site (indicated as Core 3) was near what could broadly be considered Elliott Bay. The TOC for that site ranged from 1.51% - 2.14% taken at 22 different sediment depths from 2 cm to 188 cm. PSA analysis found that the site was composed of 51% silt (particles sized from 0.0625 mm to 0.004 mm) and 45% clay (particles smaller than 0.004 mm). Due to the emphasis on chemical composition and the dearth of sampling locations within Elliott Bay, this study did not provide enough information to compare with the sediments near Seattle.

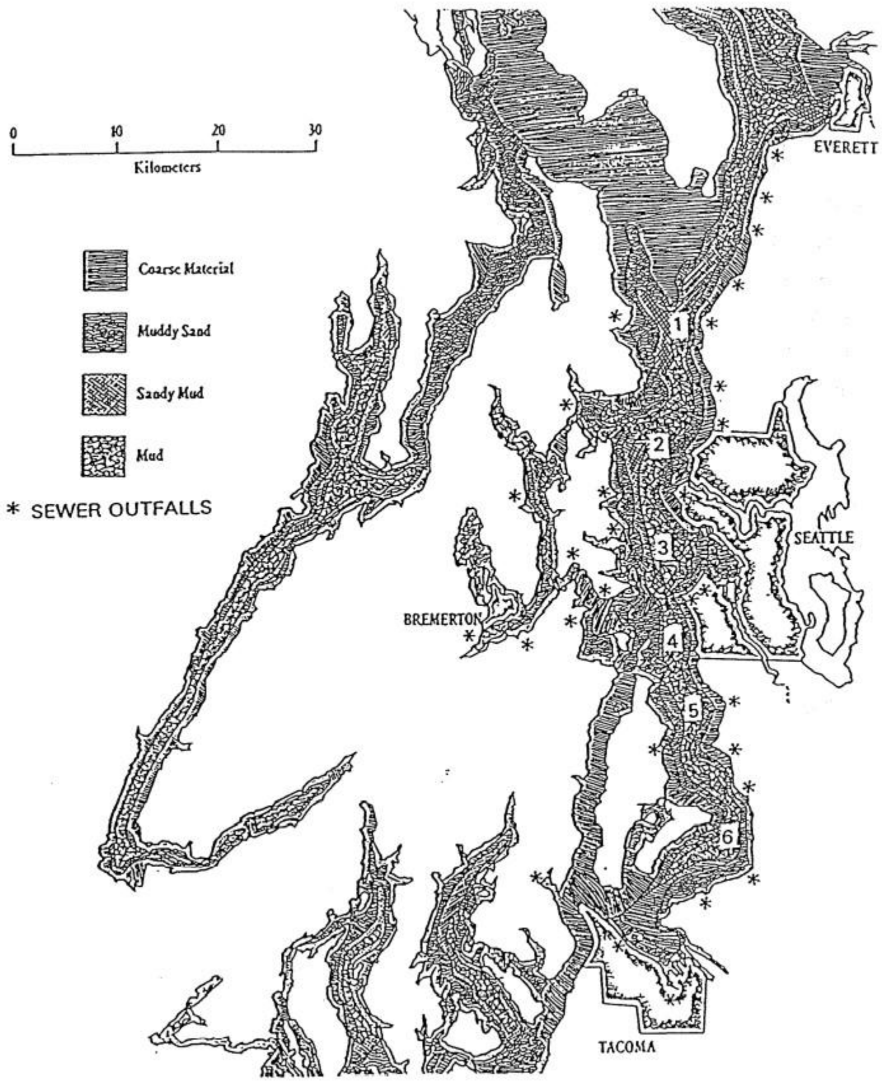

Figure 1. Map of sampling locations (Lefkovitz et al. 1997).

In 2012, Jack Rensel analyzed particle size and total organic carbon content in Deepwater Bay, Cypress Island on behalf of the Washington Department of Ecology and American Gold Seafoods. The island is located in the north of Whidbey Basin and Admiralty Inlet and east of the San Juan Islands in the Puget Sound (fig. 2). According to this study, total organic carbon content had increased in three of the four sampling locations from surveys conducted in 2010 and 2011, ranging from 1.53% to 1.93% TOC. These were all above the mean "allowable trigger of 0.5%" (Rensel 2012). Trigger level, in this case, "refers to the NPDES [National Pollution Discharge Elimination System] sediment standards for sites without initial baseline measurements" (Rensel 2012). The silt and clay percentage of the sediment declined as compared to data from the previous two years in the same sampling locations that experienced an increase in total organic carbon content. From Rensel's 2012 study, the relationship between TOC and PSA appeared to be inversely related, with TOC percentages decreasing as particle size increases. However, the significance of either measure remained unclear in their wider implications. Furthermore, the study was conducted in stations corresponding to "net pens" used for fish farming. This environment reflects a specific use case of the Puget Sound in terms of its nutrient cycling and chemical characteristics. The data found here may be more skewed by the specific activity around which the samples were collected rather than detailing a broader representation of the Puget Sound.

Figure 2. Map indicating the central Puget Sound.

Presently, studies for the Washington Department of Ecology were conducted in Elliott Bay in three separate instances in 1998, 2007, 2013. It focused on monitoring sediment toxicity, sediment quality, and the presence of benthic organisms. The report results show that while the Triad Index (which factors in chemical composition, toxicity, and benthic life indices) demonstrated marked improvement in overall sediment quality, there was less of an emphasis on the physical characteristics of the sediment samples. TOC and PSA were conducted in each of the three instances, with the particle sizes being "predominantly sandy and mixed in the shallower stations", and more "finer-grained" in the deep stations (WSDOE 2016). TOC ranged from “0.2% to 3.3%, with a median value of 1.7%”. These numbers were similar to those collected in previous iterations of this study.

The present research will provide findings of the physical sediment characteristics with an emphasis on the importance of carbon and geological cycles in the area. Analyzing the data through this lens reveals the greater importance of TOC and PSA than previously recognized in prior research, and allows for a better illustration of anthropogenic influence on the natural processes of aquatic ecosystems.

Purpose

This study aimed to establish a baseline depiction of Elliott Bay’s sediment health using total organic content and particle size analysis. TOC analysis will create a better picture of the biochemical composition in the sediments, detailing the health of the living environment and nutrient cycles. Higher TOCs in shallow areas indicate high environmental productivity, as TOC depicts the presence of benthic life. High TOC in deep waters, meanwhile, demonstrates a lack of decomposition for organic material. This coincides with reducing environments. On the other hand, PSA demonstrates external occurrences that influence sediment composition. Energy patterns as related to the waters will be indicated by the sizes of sediment found from particle size analysis. High energy levels including heavy wave activity and other high-frequency occurrences with the potential to add new sediment into the benthic layer, resulting in coarse grain sizes. Lower energy levels in calmer areas would be indicated by finer grain sizes that have been broken down over long periods of time. The graphs of each sediment sample would also include relevant data of the site’s background. Bell curves on the sediment graphs show constant energy conditions while multimodal graphs represent variable energy conditions such as storms, dumping, or landslides (fig. 3 and fig. 4). The results of this study will form the basis behind requests for policy change in the future should conditions with sediment deteriorate in the future.

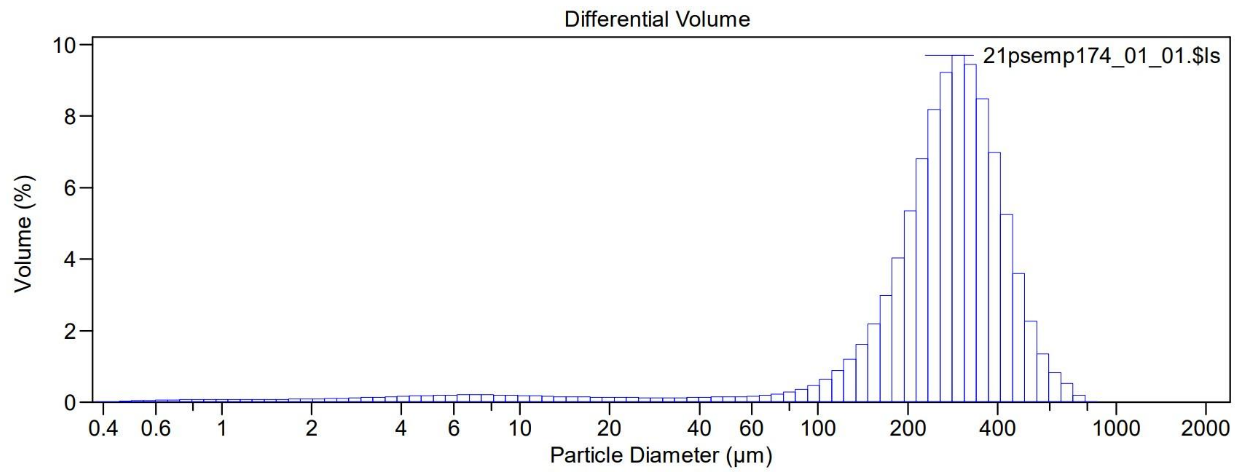

Figure 3. Bell curve with larger particle sizes.

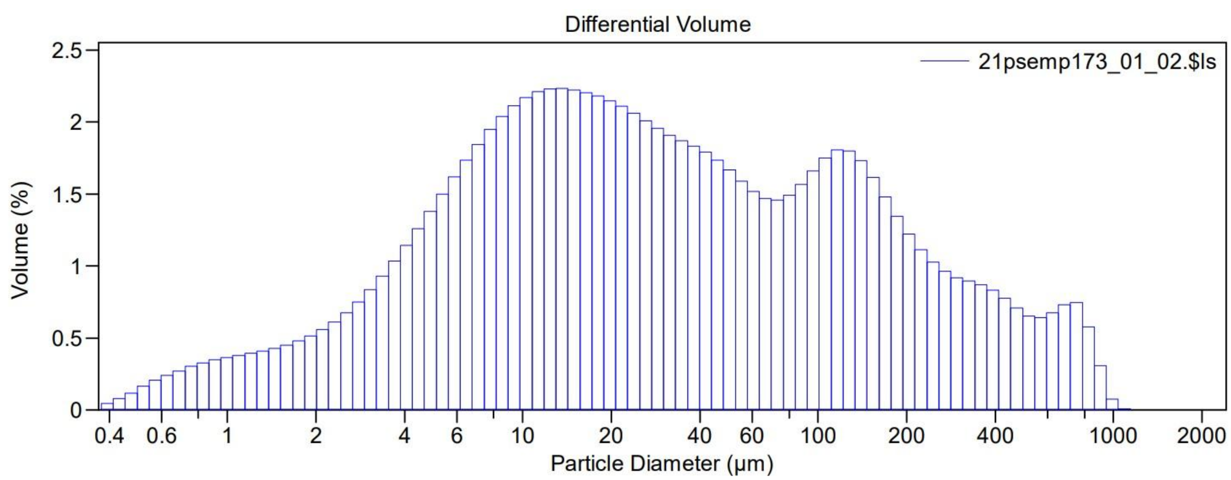

Figure 4. Multimodal graph with varying particle sizes.

Methods

Sampling

Samples were collected at 37 different locations around Elliott Bay in Seattle, WA by the Washington Department of Ecology PSEMP program. The approximate location of each sample is depicted on the map (fig. 5). A van Veen sediment grab sampler was used to extract sediment samples from the seafloor. The samples were inserted into Ziploc bags and stored at 4℃ in the dark. The samples were then shipped to the University of Washington Tacoma to be analyzed for total organic content (TOC) and particle size analysis (PSA).

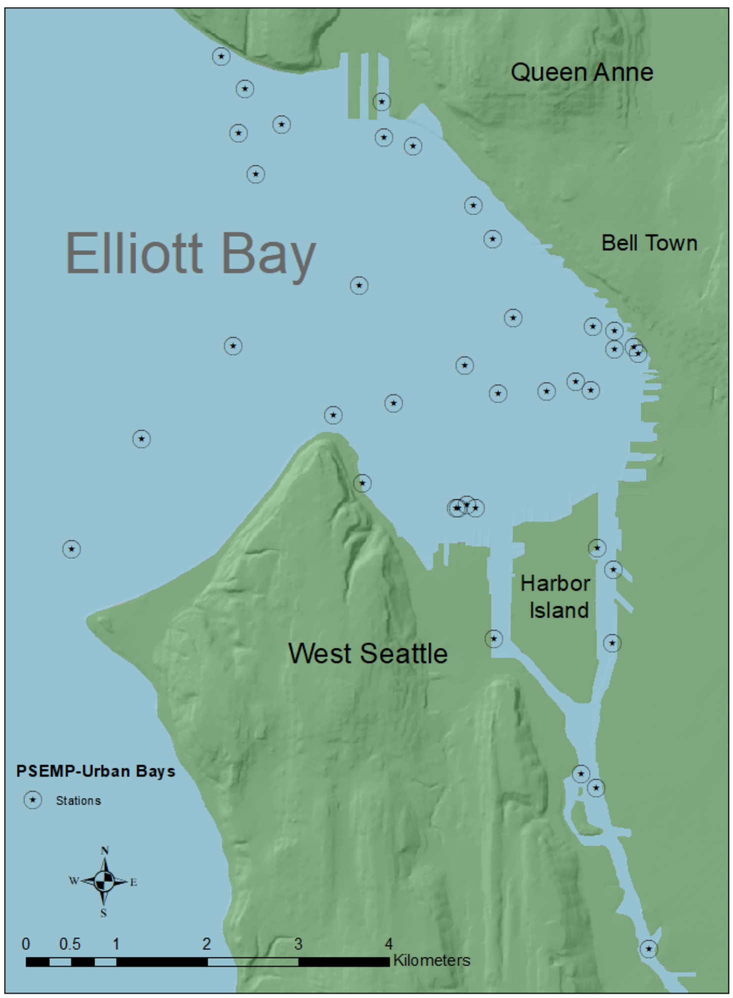

Figure 5. Map of sample sites around Elliott Bay in Washington. Each number corresponds to one sample.

Laboratory Analysis

To determine the TOC, the loss on ignition technique was used. After mixing the sediment samples, 5 mL was subsampled and weighed to measure the wet mass. The dry mass was determined after placing the sample in a drying oven at 150℃ for five hours. To obtain the ash mass, the dried sample was placed in the oven at 650℃ for eight hours. The weight of the carbon was found by subtracting the ash mass from the dry mass.

A Beckman-Coulter LS 13 320 Laser Diffractometer was used to conduct the PSA. After thoroughly mixing the sample, the subsample was placed into a beaker of water and stirred using a stir plate. A pipette was used to place the material into the diffractometer until a 10% critical obscuration was reached. The analysis conducted by instrument was based on the angle of the laser that diffracted off of individual sediment grains. The results were exported into files for analysis.

Data Analysis

For the TOC, the three masses of concern were the wet mass, dry mass, and carbon mass. The carbon mass was burnt off in the oven in the second heating cycle. This mass can be divided by the dry masses to obtain the fraction of carbon in each sample. Dividing the carbon mass by wet sediment mass yielded a more spatially-accurate distribution of carbon content. A high carbon mass correlated to high levels of organic matter in the sediment. Greater levels of organic matter may indicate effects of climate change.

Dry Total Organic Carbon: $(Mass_{Dry} - Mass_{Ash})/Mass_{Dry} \times 100\%$

Wet Total Organic Carbon: $(Mass_{Dry} - Mass_{Ash})/Mass_{Wet} \times 100\%$

In determining PSA, the diffractometer illustrated the frequency of particles at specific sizes ranging from 0.4µm to 2000µm, which were later categorized into sand, silt, and clay by Wentworth particle size classes. The sand sediments (125 µm to 2000 µm) with larger sizes correlate to high energy environments while the finer particles such as silt (8 µm to 63 µm) and clay (0.4 µm to 4 µm) correlate to low-energy conditions. A bell curve on the analysis indicated constant energy conditions, while multimodal graphs were indicative of variable energy conditions such as storms or dumping (fig. 3 and fig. 4).

Results

The wet TOC provides a better sense of the spatial characteristics of the sediment compared to dry TOC. Results for wet TOC data ranged from 1.021% to 4.642% carbon, while dry TOC ranged from 1.246% to 11.013% carbon (table 1). For the wet TOC, the mean value was 2.755% and the median value was 2.797% (table 2). For the dry TOC, the mean value was 5.550% and the median value was 4.407%. No significant outliers for neither wet nor dry TOC were present. Fig. 6 indicates the location of each site and its relative wet TOC. Fig. 7 indicates the location of each site and its relative dry TOC.

Table 1. Wet and dry masses and carbon percentages for each sampling site in Elliott Bay.

Sample Site	Wet Weight	Dry Weight	Percent Content (wet)	Percent Content (dry)
114	6.5876	3.0614	3.205	6.896
115	8.0082	5.5795	2.072	2.973
172	5.7763	1.6986	3.132	10.650
173	5.8575	1.9285	2.868	8.711
174	9.0872	6.8339	1.687	2.243
175	8.5996	6.0919	2.529	3.570
176	8.7529	6.6288	1.352	1.785
177	9.5471	7.4065	1.021	1.316
178	8.8058	7.3097	1.035	1.246
179	8.1608	5.3014	1.728	2.660
180	9.4037	6.8959	1.938	2.642
181	8.2972	5.1376	2.729	4.407
182	7.4753	4.0831	3.937	7.208
183	8.4459	5.7302	2.990	4.406
184	9.4057	6.9241	2.538	3.447
185	5.7778	1.7584	3.115	10.237
186	7.0253	4.0662	2.515	4.346
187	6.5515	2.2708	3.256	9.393
188	7.1364	3.5271	3.940	7.973
189	8.4648	6.0686	1.819	2.538
190	8.4937	6.366	1.170	1.561
191	7.3675	3.4189	2.797	6.028
192	8.696	5.8486	2.346	3.488
193	6.4392	2.8317	3.612	8.214
194	5.9084	2.0333	3.025	8.789
195	6.4743	2.9959	3.140	6.786
196	5.1025	2.1172	3.508	8.455
197	7.6115	4.9171	3.991	6.178
198	9.6891	6.9576	1.851	2.577
199	9.1279	6.2051	2.710	3.987
200	8.6752	5.507	2.411	3.799
201	8.1683	4.9471	3.025	4.995
202	6.5531	2.5129	3.806	9.925
203	6.7689	2.879	4.207	9.892
204	7.3897	3.8426	4.459	8.575
205	6.6395	2.7984	4.642	11.013
40496	10.1598	7.5191	1.814	2.451

Table 2. Mean, median, minimum, and maximum values of total organic content

Total Organic Content Type	Minimum Value	Maximum value	Median value	Mean value
Wet	1.021	4.642	2.797	2.775
Dry	1.246	11.013	4.407	5.550

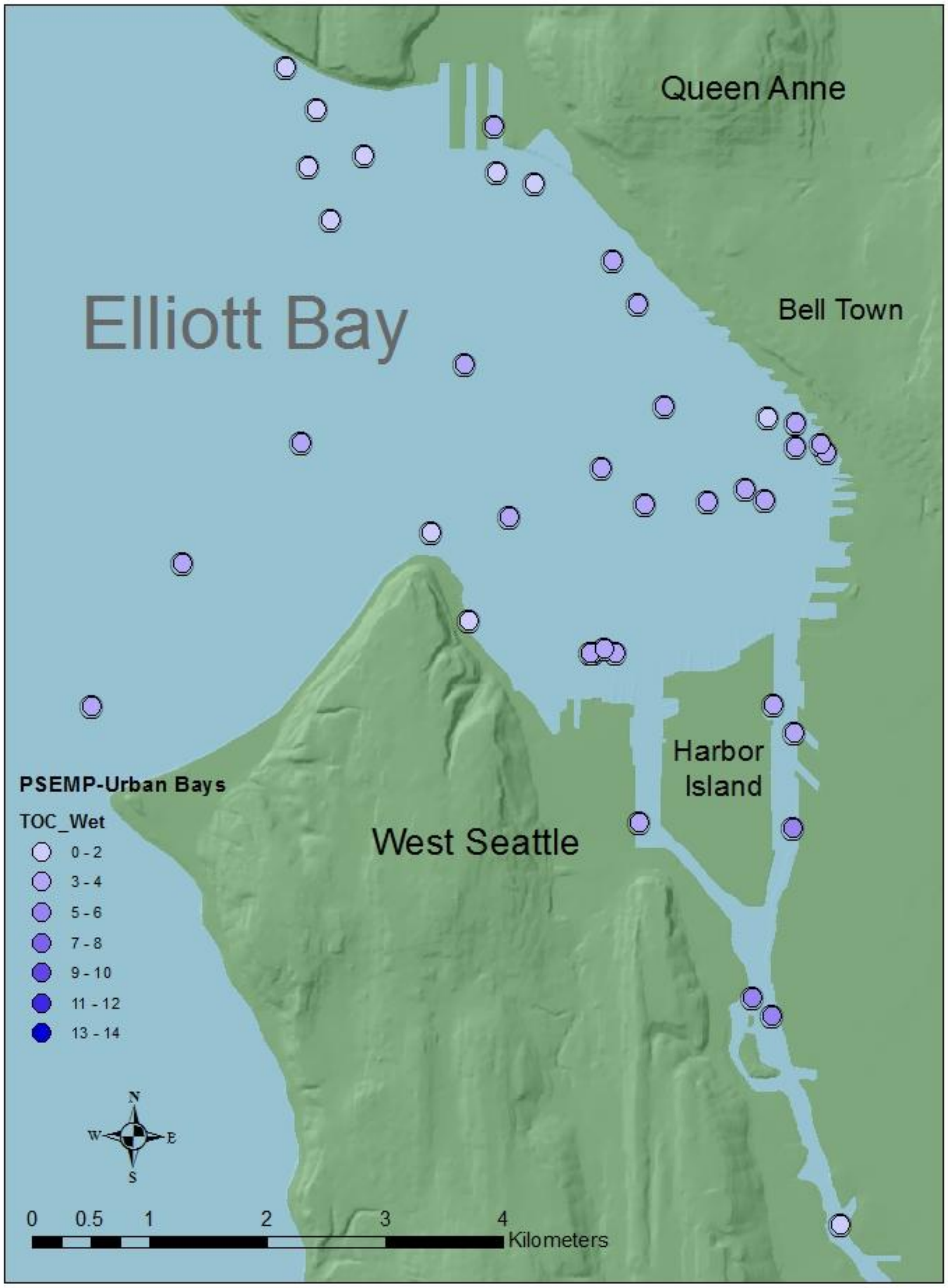

Figure 6. Wet Total Organic Content of sample sites.

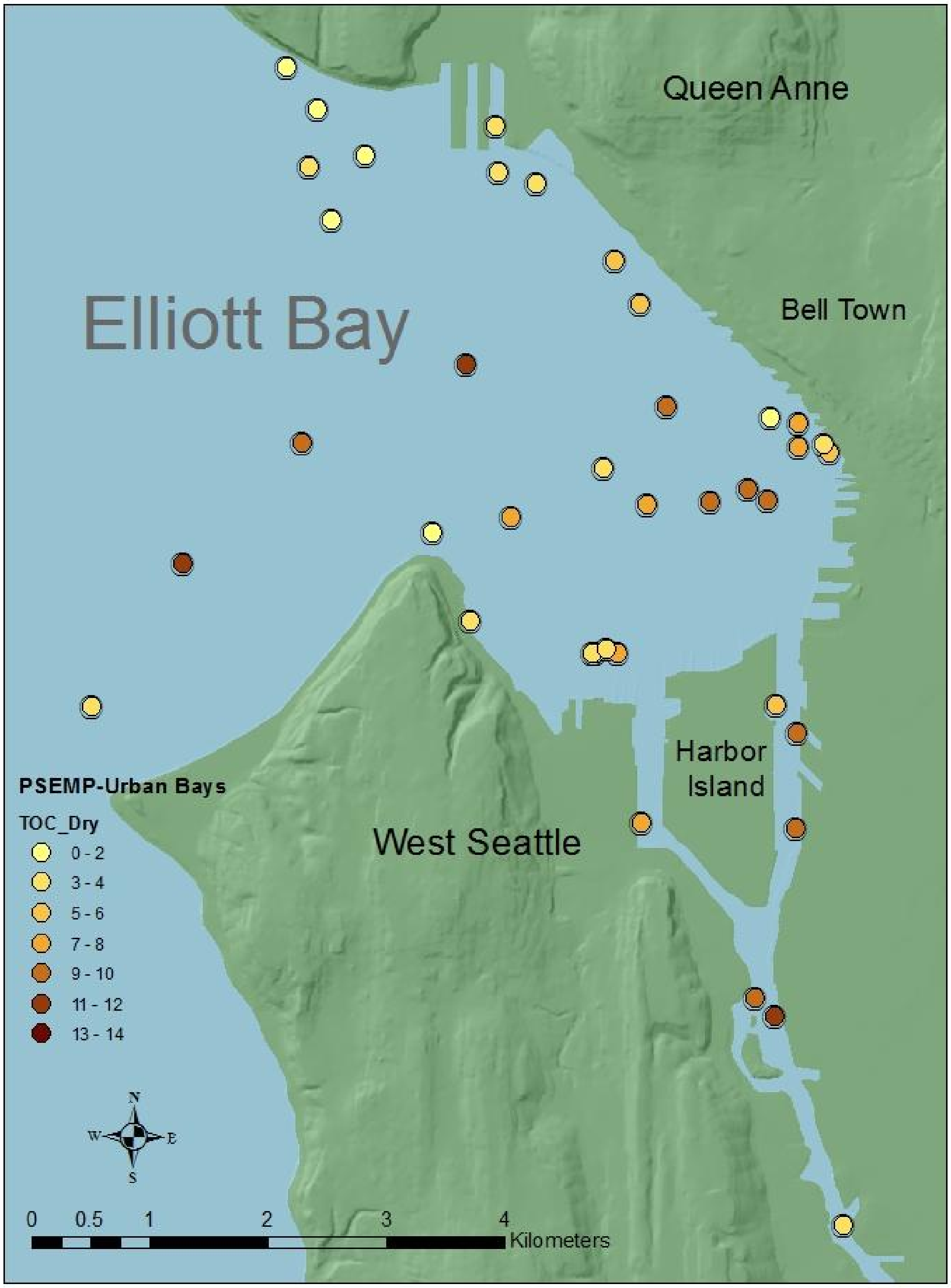

Figure 7. Dry Total Organic Content of sample sites.

PSA was diagrammed via ternary plot and was used to indicate the sediment composition of each site according to the percentage of particle sizes that were categorized into sand, silt and clay by the Wentworth size classes (fig. 8). For the ternary plot, sediments that are predominantly clay are graphed near the top center of the plot, while predominantly sandy sediments and silt sediments graph near the bottom left and bottom right of the plot, respectively. The center of the graph would represent a sediment with equal parts clay, silt, and sand. According to Shepard's ternary plot (fig. 9), data obtained via PSA methods revealed that the sites ranged from predominantly sandy sediment to silty sand or sandy silt. A few of the sites also had some clayey silt sediment.

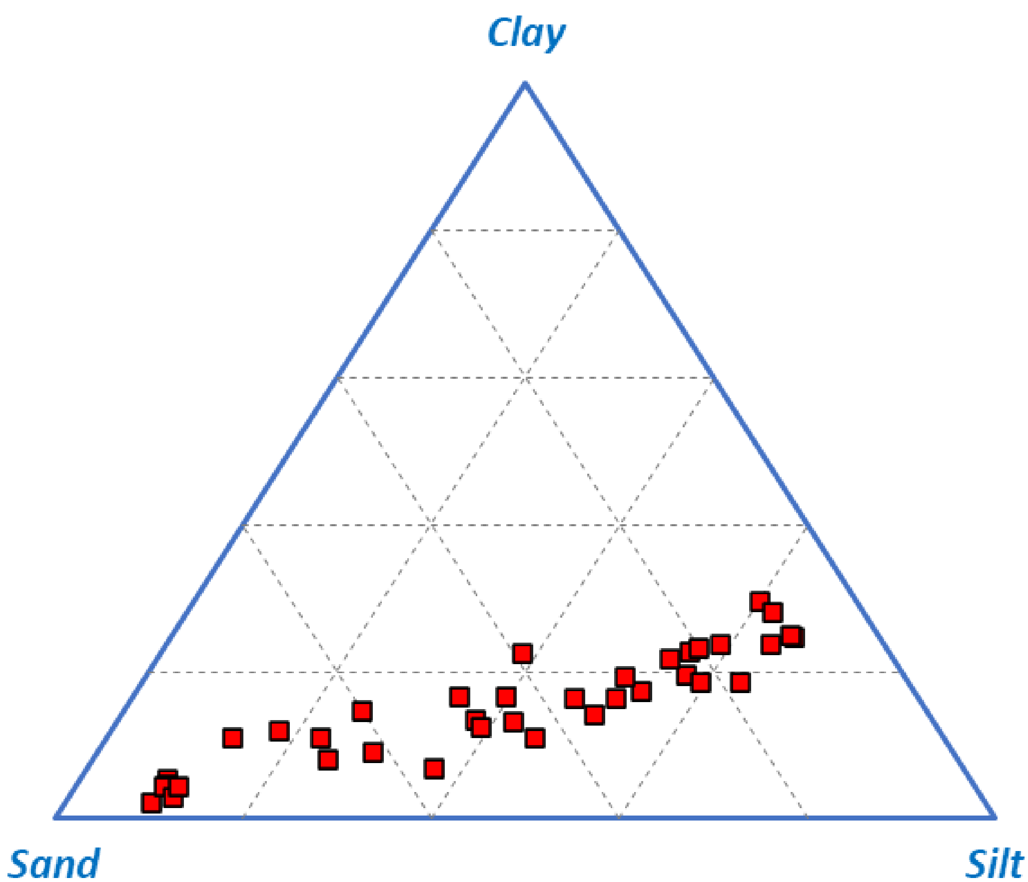

Figure 8. Ternary plot indicates the physical characteristics of sediment, as shown in Fig. 9. Sand, clay, and silt are the three categories of grain size classification. Each red square represents one sampling site.

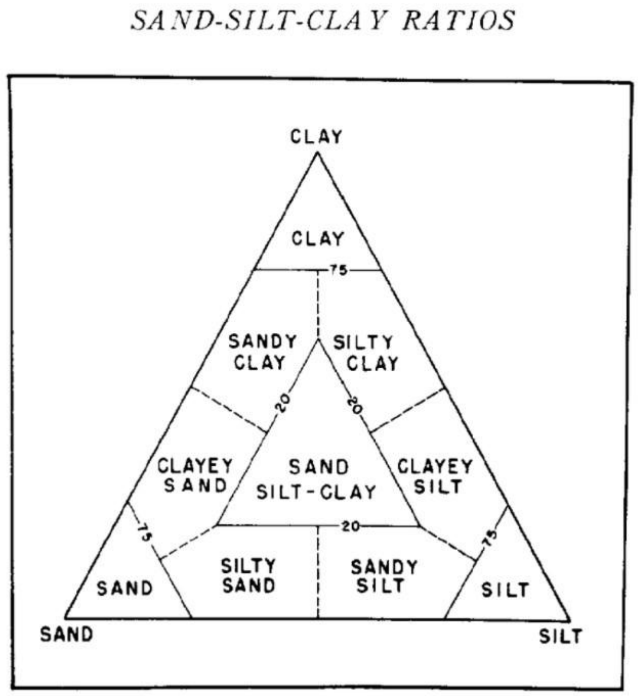

Figure 9. Ternary plot used to map particle size distribution of sample sites (Shepard 1954).

TOC and PSA data have been combined in two graphs of wet TOC and dry TOC analyzing the relationship between median grain size and total organic content of each site (fig 10 and fig. 11). A map of the median grain sizes as categorized by the Wentworth size classes is given in fig. 12 and the median grain sizes of each site are given in table 3. In fig. 10 And fig. 11, both graphs demonstrate a negative linear correlation between grain size and total organic content, in which total organic content decreases proportionally as grain size increases. The r-squared values of 0.5277 of wet TOC (fig. 10) and 0.6707 of dry TOC (fig. 11) demonstrate significant correlation between the data and the trendline.

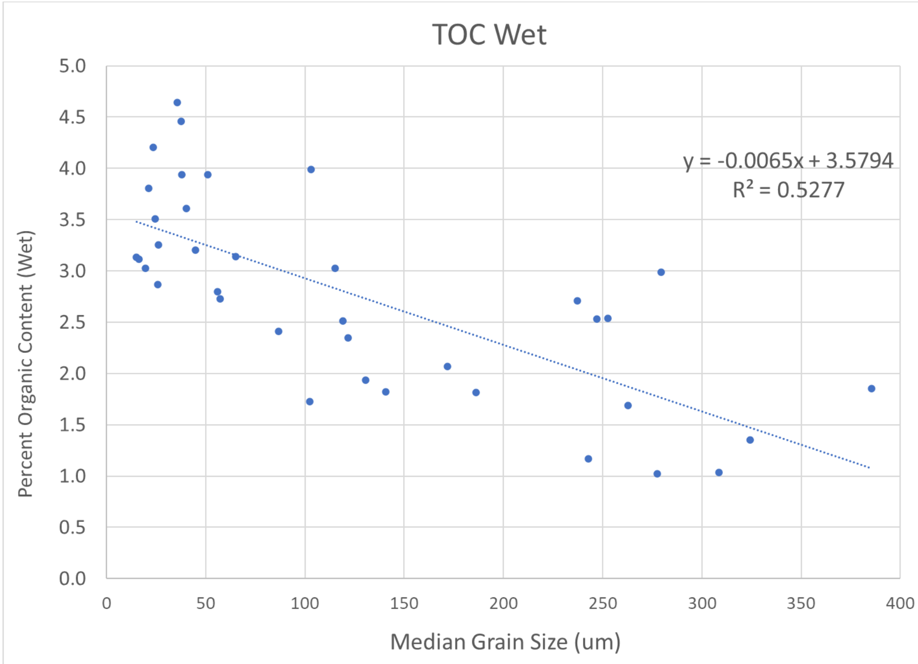

Figure 10. Wet total organic content. Percent organic content in each sediment sample as a function of median grain size of the dried sample. Each blue dot represents one sampling site.

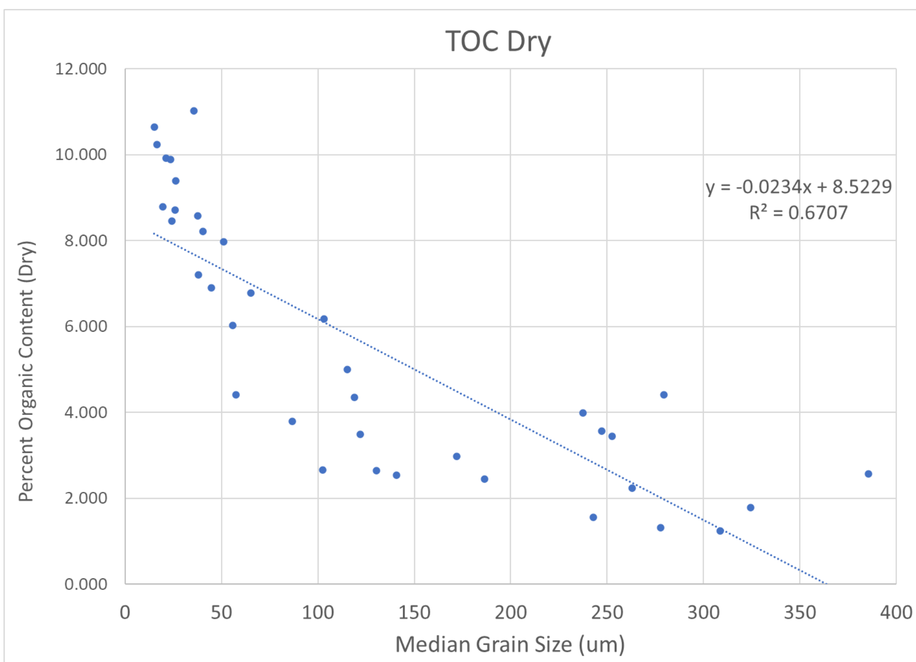

Figure 11. Dry total organic content. Percent organic content in each sediment sample as a function of median grain size of the dried sample. Each blue dot represents one sampling site.

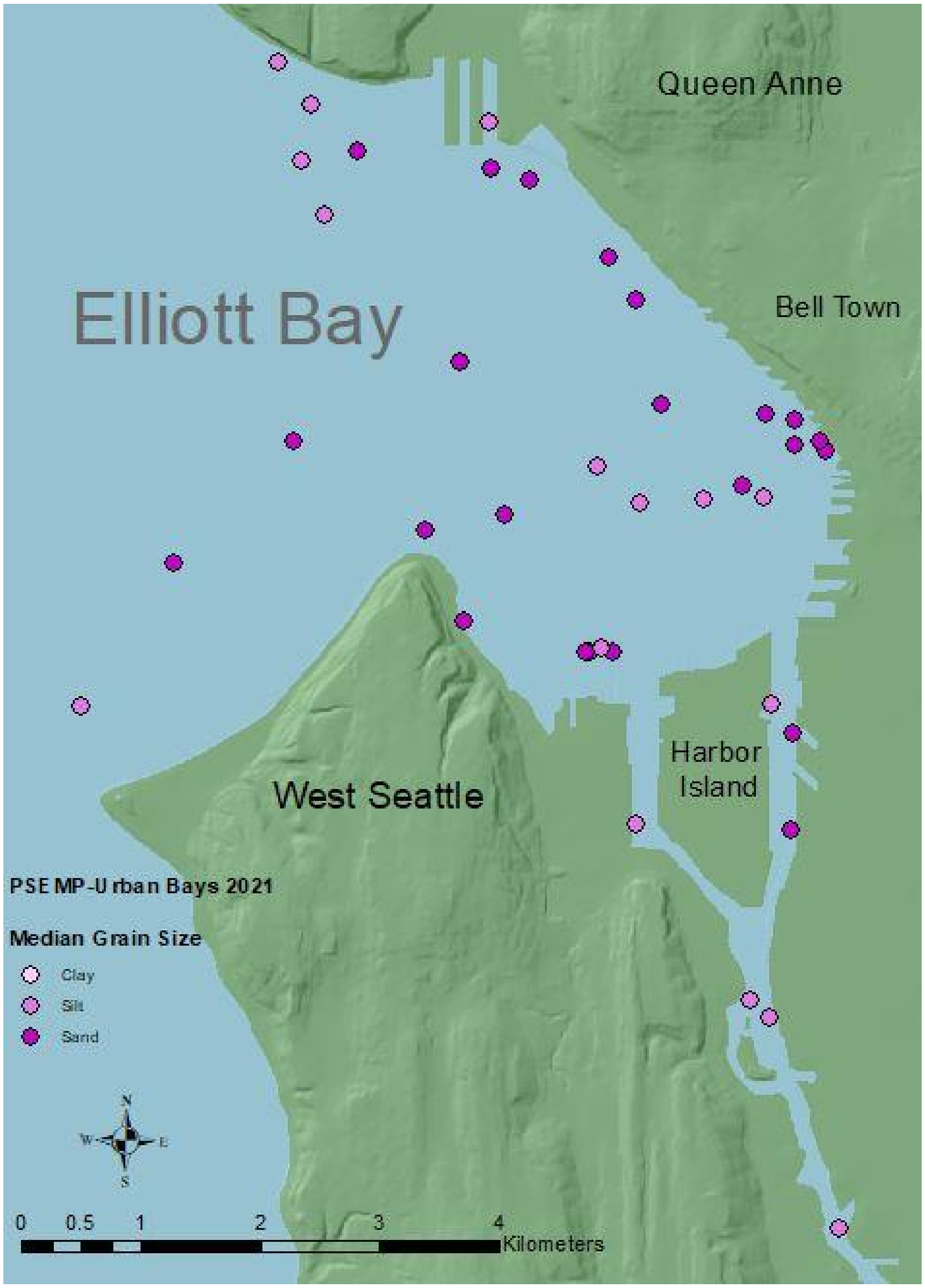

Figure 12. Median grain size of sample sites. Grain sizes are indicated by color as clay, silt, or sand.

Table 3. Median grain sizes for each sampling site in Elliott Bay.

Sample Site	Mean Grain Size	Median Grain Size	Mode
114	98.82	44.86	105.9
115	194.7	171.9	223.4
172	39.12	15.18	11.29
173	93.29	25.88	13.61
174	258.3	262.9	295.5
175	328.8	247.1	245.2
176	329.9	324.3	356.1
177	283.6	277.6	295.5
178	312	308.6	324.4
179	128.7	102.4	140.1
180	155.2	130.5	168.9
181	195.6	57.38	429.2
182	109.7	37.93	45.76
183	329	279.4	429.2
184	282.8	252.5	429.2
185	39.6	16.49	13.61
186	192.4	119	245.2
187	75.49	26.24	19.76
188	148.1	51.18	50.23
189	173.1	140.6	153.8
190	246.6	242.7	269.2
191	136.4	55.87	127.7
192	227.9	121.9	356.1
193	120.6	40.25	116.3

Sample Site	Mean Grain Size	Median Grain Size	Mode
194	41.43	19.51	21.7
195	148.7	65.22	140.1
196	88.58	24.43	19.76
197	156.4	103.2	140.1
198	391.2	385.4	429.2
199	254.8	237.3	356.1
200	136.5	86.87	153.8
201	190.7	115.1	153.8
202	50.37	21.4	41.68
203	64.61	23.66	26.15
204	93.72	37.72	50.23
205	78.73	35.61	87.9
40496	204.7	186.3	295.5

Discussion

As previously mentioned, the Washington Department of Ecology had conducted studies around Elliott Bay analyzing the total organic content and particle sizes of sampling sites around the bay. The methods to determine total organic content differed between the present study and previous studies for the Washington Department of Ecology. Dry total organic content, which was covered in the prior research mentioned at the beginning of this paper, was about an order of magnitude less than that of the present study. Therefore, the TOC results found in the present research could not be meaningfully compared to previous studies.

The methods of obtaining particle size data in the present study yielded similar findings to those of previous studies despite differing slightly in the methods by which the data was found. The University of Washington Tacoma used a laser particle size analyzer to ensure greater precision, while the previous studies did not use this instrument. Sternberg's findings on the ternary plot showed that the sediments of the Puget Sound typically tend to contain sandy and silty sand sediment, with some examples of clayey silt and silty clay (fig. 13). The present study determined that the sediments had slightly lower portions of clay particle sizes, with the silt-heavy sediments graphing closer to the bottom edge of the ternary plot than in Sternberg's findings (Sternberg 2004). This might suggest that high-energy events responsible for the larger grain sizes could have taken place recently, creating a small disturbance relative to the previous trends of low-energy environments responsible for the higher clay content in certain areas.

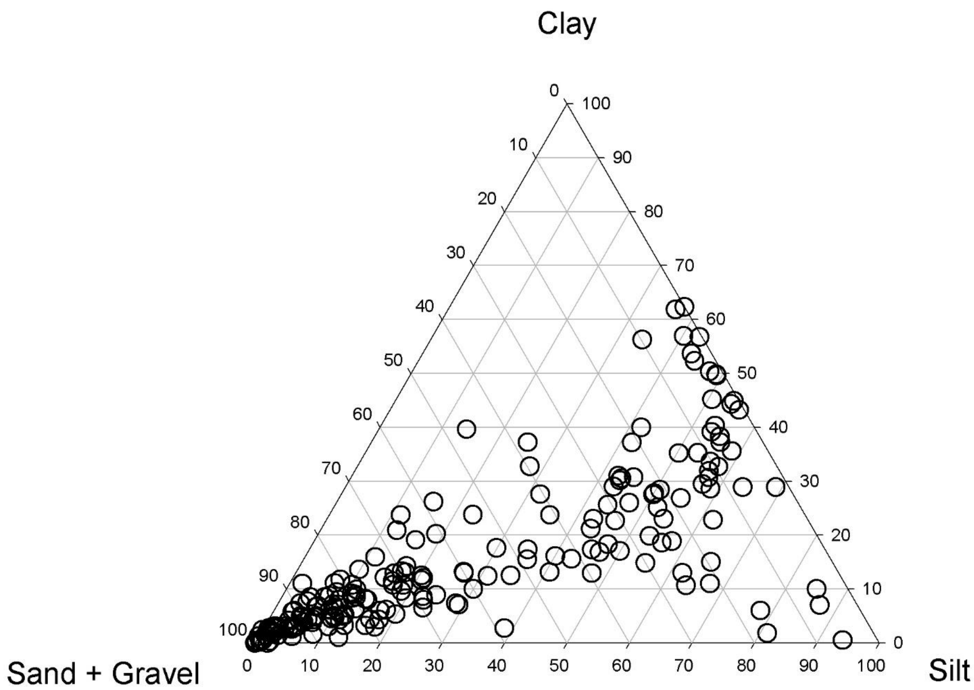

Figure 13. Sediment grain size distribution characteristic of the general Puget Sound (Sternberg 2004).

The ability to actively monitor the Elliott Bay sediments holds substantial implications. For example, deviation in future TOC and PSA data would be able to indicate highly consequential changes in the ecosystem. Such changes unearthed by comparing particle size data could be a result of increased dumping activity and erosion, while a comparison of TOC percentages could reveal ecosystem health as related to environmental productivity.

As a new format for sediment analysis in the waters around the city of Seattle, the present study offers promising opportunities for future scientists at the University of Washington Tacoma to continue monitoring Elliott Bay. Drastic changes in data could be met with modifications to policy, thereby allowing the public to better care for the environment and understand its undeniable dependence upon the land.

Bibliography

Dutch M, Partridge V, Weakland S, Burgess D, Eagleston A. 2018. Quality Assurance Monitoring Program: The Puget Sound Sediment Monitoring Program. Pub no. 18-03-109. https://apps.ecology.wa.gov/publications/documents/1803109.pdf

Frantilla A. c1995-2021. Seattle Municipal Archives [Internet]. Seattle (WA): Seattle.gov; [cited 2021 Nov 7]. Available from: https://www.seattle.gov/cityarchives/seattle-facts/brief-history-of-seattle

Lefkovitz LF, Cullinan VI, Crecelius EA. 1997. Historical Trends in the Accumulation of Chemicals in Puget Sound. Silver Spring (MD): National Oceanic and Atmospheric Administration. Report No.: Tech. Mem. NOS ORCA 111

Long P. 2001. Seattle routinely dumps garbage into Puget Sound as of 1892 [Internet]; [cited 2021 Aug 20]. Available from: https://www.historylink.org/File/3159

Rensel J. 2012. NPDES Sampling during 2012: Closure Monitoring at American Gold Seafoods Net-Pen Sites in Deepwater Bay, Puget Sound. Arlington (WA): Rensel Associates Aquatic Sciences.

Shepard FP. 1954. Nomenclature Based On Sand-Silt-Clay Ratios. Journal of Sedimentary Petrology. 24(3): 151-158

Sternberg D. 2004. Surface Sediment Characteristics in Puget Sound: a tribute to Dick Sternberg's undergraduate teaching.

Tilman D, Lehman C. 2001. Human-caused environmental change: Impacts on plant diversity and evolution. PNAS. 98(10): 5433-5440

[WSDOE] Washington Department of Ecology. 2016. Urban Bays Monitoring 2013: Sediment Quality in Elliott Bay, Seattle WA [Internet]; [cited 2021 Nov 7]. Available from: https://apps.ecology.wa.gov/publications/documents/1603010.pdf