

A Survey of Meiofaunal Communities in Beaches of Victoria, B.C.

by

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Abstract

Meiofauna are an understudied category of beach biodiversity worldwide, even though they are highly abundant. Factors that control the distribution of meiofauna, such as those related to sediment characteristics, are unclear. This study aimed to categorize the abundance and taxonomical diversity of meiofauna, the median grain size (Q50), the sediment sorting coefficient (Q25/Q75), and the organic matter content at 18 beaches in Victoria, B.C. It also investigated if those characteristics differed between two beach types, muddy and sandy, and whether meiofauna abundance was correlated with sediment characteristics. To test the hypothesis that meiofauna would be more highly abundant in fine sediment beaches (mudflats) than in coarse sediment beaches (sandy beaches), nine mudflats and nine sandy beaches were chosen based on visual inspection of the sediment. Then, sediment cores and meiofauna samples were taken at each of the 18 different beaches. Sediment size was determined using sieving, and organic matter of the sediment was quantified using loss on ignition. Meiofauna were enumerated and quantified using microscopy. The data were analyzed using two-sided t-tests and regression analyses. Meiofauna were found to be extremely abundant (on average 835 animals per 15cc of sediment) across all sample beaches. Median sediment size and sediment sorting (heterogeneity) did not vary significantly between muddy and sandy beaches, although the overall trends were in line with the prediction that muddier beaches had lower median particle size and higher sediment heterogeneity than sandy beaches. Organic matter was significantly higher in mudflats compared to sandy beaches. Meiofaunal abundance and total number of taxa were not significantly different among the beach types, and were not correlated with sediment characteristics. Based on my study I make several recommendations for future sampling programs. More research, especially time-series data collection, is needed to understand variation in these communities, as it is difficult to observe patterns from a single time point. My results illustrate how vast meiofaunal communities are (millions per square meter), yet how little we understand them. As the world changes, it is important to understand all aspects of beach biodiversity, and these tiny animals account for most of the non-microbiotic portion of it.

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Introduction

Meiofauna are littoral (benthic) organisms ranging in size between 63 μ m and 500 μ m that are an essential part of a healthy marine habitat (Andreasen, 2019; Giere, 2009). They provide food to other organisms, break down detritus in the sediment and contribute to nutrient cycling in benthic food webs (Giere, 2009; Schuckel *et al.*, 2013). Many small fish rely on meiofauna as their main food source and might select for some types of meiofauna over others. Meiofauna consumption can be constant, seasonal, or supplemented with other food sources depending on the fish (Schuckel *et al.*, 2013). Though nematodes dominate meiofauna populations numerically, harpacticoid copepods have been found to be the main food source in fish of a certain class size, with selectivity towards only certain harpacticoid species (Schuckel *et al.*, 2013). Meiofauna are found in sediments from the equator to both poles, with relatively high diversity even in the Arctic (Kotwicki *et al.*, 2005). On any beach, meiofauna species can outnumber those of macrofauna almost 25 times over due to the numerous niches within the littoral environment that are available for these smaller creatures (Armonies and Reise, 2000).

Understanding the variation in meiofaunal assemblages is very useful for predicting the effects of anthropogenic activities on marine ecosystems (Zeppilli *et al.*, 2015). Since they reproduce quickly and lack larval dispersal, meiofauna are sensitive to environmental changes (Zeppilli *et al.*, 2015). Arvai *et al.* (2002) used meiofauna as an indicator of mudflat ecosystem recovery in the Fraser River estuary after a sewage outfall was diverted. Decreased organic matter pollution in the estuary resulted in an increase in meiofaunal diversity and total meiofauna, indicating a recovering ecosystem. However, before meiofaunal diversity can be used as an indicator of environmental change, the baseline variation in meiofaunal communities in an area must be characterized. Despite their ecological importance, factors that influence the distribution and diversity of meiofauna have been poorly studied, and some meiofauna species have received more attention than others.

A few meiofauna taxa are especially useful for environmental monitoring because of their high abundance, ease of identification and sensitivity to environmental stressors: nematodes, harpacticoid copepods and ostracods. Nematodes and harpacticoid copepods are generally the most abundant taxa in meiofaunal communities (Sutherland *et al.*, 2018; Boeckner and Sharma, 2009; Bravender *et al.*, 1993). Both taxa are thought to prefer muddy (fine-grained) sediments,

making them prominent taxa in mudflats and fine-sand beaches (Boeckner and Sharma, 2009). Nematodes and harpacticoid copepod populations are thought to vary depending on sediment size, sediment texture and organic matter content (Sutherland *et al.*, 2018), so they are good candidates for observing the variation in sediment properties across different beaches. Harpacticoid copepods have shown greater variation in abundance compared to nematodes, indicating that they respond more strongly to changing sediment properties and environmental conditions (Sutherland *et al.*, 2018). Riera *et al.* (2012) showed that the copepod/nematode ratio was able to differentiate areas affected by fish farming from unaffected areas. However, the copepod/nematode ratio might not be useful for other kinds of pollution, such as detecting copper mining runoff (Lee *et al.*, 2001). Ostracods are so sensitive to pollution and environmental stress that they often disappear completely in polluted beaches (Zeppilli *et al.*, 2015). Ostracod abundance is therefore a good indicator of environmental stress across a geographical area.

Meiofaunal community surveys often reveal patchy distributions among replicates at the same site. This is expected in littoral habitats because food sources (i.e. organic matter or detritus) are patchily distributed in the sediment (Sharma and Webster, 1983). In climates with pronounced seasonal variation such as British Columbia, meiofaunal communities also fluctuate annually, with higher numbers of juveniles and adults in the summer than in the winter (Sharma and Webster, 1983; Soltwedel *et al.*, 2020). Meiofaunal communities also show interannual changes; a time-series collected in the Arctic Ocean showed a decrease in total meiofaunal abundance over fifteen years in shallow sediments (Soltwedel *et al.*, 2020).

Despite spatial and temporal variation, meiofauna are poorly monitored in Canada and across the globe. Archambault *et al.* (2010) conducted a meta-analysis on the overall diversity in Canadian oceans. They found that especially in Western Canada, there was a lack of data on benthic organisms such as meiofauna. This dearth of meiofaunal data has been noted in other meta-analyses conducted worldwide (Brustolin *et al.*, 2018; Bianchelli and Danovaro, 2019; Bluhm *et al.*, 2018). Locally, several studies have described the meiofaunal communities around Vancouver Island. However, most local studies focus on cataloguing just one, novel taxon (Van Steenkiste *et al.*, 2018; Sterrer and Sørensen, 2006; Stephenson *et al.*, 2019, etc.), or on the diversity in submerged (sublittoral), rather than intertidal sediments (Burd *et al.*, 2012).

Not much is known presently about the overall intertidal meiofaunal communities on Vancouver Island, despite it having roughly 3400km of coastline (Google Earth) that can potentially support these creatures. Rapid changes are occurring on all parts of the island either for the better, e.g., the remediation of Baikie Island in Campbell River after 50 years of sawmill operations (C Bendickson, personal communication), or for the worse, e.g., the rapid deforestation and development in areas of coastal old-growth forests in Port Renfrew, Port Alberni and Tofino/Ucluelet (N Balint, personal communication). Victoria is developing especially rapidly; by 2038, the population of the Capital Regional District is projected to grow by 20% (BC Stats, 2019). Mudflats are thought to be hotspots of meiofaunal abundance and diversity (Boeckner *et al.*, 2009; Arvai *et al.*, 2002). Beaches, especially mudflats, are often found in industrial or rapidly developing areas in Victoria, B.C., so it is important to catalogue the diversity (taxa richness) and density (total meiofauna) at these sites to provide a baseline for monitoring the impact of human activities in the future. Therefore, my first objective is to characterize the variation in meiofaunal diversity and density among beaches in Victoria B.C.

My second objective is to determine if sediment and meiofauna characteristics vary between beach classifications, and if there is a relationship between meiofaunal abundance and sediment characteristics. Softshore beaches (i.e. those in which organisms can burrow or live within the sediment) can be broadly classified based on median sediment size. Sandy beaches are exposed to more vigorous waves, which wash away fine sediments along with organic matter. Food is the limiting resource at these beaches as the grains get too big to retain organic matter (McLachlan *et al.*, 2018). On the other hand, muddy beaches are found in areas with low energy tidal currents, which allow organic matter and fine sediments to accumulate. Mudflats are therefore predicted to have a smaller median sediment grain size, more heterogeneous sediments, higher levels of organic matter, and to support a larger, more diverse community of meiofauna than sandy shores. In other words, meiofaunal abundance and median sediment size should negatively correlated, but meiofaunal abundance and organic matter should be positively correlated. However, if too much organic matter accumulates in a mudflat, a highly likely possibility in the urbanized beaches of Victoria, anoxic conditions can develop in the sediment and limit the growth of meiofauna (McLachlan *et al.*, 2018). In this case, mudflats might contain lower meiofaunal abundances compared to sandy shores, and the relationship between sediment size or organic matter and meiofaunal abundance would be hump-shaped (where maximal

abundances are achieved at intermediate sediment size and organic content). My study will serve as a starting point for cataloguing meiofaunal communities around Victoria, and for investigating links between beach characteristics, sediment size, and the meiofauna.

Methodology

1. Initial Site Scouting

Using Google Maps and ArcGIS, a map of all potentially accessible beaches around Victoria and Esquimalt was created. Known mudflats from the Capital Region District (CRD) website were added to the map. Some sites were not accessible due to being on First Nations land or private property, and these were removed from the map.

All sites were then visited during the low tide to determine accessibility and suitability for the study. Exact tidal heights during the site scouting are listed in Appendix 1. From the list of scouted beaches, 18 sites were chosen for sample collection: 9 that appeared to be mudflats (wet, mud-like sediment) and 9 that appeared to be sandy beaches (coarse sand) (Fig. 1). No rocky beaches were included in the final design. Mudflats recognized by the CRD were used as a reference for identifying muddy sites (e.g., Duffus Trail).

Please note that this study was conducted during the COVID-19 pandemic, which altered the accessibility of beaches around Victoria. No beaches on First Nations lands could be accessed, and doors could not be knocked on to enquire about sampling on private property. All beaches in this study had public access points.

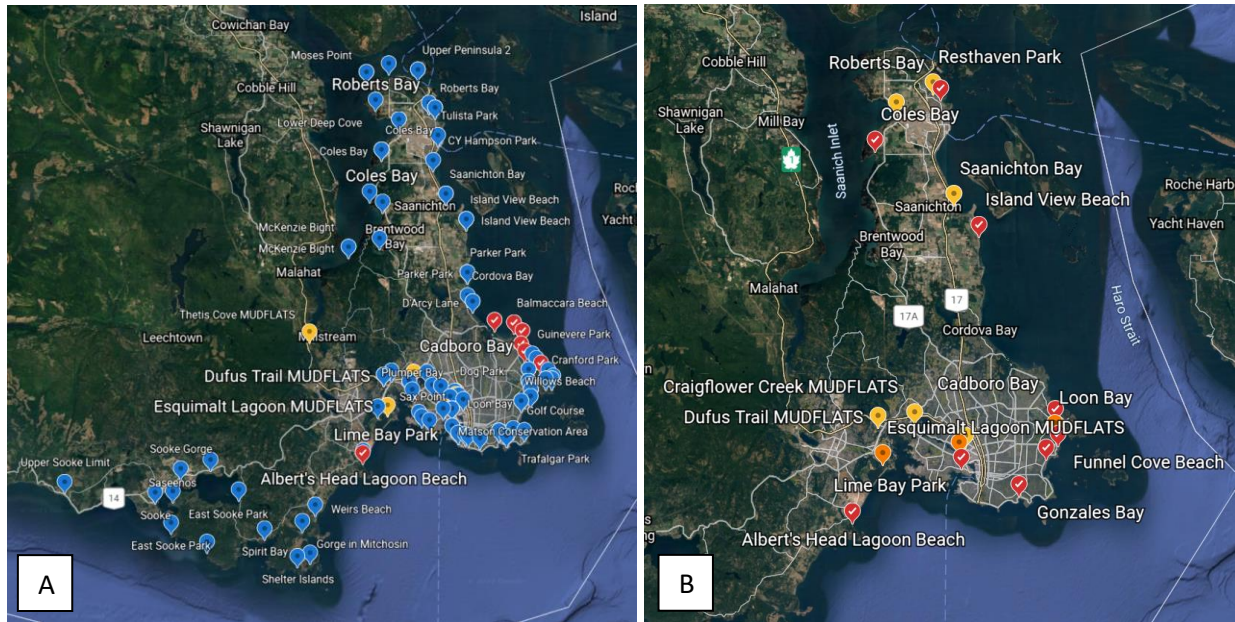


Figure 1: A) Map of potential collection sites around Victoria, B.C. B) Map of final collection sites colour coded by beach type. Orange and yellow points show potential mudflat sites: Patricia Bay Park, Resthaven Park, Saanichton Bay Park, Loon Bay Park, Gorge Waterway, Banfield Park, Mouth of Craigflower Creek, Duffus Trail and Esquimalt Lagoon Migratory Bird Sanctuary. Red points show potential sandy beach sites: Coles Bay Regional Park, Roberts Bay – Shoal Harbour Migratory Bird Sanctuary, Island View Beach Regional Park, Cadboro-Gyro Park, Funnel Cove Beach Access, Willows Beach, Gonzales Bay, Lime Bay, Albert Head Lagoon Regional Park. Maps were created using Google Earth.

2. Sample Collection

All samples were collected 2-4ft from the tideline if possible, to ensure the sediments were hydrated at the time of collection. All samples were collected between July 2 and July 21, 2020. A field exemption permit and a safe work plan were obtained from the University of Victoria prior to sampling. All meiofauna collection was conducted under the Fisheries and Oceans Canada (DFO) collecting permit given to the Department of Biology at the University of Victoria.

Sediment samples

Using a clear plastic tube (diameter = 6.7cm, length 50 cm), a sediment core was taken by pushing the tube into the sediment as far as possible, up to ~15cm. Exact sample depths are listed in Appendix 1. Visual observations on the core properties were recorded. Then, the top

~3cm of the sediment was retained for laboratory analysis. Another replicate was collected at a different spot within two meters of the first sample for a total of two replicates. Samples were frozen until laboratory analysis.

Meiofauna samples

Using a 60mL plastic syringe with the top cut off, 15cc volumes of sediment were collected for meiofauna analysis. Three replicates were collected from each site: two for immediate analysis, and a third for archival purposes. Samples were stored in 75% ethanol and stained with Bengal Rose until microscopic analysis.

3. Sediment Analysis

Methods for sediment analysis were adapted from several sources including Salter *et al.* (2018), and methods used by B.C. meiofaunal researchers including Dr. Sarah Dudas (DFO) and Ms. Emily Spencer (UVIC/Simon Fraser University, Parks Canada).

Grain Size

Sediment samples were removed from the freezer and allowed to thaw for two hours. Small dishes were weighed, and a subsample of ~12g was retained and refrozen for loss on ignition (LOI) analysis. The rest of the samples were weighed, and then placed uncovered into a drying oven for 16 hours overnight at 105°C.

The next day, samples were weighed and then transferred to a metal bowl for declumping. Using gloves, all visible aggregates were broken up gently, and the sample was then poured and brushed out onto the top of the Hubbard Scientific sieve stack containing 7 sieves: 4.00mm, 2.00mm, 1.00mm, 0.500mm, 0.250mm, 0.125mm, 0.063mm. The stack was agitated for 15 minutes with a sieve shaker (Roman-Sierra *et al.*, 2013). The sediments retained on each sieve were weighed, and the percent sediment retained on each sieve was calculated (Fig.2A). The median grain size (Q50) and sediment sorting coefficient (Q25/Q75) for each replicate at each site were interpolated graphically using cumulative percent figures (Appendix 2) (Levington, 2009). The median grain size (Q50) is used to compare particle sizes among beaches, and it increases with sediment coarseness. The sorting coefficient is a measurement of

sediment heterogeneity. Sorting coefficients close to 1 are considered to be homogenous, where most of the grains are one size, while values closer <1 are considered heterogeneous, where there is a mix of grain sizes (Levington, 2009). Values that were too small to interpolate from the figures (such as those for Resthaven Park, Duffus Trail and Gorge Waterway) were set to 0.01 to prevent zero-inflated data.

Organic Matter Content

The subsamples retained for LOI analysis were thawed in the fridge for 2 hours, and then weighed and dried uncovered in the drying oven for 16 hours at 105°C. A 3g subsample was then weighed and burned in a muffle furnace for 8 hours at 550°C. The subsamples were reweighed after cooling. The post-burning weight in the crucible was subtracted from the pre-burning dry weight in the crucible to determine loss of mass during ignition. This value was divided by the pre-burning dry weight and multiplied by 100 to give the percent composition of organic matter in the subsample.

4. Meiofauna Quantification and Identification

Meiofauna samples were a mix of ethanol, sediments, and organisms. To identify the organisms, they first had to be separated as much as possible from the sediments because sediments interfere with light absorption and make microscopic identification difficult. Sediments have a much faster settlement rate than organisms. Therefore, the samples were shaken thoroughly to evenly distribute the organisms and sediment in the ethanol and then were left for 20 seconds to let the sediments settle. After 20 seconds the liquid portion of the sample which contained the organisms was immediately run through a Hubbard Scientific sieve stack containing 500mm and 63mm sieves. The 63mm sieve was then rinsed with water and the meiofauna were collected in a Bogorov counting tray. The sediments were rinsed and filtered twice more to ensure that all animals were removed. The meiofauna were identified on a Zeiss Stemi508 dissecting microscope equipped with an ERc 5s camera (Fig. 2B).

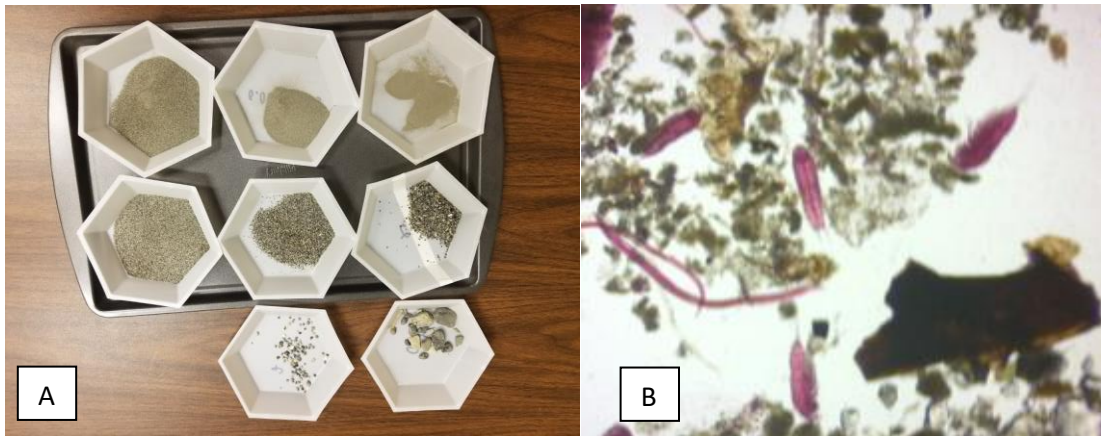


Figure 2: A) Separated sediment size fractions after sieving. The figure shows coarse fractions in the bottom row, medium fractions in the middle row and very fine fractions in the top row. The coarsest fraction (>4mm) is on the bottom right, and the finest fraction (<0.063mm) is on the top right. B) Harpacticoid copepods and nematodes stained with Rose Bengal viewed through a dissecting microscope at 50x magnification

5. Data Analysis

Replicates from each beach were averaged for use in the statistical analysis. Two replicates were analyzed for both the meiofauna data and sediment data at all beaches except for Banfield Park, Patricia Bay Park and Albert Head Lagoon, which had three meiofauna replicates.

Two-sided t-tests were performed to test whether median sediment size (Q50), sorting (Q25/Q75), % organic content, meiofaunal abundance, number of taxa, nematode abundance, harpacticoid copepod abundance, ostracod abundance, bivalve abundance and “other” taxa abundance varied with beach classification (sandy vs. muddy). Regression analyses were performed to test whether meiofaunal abundance was correlated with Q50 or organic matter. All statistical analyses were performed using the SPC for Excel package.

Results

Grain Size and Sorting

The overall average median grain size (Q50) was 0.21mm (± 0.46 standard deviation (SD)). As predicted, muddy beaches had, on average, lower Q50 values than sandy beaches (0.0856mm vs. 0.3289mm) (Table 1, Fig. 3). However, Q50 differences between sandy and muddy beaches were not significant ($t = -1.13$, $df = 8$, $p = 0.2912$) (Appendix 4: Table 1). Albert Head Lagoon had the highest Q50 in the data set (2.04mm) potentially acting as an outlier. A separate t-test without Albert Head Lagoon was run to confirm that this value did not throw off analysis, but the results were almost the same ($t = -1.106$, $df = 15$, $p = 0.2861$) (Appendix 4: Table 2, Fig 3a). Average sediment sorting across all sites was 0.38 (± 0.26 SD) (Fig. 3b). There was a wide range of sorting among both beach types: sediment sorting coefficients ranged between 0.02 at Craigflower Creek (poorly sorted, heterogeneous) and 1.0 at Resthaven Park (highly sorted, homogeneous). Muddy beaches had on average lower sorting than sandy beaches (0.319 vs. 0.448) (Table 1, Fig.3c), suggesting that they had more heterogeneous sediments. However, differences between sandy and muddy beaches were not significant ($t = -1.048$, $df = 16$, $p = 0.3101$) (Appendix 4: Table 3).

Organic Content

Average organic matter content across all sediment samples was 2.81% (± 2.37 SD). Individual sites ranged between 0 and 10%. As predicted, muddy beaches had over twice as much organic matter content on average as sandy beaches (4.028% vs. 1.588%). A few muddy beaches had especially high organic contents (Gorge Waterway = 6.38%, Duffus Trail = 9.42%, Craigflower Creek = 6.52%), while a few sandy beaches had especially low organic content (Willows Beach = 0.91%, Island View Beach = 0.88%, Cadboro Bay = 0.76%) (Table 1, Fig. 3). Muddy beaches had significantly higher organic content than sandy beaches ($t = 2.495$, $df = 10$, $p = 0.0317$) (Appendix 4: Table 4).

Table 1: Sediment characteristics by site, including median grain size (Q50), sediment sorting coefficient (Q25/Q75) and percent organic matter. Two replicates were sampled per beach. All values are averages of two replicates.

Site	Beach Classification	Q50 (mm)	Q50 standard error	Q25/Q75	Q25/Q75 standard error	% Organic matter	% Organic matter standard error
Resthaven Park	Muddy	0.01	0	1	0	1.92	0.08
Gorge Waterway (dog park)	Muddy	0.03	0	0.1	0	6.38	1.13
Duffus Trail	Muddy	0.04	0.02	0.14	0	9.42	0.26
Patricia Bay Park	Muddy	0.05	0	0.18	0.02	2.39	0.13
Craigflower Creek	Muddy	0.08	0.03	0.02	0.02	6.52	0.38
Saanichton Bay Park	Muddy	0.09	0	0.29	0.02	2.54	0.28
Banfield Park	Muddy	0.11	0.01	0.3	0.01	2.92	0.76
Loon Bay Park	Muddy	0.18	0.02	0.26	0.22	1.45	0.26
Esquimalt Lagoon	Muddy	0.18	0	0.58	0.02	2.71	0.64
Lime Bay	Sandy	0.05	0	0.17	0	4.14	0.12
Robert's Bay	Sandy	0.11	0.01	0.52	0.14	1.43	0.09
Willows Beach	Sandy	0.09	0	0.69	0	0.91	0.02
Gonzales Bay	Sandy	0.09	0	0.64	0	1.67	0.37
Island View Beach	Sandy	0.1	0	0.65	0.02	0.88	0.02
Cole's Bay	Sandy	0.12	0	0.17	0.03	1.35	0.01
Cadboro Bay	Sandy	0.17	0.01	0.52	0.02	0.76	0.03
Funnel Cove	Sandy	0.19	0.01	0.2	0	2.22	0.84
Albert Head Lagoon	Sandy	2.04	0.06	0.47	0.03	0.93	0.04
	Overall Average	0.21		0.38		2.81	
	Standard Deviation	0.46		0.26		2.37	
	Coefficient of Variation	222.24		69.24		84.48	

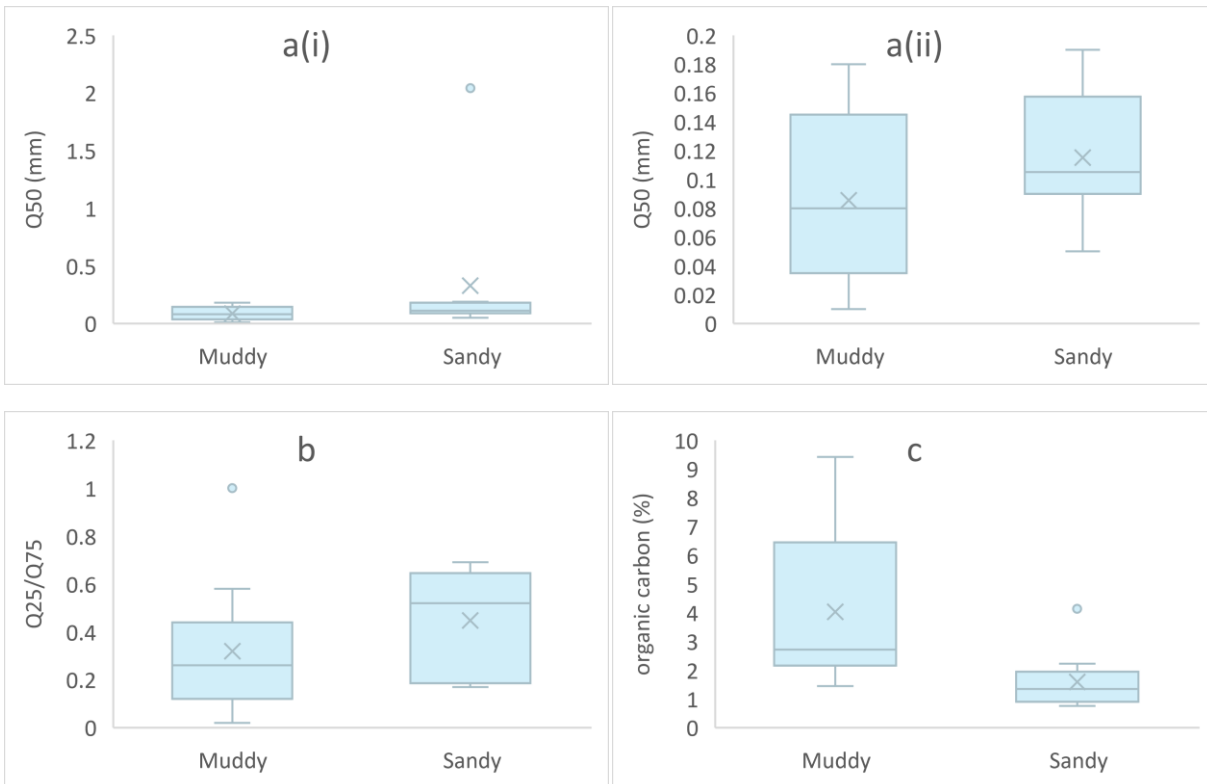


Figure 3: Beach classification vs. the a(i)) median grain size (Q50) a(ii)) median grain size omitting possible outlier from Albert Head Lagoon (2.04mm) b) sediment sorting coefficients (Q25/Q75) c) % organic carbon. Eighteen beaches were sampled, and the value from each beach is an average of 2-3 replicates.

Meiofaunal Abundance

The average number of meiofauna found across all samples was 835 meiofauna/15cc of sediment (± 530.82 SD). This large standard deviation is reflective of the wide range of meiofaunal abundance that was found between samples, from the low hundreds to over 2000 individual animals per 15cc of sediment. On average, muddy beaches had fewer meiofauna than sandy beaches (735 animals/15cc vs. 934 animals/15cc). Each sample contained on average 9 different taxa (± 2.23 SD) (Table 2, Fig. 4). However, differences in abundance and number of taxa between beach types were not significant (abundance: $t = 2.12$, $df = 16$, $p = 0.4412$; number of taxa: $t = 2.12$, $df = 16$, $p = 0.7903$) (Appendix 4: Tables 5-6). Nematodes were by far the most abundant taxon at 59.4% of total meiofaunal abundance, then harpacticoid copepods at 16.8% total abundance. Nauplius larvae (12.0% total abundance) were the next most abundant taxon,

then bivalves (4.8% total abundance) and ostracods (1.5% total abundance). The remaining taxa were *Kinorhyncha*, *Nermertinea*, *Polychaeta*, *Turbellaria*, *Pancarida*, *Syncarida*, *Mictacea*, *Cumacea*, *Corophiidae*, *Isopoda*, *Acari*, *Cladocera*, *Protista*, *Foraminifera* and *Tardigrada*, which together made up the last 5.6% of total abundance (Table 3). None of the individual taxa varied significantly between beach types (nematodes: $t = -1.14$, $df = 11$, $p = 0.2784$; harpacticoid copepods: $t = 0.965$, $df = 16$, $p = 0.3489$; nauplius larvae: $t = 0.461$, $df = 10$, $p = 0.6544$; Ostracods: $t = -1.267$, $df = 16$, $p = 0.2233$; bivalves: $t = -0.804$, $df = 8$, $p = 0.4448$). Interestingly, sandy beaches tended to have more animals of “other” taxa than muddy beaches, though the difference was only marginally significant ($t = -2.231$, $df = 9$, $p = 0.0526$) (Figure 5; Appendix 4: Tables 7-12).

Grain size and meiofaunal abundance were not significantly correlated ($F = 1.03$, $df = 1$, $p = 0.3263$) (Appendix 5: Table 1A, Fig. 6). Organic matter did not display a significant correlation with animal abundance ($F = 1.92$, $df = 1$, $p = 0.1854$) (Appendix 5: Table 2A, Fig. 6). Visually, there does not appear to be either a strong linear relationship or a hump-shaped relationship. However, a slightly negative relationship between meiofaunal abundance vs. increasing sediment size and decreasing organic matter is apparent (Fig. 6).

Table 2: Meiofauna characteristics by site. Meiofauna abundance (animals/15cc of sediment) and total number of taxa (taxa/15cc of sediment) for each replicate were determined, then the values were averaged across replicates. All sites had two replicates except Banfield Park, Patricia Bay Park and Albert Head Lagoon which had three replicates.

Site	Beach Classification	Animal abundance	Standard error animal abundance	Number of taxa	Standard error number of taxa
Resthaven Park	Muddy	1314	318	7.5	0.5
Gorge Waterway (dog park)	Muddy	596	73	10	1
Duffus Trail	Muddy	572	126	7	0
Patricia Bay Park	Muddy	589.33	97.12	10	1.15
Craigflower Creek	Muddy	504.5	91.5	13.5	0.5
Saanichton Bay Park	Muddy	1431.5	5.5	9	1
Banfield Park	Muddy	855	433.41	7.67	0.67
Loon Bay Park	Muddy	418	104	9	1
Esquimalt Lagoon	Muddy	331	67	9.5	0.5
Lime Bay	Sandy	272.5	83.5	5.5	0.5

Robert's Bay	Sandy	2311.5	131.5	11	0
Willows Beach	Sandy	856.5	192.5	7.5	0.5
Gonzales Bay	Sandy	1046.5	148.5	7	1
Island View Beach	Sandy	968	36	12.5	0.5
Cole's Bay	Sandy	708	74	8	1
Cadboro Bay	Sandy	1514.5	251.5	12	0
Funnel Cove	Sandy	411.5	65.5	10	1
Albert Head Lagoon	Sandy	321	57.01	12.3	0.88
	Overall Average	834.52		9.39	
	Standard Deviation	530.82		2.23	
	Coefficient of Variation	63.61		23.74	

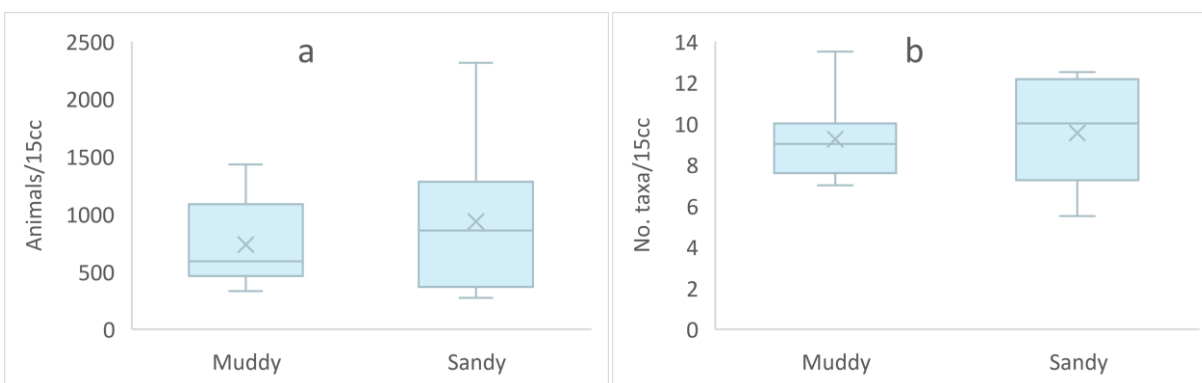
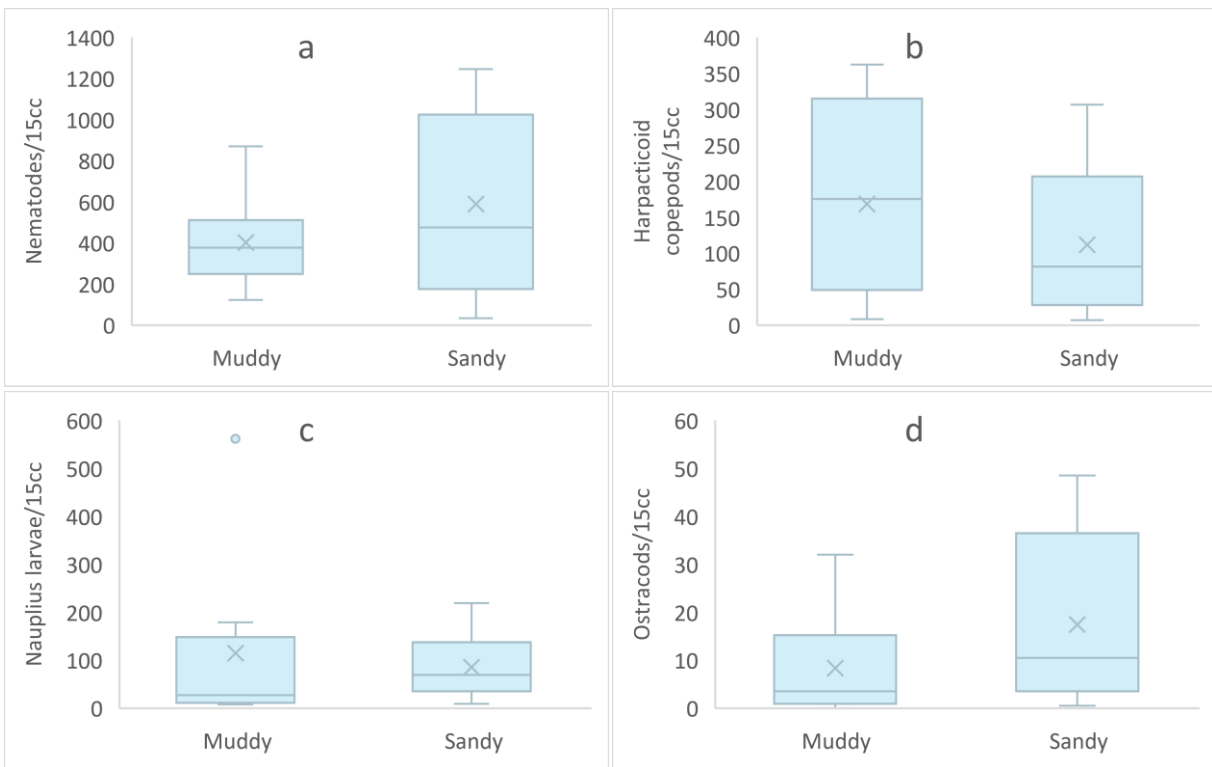


Figure 4: Beach classification vs. the a) meiofaunal abundance b) number of taxa at each site. Eighteen beaches were sampled, and the value from each beach is an average of 2-3 replicates.

Table 3: Average (standard error) meiofaunal abundance (no. meiofauna/15cc) by site. Other taxa include low occurrence taxa such as *Kinorhyncha* and *Turbellaria*. See text for details.

Site	# of replicates	Nematodes	Harpacticoid Copepods	Nauplius Larvae	Ostracods	Bivalves	Other
Resthaven Park	2	377(42)	362(127)	561.5(146.5)	2(2)	2.5(1.5)	9(6)
Gorge Waterway (dog park)	2	122.5(19.5)	322(39)	118(12)	0(0)	7(0)	26.5(2.5)
Duffus Trail	2	461.5(85.5)	8.5(3.5)	15(0)	15.5(9.5)	12.5(3.5)	59(38)
Patricia Bay Park	3	504.7(86.9)	54.3(24.4)	7.7(4.8)	0.3(0.3)	9.3(3.7)	13(1.7)
Craigflower Creek	2	271(10)	175.5(80.5)	25.5(0.5)	3.5(0.5)	2(0)	27(1)
Saanichton Bay Park	2	869.5(41.5)	307.5(23.5)	179(11)	32(7)	6(0)	37.5(5.5)

Banfield Park	3	516(220.6)	188.3(147.7)	27.3(8.3)	15(5.3)	98.3(54.2)	10.1(5.6)
Loon Bay Park	2	243.5(13.5)	51(30)	91(54)	5(1)	6(0)	21.5(5.5)
Esquimalt Lagoon	2	256(68)	47(6)	8(3)	1.5(1.5)	0.5(0.5)	18(7)
Lime Bay	2	252(81)	7(1)	9.5(0.5)	0.5(0.5)	1(1)	2.5(1.5)
Robert's Bay	2	1245.5(122.5)	306.5(40.5)	69.5(46.5)	48.5(35.5)	526.5(30.5)	115(2)
Willows Beach	2	693(223)	30(1)	39.5(5.5)	26.5(5.5)	5(2)	62.5(18.5)
Gonzales Bay	2	940(157)	49(13)	31.5(2.5)	12.5(4.5)	0(0)	13.5(2.5)
Island View Beach	2	475.5(45.5)	295(141)	45.5(12.5)	10.5(1.5)	7(5)	134.5(65.5)
Cole's Bay	2	446.5(156.5)	81.5(32.5)	92(50)	2.5(0.5)	9(5)	76.5(5.5)
Cadboro Bay	2	1107.5(312.5)	118.5(49.5)	78.5(15.5)	46.5(3.5)	5(4)	158.5(4.5)
Funnel Cove	2	100.5(19.5)	91(3)	183.5(82.5)	4.5(0.5)	12.5(5.5)	19.5(0.5)
Albert Head Lagoon	3	34.7(2.9)	26(6.2)	218.7(56.0)	4.7(2.3)	3.7(2.3)	33.3(7.3)
Overall average animals		495.4	140.0	100.1	12.9	39.7	46.5
Average % composition of total abundance		59.4	16.8	12.0	1.5	4.8	5.6



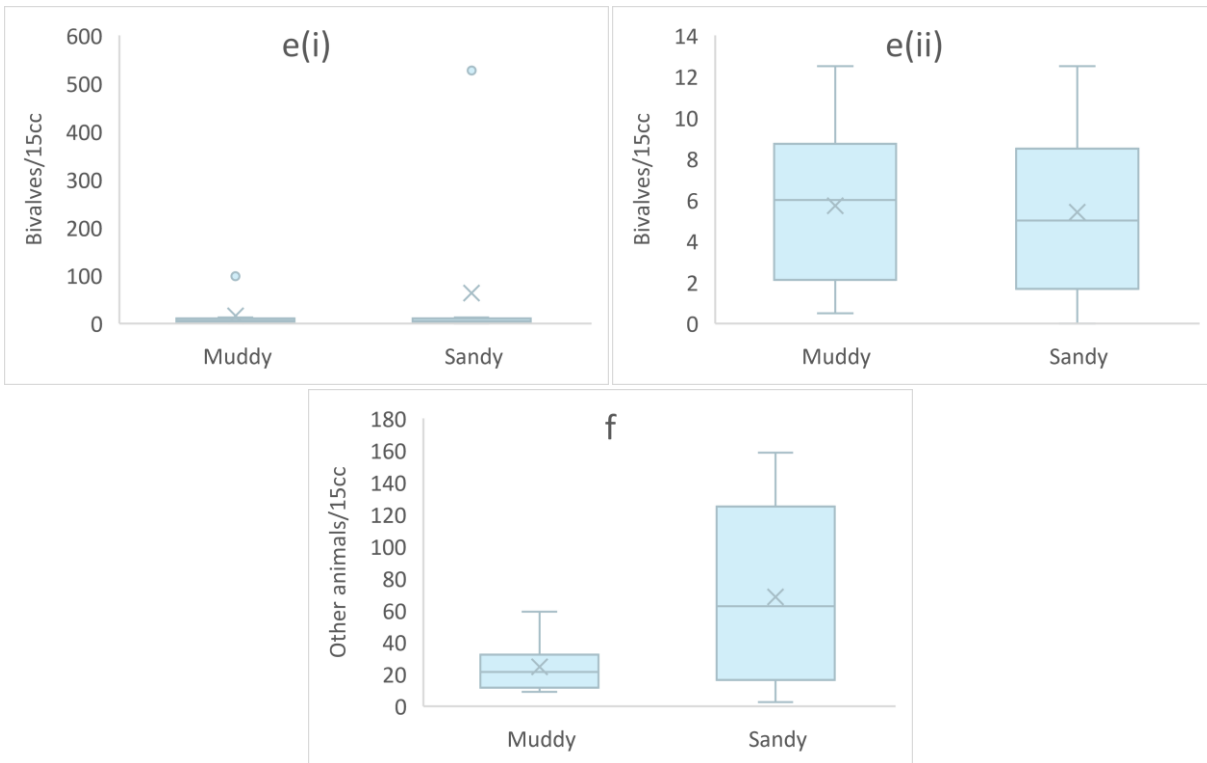


Figure 5: Beach classification vs. a) nematode abundance b) harpacticoid copepod abundance c) nauplius larvae abundance d) ostracod abundance e(i) bivalve abundance e(ii) bivalve abundance omitting potential outliers from Robert’s Bay (526.5 animals/15cc) and Banfield Park (98.3 animals/15cc) f) the abundance of all other taxa found in the samples combined. Eighteen beaches were sampled, and the value from each beach is an average of 2-3 replicates.

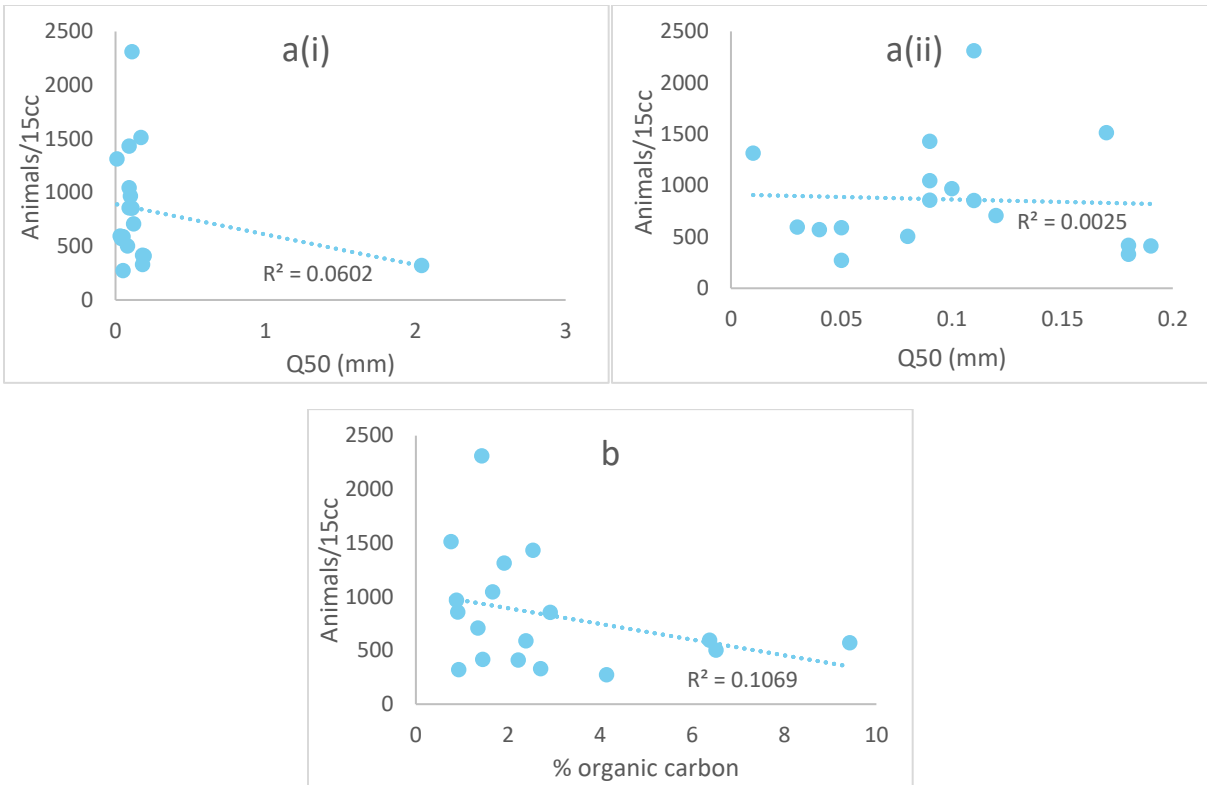


Figure 6: Animal abundance vs. a(i) median grain size, a(ii) median grain size (Q50) omitting potential outlier value (2.04mm, 321 animals/15cc) at Albert Head Lagoon, and b) percent organic matter. All values are averages of 2-3 replicates.

Discussion

Across Victoria BC, a wide range of meiofaunal abundance and diversity was discovered. The most common taxa found at all sample beaches were nematodes and harpacticoid copepods, then nauplius larvae and ostracods. This agrees with other studies done in southern British Columbia, including the Fraser River estuary (Bravender *et al.*, 1993), Baynes Sound (Sutherland *et al.*, 2018) and near the Bamfield Marine Sciences Centre (Boeckner and Sharma, 2009). One surprisingly highly abundant taxon found at a few sample beaches was *Bivalvia* (4.8% of total abundance), which even outnumbered harpacticoid copepods at Robert’s Bay (527 bivalves/15cc vs. 307 harpacticoid copepods/15cc). These are likely juvenile bivalves that settle in the top 1-2mm of sediment and eventually mature into macroscopic fauna (Coull, 1999). I have not found studies that report them as highly abundant, probably because they are seasonal members of the meiofauna size fraction (Coull, 1999). This qualifies them as “temporary

meiofauna”, which are organisms that are considered meiofauna in pre-adult life stages (McLachlan *et al.*, 2018)). The presence of these bivalves in larger than expected densities suggests that temporal or seasonal sampling of meiofauna is necessary for future studies.

I found a wide range of beach compositions in terms of grain size and levels of sorting. I sampled mostly fine sediments, but within that small size fraction (overall average ~0.21mm) there was considerable variation (coefficient of variation (COV) $Q50 = 222.96\%$; $COV Q25/Q75 = 77.09\%$; $COV \text{ percent organic matter} = 84.48\%$). Burd *et al.* (2012) also found that sediment types varied greatly in shallow waters in the northern Georgia Straight (Saanich Peninsula), which was a part of my study area. Another study in Northern B.C. recorded considerable variation in sediment grain size even though they sampled mudflats exclusively (Campbell *et al.*, 2019). I found no difference in the Q50 between the two beach types (Appendix 4, Table 1) although the overall trend matched predictions. Additionally, there was no correlation between Q50 and animal abundance (Appendix 5, Table 1A). In fact, the only significant difference between the mudflats and sandy beaches in this study was the amount of organic matter in the sediment (Appendix 4, Table 3), but there was no correlation between the organic content and number of animals (Appendix 5, Table 2A). The amount of organic matter being higher at mudflats is not a surprise, as the lack of wave exposure allows organic matter to accumulate there (Maclachlan *et al.*, 2018). Other studies have also found organic matter to be higher in silty, muddy sediments rather than coarser, sandy sediments (Boeckner *et al.*, 2009; Sutherland *et al.*, 2018). However, the lack of correlation between animal abundance and grain size or organic content is surprising, since multiple studies have reported that mudflats support greater assemblages of meiofauna than sandy beaches (Boeckner *et al.*, 2009; Boeckner and Sharma, 2009; Sutherland *et al.*, 2018; Arvai *et al.*, 2002), or that there is a hump-shaped relationship between sediment size and meiofauna abundance (McLachlan *et al.*, 2018). There are many reasons why my results may have strayed from those of previous works, either in nature or due to experimental design. A couple of these reasons are discussed below.

Classification methods

The beaches studied here were classified based on visual characteristics in an initial survey. At first, the most plausible explanation for these unexpected results was that the visible appearance of a beach did not communicate its composition properly. For example, Esquimalt

Lagoon appeared to be a mudflat during sampling, but displayed more “sand-like” characteristics when analyzed (higher median grain size, low organic matter). Since organic matter differed significantly between the muddy and sandy beaches of this study, it is possible that high organic content at some beaches made them appear “stinky” and ‘muddy” regardless of the sediment size. Future studies could conduct a more detailed investigation of the link between sediment size and organic matter content.

The sampling scheme in this study was potentially confounded with other factors, which might have been important for explaining sediment characteristics. For example, in addition to being classified as either sandy or muddy based on local characteristics, the sites in the study could be divided broadly into two groups depending on oceanographic conditions – exposed sites such as those facing onto Hecate Strait or Juan de Fuca Strait (e.g., Willows Beach, Albert’s Head Lagoon, Island View Beach), and sheltered sites in estuarine systems such as in the Gorge or Saanich Inlet (e.g., Pat Bay, Duffus Trail, Craigflower Creek). Preliminary analysis suggested that this broad oceanographic classification might be more important for explaining sediment characteristics than beach differences within each system (RW El-Sabaawi personal communication). In addition, local, site-specific factors such as pollution or development might have affected the results (Arvai *et al.*, 2002). For example, Gorge Waterway, Duffus Trail and Craigflower Creek, the sites with the highest organic matter levels, all exist in heavily developed or industrial areas of Victoria. Development in urban beaches can change sediment characteristics, negatively impacting the interstitial fauna (Morton *et al.*, 2015). Furthermore, proximity to a stream or river brings in fine sediments and organic matter, and a couple of sites (i.e., Craigflower Creek and Duffus Trail) had freshwater streams draining into them. This could limit meiofaunal abundances in those areas. Future studies can address these issues using more extensive sampling schemes, or by characterizing the degree of urban development around the beaches from GIS maps. My data provide baseline sediment measurements from several local beaches that can be used to plan future surveys or time-series collections.

Sampling locations/methods

The pattern of meiofaunal taxa abundance that was found at all sample beaches was high nematode abundance, with lower harpacticoid abundance, then the rest of the taxa, matching expectations based in the literature. McLachlan *et al.* (2018) suggest that nematode and

harpacticoid density are usually equal at around 0.3mm Q50. At lower sediment sizes, nematodes dominate and at higher sediment sizes, harpacticoids dominate. Average Q50 across all beaches was ~0.21mm (~0.1mm when Albert's Head Lagoon was excluded), so it makes sense that nematodes were the dominant taxa in my samples. Despite the diversity of beaches that I sampled for my thesis, most of my beaches are on the fine end of the scale. If this topic is explored again, I would suggest sampling more beaches on the other end of the spectrum (i.e. coarse sediment beaches such as those in Shirely, Colwood, or Sooke BC). Another interesting point that McLachlan *et al.* (2018) raise is how the highest meiofauna densities at exposed beaches occur at mid-beach where the sand stays moist throughout low tide. I sampled all beaches as close to two meters from the tideline as possible. But since Victoria's shores are often very narrow, 2 meters from the tideline tended to be mid-beach. This sampling scheme may have “boosted” the sandy beach abundances, obscuring differences between the two beach categories. The final point of interest raised by McLachlan *et al.* (2018) is that meiofauna tend to migrate downwards with the low tide to avoid desiccation. The top layer typically contains the larger animals that can withstand the surface conditions without risk of drying out. All meiofauna samples taken for this study were collected at low tide from the top 3cm of sediment, which could have under-represented meiofaunal abundance. Other studies with similar research objectives opted to take larger cores 30cm deep into the sediment (Belley *et al.*, 2016), where moisture would be fully retained, or sampled fully submerged sediments (Boeckner *et al.*, 2009) which is a sampling approach that can be used in future studies. However, deeper sediments are often anoxic and have low meiofauna densities (McLachlan *et al.*, 2018). Therefore, an ideal sampling depth needs to balance these two issues (desiccation at the surface, anoxic in the deep). Future studies should conduct detailed depth profiles to explore this issue. Sediment oxygen may be the missing key for explaining contradictory or counter-intuitive results explained above, and is probably the most important metric to test for in future studies. Tools such as a Myron L PT5 Ultrapen™ can be used to measure dissolved oxygen in the field at sample collection sites (MyronL, 2021: <https://www.myronl.com/>). Data collection would have to be timed in order to use the PT5 on water-saturated sediments, as I have found from experience that air affects readings in dry samples.

Despite the limitations described above, my results indicate the high density and diversity of a very poorly studied category of animals. According to my results, meiofaunal communities can reach abundances of 154,000,000 animals per square meter (calculated from Robert's Bay), making them an important facet of B.C. beach biodiversity. At Patricia Bay park, I calculated an average meiofaunal abundance of 39,288,889 animals per square meter. For comparison, previous sampling at Patricia Bay has revealed macrofaunal abundances of <50 animals per square meter (RW El-Sabaawi personal communication). Meiofaunal communities are present, outnumber macrofauna by millions, and are impacted by our activities like all other organisms. They are deserving of more study; we know very little about benthic life in Canada, even though our country has three oceans worth of area to study (Archambault *et al.*, 2010). Annual sampling and land-use data should be collected to see how meiofaunal communities change over time and with development. As more restoration is aimed at beach ecosystems such as estuaries (Arvai *et al.*, 2002), and ancient clam gardens (Salter, 2018), knowledge of changes in meiofaunal communities becomes more important as indicators of the success of these projects. The fact that no pattern could be found from my study shows how complex and variable meiofaunal communities are, and how little we understand them. I also had no way of going to the genus or species levels for taxonomic classification. There may be a vast number of cryptic species that vary between beach types. Improved methods based on the suggestions in this discussion along with improved taxonomical expertise could shed more light on this. Giere (2009) explains that with enough research, advanced statistics could link patterns in the meiofaunal community to large ecological trends, help us to understand pollution effects, and form links to other areas in science. My study revealed the high variability that exists over a small geographic area, and how difficult it is to understand these patterns without time-series data. This study only touched on the summer season, and I hope that seasonal sampling will continue at some of these beaches. There is a plea for more data in the literature (Archambault *et al.*, 2010; Brustolin *et al.*, 2018; Bianchelli and Danovaro, 2019; Bluhm *et al.*, 2018; Giere 2009), and I add my study to that list of pleas. Above all else, the data generated from this study is the first of the baseline monitoring of Victoria's beaches.

Appendices

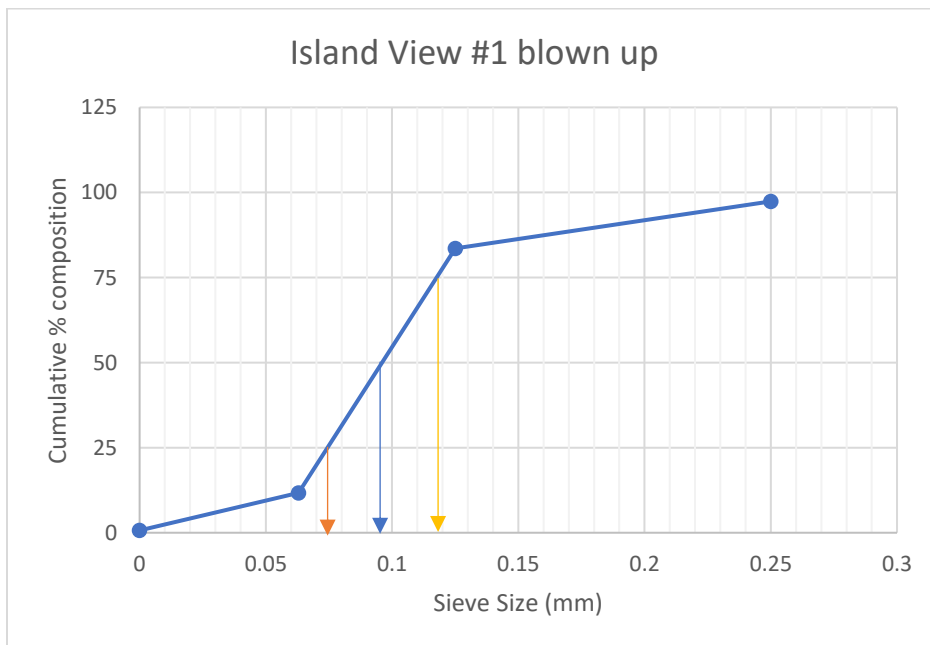
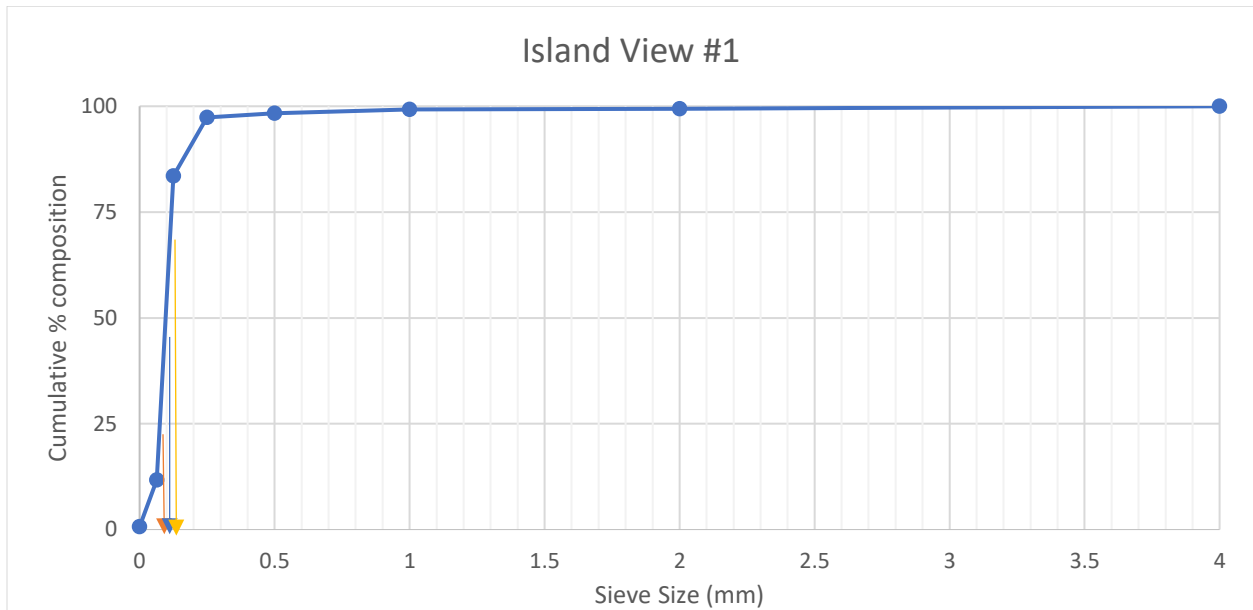
Appendix 1: Field notebook with tide heights.

Table 1: Observations of sediment collection sites. Exact tide heights were obtained after sampling from the Fisheries and Oceans Canada website, in the Canadian Station Inventory and Data Download. Information from Station 7120 was used. Reference URL: <http://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/data-donnees-eng.asp?user=isdm-gdsi®ion=PAC&tst=1&no=7120>

Site	Notes on location	Weather	Date	Time	Tide Height (feet)	Sediment sample #	Depth Achieved	Sediment size	Sediment Appearance
Albert's Head Lagoon	Right of parking lot, to the end of the beach. Sample 1ft from water.	Sunny & Windy	02-Jul-20	10:19 AM	1.3	1	15-17cm	large	even colour
Albert's Head Lagoon	Right of parking lot, to the end of the beach. Sample 1ft from water.	Sunny & Windy	02-Jul-20	10:19 AM	1.3	2	14cm	large	even colour
Cadboro Bay Beach	In front of red octopus	Cloudy & Windy	07-Jul-20	10:08 AM	0.29	1	13cm	small sand	even colour
Cadboro Bay Beach	In front of red octopus	Cloudy & Windy	07-Jul-20	10:08 AM	0.29	2	12cm	small sand	even colour
Loon Bay	Middle of beach	Cloudy & Windy	07-Jul-20	10:30 AM	0.26	1	15cm	small sand/mud	even colour
Loon Bay	Middle of beach	Cloudy & Windy	07-Jul-20	10:30 AM	0.26	2	13cm	small sand/mud	even colour
Willows Beach	By playground	Cloudy & Windy	07-Jul-20	11:20 AM	0.37	1	16cm	small sand	even colour
Willows Beach	By playground	Cloudy & Windy	07-Jul-20	11:20 AM	0.37	2	17cm	small sand	even colour
Gonzales Bay	Middle of beach	Cloudy & Windy	07-Jul-20	12:20 PM	0.65	1	11cm	small sand	even colour
Gonzales Bay	Middle of beach	Cloudy & Windy	07-Jul-20	12:20 PM	0.65	2	12cm	small sand	even colour
Funnel Cove	Down stairs, middle of beach	Cloudy & Windy	07-Jul-20	1:03 PM	0.89	1	15cm	small sand	even colour
Funnel Cove	Down stairs, middle of beach	Cloudy & Windy	07-Jul-20	1:03 PM	0.89	2	15cm	small sand	even colour
Esquimalt Lagoon	Near bridge	Sunny & Windy	08-Jul-20	11:03 AM	0.45	1	14cm	small sand/mud	even colour
Esquimalt Lagoon	Near bridge	Sunny & Windy	08-Jul-20	11:03 AM	0.45	2	14cm	small sand/mud	even colour
Dufus Trail	Anya Court access, down path, by playground	Cloudy & Windy	08-Jul-20	11:30 AM	0.47	1	10cm	fine mud	dark, even colour
Dufus Trail	Anya Court access, down path, by playground	Cloudy & Windy	08-Jul-20	11:30 AM	0.47	2	10cm	fine mud	dark, even colour
Craigflower Creek	Seabird Road, down bank to the river	Cloudy & Windy	08-Jul-20	12:15 PM	0.58	1	10cm	fine mud	dark, even colour
Craigflower Creek	Seabird Road, down bank to the river	Cloudy & Windy	08-Jul-20	12:15 PM	0.58	2	11cm	fine mud	dark, even colour
Robert's Bay	To the right of Ardwell Avenue	Cloudy	09-Jul-20	10:20 AM	0.87	1	11cm	small sand	slight darkening with depth
Robert's Bay	To the right of Ardwell Avenue	Cloudy	09-Jul-20	10:20 AM	0.87	2	15cm	small sand	slight darkening with depth
Resthaven Park Beach	Right side of beach	Cloudy	09-Jul-20	11:00 AM	0.74	1	9cm	fine mud	dark, even colour
Resthaven Park Beach	Right side of beach	Cloudy	09-Jul-20	11:00 AM	0.74	2	10cm	fine mud	dark, even colour
Coles Bay	Left side of beach	Sunny & Windy	09-Jul-20	1:55 PM	1.05	1	14cm	Sand at the top, then turns to rocks. Eelgrass on top.	Sand is even colour, then pebbles become mixed colours
Coles Bay	Left side of beach	Sunny & Windy	09-Jul-20	1:55 PM	1.05	2	13cm	Sand at the top, then turns to rocks. Eelgrass on top.	Sand is even colour, then pebbles become mixed colours
Patricia Bay	Near river	Sunny & Windy	09-Jul-20	2:30 PM	1.22	1	15cm	Mud	Even colour
Patricia Bay	Near river	Sunny & Windy	09-Jul-20	2:30 PM	1.22	2	15cm	Mud	Even colour
Island View Beach	Down from gazebo	Sunny & hot	20-Jul-20	10:30 AM	0.53	1	4.5cm --> too many rocks underneath to push in more	sand	even colour
Island View Beach	Down from gazebo	Sunny & hot	20-Jul-20	10:30 AM	0.53	2	6cm --> too many rocks underneath to push in more	sand	even colour

Saanichton Bay	Down from stairs, back from water 10m due to flooded beach and seaweed	Sunny & light wind	20-Jul-20	11:00 AM	0.71	1	15cm	mud/ sand	even colour
Saanichton Bay	Down from stairs, back from water 10m due to flooded beach and seaweed	Sunny & light wind	20-Jul-20	11:00 AM	0.71	2	14cm	mud/ sand	even colour
"Dog Park" (Gorge Waterway)	Down from bike path	Sunny & windy	21-Jul-20	10:30 AM	0.41	1	15cm	wet mud	dark, even colour
"Dog Park" (Gorge Waterway)	Down from bike path	Sunny & Windy	21-Jul-20	10:30 AM	0.41	2	16cm	wet mud	dark, even colour
Banfield Park	Down from playground to right	Sunny & Windy	21-Jul-20	11:30 AM	0.74	1	5cm --> too many rocks, clams & seaweed underneath	Mud, sand, rocks, seaweed	mixed colours
Banfield Park	Down from playground to right	Sunny & Windy	21-Jul-20	11:30 AM	0.74	2	4cm --> too many rocks, clams & seaweed underneath	Mud, sand, rocks, seaweed	mixed colours
Lime Bay	Small beach from park access	Sunny & Windy	21-Jul-20	12:15 PM	1.02	1	11cm	sand	even colour
Lime Bay	Small beach from park access	Sunny & Windy	21-Jul-20	12:15 PM	1.02	2	11cm	sand	even colour

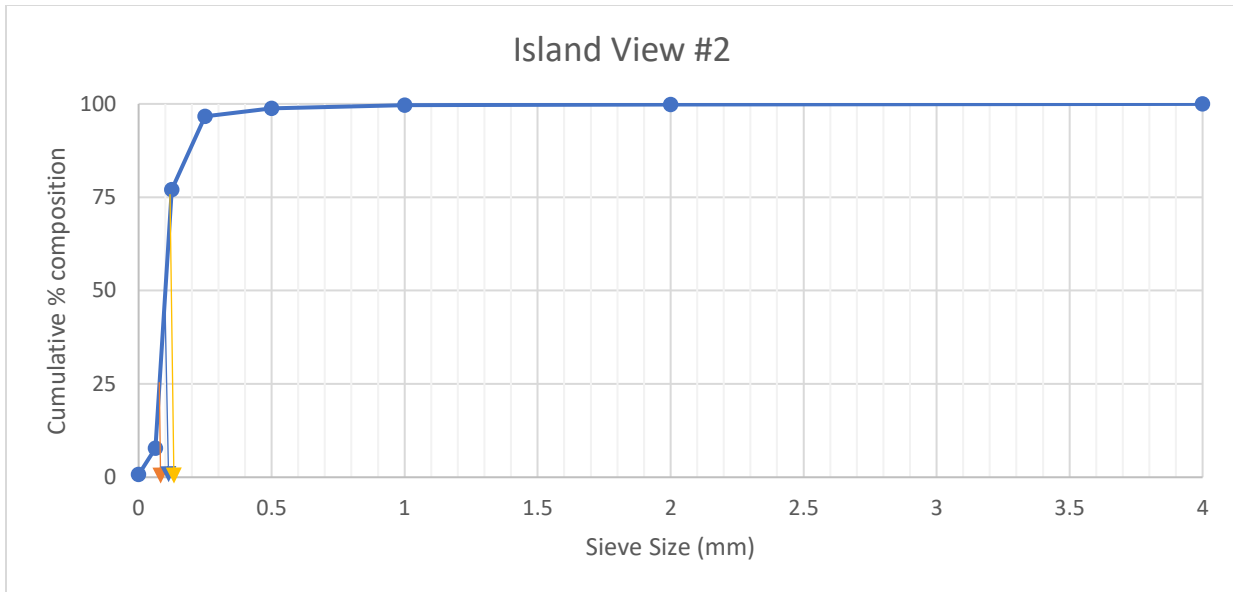
Appendix 2: Cumulative percent figures from each site.



$Q_{25}=0.075$ $Q_{50}=0.095$ $Q_{75}=0.12$

Median Grain Size = $Q_{50} = 0.095$

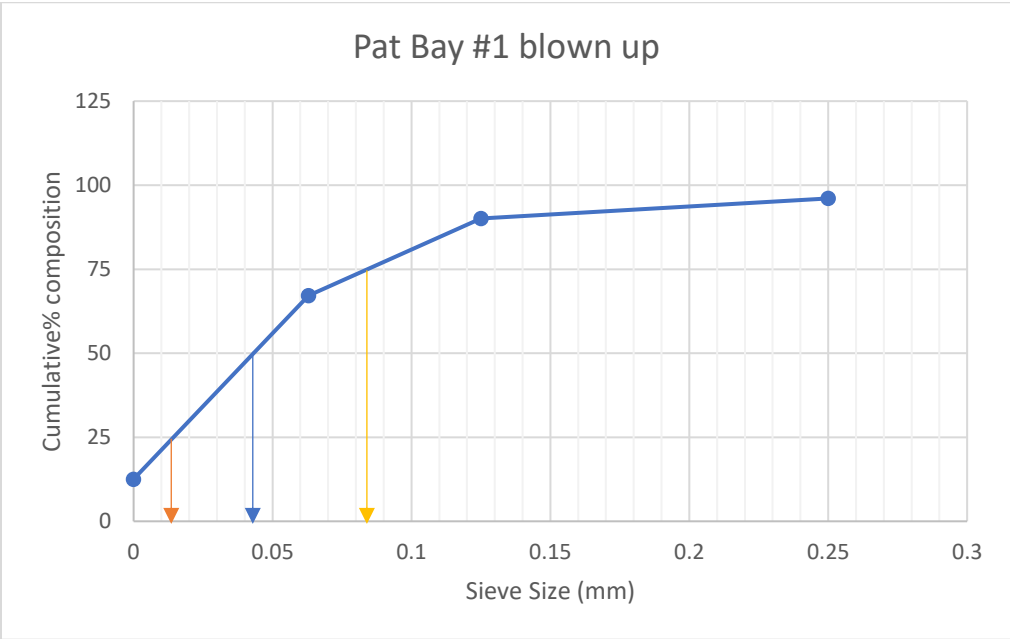
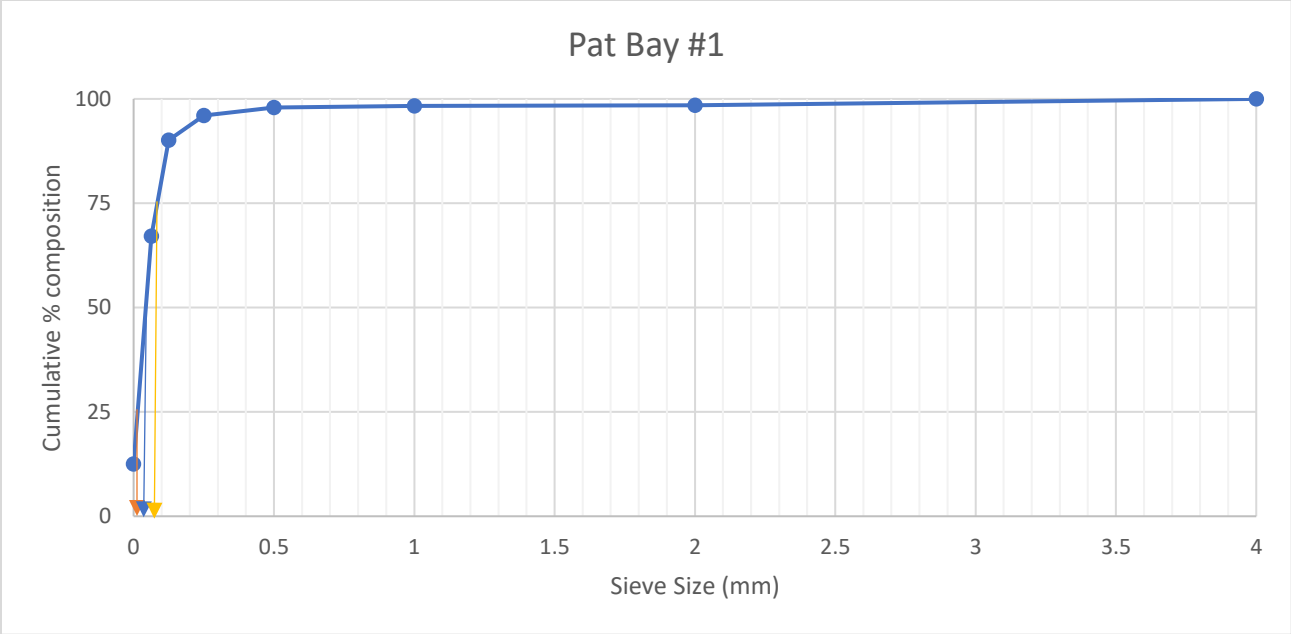
Sorting Coefficient = $Q_{25}/Q_{75} = 0.075/0.12 = 0.625$



$Q_{25}=0.080$ $Q_{50}=0.10$ $Q_{75}=0.12$

Median Grain Size = $Q_{50} = 0.10$

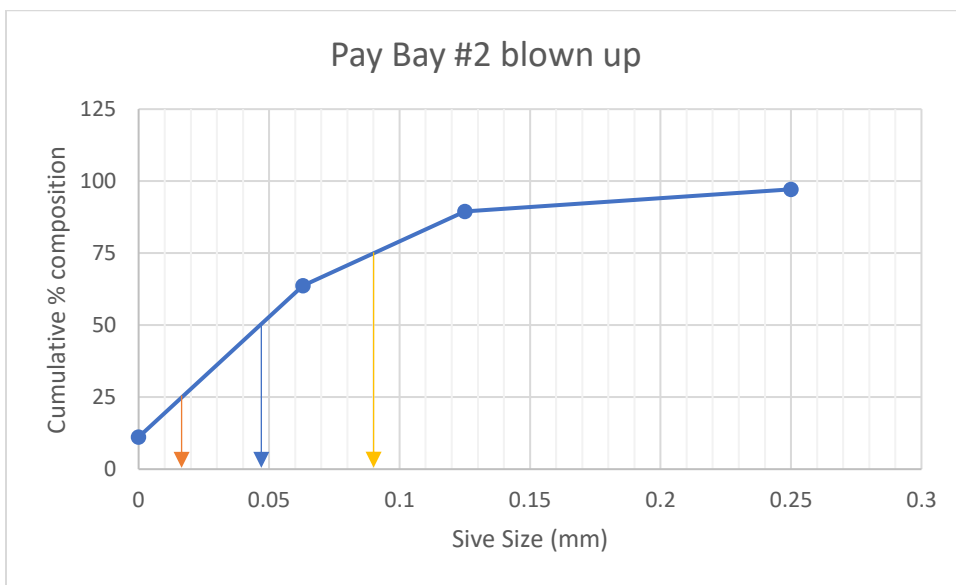
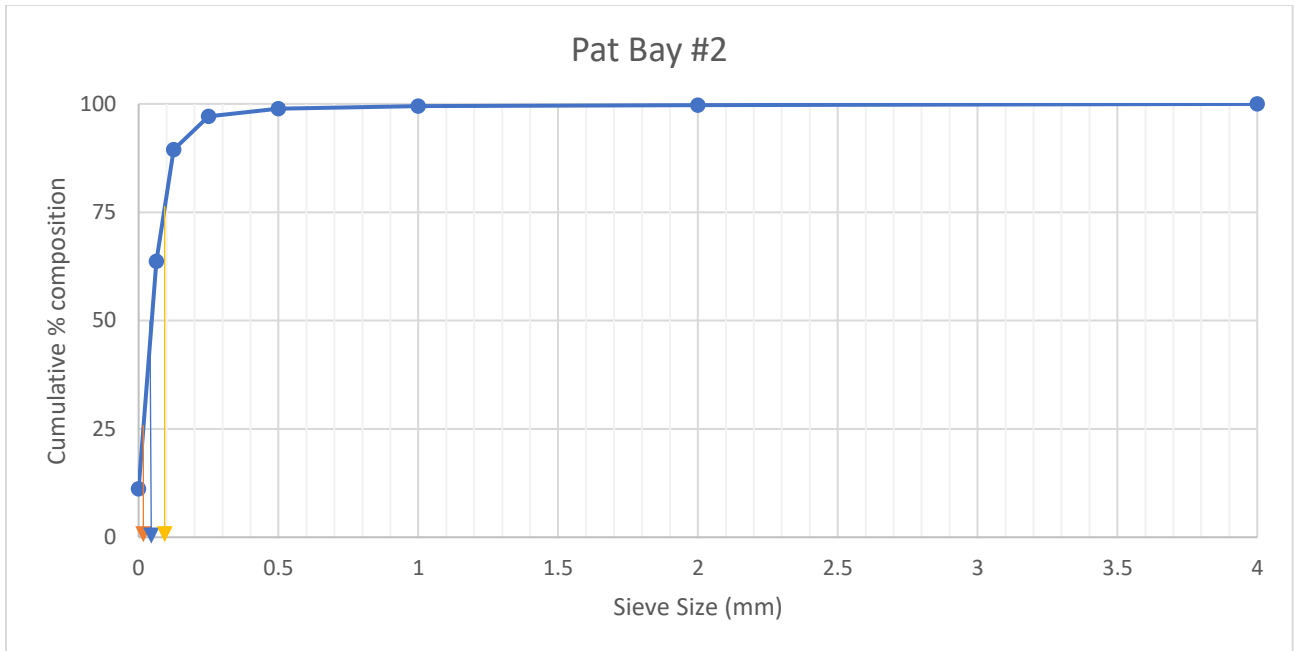
Sorting Coefficient = $Q_{25}/Q_{75} = 0.080/0.12 = 0.667$



Q25=0.014 Q50=0.042 Q75=0.083

Median Grain Size = Q50 = 0.042

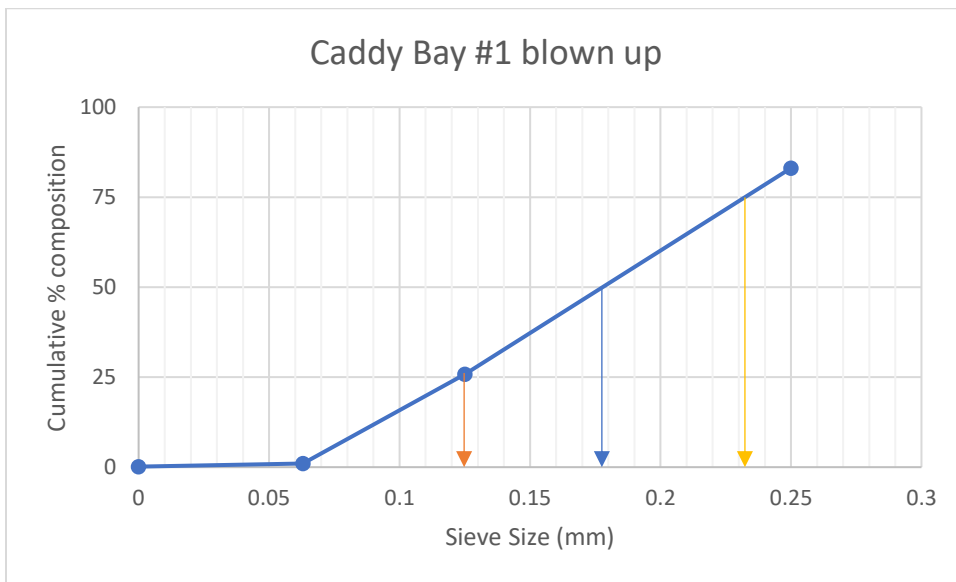
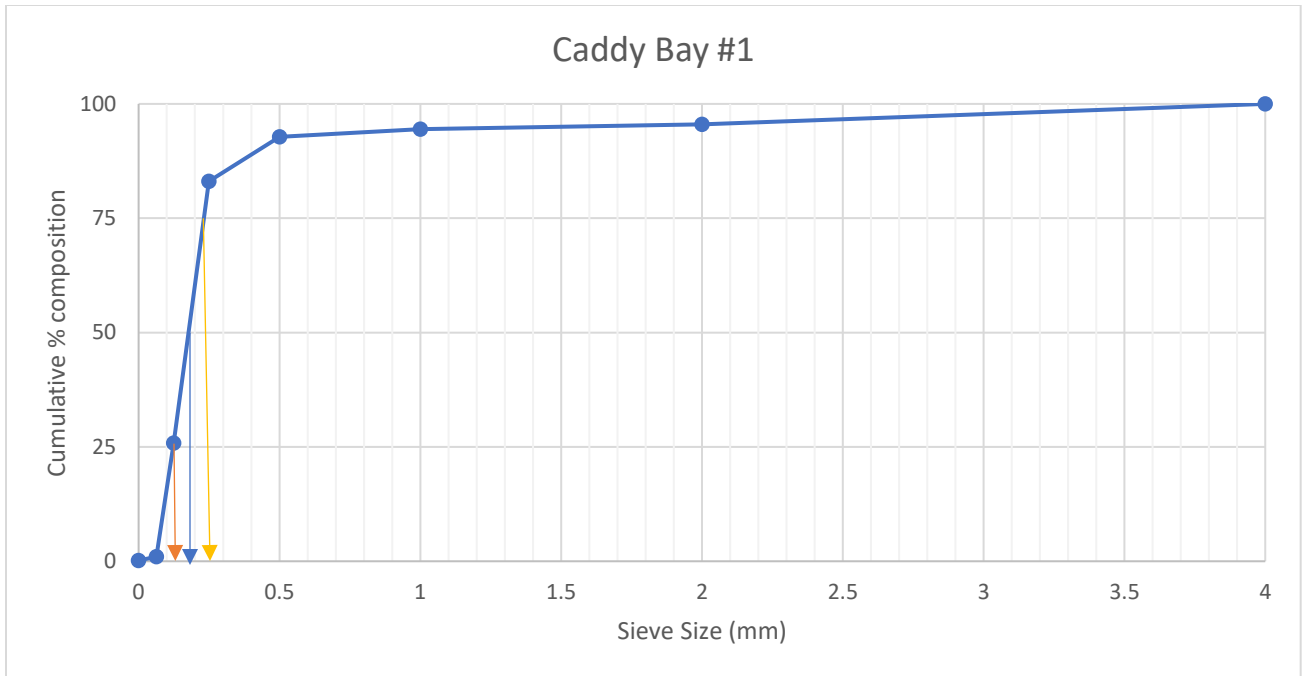
Sorting Coefficient = Q25/Q75 = 0.014/0.083 = 0.169



$Q_{25}=0.018$ $Q_{50}=0.048$ $Q_{75}=0.090$

Median Grain Size = $Q_{50} = 0.048$

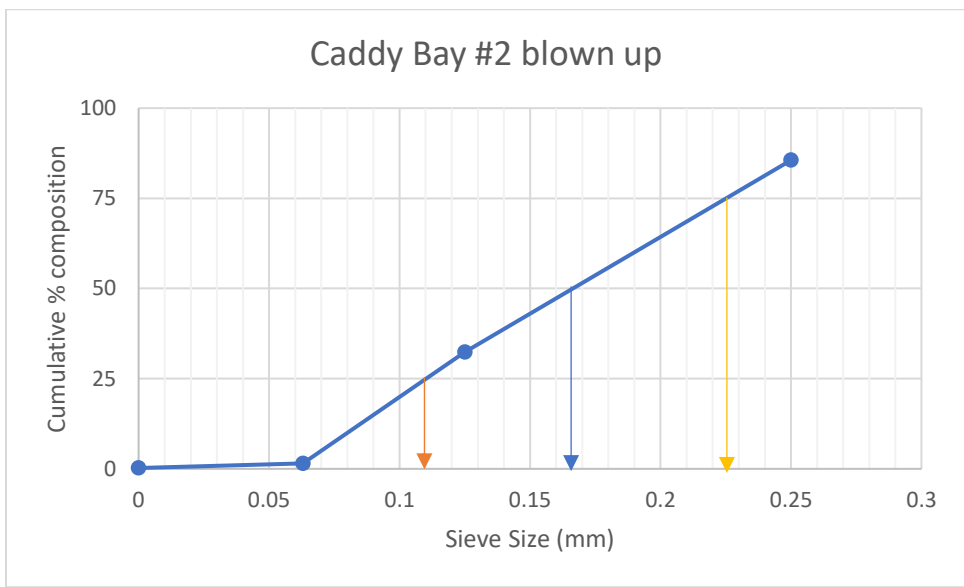
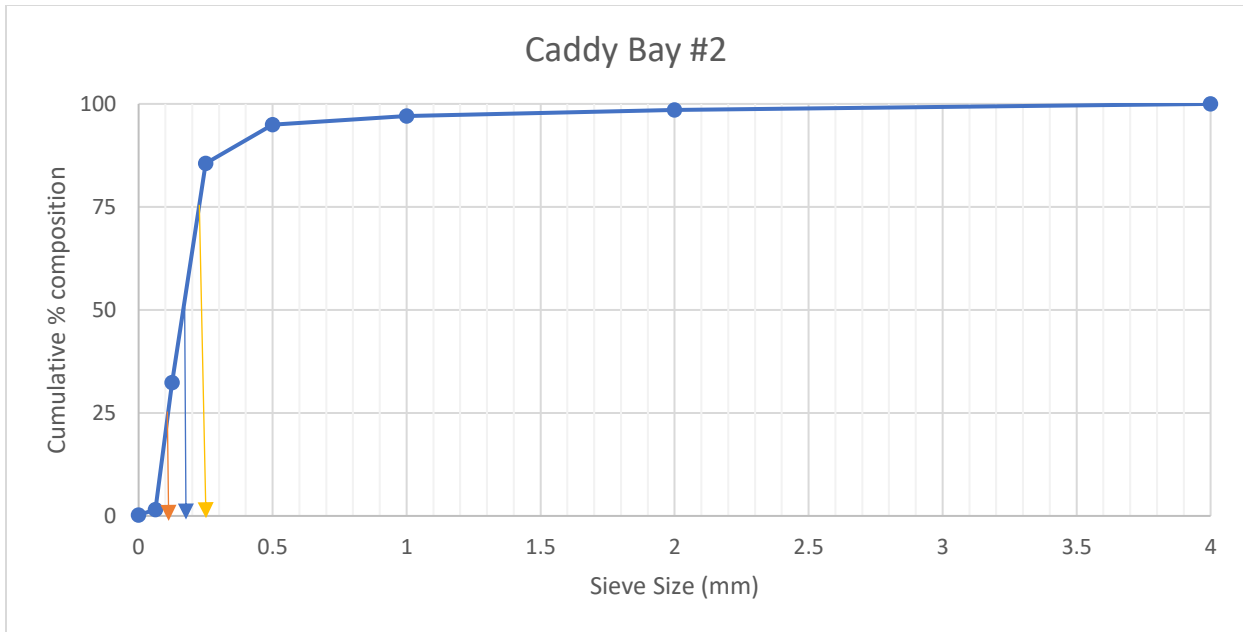
Sorting Coefficient = $Q_{25}/Q_{75} = 0.018/0.090 = 0.20$



$Q_{25}=0.125$ $Q_{50}=0.179$ $Q_{75}=0.231$

Median Grain Size = $Q_{50} = 0.179$

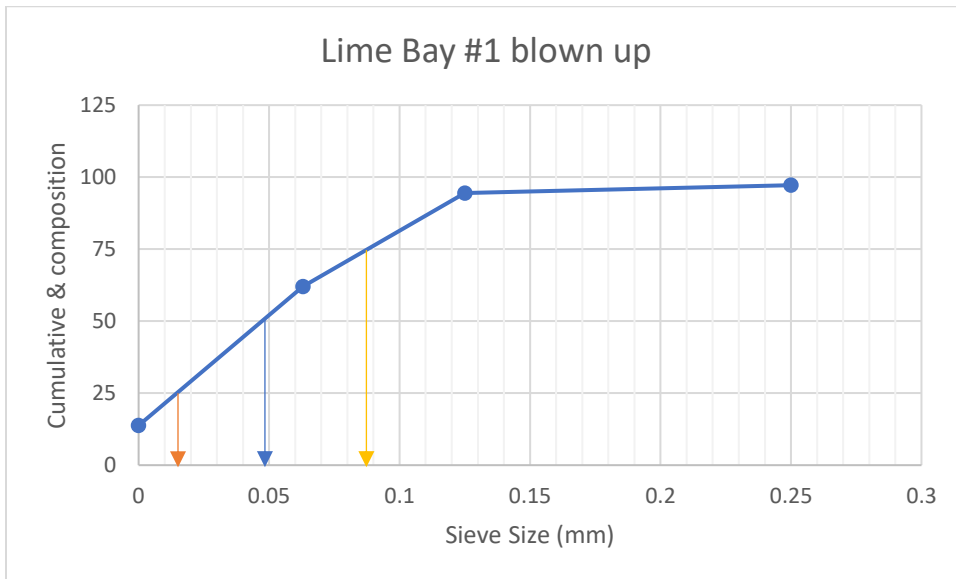
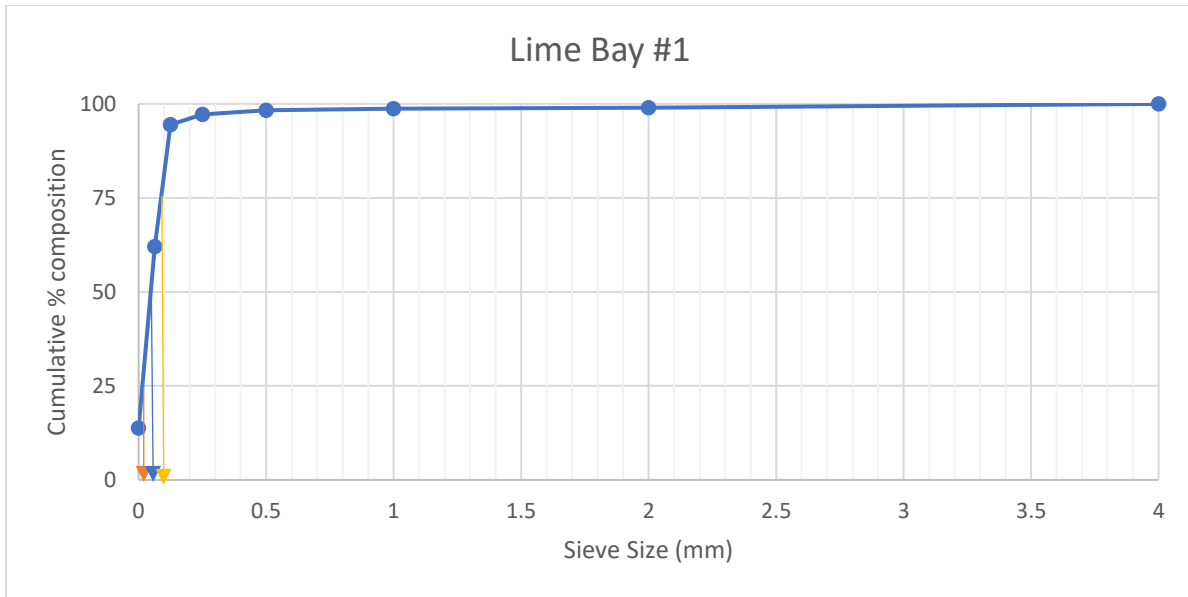
Sorting Coefficient = $Q_{25}/Q_{75} = 0.125/0.231 = 0.541$



Q25=0.11 Q50=0.166 Q75=0.221

Median Grain Size = Q50 = 0.166

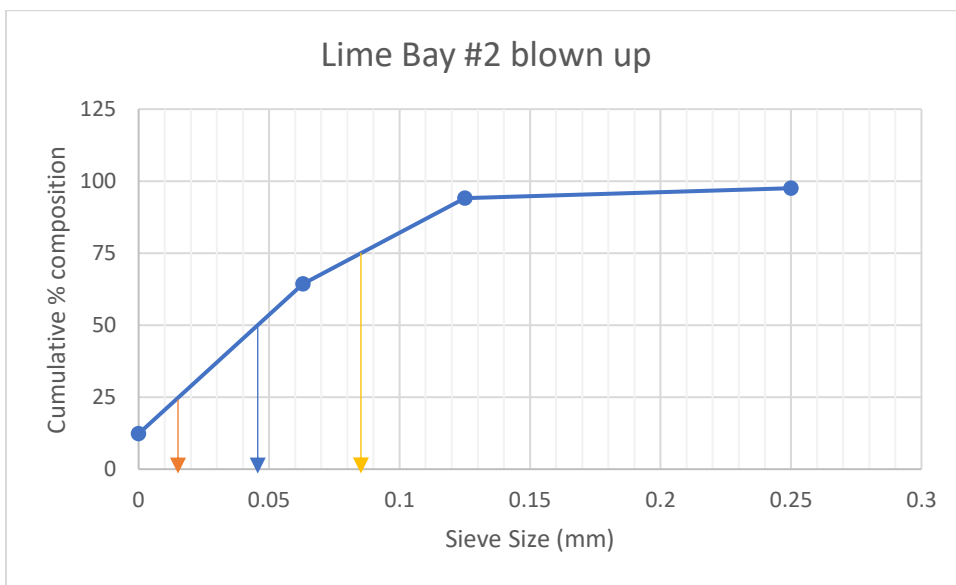
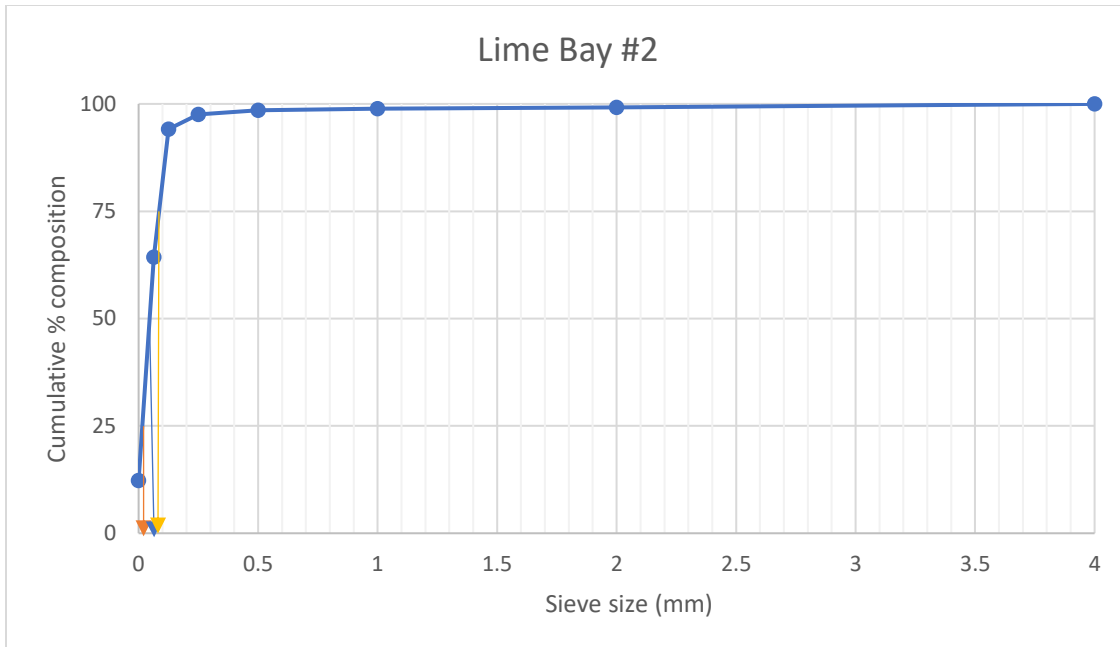
Sorting Coefficient = $Q25/Q75 = 0.11/0.221 = 0.498$



Q25=0.015 Q50=0.049 Q75=0.089

Median Grain Size = Q50 = 0.049

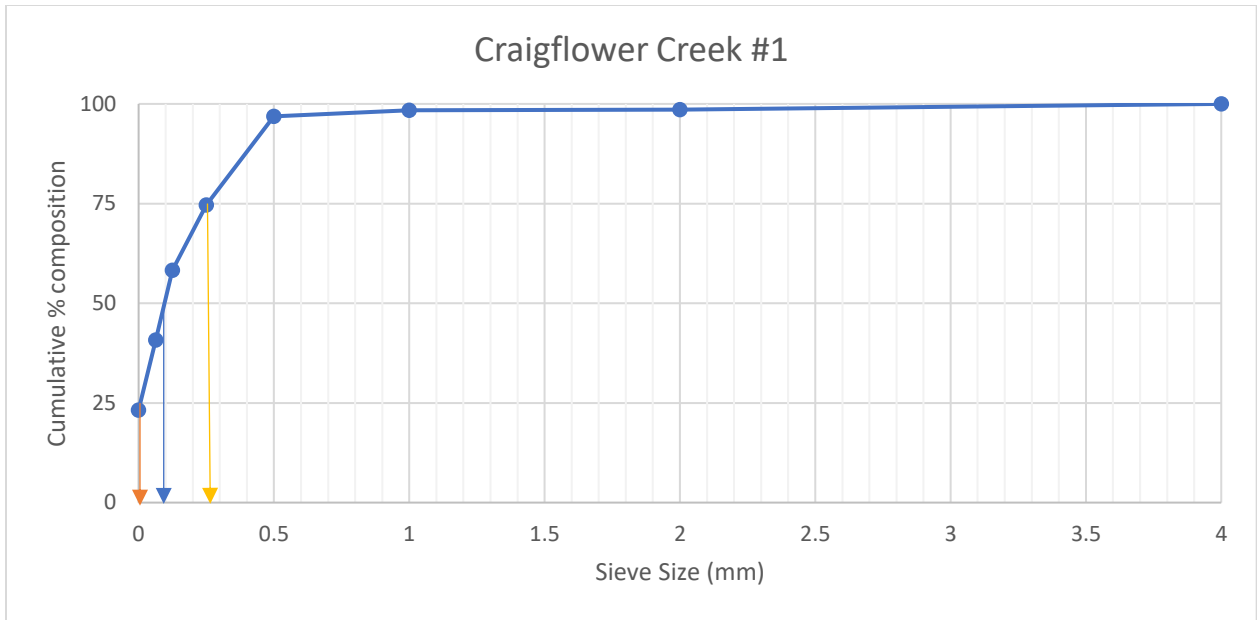
Sorting Coefficient = $Q25/Q75 = 0.015/0.089 = 0.169$



$Q_{25}=0.015$ $Q_{50}=0.045$ $Q_{75}=0.086$

Median Grain Size = $Q_{50} = 0.045$

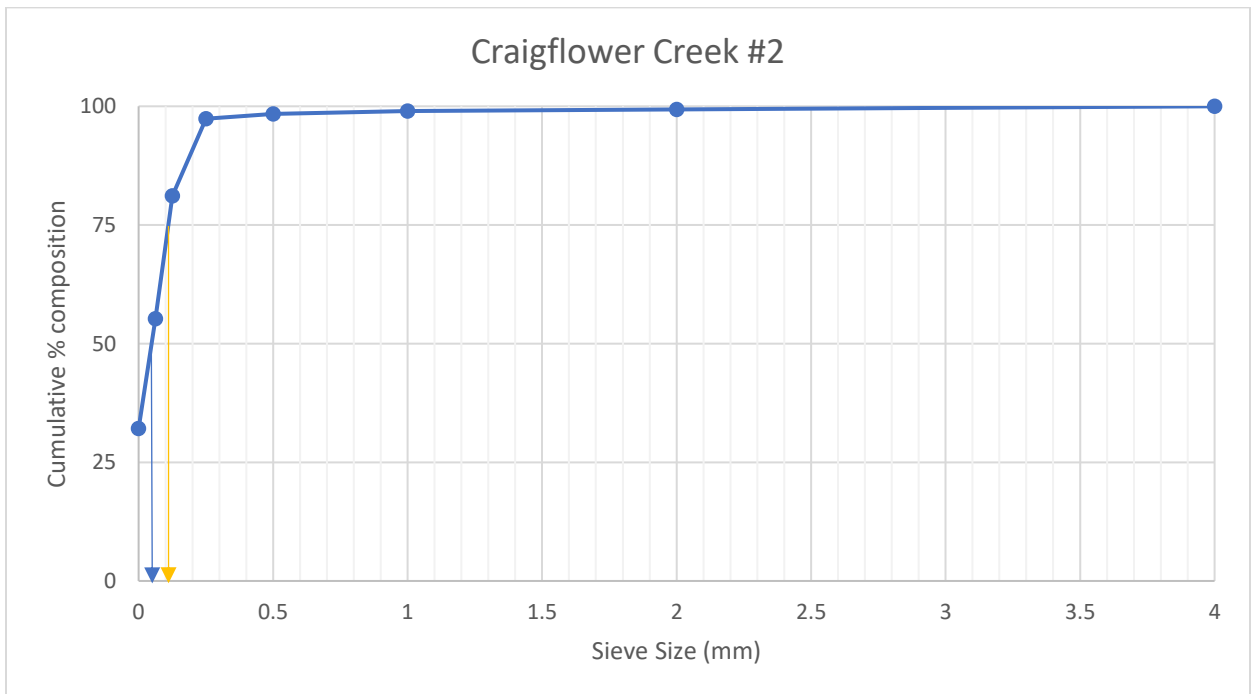
Sorting Coefficient = $Q_{25}/Q_{75} = 0.015/0.086 = 0.174$



Q25=0.01 Q50=0.10 Q75=0.25

Median Grain Size = Q50 = 0.10

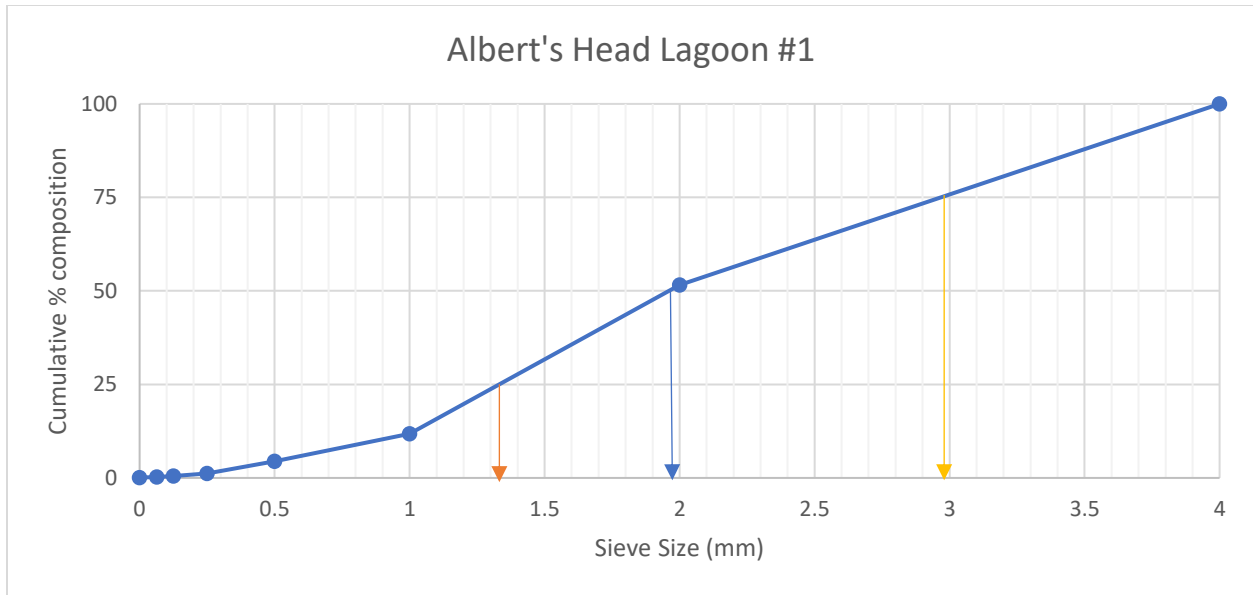
Sorting Coefficient = $Q25/Q75 = 0.01/0.25 = 0.040$



Q25=0.00 Q50=0.05 Q75=0.11

Median Grain Size = Q50 = 0.05

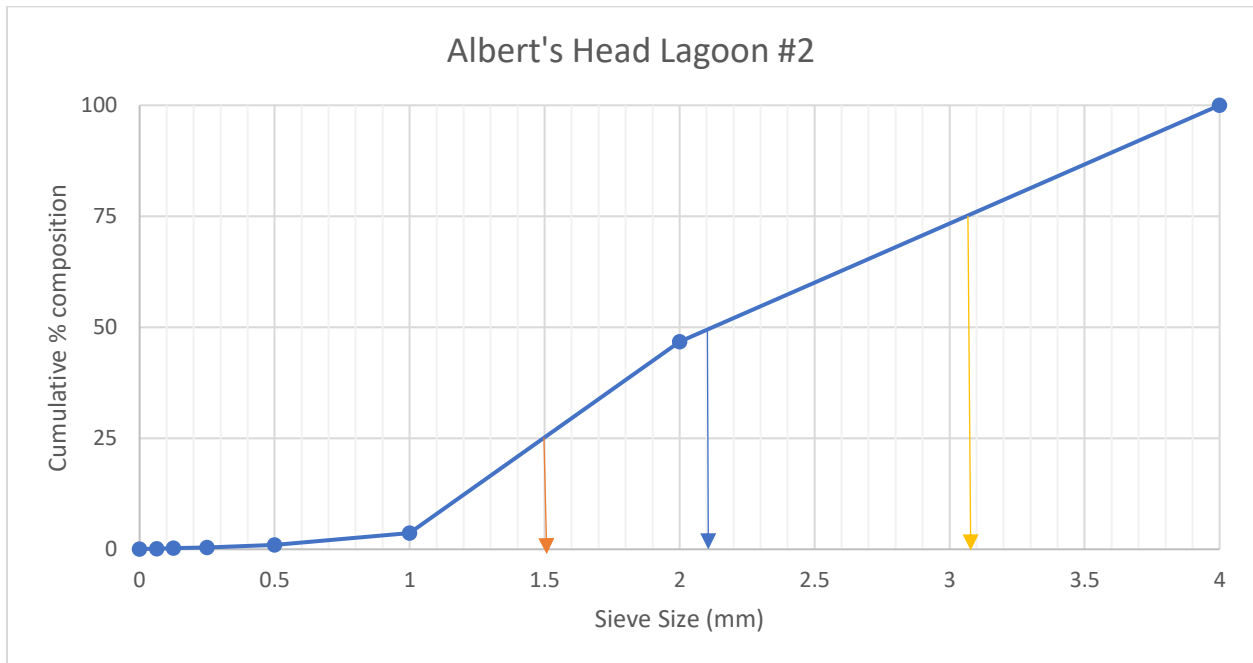
Sorting Coefficient = $Q25/Q75 = 0.00/0.11 = 0.00$



Q25=1.32 Q50=1.98 Q75=2.99

Median Grain Size = Q50 = 1.98

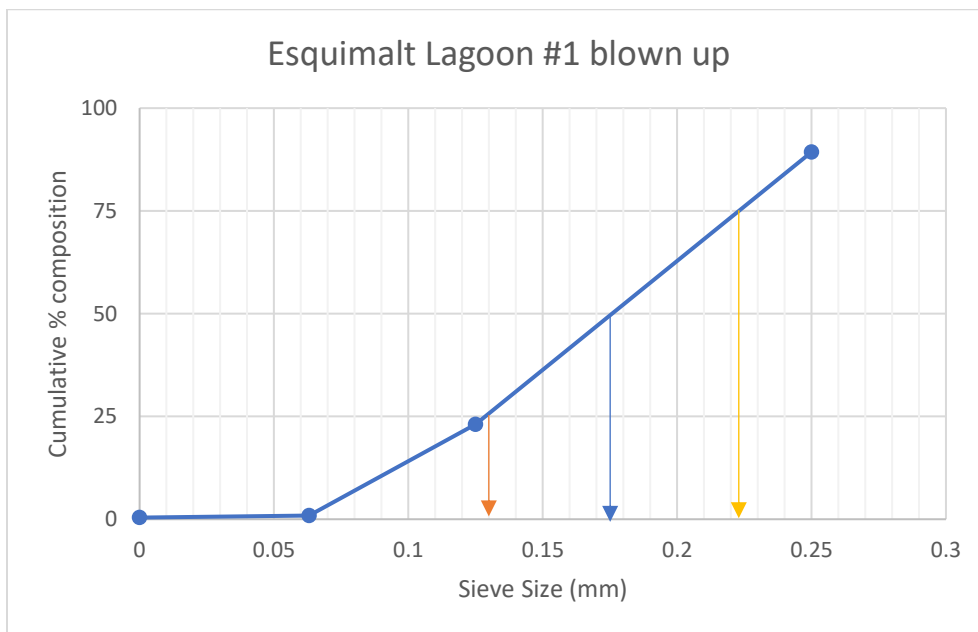
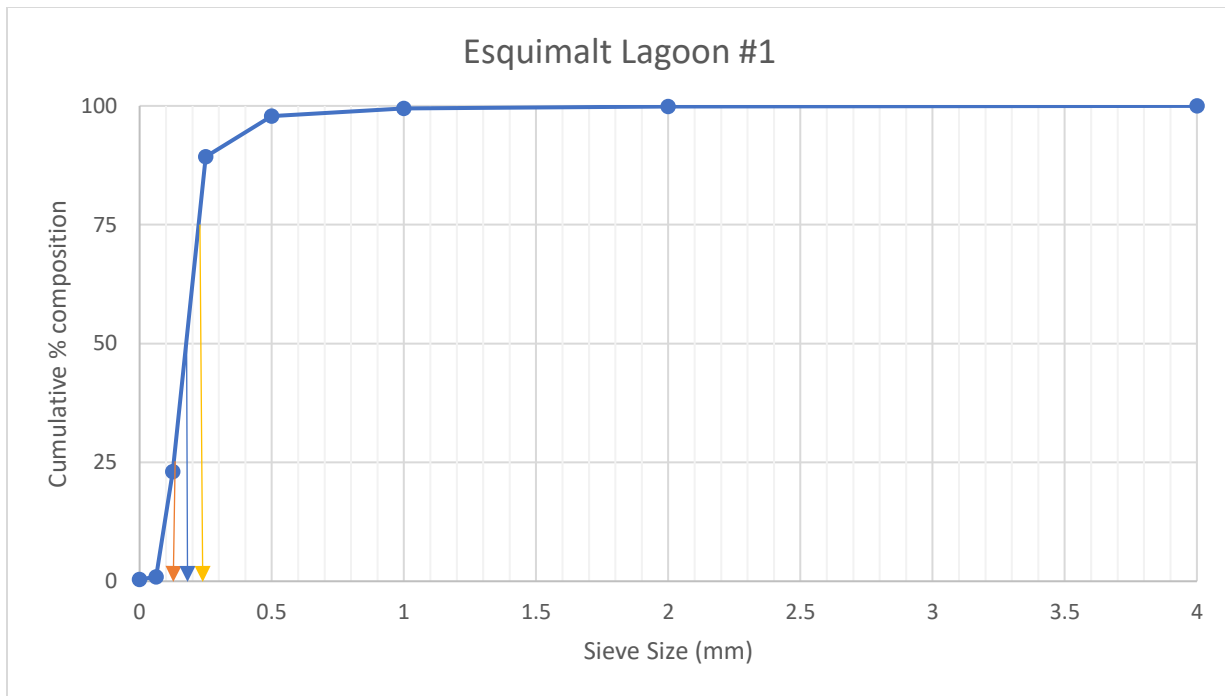
Sorting Coefficient = $Q25/Q75 = 1.32/2.99 = 0.44$



Q25=1.50 Q50=2.10 Q75=3.09

Median Grain Size = Q50 = 2.10

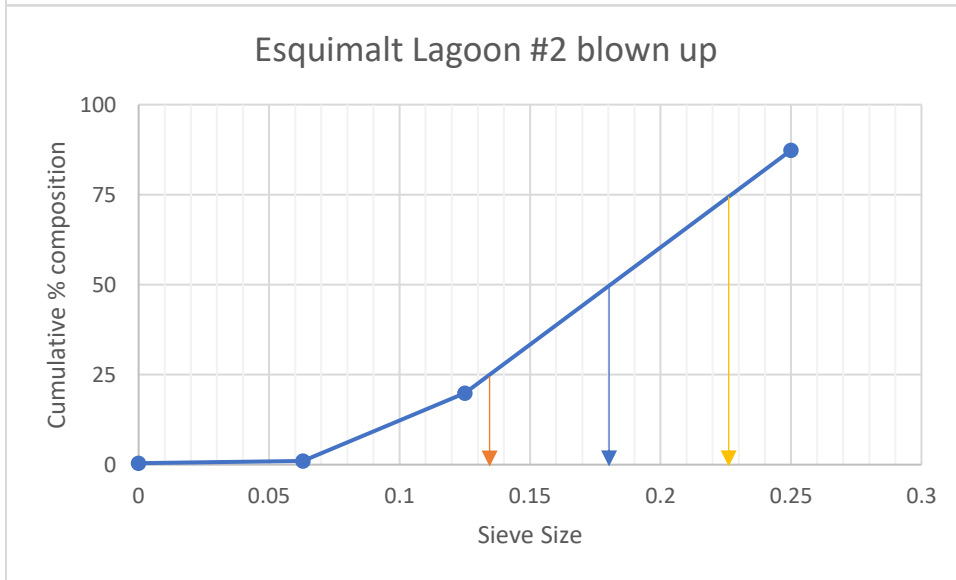
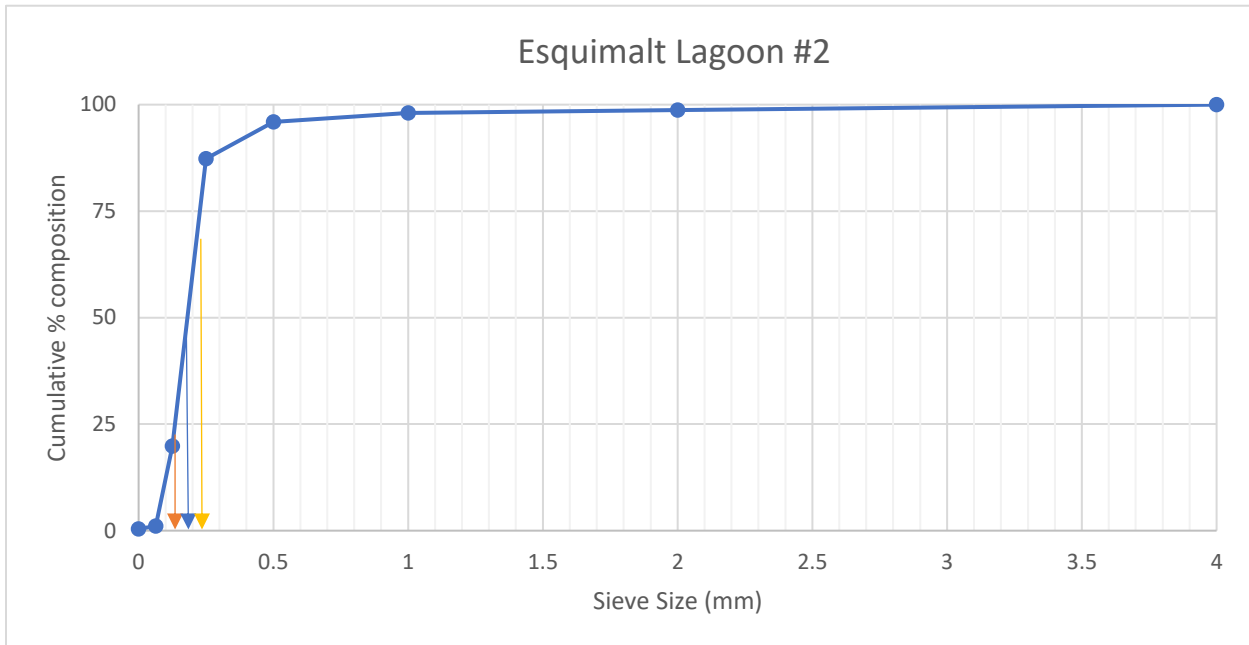
Sorting Coefficient = $Q25/Q75 = 1.50/3.09 = 0.49$



Q25=0.123 Q50=0.175 Q75=0.222

Median Grain Size = Q50 = 0.175

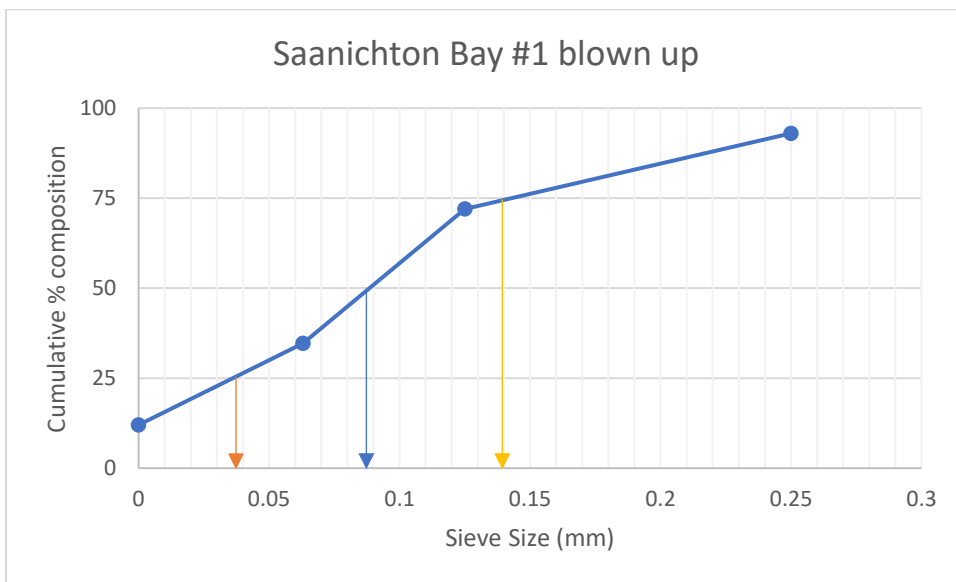
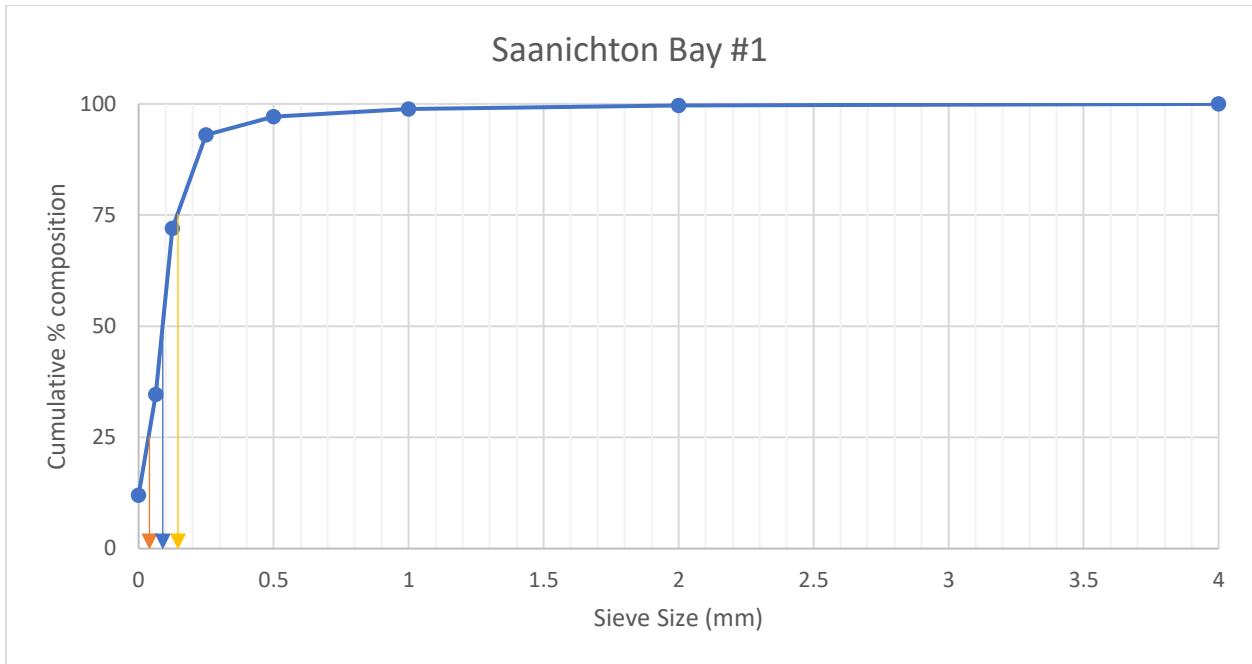
Sorting Coefficient = $Q25/Q75 = 0.123/0.222 = 0.554$



Q25=0.135 Q50=0.18 Q75=0.226

Median Grain Size = Q50 = 0.18

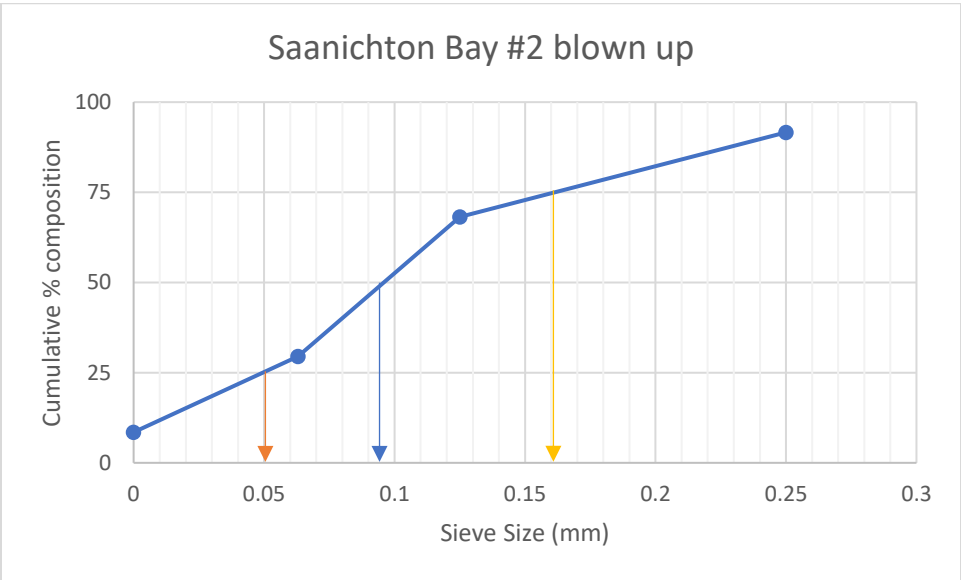
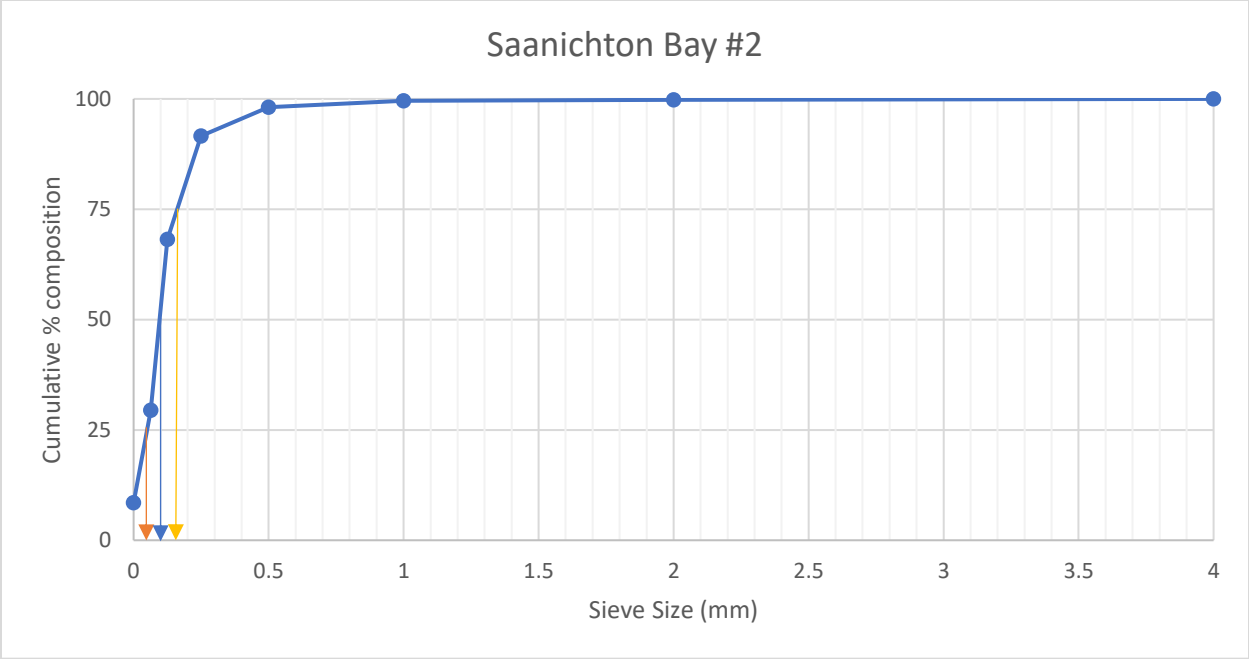
Sorting Coefficient = $Q25/Q75 = 0.135/0.226 = 0.597$



$Q_{25}=0.039$ $Q_{50}=0.089$ $Q_{75}=0.14$

Median Grain Size = $Q_{50} = 0.089$

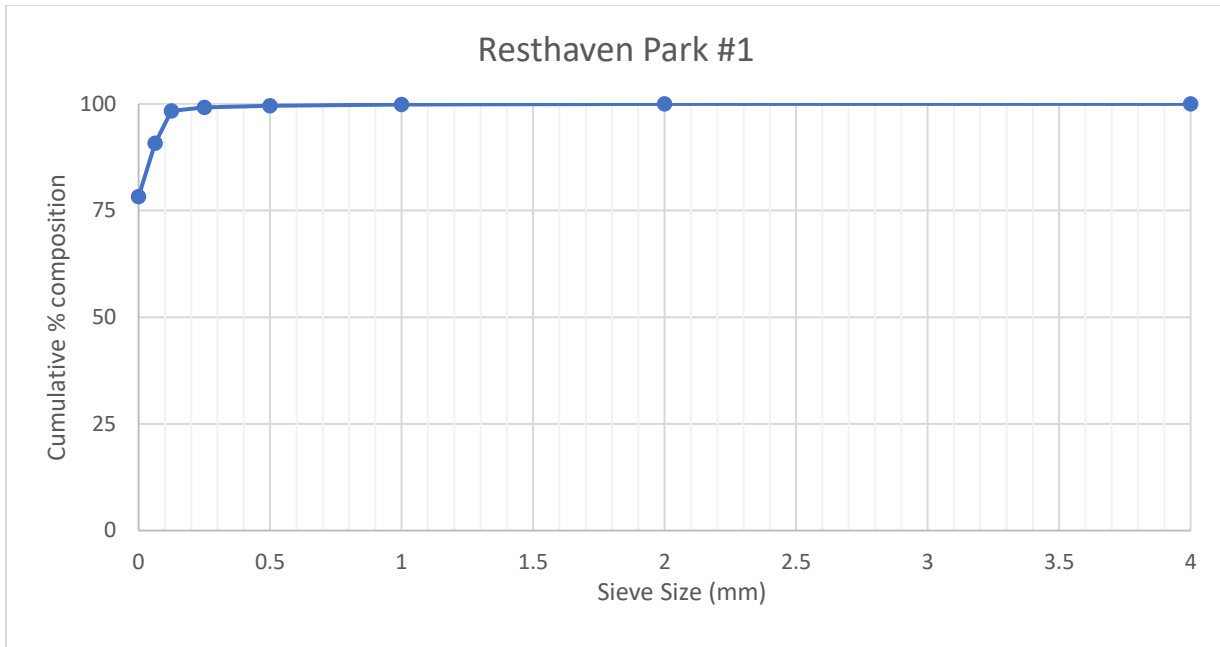
Sorting Coefficient = $Q_{25}/Q_{75} = 0.039/0.14 = 0.279$



Q25=0.05 Q50=0.095 Q75=0.16

Median Grain Size = Q50 = 0.095

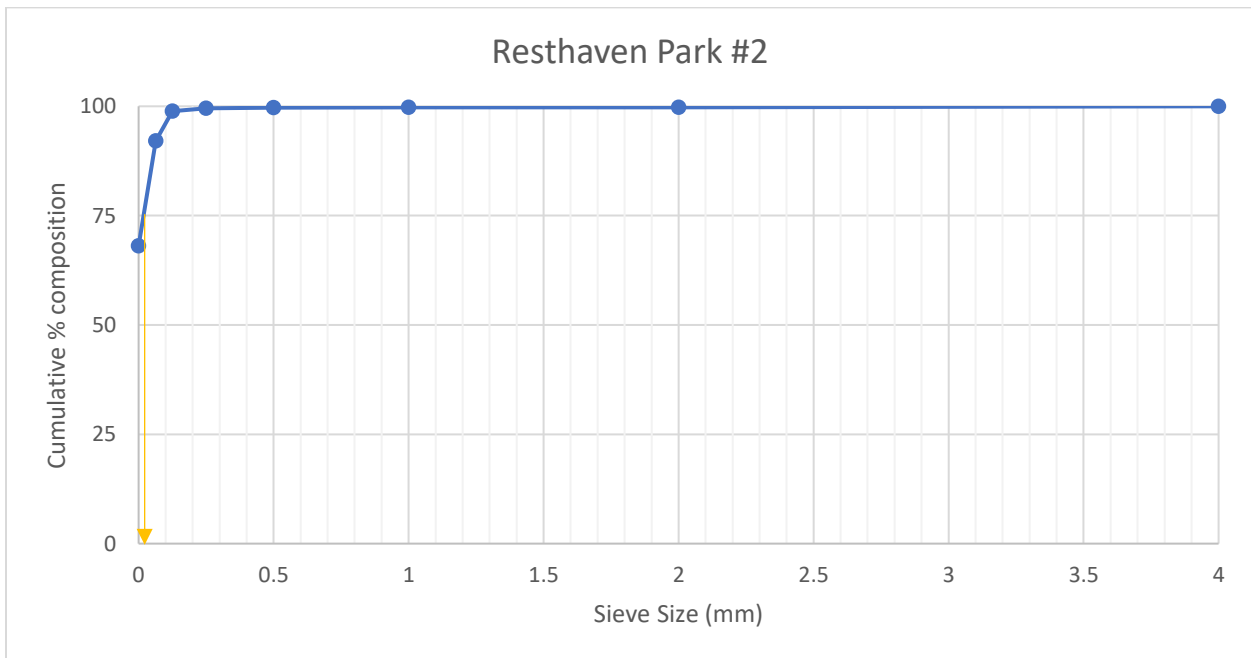
Sorting Coefficient = $Q25/Q75 = 0.05/0.16 = 0.31$



Q25=0.01 Q50=0.01 Q75=0.01

Median Grain Size = Q50 = 0.01

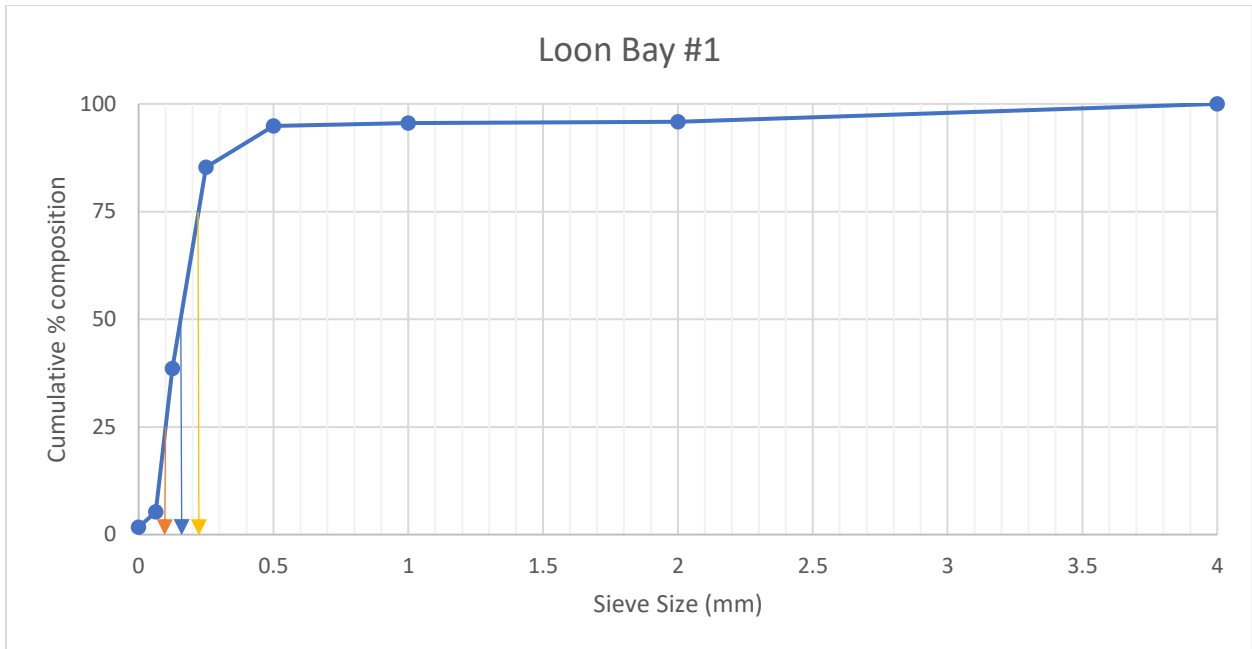
Sorting Coefficient = $Q25/Q75 = 1.00$



Q25=0.01 Q50=0.01 Q75=0.01

Median Grain Size = Q50 = 0.01

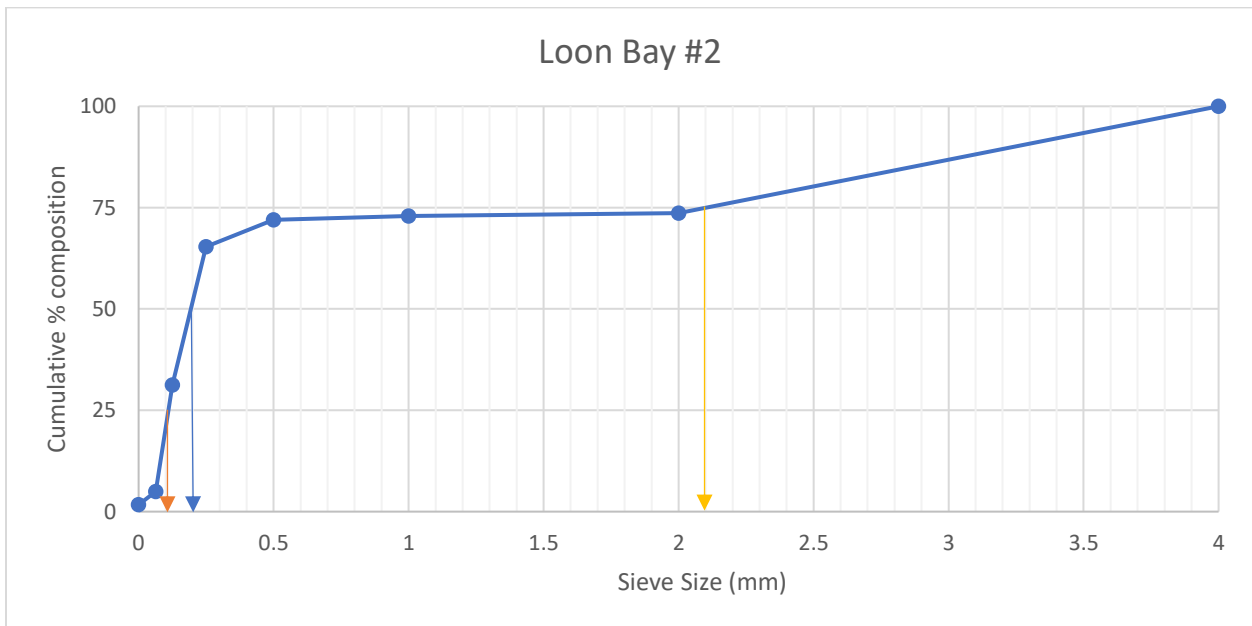
Sorting Coefficient = $Q25/Q75 = 0.01/0.01 = 1.00$



Q25=0.10 Q50=0.16 Q75=0.21

Median Grain Size = Q50 = 0.16

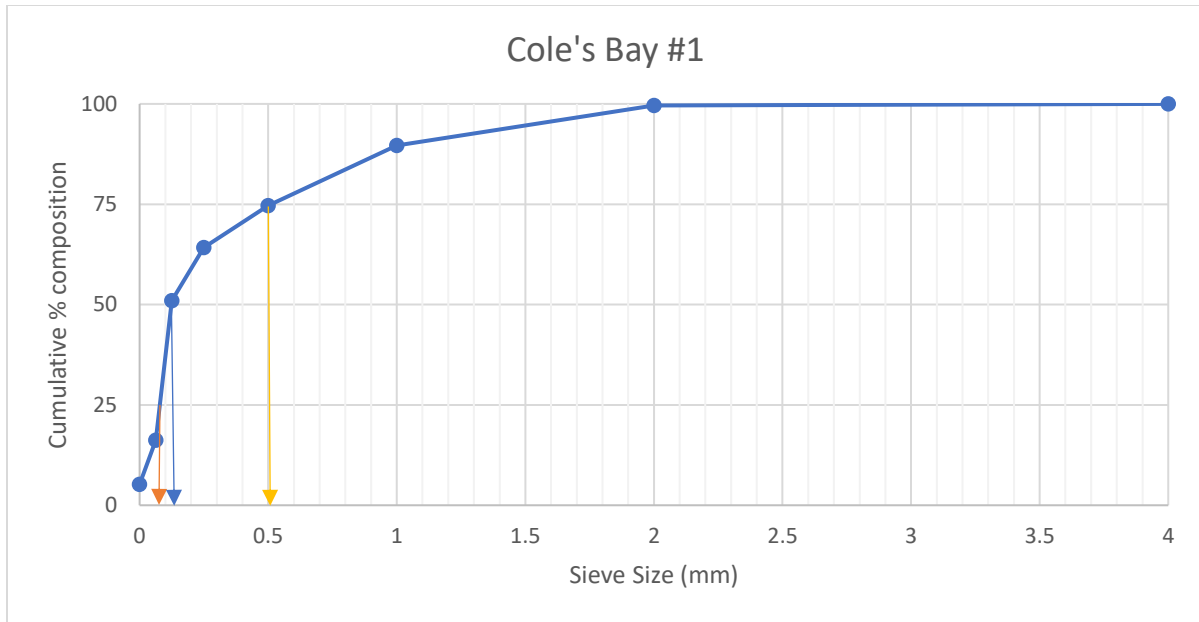
Sorting Coefficient = $Q25/Q75 = 0.10/0.21 = 0.48$



Q25=0.10 Q50=0.20 Q75=2.10

Median Grain Size = Q50 = 0.20

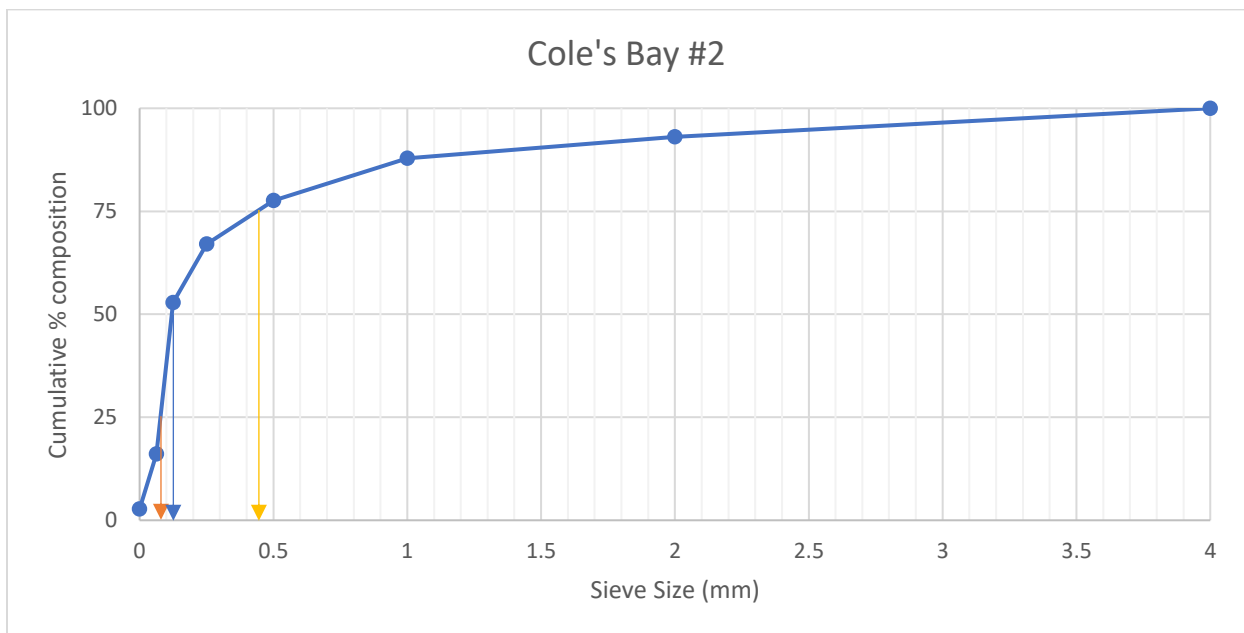
Sorting Coefficient = $Q25/Q75 = 0.10/2.10 = 0.047$



Q25=0.07 Q50=0.12 Q75=0.50

Median Grain Size = Q50 = 0.12

Sorting Coefficient = $Q25/Q75 = 0.07/0.50 = 0.14$



Q25=0.09 Q50=0.12 Q75=0.45

Median Grain Size = Q50 = 0.12

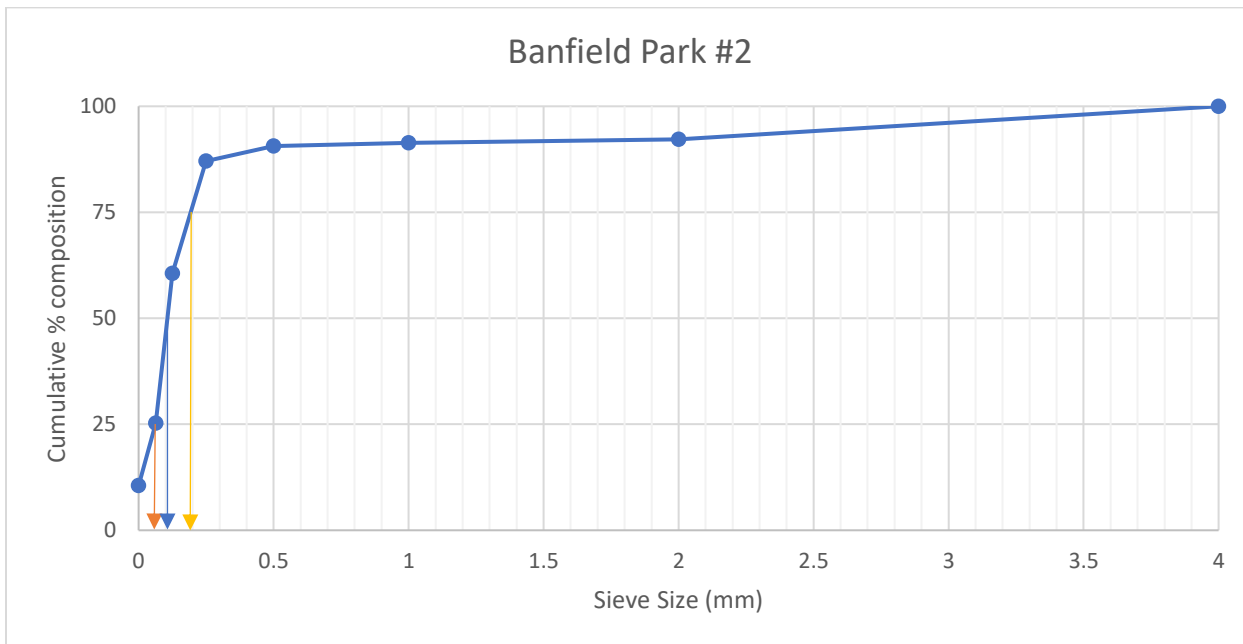
Sorting Coefficient = $Q25/Q75 = 0.09/0.45 = 0.20$



$Q_{25}=0.07$ $Q_{50}=0.11$ $Q_{75}=0.24$

Median Grain Size = $Q_{50} = 0.11$

Sorting Coefficient = $Q_{25}/Q_{75} = 0.07/0.24 = 0.29$



$Q_{25}=0.063$ $Q_{50}=0.10$ $Q_{75}=0.20$

Median Grain Size = $Q_{50} = 0.10$

Sorting Coefficient = $Q_{25}/Q_{75} = 0.063/0.20 = 0.315$



Q25=0.076 Q50=0.093 Q75=0.11

Median Grain Size = Q50 = 0.093

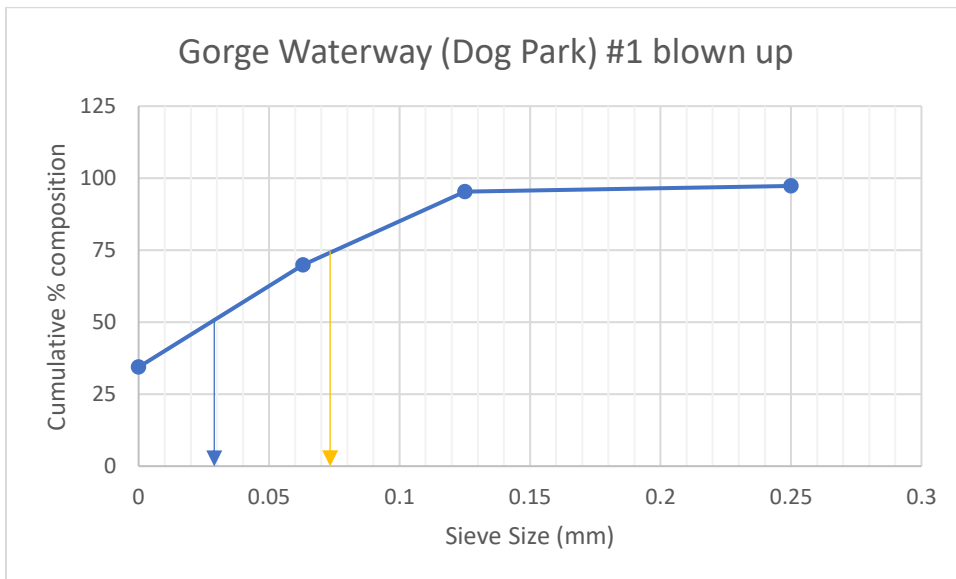
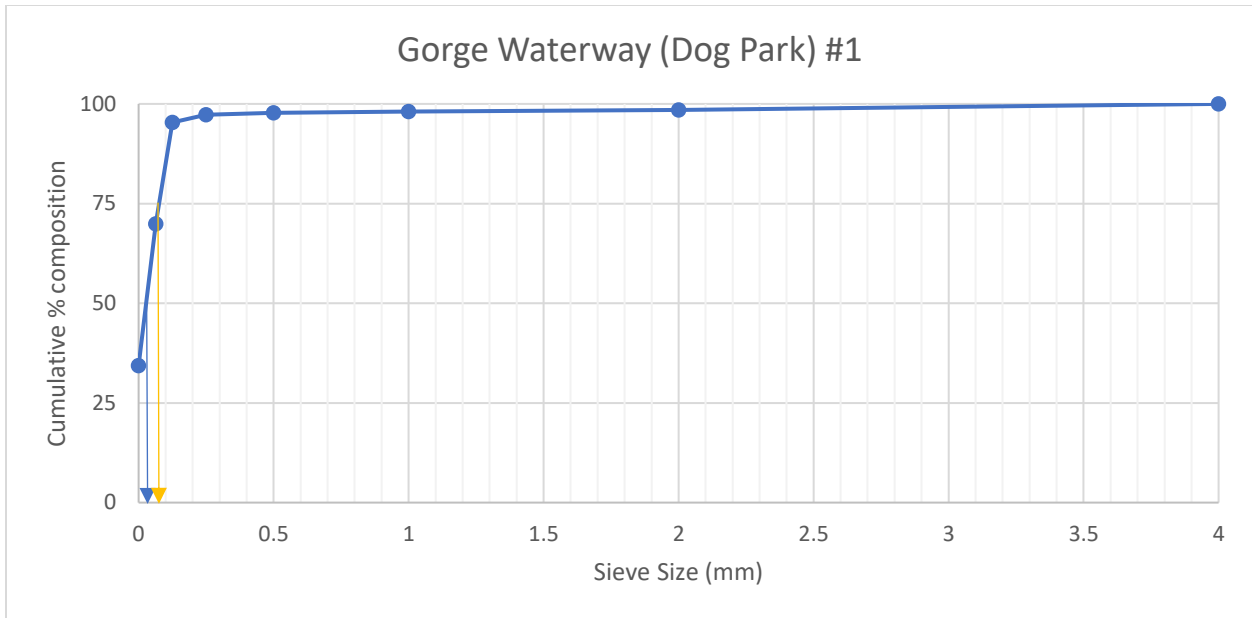
Sorting Coefficient = $Q25/Q75 = 0.076/0.11 = 0.691$



Q25=0.075 Q50=0.092 Q75=0.11

Median Grain Size = Q50 = 0.092

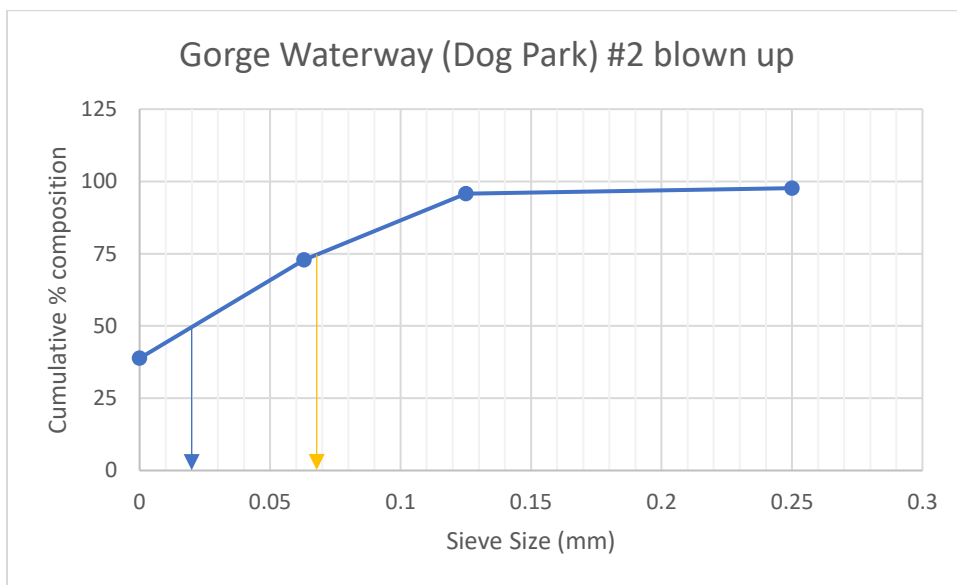
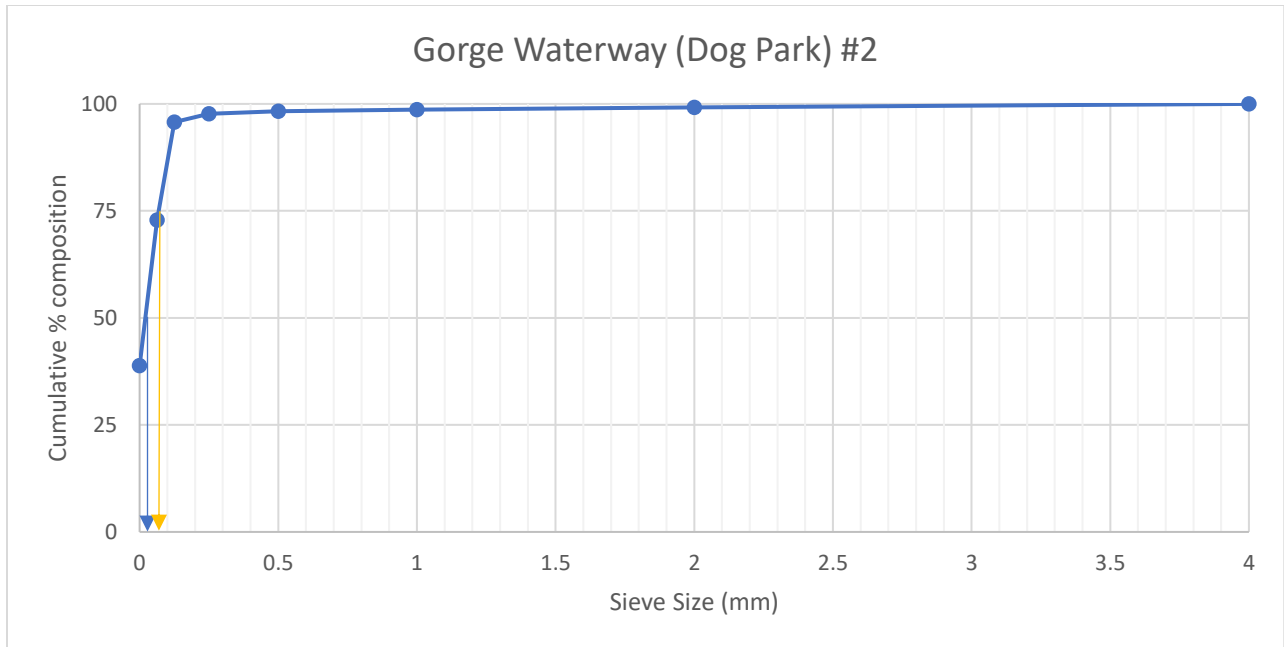
Sorting Coefficient = $Q25/Q75 = 0.075/0.11 = 0.682$



$Q_{25}=0.01$ $Q_{50}=0.03$ $Q_{75}=0.072$

Median Grain Size = $Q_{50} = 0.03$

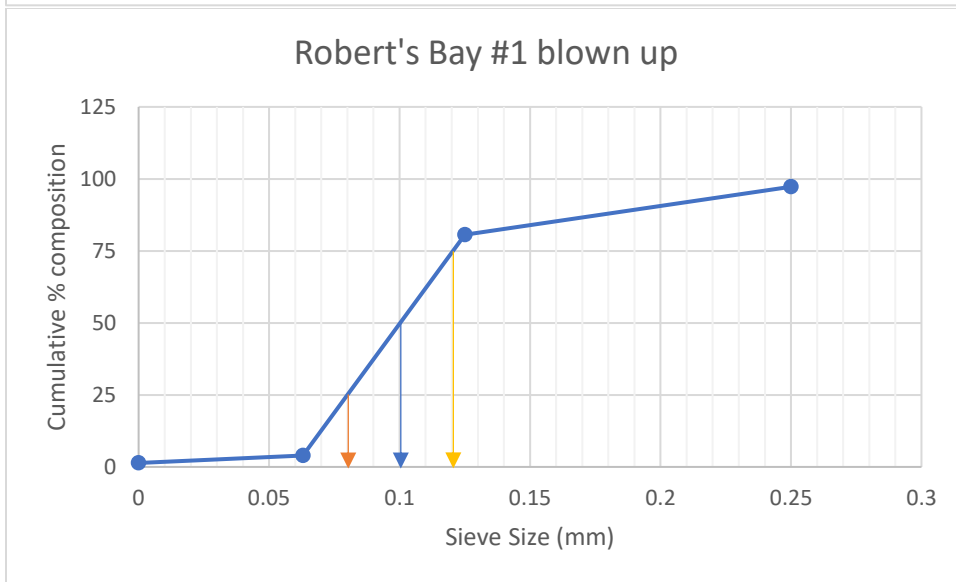
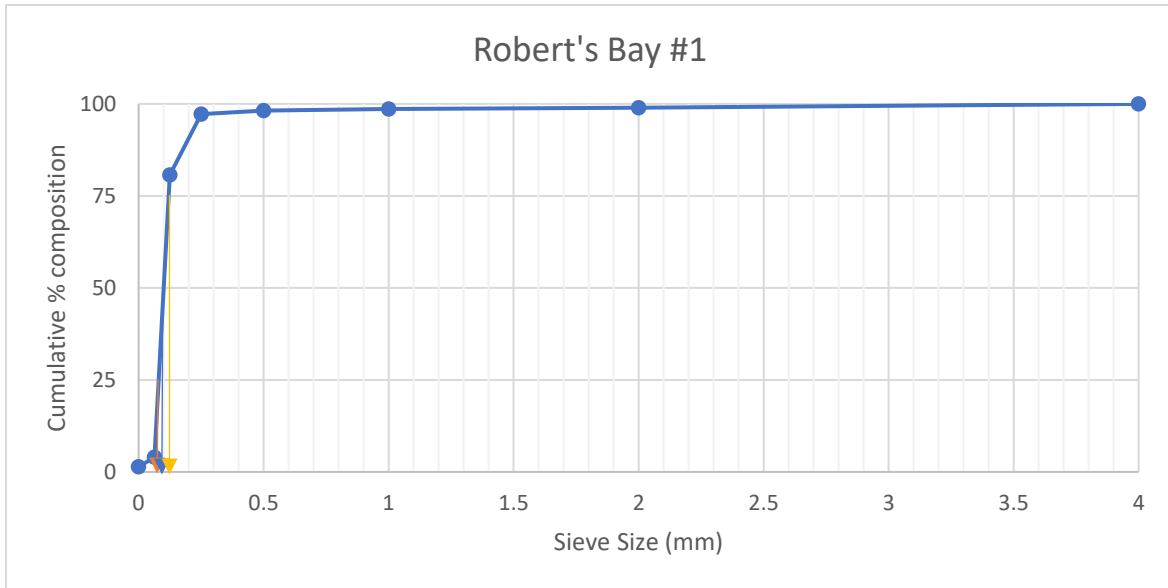
Sorting Coefficient = $Q_{25}/Q_{75} = 0.01/0.072 = 0.139$



Q25=0.01 Q50=0.02 Q75=0.069

Median Grain Size = Q50 = 0.02

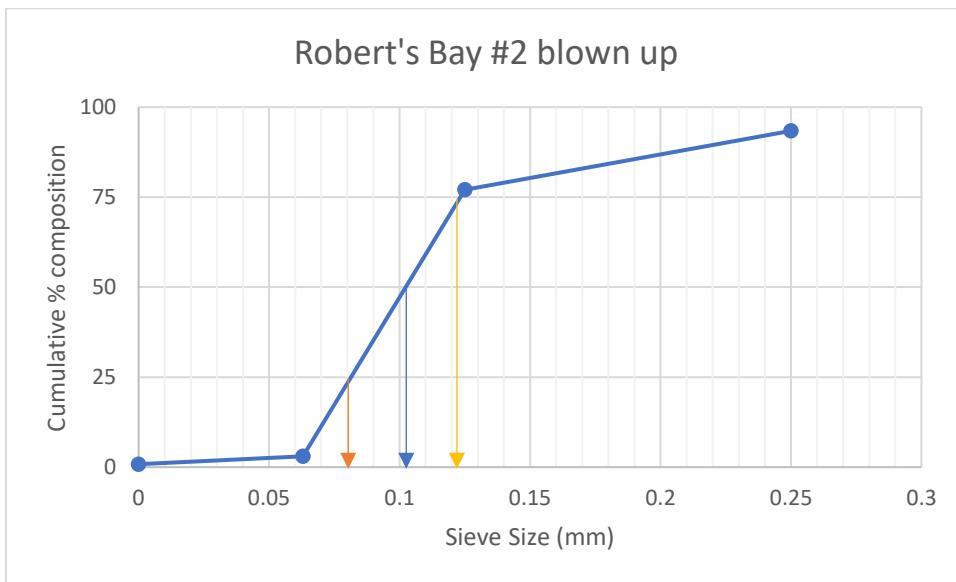
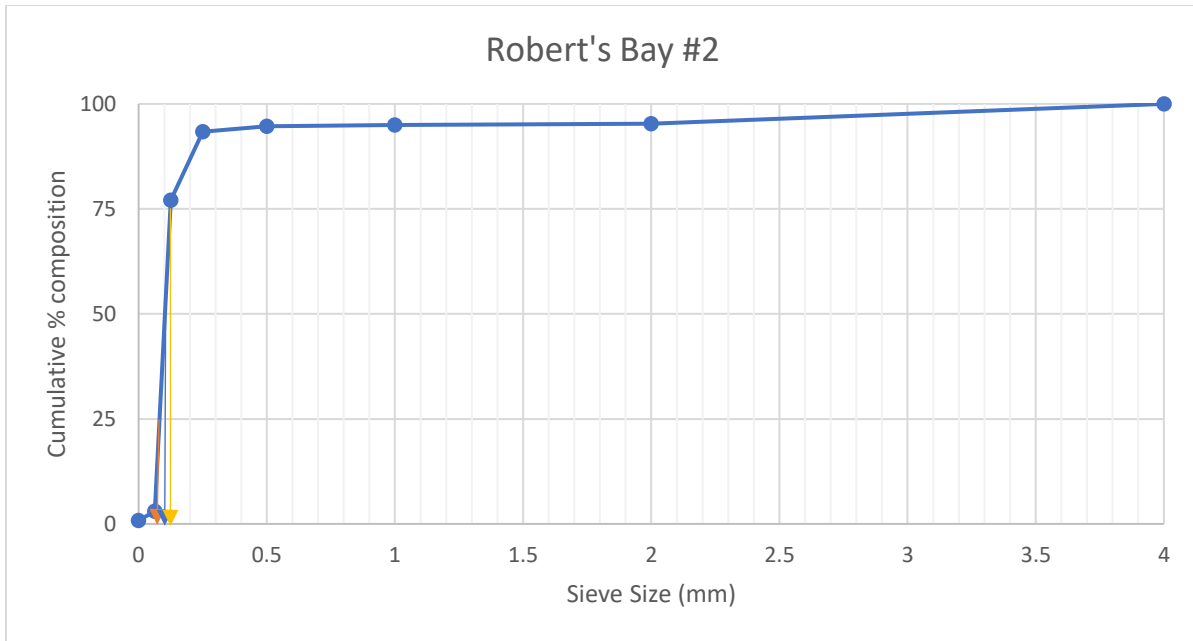
Sorting Coefficient = $Q25/Q75 = 0.01/0.069 = 0.145$



$Q_{25}=0.080$ $Q_{50}=0.10$ $Q_{75}=0.12$

Median Grain Size = $Q_{50} = 0.10$

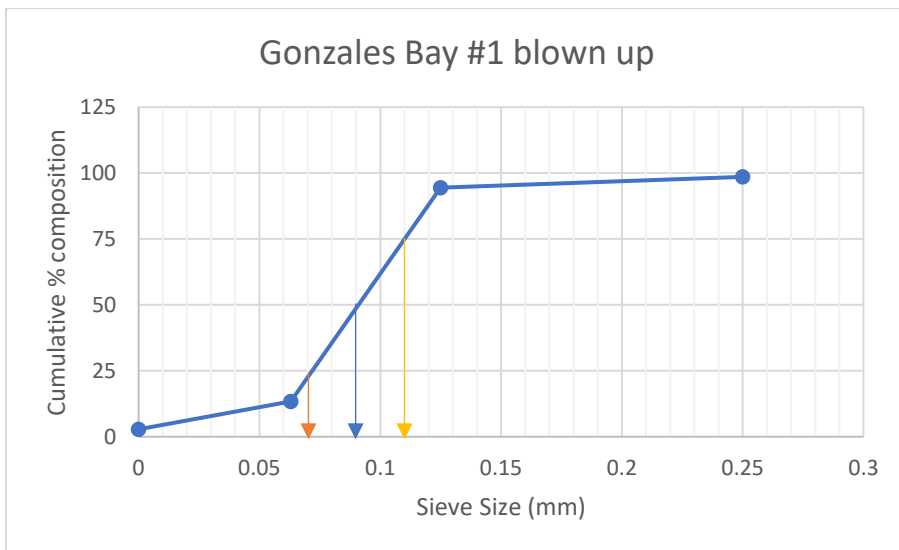
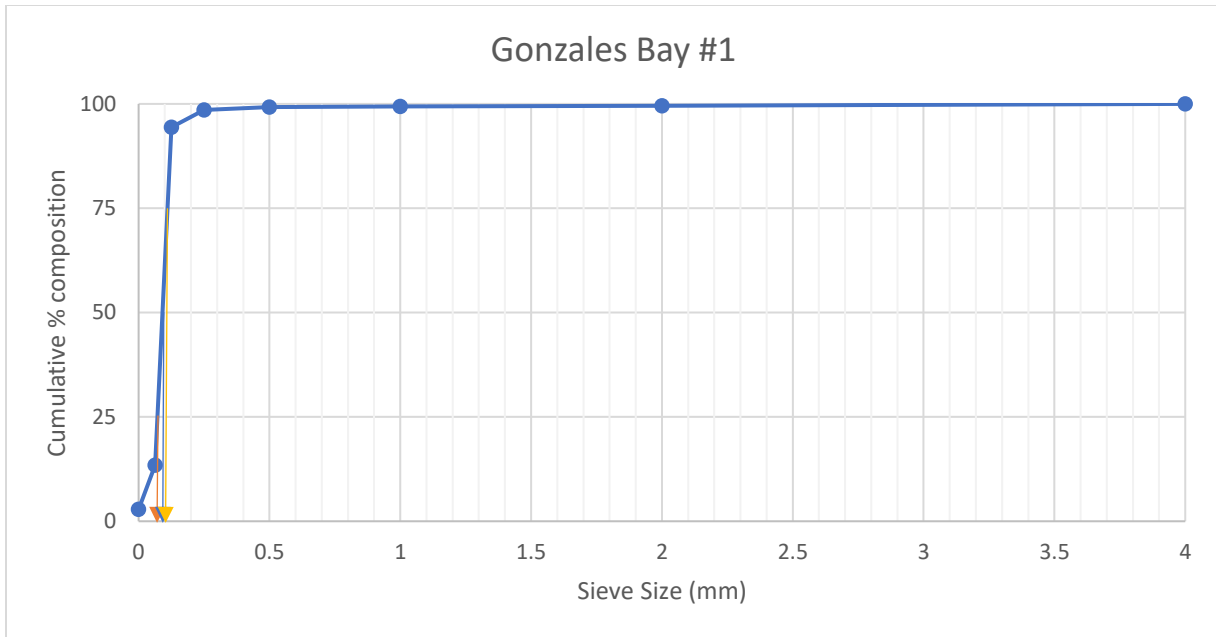
Sorting Coefficient = $Q_{25}/Q_{75} = 0.080/0.12 = 0.667$



Q25=0.080 Q50=0.11 Q75=0.21

Median Grain Size = Q50 = 0.11

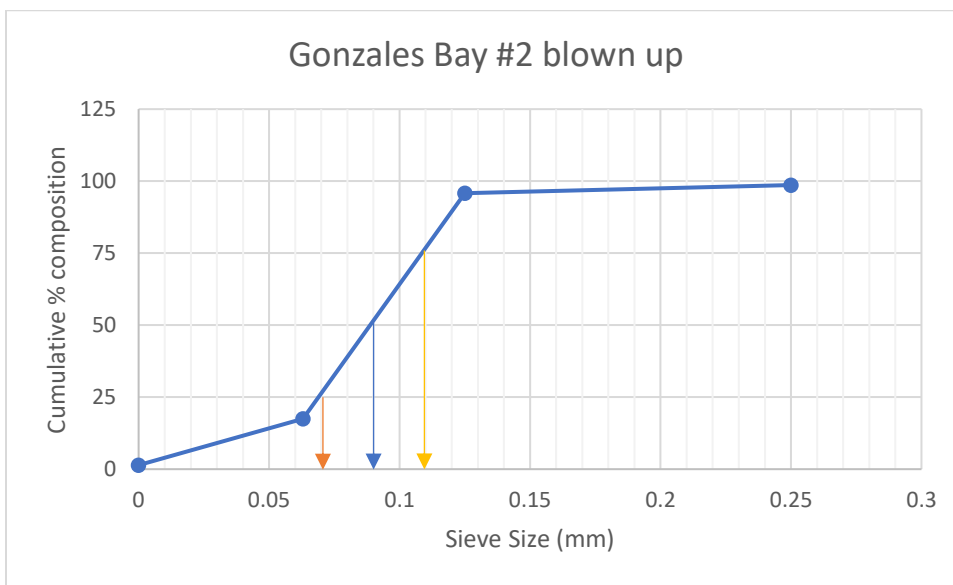
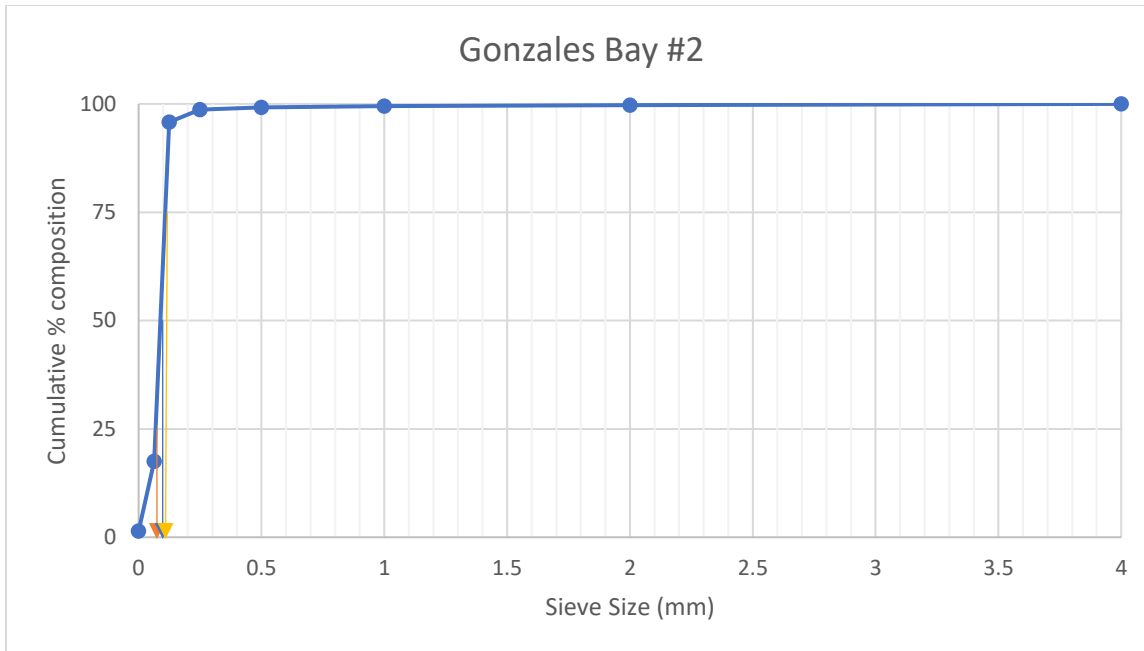
Sorting Coefficient = $Q25/Q75 = 0.080/0.21 = 0.381$



Q25=0.07 Q50=0.09 Q75=0.11

Median Grain Size = Q50 = 0.09

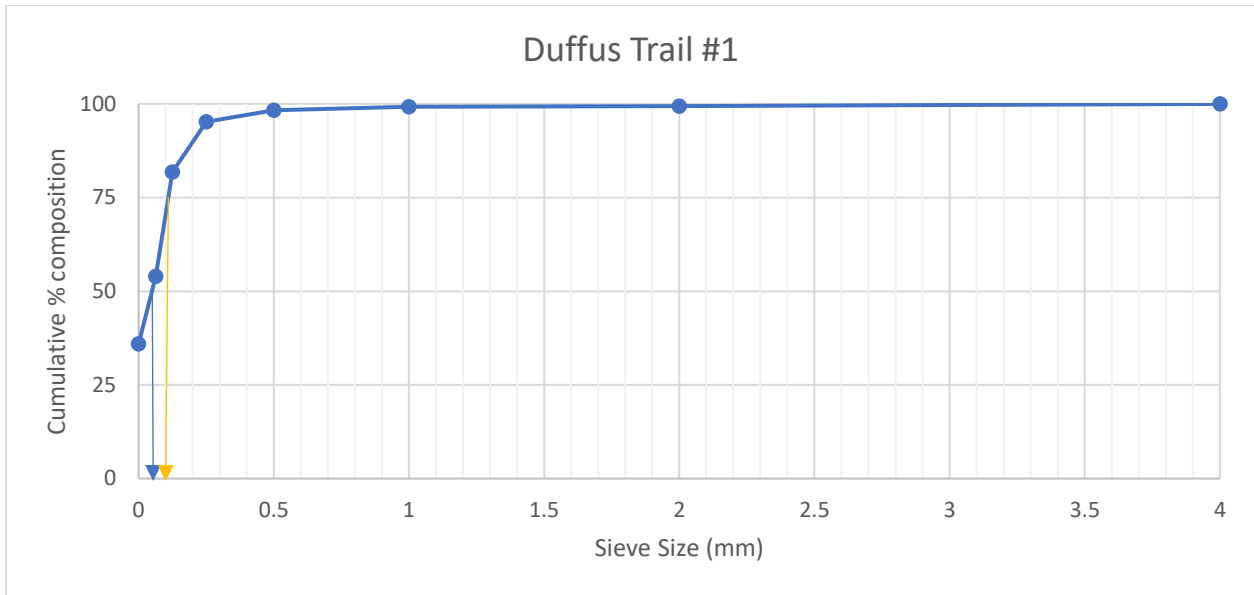
Sorting Coefficient = $Q25/Q75 = 0.07/0.11 = 0.636$



Q25=0.07 Q50=0.09 Q75=0.11

Median Grain Size = Q50 = 0.09

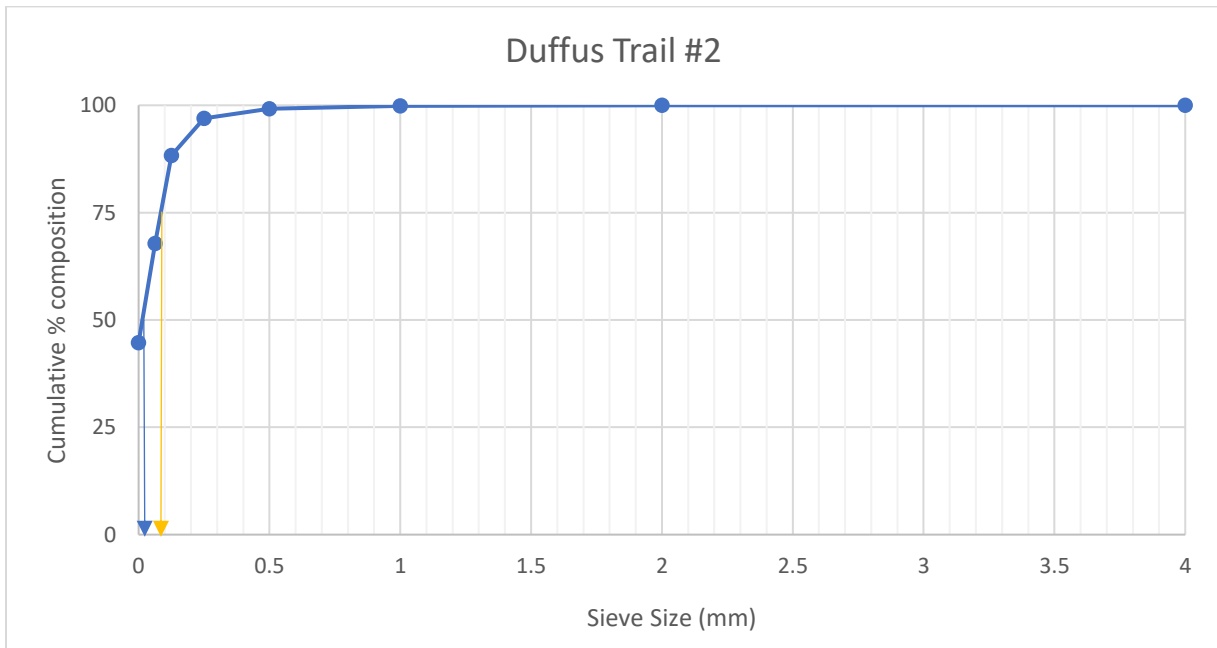
Sorting Coefficient = $Q25/Q75 = 0.07/0.11 = 0.636$



Q25=0.01 Q50=0.05 Q75=0.10

Median Grain Size = Q50 = 0.05

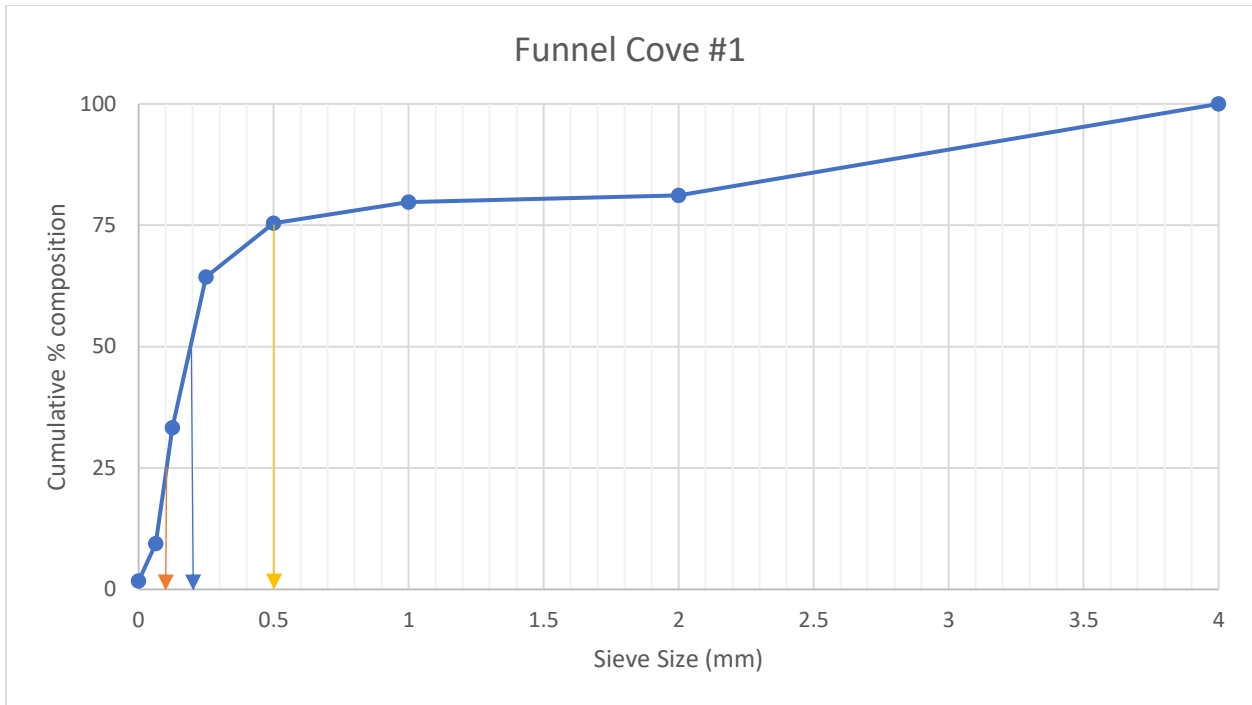
Sorting Coefficient = $Q25/Q75 = 0.01/0.10 = 0.10$



Q25=0.01 Q50=0.02 Q75=0.10

Median Grain Size = Q50 = 0.02

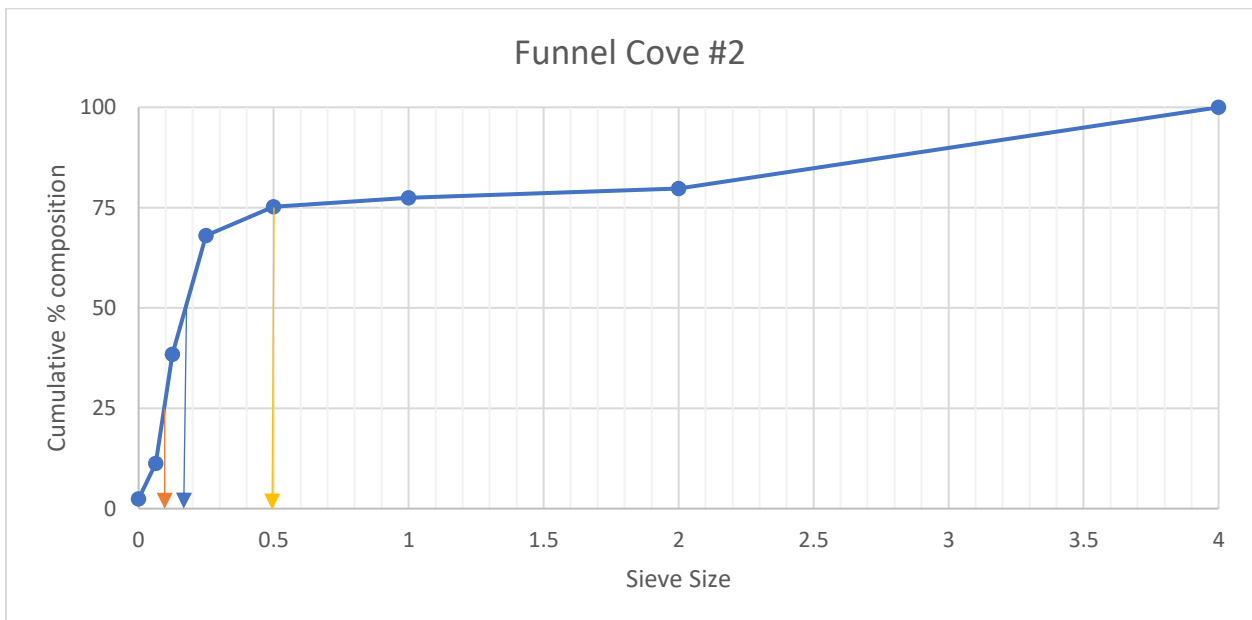
Sorting Coefficient = $Q25/Q75 = 0.01/0.10 = 0.10$



$Q_{25}=0.10$ $Q_{50}=0.20$ $Q_{75}=0.50$

Median Grain Size = $Q_{50} = 0.20$

Sorting Coefficient = $Q_{25}/Q_{75} = 0.10/0.50 = 0.20$



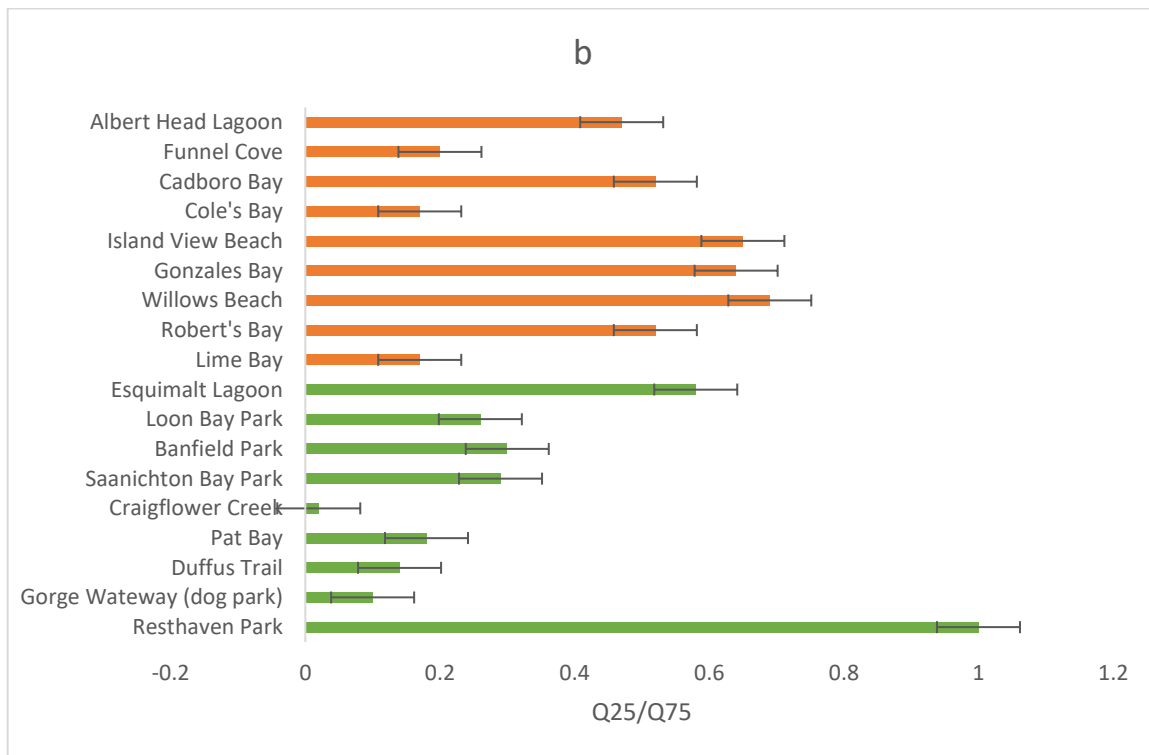
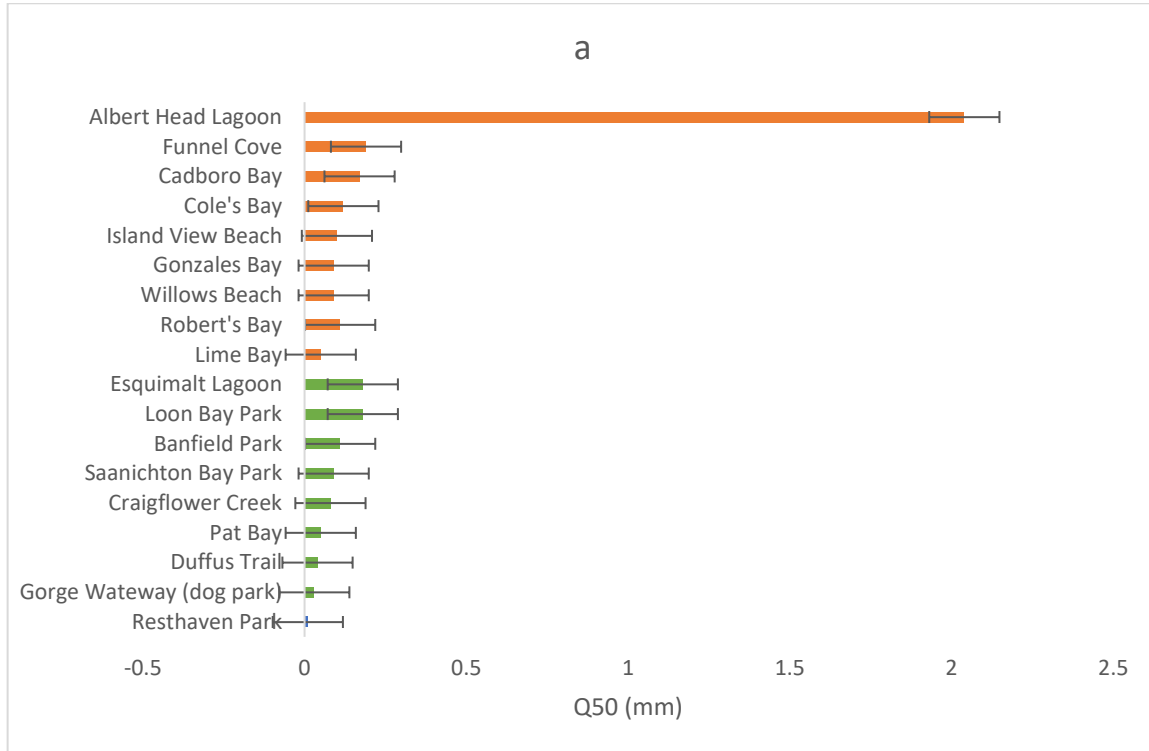
$Q_{25}=0.10$ $Q_{50}=0.18$ $Q_{75}=0.50$

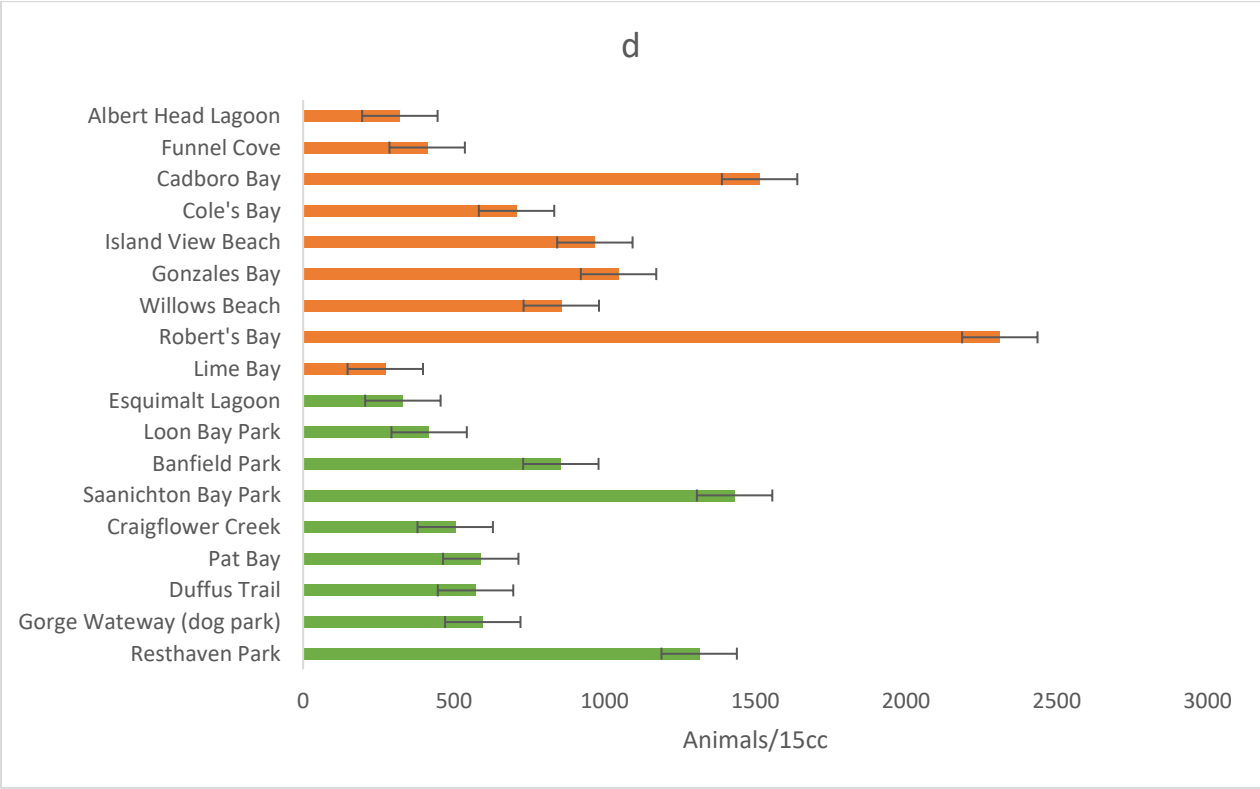
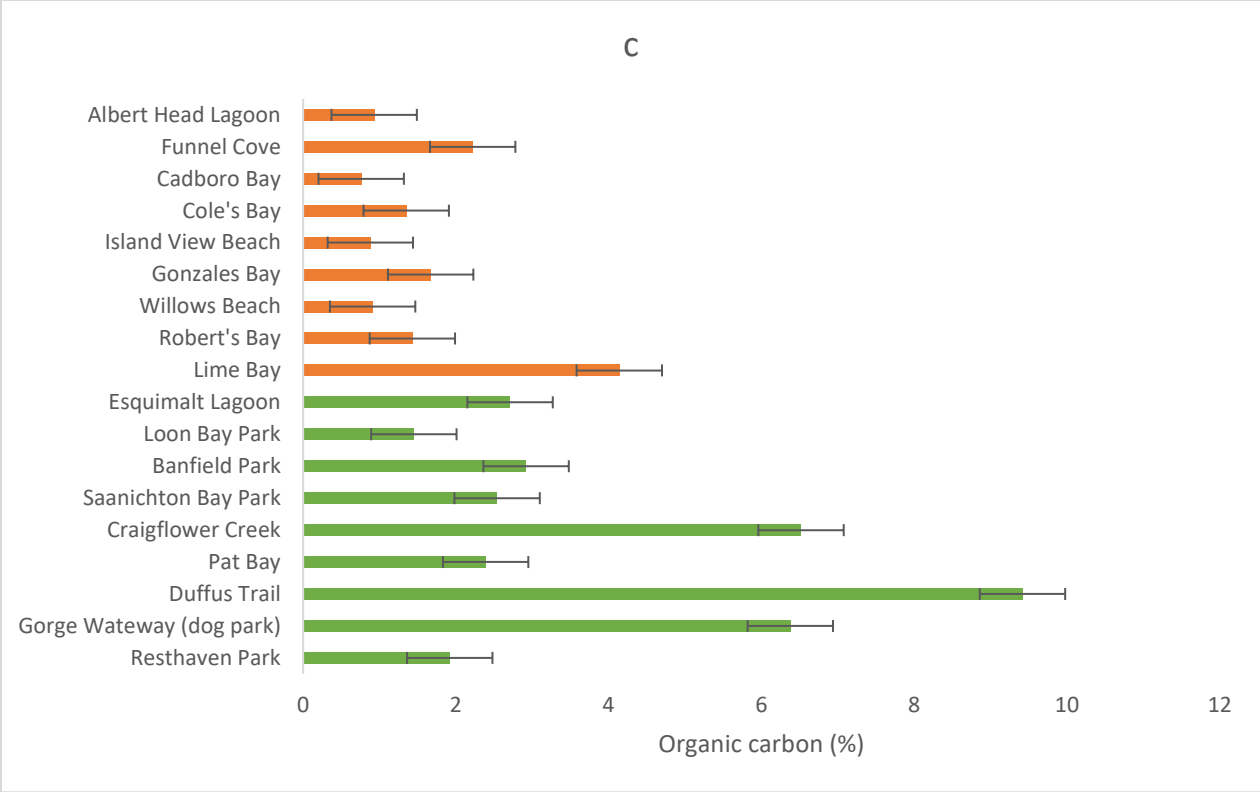
Median Grain Size = $Q_{50} = 0.18$

Sorting Coefficient = $Q_{25}/Q_{75} = 0.10/0.50 = 0.20$

Figure 1: Graphical representations of sediment data. The cumulative % composition for each replicate at each site was plotted against sieve size to determine the median grain size (Q50) and sediment sorting coefficient (Q25/Q75). “Blown up” graphs refer to replicates where the initial graph showed Q25, Q50 and Q75 too close together to determine visually, so the x-axis was shortened to zoom in on the area of interest for a more accurate determination of values.

Appendix 3: Site variation in sediment characteristics and meiofauna.





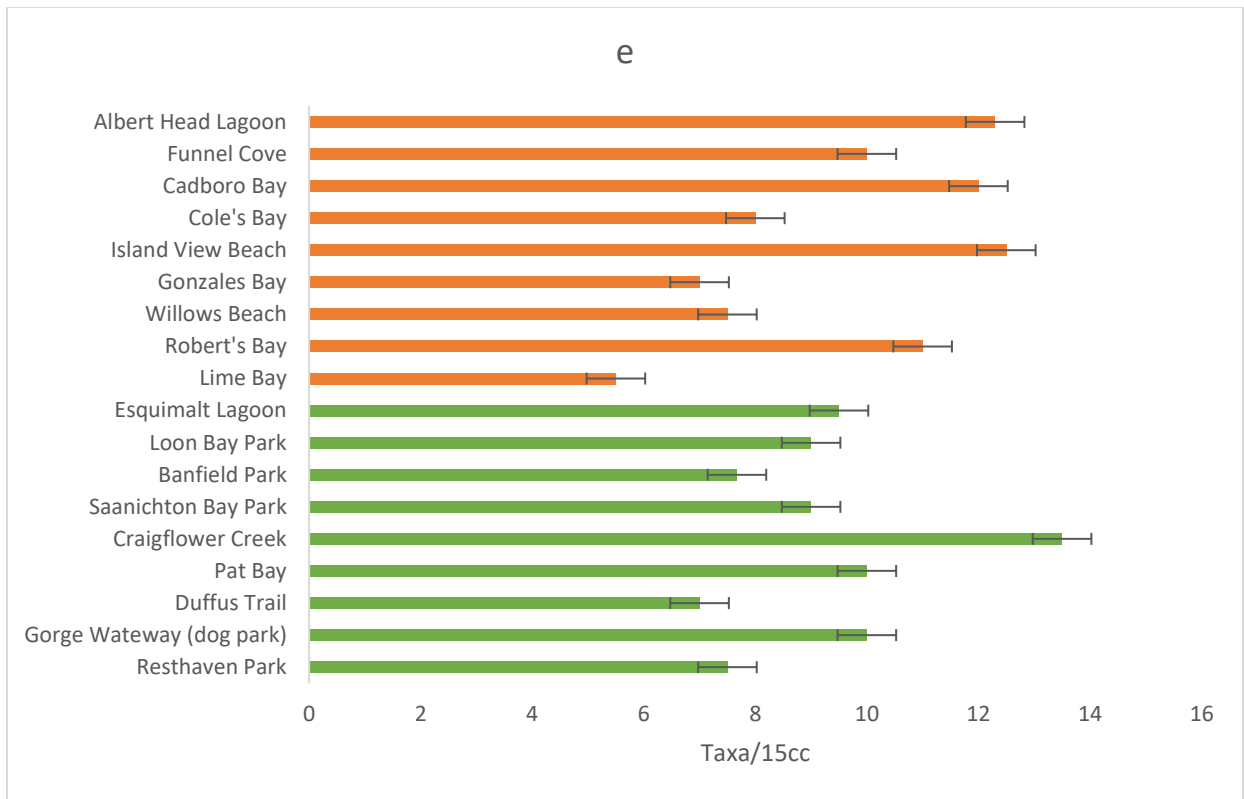


Figure 1: Sediment classification separated by site, vs. a) median grain size (Q50), b) sediment sorting coefficient (Q25/Q75), c) % organic carbon, d) animal abundance (animals/15cc) e) number of taxa (taxa/15cc). All values are averages of 2 -3 replicates. Orange = sandy beaches, green = muddy beaches.

Appendix 4: Results of t-tests.

Table 1: 95% two-sided hypothesis test for mean comparison: beach classification vs. median grain size (Q50).

	<i>Muddy</i>	<i>Sandy</i>
Mean	0.0856	0.3289
Standard Deviation	0.0619	0.6431
Variance	0.00383	0.41354
Sample Size	9	9
Difference in Means	-0.243	
Equal Variances?	No	
Pooled Variance	0.0464	
Pooled Standard Deviation	0.215	
Degrees of Freedom	8	
Alpha	0.05	
$t_{(0.025, 8)}$	2.306	
Lower Confidence Level	-0.740	
Upper Confidence Level	0.253	
t	-1.13	
p-Value	0.2912	

Table 2: 95% two-sided hypothesis test for mean comparison: beach classification vs. median grain size (Q50) excluding Albert Head Lagoon.

	<i>Muddy</i>	<i>Sandy</i>
Mean	0.0856	0.1150
Standard Deviation	0.0619	0.0454
Variance	0.00383	0.00206
Sample Size	9	8
Difference in Means	-0.0294	
Equal Variances?	Yes	
Pooled Variance	0.00300	
Pooled Standard Deviation	0.0548	
Degrees of Freedom	15	
Alpha	0.05	
$t_{(0.025, 15)}$	2.131	
Lower Confidence Level	-0.0862	

Upper Confidence Level	0.0273	
t	-1.106	
p-Value	0.2861	

Table 3: 95% two-sided hypothesis test for mean comparison: beach classification vs. sorting coefficient (Q25/Q75).

	<i>Muddy</i>	<i>Sandy</i>
Mean	0.319	0.448
Standard Deviation	0.301	0.213
Variance	0.0907	0.0454
Sample Size	9	9
Difference in Means	-0.129	
Equal Variances?	Yes	
Pooled Variance	0.0680	
Pooled Standard Deviation	0.261	
Degrees of Freedom	16	
Alpha	0.05	
t _(0.025, 16)	2.12	
Lower Confidence Level	-0.390	
Upper Confidence Level	0.132	
t	-1.048	
p-Value	0.3101	

Table 4: 95% two-sided hypothesis test for mean comparison: beach classification vs. % organic carbon.

	<i>Muddy</i>	<i>Sandy</i>
Mean	4.028	1.588
Standard Deviation	2.733	1.065
Variance	7.471	1.135
Sample Size	9	9
Difference in Means	2.440	
Equal Variances?	No	
Pooled Variance	0.956	
Pooled Standard Deviation	0.978	
Degrees of Freedom	10	
Alpha	0.05	
t _(0.025, 10)	2.228	

Lower Confidence Level	0.261	
Upper Confidence Level	4.619	
t	2.495	
p-Value	0.0317	

Table 5: 95% two-sided hypothesis test for mean comparison: beach classification vs. animal abundance.

	<i>Muddy</i>	<i>Sandy</i>
Mean	734.6	934.4
Standard Deviation	390.3	651.1
Variance	152337	423967
Sample Size	9	9
Difference in Means	-199.9	
Equal Variances?	Yes	
Pooled Variance	288152	
Pooled Standard Deviation	536.8	
Degrees of Freedom	16	
Alpha	0.05	
t _(0.025, 16)	2.12	
Lower Confidence Level	-736.3	
Upper Confidence Level	336.6	
t	-0.79	
p-Value	0.4412	

Table 6: 95% two-sided hypothesis test for mean comparison: beach classification vs. number of taxa.

	<i>Muddy</i>	<i>Sandy</i>
Mean	9.241	9.533
Standard Deviation	1.936	2.600
Variance	3.749	6.760
Sample Size	9	9
Difference in Means	-0.292	
Equal Variances?	Yes	
Pooled Variance	5.255	
Pooled Standard Deviation	2.292	
Degrees of Freedom	16	
Alpha	0.05	

t _(0.025, 16)	2.12	
Lower Confidence Level	-2.583	
Upper Confidence Level	1.999	
t	-0.27	
p-Value	0.7903	

Table 7: 95% two-sided hypothesis test for mean comparison: beach classification vs. nematode abundance.

	<i>Muddy</i>	<i>Sandy</i>
Mean	402.4	588.4
Standard Deviation	220.2	436.8
Variance	48498	190811
Sample Size	9	9
Difference in Means	-185.9	
Equal Variances?	No	
Pooled Variance	26590	
Pooled Standard Deviation	163.1	
Degrees of Freedom	11	
Alpha	0.05	
t _(0.025, 11)	2.201	
Lower Confidence Level	-544.8	
Upper Confidence Level	173.0	
t	-1.14	
p-Value	0.2784	

Table 8: 95% two-sided hypothesis test mean comparison: beach classification vs. harpacticoid copepod abundance

	<i>Muddy</i>	<i>Sandy</i>
Mean	168.5	111.6
Standard Deviation	136.0	112.8
Variance	18497	12731
Sample Size	9	9
Difference in Means	56.84	
Equal Variances?	Yes	
Pooled Variance	15614	
Pooled Standard Deviation	125.0	
Degrees of Freedom	16	

Alpha	0.05	
t _(0.025, 16)	2.12	
Lower Confidence Level	-68.03	
Upper Confidence Level	181.72	
t	0.965	
p-Value	0.3489	

Table 9: 95% two-sided hypothesis test for mean comparison: beach classification vs. nauplius larvae abundance.

	<i>Muddy</i>	<i>Sandy</i>
Mean	114.8	85.4
Standard Deviation	177.7	70.8
Variance	31588	5013
Sample Size	9	9
Difference in Means	29.42	
Equal Variances?	No	
Pooled Variance	4066.8	
Pooled Standard Deviation	63.77	
Degrees of Freedom	10	
Alpha	0.05	
t _(0.025, 10)	2.228	
Lower Confidence Level	-112.7	
Upper Confidence Level	171.5	
t	0.461	
p-Value	0.6544	

Table 10: 95% two-sided hypothesis test for mean comparison: beach classification vs. ostracod abundance.

	<i>Muddy</i>	<i>Sandy</i>
Mean	8.311	17.411
Standard Deviation	10.67	18.72
Variance	113.9	350.5
Sample Size	9	9
Difference in Means	-9.100	
Equal Variances?	Yes	
Pooled Variance	232.2	
Pooled Standard Deviation	15.24	

Degrees of Freedom	16	
Alpha	0.05	
t _(0.025, 16)	2.12	
Lower Confidence Level	-24.33	
Upper Confidence Level	6.13	
t	-1.267	
p-Value	0.2233	

Table 11: 95% two-sided hypothesis test for mean comparison: beach classification vs. bivalve abundance.

	<i>Muddy</i>	<i>Sandy</i>
Mean	16.01	63.30
Standard Deviation	31.08	173.74
Variance	966.2	30186.4
Sample Size	9	9
Difference in Means	-47.29	
Equal Variances?	No	
Pooled Variance	3461.4	
Pooled Standard Deviation	58.83	
Degrees of Freedom	8	
Alpha	0.05	
t _(0.025, 8)	2.306	
Lower Confidence Level	-183.0	
Upper Confidence Level	88.4	
t	-0.804	
p-Value	0.4448	

Table 12: 95% two-sided hypothesis test for mean comparison: beach classification vs. the abundance of all other taxa present combined.

	<i>Muddy</i>	<i>Sandy</i>
Mean	24.62	68.41
Standard Deviation	15.81	56.73
Variance	250.1	3218.3
Sample Size	9	9
Difference in Means	-43.79	
Equal Variances?	No	
Pooled Variance	385.4	

Pooled Standard Deviation	19.63	
Degrees of Freedom	9	
Alpha	0.05	
$t_{(0.025, 9)}$	2.262	
Lower Confidence Level	-88.20	
Upper Confidence Level	0.62	
t	-2.231	
p-Value	0.0526	

Appendix 5: Statistical tables for Regression analysis.

Table 1A: Regression table for animal abundance vs. median sediment size (Q50).

<i>General Linear Model</i>					
	df	SS	MS	F	p-value
Model	1	288520	288520	1.03	0.3263
Residual	16	4501647	281353		
Total	17	4790168			

Table 1B: Predictors table for animal abundance vs. median sediment size (Q50).

<i>Predictors Table</i>								
	Coeff.	Standard Error	t Stat	p-value	95% Lower	95% Upper	VIF	Stand. Coeff
Intercept	893.1	137.8	6.483	0.0000	601.1	1185.2		
Q50	-282.9	279.4	-1.013	0.3263	-875.1	309.3		

Table 1C: Regression statistics for animal abundance vs. median sediment size (Q50).

<i>Regression Statistics</i>	
R ²	6.02%
Adjusted R ²	0.15%
Mean	834.5
Standard Error	530.4
Coefficient of Variance	63.56
Observations	18
Durbin-Watson Statistic	2.316
PRESS	5231761
R ² Prediction	-9.22%

Table 2A: Regression table for animal abundance vs. % organic carbon.

<i>General Linear Model</i>					
	df	SS	MS	F	p-value
Model	1	512055	512055	1.92	0.1854
Residual	16	4278113	267382		
Total	17	4790168			

Table 2B: Predictors table for animal abundance vs. % organic carbon.

<i>Predictors Table</i>								
	Coeff.	Standard Error	t Stat	p-value	95% Lower	95% Upper	VIF	Stand. Coeff
Intercept	1040.0	192.1	5.414	0.0001	632.8	1447.2		
% Organic carbon	-73.17	52.87	-1.384	0.1854	-185.3	38.92		

Table 2C: Regression statistics for animal abundance vs. % organic carbon.

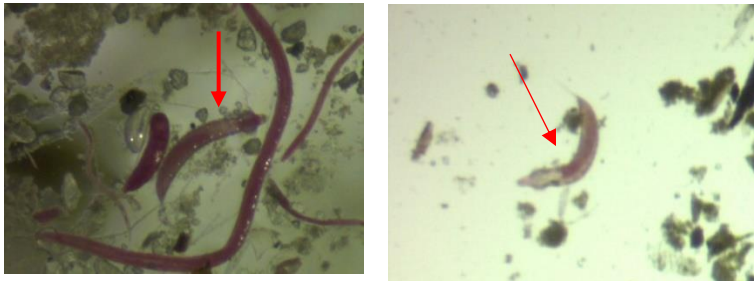
<i>Regression Statistics</i>	
R ²	10.69%
Adjusted R ²	5.11%
Mean	834.5
Standard Error	517.1
Coefficient of Variance	61.96
Observations	18
Durbin-Watson Statistic	2.068
PRESS	5145669
R ² Prediction	-7.42%

Appendix 6: Microscope Images

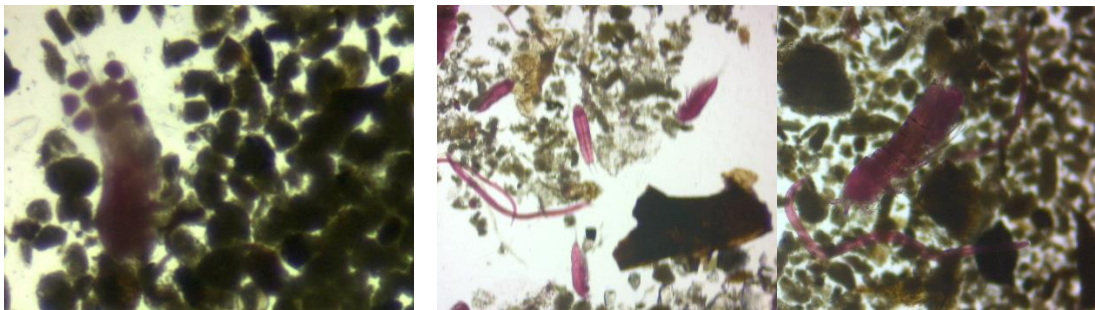
Nematoda



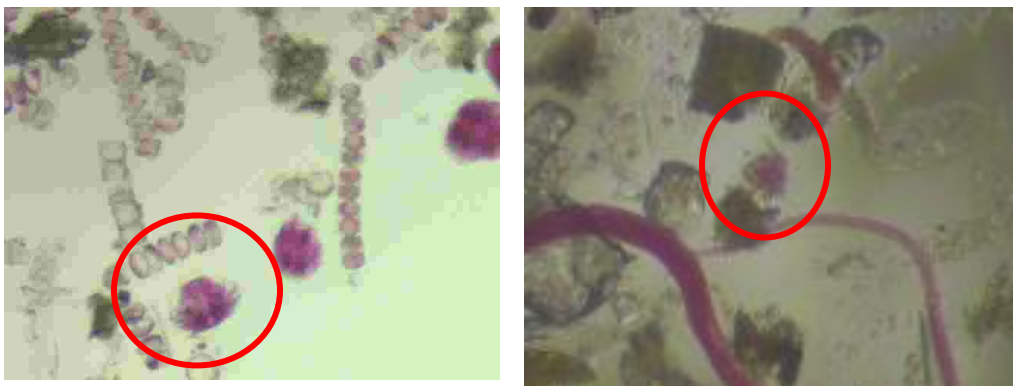
Kinorhyncha



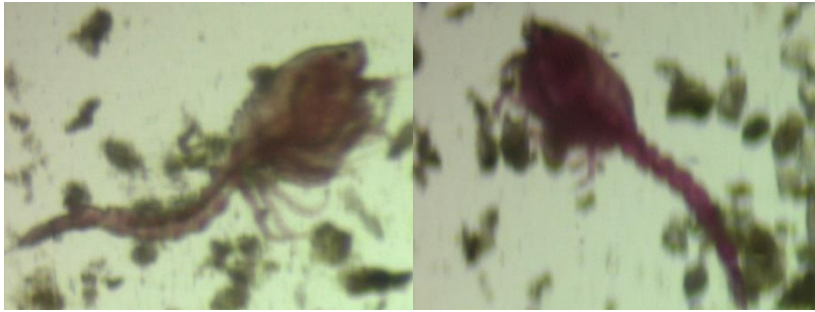
Harpacticoid copepods



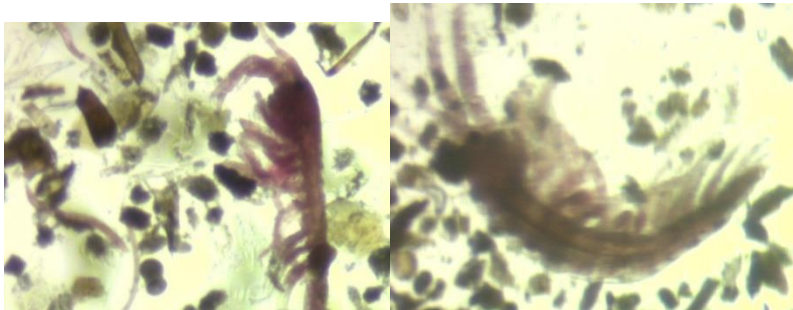
Nauplius larvae



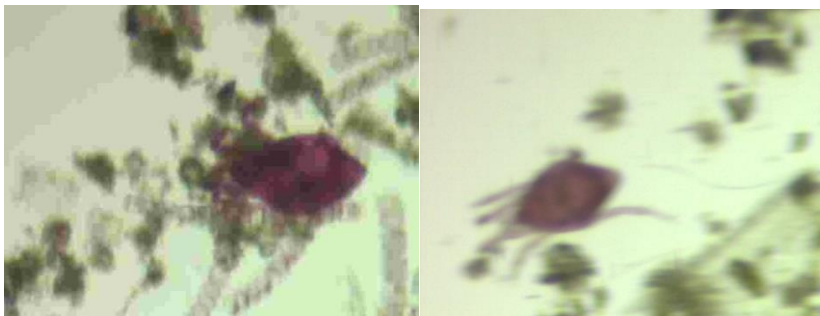
Cumacea



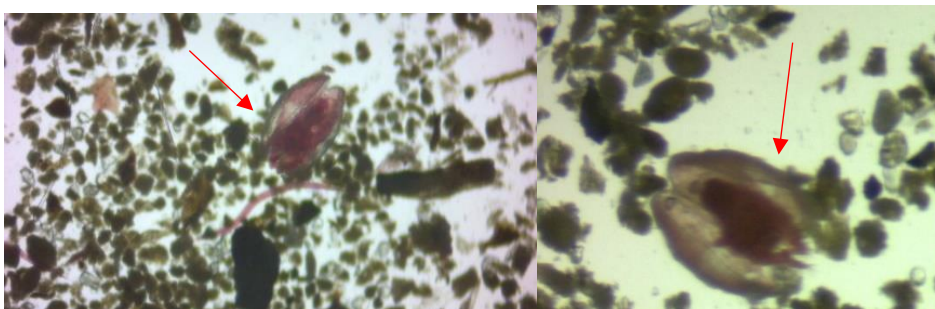
Corophiidae (Amphipod)



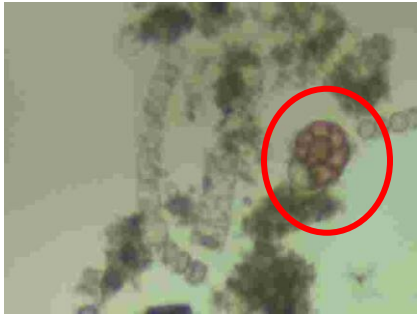
Acari



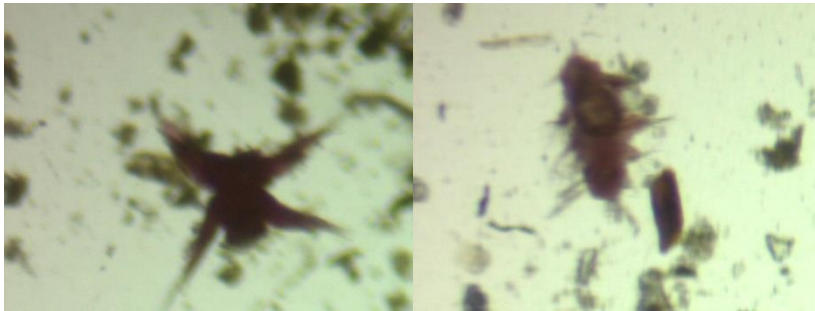
Ostracoda



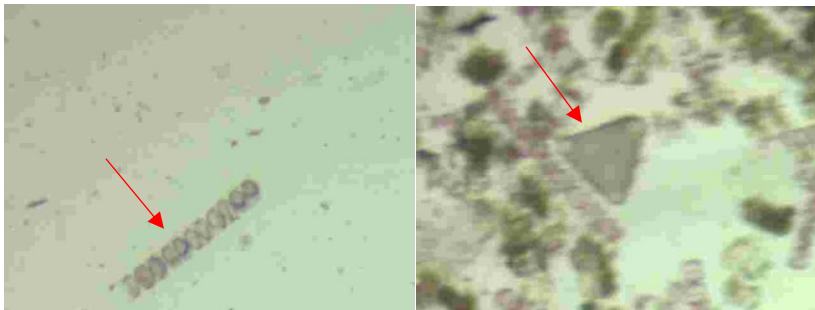
Foraminifera



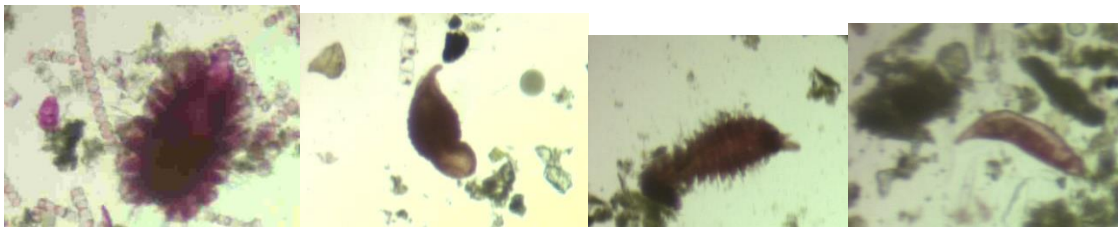
Tardigrada



Diatoms (food for meiofauna)



Unknown:



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