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Influences of False Bay Creek and Waves on Sediment

Abstract

The primary objective of this study was to increase the understanding of the influence of False Bay Creek and wave processes on grain size distribution and sediment organic carbon in a shallow, enclosed bay. Two parallel transects were sampled to compare grain size distribution change over distance from the shoreline near False Bay Creek (Transect 1) and 250 m from the creek mouth (Transect 2). The distributary channel created by False Bay Creek also was sampled to compare grain size distribution and organic carbon to Transect 1 and Transect 2. Grain size analysis was quantified by sieving and organic carbon was quantified through loss on ignition. False Bay Creek forms a small delta that is composed of poorly sorted, sandy gravel and has an edge visible in satellite imagery. Past the delta, the sediment is better sorted, and the amount of fine sand increased. As distance from the shoreline increased, the amount of medium sand increased. Along Transect 2, the amount of fine and very fine sediment decreased, and medium sand increased as distance from the shoreline increased. Due to the bathymetry, roughly circular shape, and narrow mouth of False Bay, wave refraction and diffraction likely results in the transport of fine and very fine sediment to the head of the bay and wave action increases sorting of sediment as distance from the shoreline increases.

Keywords: shallow bay, grain size distribution, fluvial processes, wave refraction, and diffraction

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Introduction

The spatial variability of fluvial sediment deposition in coastal areas and estuaries affects both biotic and abiotic patterns and conditions. The environmental variability generated from fluvial sediment deposition into estuaries impacts the bathymetry of the area and sediment grain size distribution. Through deposition of fluvial sediment, a delta containing various grain sizes can form. Rivers also transfer terrestrial organic carbon to marine environments, which plays a key role in the global carbon cycle (Repasch et al., 2021).

False Bay is on the southwestern side on San Juan Island, Washington, USA, and faces Haro Strait and the Strait of Juan de Fuca. The bay is roughly circular in shape and has a narrow mouth (approximately 500 m in width). At high tide the bay is covered entirely by water and at mean lowest low water, the bay empties and reveals a tide flat brimming with benthic organisms, algae, and a range of sediment grain sizes.

Most prior research conducted in False Bay has been focused on biology with the occasional researcher analyzing sediment grain size from scattered sediment samples collected around the bay. The most relevant sediment grain size research was by Pamatmat (1966). In this study, sediment samples were collected at three stations in the bay and fine sand was the median grain size for all stations. Pamatmat (1966) stated that “most of the sediment in the bay is sand of unknown thickness overlying a clay substrate. Pebbles and boulders occur mostly near the head of the bay while a few solitary boulders are found in the middle.”

In a study focused on the feeding and ecology of polychaetes, Hobson (1967) collected approximately 45 sediment samples mainly in the eastern half of False Bay. The methods of sediment sample collection were unspecified. Generally, the highest mud fraction was found near the head and margin of the bay and the median grain size ranged from 2.0 to 3.0 phi (fine sand)

(Hobson, 1967).

Sediment can be transported by rivers and streams before being deposited in coastal areas (Colby, 1963). Therefore, sediment is likely transported into False Bay by False Bay Creek and then is reworked by waves and tidal currents. Google Earth satellite images reveal a small delta that has formed at the mouth of False Bay Creek (Fig. 1), which also suggests that sediment is deposited in False Bay by the creek. Pamatmat (1966) stated that False Bay Creek creates a distributary channel that meanders across the tide flat. The channel is more important than waves and tidal currents in moving sand bars, but its influence is limited to its vicinity during low tide. Pamatmat (1966) also noted that sediment along the head and margin of the tide flat may contain a higher fine sediment fraction because False Bay is relatively broad, flat, and sheltered from waves. Due to False Bay's narrow mouth and broad, circular shape, it's likely wave refraction and diffraction occur, and wave energy is significantly reduced by the time waves reach the head of the bay, which limits the grain size of sediment that can be moved by waves and tides.

Therefore, the primary objective of this study was to increase the understanding of the influence of False Bay Creek and waves on grain size distribution and sediment organic carbon. Two parallel transects were sampled to compare grain size distribution near False Bay Creek and farther away from the creek. Transect 1 was hypothesized to have a grain size distribution containing large amounts of gravel and sand where the fraction of sand increased as distance from the creek mouth increased because there would be less fluvial processes affecting grain size distribution as distance from the creek mouth increased. The purpose of grain size analysis along Transect 2 was to examine whether the head of False Bay contained a high fine sediment fraction as hypothesized by Pamatmat (1966). It was hypothesized that Transect 2 would have a grain size distribution composed of mainly gravel and mud that transitioned to a higher sand content as distance from the shoreline increased. Shoreline erosion could increase the amount of gravel at the beginning of Transect 2 and waves likely transport fine sediment to the head of the bay. The distributary channel transect was sampled to examine how grain size distribution changes relative to Transect 1 and 2 and as distance from False Bay Creek mouth increases. It was hypothesized the transect would contain mostly mud and transition to sand because rivers can deposit fine sediment into coastal areas (Dyer, 1986). All transects were predicted to transition from poorly sorted to well sorted sediment because prolonged wave activity usually removes finer sediment and increases sorting (Dyer, 1986) and there was likely more wave activity along the transects near the mouth of the bay.

The second objective was to examine how False Bay Creek impacts sediment organic carbon. I hypothesized that sediment organic carbon would be highest in sampling areas close to the mouth of the creek and would decrease with distance along a transect, away from the creek mouth, because rivers transfer organic carbon to marine environments (Repasch et al., 2021) and organic carbon is less likely to be buried where wave energy is high (Tissot & Welte, 1978).

Methods

Sediment sampling

Two parallel 300 m transects were placed in False Bay that began near the head of the bay and extended toward the mouth (Fig.1). The beginning of Transect 1 was approximately 20 m from the mouth of False Bay Creek and on the bank of the distributary channel it creates. Transect 2 began approximately 250 m from Transect 1 and 20 m from the shoreline. The distributary channel transect was 340 m in length and followed the channel present in November 2021. It began at the mouth of False Bay Creek, which is approximately 20 m above Transect 1 and 2, so all figures show it starting at -20 m. None of the transects intercepted. The GPS coordinates were recorded at 0, 60, 100, 160, 200, 260, and 300 m along Transect 1 and 2 and every 20 m in the distributary channel. Two supplemental samples also were collected from the middle of the bay and the lower bay to compare to the transect samples. The mid bay sample was approximately 172 m from the end of Transect 1 and Transect 2 and the lower bay sample approximately 412 m.

Sediment samples were collected from October 28th to November 18th, 2021, coincidently after a period of strong wind, which occurred from approximately October 24th to 26th, 2021. The highest wind speed recorded during this period was 21 kn and the wind direction was 151° (NOAA) and 2.4 cm of precipitation was recorded on October 28th (NOAA, 2021). Samples were collected at 20 m intervals along each transect and were approximately 10 cm deep. In total, 52 samples were collected for grain size analysis and organic carbon was measured in a subset of these, from samples collected at the beginning of each transect and every 100 m along each transect. Organic carbon was measured from 12 samples.

Grain Size Distribution

Sediment samples were dried at 100 °C for 24 hours and disaggregated using a porcelain mortar and pestle. Dried sediments smaller than 16 mm were sieved on a nest of sieves spaced at 1 phi intervals (Wentworth, 1922) and sieved for eight minutes using a Ro-Tap machine. Coarser sediments larger than 16 mm were individually measured. The sediment retained in each sieve was weighed and its percentage of the total sediment mass was calculated.

The sample collected in the distributary channel at 120 m along the transect contained a large amount of silt and clay and was disaggregated using a 0.05% sodium metahexaphosphate solution. A small portion of the sample was wet sieved through a 63 μm sieve (Dyer, 1986). The remainder of the sample was dried, disaggregated using a porcelain mortar and pestle, and then sieved on the nest of sieves of 1 phi interval and shaken using the Ro-Tap sieve shaker.

Loss on Ignition- Organic Carbon

Organic carbon was measured through a loss-on-ignition method in sediment samples collected every 100 m along each transect. Loss-on-ignition (LOI) procedures followed Kennedy and Woods (2013). A crucible and lid were heated for 2 hours at 400 °C and the weight of the crucible and lid was recorded as Weight (a). Then, 1–3 g sediment dried at 105 °C for 24 hours was added to the crucible. The crucible and sample were weighed and recorded as Weight (b). The crucible was then placed in a muffle furnace at 400 °C for 16 hours and after cooled, the crucible and sample were weighed and recorded as weight (c). The % LOI was calculated using the equation

$$\mathrm{LOI}\,\% = \frac{W_{105} - W_{400}}{W_{105}} \times 100$$

where W_{105} = Weight (b) - Weight (a) and W_{400} = Weight (c) - Weight (a). Organic matter content is assumed to be equal to the LOI% (Kennedy and Woods, 2013).

Statistical Analysis

Statistical analysis of grain size distribution used Gradistat to determine % weight, D_{50}, and sorting (Blott & Pye, 2001). Sorting is given by the standard deviation, which is calculated as the second moment of mean (Dyer, 1986). The sorting was characterized, according to Folk and Ward (1957) as $\sigma I < 0.35$ very well sorted, $0.35 < \sigma I < 0.50$ well sorted, $0.50 < \sigma I < 1.00$ moderately sorted, $1.00 < \sigma I < 2.00$ poorly sorted, $2.00 < \sigma I < 4.00$ very poorly sorted, $4.00 < \sigma I$

extremely poorly sorted.

Results

% Weight of sediments in the distributary channel

The % weight of sediments in the distributary channel (DC) samples showed variation in grain size distribution throughout the transect (Fig. 2a). The coarse gravel fraction increased from DC 0 m to DC 80 m (Table 1). DC 0 m, 180 m, 300 m, and 320 m contained no coarse gravel. Grain sizes larger than 1 phi constituted approximately 10% of DC 280 m, and approximately 6% of DC 300 m and DC 320 m (Table 1). Fine sand was <1% from DC -20 m to 80 m. DC 280 m had the largest fraction of fine sand. DC 300 m and 320 m contained similar fractions of fine sand and medium sand (Table 1). On average, very fine sand, silt, and clay each constituted ≤1% of the distributary channel samples (Table 1). DC 100 m had anomalously high fractions of silt and clay (Table 1). This sample was collected from underneath a layer of woody debris in the distributary channel with a layer of mud overlaying gravel and sand of varying grain sizes. No other samples were collected from underneath a layer of woody debris.

% Weight of sediments along Transect 1

Transect 1 (T1) samples also showed variation in grain size distribution throughout the transect (Fig 2b). The highest fraction of coarse gravel was at the beginning of the transect (T1 0 m). There was no coarse gravel from T2 240 m to 300 m (Table 2). The fraction of sediments coarser than 1 phi was high from 120 m to 160 m relative to the previous sample (T1 100 m) and following sample (T1 180 m) (Fig. 2b). The fraction of medium, fine, and very fine gravel decreased from 160 m to 300 m (Table 2). Fine sand generally increased from T1 0 m to T1 240 m, then decreased until the end of the transect (Table 2). Medium sand increased from T1 240 m to T1 300 m. On average, the % weight of very fine sand was <2 and silt and clay were both <1 (Table 2).

% Weight of sediments along Transect 2

Transect 2 (T2) 0 m was collected from a gravelly area close to the shoreline and a man-made retaining wall. The sample contained the largest fraction of grain sizes coarser than 1 phi of T2 samples (Table 3). From T2 20 m to 300 m, the % weight of each gravel grain size was <1 (Table 3). Medium and fine sand constituted the majority of the sediment from T2 20 m to 300 m. T2 40 m, 60 m, and 120m had larger fractions of fine sand than medium sand (Table 3). The fraction of very fine sand was relatively large at T2 60 m and 120 m. From 140 m to 300 m, the fraction of medium sand was larger than fine sand (Table 3). On average, the % weight of silt and clay was <1 (Table 3).

% Weight of Supplemental Samples

The lower bay and mid bay samples consisted mostly of medium sand (Fig. 2d). The samples had similar fractions of coarse sand, medium sand, and fine sand (Table 5).

Sorting

The distributary channel was very poorly and poorly sorted from -20 m to 280 m. The channel was moderately sorted at 300 m and moderately well sorted at 320 m (Table 5, Fig. 3). Transect 1 was very poorly sorted from 0 m to 80 m and 120 m to 160 m and poorly sorted at 100 m, and from 180 m to 220 m. The transect was moderately well sorted from 240 m to 300 m

(Table 5). Transect 2 was poorly sorted at 0 m. Transect 2 was moderately well sorted from 20 to 40 m, 80 to 140 m, and 180 to 240 m. The transect was well sorted at 160 m, 260 m, and 300 m. The lower bay and mid bay samples were both well sorted (Table 5).

D_{50}

The distributary channel D_{50} increased from very coarse sand at DC -20 m to coarse gravel at DC 80 m (Table 6, Fig. 4). The D_{50} was medium sand at DC 300m and 320 m. The D_{50} of Transect 1 was fine gravel from T1 0 m to 60 m and approximately very fine gravel from T1 120 m to 160 m (Table 6). The D_{50} was finer from T1 180 m and 300 m and was mostly medium sand. The coarsest D_{50} of Transect 2 was 0 m (Table 6). From T2 20 m to 120 m, the average D_{50} was 2.128 phi (fine sand). From 140 m to 300 m, the average D_{50} was 1.65 phi (medium sand) (Table 6). The D_{50} of the mid and lower bay samples was medium sand (Table 6).

Loss on Ignition

The % LOI was variable for the distributary channel (Fig. 5). The % LOI increased from -20 m to 80 m, then decreased until 180 m, and then increased. The highest % LOI was at 80 m and the lowest was at 180 m. The % LOI was relatively stable for Transect 1 (Fig. 5). The highest % LOI was at 100 m and the lowest was at 0 m. For Transect 2, the highest % LOI was at 0 m and the lowest was at 200 m. The % LOI was the same at T2 100 m and 300 m (Fig. 5). The % LOI of Transect 1 and 2 approach each other in value from 100 m to 300 m.

Discussion

Sediment samples in False Bay show striking patterns of change from near the shoreline to near the mouth of the bay. Patterns seen in grain sizes may all be driven by wave transformations, the gradient in wave energy, and the fluvial processes of False Bay Creek.

Wave diffraction likely occurs in False Bay because of its narrow mouth (approximately 500 m in width) and large, roughly circular shape (1.2 km from east to west at its farthest shores). This wave transformation begins when a wave front encounters an obstacle or narrow opening and becomes more circular after passing the obstacle. As a wave front expands laterally, the wave energy density decreases, and wave rays diverge. Wave energy density is likely highest close to the mouth of the bay and decreases toward the head. Sediment deposition is more likely to occur where wave rays diverge, and energy density is decreasing. Figure 6 is a hypothetical sketch of how waves change as the enter and propagate through the bay. Based on the sketch, deposition of fine sediment is most likely to occur at the margins and head of the bay.

Another wave transformation that occurs is wave refraction. This occurs when waves propagate over changing depths and the wave fronts bend to align with depth contours. In shallow water, waves propagate slower than in deep water. The depth of False Bay decreases from the mouth of the bay to head (Pamatmat, 1966), which results in wave celerity decreasing as waves approach the head. Wave energy density decreases as wave fronts expand laterally and curve to follow the bathymetry of False Bay and wave rays diverge.

The bathymetry of False Bay and wave transformations may influence the amount of fine sediment present close to the shoreline compared to the center of the bay. According to Pamatmat (1966), sediment along the head and margins of the tide flat may contain a higher fraction of fines because False Bay is relatively broad, flat, and sheltered from waves. This is likely somewhat true because wave transformations do occur because the bay is relatively broad and flat. However, the bay's narrow mouth and decrease in depth from the mouth to the shoreline are also important factors that result in wave transformation and the transport of fines to the margins and head of the bay. There is also often a sandier area near the low water mark on interdistributary flats, which can be a result of more active and prolonged wave activity, or stronger distributary currents removing finer material (Dyer, 1986). Both observed tendencies may be seen in the decrease of fine and very fine sand as distance from the shoreline increases along Transect 2 (Fig. 2c). Except for the sample near the shoreline, which contained an anomalously large fraction of coarse sediments (grain sizes larger than 0 phi), medium and fine sand were the main constituents of the Transect 2 samples (Fig. 2c). The grain size distribution of the sample nearest the shoreline was likely influenced by erosion of the bank and man-made retaining wall that introduced gravel to the area.

The average D_{50} was fine sand in the shallower portions, grading to slightly coarser sediments further from shore. (Fig. 4). This change in D_{50} supports the observed decrease in the fraction of fine sand and the increasing dominance of medium sand along Transect 2. Waves are likely transporting fine sediment to the shallow area of Transect 2, which resulted in the median grain size being fine sand as opposed to medium sand toward the center of the bay.

Waves also tend to make sediments better sorted. With the exception of the sample near the shoreline, which was collected from an anomalous poorly sorted area, Transect 2 became slightly more sorted as distance along the transect increased (Fig. 3). The supplemental samples, exposed to substantial wave energy in the middle of the bay, were also well sorted (Table. 4). This change in sorting throughout Transect 2 suggests that waves have more influence on sorting as distance from the shoreline and wave energy increases, and that sediment was well sorted between the end of the transect and the supplemental samples.

The combination of wave diffraction and refraction in False Bay could explain the low fraction of fine sediment in the supplemental samples and the end of Transect 2 (Fig. 2c, 2d). The relatively low fractions of fine and very fine sand could be because fine sediment is less likely to be deposited at the center of the bay where the wave energy is high.

The supplemental samples and the end of Transect 2 also had similar fractions of medium and fine sand (Fig. 2c, 2d). Although the area between the end of Transect 2 and the supplemental samples likely had some degree of variability in the fraction of medium and fine sand, similarity between the samples suggests the medium and fine sand fractions do not change drastically in the area between the end of Transect 2, the center of the bay, and the lower bay sample. This is likely because the wave climate does not differ substantially between these samples.

In addition to waves, fluvial transport also can influence grain size distribution. Fluvial sediment can be transported into coastal areas through rolling, saltation, and suspension (Dyer, 1986). False Bay Creek likely transports sediment through these processes and deposits both gravel and finer sediments into False Bay. Fluvial transport of sediment also can result in the formation of a delta as fluvial sediment is deposited at the mouth of a river. As seen in Fig. 1, False Bay Creek creates a small delta that appears to have a boundary edge between 140 m and 160 m along Transect 1 and the distributary channel transect based on the Google Earth satellite image.

Transect 1 and the distributary both contained much larger fractions of coarse sediment than Transect 2. The beginning of Transect 1 was mainly composed of coarse sediment which generally decreased along the transect, except from 120 m to 160 m (Fig. 2b). The D_{50} from 120 m to 160 m was coarser than the previous and following samples (Fig. 4). The increase of coarse sediment and the coarse median grain size from 120 m to 160 m aligns with the edge of the delta present in the Google Earth imagery and suggests the edge of delta was coarser than its surrounding areas. The distributary channel transect somewhat displayed a shift to a coarser D_{50} from 120 m to 160 m, like Transect 1, but more variation in the D_{50} was present throughout (Fig. 4). The distributary channel likely had a less noticeable change in coarse sediment and D_{50} from 120 m and 160 m because sediment in the channel is constantly being disturbed by river discharge, waves, and tides.

After the edge of the delta, the fraction of coarse sediment decreased dramatically along Transect 1 and the fraction of medium and fine sand began to increase (Fig. 2b). Then, similarly, to Transect 2, the fraction of fine sand decreased as distance along Transect 1 increased (Fig. 2b). It is likely that after the end of the transect, the fine sand continued to decrease, and medium sand continued to increase and approached the grain size distribution observed in the supplemental samples (Fig. 2d). The decrease in fine sand suggests that wave action resulted in this decrease after the delta because a decrease of fine sand was also observed in Transect 2, which was only affected by wave action.

For the distributary channel transect, the fraction of fine sand generally increased for most of the transect and did not display a clear decrease in fine and very fine sand (Fig. 2a). Although the last two samples of the transect did have similar fractions of medium and fine sand, it is difficult to predict whether the fraction of fine sand would have increased or decreased after the end of the transect. The distributary channel was influenced by fluvial processes beyond the end of the transect because a clear decrease in fine sand was not observed.

The sediment along Transect 1 and in the distributary channel became more sorted after the delta (Fig. 3). Because waves usually increase sorting, this suggests that waves are beginning to have more of an influence on sediment after the delta ends and indicates the point where the influence of fluvial processes on sediment disappears and wave processes become the dominant physical process influencing sediment. At the end of all the transects, Transect 1 and the distributary channel were moderately well sorted while Transect 2 was well sorted (Table 4). This difference in sorting suggests that Transect 1 and the distributary channel had not yet reached the same level of wave influence as Transect 2. It is probable that sediment will continue to become more sorted as distance from the mouth decreases and wave energy increases.

Storms have the potential to resuspend sediment and transport sediment along shores in the direction the wind is going toward (Warner, 2008). Sediment transport also increases with river discharge (Dyer, 1986). As previously mentioned, a period of strong wind occurred and likely resuspended fine sediment and resulted in onshore transport of sediment. The high amount of precipitation during this time also could have resulted in more sediment and organic matter deposition by False Bay Creek and while in the field, I observed woody debris in the distributary channel for 100 m after the mouth of the creek.

One sample in particular was influenced by the large amount of woody debris in the distributary channel. DC 100 m was collected from underneath a layer of woody debris that covered the entire width of the distributary channel and had an anomalously high fraction of very fine sediment (Fig. 2a). Below the layer of woody debris, I observed a layer of silt and clay overlaying the sandy gravel that was typical in other distributary channel samples. DC 100 m contained the highest fraction of silt and clay of all the samples collected in False Bay (Fig. 2a-d). The sand and gravel observed was most likely present before the period of strong wind and rain because it is unlikely that 2.4 cm of precipitation could produce river discharge strong enough to move the gravel measured in the sample. The silt and clay were likely deposited during or after this period of rainfall and retained by the overlaying deposit of woody debris. The wind could have resuspended sediment and resulted in sediment deposition in the distributary channel, but due to the sample's position in the distributary channel and close proximity to False Bay Creek, it is likely the silt and clay were fluvial. No other sampling points were observed to have a layer of silt and clay similar to DC 100 m and without a layer of woody debris.

If this study was repeated, a dispersing agent should be used for either all samples or samples collected at the head or margin of the bay. For DC 100 m the sample was chemically disaggregated, and part of the sample was wet sieved. The combination of these methods likely resulted in a higher fraction of silt and clay than if the sample was only disaggregated using a mortar and pestle. It is very likely that because a dispersing agent was not used, samples such as T1 60 m and 120 m, which contained a large fraction of fine and very fine sand (Fig 2b), had a larger fraction of silt and clay than what was measured.

The supplemental samples were collected at similar locations as those of Pamatmat (1966). My mid bay sample was relatively close to Station 2 and the lower bay sample to Station 3. Pamatmat (1966) measured % weight through sieving dried sediment samples through a nest of sieves of 0.5 phi interval on an Aminco sieve shaker and did not specify how the mean or median grain size were calculated. The mean grain sizes were relatively similar between Stations 2 and 3 and my supplemental samples. The samples I collected were generally coarser in median grain size than what Pamatmat (1966) reported at nearby locations. The difference in median grain size could have been due to difference statistical calculations or different sieving methods. I used sieves at 1 phi intervals while Pamatmat (1966) used 0.5 phi interval sieves. One study could have also had a more accurate measure of grain size distribution or there could have possibly been more fine sand in 1966.

Organic carbon also was examined via LOI methods. The % LOI from 100 m to 300 m along Transect 1 and Transect 2 was more stable than the % LOI of the distributary channel transect (Fig. 5). This could have been a result of biological activity using the available carbon or there may have been a lack of organisms, such as bioturbators, that create a carbon sink (Kristensen, 2000).

Woody debris can be transported during a storm to marine areas and may play an important role in carbon cycling (West et al., 2011). As discussed previously, woody debris were observed in the distributary channel for 100 m after the mouth of the creek following a period of strong wind and high precipitation. *Ulva* sp. were also observed in the distributary channel, which could increase the organic carbon because the direct burial of macroalgae provides a net carbon sink (Smith, 1981). The distributary channel displayed the most variability in % LOI (Fig. 5) and could have been a result of *Ulva* sp. and woody debris in the distributary channel. The beginning of Transect 2 also contained a large amount of *Ulva* sp. T2 0 m had highest % LOI of all samples could have been a result of the burial of *Ulva* sp.

Future areas of study

This study aimed to increase the understanding of the influence of False Bay Creek and waves on grain size distribution and sediment organic carbon. More research can be done to further understand False Bay Creek, waves and circulation in False Bay, and the sediment grain size distribution and organic carbon throughout the bay.

The sediment grain size information gained in this study could also be used to formulate a preliminary hypothesis on where infauna, such as *Hemigrapsus oregonensis, Palaemonetes* *paludosus*, and bivalves, are likely to be found in False Bay based on the sediment grain size that is preferred and where the sediment grain size was found in this study.

No prior known research has been conducting in quantifying the river discharge at the mouth of False Bay Creek. Measuring river discharge during storms and periods of high precipitation could provide information on the relationship between river discharge and suspended sediment. An optical backscatter sensor also could be used to examine the suspended sediment concentration in False Bay to understand the amount of sediment and organic carbon being transported. An Acoustic Doppler current profiler also could be used to measure water currents in False Bay to understand how currents change during tides and to increase the understanding of how water moves in the Bay.

Pamatmat (1966) stated there is a clay layer underlying sand layer of unknown depth. Sediment cores could be in collected from various places in False Bay to examine if there is a clay layer and at what depth. I recommend initially sampling close to False Bay Creek and then expanding the sampling area outward because rivers are a source of sediment, and a single brief flood could introduce more sediment than many years of normal flow (Dyer, 1986) and could create a layer of fine sediment. Sediment also can be transported onshore and enter through the mouth of False Bay. It would also be necessary to determine if a clay layer is present throughout the bay or close to a False Bay sediment source.

Further grains size analysis and sediment organic carbon also could be done to increase the understanding on the variation of sediment grain size and organic carbon throughout False Bay.

Table 1.

% weight of sediments in the distributary channel transect. The 'Average' row contains the average of % weights for each grain size column.

Transect	**Distance Along Transect (m)**	**% COARSE GRAVEL:**	**% MEDIUM GRAVEL:**	**% FINE GRAVEL:**	**% V FINE GRAVEL:**	**% V COARSE SAND:**	**% COARSE SAND:**	**% MEDIUM SAND:**	**% FINE SAND:**	**% V FINE SAND:**	**% SILT:**	**% CLAY:**
DC	-20	7.71	16.2	8.95	5.68	7.15	19.66	34	0.26	0.39	0	0
DC	0	0	4.93	13.56	20.04	22.85	15.4	22.61	0.43	0.2	0	0
DC	20	6.31	11.49	17.42	14.13	15.58	20.26	14.35	0.39	0.06	0	0
DC	40	19.68	18.47	15.49	11.07	8.51	10.64	14.99	0.85	0.2	0.1	0.02
DC	60	40.96	14.55	12.22	7.98	6.3	6.8	10.38	0.62	0.09	0.1	0.02
DC	80	55.58	11.78	8.62	7	5.69	3.83	6.74	0.57	0.2	0	0
DC	100	12.37	10.55	8.24	6.17	6.67	15.9	19.99	4.01	0.18	13.25	2.65
DC	120	16.29	11.56	10.92	9.17	12.38	13.17	22.66	1.05	2.78	0	0
DC	140	12.48	14.73	11.9	5.97	6.68	10.33	28.5	9.18	0.18	0.05	0.01
DC	160	11.7	14.34	23.12	13.59	7.84	6.6	17.8	4.84	0.17	0	0
DC	180	0	8.4	13.5	11.51	7.93	8.77	39.34	10.47	0.08	0	0
DC	200	0.83	4.99	6.73	8.44	7.29	8.5	45.5	16	1.73	0	0
DC	220	4.94	11.61	12.67	13.24	10.49	8.56	28.41	9.79	0.3	0	0
DC	240	5.53	11.13	10.87	9.27	7.47	8.8	31.63	14.61	0.66	0	0
DC	260	2.78	11.95	15.22	11.59	7.07	4.02	28.14	18.92	0.3	0	0
DC	280	2.36	1.18	2.17	1.42	1.12	1.98	12.42	67.23	8.99	0.95	0.19
DC	300	0	0.94	1.2	0.91	0.86	2.14	54.37	38.7	0.86	0	0
DC	320	0	0	0.33	0.55	1.13	4.3	53.9	39.2	0.6	0	0
DC	Average	11.08	9.93	10.73	8.76	7.95	9.43	26.99	13.17	1	0.8	0.16

Table 2.

% weight of sediments along Transect 1. The ‘Average’ row contains the average of % weights for each grain size column.

Transect	Distance Along Transect (m)	% COARSE GRAVEL:	% MEDIUM GRAVEL:	% FINE GRAVEL:	% V FINE GRAVEL:	% V COARSE SAND:	% COARSE SAND:	% MEDIUM SAND:	% FINE SAND:	% V FINE SAND:	% SILT:	% CLAY:
1	0	26.02	16.44	14.18	8.71	6.46	7.48	20.26	0.32	0.14	0	0
1	20	19.18	26.08	14.93	7.75	4.97	5.7	20.32	0.62	0.38	0.05	0.01
1	40	17.72	26.14	17.75	8.89	5.08	6.11	16.67	1.4	0.24	0	0
1	60	22.71	22.99	13.48	7.96	6.39	8.27	16.85	1.15	0.18	0.01	0
1	80	11.33	13.78	10.51	10.65	9.96	12.49	29.7	1.48	0.11	0	0
1	100	2.55	2.73	2.96	3.21	11.61	18.25	45.73	12.32	0.62	0.01	0
1	120	3.05	14.7	36.34	12.67	5.09	4.34	14.53	8.91	0.33	0.03	0.01
1	140	0	17.55	18.23	13.11	8.55	10.13	20.84	11.1	0.45	0.03	0.01
1	160	13.68	13.13	13.79	11.54	9.14	9.69	22.26	6.72	0.04	0	0
1	180	1.05	2.45	4.08	5.09	6.37	9.3	30.77	35.68	5.04	0.13	0.03
1	200	2.75	4.52	5.02	4.93	4.67	9.17	45.5	20.32	3.12	0	0
1	220	5.32	0.16	0.05	0.16	0.56	3.67	47.89	38.94	3.25	0	0
1	240	0	0	0.02	0.15	0.41	1.83	41.17	52.59	3.83	0	0
1	260	0	0	0	0.06	0.12	1.45	51.68	43.98	2.66	0.05	0.01
1	280	0	0	0	0.11	0.31	1.91	57.01	38.13	2.48	0.05	0.01
1	300	0	0	0	0.02	0.12	1.74	76.76	20.87	0.5	0	0
1	Average	7.84	10.04	9.46	5.94	4.99	6.97	34.87	18.41	1.46	0.02	0.01

Table. 3

% weight of sediments along Transect 2. The ‘Average’ row contains the average of % weights for each grain size column.

Transect	**Distance Along Transect (m)**	**% COARSE GRAVEL:**	**% MEDIUM GRAVEL:**	**% FINE GRAVEL:**	**% V FINE GRAVEL:**	**% V COARSE SAND:**	**% COARSE SAND:**	**% MEDIUM SAND:**	**% FINE SAND:**	**% V FINE SAND:**	**% SILT:**	**% CLAY:**
2	0	47.43	3.49	2.49	2.48	6.69	9.68	21.29	6.19	0.16	0.05	0.01
2	20	0	0	0.07	0.55	1.14	2.03	54.36	38.14	3.31	0.35	0.07
2	40	0	0	0	0.09	0.86	1.88	44.43	49.78	2.91	0.05	0.01
2	60	0	0	0	0.33	0.69	1.21	23.49	55.42	15.86	2.5	0.5
2	80	0	0	0	0.06	0.71	1.29	49.1	45.91	2.05	0.7	0.14
2	100	0	0	0	0.05	0.16	0.52	52.04	43.01	3.74	0.4	0.08
2	120	0	0	0.07	0.22	0.94	0.96	10.77	74.05	10.84	1.8	0.36
2	140	0	0	0	0.36	0.98	1.71	63.14	31.71	1.43	0.55	0.11
2	160	0	0	0.02	0.7	1.14	1.14	80.34	16.31	0.24	0.1	0.02
2	180	0	0	0	0.36	0.57	1.03	74.03	21.83	1.81	0.3	0.06
2	200	0	0	0.02	0.48	0.78	1.24	77.04	20.12	0.23	0.1	0.02
2	220	0	0	0	0.07	0.33	0.89	64.95	32.4	1.14	0.2	0.04
2	240	0	0	0	0.09	0.79	1.86	61.81	34.26	0.9	0.25	0.05
2	260	0	0	0.09	0.12	0.26	2.78	86.34	10.33	0.08	0	0
2	280	0	0	0	0.48	1.07	2.09	71.13	24.67	0.43	0.1	0.02
2	300	0	0	0	0.07	0.13	1.46	88.05	10.12	0.12	0.05	0.01
2	Average	2.96	0.22	0.17	0.41	1.08	1.99	57.64	32.14	2.83	0.47	0.09

Table 4

% weights of sediment in supplemental samples.

	% V COARSE GRAVEL:	% COARSE GRAVEL:	% MEDIUM GRAVEL:	% FINE GRAVEL:	% V FINE GRAVEL:	% V COARSE SAND:	% COARSE SAND:	% MEDIUM SAND:	% FINE SAND:	% V FINE SAND:	% SILT:	% CLAY:
Mid Bay sample	0	0	0	0	0.07	0.13	1.77	85.33	11.99	0.53	0.15	0.03
Lower Bay sample	0	0	0	0	0.06	0.09	1.99	87.78	9.21	0.69	0.15	0.03

Table 5

Sorting of sediments in Transect 1, Transect 2, distributary channel transect, and supplemental samples.

Transect	Distance Along Transect (m)	SORTING (σI)	Sorting (Description)
1	0	2.164	Very Poorly Sorted
1	20	2.346	Very Poorly Sorted
1	40	2.293	Very Poorly Sorted
1	60	2.346	Very Poorly Sorted
1	80	2.268	Very Poorly Sorted
1	100	1.506	Poorly Sorted
1	120	2.126	Very Poorly Sorted
1	140	2.175	Very Poorly Sorted
1	160	2.395	Very Poorly Sorted
1	180	1.653	Poorly Sorted
1	200	1.874	Poorly Sorted
1	220	1.449	Poorly Sorted
1	240	0.65	Moderately Well Sorted
1	260	0.64	Moderately Well Sorted
1	280	0.638	Moderately Well Sorted
1	300	0.532	Moderately Well Sorted
2	0	1.536	Poorly Sorted
2	20	0.658	Moderately Well Sorted
2	40	0.65	Moderately Well Sorted
2	60	0.814	Moderately Sorted
2	80	0.645	Moderately Well Sorted
2	100	0.646	Moderately Well Sorted
2	120	0.604	Moderately Well Sorted
2	140	0.624	Moderately Well Sorted
2	160	0.476	Well Sorted
2	180	0.572	Moderately Well Sorted
2	200	0.524	Moderately Well Sorted
2	220	0.608	Moderately Well Sorted
2	240	0.619	Moderately Well Sorted
2	260	0.425	Well Sorted
2	280	0.573	Moderately Well Sorted
2	300	0.418	Well Sorted
DC	-20	2.201	Very Poorly Sorted
DC	0	1.603	Poorly Sorted
DC	20	1.917	Poorly Sorted
DC	40	2.279	Very Poorly Sorted
DC	60	1.3	Poorly Sorted
DC	80	1.306	Poorly Sorted
DC	100	3.54	Very Poorly Sorted
DC	120	2.374	Very Poorly Sorted
DC	140	2.453	Very Poorly Sorted
DC	160	2.265	Very Poorly Sorted
DC	180	1.974	Poorly Sorted
DC	200	1.828	Poorly Sorted
DC	220	2.197	Very Poorly Sorted
DC	240	2.289	Very Poorly Sorted
DC	260	2.266	Very Poorly Sorted
DC	280	1.255	Poorly Sorted
DC	300	0.718	Moderately Sorted
DC	320	0.689	Moderately Well Sorted
Mid Bay Sample		0.424	Well Sorted
Lower Bay Sample		0.443	Well Sorted

Table 6

D_{50} of sediments along Transect 1, Transect 2, distributary channel transect, and supplemental samples.

Transect	Distance Along Transect (m)	D50 (φ)
1	0	-2.468
1	20	-2.683
1	40	-2.654
1	60	-2.681
1	80	-0.625
1	100	1.19
1	120	-2.112
1	140	-0.87
1	160	-1.186
1	180	1.704
1	200	1.416
1	220	1.837
1	240	2.122
1	260	1.936
1	280	1.836
1	300	1.627
2	0	-3.262
2	20	1.85
2	40	2.055
2	60	2.438
2	80	1.976
2	100	1.947
2	120	2.5
2	140	1.744
2	160	1.585
2	180	1.649
2	200	1.616
2	220	1.75
2	240	1.765
2	260	1.541
2	280	1.652
2	300	1.549
DC	-20	0.219
DC	0	-0.498
DC	20	-0.959
DC	40	-2.235
DC	60	-3.379
DC	80	-4.146
DC	100	0.377
DC	120	-0.834
DC	140	-0.263
DC	160	-1.939
DC	180	0.988
DC	200	1.291
DC	220	-0.281
DC	240	0.651
DC	260	0.345
DC	280	2.407
DC	300	1.808
DC	320	1.811
Mid Bay sample		1.563
Lower Bay sample		1.545

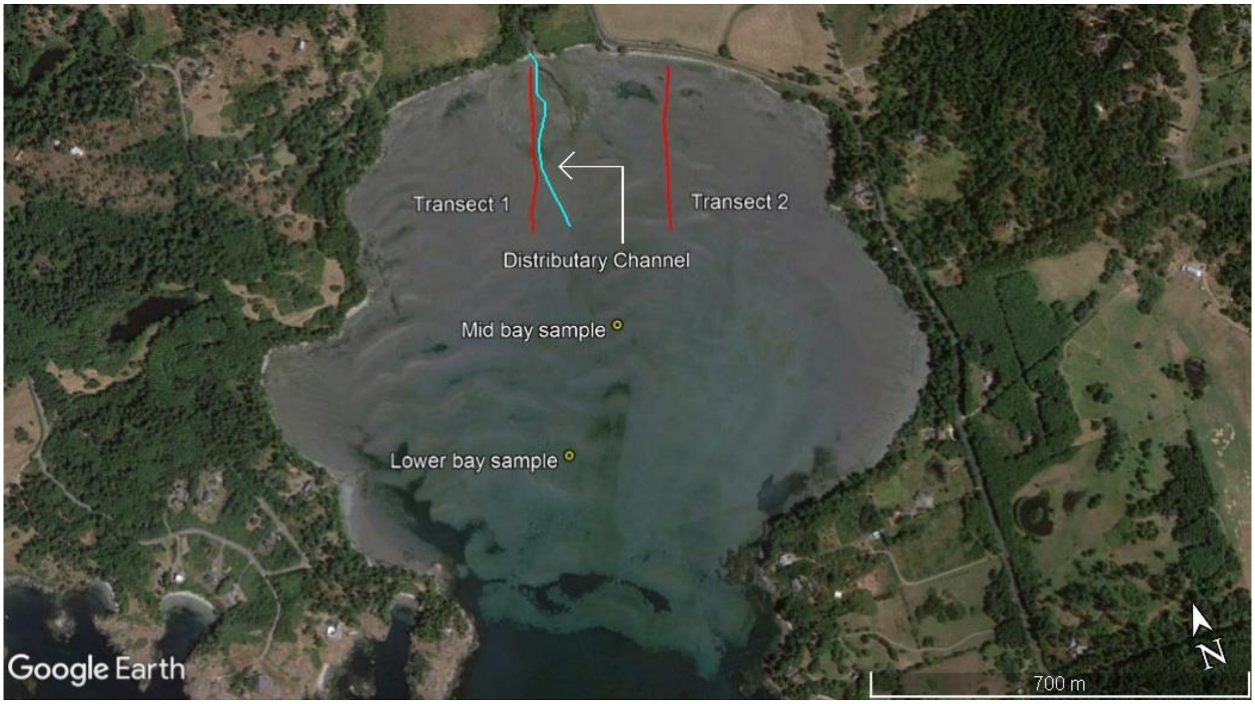
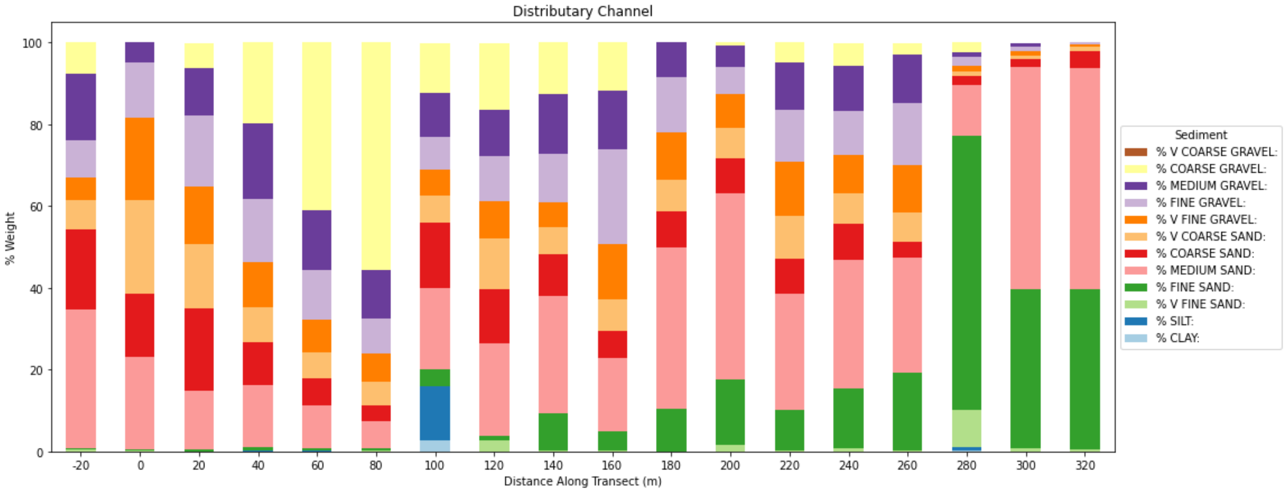


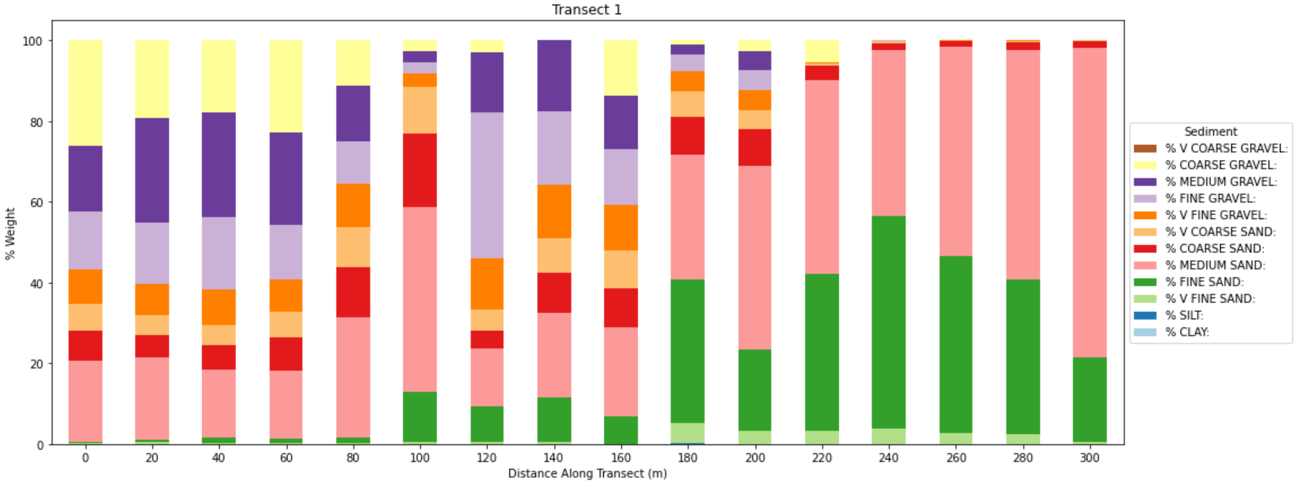
Figure 1.

Map of sampling transects and supplemental samples in False Bay, San Juan Island.

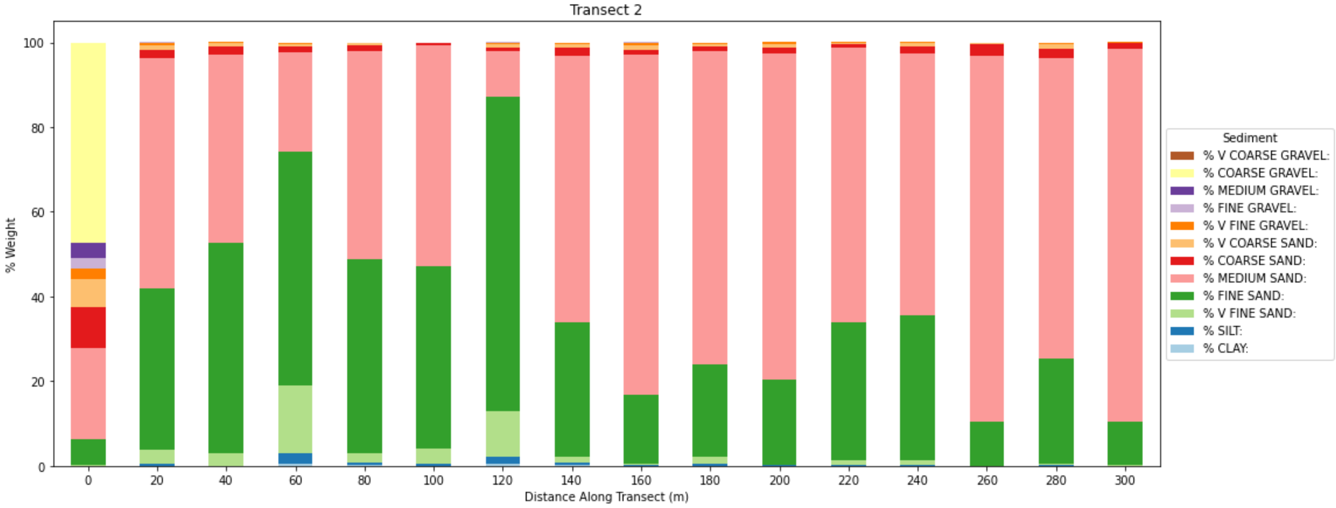
a


Distributary Channel
% Weight
0
20
40
60
80
100
-20
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
Distance Along Transect (m)
Sediment
% V COARSE GRAVEL:
% COARSE GRAVEL:
% MEDIUM GRAVEL:
% FINE GRAVEL:
% V FINE GRAVEL:
% V COARSE SAND:
% COARSE SAND:
% MEDIUM SAND:
% FINE SAND:
% V FINE SAND:
% SILT:
% CLAY:

b


Transect 1
% Weight
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance Along Transect (m)
Sediment
% V COARSE GRAVEL:
% COARSE GRAVEL:
% MEDIUM GRAVEL:
% FINE GRAVEL:
% V FINE GRAVEL:
% V COARSE SAND:
% COARSE SAND:
% MEDIUM SAND:
% FINE SAND:
% V FINE SAND:
% SILT:
% CLAY:

c


Transect 2
% Weight
0
20
40
60
80
100
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
Distance Along Transect (m)
Sediment
% V COARSE GRAVEL:
% COARSE GRAVEL:
% MEDIUM GRAVEL:
% FINE GRAVEL:
% V FINE GRAVEL:
% V COARSE SAND:
% COARSE SAND:
% MEDIUM SAND:
% FINE SAND:
% V FINE SAND:
% SILT:
% CLAY:

d

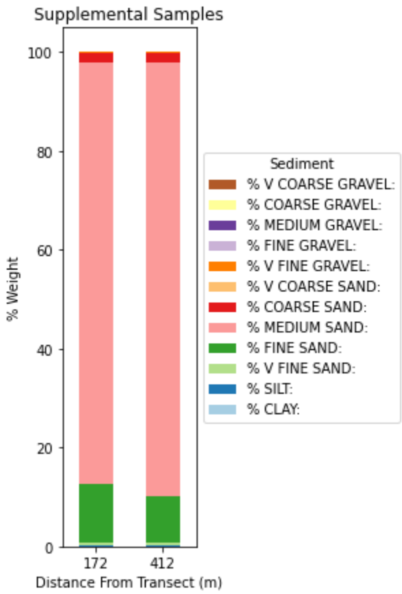


Figure 2.

% weights of sediment grain sizes for Transect 1 (a), Transect 2 (b), the distributary channel transect (c), and supplemental samples (d).

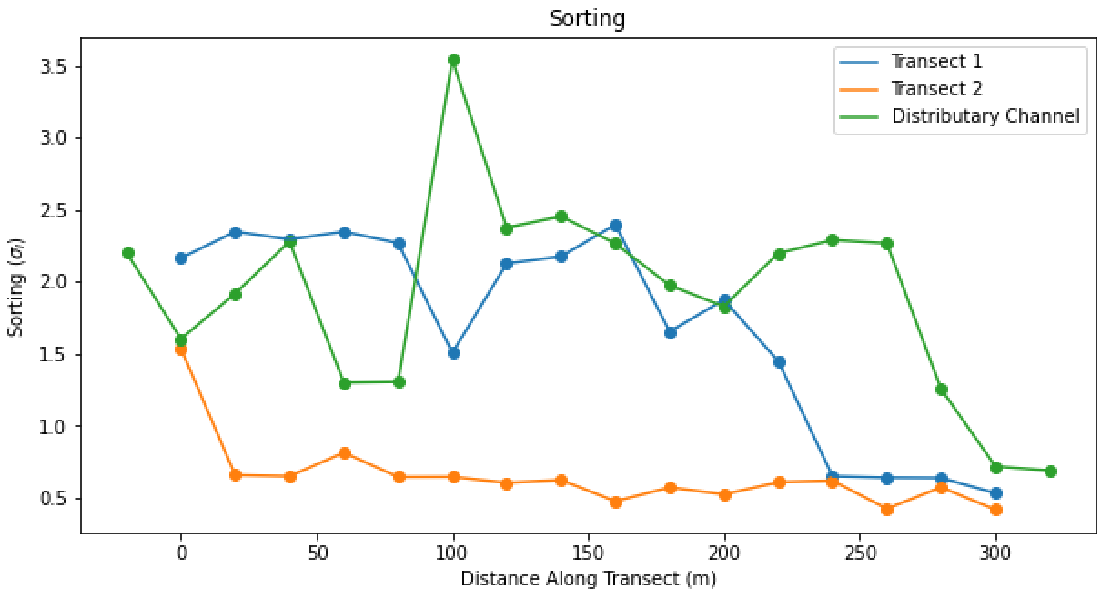


Figure 3.

Sorting of sediments along Transect 1, Transect 2, and the distributary channel transect.

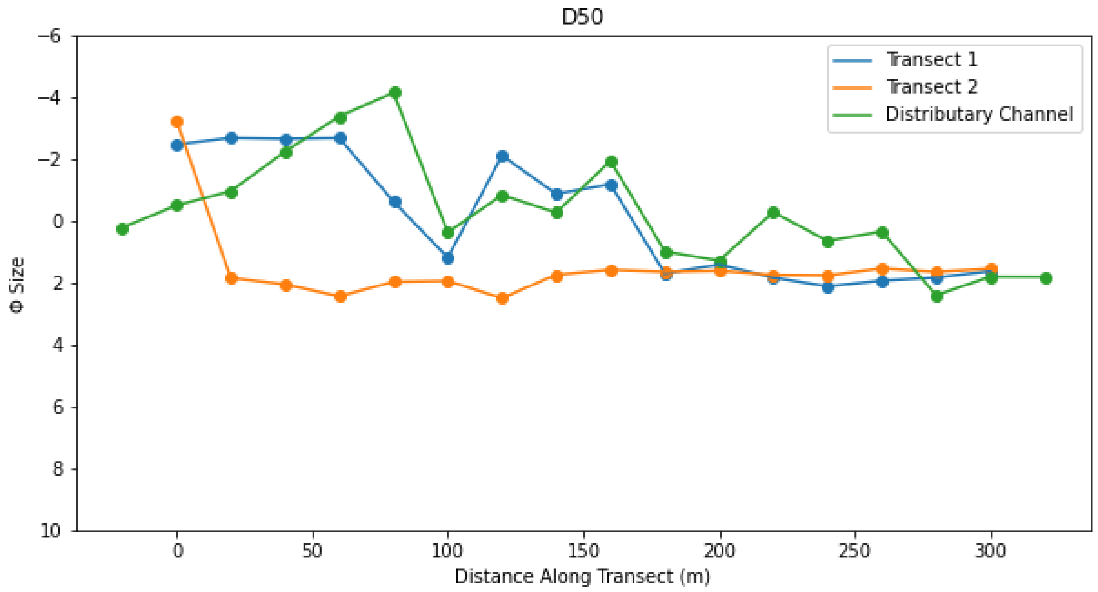


Figure 4.

D_{50} of sediments along Transect 1, Transect 2, and the distributary channel transect.

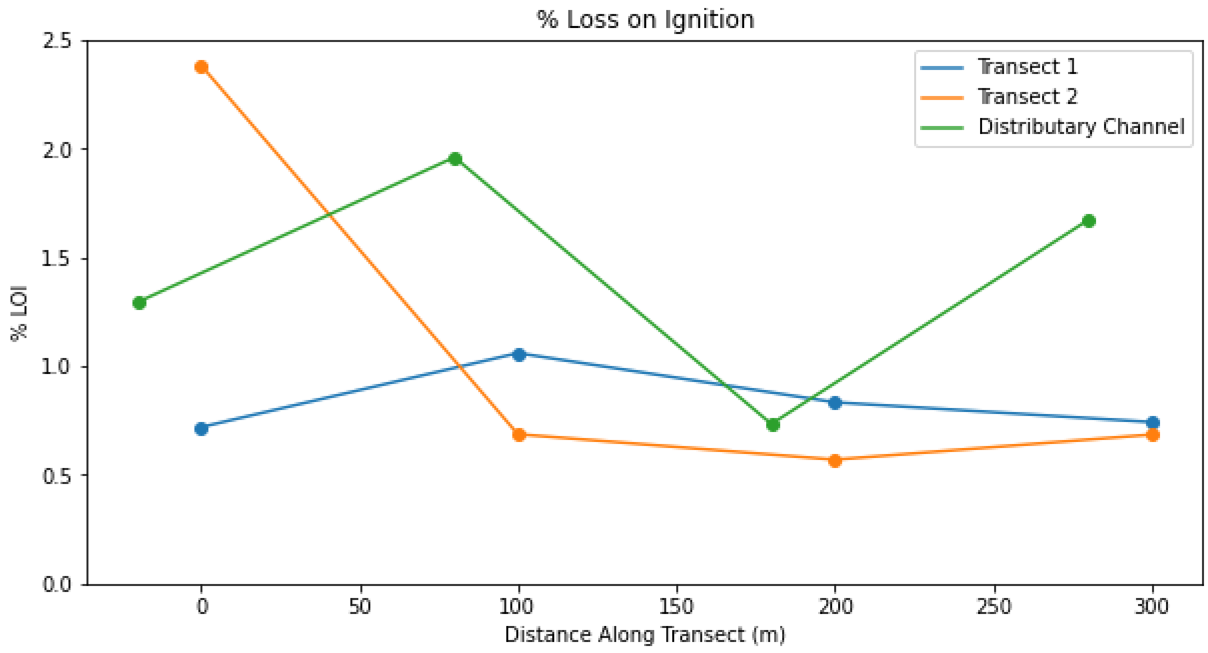


Figure 5.

% LOI of sediments along Transect 1, Transect 2, and the distributary channel transect.

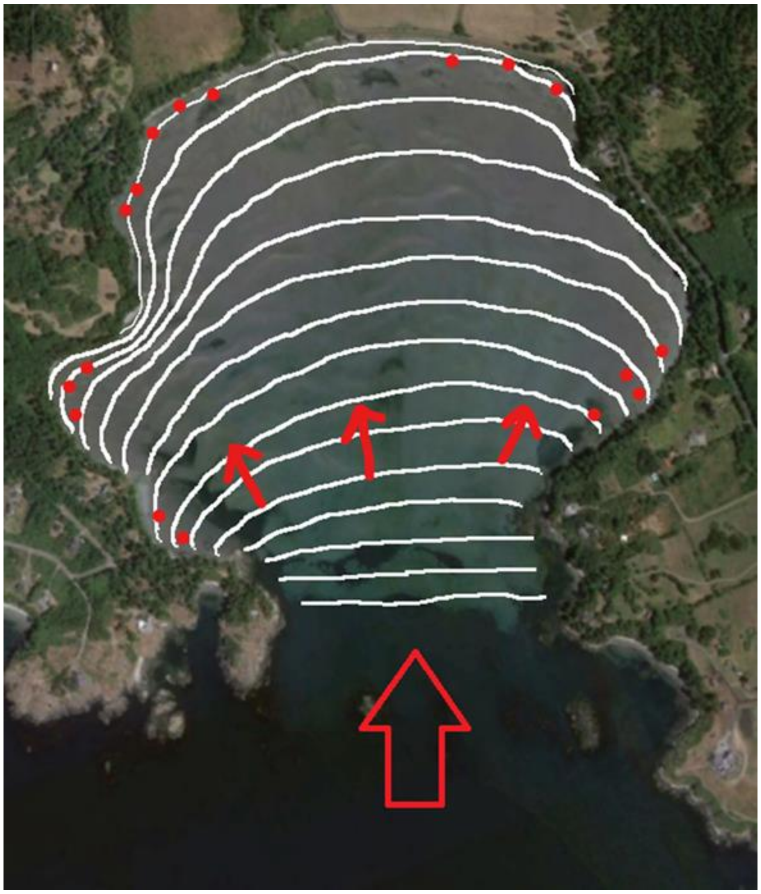


Figure 6.

Hypothetical sketch of wave refraction and diffraction in False Bay. The red arrow outline is the directions of waves entering the bay. The white lines are wave fronts. The small red arrows represent wave rays diverging. Red dots represent where fine sediment deposition occurs.

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