Olympia Oyster Broad Brush

Phase 1 Report

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1.0 Introduction

The Olympia oyster (*Ostrea lurida*, Carpenter 1864) is the only oyster species native to British Columbia (Gillespie, 1999). Traditionally, their range extended from Sitka, Alaska, to Baja California, Mexico (Baker, 1995), and predominantly occupied subtidal areas within estuaries, protected bays, and saltwater lagoons (Gillespie, 2009). In the early 1900s, the Victoria area, and Vancouver Island at large, supported substantial Olympia oyster fisheries. Over-exploitation, as well as urban pressures through habitat depletion, pollution, and invasive fouling organisms, led to significant declines in Olympia oyster numbers that have not been reversed (Gillespie, 2009, Kirby, 2004; Pritchard et al., 2015; Stanton et al., 2011). Under Canada's Species At Risk Act (SARA), the Olympia oyster was designated as a species of "Special Concern" in 2003 (Fisheries & Oceans Canada, 2009). Despite existing only in scattered, remnant populations on the west coast, a significant Olympia oyster population persists in the Gorge Waterway and Portage Inlet (Archipelago Marine Research, 2000; Gillespie, 2009; Stanton et al., 2011, WFT, unpublished).

In 2009, WFT contributed to an assessment of Olympia oysters on the west and south coast of British Columbia (Stanton et al., 2011). Surveys included quantifying site-specific Olympia oyster density and distribution, as well as comparing modern-day populations with historical records. Stanton et al. (2011) report that the Gorge Waterway supports healthy Olympia oyster populations in the intertidal and subtidal habitats. As depth increased from low intertidal zones to subtidal habitat, abundance of Olympia oyster increased drastically, and the oyster reefs observed created robust, three-dimensional structures (Stanton et al., 2011).

Through support and guidance from the Capital Regional District (CRD), WFT has completed a similar, although more rigorous survey of Olympia oyster abundance and distribution. This study re-examined Portage Inlet and the Gorge Waterway survey sites from the 2011 report and further extended the survey to include 11 sites in the Victoria Harbour, as well as an additional site in Portage Inlet. Density and distribution of Olympia oysters were estimated. Substrate, vegetation, encrusting invertebrates, and slope were documented to better understand the occurrence of Olympia oysters in particular zones, as well as their association with other species. This information will provide a better understanding of Olympia oyster's intertidal distributions and will serve as a guideline for completing similar studies in the future. Additionally, the spatial data described will be included in the CRD's Harbour Atlas.

2.0 Study Area

The Gorge Waterway is a narrow 7km urban inlet that begins in Victoria Harbour and extends into Portage Inlet (Figure 1). All of this urban waterway is part of the Victoria Migratory Bird Sanctuary and supports many ecological and human communities. The study area can be divided into six key geographic areas with differing characteristics: Portage Inlet, Upper Gorge Waterway, Lower Gorge Waterway, Selkirk Water, the Upper Harbour and the Inner and Middle Harbour. Forty-six sampling sites were established within the study area, including the 34 sites surveyed in 2011 (Fig. 2).

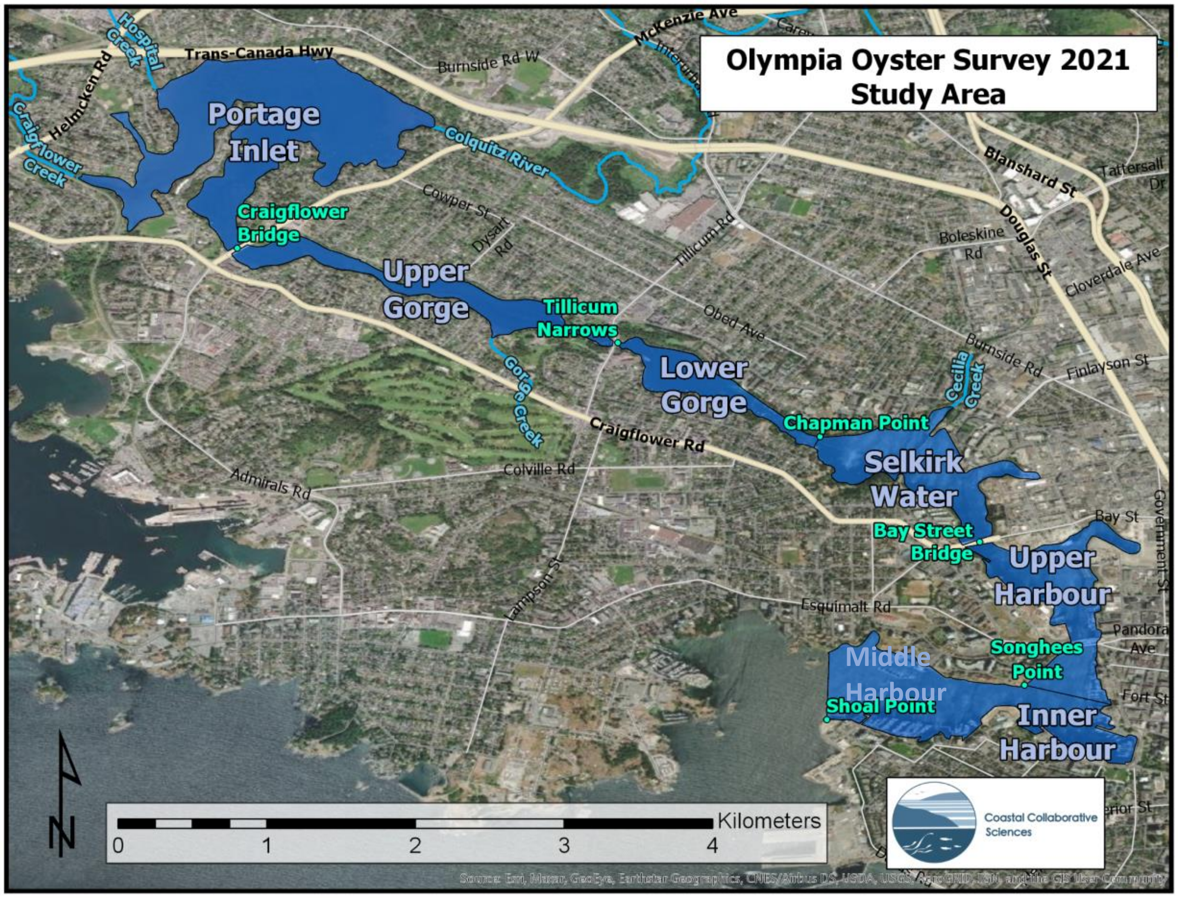


Figure 1. 2021 Olympia oyster survey area, showing regions of the waterways. Demarcation points are indicated in teal labelling. Regions are described in the text. Note: The Middle Harbour extends from Songhees Point and Laurel Point west to Shoal Point.

Portage Inlet

Portage Inlet is a shallow basin dominated by intertidal mud flats and eelgrass beds. Three urban watersheds (Colquitz river, Craigflower creek, and Hospital creek) drain freshwater into the inlet and deposit various types of sediment such as sand, silt, and mud. Due to its distance from the Salish Sea, this area is least affected by an input of seawater during tidal cycles and experiences warm water temperatures in the summer months. Suburban homes line the shore of Portage Inlet and hard armoring of shorelines is common. Eleven sampling sites were surveyed in Portage Inlet.

Gorge Waterway

The Gorge Waterway is a narrow tidal inlet that runs between Craigflower Bridge and Chapman Point. In the Gorge Waterway, strong currents mix sediment with freshwater deposits from the land and saltwater from the sea, which creates a very dynamic environment. The waterway is divided into the Upper Gorge and the Lower Gorge by Tillicum Narrows, a tidal fall directly beneath Tillicum Bridge. Due to tidal ebb and flow, Tillicum Narrows creates the highest energy environment in the study area. Here, brackish water is churned up with the tidal cycles and leads to significant nutrient mixing. Strong currents prevent sediments from depositing. Gorge Creek flows into the Waterway above Tillicum

Narrows. Mixed density suburban homes line the shore of the Gorge Waterway and hard armoring of shorelines is common. In total, sixteen sampling sites were surveyed in the Gorge Waterway, eight each in the Upper Gorge and Lower Gorge.

Selkirk Waterway

The Selkirk Waterway extends from Chapman Point to the Bay Street Bridge, traversed by the Selkirk Trestle at the Cecilia Creek estuary. This creek, draining a heavily urbanized watershed, enters north of the Trestle. In the Selkirk Waterway area, the shoreline use shifts from suburban to industrial land use. Intertidal mud flats dominate the natural shorelines. Hard armoring of the shoreline is common. Six sampling sites were surveyed in the Selkirk Waterway.

Victoria Upper, Inner, and Middle Harbour

Victoria's Upper Harbour covers the area from the Bay Street Bridge south to the Johnson Street Bridge and includes Rock Bay. The Inner Harbour extends from the Johnson Street Bridge southwest to Songhees Point in Vic West and Laurel Point in James Bay. The Middle Harbour, which represents the furthest limits of our survey, extends west from the Inner Harbour to Shoal Point. The shoreline in this area has been heavily modified and is predominantly used for industrial purposes or marinas. Despite efforts to clean up and restore the Inner and Upper Harbours, high levels of pollution still exist within the sediments and organisms (Ocean Wise, 2018). The Middle Harbour opens to the Strait of Juan de Fuca via the Outer Harbour, reflected by more oceanic water conditions than those of Portage Inlet and the Gorge Waterway. Seven sites were surveyed in the Upper Harbour, three sites were surveyed in the Inner Harbour and two sites were surveyed in the Middle Harbour.

3.0 Methods

The methodology used in this study was adapted from the 2009 Olympia oyster study (Stanton et al., 2011). In this 2009 study, a starting site was randomly selected in Portage Inlet and transects were placed systematically every 500 m, perpendicular to the shore and extending from the high tide line to the water line. Along the transects, quadrats were placed to assess Olympia oyster density. However, it was found that the quadrat sampling was too variable for analysis, so the publication only reports presence or absence of Olympia oysters. In addition, our subsequent experience suggests that some of the transects likely did not extend far enough to include the main zone of intertidal oysters.

Evaluation of data from our regular indicator sites indicated that the mid-zone of the intertidal oyster distribution in Portage Inlet was at -0.2 m relative to chart datum. Thus, in the current survey our transects all extended from the high tide mark to at least -0.2m depth (CD), snorkeling as needed, to ensure detection of oysters if present. The transects were extended further to the end of the oyster band, if present and where feasible. The average tabulated tides above the Tillicum narrows are considerably lower than those below the narrows, so this depth was also a conservative target for the remainder of the survey. Surveys were conducted as close to low tide as possible to maximize exposed shoreline and minimize the snorkeling required and were limited to day-time low tides.

Sites

The same 34 sampling sites surveyed in 2009 were surveyed in the present study, as well as an additional 11 sites to better characterize the extent of the oyster population in the harbours (fig. 2). Transects were located at 500m intervals along the shoreline, as was done in 2009. In addition, an extra site (Site 13.5) was surveyed between sites 13 and 14 as part of a training exercise and included in the data.

Sites above Tillicum Narrows (Sites 7 - 27) were surveyed from September 29th to October 3rd, 2020, while sites below Tillicum Narrows (Sites 1 – 6, and Sites 28 – 45) and site 14 were surveyed from March 18th to April 2nd, 2021. Dates were staggered to allow time to assess the field methodology. Winter surveys were avoided as low tides often occur at night and water turbidity is generally high.

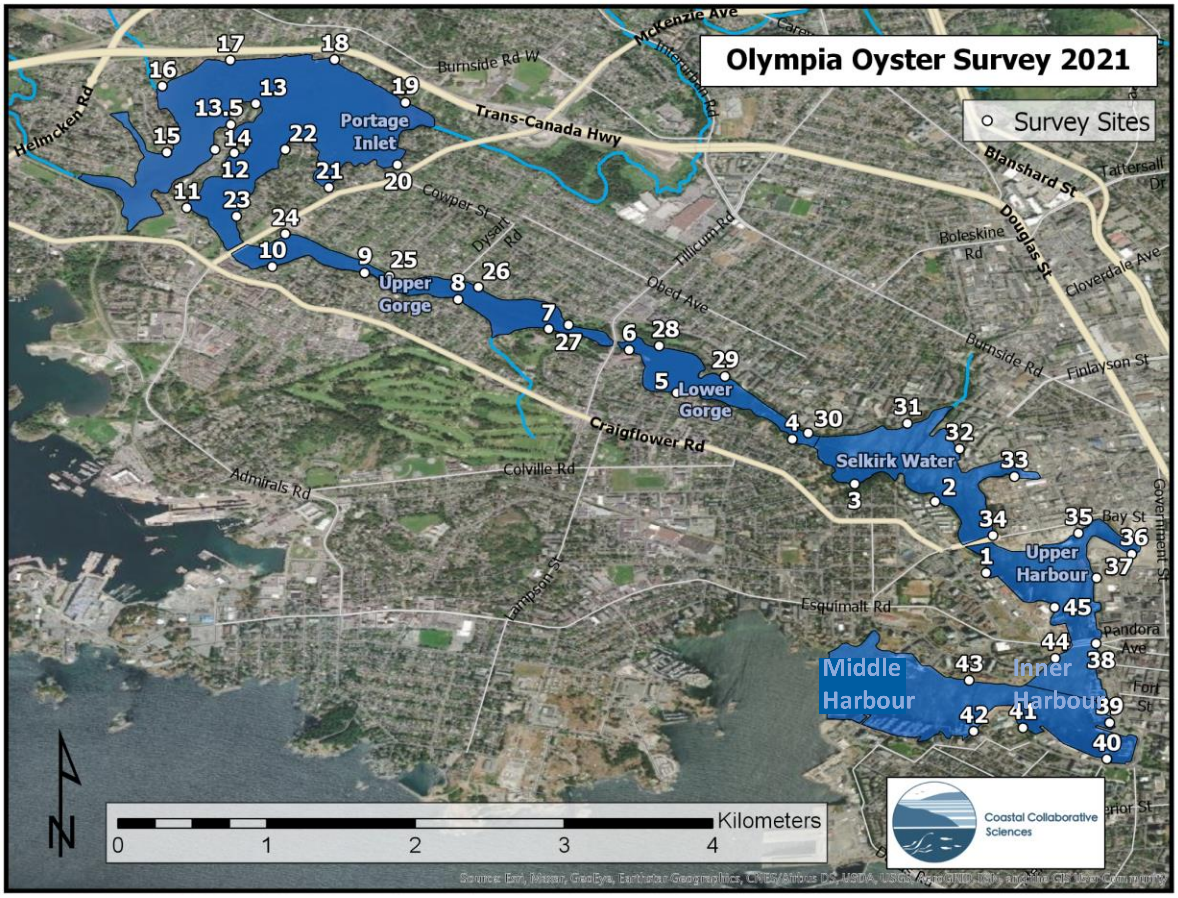


Figure 2. 2021 Olympia Oyster Survey Site Map. At each site, Olympia oyster presence, density, and distribution were recorded. Surveys were completed from September 29th to October 3rd, 2020 and March 12th to April 2nd, 2021 in Victoria, BC. Note the Inner Harbour lies between the Johnson Street Bridge to Songhees Point and Laurel Point, while the Middle Harbour occupies the waters west of the Inner Harbour to Shoal Point. Sites 42 and 43 lie within the boundaries of the Middle Harbour, while Sites 39, 40, 41 and 44 are located within the Inner Harbour.

Transects

At each site, a 60m transect was placed perpendicular to the shoreline. The transect extended from the highest high-water line to a minimum of -0.2 meters (CD). The length of the transect was extended, if needed, to reach this point. The average highest high-water line was taken as the bottom of the black *Verucarria* lichen band (where present), the highest level of flotsam, or the lower edge of tree branch vegetation if hanging in the water.

The -0.2m depth was calculated from the level of the water at the survey time, relative to the Canadian Hydrographic Tide tables for Portage Inlet (above Tillicum Narrows) or Victoria Harbour (below Tillicum Narrows) (Fisheries and Oceans Canada, 2021). When Olympia oysters continued past -0.2m chart datum into the subtidal zone, surveyors extended the transect until the end of the Olympia oyster band where possible. In some instances, the Olympia oyster band did not end and the transect was described as “Continuous”.

Biological Bands, Density, & Distribution

Along the transect, biophysical bands were identified based on dominant biotic and abiotic characteristics. Changes in substrate, vegetation and encrusting organisms were recorded as band breaks. These were labelled alphabetically from highwater line to -0.2m chart datum, beyond which they were categorized as subtidal. The location of band breaks was recorded as the distance on the transect line and elevation relative to the start of the transect line and the previous band break. The transect distance and time of the water line was also recorded.

Biological band characteristics were based on the substrate and organisms found within a one-meter area to either side of the transect tape. Substrate in each band was described as an estimation of percent composition on the surface, using Wentworth scale descriptors (Wentworth, 1922).
The vegetative algal cover and presence of encrusting invertebrates were likewise described on a % cover basis. Density of other species within each band were described semi-quantitatively Polson’s classification system (Polson et al., 2009) for density. A secondary measure was recorded for all algae and invertebrates to describe the type of distribution (i.e. level of patchiness).

Surveyors walked and snorkeled the length of the transect and estimated the average number of organisms per 0.25m^2 within each band, using a quadrat for reference as needed. Table 1 shows the density and distribution classifications used along with the corresponding description. Figure 3 shows photographs of typical density classifications. Photographs were taken to document the site and presence and distribution of Olympia oysters and to supplement verification of any irregularities in the datasheets.

Table 1. Density and distribution classification schematic.

Density class	Organisms per 0.25m^2	Distribution class	Description
Absent	0	Absent	None
Rare	1 to 2	Few	A single or few sporadic individuals
Present	3 to 10	Patchy	A grouping, several individuals, or a few groups
Common	10 to 100	Uniform	Uniform occurrence
Abundant	>100	Continuous	Continuous occurrence with gaps
-	-	Dense	Continuous dense occurrence

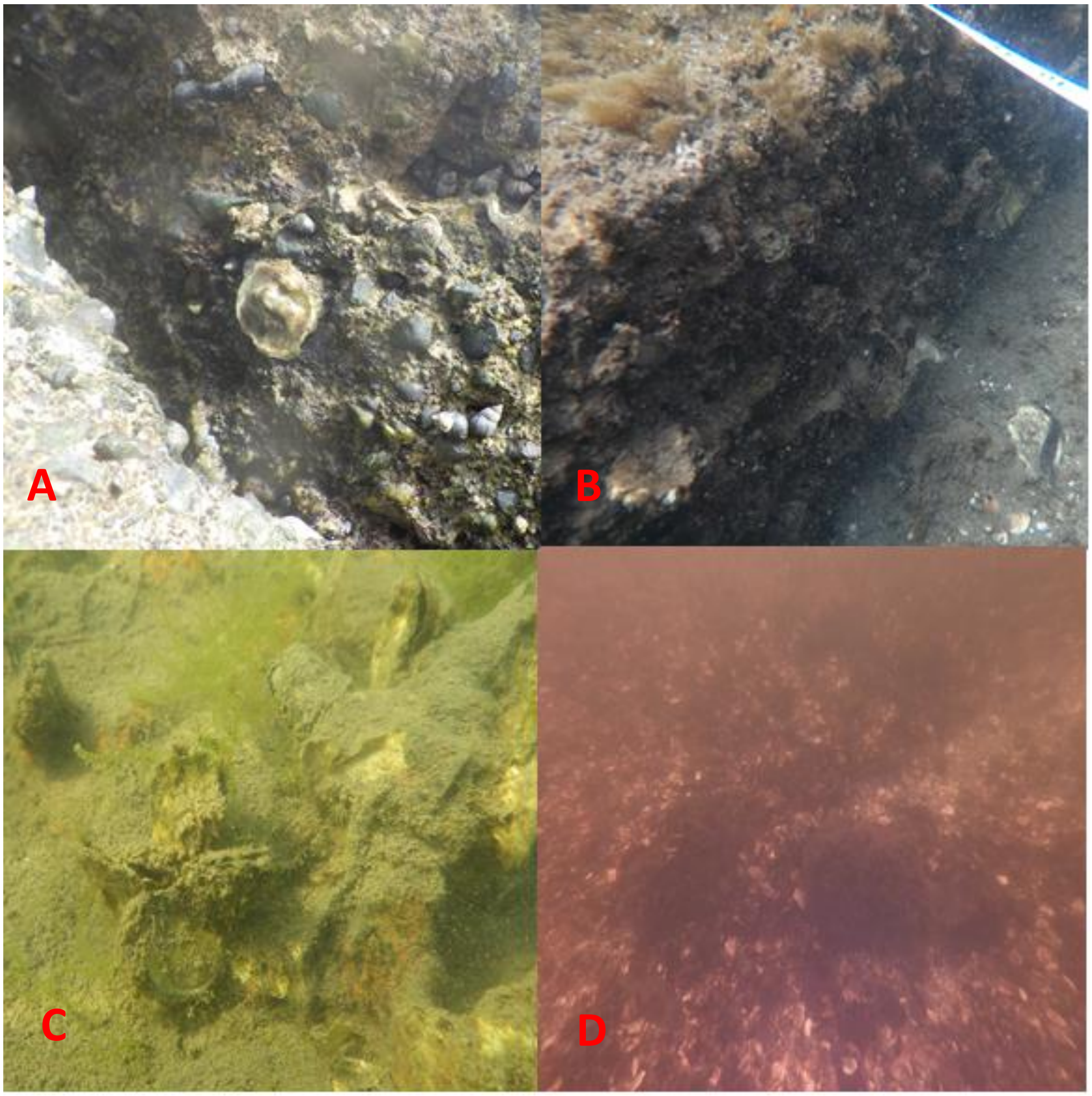


Figure 3. Typical Olympia oyster density classification used in 2021 Olympia oyster survey. Density classes are: *Rare* (A, Site 35), 1 to 2 Olympia oysters/0.25m²; *Present* (B, Site 30), 3 to 10 Olympia oysters/0.25m²; *Common* (C, Site 11), 10 to 100 Olympia oysters/0.25m²; *Abundant* (D, Site 6), >100 Olympia oysters/0.25m².

Olympia and Pacific oyster densities were recorded with the same semi-quantitative scale, though absence and presence of dead oyster shells was also specifically recorded. Quadrat sampling was not pursued in the current survey, as the 2009 survey indicated that the sampling effort required for accurate estimates is not feasible.

Data Tables

A data table was created for each site. This table includes the major species and substrate as well as the density and distribution of Olympia oysters observed at the site (Table 2). The biophysical bands were labelled alphabetically and can be referenced to the bands shown in the corresponding profile diagram. The data table has 6 categories:

1. Location
    - Site
    - Date
    - Time *(at beginning of survey)*
    - Tide *(at beginning of survey)*
    - Biophysical Band
    - Transect distance *(at the beginning of band)*
    - Chart Datum height [*(at the beginning of band)]*
2. Substrate
    - Type
    - Substrate percent cover
3. Vegetation
    - Type
    - % cover
    - Distribution
4. Encrusting Invertebrates
    - Type
    - % cover
    - Distribution
5. Olympia Oysters
    - Density
    - Distribution
6. Notes

Table 2. Data table of Site 18. All information regarding Olympia oysters is in bold

Date	Time	Tide	Site	Band	Transe	Datur	bstrate	ıbstrate C	getatio	etation	ation Dist	rusting	usting I	ting Dis	nvert T	vert De	ert Distrib	OO Den	OO Distribu	Notes
Location							Substrate		Vegetation			Encrusting Invertebrates			Other Invertebrates			**Olympia Oysters**		Notes
Date	Time	Tide	Site	Band	Transect Distance	Datum Height	Type	Substrate cover	Type	Density	Distribution	Type	Density	Distribution	Type	Density	Distribution	Density	Distribution	Notes
Oct-20	1:45 PM	0.7	18	A	0	1.66	Mud	80%	Grass	30%		N/A			N/A			**N/A**		
							Boulder	20%	Silverwee	10%										
Oct-20	1:45 PM	0.7	18	B	2.5	0.8	Mud	60%	Diatom Bi	100%		N/A			N/A			**N/A**		Lots of eelgrass drift; anoxic
							Cobble	30%												
							Shell hash	10%												
Oct-20	1:45 PM	0.7	18	C	6	0.62	Mud	20%	N/A			N/A			Mud snail	Rare	Patchy	**Rare**	**Patchy**	**First Olympia Oyster at 9.8m;**
							Pebble	20%							Clam	Present	Patchy			
							Gravel	40%												
							Cobble	20%												
Oct-20	1:45 PM	0.7	18	D	13	0.29	Shell hash	20%	N/A			Sponge	Rare	Patchy	Bubble Sr	Present	Uniform	**Present**	**Patchy**	**Olympia Oyster present on substrate, more**
							Woody m	80%				Ascidian	Rare	Patchy	Shrimp	Few	Patchy			
Oct-20	1:45 PM	0.7	18	Beyond	25.8	-0.2			Eelgrass	Dense	Continuous									Eelgrass dense

Transect profiles

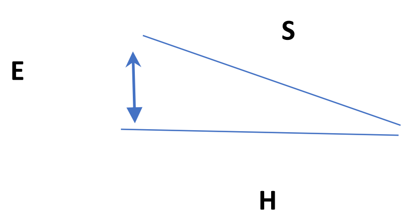
A stadia rod and clinometer were used to measure elevation differences between all biophysical band and slope breaks on land, whereas the depth of water was used to assess elevation difference of underwater point breaks. The two types of elevation measures were coalesced to provide standard elevation changes per section of the transect. The position of the waterline on the transect was recorded, as was the time, allowing for correspondence with tabulated tide height (Fisheries and Oceans) and chart datum. The tide heights at the time of sampling were accessed through the "Tide Charts – 7th Gear" telephone app., using Portage Inlet location above Tillicum Rapids and Victoria Harbour below. Elevation differences between points that did not have direct measures were extrapolated, and elevations relative to chart datum were derived as described below.

Profiles were drawn of the transects, using calculated horizontal distances and elevations relative to chart datum.

Horizontal distance:

As the transects measured slope distances, the corresponding horizontal distances (H) were calculated with Pythagorean's Theorem, using calculated elevation changes (E) for each section of the transect.

$H = \sqrt{(S^2 - E^2)}$



Where:

S = distance measured on transect tape between band or slope breaks

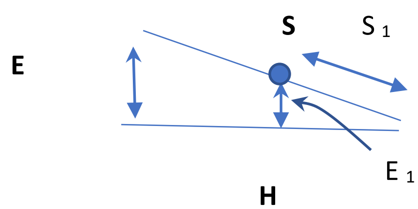
E = elevation difference between band or slope breaks, as measured with a stadia rod and/or water depth. These are corrected for eye height of stadia observer as needed.

H = calculated horizontal difference between band or slope breaks

Relative Elevation of intermediate points on a slope (e.g. waterline or start of oysters):

Not all points of interest along a transect had elevation measurements, though all had slope distance measurements. To calculate the required elevation changes, we used a proportion estimate based on the slope distances:

$E_1 = S_1/S * E$



Where:

S, H, and E as above

S_1 = distance from point of interest to end of the band

E_1 = elevation to point of interest from end of band

This calculation is based on the observation that the slope is constant throughout the distance, so dimensions of the triangle of slope, horizontal and elevation distances are all proportionate.

Calculation of elevation relative to chart datum

Elevations relative to chart datum were calculated from the predicted tidal height of the water line at time of observation, derived from the telephone app described above. Elevation changes of sections above the water line were added to this value, whereas those below the water line were subtracted. This allowed us to construct the profiles relative to chart datum, including noting the current water level, break points at the different transect segments, and the start and end of the oyster "band", if there is one.

4.0 Results

Olympia Oyster Presence

Olympia oysters were observed at thirty-five of the forty-six sites. In general, Olympia oyster presence increased as our survey moved from the Middle Harbour up to Portage Inlet. Olympia oysters were not observed at any site in the Middle Harbour, whereas Olympia oysters were observed at all the sites in Portage Inlet (Table 3).

Table 3. Percentage of Ostrea lurida present at sites by geographic area

Area	Present Sites / Total Sites	Percent
Middle Harbour	0/2	0%
Inner Harbour	1/4	25%
Upper Harbour	5/7	71%
Selkirk Water	3/6	50%
Gorge Waterway	13/14	93%
Portage Inlet	14/14	100%
Total	**35/46**	**76%**

2009 Vs 2021

Of the thirty-four sites surveyed in the 2009 study, *O. lurida* were observed at twenty-eight sites (Stanton et al., 2011). Out of the six remaining sites, three sites (Sites 7, 26, 33) could not be surveyed in 2009 for lack of access. The three sites that did not have Olympia oysters in 2009 were Sites 1, 24, and 32. In 2021, Olympia oysters were observed at twenty-nine of the same thirty-four sites surveyed in 2009(Figure 4). Olympia oysters were not observed at Sites 1, 2, 24, 31, and 32. No Olympia oysters were observed at Sites 1, 24, and 32 during either study. Olympia oysters were initially observed at Sites 2 and 31 during the 2009 survey but were not seen at either of those sites in the 2021 survey. In 2021, an additional site (Site 13.5) was surveyed in Portage Inlet between Sites 13 and 14 where Olympia oysters were observed.

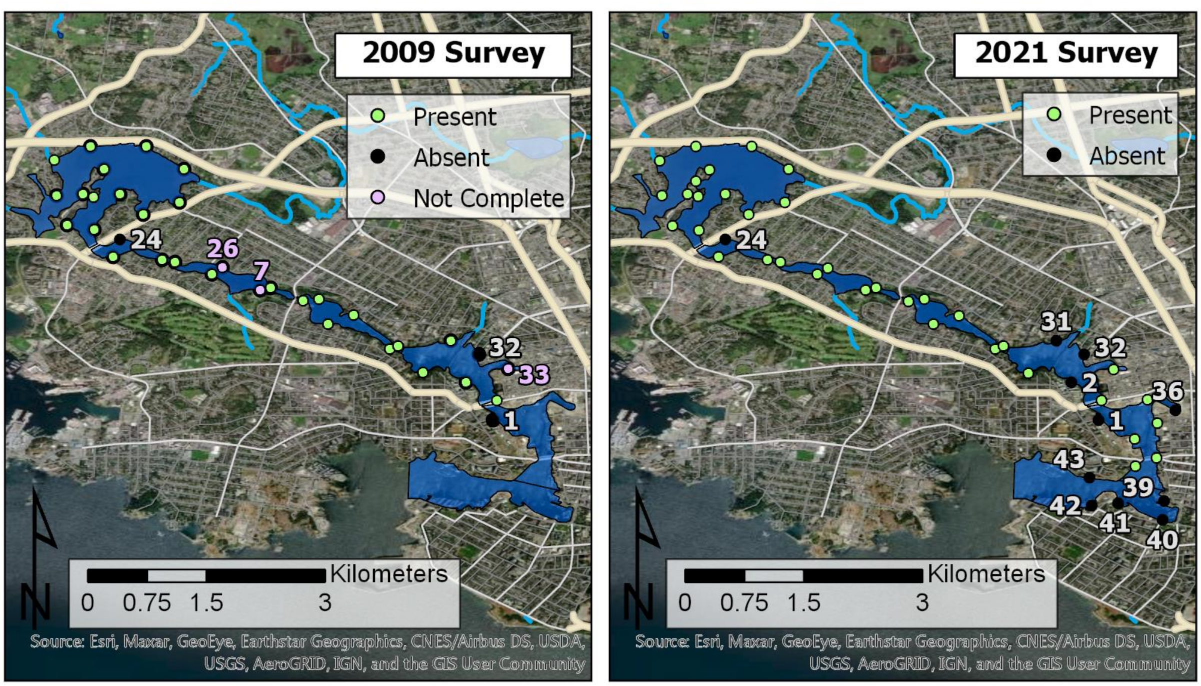


Figure 4. Olympia oysters at sites surveyed in 2009 and 2021. 34 sites were surveyed in 2009 out of which three site surveys (Sites 7, 26, and 33) could not be completed. *O. lurida* were observed at

twenty-eight sites in 2009. The survey was extended by 11 sites into Victoria's Upper, Inner, and Middle Harbours in 2021 for a total of 46 sites. Olympia oysters were observed at thirty-two sites including at twenty-nine of the sites surveyed in 2009. An additional site (Site 13.5) was surveyed in Portage Inlet in 2021. Only those sites that were either not surveyed (2009) or where oyster populations were absent are labeled in the maps above.

Olympia Oyster Density

Across the entire study area, the dominant density category was "Common" at 28% of sites (Table 4). The lowest density, *Rare,* was found at 71% of sites in the Upper Harbour but Olympia oysters were found to be *Rare* across the study area as well. Olympia oysters were classified as *Abundant*, the highest density, in the Lower Gorge below Tillicum Narrows. While in the Gorge Waterway, Olympia oysters were classified predominantly as *Common* in 57% of the sites surveyed. Olympia oysters were classified as *Present* in Portage Inlet at 57% of the sites surveyed.

Olympia oysters were *Absent* at 100% of sites in the Middle and Inner Harbours (Table 4). In the Selkirk Waterway and Gorge Waterway, Olympia oysters were classified as *Common* and *Abundant* at 17% and 7% of sites, respectively (Table 4). In Portage Inlet, the highest Olympia oyster density classification was *Common* at 29% of sites. Overall, the highest density classification was *Abundant* and was only observed at Site 6 in the Lower Gorge (Tillicum narrows).

Table 4.

Table 4.Dominant and highest Olympia oyster density classification by geographic area.

Area	Dominant Density Classification	Highest Density Classification
Middle Harbour	Absent – at 100% of sites	Absent – at 100% of sites
Inner Harbour	Absent - at 100% of sites	Rare – at 25% of sites
Upper Harbour	Rare - at 71% of sites	Rare – at 71% of sites
Selkirk Water	Absent - at 50% of sites	Common – at 17% of sites
Gorge Waterway	Common - at 57% of sites	Abundant – at 7% of sites
Portage Inlet	Present - at 57% of sites	Common – at 29% of sites
Study Area	**Common – at 28% of sites**	**Abundant – at 2% of sites**

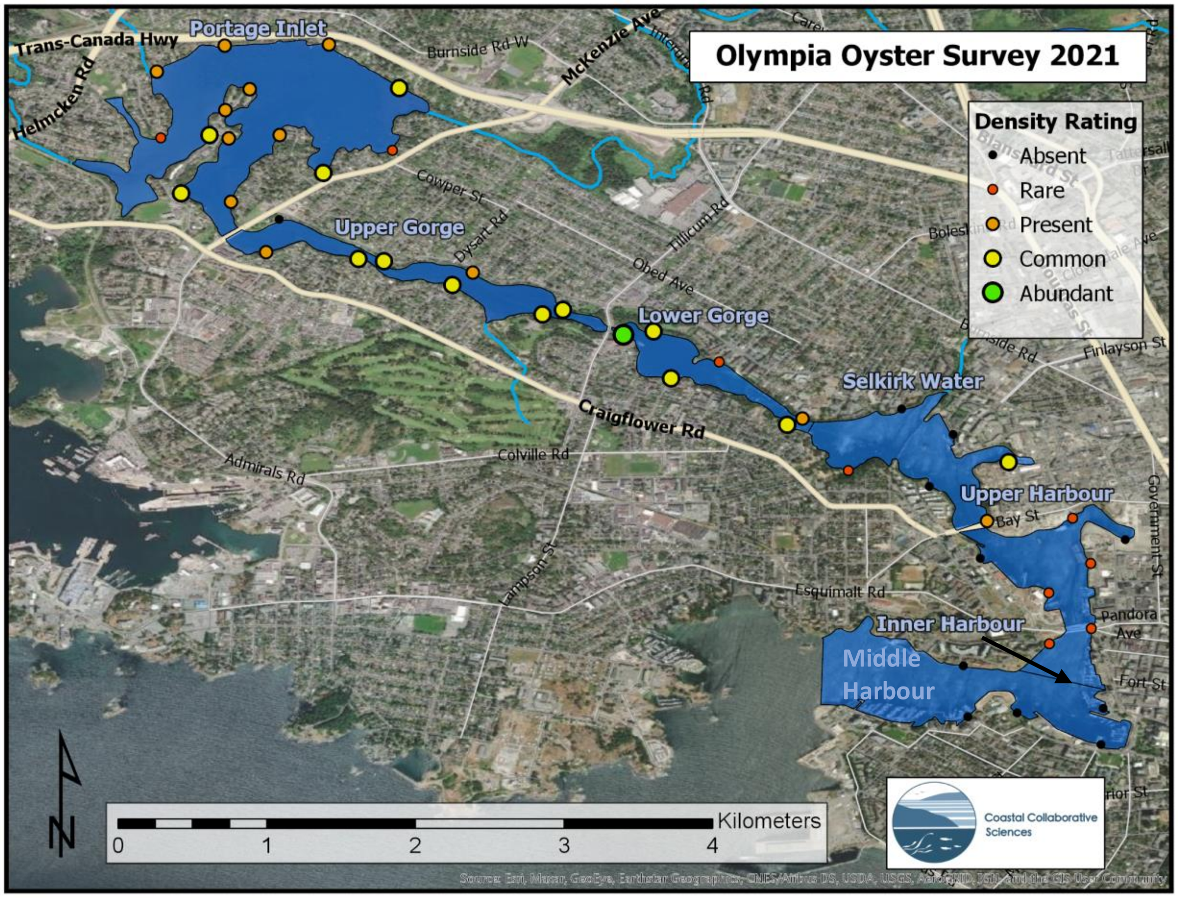


Figure 5. Highest Olympia oyster density rating across all 46 sites surveyed in the 2021 Olympia oyster survey

Olympia Oyster Distribution

Across the whole study area, the predominant distribution classification was *Patchy*. The lowest distribution classification, *Few,* was observed at sites across the study area but was observed most in the Upper Harbour at 71% of the sites (Table 5). While *Few* and *Patchy* distributions were observed in the Selkirk Waterway, no oysters were observed at half of the sites.

Distribution classifications in the Gorge Waterway ranged from *Few* to *Dense* with the highest distribution classes found below Tillicum Bridge (Figure 6). The highest distribution classification, *Dense*, was observed only at Site 6. Distribution at sites in Portage Inlet ranged from *Few* to *Patchy* however, *Patchy* was the predominant classification at 86% of sites (Table 5).

Table 5. Dominant and highest Olympia oyster distribution classification by geographic area.

Area	Dominant Distribution Classification	Highest Distribution Classification
Middle Harbour	Absent – at 100% of sites	Absent – at 100% of sites
Inner Harbour	Few - at 25% of sites	Few – at 25% of sites
Upper Harbour	Few - at 71% of sites	Few – at 71% of sites
Selkirk Water	Absent - at 50% of sites	Patchy – at 33% of sites
Gorge Waterway	Patchy - at 36% of sites	Dense – at 7% of sites
Portage Inlet	Patchy - at 86% of sites	Patchy – at 86% of sites
Study Area	**Patchy - at 41% of sites**	**Dense – at 2% of sites**

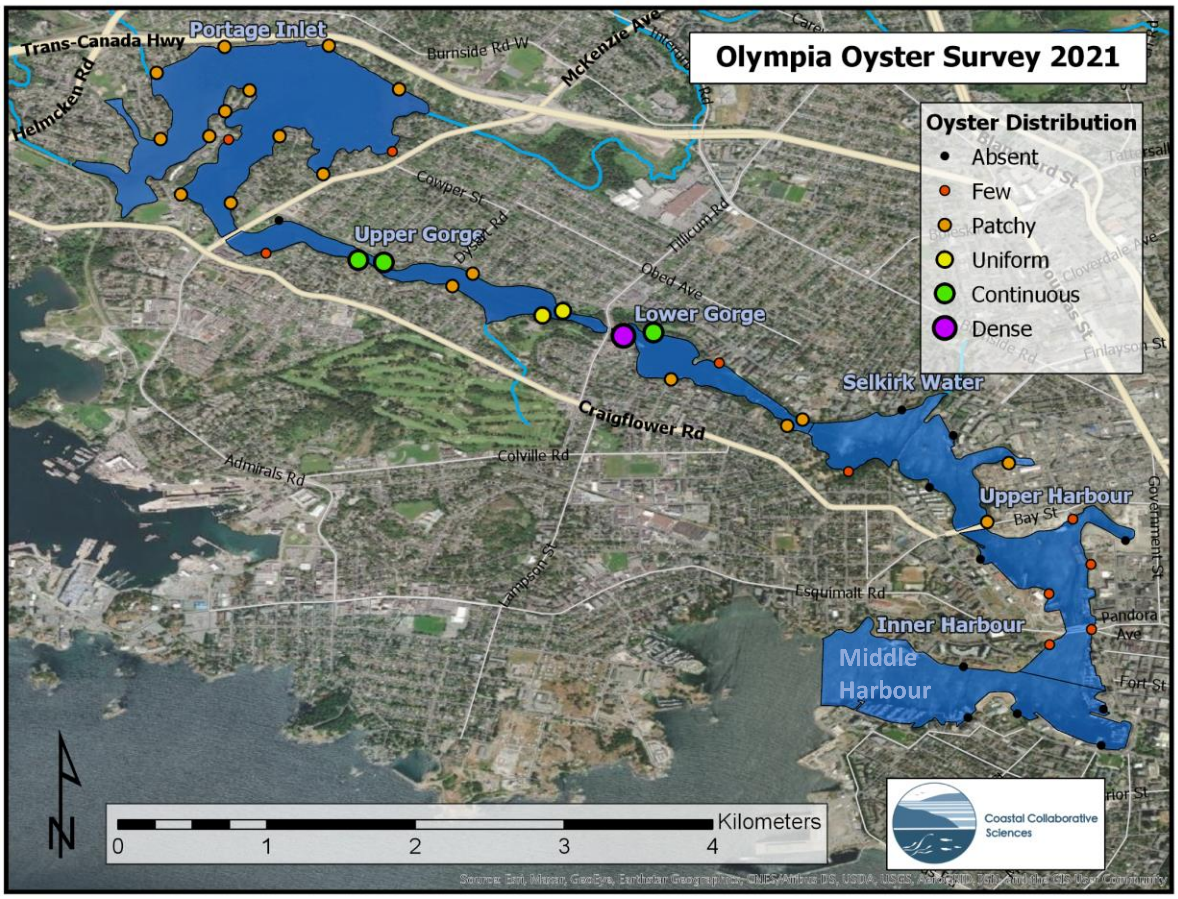


Figure 6. Highest Olympia oyster distribution across all 46 sites surveyed in the 2021 Olympia oyster survey.

Olympia oyster vertical distribution

Appendix 1 shows the transect profiles grouped by harbour segment. Surveys in general were done with the tide around 0.5 m, with some lower and some as high as 1.2 – particularly in the harbour region. Nevertheless, the transects extended to depths of at least -0.2 m, with the exception of transect 13. In some cases, extending the transects to depths of 8 m was warranted to search for oysters.

The oyster “band” varied in its vertical positioning between areas. In the sections below the Tillicum Narrows, oysters were generally present only as narrow bands, in the range of 1.8 m in elevation (with some exceptions – e.g. at the Tillicum Narrows (site 28) oysters were particularly abundant and the band was uncharacteristically wide). The band at site 44 was also quite wide, possibly as the riprap allowed for protected pockets. Site 5 showed oysters in a very low tidal zone, for unknown reasons. Debris may be affording these oysters habitat that is not as abundant elsewhere. Site 29, across the waterway, also had some deep oysters, though very few. A downwelling associated with tidal exchange and the influence of the Tillicum falls may be a factor.

Above the Narrows, the oyster bands generally started lower, relative to chart datum, in the range of -0.1 or -0.2 m. This is likely due to differences in the tidal ranges in this portion of the waterway. The bands also tend to be wider, at times without an end recorded on the transect. Subtidal oysters have been reported in this section of the waterway and Portage Inlet. On transects where an end was observed, it generally coincided with the start of an eelgrass bed.

5.0 Discussion

Changes in Olympia Oyster Presence

Some sites showed a lack of Olympia oysters in 2021, compared with 2009, but in general oyster presence at the resurveyed sites was similar. In Sites 1, 24, and 32, where no Olympia oysters were observed in either study, the predominant substrate present was mud and sand. However, oysters are present in many muddy areas of the waterway, so while lack of hard substrate could be considered a limiting factor to oyster settlement, other factors are likely to be influencing the presence of oysters in these locations. Site 24 is a sandy, fine gravel beach that was human engineered. The lack of oyster presence may suggest there is too much movement in the substrate to allow survival of spat, which should be taken into consideration when future shoreline modification is considered. Site 32 is by the Cecilia Creek estuary, with sites on both sides showing a lack of oysters in 2021. This creek is renowned for persistent contamination from industrial uses, which may be influencing settlement of oysters. Site 1 is likewise in the region of historical industrial contamination, reported to be persistent by Ocean Wise (2018). Continuing absence of oysters in these locations may thus be an environmental indicator of contamination that is persisting.

Our results suggest that the perceived limitation of surveying for intertidal oysters only to the waterline in 2009 did not significantly affect the data at a presence/absence level of evaluation. Nevertheless, a precautionary approach would target a minimum depth to achieve. The upper edge of the oysters in the upper Gorge and Portage Inlet was at a negative tide level, whereas those in the main harbour were more accessible (in most cases).

Olympia Oyster Density and Population range

Extending our survey into Victoria Harbour in 2021 provided improved information on the range of the Olympia oyster in this waterway. Olympia oysters were observed on docks in the Inner Harbour in 2020 by the authors (Unpub. observation, 14 July 2020), specifically, on the Johnson Street Bridge Dock, the Wharf Dock, and the Causeway dock, raising the question of how far the population extends.

Olympia oysters decreased in density and distribution at intertidal sites in the Upper Harbour, and no oysters were observed at sites in the Middle Harbour. One site in the Inner Harbour had oysters. Nevertheless, our survey indicates that the outer edge of the population in the intertidal zone is generally at the bottom of the Upper Harbour. The observation on docks suggests that this range may extend a bit further into the harbour on dock substrates, which needs further investigation. This outer limit suggests that either the more oceanic conditions of the outer harbor are not conducive to persistent Olympia oysters, as reported by Pritchard et al., (2015), and/or the harbor populations are maintained only by larval supply of the upper Gorge. Recent reports of Olympia oysters in Esquimalt Harbour, our own results of survival in suspended cages by Fisherman's Wharf (unpublished data), and the literature on environmental limits to their survival suggest that oceanic conditions would not be limiting to the survival of the oysters. The survey results may thus more likely represent the limits of a larval plume being washed out from the Gorge Waterway, suggesting that oysters in the harbours do not have adequate reproductive capacity to feed an outward growth of the population limits. More research is needed to corroborate this hypothesis.

The highest densities of intertidal Olympia oysters were recorded in the Gorge Waterway at the Tillicum Narrows. The tidal falls at this site promote the mixing of nutrients and washes away loose sediments. These factors, along with the presence of hard substrate, likely encourage a dense Olympia oyster population at this location. Similarly, our study of the footings of the Craigflower Bridge, also in a high current environment, reported dense oyster growth (World Fisheries Trust, 2018). Higher currents that carry away sediments could also explain why oyster populations appear to be denser in the Gorge Waterway compared to Portage Inlet.

Olympia oysters seem to favour the brackish environment of the upper reaches of the inlet, also reported for the species by Pritchard et, al. (2015). In the case of Portage Inlet and the upper Gorge Waterway, this includes subtidal aggregations (Stanton et al., 2011). This may be due, in part, to the absence of starfish predators (Archipelago Marine Research, 2000). Echinoderm larvae are unable to survive large fluctuations of temperature and salinity (Russell, 2014), which are observed in the Gorge with every tidal cycle. These same fluctuations likely stimulate spawning in the oysters, maximizing their reproductive output, even if it also results in mortalities.

The Oyster distribution in the intertidal zone tended to be patchy, becoming more uniform as density increased. This is likely due to settlement cues for spat that are not yet understood. Nevertheless, this poses a substantial challenge to sampling, as errors of estimation can be very high. A potential statistical solution to this problem is proposed in a recent report (World Fisheries Trust, 2020).

6.0 Conclusion

Our 2021 Olympia oyster survey of forty-six systematically placed intertidal transects in Portage Inlet, the Gorge Waterway, Selkirk Waterway and Victoria Harbour indicates that Olympia oyster density and distribution is highly variable between sites, favouring the upper Gorge and reaching an outer limit at the edge of the Inner Harbour. Olympia oyster density and distribution were highest in the Gorge Waterway, followed by Portage Inlet and the Selkirk Waterway. The greater densities in the Gorge Waterway are likely explained by a combination of factors, including the presence of hard, rocky substrate, good currents and phytoplankton production, a lack of starfish predation, low competition for space in the intertidal zones, and maximized reproduction stimulated by tidal fluctuations in temperature and salinity. Some sites of persistent oyster absence between 2009 and 2021 may indicate ongoing environmental contamination at the Cecelia Creek estuary and by the Bay St. bridge. This may be true of other sites in the harbour where oysters have not yet been observed. Oysters may extend further into the harbours on dock environments, but this has not yet been adequately studied.

The lower end of the intertidal oyster band was often coincident with the upper edge of eelgrass meadows in Portage Inlet and the Upper Gorge, indicating competition for space between the two. In the absence of eelgrass, the oyster band continued beyond the end of the transects into the subtidal zone.

7.0 References

Archipelago Marine Research. (2000). Subtidal Survey of Physical and Biological Features of Portage Inlet and The Gorge Waterway. Prepared for Capital Regional District. Archipelago Marine Research. 48pp.

Baker, P. (1995). Review of ecology and fishery of the Olympia oyster, Ostrea lurida, with Annotated Bibliography. *The Journal of Shellfish Research,* 14(2): 501-518

Fisheries & Oceans Canada. (2009). Management Plan for the Olympia oyster (*Ostrea concaphila*) in Canada. *Species at Risk Act* Management Plan Series. Fisheries & Oceans Canada, Ottawa. vi + 31 pp.

Fisheries and Oceans Canada. (2021). 2021 Tide Tables - Tides, Currents, and Water Levels. https://www.tides.gc.ca/eng/data/predictions/2021#vol5

Gillespie, G.E. (1999). Status of the Olympia oyster, *Ostrea concaphila*, in Canada. *Fisheries and Oceans Canada Stock Assessment Division*. Fisheries & Oceans Canada, Ottawa.

Gillespie, G. E. (2009). Status of the Olympia oyster, *Ostrea lurida* Carpenter 1864, in British Columbia, Canada. *The Journal of Shellfish Research,* 28(1): 59-68

Kirby, M.X. (2004). Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. *Proceeding of the National Academy of Sciences of the United States of America,* 101(35): 13096-13099.

Ocean Wise. (2018). Contaminants – Pollution Tracker. Pollution Tracker. https://pollutiontracker.org/contaminants/#Map|PWPPMV3|sediment

Polson, M. P., and Zacherl, D. C. (2009). Geographic distribution and intertidal population status for the Olympia oyster, *Ostrea lurida* Carpenter 1864, from Alaska to Baja. *The Journal of Shellfish Research*, 28(1), 69-77.

Pritchard, C., Shanks, A., Rimler, R., Oates, M., and Rumrill, S. (2015). The Olympia Oyster *Ostrea lurida:* Recent Advances in Natural History, Ecology, and Restoration. *The Journal of Shellfish Research*, 34(2): 259-271.

Russell, M.P. (2014). Chapter 3. Echinoderm Responses to Variation in Salinity. IN: Advances in Marine Biology, Volume 66. pp 174-212.

Stanton, L. M., Norgard, T.C., MacConnachie, S.E.M., and Gillespie, G.E. (2011). Field verification of historic records of Olympia oysters (*Ostrea lurida* Carpenter, 1864) in British Columbia - 2009 *Canadian Technical Report of Fisheries and Aquatic Sciences 2940*: vi + 115 p.

Wentworth, C. K. (1922). A scale of grade and class terms for clastic sediments. The journal of geology, 30(5), 377-392.

World Fisheries Trust. (2018). Craigflower Bridge Replacement Project, Olympia Oyster re-location & enhancement, 3-yr monitoring report. Prepared for Corporation of the District of Saanich. World Fisheries Trust. 21 pp.

World Fisheries Trust. (2020). Test of Inter-Tidal Native Oyster Survey Methodology, Portage Inlet Boat Ramp Project. World Fisheries Trust. 16pp.

APPENDIX 1. Site Profiles by Harbour location.

To better assess the slope profiles between sites, as well as the distribution of Olympia oysters at each site, Table 1 and the corresponding figures (Figure 1 – Figure 47) were elaborated.

Table 1. Survey sites located within each geographical location.

Geographical Location	Sites Within Geographical Location
Middle Harbour	42, 43
Inner Harbour	39, 40, 41.44
Upper Harbour	1, 35, 36, 37, 38, 45
Selkirk Waterway	2, 3, 31, 32, 33, 34
Lower Gorge	4, 5, 6, 28, 29, 30
Upper Gorge	7, 8, 9, 10, 24, 25, 26, 27
Portage Inlet	11, 12, 13, 13.5, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23

Middle Harbour

Figure 1. Site 42.

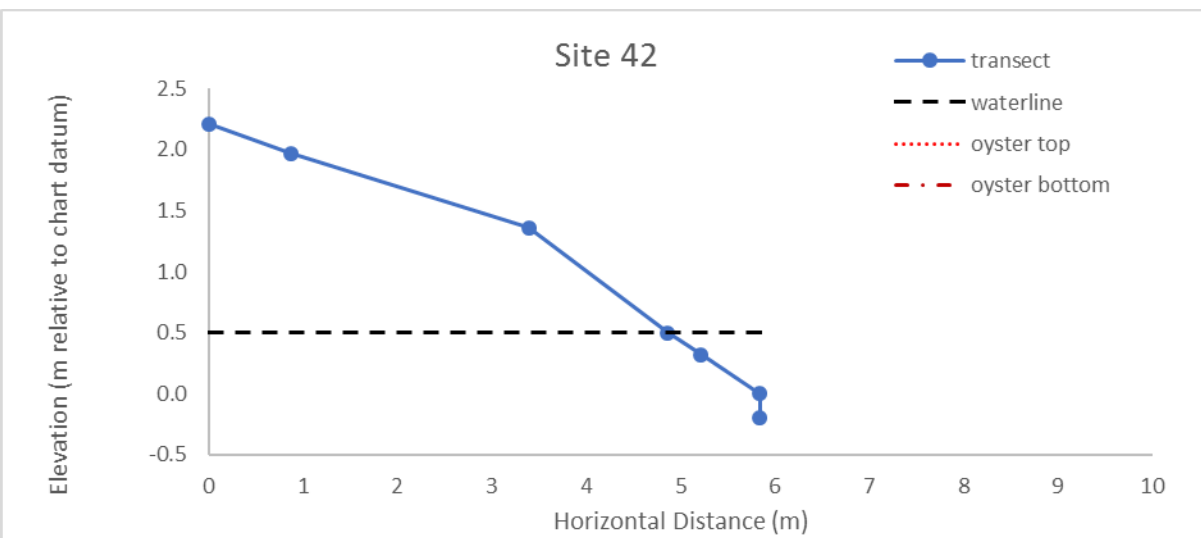
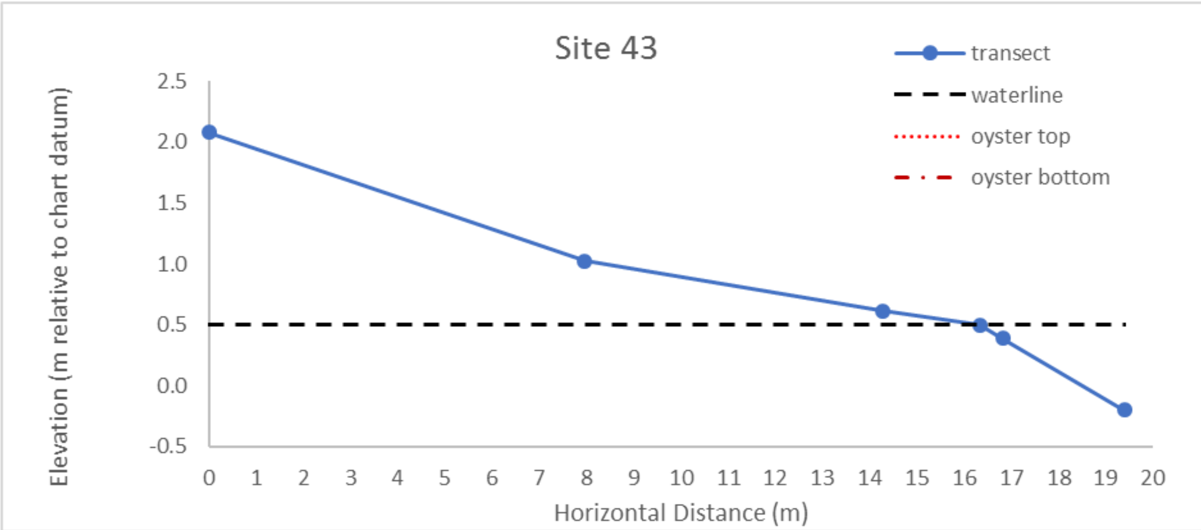
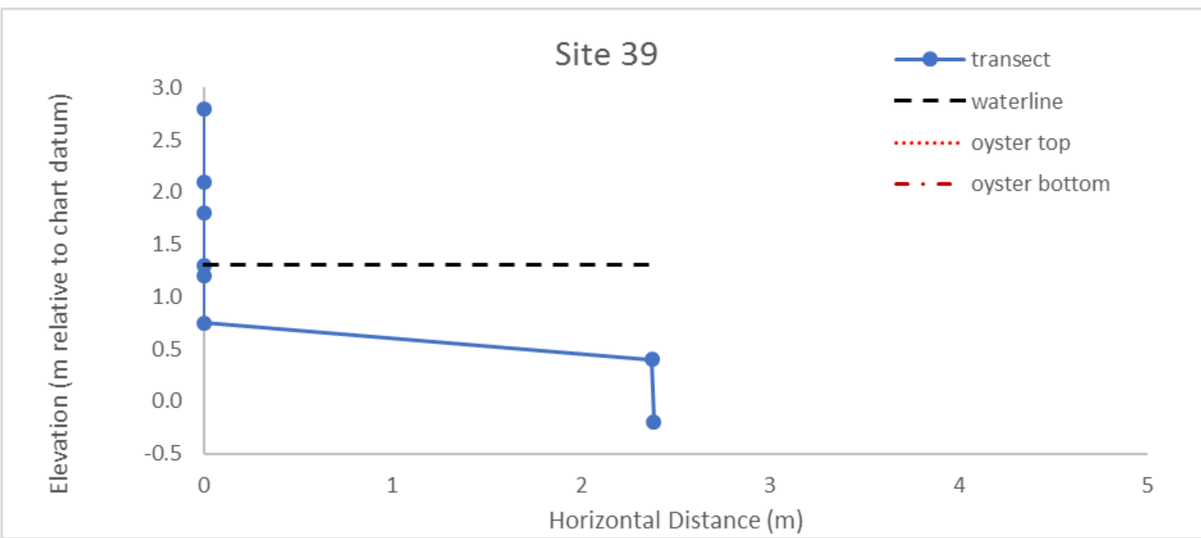


Figure 2. Site 43.



Inner Harbour

Figure 3. Site 39.



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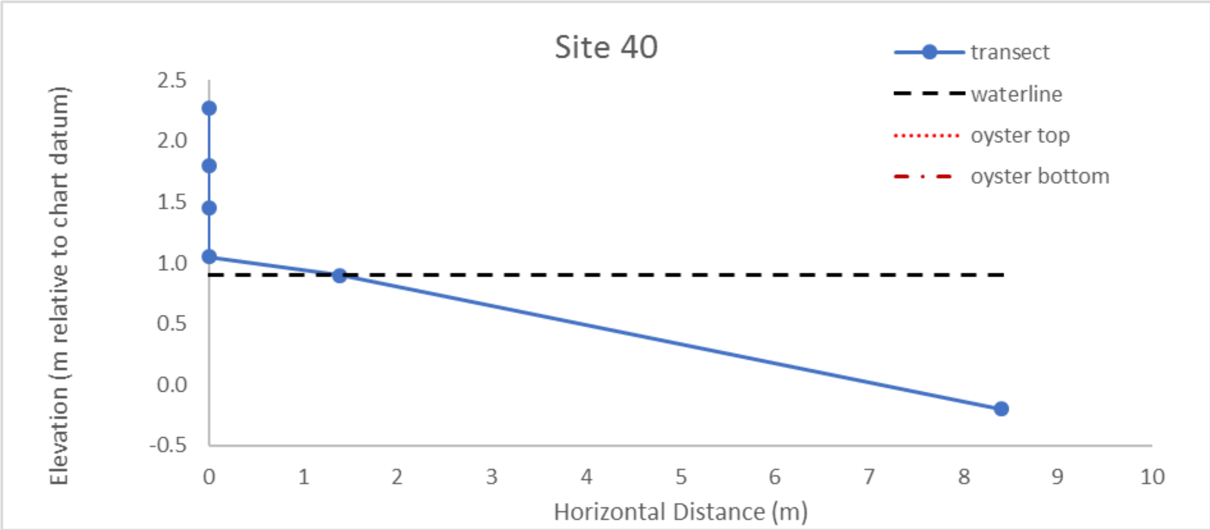


Figure 5. Site 41

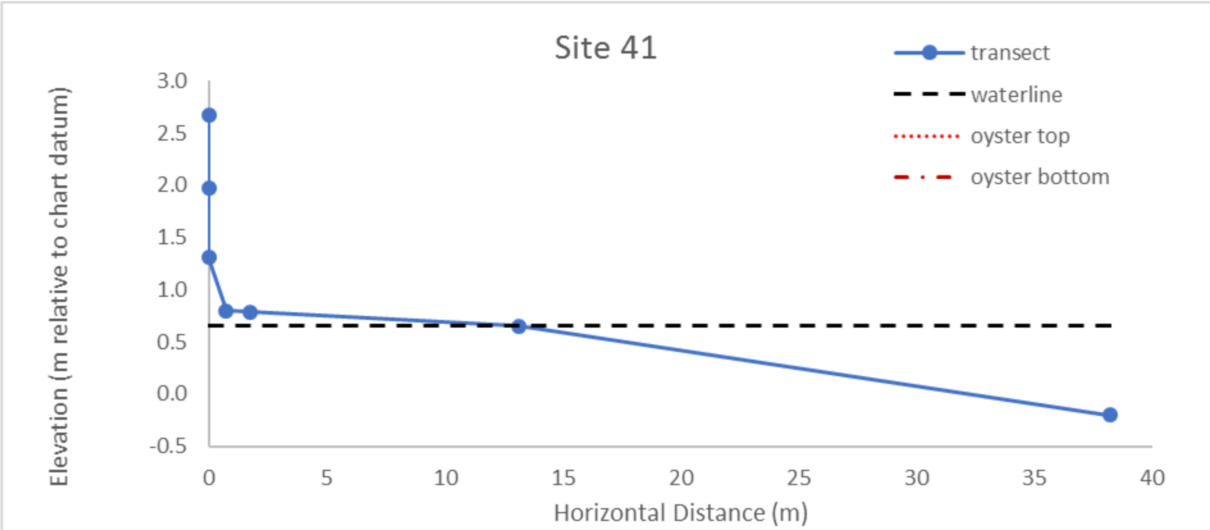
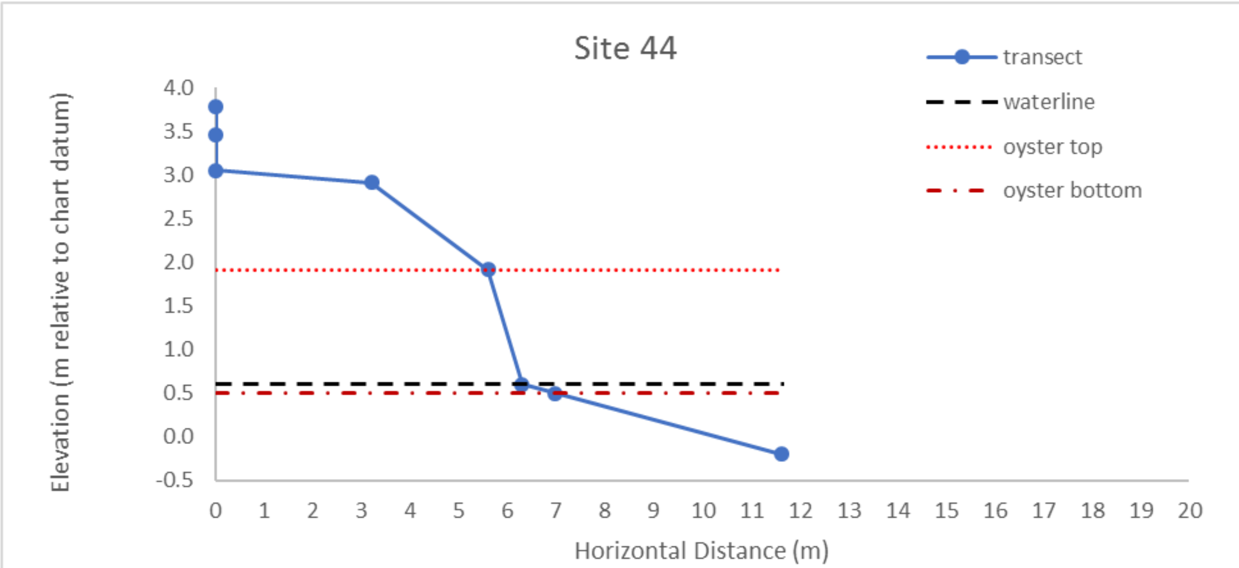


Figure 11. Site 44.



Upper Harbour

Figure 6. Site 1.

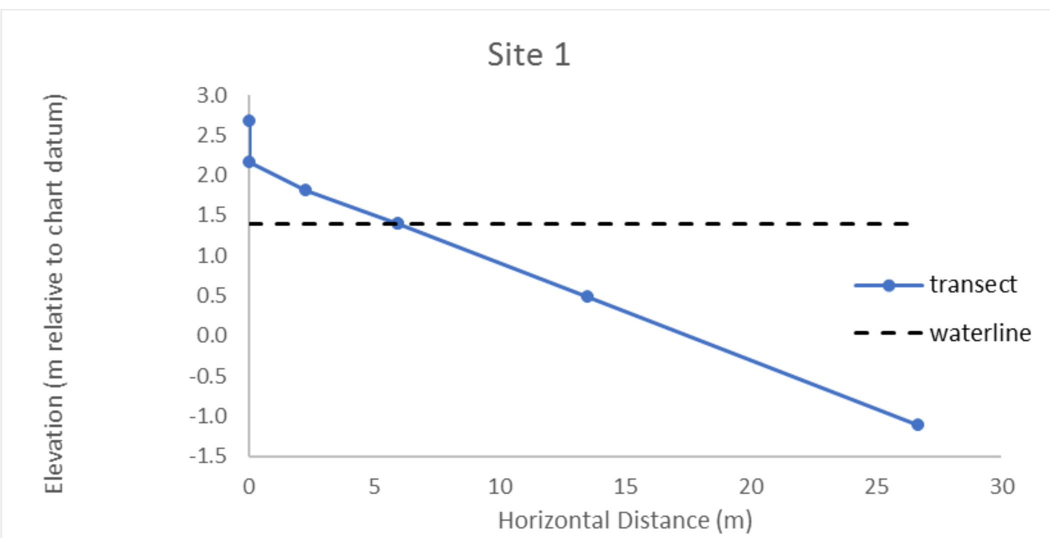
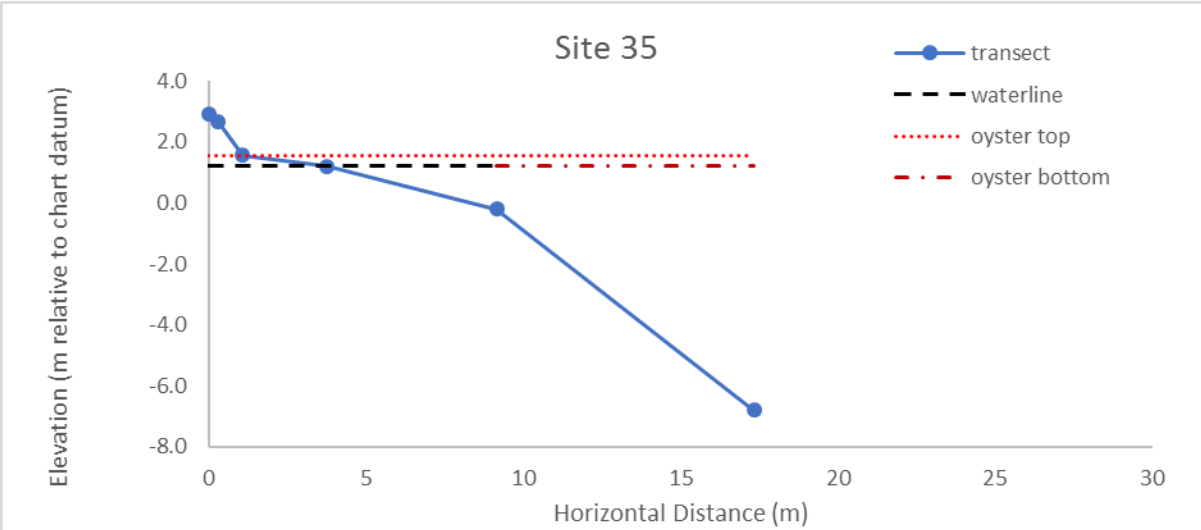


Figure 7. Site 35



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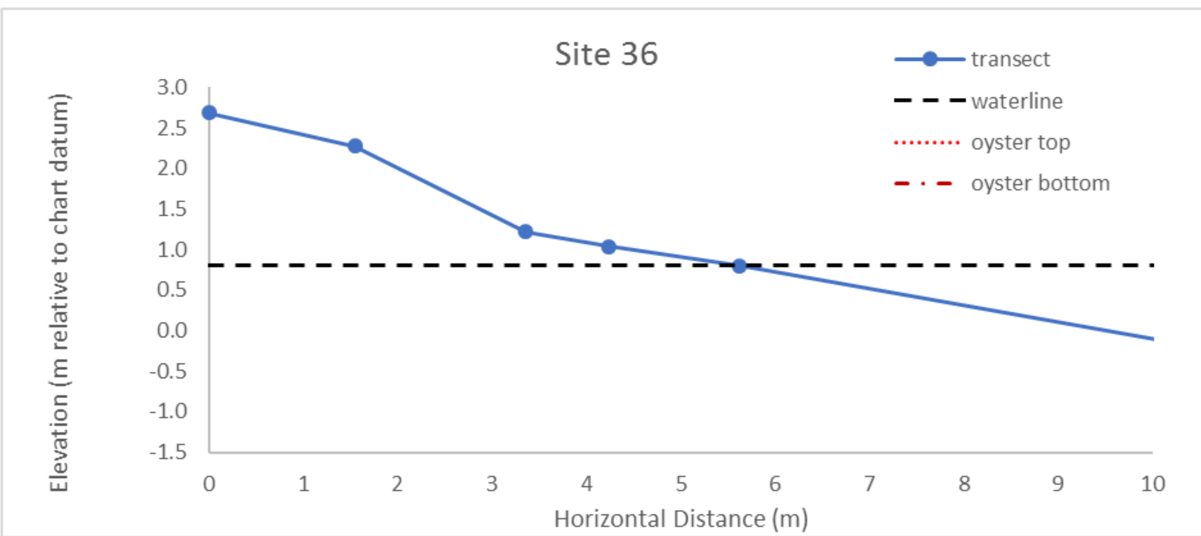
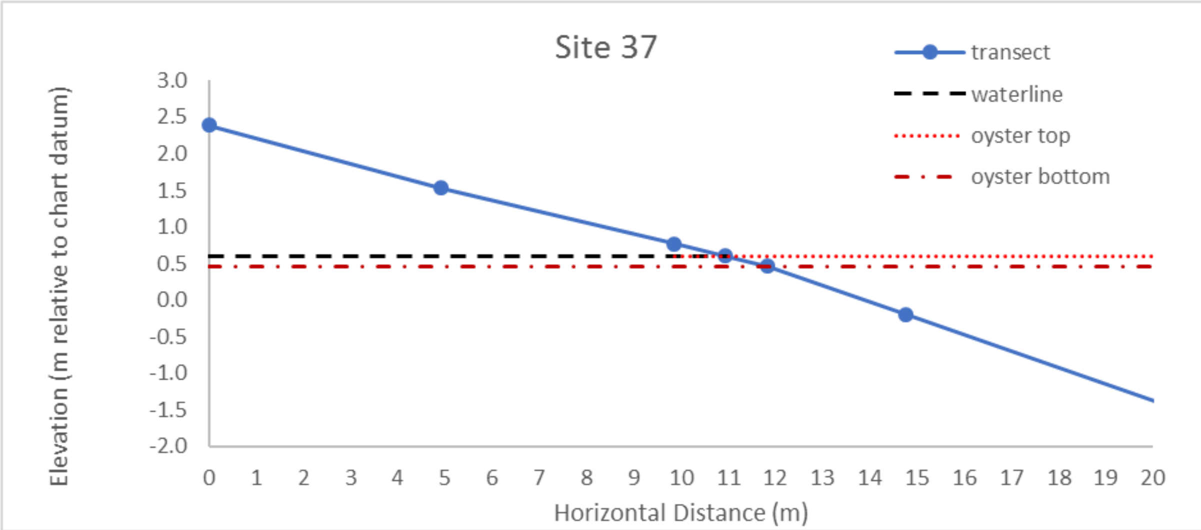


Figure 9. Site 37



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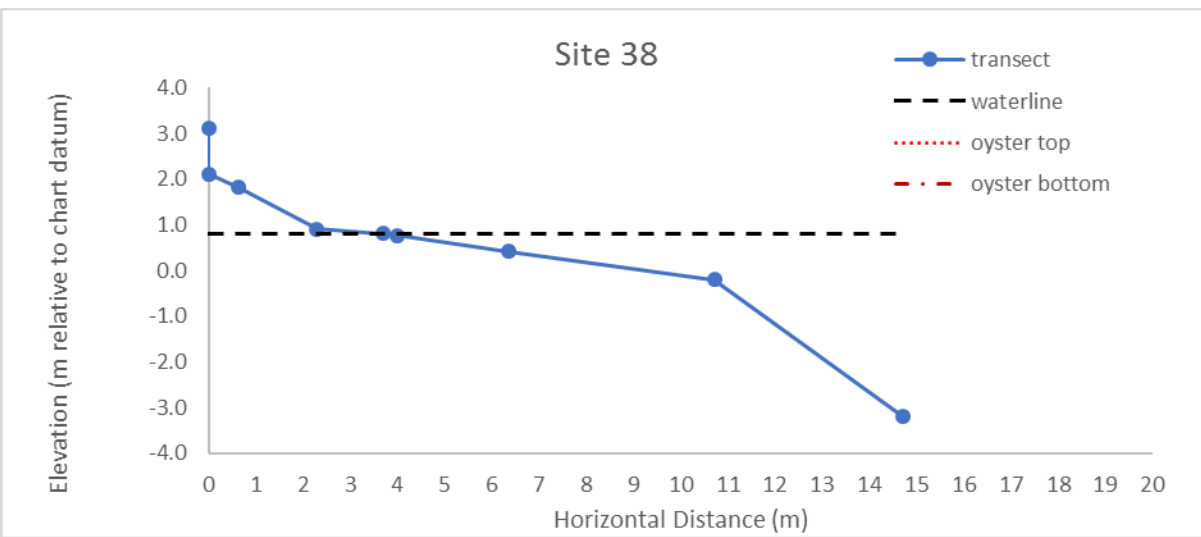

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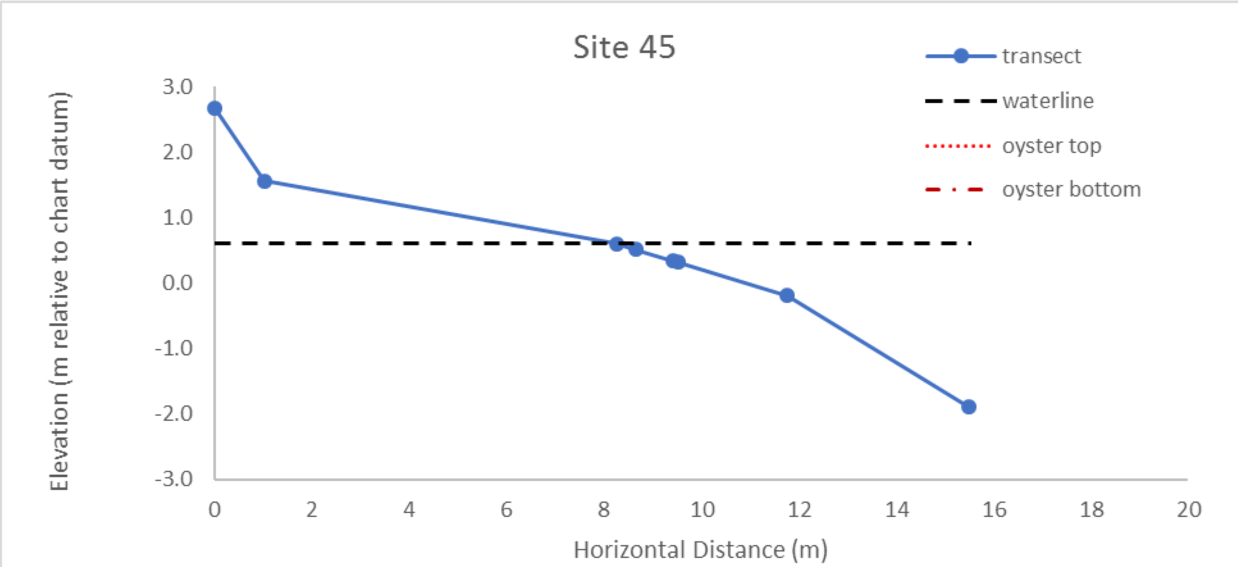
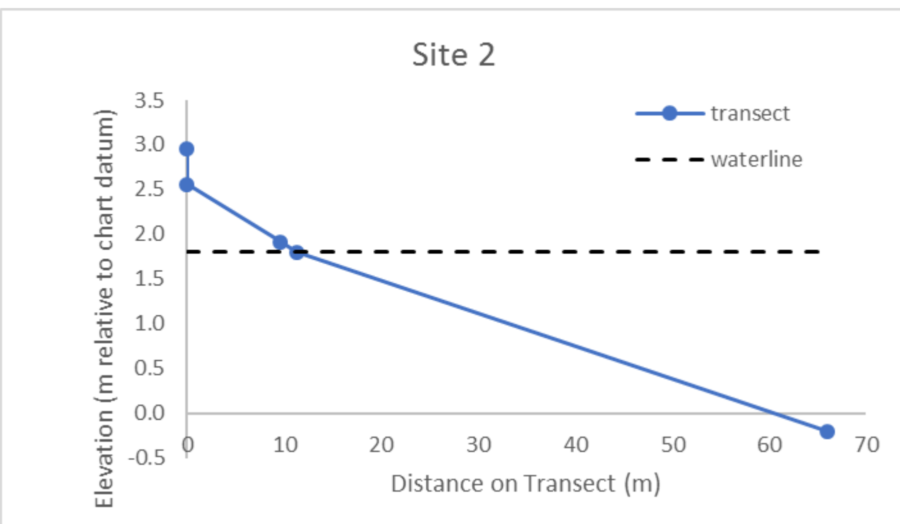


Selkirk Waterway

Figure 13. Site 2.



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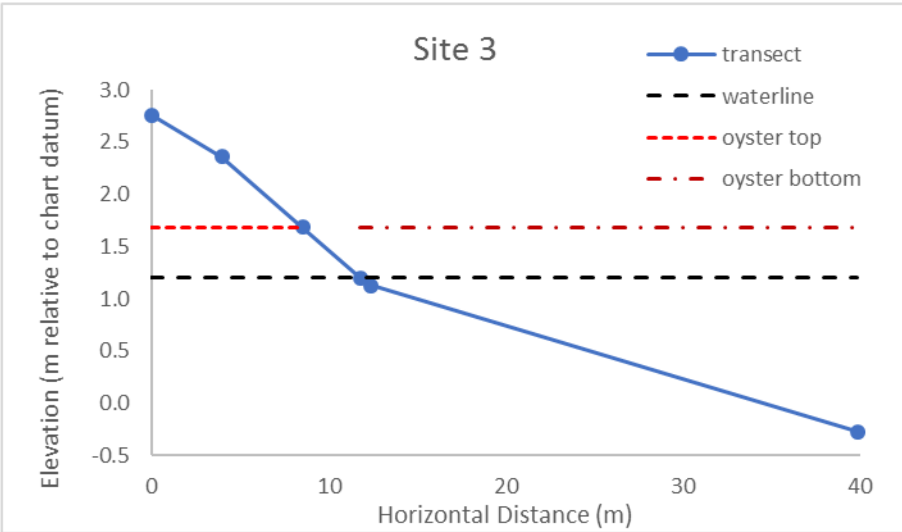

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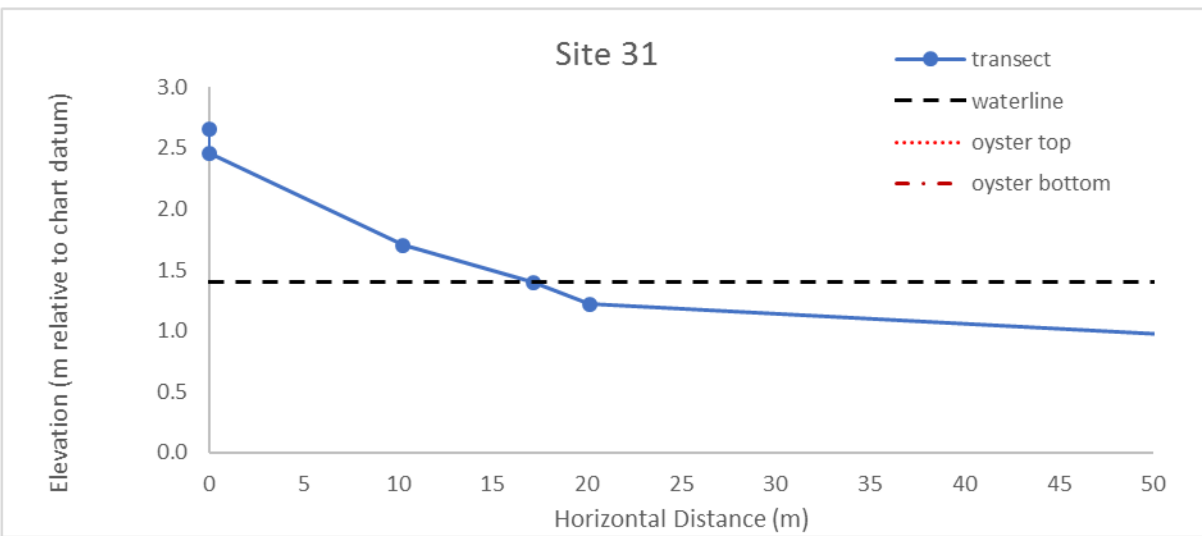

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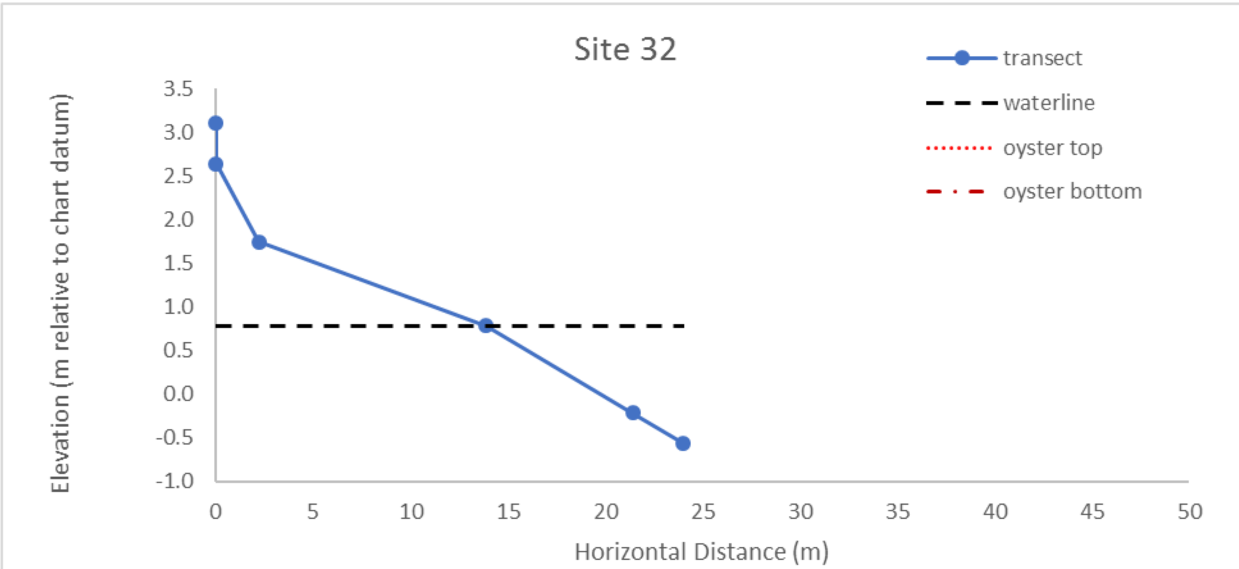

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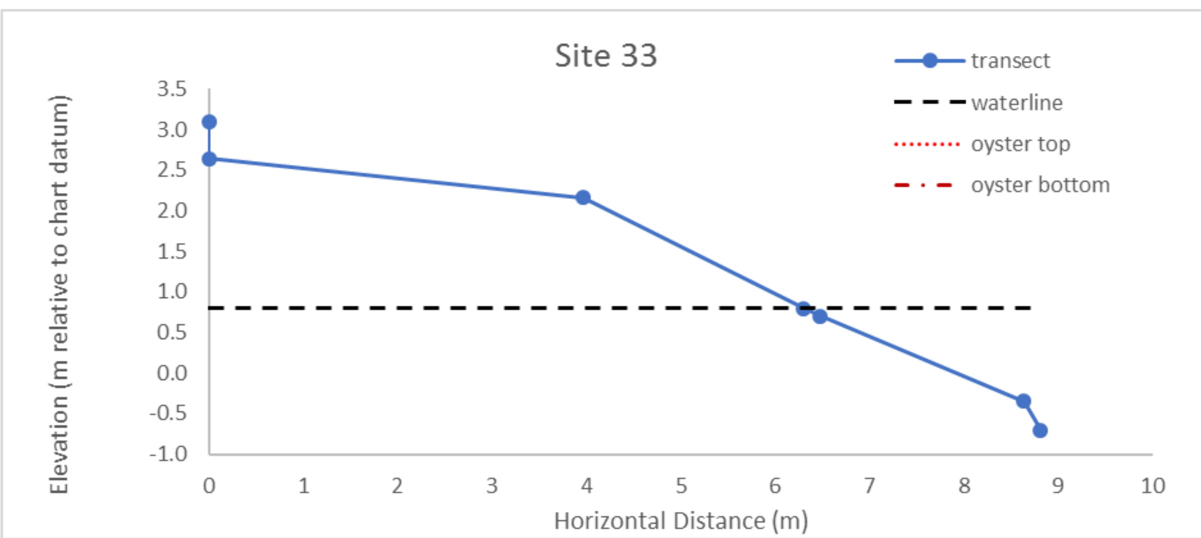

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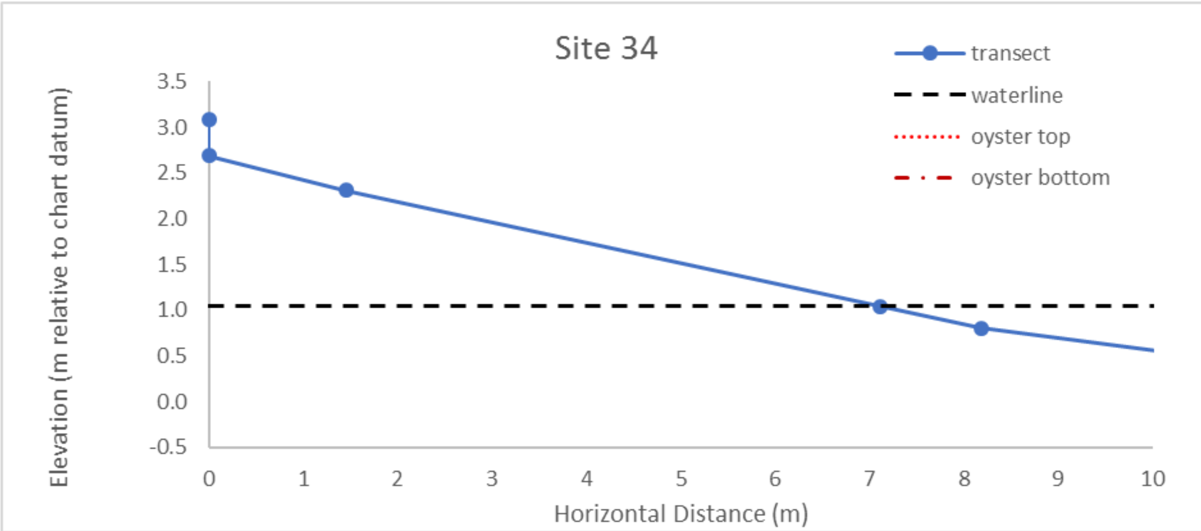
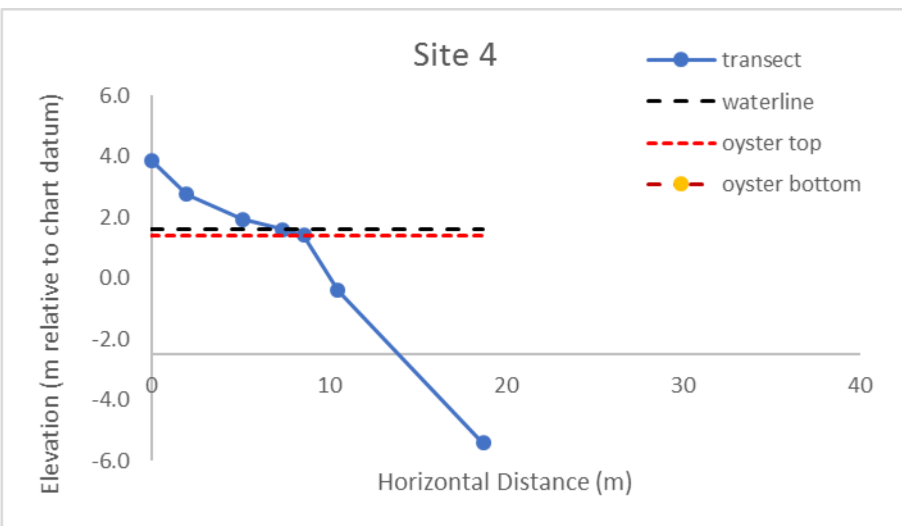


Lower Gorge

Figure 19. Site 4.



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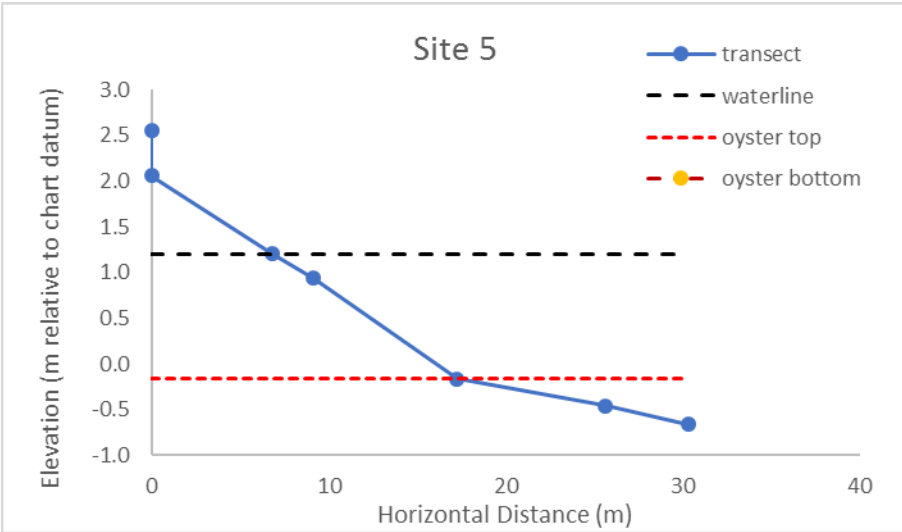

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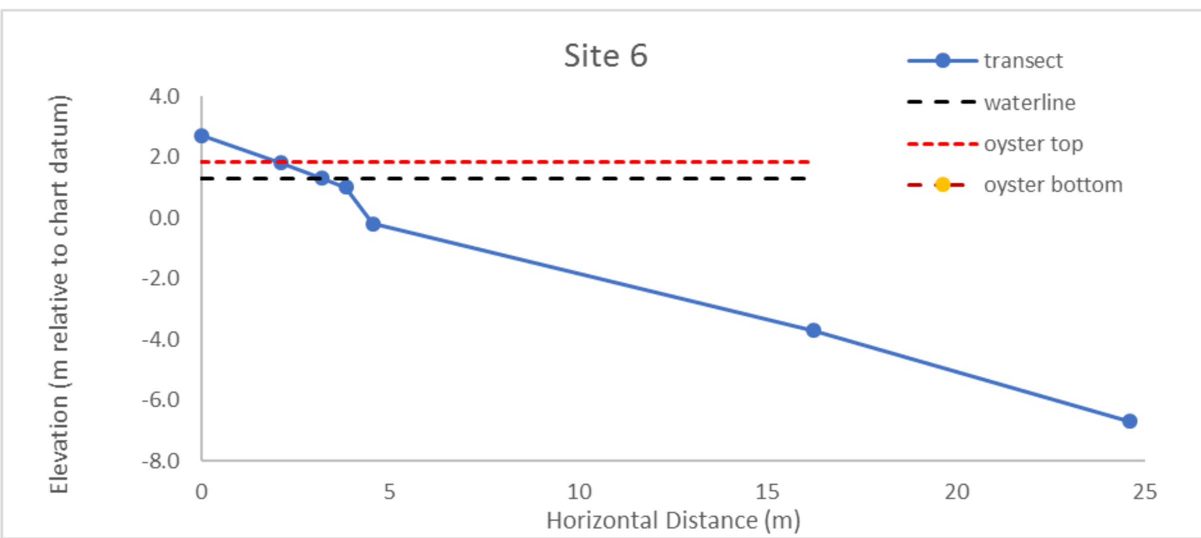

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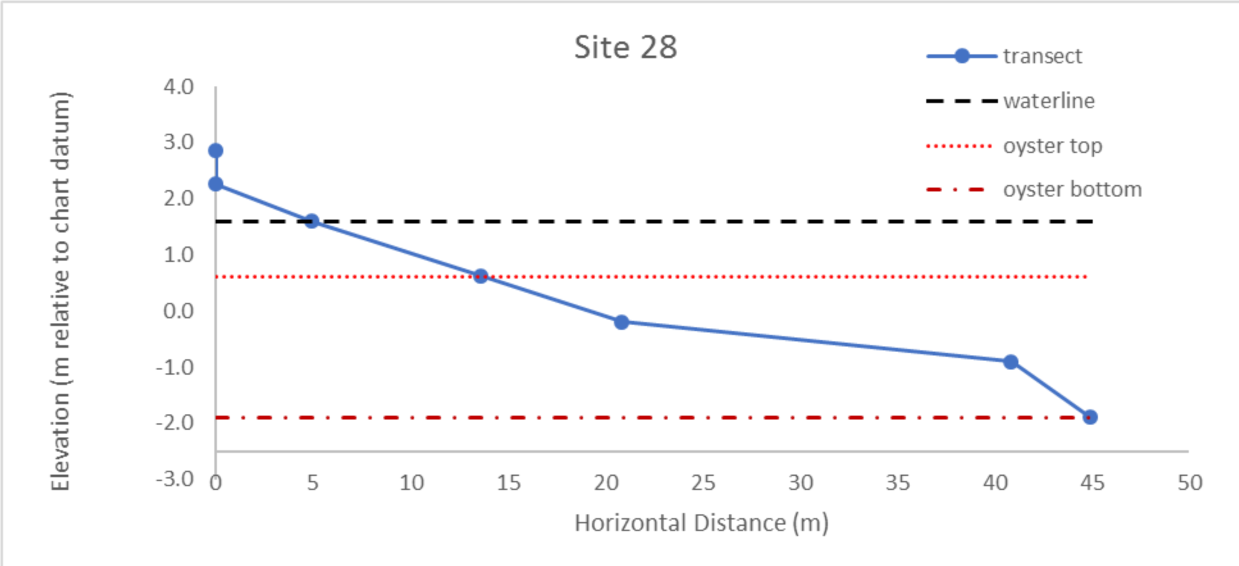

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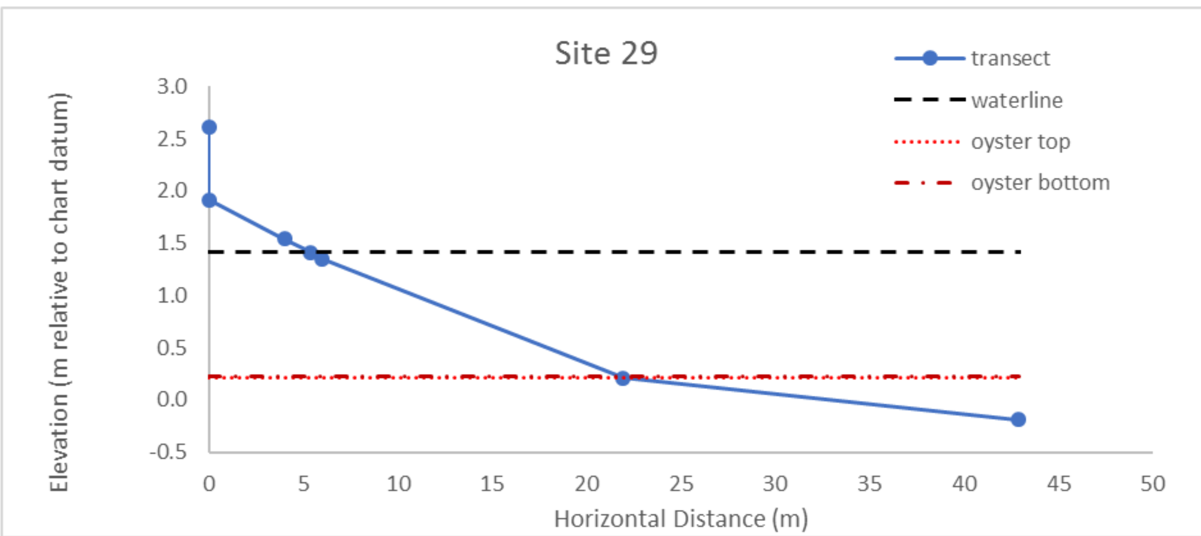

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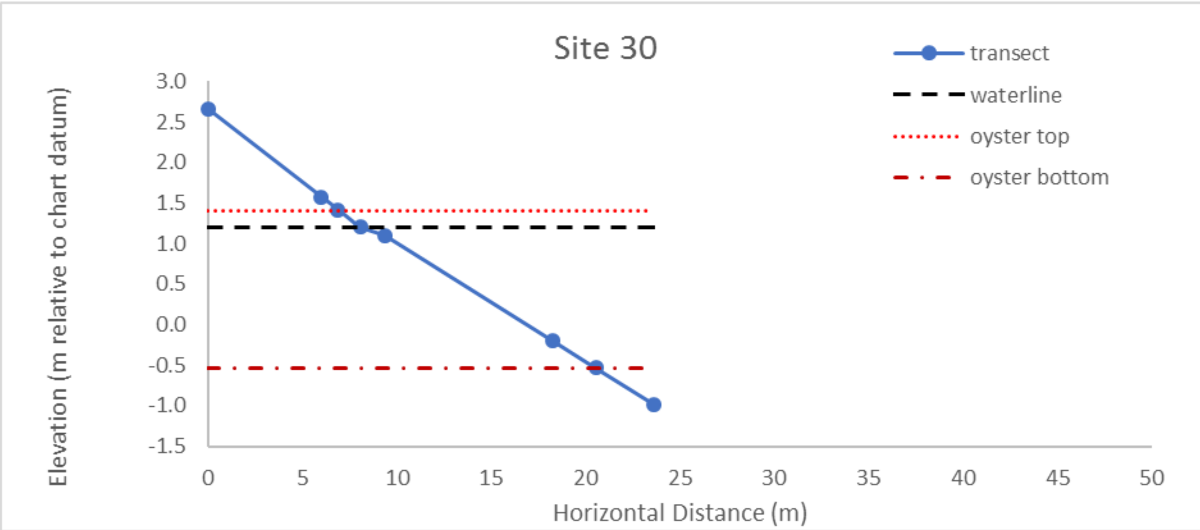
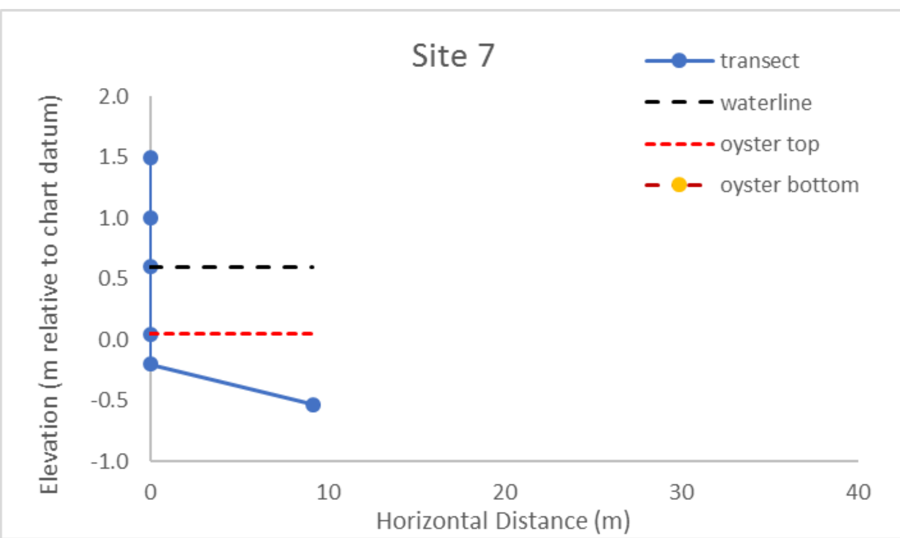


Upper Gorge

Figure 25. Site 7.



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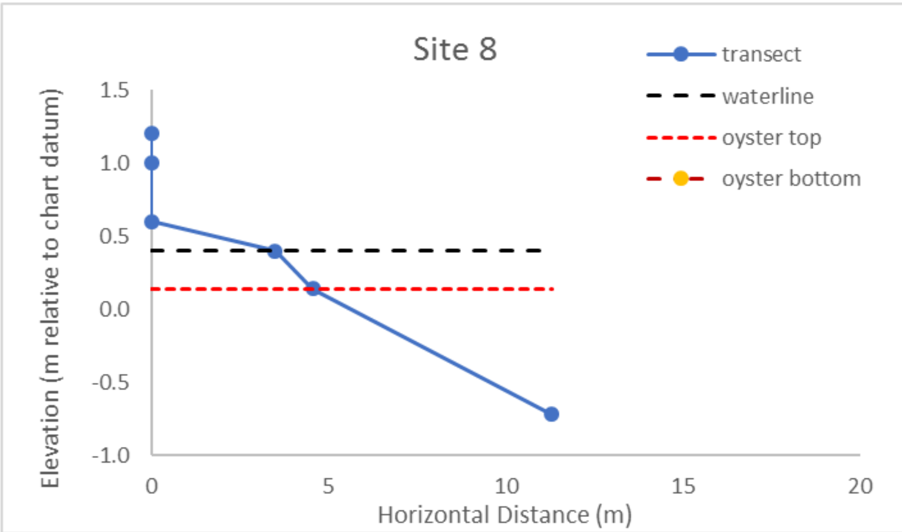

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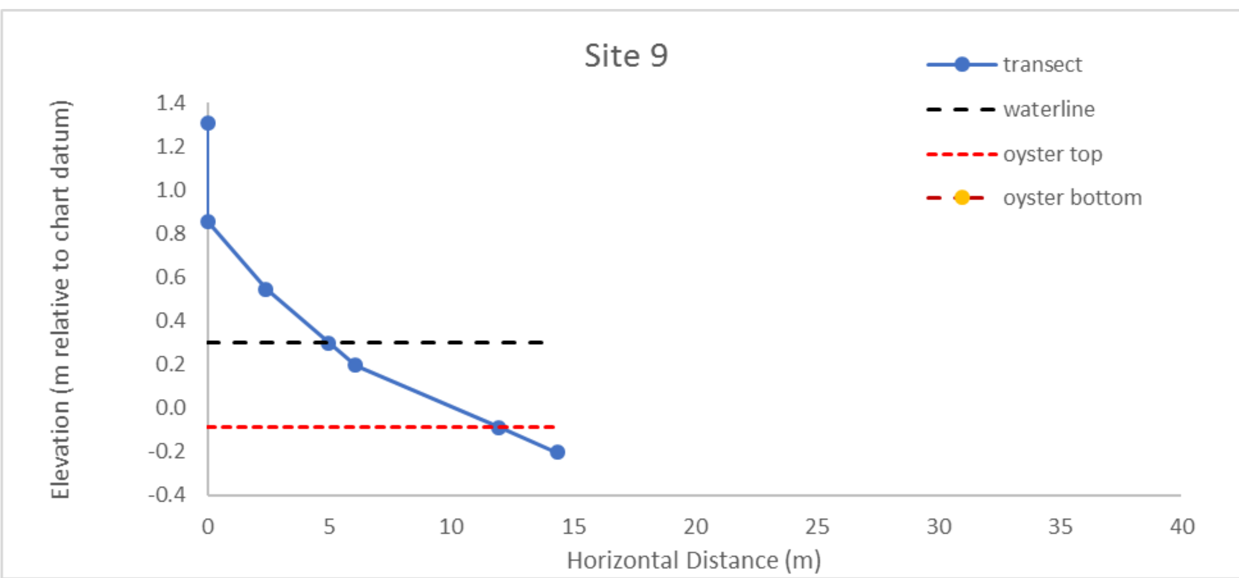

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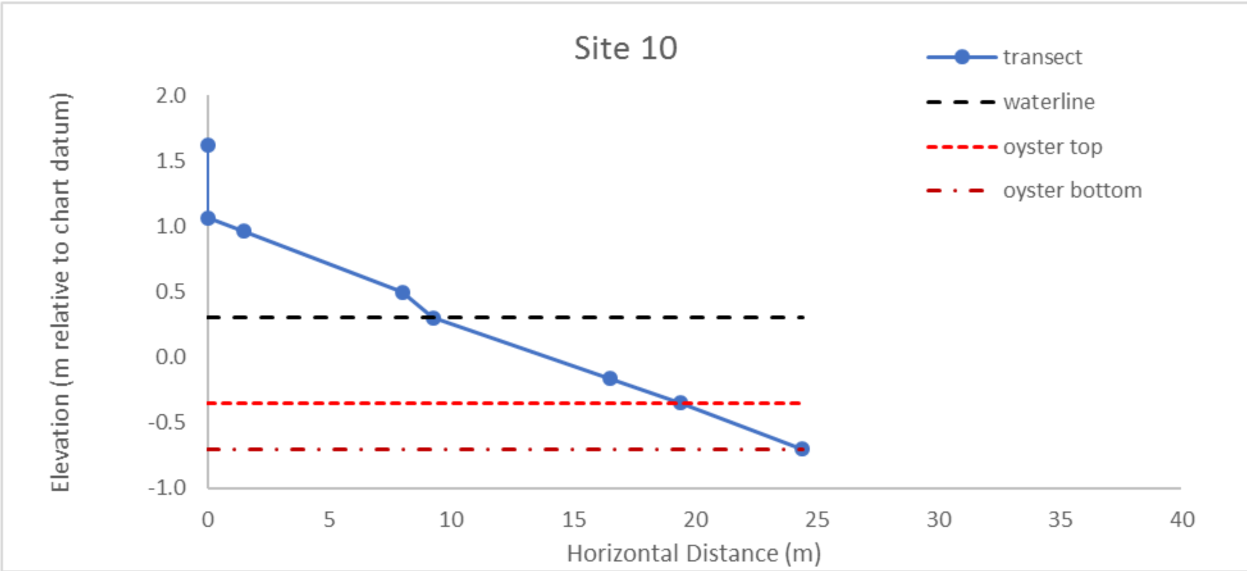

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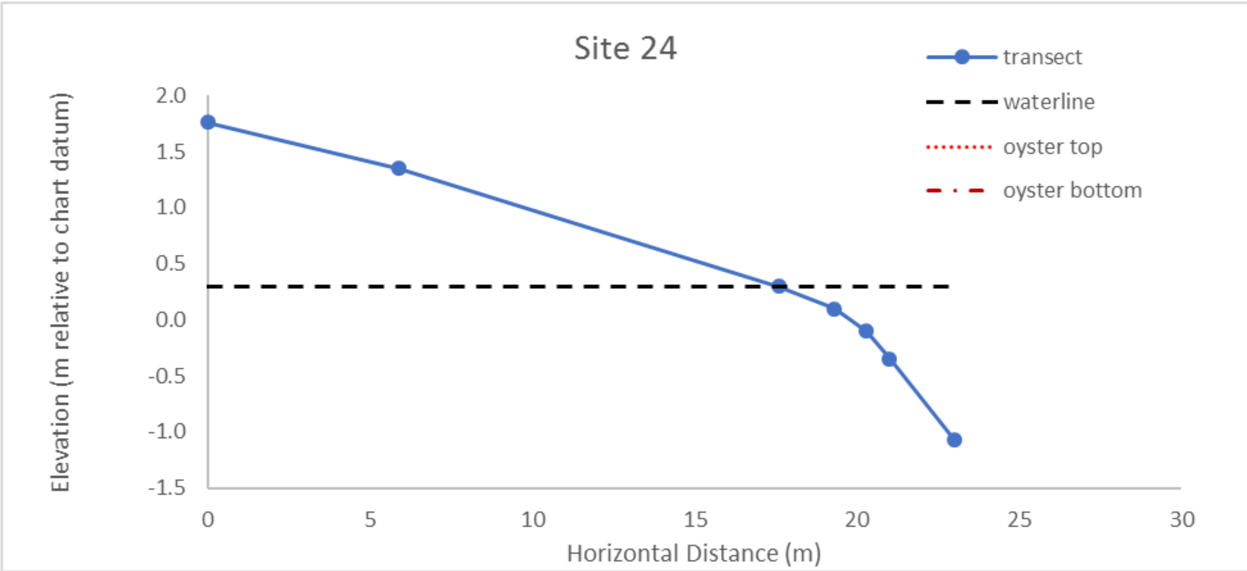

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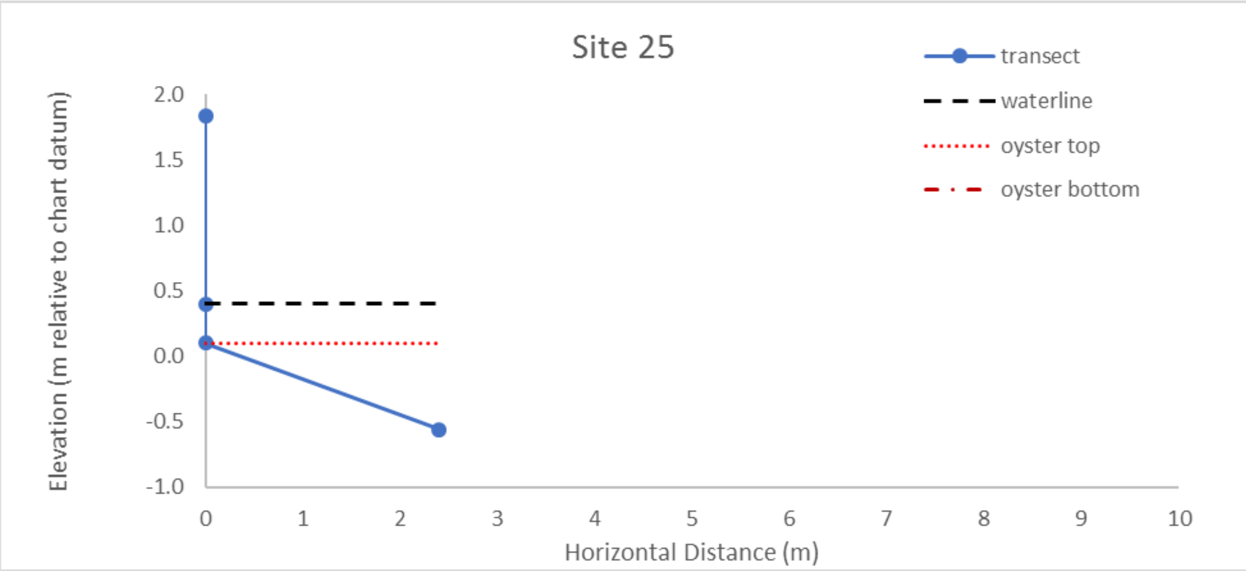

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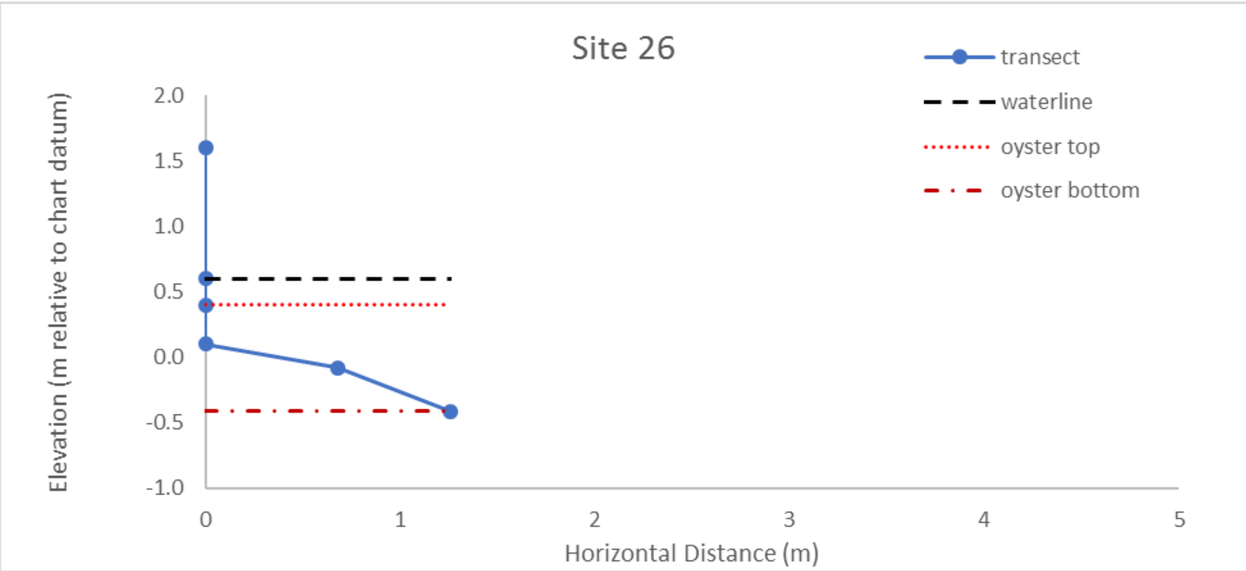

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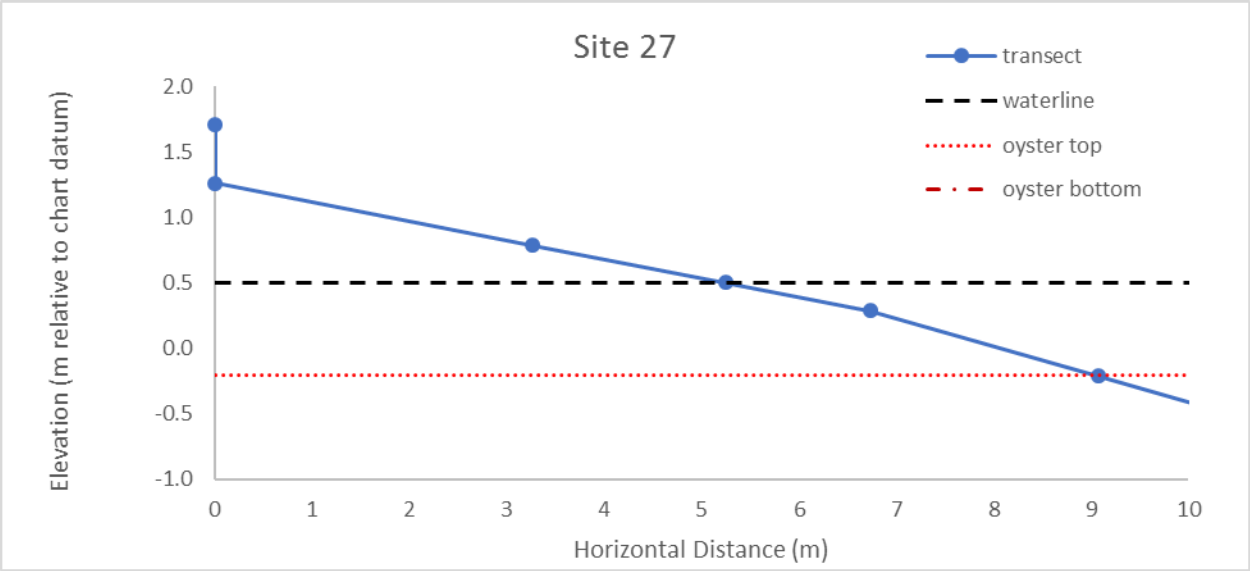
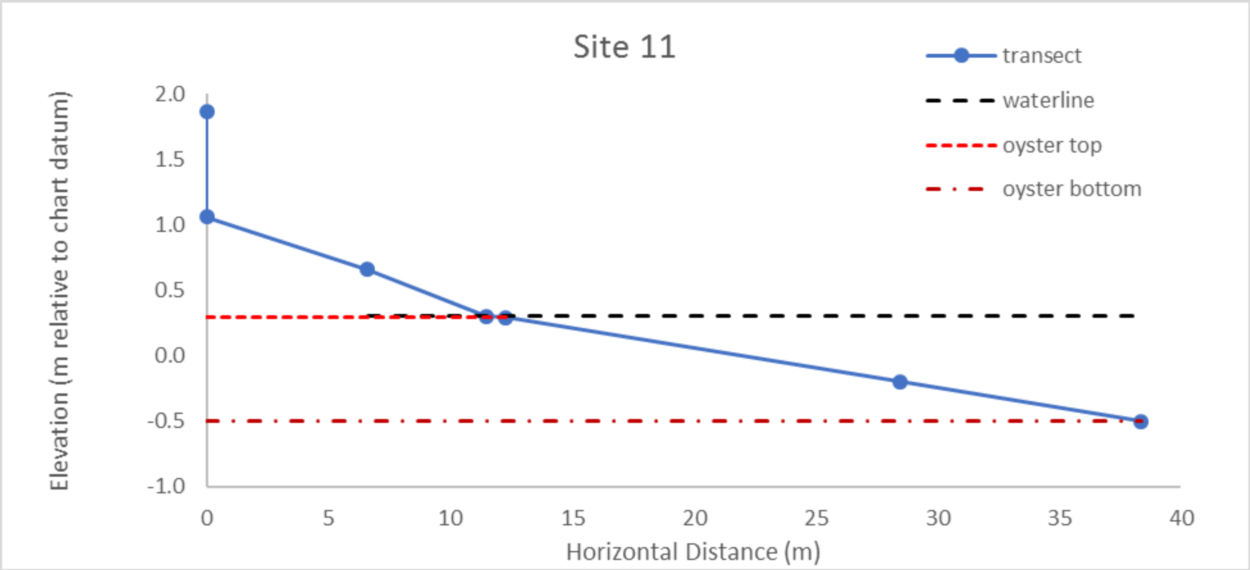


Portage Inlet

Figure 33. Site 11.



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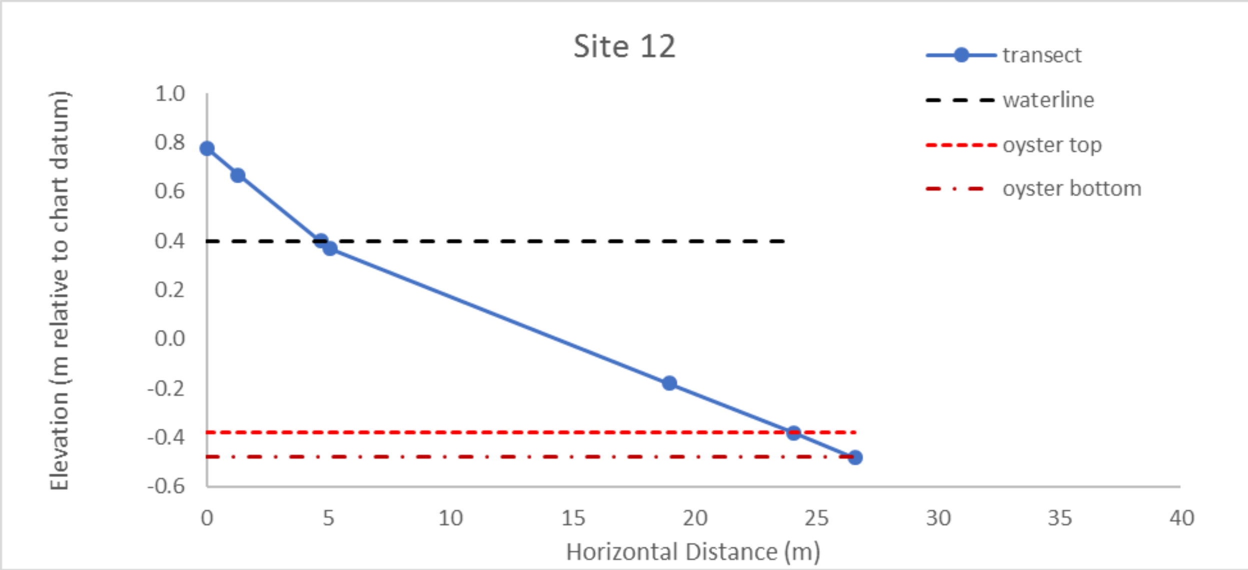

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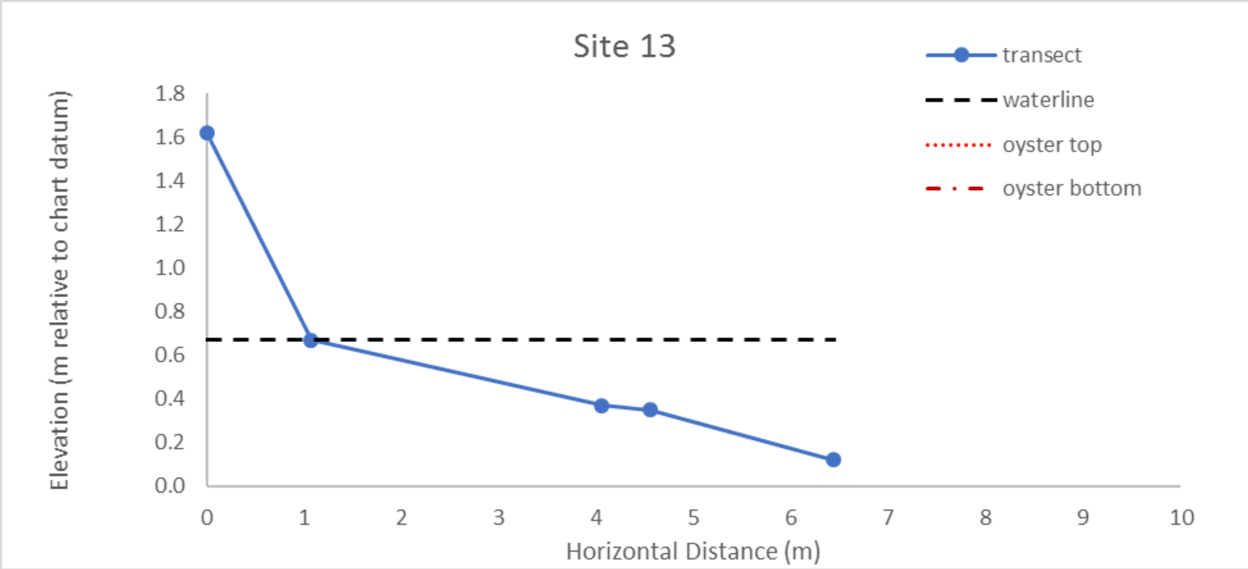

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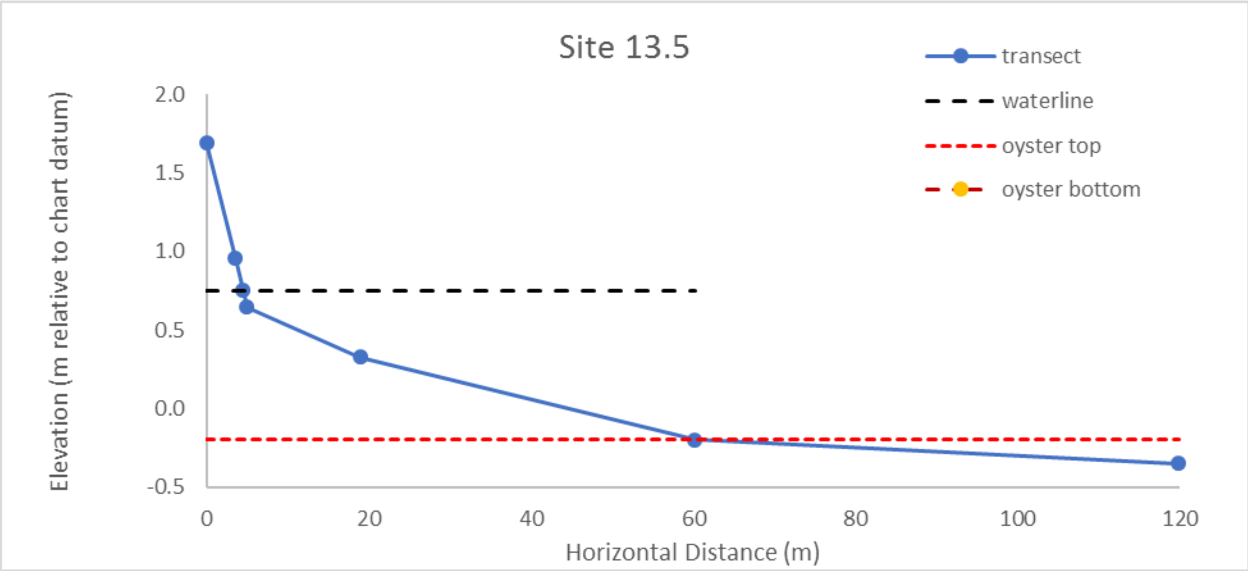

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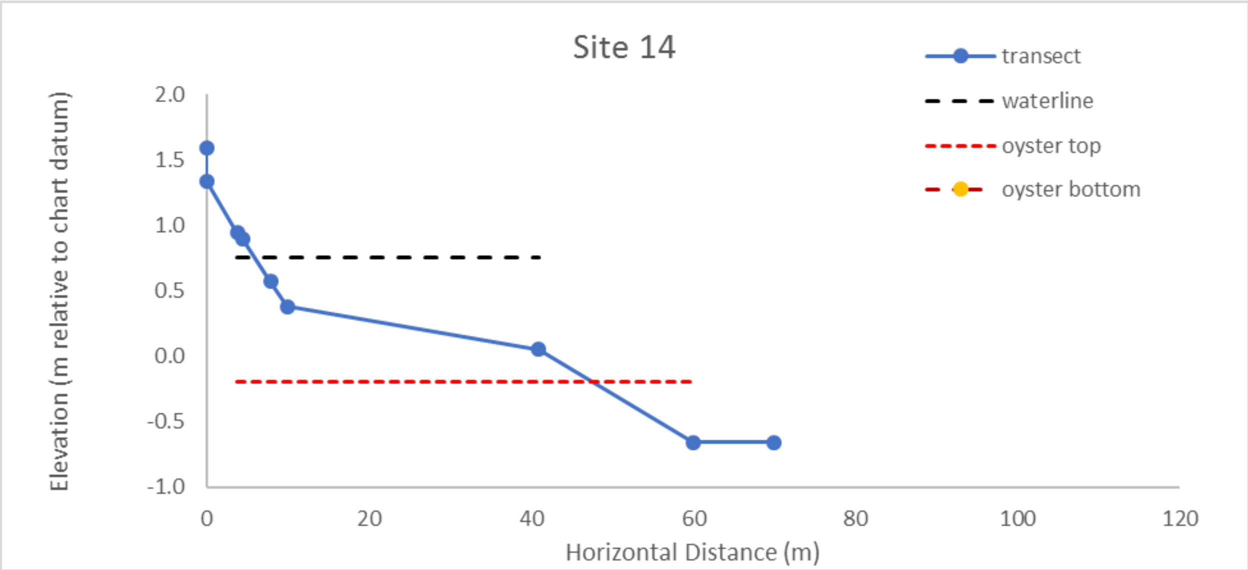

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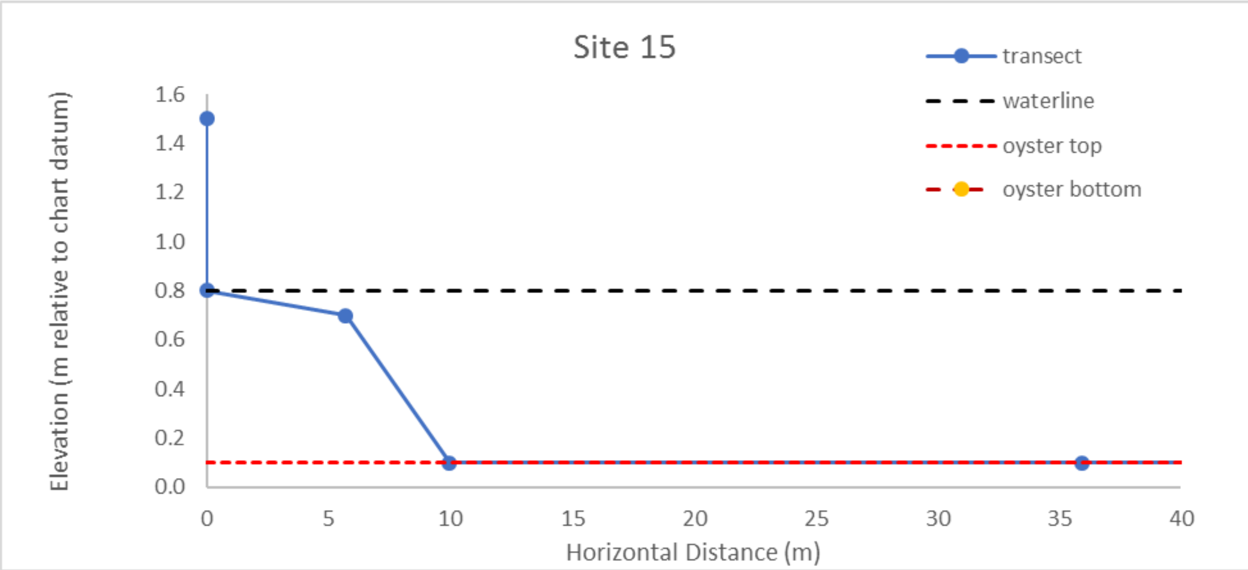

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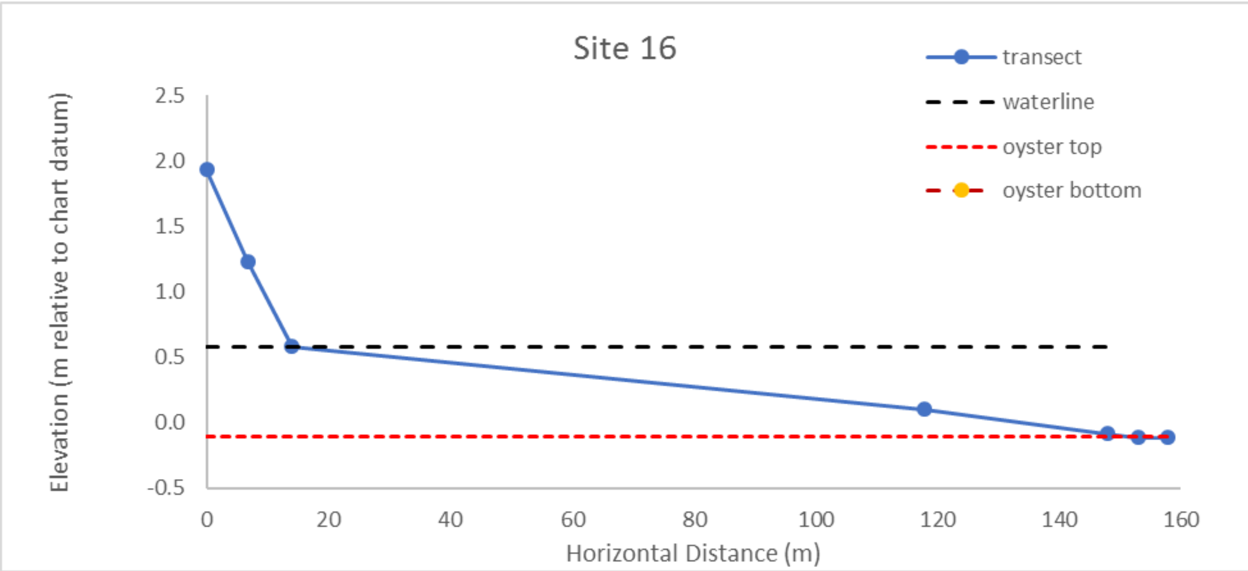

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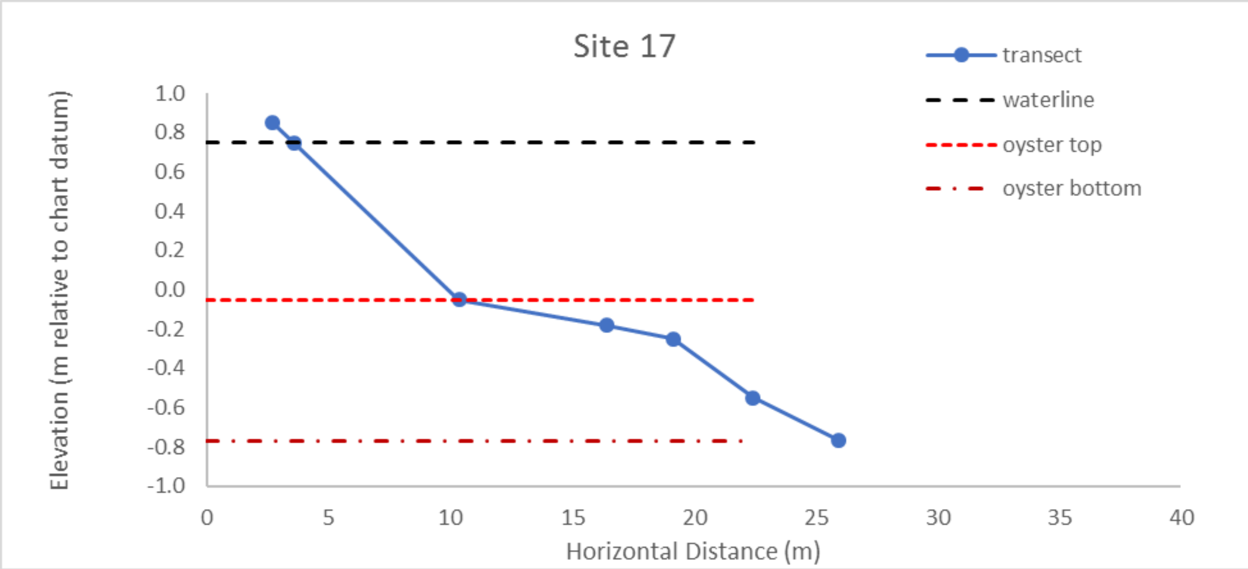

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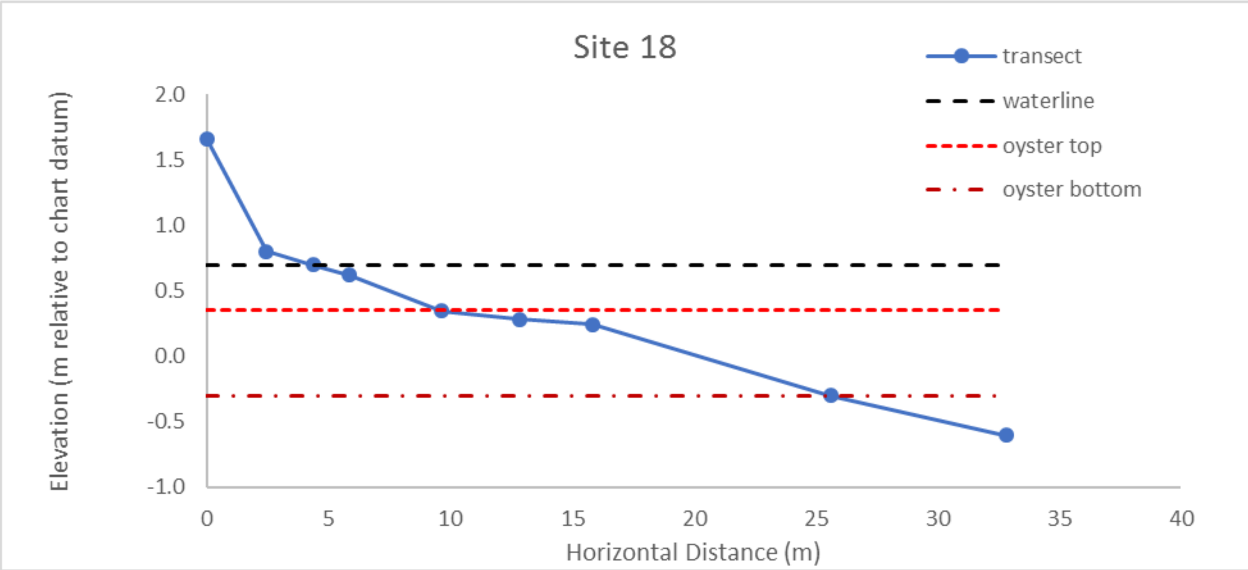

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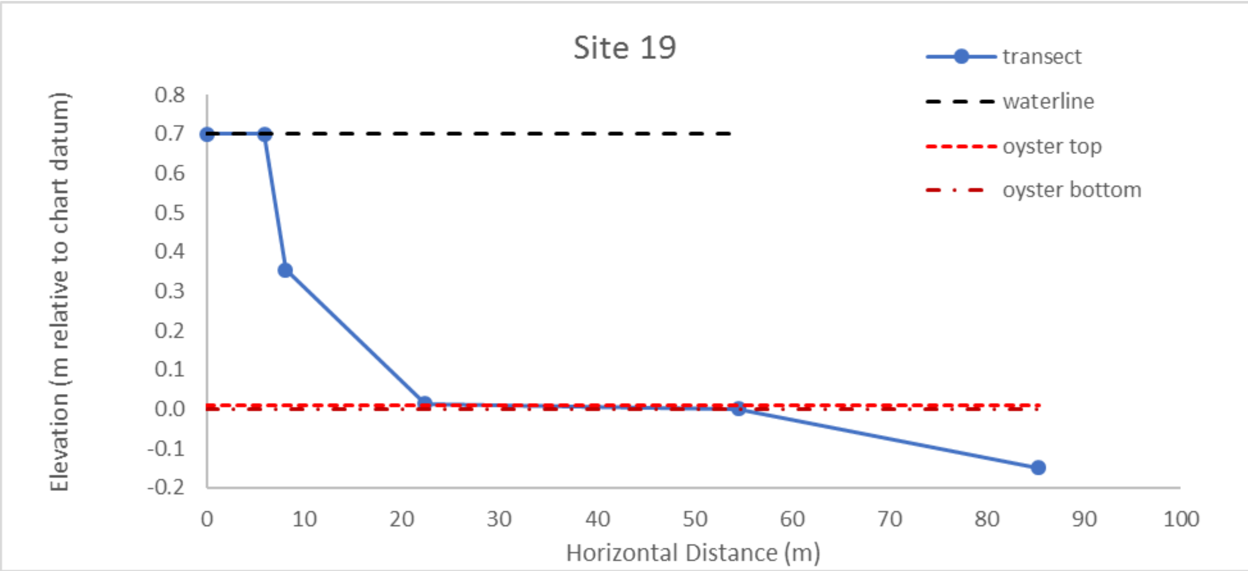

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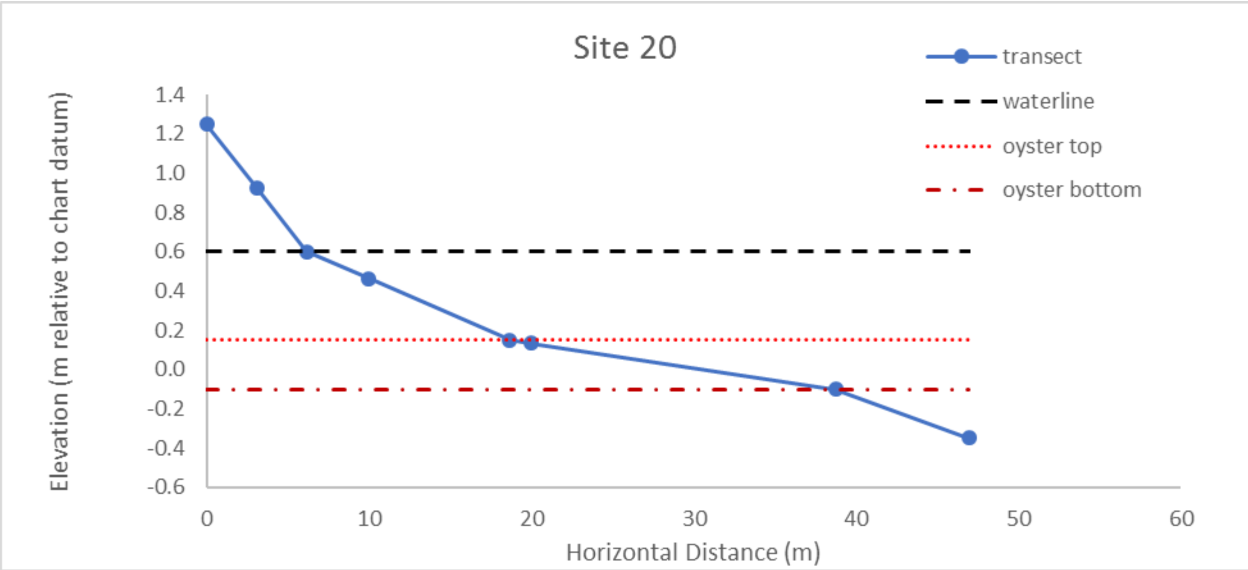

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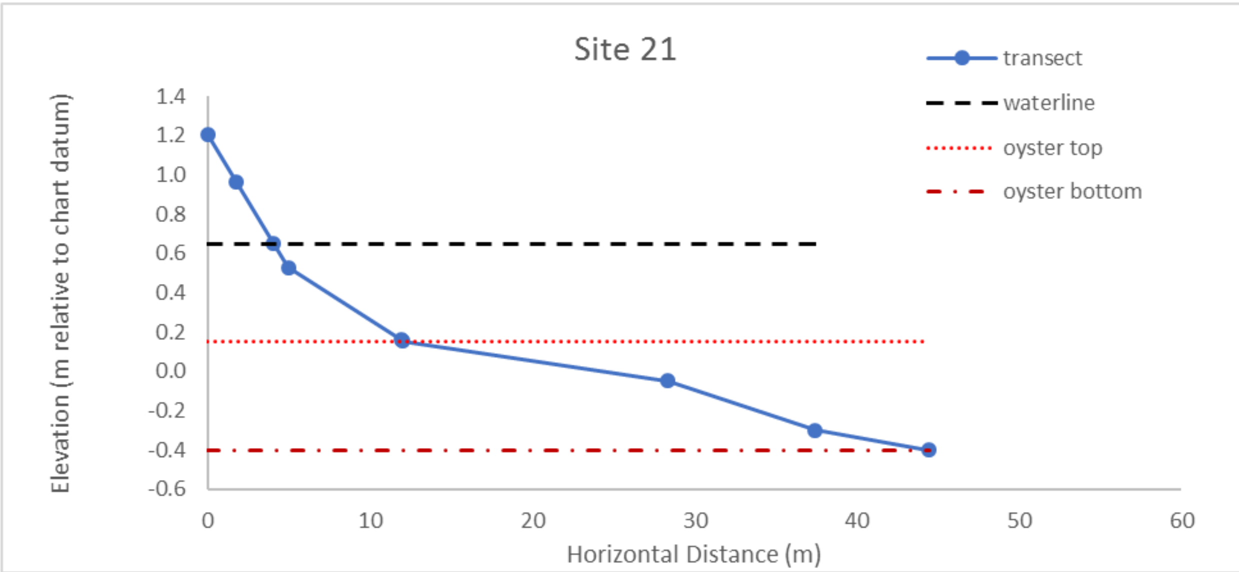

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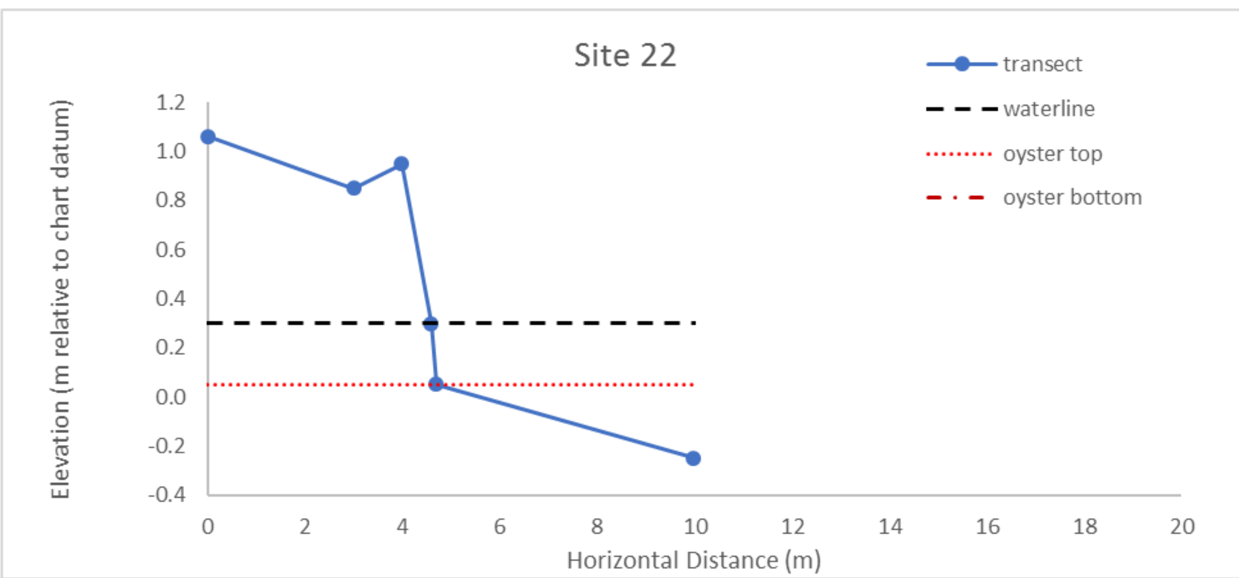

Figure 46. Site 23.