Roberts and Sturgeon Banks 2011

Habitat Inventory

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1. Introduction

1.1 Objectives and Introduction to 2011 Projects

The overall objective for the Roberts and Sturgeon Banks (RSB) Habitat Inventory is to further understanding of the environmental processes, biological conditions, and chemical conditions of Roberts and Sturgeon Banks. This has been or will be achieved through field sampling, mapping, laboratory analysis, statistical analysis, spatial analysis, and comparisons to previous studies. The information gathered through these studies will be used to monitor the environmental health of the estuary in the intertidal zone and upland marsh areas as these areas are essential habitat for juvenile salmon and migratory birds. In addition to the overall objective, each separate project has its own specific objectives.

Transect Survey

Field sampling and mapping for the 2011 RSB Habitat Inventory took place between May and August 2011 at Roberts and Sturgeon Banks. Five separate field or field preparation projects were conducted over this time period. The main project, the Transect Survey, was a baseline study and involved the establishment of 15 transects. At each transect, sample sites were spaced at 200 metre intervals starting at the shoreline (at the dike or high tide mark). Transects were spaced fairly evenly and ranged from Tsawwassen in the South to Iona Beach in the North. They extended perpendicular to the shoreline to a maximum of 2 kilometres. This distance was due to limitations caused by tidal conditions, although the mudflat extends further than 2 kilometres in many areas. At each sample site 2 wooden stakes were hammered into the sediment and baseline height measurements were taken. Surface biofilm samples, benthic invertebrate samples, and sediment grain size samples were also taken at each site. Sampling and transect establishment took place between May and June 2011. The May/June 2011 Habitat Survey established the parameters, sampling methods, sampling sites, and baseline measurements required to continue future sampling and comparisons each year.

Mid Summer Transect Measurements

The second part of this project, the Mid Summer Transect Measurements, took place in mid to late July and early August when the sample sites were revisited. At this time, measurements were taken from the same stakes used for the Transect Survey to calculate sediment accretion or erosion rates based on comparisons with measurements taken in May and June. Salinity measurements were also taken at each sample site where surface water was available. Additionally, eelgrass percent cover was mapped along each transect for Sturgeon Bank only. The Mid Summer Transect Measurements have established a baseline for future measurements taken in the middle of the summer during the spring freshet sediment deposits. In addition, a future mapping project for eelgrass can be created from transect data collected at Sturgeon Bank.

Marsh Edge Mapping

The third project was marsh edge mapping, where marsh areas in Sturgeon and Roberts Banks was mapped using a Trimble GPS. This mapping took place at the end of July and early August and included the leading edge of the marsh off of Lulu Island, Westham Island, and vegetated islands beyond the Westham Island marsh. This map will provide a geospatially referenced line marking the marsh extent in the summer of 2011. This can be compared with the extent of the marsh in future years, or with previous years possibly through photo interpretation. The methods used for marsh edge mapping for this project can also be used to map the marsh extent at Sea Island, the vegetation islands off of Lulu Island, and at Brunswick Point.

Vegetation Polygon Validation

The final field project was vegetation polygon validation, which had been previously photo interpreted. Part of Sea Island was visited and mapped during July. The vegetation polygon validation will show changes in the intertidal and upland marsh and compare field observations with photo interpreted observations.

Sediment Quality Parameters, Methods, and Recommendations

In addition to the field component, a document outlining sediment quality parameters, methods, and recommendations (see Appendix 5) was prepared for a potential field project in the future. The sediment quality document was created to outline possible parameters, sampling locations, sampling methods, and costs to guide the decisions for field sampling. This document will also provide FREMP with ideas and options for a project which is appropriate for the environmental conditions of the sampling area, budget constraints, and which compliments other projects located in the same sampling area.

1.3 Site Description

Sturgeon and Roberts Banks were created through sediment deposition from the Fraser River as it entered the Strait of Georgia and formed the coastal portion of the Fraser River Estuary. Sturgeon Bank extends westward from Sea and Lulu Islands which include the Vancouver International Airport (Managed by the Vancouver Airport Authority) and the City of Richmond. Major developmental and environmental pressures come from the airport and its possible expansion, the Iona sewage outfall, urban runoff, boat and seaplane traffic, agricultural runoff from upstream farms as well as one farm along the Richmond west dike, and other upstream developments such as sawmills and warehouses. Roberts Bank extends westward from Westham Island, Brunswick Point, and Tsawwassen. This area is a part of the Corporation of Delta and includes the Alaksen National Wildlife Sanctuary (Managed by the British Columbia Waterfowl Society), the Deltaport (Managed by Port Metro Vancouver), and the Tsawwassen Ferry Terminal (Managed by BC Ferries). Major developmental and environmental pressures come from the terminal and port, agricultural runoff, urban runoff, and boat traffic.

Vegetated marsh extends from the north end of Tsawwassen north to just south of Iona Beach. The vegetated marsh extends furthest out into the intertidal area at the north end of Lulu island along the middle arm of the Fraser River, along the south arm of the Fraser off of Steveston and Westham Island, and at Brunswick Point. At Tsawwassen and Iona, there is no marsh in the intertidal area and the shoreline is sandy. The main marsh plant species include *Scirpus maritimus*, *Scirpus americanus*, *Carex lyngbyei*, *Typha latifolia*, *Juncus sp*., *Triglochin maritimum*, *Distichilis spicata*, as well as others**.**

1.3 Description of Parameters

Parameters used for the field sampling portion of the projects include accretion/erosion measurements in May/June during the site establishments and then again in July, biofilm sampling, benthic invertebrate sampling, sediment grain size sampling, and salinity measurements. The parameters for the possible future sediment quality sampling are described in the document *Sediment Quality Parameters, Methods, and Recommendations* (See Appendix)***.*** The methods for the field sampling parameters will be discussed later in the methods section.

May/June Accretion and Erosion Baseline Measurements

The accretion/erosion baseline measurements were conducted as a part of the transect and sample site set up. There was no previously collected data for this parameter as it is a baseline measurement so analysis can not be completed from this parameter alone. The data collected can be used to compare with future years in the pre spring freshet period or with measurements of the same site conducted later in the year.

July/August Accretion and Erosion measurements

The July/August accretion and erosion measurements were a re-visitation and measurement of the May/June accretion and erosion baseline measurements. This was conducted to compare data between the pre spring freshet period and the post freshet period. However, the spring freshet of 2011 was later than usual and flooding in the interior portions of the Fraser watershed caused high water levels in the estuary during the July re-measurement period. Therefore measurements may have to take place later in the year to accommodate for the Mid Summer Transect Measurements taking place during the freshet. Assumptions for this parameter are that there will be sediment accretion found at most sample sites as the Fraser deposits sediments carried from upstream locations. There also may be more accretion in sheltered areas and in areas with more influence from the river.

Biofilm sampling

Biofilm is made up of secretions from bacteria and microphytobenthos as well as decomposing organic matter, microbes, and sediment (Kuwae, et al. 2008). This composition gives it a high nutritional value and a high energy value from carbohydrates. It is found mainly on the surface of mudflats with higher water contents. Sampling was conducted in May and June by collecting the top 2mm of surface sediment at each sample site. Biofilm is an important food source for rasping invertebrates, some fish species, and birds such as the Western Sandpiper that depend on the estuary for their habitat (Kuwae, et al. 2008). Biofilm was found to provide 50% of the daily energy requirements of the Western Sandpiper during migration and possibly up to 68% of the daily energy requirement if nocturnal biofilm feeding is accounted for (Kuwae, et al. 2008).

Benthic invertebrate sampling

Benthic invertebrate sampling was based on a previous study entitled Data Report on the Distribution and Abundance of Mieofauna on Roberts Bank, British Columbia (Sutherland, et al.). The sampling method used was appropriate for the collection of mieofauna, however a different method will have to be used for the collection of macrobenthic invertebrates if this information is required. This method is discussed in the recommendations section of this report.

Sediment grain size sampling

Sediment grain size sampling was conducted to gain an understanding of the sediment grain size distribution throughout the coastal portion of the estuary. This will be useful in determining plant growth conditions for the marsh as well as ion to sediment bonding strength depending on the grain size distribution.

Salinity measurements

Salinity measurements were conducted in July during the middle of the 2011 spring freshet. They were conducted to determine the distribution of salinity throughout the coastal portion of the estuary. This is important because the distribution and ecology of marsh vegetation depends on the salinity of the water. For example, three-square bulrush (*Scirpus americanus*) is a marsh plant with rhizomes providing an important food source for lesser snow geese (*Anser caerulescens caerulescens*) (Boyd, 1983). High salinity levels in the spring can have adverse effects on the growth of the plant during the early growth period due to osmatic pressure differences between the marsh water and the internal water of the plant (Ustin, 1984). The assumptions for salinity are that water sampled closer to the river will have lower salinity values and water sampled further into the intertidal zone and away from the river will have higher salinity values.

1.4 History

The Fraser River has experienced large fluctuations in discharge from year to year since 1950 (Rand et al., 2006). Discharge in the Fraser River seems to follow a trend of oscillation, where values will peak then plummet either back to the beginning discharge or lower than it. The mean July discharge rate in the Fraser River was found to be decreasing by 17.05 m3/s per year, based on data collected from 1950 to 2006 (Rand et al., 2006). In the summer of 2011, most high altitude areas the Fraser River watershed contained higher than normal snowpack levels (Corbett, 2011). Based on historical hydrometric data of discharge at Hope, the 2011 Fraser River freshet started the beginning of May (2000 m^3/sec.) and may end sometime in the middle of September. At the time this report was written (August 23, 2011), the discharge in the Fraser River was at 4000 m^3/sec. Fraser River discharge also peaked twice during summer of 2011, on July 5th and July 13th, by 2000 m^3/sec to 10000 m^3/sec (Environment Canada, 2011). Each peak was followed by an equal, subsequent decrease in discharge. These dates correspond with flooding in cities located up-river from the estuary (Williams, 2011).

The spring of 2011 experienced cooler than normal temperatures, with above normal levels of precipitation due to the effects of La Nina (The Weather Network, 2011). This resulted in a later growing season for marsh plants.

Dredging of the Fraser River began in the 1800's, when the first navigational channel was established on the river. Since the 1800's many different dredging programs have been created by government and commercial stakeholders (Bros, 1993). Currently dredging operations occur around the Delta Port Container Terminal, along the South Arm of the Fraser River near Steveston Point, at the east end of Westham Island, and at North Arm Jetty (Fraser River Estuary Management Program, 2006).

2. Methods

2011 Habitat Survey

Methodology for the 2011 Roberts and Sturgeon Banks Habitat Inventory are described in the order in which the sampling procedures were conducted.

2.1 Surveying

Fifteen transects were established along Sturgeon and Roberts Banks, and were spaced at an approximate even distance away from each other from Iona Beach in the north to Tsawwassen Beach in the south. Transects originated at the shoreline (the dike or beach) and extended perpendicular to the shoreline towards the Strait of Georgia. Transect length was dependant on tide conditions during sampling, with a maximum length of 2 kilometres for transects where tidal conditions would allow. In many cases, the incoming high tide was met at 2 kilometres; therefore, to be consistent 2 kilometres was chosen as a distance for each transect. Transect locations were determined using air photo interpretation and were cross referenced using GPS waypoints. GPS waypoints at each sample site were collected for at least one minute and until the unit determined 100% location accuracy.

Samples were collected every two-hundred metres along each transect. The orientation of the transect line was maintained by first fore-sighting with a compass set to the bearing of each transect onto a recognizable and stationary feature such as a navigation structure and then back-sighting onto the start point or the last sample site marker (the wooden deposition marker stake) at each sample site. In conjunction, transect orientation was monitored using tracks in the GPS (Garmin GPSmap 62S) (See Figures 1 and 2). Sample site distance was determined by measuring the distance from previous waypoints collected using the GPS.

Observations of contamination, water depth, vegetation, weather conditions, sediment surface structures, and sediment composition were collected at each sample site in order to explain data variation. To avoid bias, sampling locations for biofilm, benthic invertebrates, and sediment grain size within each sampling site were determined by placing a 183cm long metal pole down from the northernmost edge of the stakes (See Figure 3). The sampling locations were then placed at specified distances from the end of the pole (See Figure 4). These sampling locations can be changed in future years to avoid re-sampling the exact same locations. If the pole could not be used due to barriers such as logs or thick vegetation, an appropriate site nearby was chosen for the sampling to take place. In locations with heavily vegetated marsh, some samples could not be collected due to the absence of exposed sediment and heavy root structure.

Figure 1. Transect Set Up Using Stationary Objects for Transect Orientation

Figure 2. Transect Orientation Using a Compass

Figure 3. Stake Set Up Showing Pole Distance to Sample Sites

Figure 4. Sampling Locations at end of Pole

2.2 Substrate Accretion and Erosion Measurement Stakes

To measure accretion and erosion, 2 inch x 2 inch x 3 foot wood stakes were used. Two stakes were inserted using a rubber or metal mallet into the sediment at each sample site to a depth where the top 20 cm of the stake remained above the surface. The stakes were inserted 1.5 metres apart from each other using a metal pole measuring device for determining distance. The first stake was inserted along the transect at the location of the sample site centre and the second was inserted perpendicular to the transect to the Northerly side (See Figure 3). In order to prevent the disturbance of sediment, stakes were placed one metre from any structures present at the sample site. Care was taken not to step within the measurement area between the stakes, or near the western, coastal side of the stakes.

The metal pole was laid on top of the stakes with one end flush with the outer edge (the edge facing away from the next stake) of the sample site centre stake (See Figure 5). The metal pole was checked to be horizontally level, and adjusted if necessary, in order to accommodate for the possibility of future disturbance to the stakes (disturbance would cause the pole to become off-level when measured in the future). Three measurements were taken along the metal pole at 65 cm, 75 cm, and 85 cm from the end of the pole measuring device located at the sample site centre stake. The depth measurements were collected in-between the stakes in order to accommodate sediment height variability at the sample site. The height measurements were then averaged to determine a future reference for accretion or deposition rates for the estuary. In areas of soft sediment where there was the potential for the ruler to sink below the sediment surface or where the sediment surface was not well defined, a 38.5 cm long x 11.5 cm wide x 3.75 mm deep corrugated plastic sheet was laid down and used as a measuring platform to ensure a stable, rigid measuring surface. If the plastic sheet was not necessary, care was taken to prevent the ruler from moving below the sediment surface. Before taking measurements, the ruler was adjusted so it was vertically level.

Figure 5. Accretion/Erosion Measurements Using the Sliding Ruler Placed at the Bottom of the Pole and to the Plastic Sheet on Mud

2.3 Sediment Grain Size Sampling

Sediment grain size samples were collected 25 cm to the west of the end of the pole. A plastic corer (5.5 cm diameter, 12.5 cm long) with an air hole at the bottom was used to collect sediment samples. Before sampling sediment, the core sampler was rinsed initially with sea water to remove course sediment, and then rinsed with filtered water to remove fine sediment. The core sampler was then inserted into the sediment and taken out with the hole at the bottom of the corer plugged to create suction and avoid sediment from being lost. The sediment sample was then put into a Ziploc bag. The Ziploc bags used were free of contaminates. One core sample was collected at each sample site for a total of 5-10 samples per transect (dependant on transect length). Eight replicates were collected over the entire sampling area (Roberts Bank and Sturgeon Bank) with no more than one replicate per transect. Replicates were labeled as sample site 11. Water in the core sample was also added to the Ziploc bag in order to included any suspended fine sediment in the water.

Figure 6. Sediment Grain Size Sampling Method Using a Core Sampler

2.4 Sediment Grain Size Analysis Methodology

Sediment samples were checked for grain size composition by feel and separated by samples that contained sediment grains greater than and less than 0.125 mm. Samples with sediment grains greater than 0.125 mm needed to be homogenized and sieved in order to prevent system failure with the Sedigraph. A Sedigraph is a laboratory instrument that determines the sediment grain size composition of a sediment sample. A Sedigraph only uses a small portion of the sample in a solution and measures differences in X-ray intensities with height as sediment grains are settling. First the coarse sample was emptied into a large metal pan. The sample bag was scraped with a stainless steel spoon so only a thin film of sediment remained. Before removing large debris, such as sticks and clams, the material was sprayed overtop the pan with tap water in order to collect any residual sediment. Labels were also removed in the same fashion. The sample was then mixed with a stainless steel spoon until it showed homogenous texture and colour. A portion of the homogenized sample was then scooped into an aluminum cupcake tray cup, so that the cup was three-quarters full. The transect and sample number were written on the side of each cup. Cupcake trays were then placed into an oven at 275°F for over 24 hours. This methodology was provided from Professor Jeremy Venditti, Simon Fraser University Department of Geography.

Each cup in the cupcake tray was cut out with scissors. The dried sediment sample was then placed into a small steel tray and crushed with a stainless steel spoon in order to prevent clumping during sieving. The loose sediment sample was then placed back into the cup before being weighed and placed into a 0.125 mm sieve. The spoon and tray were cleaned with a brush after each sample. Samples were weighed to 3 decimal places on a stainless steel cup, previously tarred on the scale. Values were not recorded until readings were maintained for ten seconds.

Once placed into the 0.125 mm sieve, the sample was shaken for 3 minutes and then left to settle. The cover to the sieve was never removed until all fine sediment had settled. If the sample contained any sediment clumps it would be gently pushed down by a spoon and sieved for one minute. The remaining grains greater than 0.125 mm were then poured into a measuring cup, that was previously tarred on the scale. In order to maintain accuracy, the mesh of the sieve was cleaned with a brush and any dislodged sediment was also poured into the measuring cup. The measuring cup was then weighed and recorded. Sediment grains greater than and less than 0.125mm were placed into separate small, labeled Ziploc bags. Sediment samples that were initially felt to contain only fine grains also had to undergo the same homogenization, drying, and sieving process as the others. This was due to organic debris clogging the Sedigraph.

A Micromeritics Sedigraph 5100 was then used to analyze the fine grain (silt and clay) constituents in half of the sample bags containing grains less than 0.125 mm in size. Sedigraph operation instructions were followed throughout the analysis. To maintain accuracy, the average X-ray intensity and intensity variability during the analysis were recorded on each report. If the variability of the X-ray intensity was greater than 5 kilocounts/s, then the analysis was cancelled and repeated with the same solution. If the variability on the second analysis was still found to be too high, then the system would be rinsed and a new solution from the same sample would be analyzed. If the system continued to return variable results, it was rinsed twice and calibrated again using a beamsplit at a cell position of ten.

Once the solution had been properly analyzed, the cell and tubes were visually inspected with a flashlight while the Sedigraph was rinsing. If the cell or tubes contain any visible amounts of sediment, the system was rinsed another time before processing the next sample in order to prevent cross-contamination.

2.5 Biofilm sampling

Biofilm samples were collected directly at the end of the pole. Before collecting biofilm samples, the syringe (2.6 cm diameter, 13 cm long) and knife were thoroughly rinsed with filtered water and visually inspected for any contamination. The syringe was then inserted into the sediment at the location of 183 cm from the most northerly deposition stake (1.5 m from the sample site centre stake) to a depth greater than 30 mm and taken out of the sediment (Figure 7). The plunger was then taken out of the syringe and the end smeared along the inside of the WHIRL-PAK bag to remove and include any biofilm left on the surface of the plunger into the sample bag. The plunger was then placed into the opposite end of the syringe and the sample was pushed out the other end until only the top 2mm of sediment including was exposed.

Water was removed from the sediment core before being added to the sample bag. The top 2mm of sediment was cut along the surface of the syringe and placed into the WHIRL-PAK bag. The rest of the sample was discarded at a distance away from the sample site and the knife and syringe was washed with sea water.

One biofilm sample was collected at each sample site for a total of 5-10 samples per transect (dependant on transect length). Eight replicates were collected over the entire sampling area (Roberts Bank and Sturgeon Bank) with no more than one replicate per transect. Replicates were labeled as sample site 11.

Figure 7. Biofilm Sample Site Location and Sampling Procedure

Figure 8. Biofilm Sample Size with Syringe

2.6 Benthic Invertebrate sampling

Benthic invertebrate samples were collected at one syringe length to the north of the Biofilm sample collection site in order to reduce contamination. The same syringe from Biofilm sampling was used to collect the benthic invertebrate samples. Before sampling, the syringe and knife were thoroughly rinsed with sea water and then with filtered water to remove contaminants. Cores were collected to a depth greater than 30 mm, but not exceeding the length of the syringe. The plunger was reversed, while the sample remained horizontal to prevent the loss of core contents.

Samples were collected by slicing each 10 mm increment of core, to a maximum of 30 mm, and placed into 2oz. WHIRL-PAK bags. Surface water and fine sediments were collected in the sample bag for the first 0-10 mm sediment sample slice to properly represent all surface invertebrates within the first 10mm of the sediment core. After removing each 10mm increment of sample from the sediment core, the knife was cleaned with filtered water to avoid contamination from previous samples. Sample bags were sterile.

One benthic invertebrate core sample was collected at each sample site for a total of 5-10 samples per transect (dependant on transect length). Eight replicates were collected over the entire sampling area (Roberts Bank and Sturgeon Bank) with no more than one replicate per transect. Replicates were labeled as sample site 11.

Figure 9. Invertebrate Sample Size with Syringe and WHIRL-PAK Sample Bag

2.7 Biofilm and Benthic Invertebrate Sample Storage

Biofilm and benthic invertebrate samples were placed into a cooler, with frozen ice packs, during the field day and then transferred to a dry ice cooler for the sampling week. At the end of each sampling week, the samples were transferred to an industrial, walk-in freezer with a temperature of -23°C. At the end of each field day, the temperature of the dry ice cooler was checked to ensure the temperature was below -23°C. This temperature is necessary to prevent biological activity and chemical breakdown.

2.8 July/August Height Measurements

July/August height measurements were taken at sample sites established during the initial transect survey in May and June. Wooden stakes used during the initial survey were also used in July and August to re-measure heights in order to establish a baseline for future years and also calculate accretion/erosion rates from May to August. The stakes were located using a GPS or visually. The tops of the stakes were cleaned of sediment build-up and a metal pole was laid across the tops of the stakes in the same manner as the initial May/June measurements. The pole was checked to be level, and if it was not this was noted.

As during the initial May/June measurements, three measurements of height from the sediment surface to the bottom of the pole were taken along the metal pole. The three measurements were taken along the metal pole at 65 cm, 75 cm, and 85 cm from the end of the pole located at the sample site centre stake. The depth measurements were collected in-between the stakes in order to accommodate sediment height variability at the sample site. The height measurements were then averaged to determine a future reference for accretion or deposition rates for the estuary during the mid summer, spring freshet period.

In areas of soft sediment where there was the potential for the ruler to sink below the sediment surface or where the sediment surface was not well defined, a 38.5 cm long x 11.5 cm wide x 3.75 mm deep corrugated plastic sheet was laid down and used as a measuring platform to ensure a stable, rigid measuring surface (See Figure 5). If the plastic sheet was not necessary, care was taken to prevent the ruler from moving below the sediment surface. Before taking measurements, the ruler was adjusted so it was vertically level. Net accretion was calculated by subtracting May/June height measurements with July/August height measurements.

2.9 Salinity Sampling and Measurements

Salinity measurements were taken between the middle of July and early August at each sample site established for the 2011 Habitat Survey. Salinity measurements were only taken at sites with surface water available. Some vegetated marsh sites close to the dike did not have surface water and could not be sampled. For transects B,C,F (sites 6-9), E, K, L, M, and N, WIRL-PAC bags were used to collect sample water. Water was collected in surface puddles, water film, or channels and this was noted along with the time of day and weather. Water was collected from the middle or surface of the channel. The bags were folded so that evaporation could not occur and stored in a dark and cool spot. Drops of water were then taken from the bags and poured onto a refractometer to record salinity values. For transects A, D, F (sites 0-5), G, Z, H, I, and J, the refractometer was taken into the field and was dipped directly into water to get a sample for measurement. Samples measured with the refractometer in the field were taken in similar locations to those collected with the bag.

2.10 Eelgrass Survey

Eelgrass percent cover was surveyed along each transect in Sturgeon Bank. A GPS waypoint was collected at the beginning of a transect area with unique eelgrass density extending to west. The area would end at the next waypoint, which marked a new eelgrass density area. Percent cover was based on an overall analysis of an area stretching 20 m to the north and south of the transect. GPS waypoints were collected at 100 percent unit confidence. For areas that contain not only an overall eelgrass density but a pattern of high density patches, the eelgrass percent cover in those patches was also recorded (with the name pool or patch to distinguish the value). In areas where eelgrass density was either lower than three percent or in patches spaced more than 20 m apart, eelgrass percent cover was recorded as trace.

2.11 Vegetation Polygon Validation

The validation of 2006 FREMP Habitat Inventory Vegetation Polygons took place on some high tide days in early July, 2011. An Archer Field PC was connected to a GPS and used for navigation, polygon attribute identification, and for recording information regarding whether the polygon was checked true or false. If the polygon was found to be false, the observed attributes of the polygon were recorded on the Archer. Changes in the size or shape of polygons were recorded on a printed map of the polygons. There were problems with the reliability of this methodology as the Archer froze constantly. A recommended method for validating polygons is discussed in the Recommendations portion of this report.

2.12 Marsh Edge Mapping

Marsh edge mapping took place between late July and early August. The leading edge of the vegetated marsh was mapped using a Trimble TSC1 GPS. The GPS was set to line mode with a point location taken every second. To record the position of a point feature, a point was nested and the position was recorded for 60 sections to assure accuracy. The marsh edge was mapped by walking along the boundary between vegetation and non-vegetated mud or sand flat (See Figure 15). Channels through the vegetation were not mapped and the line was made to be continuous between channel banks. Islands of vegetation were mapped a separate line. Small clumps of vegetation, such as those found on mounds of old marsh, which had become detached from the main marsh were not included unless they were close to the main marsh (See Figure 16). If the clumps of vegetation were close to the main marsh, they were mapped by walking from the main marsh, around the clump and back to the main marsh along the same line without stopping the GPS line tracking (See Figure 13). The marsh at Lulu Island was mapped from south to north so that the marsh was always on the right side of the GPS mapping person. The marsh at Westham Island was mapped from north to south so that the marsh was always on the left side of the GPS mapping person.

Figure 10. The Leading Edge of the Marsh

Figure 11. Footprints Showing the Division of the Leading Edge of the Marsh

Figure 12. *Scirpus americanus* at the Edge of the Vegetated Marsh

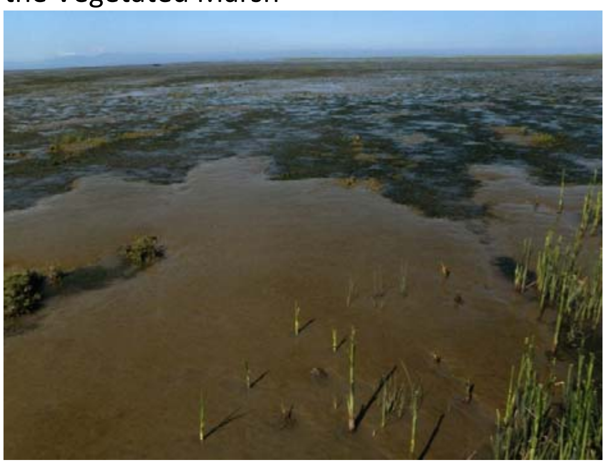


Figure 13. Footprints Showing the Line to Islands of Vegetation

Figure 14. The Hard to Distinguish Marsh edge of *Scirpus americanus*

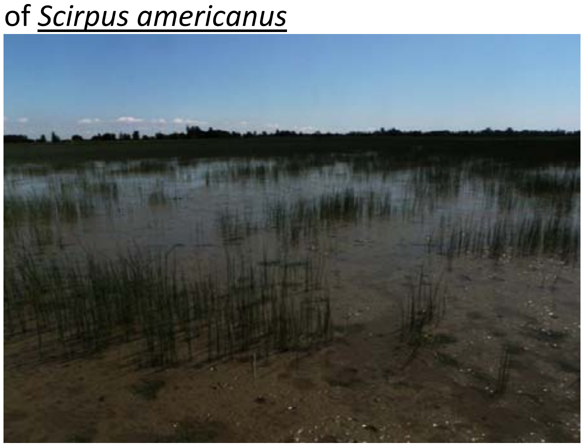


Figure 15. Areas of Non vegetated Mudflat within the Vegetated Marsh

Figure 16. Hummocky Marsh Showing the Extent of the Older Marsh

Figure 17. Hummocky Marsh off of Westham Island

2.13 GIS Analysis

All waypoints from the Garmin GPS were imported to a computer using Garmin BaseCamp version 3.2.1. Waypoints were then saved as a .gpx file with the date of when the data was transferred in the title. The data was then opened using a trial of GPSExpert version 4.30, TopoGrafix Edition and exported as an ArcGIS point shapefile. The shapefile was then added to ArcGIS, version 9.3.1. The Toolbox tool Project was then used to change the projection of the shapefile from WSG 1984 to NAD 1983 UTM 10N. This can also be achieved by transforming the projection in an error box created when the shapefile is added. The “NAD_1983_To_WSG_1984_1” Geographic Trasformation was used when the shapefile projection was changed. Field Data was entered into several spreadsheets using Microsoft Excel and then combined into one master spreadsheet. The master spreadsheet was then joined to the sample site shapefile in order to create a comprehensive attribute table. Many different shapefiles were created from the master shapefile in order to show correct data values for each parameter.

The Geostatistical Analyst 9.3 extension was added to ArcGIS, as a 30 day trial, in order to extrapolate point values over a spatial distance. Before a geostatistical model was applied to a point shapefile, the data was first analyzed using the Geostatistical Analyst.

A Histogram and Normal QQPlot were created for each shapefile in order to determine if the data was normally distributed. If the data was not normally distributed and could not be transformed using the Geostatistical Analyst, then it was rejected. The Geostatistical Analyst was also used to analyze if any trends were present in the data set. If trends were present, the analysis settings were adjusted to accommodate the number of trends found. If a data set was normally distributed, then the Ordinary Kriging Prediction Module was used to create a spatial representation of the data. Before the analysis was started, the data was also checked that it matched the Kriging assumption of autocorrelation (values near by are more similar than those farther apart) through the use of a Semivariogram. The covariance graph was not used to interpret if this assumption was appropriate, as covariance is assumed to be already known as a covariance function. A different model was applied if data values (at any lag distance) did not match the proper trend required to prove autocorrelation in the Semivariogram. In order to accommodate for unseen spatial trends, anisotrophy was turned on in the analysis settings. The number of neighbours was changed several times until the lowest amount of error was achieved between predicted and actual values through cross-validation. Some analyses were smoothed either to allow the analysis to rely more on neighbours than local data or for visual appeal. Before the analysis was finalized, the error graph of error versus measured values and QQplot of standardized error versus normal values were checked for correct trends.

Once the analysis was complete, the new raster layer was changed so its extent covered the entire study area. The layer was then exported as a vector shapefile with filled contours. A new polygon was created, outlining the extent of the Fraser River Delta covered by the project. The spatial analysis vector file was then clipped using the outline polygon in order to reduce the amount of error outside of the transects. A standard error plot was created from one original raster file and compared to its clipped vector counterpart in order to ensure the clipped area only included areas with low standard error.

3. Results

3.1 Tabular Data and Statistics

Table 1. Measured Salinity, Bivalve Tube Density, Sediment Accretion, and Calculated Sediment Grain Size for each Sample Site

Sample Site	Salinity (/ppt*)	Bivalve Tube Density (/m^2)	Sediment Accretion May/June to July (/cm)	Sediment Grain Size		
				% Sand	% Silt	% Clay
A1	22		0.1	79.4	18.0	2.5
A2	21		-0.6			
A3	21		-0.7	94.5	4.4	1.1
A4	20		-0.5			
A5	21		-0.3			
B1	12	trace	-0.1			
B2	15	trace	-4.3	51.5	41.9	6.5
B3	12	trace	-1.0			
B4	11	trace	-0.5	42.5	50.2	7.2
B5	12	22	1.1			
B6	10	22	0.8	53.6	39.5	6.9
B7	10	10	1.3			
B8	10	10		71.3	28.7	0.0
B9	10	12				
B10	11	15		74.7	21.9	3.4
C1	8	trace	0.2	3.1	89.6	7.3
C2	8	0	-0.1			
C3	8	0	0.6	7.6	74.7	17.7
C4		trace	0.1			
C5	7	trace	-0.2	40.2	53.7	6.1
C6	7	trace	0.4			
C7	8	trace	0.5	66.8	28.4	4.9
C8	8	trace	0.0			
C9	8	10	-0.2	72.6	17.6	9.9
C10	9	11				
D0		0				
D1		0	-0.5			
D2	0	0	0.1			
D3	1	0	1.6			
D4	2	0	0.2	52.4	41.9	5.7
D5	0	trace	-1.2			
D6	2	3	0.2	88.8	9.2	2.0
D7	8	3	1.1			
D8	1	5	-0.9	85.5	11.4	3.0
D9	2	7	0.1			
F0		0				
F1	0	0	-0.5			

F2	0	0	0.6				
F3	0	0	1.2		24.3	67.0	8.6
F4	0	0	-0.2				
F5		0			36.2	63.8	0.0
F6		0					
F7	0	0			56.6	37.5	6.0
F8	0	0					
F9	0	trace			94.3	4.7	0.9
E1	2	0	0.4				
E2	2	0	1.7		20.5	70.4	9.1
E3	2	0	0.8				
E4	1	0	0.6		13.0	69.8	17.2
E5	1	0	-1.4				
E6	1	0	0.7		31.5	56.5	11.9
E7	1	0	-1.1				
E8	0	trace	0.1		46.1	53.9	0.0
E9	0	0	-2.9				
E10	0	0	-1.8		67.9	30.8	1.3
G1	0	0	-0.2				
G2	0	0	0.2		7.6	92.4	0.0
G3	0	0	0.1				
G4	0	0	0.1		7.6	80.9	11.5
Z1		0	-0.3				
Z2		0	0.3		14.3	85.7	0.0
Z3	2	0	0.6				
Z4	2	0	0.1		6.1	93.9	0.0
Z5	4	5	1.0				
Z6	2	5	0.8		9.4	78.9	11.7
H1		0	-0.5		38.3	61.7	0.0
H2	4	0	0.3		11.4	86.1	2.6
H3	4	0	-0.4		9.3	78.4	12.3
H4	5	0	0.4				
H5	4	0	0.1		27.4	60.0	12.6
H6	4	trace	0.0				
H7	4	14	0.2		31.5	59.3	9.2
H8	5	11	-0.5		86.0	3.9	10.1
H9	4	0	0.9				
I1			-0.6				
I2	2		-0.4		14.0	74.7	11.5
I3	4		1.9				
I4	4		-0.1		60.3	33.5	6.2
I5	4		-0.1				
I6	4		-0.3		93.1	5.7	1.1
I7	4		0.8				
I8	4	trace	0.2		97.6	2.1	0.3
I9	4	0	0.9		96.1	3.5	0.4
I10	4	0	0.5		89.0	9.0	2.1
J1		0	0.1		45.4	46.9	7.7
J2	4	0	3.0				

J3	4	trace	-0.7				
J4	2		-0.2				
J5	4		-0.2		86.6	13.4	0.0
J6	2	5	0.1				
J7	2	5	1.4				
J8	4	5	-3.3				
J9	4	5	-1.4				
K0		0	-1.7				
K1		0	0.0				
K2	3	0	-0.3		28.7	62.4	8.9
K3	4	0	0.7		57.2	38.4	0.0
K4	4	0	0.0		64.2	30.5	5.3
K5	4	trace	-0.1				
K6	4	0	0.2		61.7	33.3	5.0
K7	4	0	-1.3				
K8	4	0	-2.1		94.6	5.0	0.4
K9	5	0	4.8				
L0	2	0	0.5				
L1	0	0	1.4		7.3	81.1	11.6
L2	2	0	-0.3				
L3	2	0	0.0		22.6	67.6	9.8
L4	3	15	-0.1				
L5	3	25	0.0		27.6	61.9	10.5
L6	3	45	0.4				
L7	3	20	-0.3		67.7	26.7	5.6
L8	4	15	-0.6		81.4	15.7	2.9
L9	2	15	0.3		78.0	18.3	3.7
M1	5	0	1.4				
M2	6	0	-3.9		15.9	74.5	9.7
M3	6	0	0.6				
M4	5	0	0.1		34.4	54.8	10.8
M5	6	0	0.1				
M6	6	0	0.3		44.2	55.8	0.0
M7	6	0	0.5				
M8	6	trace	0.0		74.4	20.4	5.2
M9	5	0	-1.8				
M10	6	trace	1.3		88.5	9.4	2.2
N1	9		0.3		17.7	71.7	10.6
N2	9		-0.1		37.1	57.5	5.4
N3	9	trace	-4.2				
N4	9	0	-4.1				
N5	10	trace	-1.8		35.1	60.6	4.3
N6	10	5	0.2				
N7	10	6	-0.8		76.2	20.9	2.8
N8	10	trace	-0.6				
N9	11	10	-0.2		91.1	7.3	1.6
N10	12	6	0.5				

***ppt = parts per thousand**

Table 2. Mean, Median, Standard Deviation, and Variance Statistics for Salinity, Bivalve Density, Sediment Accretion, and Grain Size Measurements

Statistic	Salinity (/ppt*)	Bivalve Tube Density ($/m^2$)	Sediment Accretion May/June to July (/cm)	Sediment Grain Size		
				% Sand	% Silt	% Clay
Mean	5.3	3.1	-0.1	50.2	44.2	5.5
Median	4.0	0.0	0.1	48.8	44.4	5.3
Standard Deviation	4.8	6.6	1.2	30.1	27.7	4.6
Variance	23.2	43.7	1.5	906.9	770.0	21.4

3.2 Limitations and Challenges

Table 3. Data Limitations and Challenges for Each Parameter

Parameter	Limitation and Challenges
Salinity	• Differences in weather between sampling days and the corresponding effect on evaporation rates. • Unusual freshwater input from flooding and the Fraser River freshet. • Salinity sample residue found in the storage bag. This means one or more sample bags leaked and may have mixed together. • Evaporation of salinity samples on the refractometer (only after a given period of time). • Differences in tide conditions between sampling days.
Sediment Grain Size	• Cross-contamination in Sedigraph of coarse grains from previous samples (only a small limitation, as the system can be rinsed several times). • Differences in Sedigraph X-ray intensity between sample analysis (adds ± 2% as confidence interval).
Marsh Edge Mapping	• Boundary between bulrush and mudflat is hard to determine in some areas where vegetation is thin
Sediment Accretion and Erosion	• Thick detritus and root layer in marsh makes it hard to collect height measurements (adds ± 2 cm as confidence interval for marsh accretion values). • Sediment displacement from the use of the plastic sheet (adds ± 0.2 cm as confidence interval for sites where a plastic sheet was used). • Once the ruler became rusty it became more difficult to collect correct height measurements.

	• Sites B-10, B-9, and C-9 would push stakes up when they were being banged into the sediment. • Some sites are missing field data explaining if the stakes were level and if they were checked. • Due to tide conditions, dense vegetation, and hidden stakes some accretion data was not collected at sample sites.
Bivalve Density	• Tube identification was challenging. Small tubes were ignored.
Eelgrass Percent Cover	• The survey was an overall estimate and did not include the large amount of small scale variation that was observed.
Benthic Invertebrates	• Only microfuna was collected. • Storage temperatures may have caused organisms to burst
Biofilm	• A small potion of the Biofilm sample might have been lost during water decantation • At some sites Biofilm was present, but not sampled due to high Biofilm variability within the sampling area.

3.3 GIS Maps

Figure 18. Sample Site Locations and Numbers at Sturgeon Bank

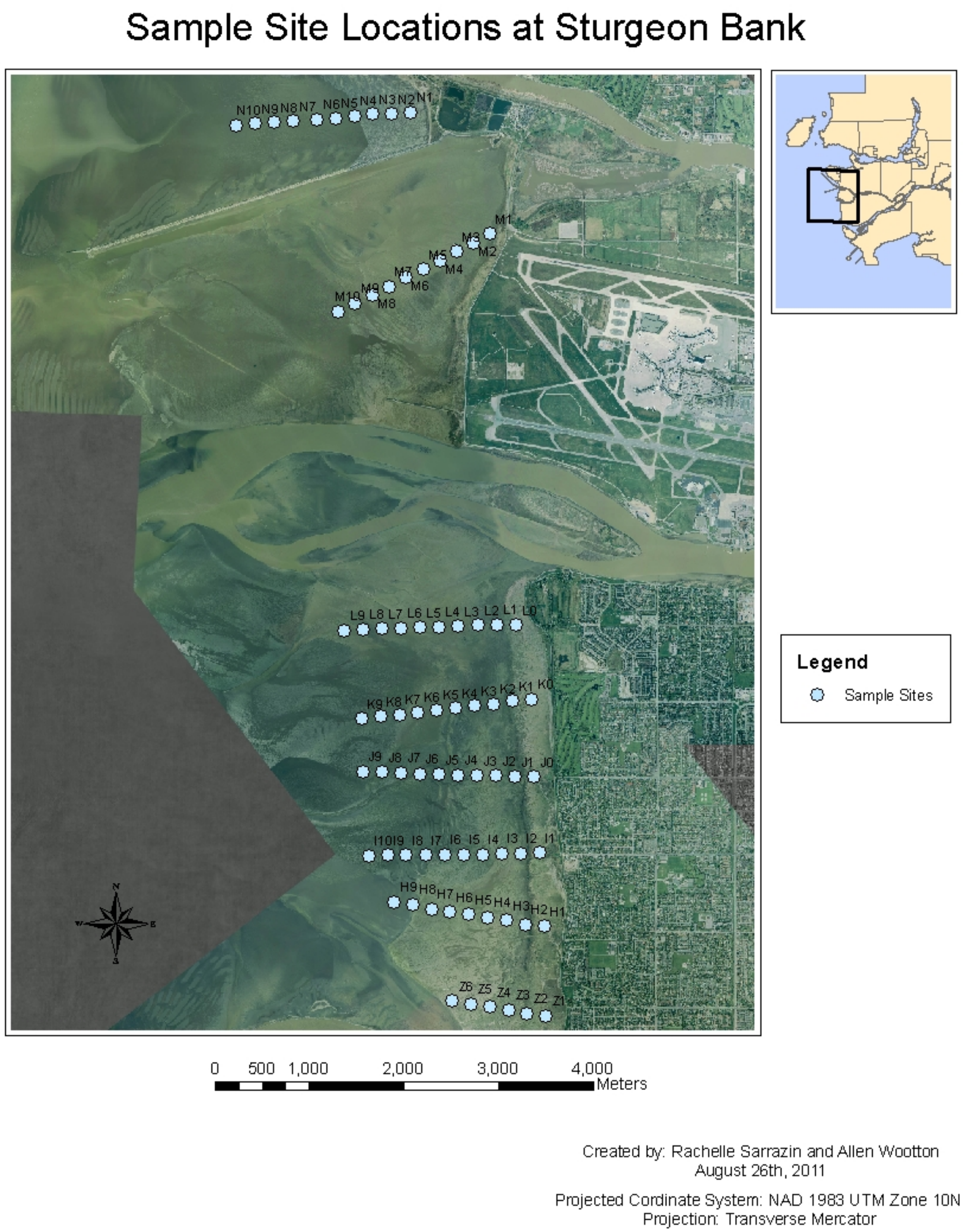


Figure 19. Sample Site Locations and Numbers at Roberts Bank

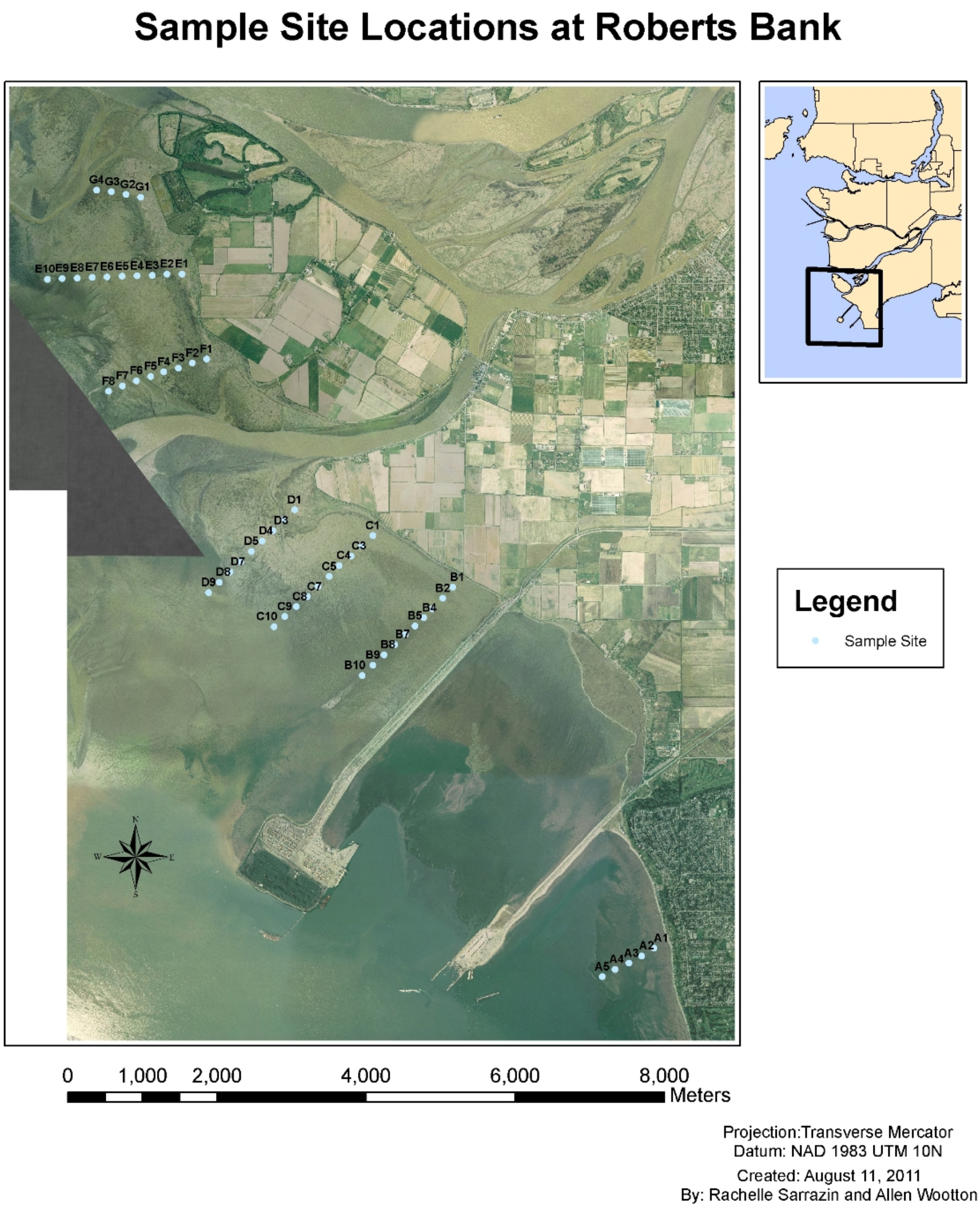


Figure 20. Bivalve Density over Region and at Sample Sites in Roberts Bank

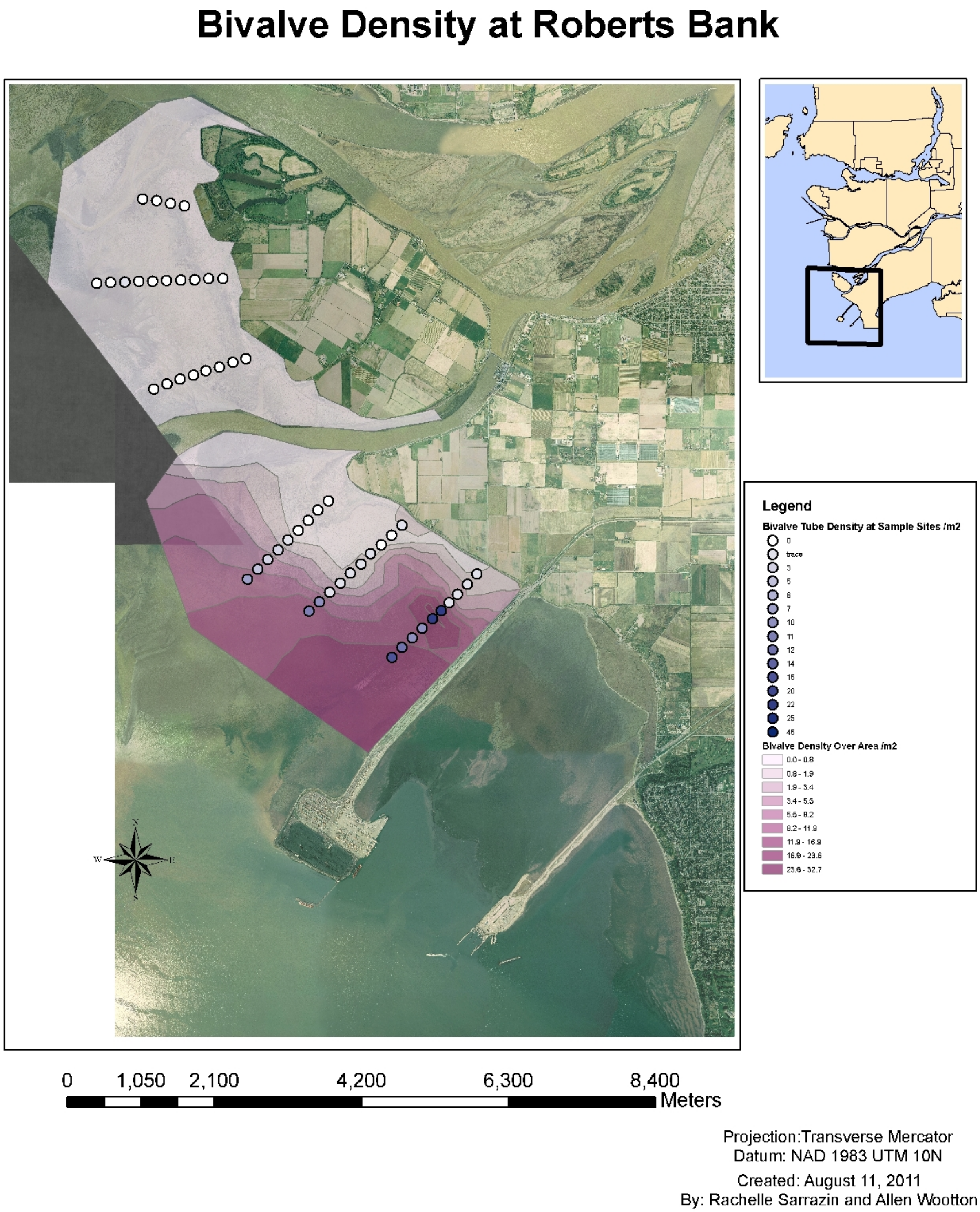


Figure 21. Bivalve Density over Region and at Sample Sites in Sturgeon Bank

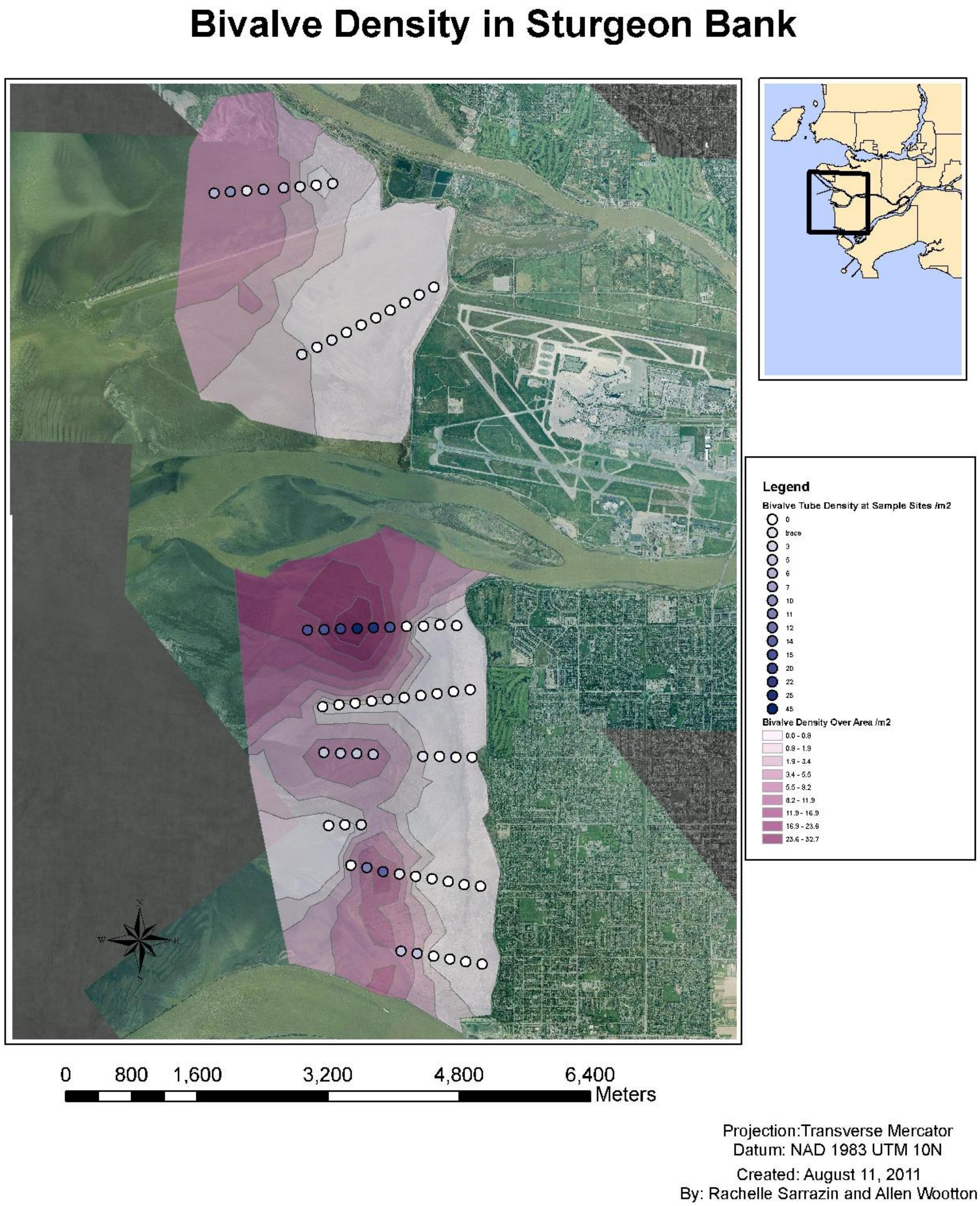


Figure 22. Eelgrass Percent Cover over Region and at Sample Sites in Sturgeon Bank

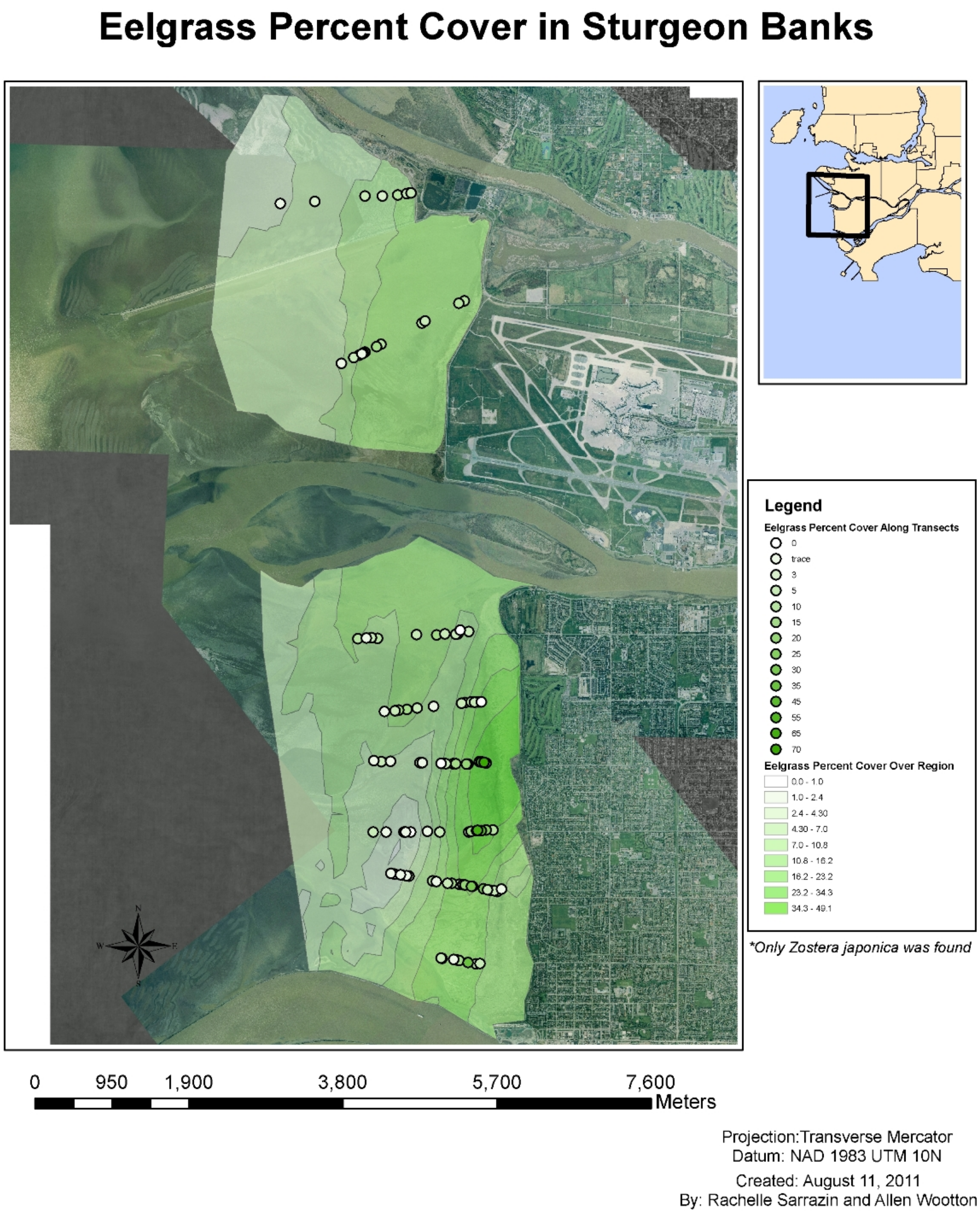


Figure 23. Salinity over Region and at Sample Sites at Roberts Bank

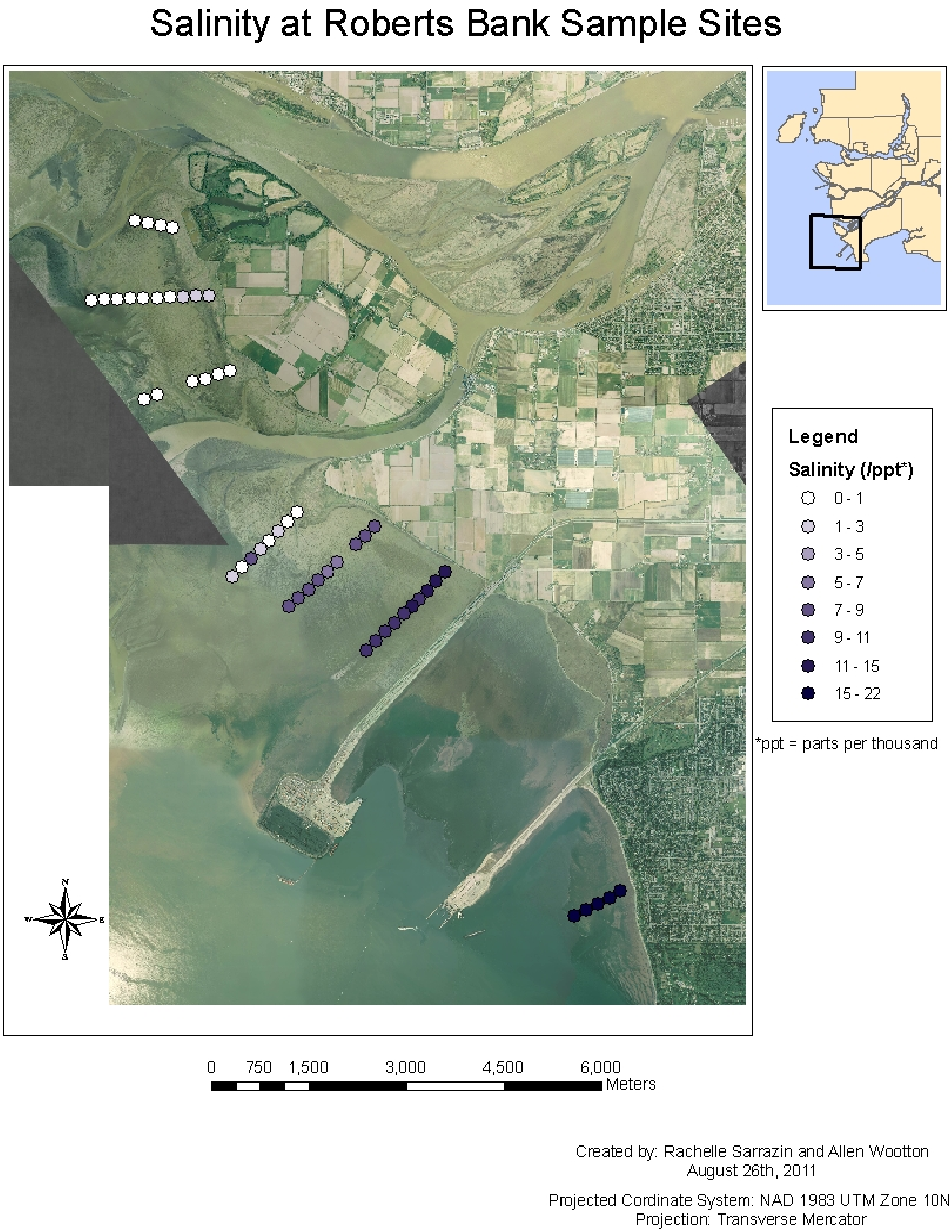


Figure 24. Salinity at Sample Sites and over Region at Sturgeon Bank

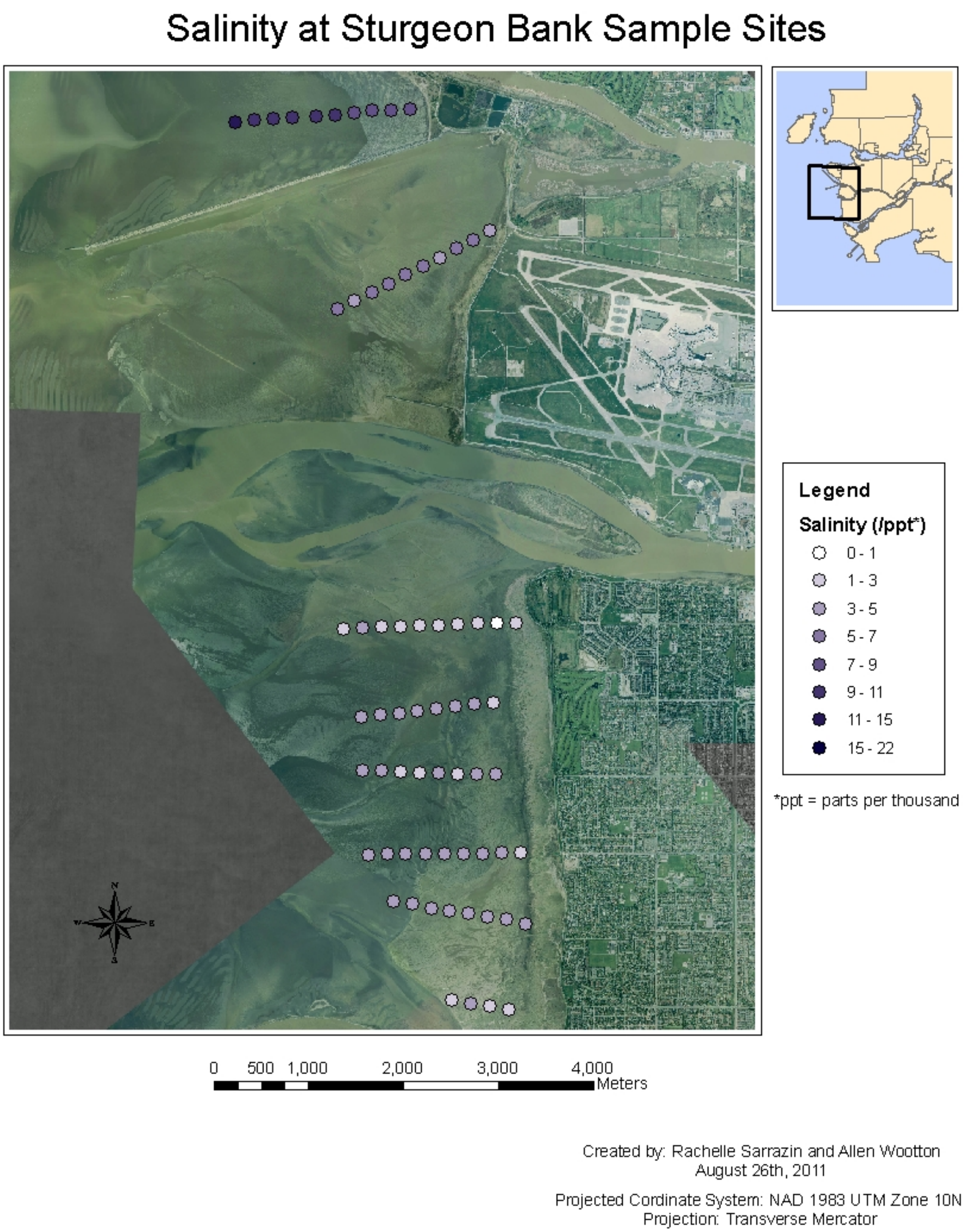


Figure 25. Sediment Accretion at Roberts Bank Sample Sites

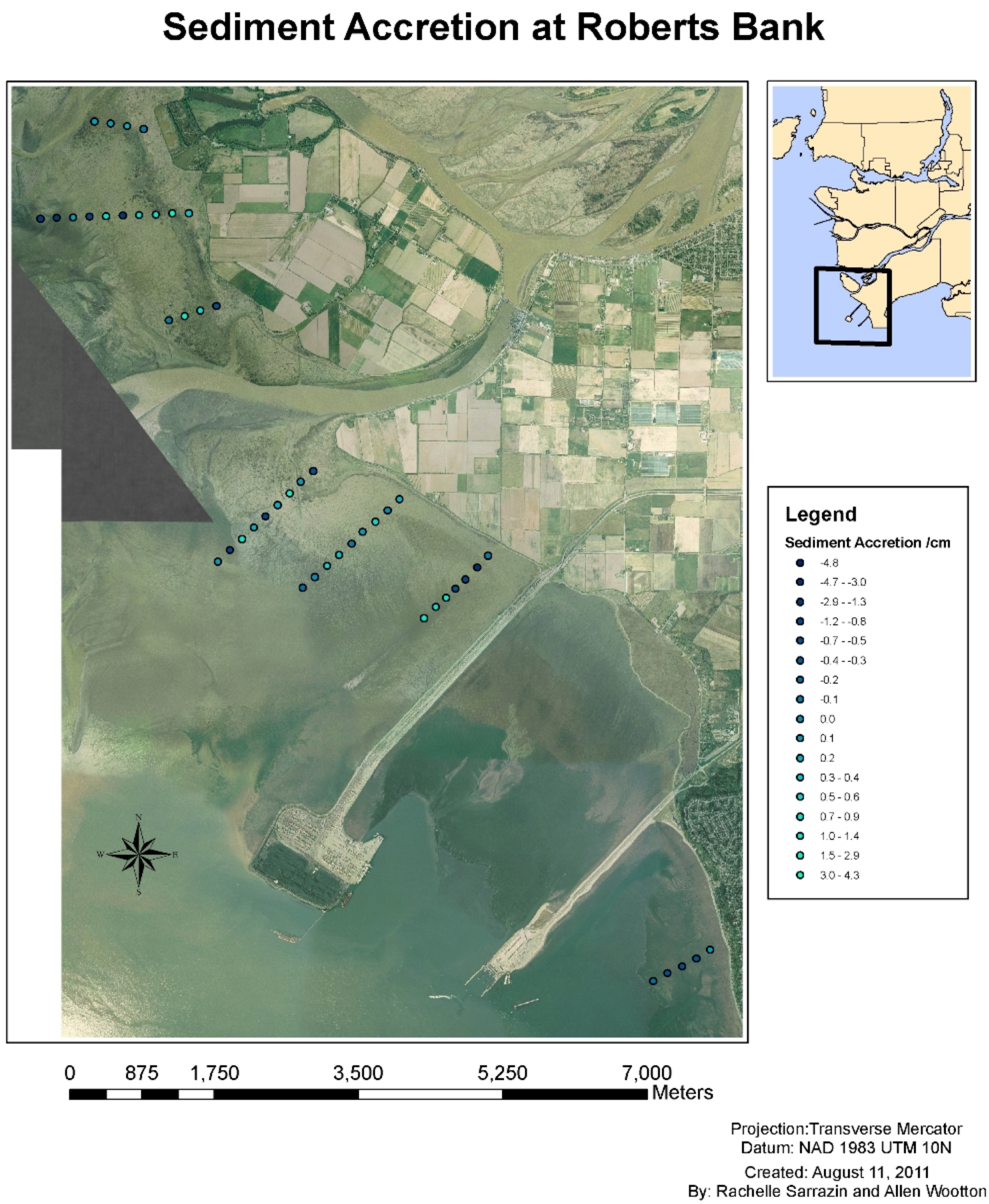


Figure 26. Sediment Accretion at Sturgeon Bank Sample Sites

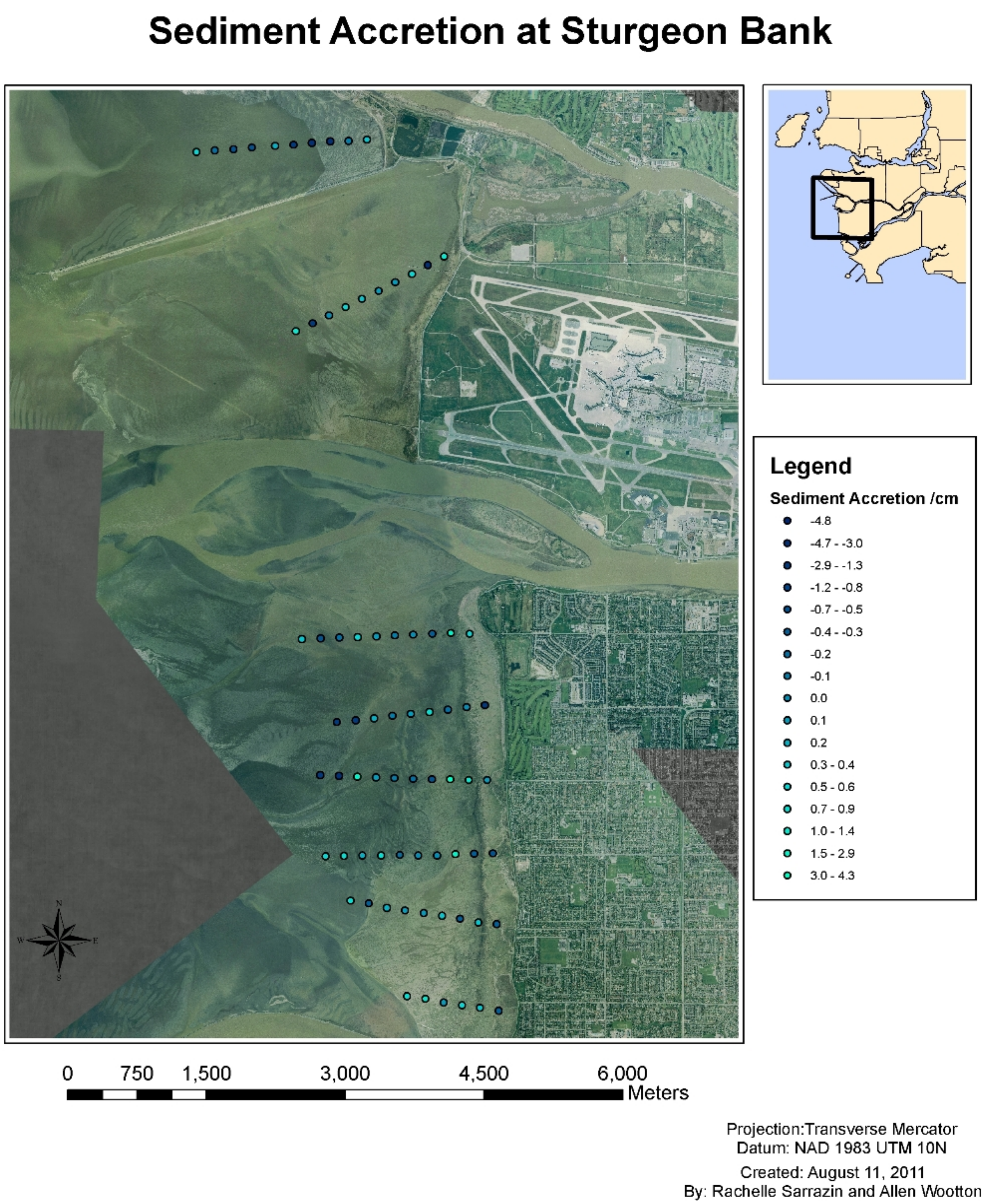


Figure 27. Sand Percentage at Sample Sites and over Region at Roberts Bank

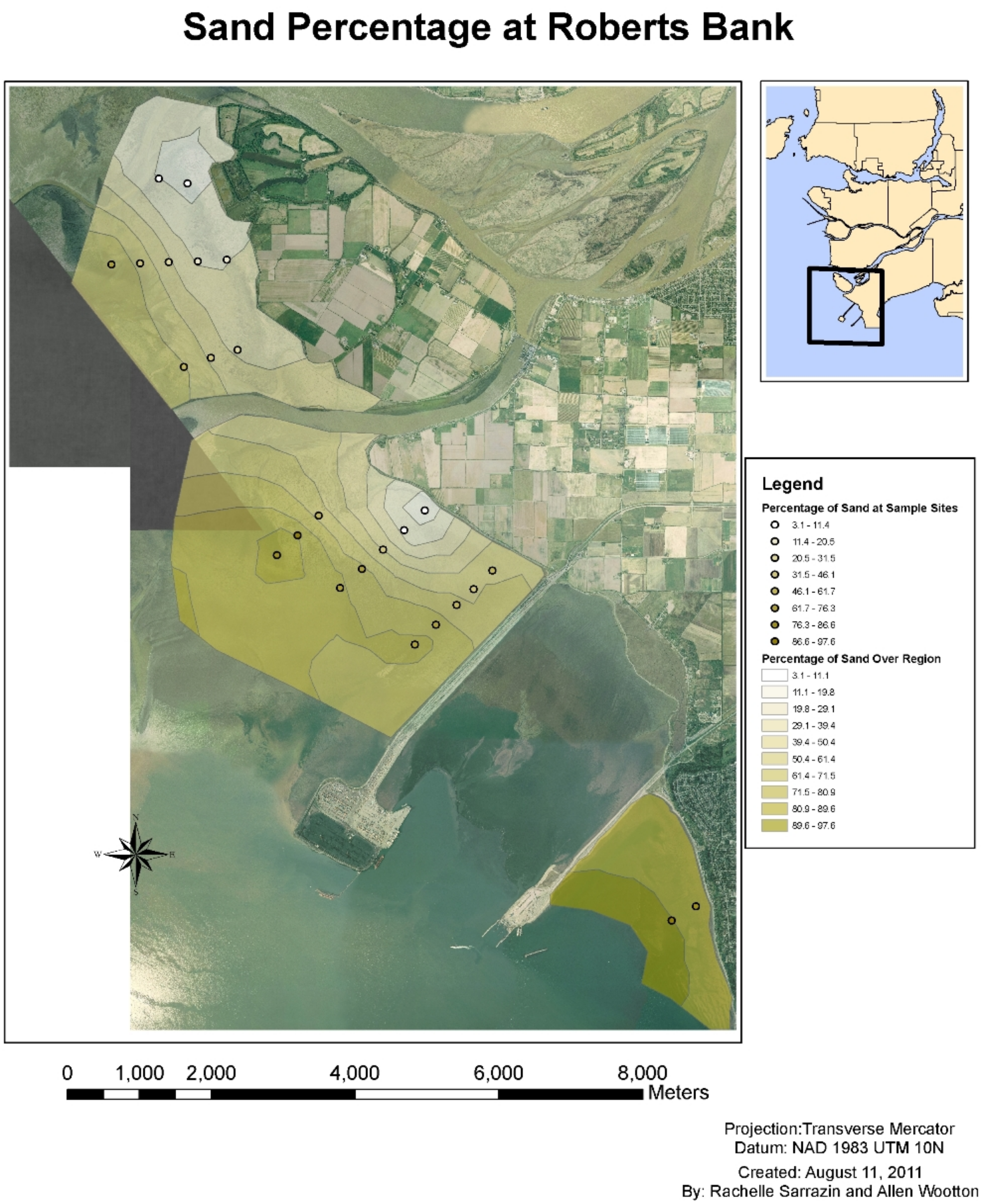


Figure 28. Sand Percentage at Sample Sites and over Region at Sturgeon Bank

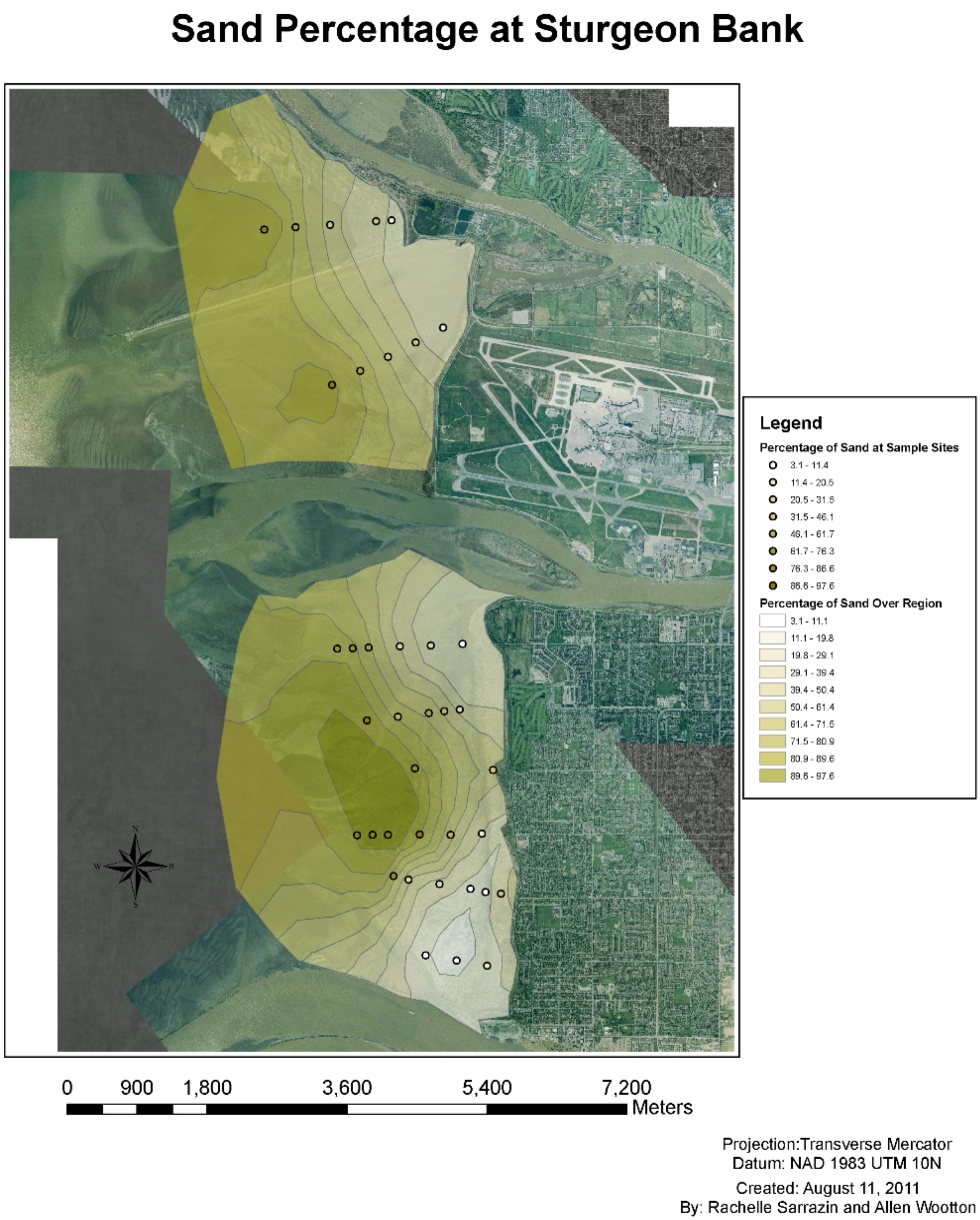


Figure 29. Silt Percentage at Sample Sites and over Region at Roberts Bank

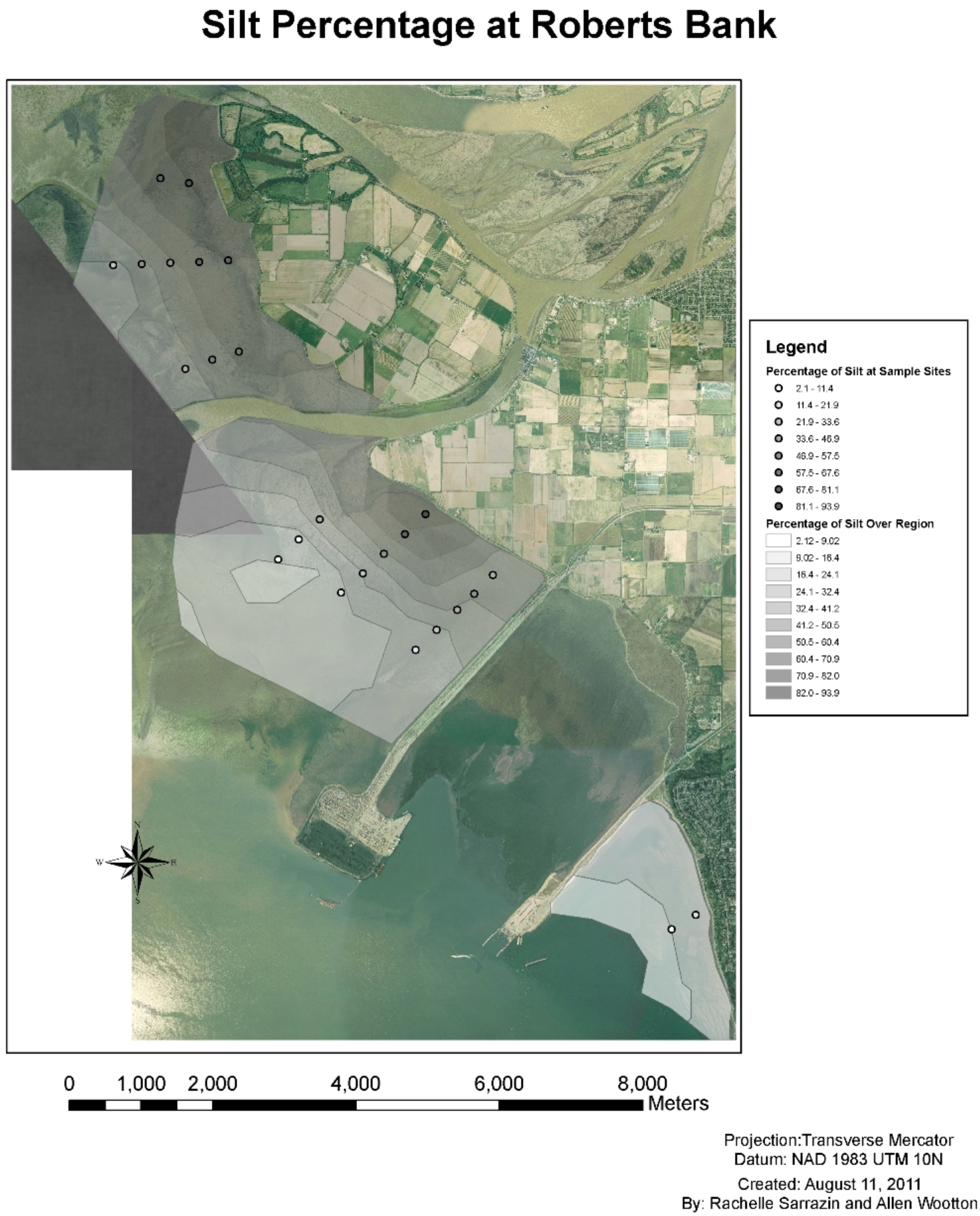


Figure 30. Silt Percentage at Sample Sites and over Region at Sturgeon Bank

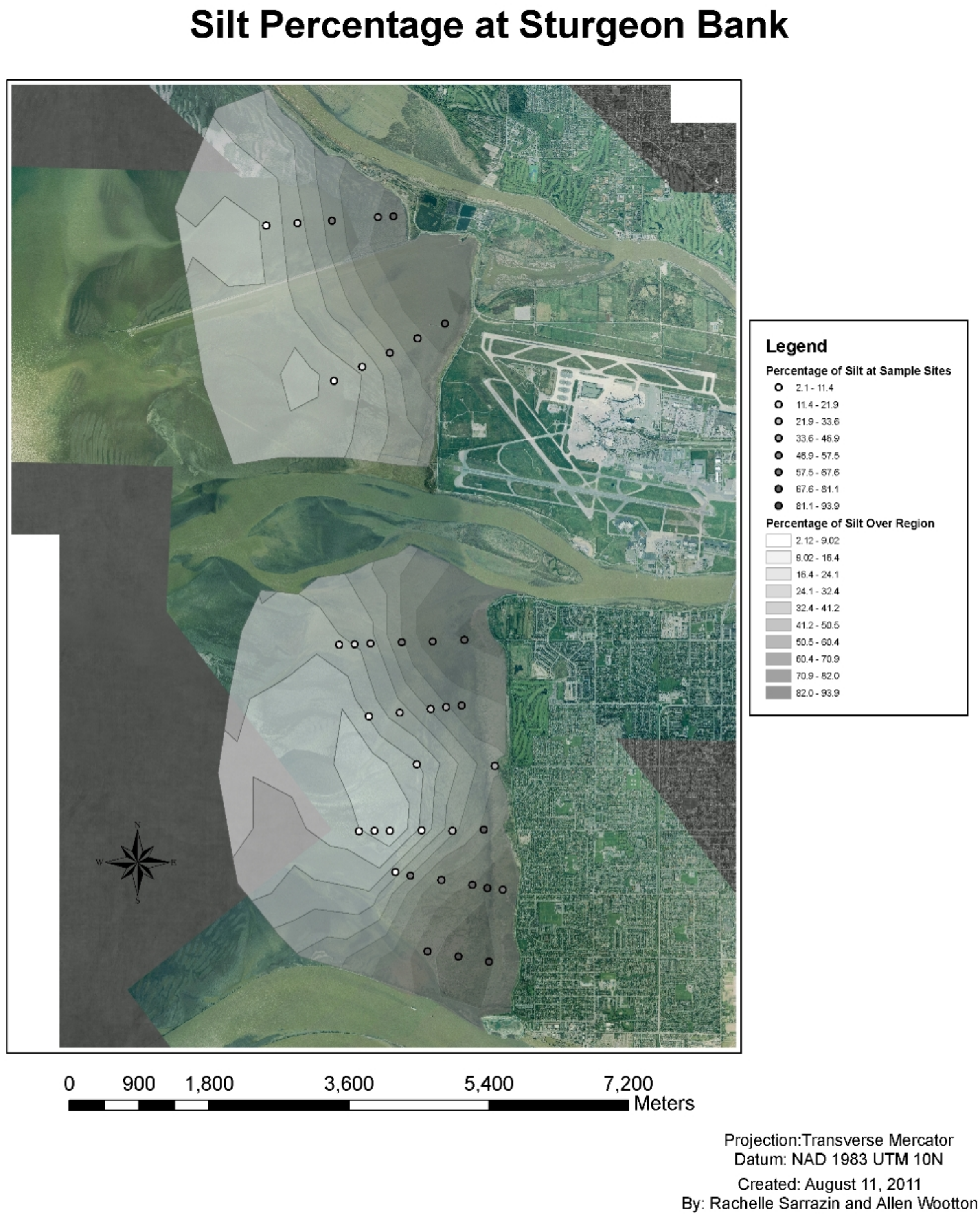


Figure 31. Clay Percentage at Sample Sites and over Region at Roberts Bank

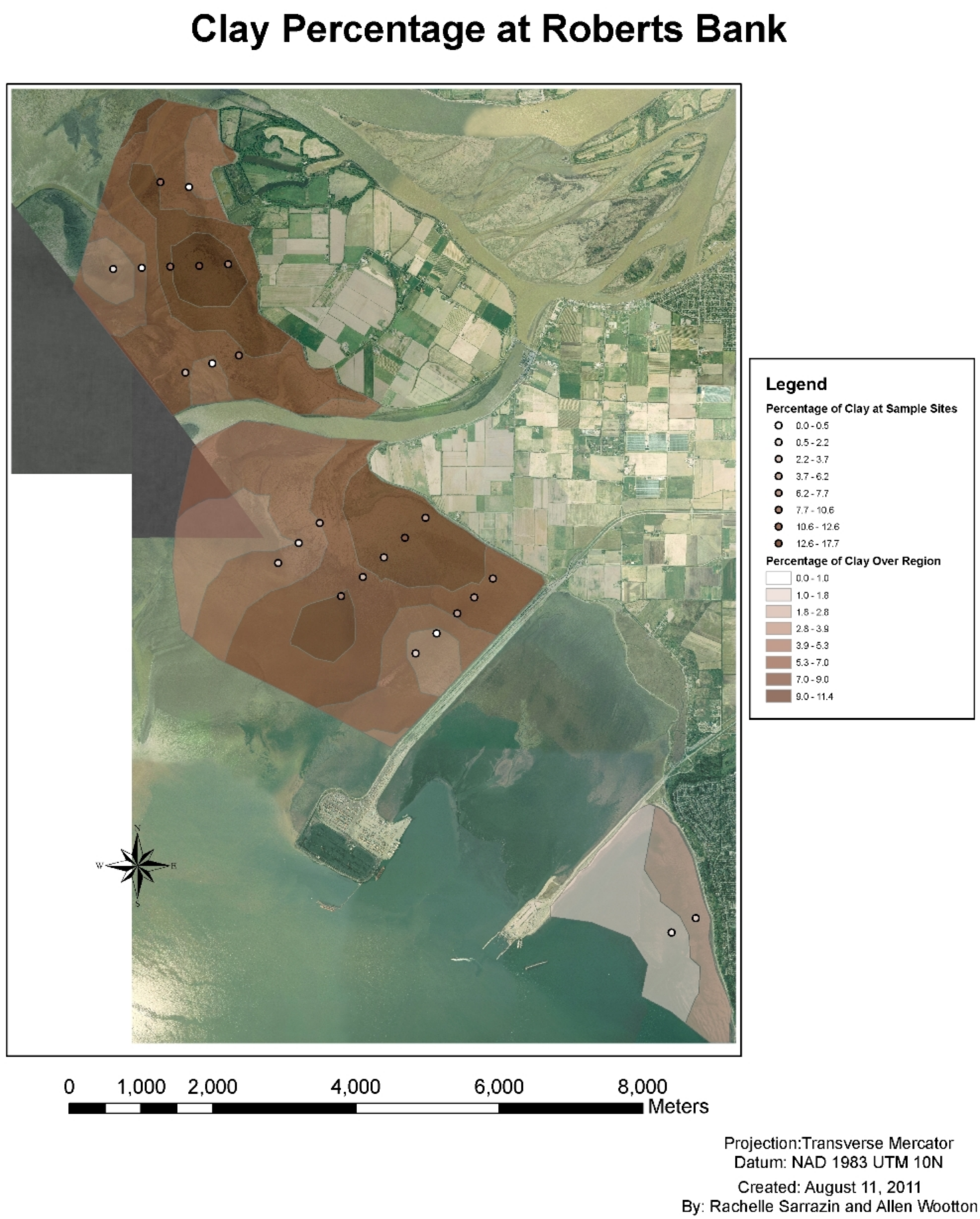
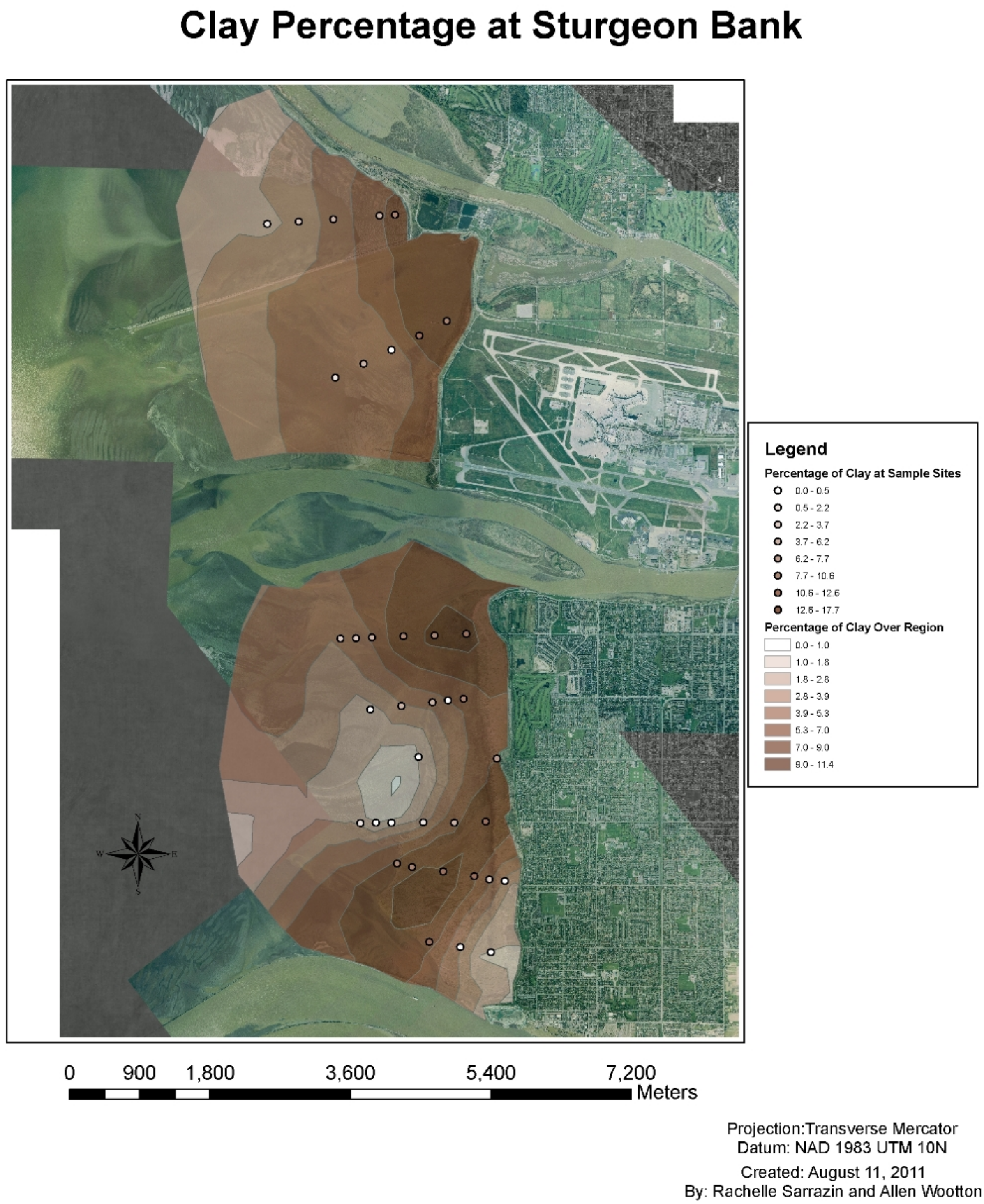


Figure 32. Clay Percentage at Sample Sites and over Region at Sturgeon Bank



4. Discussion

Salinity

The results of salinity measurements varied greatly between some sample site transects depending on geographic location. Variation of salinity levels was low between sample sites along the same transect for the most part except in some cases of single sample sites with a high variation from the mean.

Salinity measurements taken at transect A in Tsawwassen showed the highest values ranging from 20 to 22 ppt (See Table 1). This transect was furthest from the freshwater influence of the Fraser River of all the transects and river currents have been further blocked from reaching this area by the Deltaport causeway and the Tsawwassen Ferry Terminal. Tidal currents flow into the Tsawwassen Beach shore from the southwest off of major currents from the southeast (Stronach and Zaremba). These currents originate from a location which is not heavily influenced by the freshwater conditions of the Fraser River.

The 3 Delta transects between the Deltaport causeway and Brunswick Point showed a trend of salinity values decreasing towards the influence of the river. Transect B, closest to the causeway showed values ranging from 10 to 15 ppt, transect C in the middle showed values ranging from 7 to 9 ppt, and transect D at Brunswick point showed values ranging from 0 to 8 ppt although if not counting site D8, the values range from 0 to 2 ppt (See Table 1).

The Westham Island transects had very low salinity results. Transects F and G, the transects to the north and south of transect E and closest to the influence of the river, showed salinity values of 0 at all sample sites. These area are therefore completely under the influence of the fresh water from the river at the time of sampling (mid to late July). Transect E, located in the middle of the Westham Island coast and furthest from the islands river channels, had slightly higher salinity values ranging from 0 to 2 ppt. The higher values of 2 ppt were recorded in the marsh and values of 0 ppt were recorded at the far end of the transect (away from the shore).

All the Richmond transects off of Lulu Island showed similar levels of salinity. The salinity values measured in this area ranged from 0 to 5 ppt. The values between sample sites at each transect did not vary significantly or show a trend. The 2 Sea Island Transects M and N showed higher salinity values. Transect M, south of the Iona sewage outfall, showed values ranging from 5 to 6 ppt. Transect N, north of the outfall, showed values ranging from 9 to 12 ppt. The influence of the river is less at this transect because of the sewage outfall, therefore the salinity values are higher.

When comparing 2011 Lulu Island salinity results with results taken in the same locations at the same time in 1981, some similar trends are noted. Samples taken at transects K and L on the 11th of July correspond well with values recorded in 1981 at the same time in the same sites (Boyd, 1983). Salinity results at transects Z, H, I, and J taken between July 28 and July 29 are in some cases quite different. For example site J3 shows a value in 2011 of 4 ppt, and in 1981 of 13 ppt (Boyd, 1983). This difference between values could be attributed to the later freshet in 2011 which has resulted in lower salinity values later in the year. The same site 2 weeks earlier in 1981 had a value of 7 ppt (Boyd, 1983), closer to the value measured in 2011.

Weather and date of collection may have influenced the results of salinity measurements. For example, more surface water evaporation will occur on a hot, sunny day than on a cool cloudy day. Greater evaporation rates may lead to higher salinity values as the salinity becomes more concentrated. Most sampling days were sunny or overcast but warm. Transects B and C were sampled on a cooler overcast day. Flooding occurred upriver in the Fraser during July 2011. Increased fresh water levels entering the estuary because of the flooding may have influenced the results and lowered the observed salinity values. Another possible source of error involved the possible mixing of samples in bags, as a small volume from one or more of the WHIRL-PAC bags may have leaked. Mixing is unlikely due to the fact each WHIRL-PAC bag remained upright at all times. Other sources of error include the evaporation of sample water while placed on the refractometer, and tidal conditions. Evaporation on the refractometer can be prevented by reading measurements quickly, once the sample has been collected. Variation based on tidal conditions can be minimized by collecting samples on consistent tidal conditions. Some sites such as transect A in Tsawwassen were always covered in water and some were samples after the tide had been out for hours. There will have been more evaporation in pools in this case and this could affect salinity values.

Sediment Grain Size

Sediment samples have been analyzed and grouped into the categories % sand (defined as >0.063 mm), % silt (0.002-0.063 mm), and % clay (<0.002 mm). Other studies in the same area have defined the divisions as medium (>0.250 mm), fine (0.125-0.250 mm), and very fine sand (0.063-0.125 mm), silt (0.004-0.063 mm), and clay (<0.004 mm) (Hales 2000). To compare 2011 sediment grain size results with other studies adjustments can be made based on the raw data from the sedigraph analysis and sieved sediments. The methodology for the sediment grain size analysis portion of the doctoral thesis, *The Impact of Human Activity on Deltaic Sedimentation, Marshes of the Fraser River Delta, British Columbia* written by Wendy Hales, involved splitting a sediment core into 2 cm intervals (Hales, 2000. p. 72). Samples were measured for organic content using the loss of ignition approach (LOI) (Hales, 2000. p. 71). This method differed from the one used in the RSB Habitat Inventory because the Habitat Inventory method used entire 12.5 cm core was mixed and a sample has analyzed from that mixture. Also, organic matter was only removed if it was visible and the samples were not burned during the Habitat Inventory grain size analysis. Core sampling took place at the marsh areas of the mouth of the south arm of the Fraser River around Westham Island, Steveston, and Brunswick Point (Hales, 2000. p. 61). The results from the coastal portion of these areas may be compared with the Habitat Inventory at sample sites Z1, G1, E1, F1, and D1.

The results of grain size analysis showed the same trend of higher sand composition further out from the shore for all of the transects. Sediment samples taken from sample sites located within vegetated marsh areas and/or located closer to the Fraser River contained lower sand compositions and higher silt and clay compositions (See Table 1). Areas within the vegetated marsh have lower tidal energy input due to the turbulence caused by the presence of vegetation and unsmooth surfaces. Therefore these areas have more silt and clay deposition and less erosion than more open areas further out along the transects. The river also deposits sediments carried from upstream sources at its mouth and these fine sediments are deposited at sample sites located close to the mouth of the river. The sites with the highest clay values (sites C-3 at 17.7%, and E-4 at 17.2%) were located in the low energy current areas at the shore of the marsh away from strong tidal and river influences (See Table 1). Stronger directional currents moving from the Strait of Juan de Fuca greatly influence transect A located off of Tsawwassen Beach (Stronach and Zaremba). The strong forces from this current create an environment where finer sediments are eroded and only coarser sediments remain. This is also an area without a vegetated marsh. As the current moves northward it has its most influence on those sample sites further out on Sturgeon and Roberts Banks. These are also areas with higher sand and lower silt and clay content (See Table 1).

A source of error when calculating grain size may have been cross contamination of coarse fraction sediments within the sedigraph. This error was greatly reduced by taking such precautions as rinsing the machine multiple times to clean it. The results of % sand, silt, and clay analyzed with the sedigraph can be considered to be within 2% accuracy based on the x-ray intensity of the machine. The sedigraph manual suggested an intensity between 13% and 70% and all samples maintained intensity readings in-between this range. The sedigraph operating instructions suggested a more stringent intensity range between 60% and 70%, which only a few samples fell slightly below.

Samples that fell below the 60% intensity boundary resulted in sediment grain size composition percentages that were either 2% greater or less than correctly analyzed samples. Therefore, X-ray intensity was achieved at an acceptable range for all samples.

Marsh Edge Mapping

The map created from walking the leading edge of the vegetated marsh and vegetated islands can be compared in the future with new maps created using the same mapping method that was used in 2011. Information included in the 2011 Habitat Survey and data gathered in future years can be used to possibly explain the changes occurring over time. Accretion/erosion measurements taken in the marsh will show changes in relative elevation over time. This will be important when compared to sea level rise to see if certain areas of the marsh will eventually become submerged at all times. Sediment grain size analysis will show patterns over the tidal flats and changes over the years. This will be useful when analyzing changes to the marsh. For example, sand flats provide a protective barrier against wave energy which can enter and affect the marsh (Hales, 2000). Tracking changes in sediment grain size over time may be used to explain some of the changes in the marsh.

Some marsh plants are more salt tolerant than others. Changes in salinity results recorded over time can be useful to assess the susceptibility of plants to changes in salinity and in which part of the growing season these changes are occurring at. The results of sediment grain size analysis will provide useful information on the growing conditions of the marsh over time. Sample sites along the transects which were within the vegetated marsh had much higher silt and clay contents and lower sand contents than found at non vegetated sample sites.

The GPS is considered accurate to within 1 metre. There may also be up to 1.5 metres uncertainty in some areas of sparse vegetation where the marsh edge is unclear, hummocky, and or spotty.

Sediment Accretion and Erosion

Rates of accretion across a marsh habitat are not uniform. Data collected off of Westham Island shows a 400 m wide band of accretion located 400 m away from the dyke in a knobby, eroded marsh (See Figure 17). Factors controlling marsh accretion rates are vegetation cover, concentration of sediment, the distance from the source of sediment, as well as time of inundation and local elevation (Friedrichs and Perry, 2001). It is likely that the band of accretion off of Westham Island was created by its close proximity to the Fraser River and dense vegetation cover. Although many other areas in the project area are exposed to the same influences of river sediments and tides, it is likely that Westham Island maintained the band of accretion due its large and dense marsh. As vegetation surface area increases, with increased vegetation density, friction in tidal currents increases. Increased friction causes reduced water velocity, reducing the ability of moving water to transport and suspend sediment (Boorman et al., 1998).

Westham Island was found to contain many, dense, large mounds of browsed vegetation (See Figure 17). As water flows through these small scale topographic features, it begins to loose energy as it is forced to collide with the mounds. This process also causes reduced water velocity, allowing sediment to be deposited in low lying areas (Boorman et al., 1998). The accretion band off of Westham Island may be the cause for the band of clay rich sediment at the same location (See Figure 25). This would mean that currents entering the area would need to be extremely low in order to deposit clay onto the marsh. Although the location of clay rich sediment is almost exactly at the location of the Westham Island accretion band, it is unlikely that such high clay levels were caused only by accretion in the last two months due to the depth of sample collected.

The band of accretion found near Westham Island is also shown in Environment Canada's report on the Sediment Transport Patterns of Lower Fraser River and Fraser Delta at the same location (McLaren and Tuominen, 1999). The report suggests that the accretion band is caused by ocean currents moving towards the main Fraser River arm that collide with Westham island and bend through the marsh to the south west (McLaren and Tuominen, 1999).

It is important to stress that all sediment accretion measurements made in marsh habitats were very hard to measure. This was due a thick detritus and root layer at the base of vegetation. Therefore, these sediment accretion values have a confidence interval of ± 2 cm. Due to such a poor confidence interval; no conclusions can be made on the different accretion dynamics in marsh habitats between May and August. At sample sites with loosely compacted sediment and where a plastic sheet was used, approximately 2 mm of sediment was found to be displaced. Therefore, sediment accretion values measured at sites where a plastic sheet was used have a confidence interval of ± 0.2 cm.

Another source of error for sediment accretion measurements was the use of a rusty ruler. During measurements, the slider on the ruler would become stuck. In order to dislodge the slider, the ruler would occasionally become indented in the substrate. This error was missed on several occasions. Stakes placed in C-10, B-10 and B-9 sample sites were found to be unstable and would move up once pushed down. Although it is likely this was caused by temporary groundwater pore pressure, stakes at these sample sites are either too high or too low.

Additionally, there were several transects where the stakes were not adjusted to be level with one another. Without knowing if the stakes are level, measurement errors caused by stake position shifting cannot be recorded and adjusted for. This error is minor due to the fact that stakes placed in areas with uneven topography were always leveled (through the entire study region). Additionally, due to the fact that stakes were placed at the same height, it is likely that stakes are level at almost every area with even topography. When transects where revisited in August and July, only the stakes at sample at L-2 were found to be slightly off from level. Therefore, the uncertainty caused by implementing the leveling methodology a quarter way through the transect survey is not high enough for any values to be discarded.

Bivalve Density

Bivalve tube density was observed to spike along the edge of micro-channels throughout the project area. The highest density of bivalve organisms can be found along the edge of large channels, such as along the middle Fraser River arm in Figure 21 and along a wide channel found along the Deltaport causeway in Figure 20. Bivalve species require locations exposed to moving saltwater or freshwater in order to feed, breath, and reproduce (Bird, 2007). Channels along the Fraser River Estuary may provide greater amounts of fresh water, required for bivalve colonization, for longer periods of time.

The distribution of bivalve organisms seems to be substantially different between Brunswick Point and Westham Island (See Figure 21). Bivalve density in Delta seems to increase with distance, whereas bivalve density at Westham Island stays at zero until 1.6 km from the dyke (See Table 1). It is likely this is explained by presence of marsh throughout most of Westham Island transects, which provides poor living conditions for bivalve organisms (such as limited current and high root density in substrate). The distribution of *Malcoma balthica*, the most common species of Bivalve found in the Fraser River Estuary, was found to depend on food availability, tidal height, sediment grain size, and the carbon and nitrogen concentration in the sediment (McGreer, 1971). Overall sediment grain size differs only slightly between Westham Island and Brunswick (See Figure 28). Therefore it is unlikely that sediment grain size is the dominate factor controlling Bivalve Distribution. Point Bivalve measurements were taken only as rough estimates. Only large tubes greater than 4 mm in diameter were measured while smaller tubes were ignored. By ignoring smaller tubes, it is likely that the estimates are too low compared to actual bivalve densities in the region. Unfortunately, there have been limited studies on number and distribution of different bivalve tube sizes in the Fraser River Estuary.

Eelgrass Percent Cover

Eelgrass density in Sturgeon Bank varied greatly over small distances. The large number of different density waypoints located throughout the Lulu Island mudflat reflects a large amount of variation in Eelgrass Density (See Figure 22). The large variability in eelgrass density maybe explained by field observations of higher eelgrass density in low-lying areas and channels. Low-lying areas, such as shallow pools, may provide some shelter from desiccation (drying out during low tide) and explain why *Zostera japonica* prefers these areas (Precision Identification Biological Consultants, 2006). *Zostera marina's* habitat is found in lower intertidal and subtidal areas (Precision Identification Biological Consultants, 2006). Therefore, the observed absence of *Zostera marina* along Sturgeon Bank is expected.

Overall eelgrass density seems to decrease with distance away from the shore (See Figure 22). Due to the fact that *Zostera japonica* prefers soft, sandy or muddy sediment, it could be assumed that sediment compaction may also increase over distance (Precision Identification Biological Consultants, 2006). It is likely that the trend of eelgrass density decreasing with distance is caused by a combination of changes in sediment compaction and transition out of the species' niche. Eelgrass density also seems to decrease in a 500 m wide region, 1.8 km from the shoreline between transects H and I (See Figure 22). The area of low eelgrass density at Lulu Island may be explained by high concentrations of sand at the same location, although it is unknown if the presence of sand indicates high sediment compaction for the region (See Figure 22).

Sample Site Distribution

The variation and spatial distribution of the results of each parameter analyzed shows that the transect location and orientation, and number (15) of transects properly distributed sample sites through the coastal portion of the estuary. These locations properly represented the spatial extent and changes in environmental characteristics of Robert and Sturgeon Banks.

5.0 Recommendations

The 2011 field season involved taking on many projects in a short time period. The field work portion was mainly limited to low tide days which usually occurred every 2nd week. This further limited the amount of time in which field projects could be completed. Most field days ranged between 9 and 11 hours. Each field week was then followed by: sample preparation and lab analysis, spreadsheet data management, GPS data management, equipment and supply collection, research, methods write ups, GIS map creation, and report writing. Therefore it was hard to limit the work week to only 35 hours per week and this should be accounted for with future projects.

The main focus of the season was the transect sample site set up and baseline sample collection. Since this is a baseline study, all samples should be analyzed so future projects can be based on these results. 64 of 131 sediment samples collected have been processed and analyzed and the other samples should be analyzed as well. This will provide a complete set of data so that in future years, if only a selection of sample sites is required, a data set with which to base this on will exist. At the time of this report, none of the biofilm or benthic invertebrate samples had been analyzed. These samples should also be analyzed so that this important biological data can be included within this project.

It is important to have continued guidance from experts in each area of interest throughout the course of the summer. Future projects should be designed according to time and resource availability from each FREMP partner agency and academic institution representative so that training and guidance area sustained throughout the entire project. This will help determine the methods of sample collection, equipment required, and knowledge of sample analysis once the samples have been collected. A working group meeting at the start of the project should take place again to discuss the parameters and goals of the project. Funding associated with analyzing the samples should be secured before making decisions on which samples to collect and the reasons for collecting the samples should be clear before making decisions on projects.

Future Projects

The estuary environment experiences large seasonal variations. It would be useful to base future projects on these changes in seasonal conditions. For these projects, seasonal changes should be well researched and discussed before sampling takes place.

The contract period (May to August) may not be enough time to record the extremes of seasonal variability, as this is the time in which the Fraser River freshet occurs and rapid changes take place. Measurements taken during the freshet at the same dates year to year may be not provide appropriate comparisons as the freshet may be occurring at different times each year. Measurements taken in April, before the freshet, and in September, after the freshet, will be required to properly track changes which occur in the estuary banks over the seasons and these can be compared year to year.

The vegetated marsh and non vegetated mudflats are quite different environments and it may be useful to set up projects which separate research objectives between these different conditions.

The 60cc 2.6 mm diameter syringe works well for benthic invertebrate mieofauna, however a larger 10cm diameter syringe would be required for macroinvertebrates. The sampling method for these larger invertebrates may have to be changed as well as the distribution of macroinvertebrates in a small spatial area within the mudflat is still very variable. There may be a need for more sampling within the sample site to account for the spatial variation.

Sampling for biofilm may also require multiple samples over a sample site to account for the variability that was observed. Another option is to selectively sample for biofilm based on observations during field sampling instead of using random sampling locations so that it is more likely that biofilm will be present where sampled. In many areas with sediment rippling, biofilm was observed at the bottom between ripples but not at the top of the ripple. Future sampling of biofilm may require the 2mm high syringe core to be cut in half horizontally at the time of field sampling so that one part can be sampled for chlorophyll and the other for carbohydrates from mucus. Analysis should be organized before sampling takes place, so storage techniques can be confirmed with the lab. For example the samples collected in the 2011 field season were frozen with dry ice and then placed in a freezer at -23 degrees Celsius. Other options include storing the invertebrate samples in formaldehyde solution. Sampling for bulk density may be another useful sampling project.

If additional funding is available for sample analysis, more replicates should be collected and analyzed. The number of replicates should represent 10% of total number samples (Water, Air and Climate Change Branch, 2003). Therefore one replicate should be collected at one sample site along each transect.

Sediment Quality

If a sediment quality project is to take place in the future, an understanding of the sediment quality parameters outlined in the document *Sediment Quality Parameters, Methods, and Recommendations* is essential to assess the environmental health and conditions of the Fraser River estuary at Sturgeon Bank. Information gathered through a study of sediment quality can be complimented with data obtained from the 2011 FREMP Habitat Inventory.

For example, sediment grain size analysis and salinity results will be useful in determining conditions favourable for the prevalence of contaminants within the sediment. Sediment deposition and erosion measurements will help to determine the levels of sediment which are deposited at the site which may carry contaminants. The parameters to be analyzed in the laboratory will be costly; therefore there must be clear objectives when deciding which parameters to analyze and where to take them.

The Sturgeon Bank area is a relatively small study size but it contains many different habitats, environmental conditions, and development pressures. A vegetated marsh habitat may have different management objectives from a sand flat. Some contaminants may affect certain organisms more than others. Experts in this field may have to be contacted to develop a causal relationship between certain organisms and some of the possible sediment quality parameters such as chemical contaminants and heavy metals.

The results of the benthic invertebrate samples taken in the 2011 FREMP Habitat Inventory will be useful in determining which invertebrates are most prevalent at the sample locations where sediment quality samples can also be taken. Those invertebrates identified as important food sources for birds and fish species can be used to correlate relationships between the affect of certain sediment quality parameters on food sources and the related affect on fish and bird populations. An intertidal system is very open to outside influences and is constantly changing year to year. Intertidal conditions will be changing between seasons as well. These are all factors which must be taken into account when deciding the final parameters, sampling locations, and methodology for sediment quality analysis.

The following recommendations deal with specific field and lab methods from the 2011 field season.

2011 Habitat Transect Survey

The 2011 Habitat Survey involved the establishment of baseline transects and sample sites. The distance of 2 km was required based on time constraints due to tidal conditions. Some transects off of Sea Island, Lulu Island, and Brunswick Point could be extended under extreme low tide conditions although tidal channels and direction of tide movement should be taken into account for safety reasons.

In order to maximize efficiency under tight time constraints, the establishment of sample sites moving away from the shore and sampling on the way back to shore is helpful.

In some cases it was difficult to find stakes and sample sites again during re-visits later in the year, as marsh vegetation grows very rapidly during the summer. The GPS could not accurately define sample site locations within a 3 metre radius. Orange flagging tape should be tied on each stake and at the top of the tallest vegetation beside the stakes so that it is possible to re-locate the site again. This is also useful in areas of high water at low tide such as at Tsawwassen. At this location finding sample site stakes is also difficult in some areas because of high amounts of eelgrass in the water.

The ruler needs to be washed, dried, and oiled with a product such as DW40 to prevent rusting and sticking. A large backpack is required to carry wooden stakes over the marsh. The plastic sled worked well for transporting equipment over the mud and sandflats.

Salinity is an important parameter to record and study. It is useful to take the refractometer out into the field rather than using WIRL-PAC bags to collect the water samples then analyzing them later. FREMP should purchase a refractometer for future use.

Lab Analysis

Sediment samples were sieved at 125 micrometres and the sediment that was less than this sieve size was put through the sedigraph at UBC. The sedigraph would become clogged at times when coarser grained sediments were put into it. This problem may be lessened if sediments are first sieved at 63 micrometres instead of 125 micrometres. Also, samples greater than 63 micrometres can be sieved at mesh sizes of 125 and 250 micrometres in order to compare with previous studies if required. Previously sieved sediment samples greater than 125 micrometres could also be sieved at 250 micrometres.

Eelgrass Mapping

Eelgrass mapping worked well along the transects. A large amount of Zostera japonica was observed along the transects at Sturgeon Bank but it was very variable in localized areas. Further detailed mapping should be conducted based on the distribution map created from the transect mapping (See Figure 22). A recommended detailed eelgrass mapping method based on a method developed by Cynthia Durance and adopted to fit the environmental conditions of Sturgeon Bank and the objectives of the 2011 Habitat Survey is included in appendix: 6. It is entitled *Eelgrass Sampling Methodology*. This is a proposed methodology for future eelgrass mapping at Sturgeon Bank.

Marsh Edge Mapping

Mapping the marsh edge using GPS field surveying methodology is much more effective and reliable than air photo interpretation. Air photo interpretation may be unreliable for this project because areas of algae mats or other thin surface vegetation may be improperly identified as vegetated marsh in a air photo. The edge between vegetated and non-vegetated marsh is difficult to determine in the field; therefore using air photos to determine the marsh edge would be even more difficult due to a lack of detail at the scales at which they are taken. Marsh edge mapping should be done during the greatest height of plant growth. This will ensure the maximum seasonal extent of the marsh will be mapped.

The Trimble GPS worked well for the marsh edge mapping. The accuracy of less than one metre was useful for this project. The 2 main batteries lasted approximately 4 hours and the backup battery did not charge well and only lasted approximately 20 minutes. A new backup battery would increase the amount of time in which mapping could take place and should be acquired. At Westham Island, the leading edge of the marsh and vegetation islands, as well as the leading edge of the marsh at Lulu Island have been mapped. However the marsh at Sea Island and Brunswick Point, and the vegetation islands off of Lulu Island remain and should be completed in 2011 to formulate a complete a baseline map of the marsh edge.

In 2012, the marsh edge should be mapped again to compare results with 2011 and errors associated with distinguishing between vegetated and non-vegetated areas. In some areas, the boundary between bulrush and the mudflat was not too clear and mapping became somewhat subjective (See Figure 11 and Figure 3 for examples on how the edge was determined). There are some options for eliminating most of the variability between marsh edge interpretation completed by different people. One option is to use the same field technician each time mapping is required. Anther option is for a new field technician to review all previous marsh edge photos (with footprints showing the marsh edge route) and spend adequate time training with Sean Boyd.

Vegetation Polygon Validation

Validation of vegetation polygons is a time consuming imitative and should be separated into a quite full time project. It may be difficult to complete this work in the field because of the high degree of changes occurring in marsh vegetation composition over time. As time goes on, it gets more difficult to verify the polygons because changes are constantly occurring naturally and it is unclear if difference are attributed to improper photo interpretation or if they are a result of seasonal and/or annual changes in marsh conditions.

Future staff verifying vegetation polygons should have a day of training in marsh plant identification in the field before validation takes place. This should include expectations of divisions between vegetation polygons and how to assess the dominant species, as in some cases the vegetation is mixed. Plant identification books are useful but field training is also helpful, as plants change a lot throughout the summer.

The Archer was not useful for making information points or accessing information because it constantly froze in the process. However, it was useful for navigation between the polygons when it was used with the GPS. When recording observations, maps of the polygons should be printed with the attributes (dominant, subdominant species) label showing in each polygon. Also different maps should be printed for different attributes, such as one map for dominant species, and one for subdominant. Any observed differences should be recorded on the map. The maps should also be zoomed in to a level where edits on the maps don't become clustered.

6. Conclusion

The results from this report provide valuable insight into the biological and chemical nature of the Fraser River estuary. Sediment grain size and accretion measurements also represent the geological and hydrological conditions of the estuary. Salinity was found to vary significantly between some transects and is strongly associated with the location of Fraser River freshwater input. Sediment grain size was found to increase with distance away from shore for all transects. Overall the dominate grain sizes in the study area were sand and silt. Areas under the influence of stronger ocean currents had sediment with a higher sand component. Areas with low energy currents, such as vegetated marshes or locations near the Fraser River, were able to maintain small grain size sediment. Sediment accretion and erosion measurements were extremely variable between sample sites. Transect A in Tsawwassen showed an overall trend of erosion in the area, which could be due to strong ocean currents scouring the region. Also, Westham Island showed a unique north-south band of accretion throughout two of its three transects. Bivalve density was found to be dependant on the location of channels at both large and small scales. Only *Zostera japonica* was found at Sturgeon Bank. Eelgrass density was dependant on the locations of low-lying areas, but also decreased with distance from the shore.

There are many recommendations which would make a large impact for continued studies at the Fraser River Estuary. This study should be continued throughout the year and into future years to account for seasonal and yearly environmental variation.

Measurements were collected during the Fraser River freshet when large fluctuations in river discharge are occurring. This has had a large influence on project results. There are still 69 sediment samples out 133 collected that have not been analyzed. Biofilm and benthic invertebrate samples have also been collected but not analyzed. Since this is a baseline study, all samples should be analyzed so future projects can be based on these results. Approximately half of the leading edge of the marsh and vegetated islands have been mapped. The rest of the marsh extent should be mapped in order to provide a comprehensive representation of marsh extent in the Fraser River estuary. This data can then be compared with future mapping projects to show important changes in the continued disappearance of valuable marsh habitat. Future measurements of sediment accretion, salinity, sediment quality, and sediment grain size will help to explain changes shown in marsh edge maps. Additional data collected in future years for this study will help develop a better picture of the environmental conditions of the Fraser River Estuary. This data will be fundamental in informing the Fraser River Estuary Management Program and its partners of the risks associated with future development within the Fraser River estuary habitat.

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Appendices

Appendix 1: Salinity and Bivalve Tube Density

Note: All salinity measurements were taken from surface water. Bivalve tube density data was taken at a different date from salinity measurements.

Sample Site	Salinity (ppt)	Sampling Date	Weather	Bivalve Tube Density (/m^2)
A1	22	30-Jul	Sunny	no data
A2	21	30-Jul	Sunny	no data
A3	21	30-Jul	Sunny	no data
A4	20	30-Jul	Sunny	no data
A5	21	30-Jul	Sunny	no data
B1	12	12-Jul	Overcast/wind	trace
B2	15	12-Jul	Overcast/wind	trace
B3	12	12-Jul	Overcast/wind	trace
B4	11	12-Jul	Overcast/wind	trace
B5	12	12-Jul	Overcast/wind	22
B6	10	12-Jul	Overcast/wind	22
B7	10	12-Jul	Overcast/wind	10
B8	10	12-Jul	Overcast/wind	10
B9	10	12-Jul	Overcast/wind	12
B10	11	12-Jul	Overcast/wind	15
C1	8	12-Jul	Overcast/wind	trace
C2	8	12-Jul	Overcast/wind	none
C3	8	12-Jul	Overcast/wind	none
C4	Too Dirty	12-Jul	Overcast/wind	trace
C5	7	12-Jul	Overcast/wind	Trace
C6	7	12-Jul	Overcast/wind	Trace
C7	8	12-Jul	Overcast/wind	Trace
C8	8	12-Jul	Overcast/wind	Trace
C9	8	12-Jul	Overcast/wind	10
C10	9	12-Jul	Overcast/wind	11
D0	Missing			None
D1	Dry	30-Jul	Sunny	None
D2	0	30-Jul	Sunny	None
D3	1	30-Jul	Sunny	None
D4	2	30-Jul	Sunny	None
D5	0	30-Jul	Sunny	Trace
D6	2	30-Jul	Sunny	3
D7	8	30-Jul	Sunny	3
D8	1	30-Jul	Sunny	5
D9	2	30-Jul	Sunny	7
F1	0	30-Jul	Sunny	None
F2	0	30-Jul	Sunny	None
F3	0	30-Jul	Sunny	None
F4	0	30-Jul	Sunny	None
F5	Missing			None
F6	Missing			None
F7	0	18-Jul	Sunny	None
F8	0	18-Jul	Sunny	None

Sample Site	Salinity (ppt)	Sampling Date	Weather	Bivalve Tube Density (/m^2)
E1	2	18-Jul	Overcast/warm	None
E2	2	18-Jul	Overcast/warm	None
E3	2	18-Jul	Overcast/warm	None
E4	1	18-Jul	Overcast/warm	None
E5	1	18-Jul	Overcast/warm	None
E6	1	18-Jul	Overcast/warm	None
E7	1	18-Jul	Overcast/warm	None
E8	0	18-Jul	Overcast/warm	Trace
E9	0	18-Jul	Overcast/warm	None
E10	0	18-Jul	Overcast/warm	None
G1	0	2-Aug	Sunny	None
G2	0	2-Aug	Sunny	None
G3	0	2-Aug	Sunny	None
G4	0	2-Aug	Sunny	None
Z1	Dry	29-Jul	Sunny/warm	None
Z2	Dry	29-Jul	Sunny/warm	None
Z3	2	29-Jul	Sunny/warm	None
Z4	2	29-Jul	Sunny/warm	None
Z5	4	29-Jul	Sunny/warm	5
Z6	2	29-Jul	Sunny/warm	5
H1	Dry	29-Jul	Sunny/warm	None
H2	4	29-Jul	Sunny/warm	None
H3	4	29-Jul	Sunny/warm	None
H4	5	29-Jul	Sunny/warm	None
H5	4	29-Jul	Sunny/warm	None
H6	4	29-Jul	Sunny/warm	Trace
H7	4	29-Jul	Sunny/warm	14
H8	5	29-Jul	Sunny/warm	11
H9	4	29-Jul	Sunny/warm	None
I1	Dry	28-Jul	Sunny	no data
I2	2	28-Jul	Sunny	no data
I3	4	28-Jul	Sunny	no data
I4	4	28-Jul	Sunny	no data
I5	4	28-Jul	Sunny	no data
I6	4	28-Jul	Sunny	no data
I7	4	28-Jul	Sunny	no data
I8	4	28-Jul	Sunny	Trace
I9	4	28-Jul	Sunny	None
I10	4	28-Jul	Sunny	None
J0	Dry	28-Jul	Sunny	None
J1	Dry	28-Jul	Sunny	None
J2	4	28-Jul	Sunny	None
J3	4	28-Jul	Sunny	Trace
J4	2	28-Jul	Sunny	no data
J5	4	28-Jul	Sunny	no data
J6	2	28-Jul	Sunny	5

J7	2	28-Jul	Sunny	5
J8	4	28-Jul	Sunny	5
J9	4	28-Jul	Sunny	5
K0	Dry	11-Jul	Sun/cloud	None
K1	Dry	11-Jul	Sun/cloud	None
K2	3	11-Jul	Sun/cloud	None
K3	4	11-Jul	Sun/cloud	None
K4	4	11-Jul	Sun/cloud	None
K5	4	11-Jul	Sun/cloud	Trace
K6	4	11-Jul	Sun/cloud	None
K7	4	11-Jul	Sun/cloud	None
K8	4	11-Jul	Sun/cloud	None
K9	5	11-Jul	Sun/cloud	None
L0	2	11-Jul	Sun/cloud	None
L1	0	11-Jul	Sun/cloud	None
L2	2	11-Jul	Sun/cloud	None
L3	2	11-Jul	Sun/cloud	None
L4	3	11-Jul	Sun/cloud	15
L5	3	11-Jul	Sun/cloud	25
L6	3	11-Jul	Sun/cloud	45
L7	3	11-Jul	Sun/cloud	20
L8	4	11-Jul	Sun/cloud	15
L9	2	11-Jul	Sun/cloud	15
M1	5	15-Jul	Sun/cloud	None
M2	6	15-Jul	Sun/cloud	None
M3	6	15-Jul	Sun/cloud	None
M4	5	15-Jul	Sun/cloud	None
M5	6	15-Jul	Sun/cloud	None
M6	6	15-Jul	Sun/cloud	None
M7	6	15-Jul	Sun/cloud	None
M8	6	15-Jul	Sun/cloud	Trace
M9	5	15-Jul	Sun/cloud	None
M10	6	15-Jul	Sun/cloud	Trace
N1	9	13-Jul	Sun/cloud	no data
N2	9	13-Jul	Sun/cloud	no data
N3	9	13-Jul	Sun/cloud	Trace
N4	9	13-Jul	Sun/cloud	None
N5	10	13-Jul	Sun/cloud	Trace
N6	10	13-Jul	Sun/cloud	5
N7	10	13-Jul	Sun/cloud	6
N8	10	13-Jul	Sun/cloud	Trace
N9	11	13-Jul	Sun/cloud	10
N10	12	13-Jul	Sun/cloud	6

Appendix 2: Sediment Grain Size Composition and Sediment Weights Before and After Sieving

Sample #	Dry Weight Before Sieving	Weight > 0.125 mm /g	Weight < 0.125 mm /g	**% Sand in Sample (>0.063mm)**	**% Silt in Sample (0.002-0.063mm)**	**% Clay in Sample (<0.002mm)**
A-1	77.229	38.186	39.043	**79.4**	**18.0**	**2.5**
A-2	68.351	44.015	24.336			
A-3	45.939	37.240	8.699	**94.5**	**4.4**	**1.1**
A-4	90.298	83.174	7.124			
A-5	50.487	48.058	2.429			
B-1	50.736	5.391	45.345			
B-2	93.260	26.290	66.970	**51.5**	**41.9**	**6.5**
B-3	66.378	6.799	59.579			
B-4	92.247	18.930	73.317	**42.5**	**50.2**	**7.2**
B-5	50.065	13.137	36.928			
B-6	90.808	29.857	60.951	**53.6**	**39.5**	**6.9**
B-7	52.486	20.321	32.165			
B-8	64.827	38.578	26.249	**71.3**	**28.7**	**0.0**
B-9	50.341	26.871	23.470			
B-10	91.223	55.202	36.021	**74.7**	**21.9**	**3.4**
C-1	64.763	0.887	63.876	**3.1**	**89.6**	**7.3**
C-2	75.816	1.509	74.307			
C-3	72.626	4.427	68.199	**7.6**	**74.7**	**17.7**
C-4	60.770	10.680	50.090			
C-5	79.095	8.077	71.018	**40.2**	**53.7**	**6.1**
C-6	77.853	15.621	62.232			
C-7	72.323	25.275	47.048	**66.8**	**28.4**	**4.9**
C-8	81.607	35.820	45.787			
C-9	70.754	31.700	39.054	**72.6**	**17.6**	**9.9**
D-3	47.048	8.277	38.771			
D-4	64.567	25.292	39.275	**52.4**	**41.9**	**5.7**
D-5	100.754	65.563	35.191			
D-6	68.960	54.267	14.693	**88.8**	**9.2**	**2.0**
D-7	79.922	69.340	10.582			
D-8	77.418	49.497	27.921	**85.5**	**11.4**	**3.0**
D-9	74.409	40.056	34.353			
F-2	47.624	3.495	44.129			
F-3	66.938	15.365	51.573	**24.3**	**67.0**	**8.6**
F-5	73.776	22.874	50.902	**36.2**	**63.8**	**0.0**
F-7	75.248	32.588	42.660	**56.6**	**37.5**	**6.0**
F-9	96.335	77.024	19.311	**94.3**	**4.7**	**0.9**

Sample #	Dry Weight Before Sieving	Weight > 0.125 mm /g	Weight < 0.125 mm /g	**% Sand in Sample (>0.063mm)**	**% Silt in Sample (0.002-0.063mm)**	**% Clay in Sample (<0.002mm)**
E-1	44.260	4.190	40.070			
E-2	43.513	8.648	34.865	**20.5**	**70.4**	**9.1**
E-3	41.942	3.206	38.736			
E-4	58.854	4.491	54.363	**13.0**	**69.8**	**17.2**
E-5	56.615	13.143	43.472			
E-6	76.592	18.062	58.530	**31.5**	**56.5**	**11.9**
E-7	74.636	11.747	62.889			
E-8	72.895	22.294	50.601	**46.1**	**53.9**	**0.0**
E-9	60.863	32.483	28.380			
E-10	46.523	26.885	19.638	**67.9**	**30.8**	**1.3**
G-1	36.069	2.691	33.378			
G-2	43.116	3.257	39.859	**7.6**	**92.4**	**0.0**
G-3	53.656	5.535	48.121			
G-4	67.158	3.996	63.162	**7.6**	**80.9**	**11.5**
Z-1	21.425	5.304	16.121			
Z-2	36.962	5.206	31.756	**14.3**	**85.7**	**0.0**
Z-3	46.300	5.270	41.030			
Z-4	57.86	1.108	56.752	**6.1**	**93.9**	**0.0**
Z-5	56.447	4.830	51.617			
Z-6	65.464	1.688	63.776	**9.4**	**78.9**	**11.7**
H-1	18.166	6.84	11.326	**38.3**	**61.7**	**0.0**
H-2	53.402	4.55	48.852	**11.4**	**86.1**	**2.6**
H-3	44.543	1.843	42.700	**9.3**	**78.4**	**12.3**
H-4	52.473	2.097	50.376			
H-5	72.453	2.361	70.092	**27.4**	**60.0**	**12.6**
H-6	73.527	2.050	71.477			
H-7	92.797	7.219	85.578	**31.5**	**59.3**	**9.2**
H-8	93.159	56.617	36.542	**86.0**	**3.9**	**10.1**
H-9	53.314	50.044	3.270			
I-1	16.030	2.450	13.580			
I-2	53.085	3.287	49.798	**14.0**	**74.7**	**11.5**
I-3	70.030	4.019	66.011			
I-4	52.320	7.444	44.876	**60.3**	**33.5**	**6.2**
I-5	62.403	26.077	36.326			
I-6	61.679	42.724	18.955	**93.1**	**5.7**	**1.1**
I-8	88.013	84.625	3.388	**97.6**	**2.1**	**0.3**
I-9	69.870	57.331	12.539	**96.1**	**3.5**	**0.4**
I-10	62.895	41.369	21.526	**89.0**	**9.0**	**2.1**
J-1	36.428	15.706	20.722	**45.4**	**46.9**	**7.7**

Sample #	Dry Weight Before Sieving	Weight > 0.125 mm /g	Weight < 0.125 mm /g	**% Sand in Sample (>0.063mm)**	**% Silt in Sample (0.002-0.063mm)**	**% Clay in Sample (<0.002mm)**
J-2	67.051	8.347	58.704			
J-4	50.839	50.025	0.814			
J-5	53.814	48.027	5.787			
J-6	77.692	28.025	49.667			
J-7	73.060	33.766	39.294	**86.6**	**13.4**	**0.0**
J-8	61.047	27.293	33.754			
J-9	55.792	39.478	16.314			
K-1	38.145	3.121	35.024			
K-2	58.060	7.073	50.987	**28.7**	**62.4**	**8.9**
K-3	64.619	28.730	35.889	**57.2**	**38.4**	**0.0**
K-4	52.010	23.992	28.018	**64.2**	**30.5**	**5.3**
K-5	49.569	6.797	42.772			
K-6	76.982	17.880	59.102	**61.7**	**33.3**	**5.0**
K-7	82.496	50.085	32.411			
K-8	85.297	57.954	27.343	**94.6**	**5.0**	**0.4**
L-1	55.059	1.565	53.494	**7.3**	**81.1**	**11.6**
L-2	34.448	5.468	28.980			
L-3	73.417	3.044	70.373	**22.6**	**67.6**	**9.8**
L-4	38.502	1.922	36.580			
L-5	67.078	1.922	65.156	**27.6**	**61.9**	**10.5**
L-6	70.950	8.519	62.431			
L-7	80.524	34.748	45.776	**67.7**	**26.7**	**5.6**
L-8	87.735	55.303	32.432	**81.4**	**15.7**	**2.9**
L-9	53.371	21.807	31.564	**78.0**	**18.3**	**3.7**
M-1	50.270	13.600	36.670			
M-2	74.572	3.195	71.377	**15.9**	**74.5**	**9.7**
M-3	67.868	2.643	65.225			
M-4	72.839	4.308	68.531	**34.4**	**54.8**	**10.8**
M-5	65.543	11.458	54.085			
M-6	97.466	22.156	75.310	**44.2**	**55.8**	**0.0**
M-7	63.696	15.816	47.880			
M-8	66.266	38.222	28.044	**74.4**	**20.4**	**5.2**
M-9	83.387	26.814	56.573			
M-10	98.238	55.490	42.748	**88.5**	**9.4**	**2.2**
N-1	66.970	5.194	61.776	**17.7**	**71.7**	**10.6**
N-2	46.493	4.239	42.254	**37.1**	**57.5**	**5.4**
N-3	70.218	2.967	67.251			
N-4	64.244	4.736	59.508			
N-5	45.302	7.496	37.806	**35.1**	**60.6**	**4.3**

Sample #	Dry Weight Before Sieving	Weight > 0.125 mm /g	Weight < 0.125 mm /g	**% Sand in Sample (>0.063mm)**	**% Silt in Sample (0.002-0.063mm)**	**% Clay in Sample (<0.002mm)**
N-6	66.151	33.247	32.904			
N-7	48.959	31.070	17.889	**76.2**	**20.9**	**2.8**
N-8	71.384	47.005	24.379			
N-9	98.183	78.354	19.829	**91.1**	**7.3**	**1.6**
N-10	99.209	90.471	8.738			
N-11	64.001	58.337	5.664			

Appendix 3: May/June and July Height Measurements and Calculated Net Accretion

May/June Height Measurements						July Height Measurements					Net Accretion	
Sample Site	Height 1	Height 2	Height 3	Average Height	Standard Deviation	Height 1	Height 2	Height 3	Average Height	Standard Deviation	May/June to July (/cm)	Days Between Measurements
A1	19.0	18.5	18.9	18.8	0.3	18.6	18.7	18.8	18.7	0.1	**0.1**	58
A2	16.4	16.7	16.7	16.6	0.2	17.2	17.2	17.3	17.2	0.1	**-0.6**	58
A3	18.3	18.2	17.9	18.1	0.2	18.8	18.6	19.2	18.9	0.3	**-0.7**	58
A4	17.0	17.0	17.1	17.0	0.1	17.9	17.3	17.4	17.5	0.3	**-0.5**	58
A5	18.1	17.7	18.4	18.1	0.4	18.3	18.3	18.4	18.3	0.1	**-0.3**	58
B1	19.9	19.9	19.9	19.9	0.0	20.1	20.1	19.9	20.0	0.1	**-0.1**	55
B2	19.9	20.0	19.4	19.8	0.3	25.1	23.8	23.2	24.0	1.0	**-4.3**	55
B3	19.4	19.0	19.2	19.2	0.2	19.9	20.1	20.7	20.2	0.4	**-1.0**	55
B4	19.0	18.5	18.7	18.7	0.3	19.3	19.3	19.1	19.2	0.1	**-0.5**	55
B5	19.3	19.3	18.5	19.0	0.5	17.4	18.4	18.1	18.0	0.5	**1.1**	55
B6	17.3	17.1	17.0	17.1	0.2	16.5	16.3	16.1	16.3	0.2	**0.8**	55
B7	18.4	18.0	17.6	18.0	0.4	16.7	16.8	16.6	16.7	0.1	**1.3**	55
B8						18.0	17.3	18.0	17.8	0.4		
B9						16.6	15.8	16.9	16.4	0.6		
B10						17.5	17.3	18.5	17.8	0.6		
C1	18.6	18.3	18.1	18.3	0.3	18.2	18.1	18.2	18.2	0.1	**0.2**	14
C2	18.9	19.1	19.0	19.0	0.1	19.0	19.2	19.0	19.1	0.1	**-0.1**	14
C3	18.7	18.4	18.1	18.4	0.3	18.2	17.6	17.6	17.8	0.3	**0.6**	14
C4	20.9	21.0	21.2	21.0	0.2	20.8	20.9	21.1	20.9	0.2	**0.1**	14
C5	18.0	18.0	17.8	17.9	0.1	18.3	18.2	17.8	18.1	0.3	**-0.2**	14
C6	19.6	19.5	19.0	19.4	0.3	19.3	19.0	18.7	19.0	0.3	**0.4**	14
C7	18.0	17.6	17.8	17.8	0.2	17.4	17.3	17.3	17.3	0.1	**0.5**	14
C8	17.7	17.5	17.7	17.6	0.1	17.8	17.5	17.7	17.7	0.1	**0.0**	14
C9	16.8	16.6	17.7	17.0	0.6	17.5	16.9	17.4	17.3	0.3	**-0.2**	14
C10						17.3	18.2	17.0	17.5	0.6		
D0	19.1	20.8	19.2	19.7	1.0	Could not find stakes						
D1	20.4	19.9	20.4	20.2	0.3	21.3	20.3	20.6	20.7	0.5	**-0.5**	45

May/June Height Measurements						July Height Measurements					Net Accretion	
Sample Site	Height 1	Height 2	Height 3	Average Height	Standard Deviation	Height 1	Height 2	Height 3	Average Height	Standard Deviation	May/June to July	Days Between Measurements
D2	23.1	21.5	17.6	20.7	**2.8**	23.1	20.7	18.0	20.6	2.6	**0.1**	45
D3	19.7	19.7	20.1	19.8	0.2	17.6	18.7	18.3	18.2	0.6	**1.6**	45
D4	18.8	18.7	18.7	18.7	0.1	18.6	18.6	18.3	18.5	0.2	**0.2**	45
D5	17.0	17.8	18.2	17.7	0.6	19.3	18.6	18.6	18.8	0.4	**-1.2**	45
D6	14.2	14.2	14.1	14.2	0.1	14.2	14.2	13.4	13.9	0.5	**0.2**	45
D7	18.3	17.9	17.7	18.0	0.3	17.0	16.9	16.7	16.9	0.2	**1.1**	45
D8	16.7	16.8	16.8	16.8	0.1	17.7	17.7	17.7	17.7	0.0	**-0.9**	45
D9	17.4	17.2	17.4	17.3	0.1	17.4	17.2	17.1	17.2	0.2	**0.1**	45
F0	18.2	18.5	18.6	18.4	0.2	Could not find stakes						
F1	19.4	18.7	19.3	19.1	0.4	19.6	19.0	20.3	19.6	0.7	**-0.5**	33
F2	24.3	22.4	21.2	22.6	1.6	23.0	22.2	20.8	22.0	1.1	**0.6**	33
F3	16.1	16.2	15.7	16.0	0.3	15.3	14.8	14.4	14.8	0.5	**1.2**	33
F4	18.3	18.8	20.1	19.1	0.9	18.2	19.2	20.3	19.2	1.1	**-0.2**	33
F5	20.7	20.7	20.5	20.6	0.1	Tide too high for survey						
F6						18.4	18.1	18.2	18.2	0.2		
F7						19.1	19.4	19.4	19.3	0.2		
F8						16.4	16.6	16.8	16.6	0.2		
F9						18.7	17.3	16.5	17.5	1.1		
E1	15.6	16.3	16.1	16.0	0.4					15.4	15.8	15.7
E2	16.4	17.8	15.7	16.6	1.1	13.1	16.4	15.3	14.9	1.7	**1.7**	19
E3	20.3	19.8	19.6	19.9	0.4	19.5	18.9	18.9	19.1	0.3	**0.8**	19
E4	19.2	19.1	19.1	19.1	0.1	18.5	18.6	18.6	18.6	0.1	**0.6**	19
E5	16.4	16.1	15.9	16.1	0.3	17.8	17.3	17.4	17.5	0.3	**-1.4**	19
E6	18.5	19.3	18.6	18.8	0.4					17.8	18.2	18.2
E7	18.8	18.0	17.1	18.0	0.9	19.6	18.2	19.3	19.0	0.7	**-1.1**	19
E8	17.9	18.0	18.4	18.1	0.3	18.1	17.9	18.1	18.0	0.1	**0.1**	19
E9	18.8	18.5	18.3	18.5	0.3	21.0	21.5	21.7	21.4	0.4	**-2.9**	19
E10	18.6	18.5	18.6	18.6	0.1	20.5	20.4	20.2	20.4	0.2	**-1.8**	19
G1	18.7	19.1	18.8	18.9	0.2	18.7	19.4	19.0	19.0	0.4	**-0.2**	46
G2	25.3	25.3	24.5	25.0	0.5	25.2	25.0	24.3	24.8	0.5	**0.2**	46

May/June Height Measurements						July Height Measurements					Net Accretion	
Sample Site	Height 1	Height 2	Height 3	Average Height	Standard Deviation	Height 1	Height 2	Height 3	Average Height	Standard Deviation	May/June to July	Days Between Measurements
G3	18.3	18.3	18.6	18.4	0.2	18.4	18.0	18.4	18.3	0.2	**0.1**	46
G4	24.2	24.2	26.0	24.8	1.0	24.0	24.6	25.6	24.7	0.8	**0.1**	46
Z1	20.2	19.4	18.5	19.4	0.9	20.4	20.0	18.7	19.7	0.9	**-0.3**	59
Z2	19.5	19.0	18.4	19.0	0.6	18.9	18.7	18.3	18.6	0.3	**0.3**	59
Z3	20.5	18.6	18.3	19.1	1.2	18.6	18.4	18.6	18.5	0.1	**0.6**	59
Z4	19.7	19.8	19.9	19.8	0.1	19.7	19.8	19.6	19.7	0.1	**0.1**	59
Z5	18.7	19.4	19.8	19.3	0.6	17.7	18.5	18.7	18.3	0.5	**1.0**	59
Z6	19.0	18.9	18.9	18.9	0.1	18.1	18.2	18.1	18.1	0.1	**0.8**	59
H1	22.3	21.8	17.3	20.5	**2.8**	23.2	21.8	17.9	21.0	2.7	**-0.5**	60
H2	20.7	20.4	17.1	19.4	**2.0**	20.9	18.7	17.7	19.1	1.6	**0.3**	60
H3	18.7	18.6	18.7	18.7	0.1	19.1	19.1	19.1	19.1	0.0	**-0.4**	60
H4	19.3	19.2	19.2	19.2	0.1	18.8	18.8	19.0	18.9	0.1	**0.4**	60
H5	18.7	18.5	18.5	18.6	0.1	18.5	18.5	18.4	18.5	0.1	**0.1**	60
H6	19.1	19.1	18.9	19.0	0.1	19.0	19.0	19.0	19.0	0.0	**0.0**	60
H7	18.2	18.4	18.4	18.3	0.1	18.2	18.2	18.0	18.1	0.1	**0.2**	60
H8	18.8	18.4	18.8	18.7	0.2	19.8	19.3	18.3	19.1	0.8	**-0.5**	60
H9	18.0	18.0	19.1	18.4	0.6	17.6	17.5	17.4	17.5	0.1	**0.9**	60
I1	28.5	29.5	29.5	29.2	0.6	29.7	29.9	29.6	29.7	0.2	**-0.6**	70
I2	19.0	19.5	19.3	19.3	0.3	19.5	19.7	19.7	19.6	0.1	**-0.4**	70
I3	19.0	18.5	18.8	18.8	0.3	16.8	16.9	17.0	16.9	0.1	**1.9**	70
I4	17.5	17.5	17.9	17.6	0.2	17.6	17.7	17.8	17.7	0.1	**-0.1**	70
I5	18.0	18.0	17.8	17.9	0.1	18.0	17.9	18.1	18.0	0.1	**-0.1**	70
I6	19.0	20.5	20.5	20.0	0.9	19.8	20.1	21.0	20.3	0.6	**-0.3**	70
I7	18.0	18.6	17.1	17.9	0.8	17.0	17.1	17.2	17.1	0.1	**0.8**	70
I8	16.0	16.1	17.0	16.4	0.6	15.8	15.9	16.7	16.1	0.5	**0.2**	43
I9	18.1	18.1	17.9	18.0	0.1	17.2	16.9	17.3	17.1	0.2	**0.9**	43
I10	17.5	17.2	17.4	17.4	0.2	17.3	16.7	16.6	16.9	0.4	**0.5**	43
J0	21.3	22.0	20.2	21.2	0.9	21.4	21.0	20.9	21.1	0.3	**0.1**	57
J1	22.9	23.2	17.9	21.3	**3.0**	23.3	21.6	16.0	20.3	3.8	**1.0**	57

	May/June Height Measurements					July Height Measurements					Net Accretion	
Sample Site	Height 1	Height 2	Height 3	Average Height	Standard Deviation	Height 1	Height 2	Height 3	Average Height	Standard Deviation	May/June to July	Days Between Measurements
J2	19.0	18.8	18.6	18.8	0.2	16.0	15.8	15.6	15.8	0.2	**3.0**	57
J3	18.7	18.7	18.6	18.7	0.1	19.7	19.0	19.3	19.3	0.4	**-0.7**	57
J4	20.5	18.1	18.6	19.1	1.3	20.5	19.4	18.0	19.3	1.3	**-0.2**	57
J5	17.3	18.3	17.7	17.8	0.5	17.8	17.7	18.4	18.0	0.4	**-0.2**	57
J6	19.8	19.7	20.5	20.0	0.4	19.6	19.8	20.2	19.9	0.3	**0.1**	57
J7	19.9	20.1	20.3	20.1	0.2	18.4	18.6	19.1	18.7	0.4	**1.4**	57
J8	17.9	18.0	18.2	18.0	0.2	21.0	21.5	21.4	21.3	0.3	**-3.3**	57
J9	18.1	18.0	18.3	18.1	0.2	20.1	19.1	19.3	19.5	0.5	**-1.4**	57
K0	18.8	18.0	20.4	19.1	1.2	19.9	21.4	21.0	20.8	0.8	**-1.7**	38
K1	18.6	19.8	20.8	19.7	1.1	Could not find stakes						
K2	19.1	19.3	19.5	19.3	0.2	19.6	19.5	19.6	19.6	0.1	**-0.3**	38
K3	19.1	18.7	18.8	18.9	0.2	18.5	18.3	17.7	18.2	0.4	**0.7**	26
K4	18.9	19.0	18.8	18.9	0.1	18.7	19.2	18.7	18.9	0.3	**0.0**	26
K5	18.4	18.5	18.5	18.5	0.1	18.6	18.7	18.5	18.6	0.1	**-0.1**	26
K6	18.6	18.3	18.5	18.5	0.2	18.2	18.3	18.4	18.3	0.1	**0.2**	26
K7	18.7	18.3	18.6	18.5	0.2	19.8	19.8	20.0	19.9	0.1	**-1.3**	26
K8	17.4	18.4	18.4	18.1	0.6	19.7	20.0	20.9	20.2	0.6	**-2.1**	26
K9	21.2	21.4	21.6	21.4	0.2	16.6	16.0	17.1	16.6	0.6	**4.8**	26
L0	20.9	19.6	19.6	20.0	0.8	19.9	20.0	18.8	19.6	0.7	**0.5**	39
L1	20.4	19.5	15.3	18.4	**2.7**	16.8	19.2	14.9	17.0	**2.2**	**1.4**	39
L2	19.0	19.7	20.1	19.6	0.6	19.3	20.1	20.4	19.9	0.6	**-0.3**	39
L3	18.8	18.9	18.6	18.8	0.2	18.8	18.7	18.8	18.8	0.1	**0.0**	39
L4	18.9	18.9	19.0	18.9	0.1	19.0	19.0	19.2	19.1	0.1	**-0.1**	39
L5	20.0	19.4	19.4	19.6	0.3	19.8	19.6	19.3	19.6	0.3	**0.0**	39
L6	18.1	18.3	18.4	18.3	0.2	17.7	17.8	18.0	17.8	0.2	**0.4**	39
L7	18.5	18.2	18.3	18.3	0.2	18.6	18.4	18.8	18.6	0.2	**-0.3**	39
L8	18.3	17.5	17.8	17.9	0.4	18.4	18.5	18.4	18.4	0.1	**-0.6**	39
L9	18.2	18.4	18.1	18.2	0.2	17.8	18.0	18.1	18.0	0.2	**0.3**	39
M1	20.0	21.2	21.4	20.9	0.8	18.9	18.5	21.1	19.5	1.4	**1.4**	31
M2	18.8	19.0	18.6	18.8	0.2	19.3	19.7	29.0	22.7	**5.5**	**-3.9**	31

May/June Height Measurements						July Height Measurements					Net Accretion	
Sample Site	Height 1	Height 2	Height 3	Average Height	Standard Deviation	Height 1	Height 2	Height 3	Average Height	Standard Deviation	May/June to July	Days Between Measurements
M3	18.6	18.7	18.8	18.7	0.1	17.7	18.3	18.4	18.1	0.4	**0.6**	31
M4	18.7	18.6	18.7	18.7	0.1	18.6	18.3	18.7	18.5	0.2	**0.1**	31
M5	19.5	19.6	19.5	19.5	0.1	19.4	19.5	19.5	19.5	0.1	**0.1**	31
M6	19.6	19.6	19.6	19.6	0.0	19.2	19.4	19.2	19.3	0.1	**0.3**	31
M7	19.0	18.9	19.0	19.0	0.1	18.3	18.5	18.5	18.4	0.1	**0.5**	31
M8	17.6	17.3	17.3	17.4	0.2	17.3	17.4	17.5	17.4	0.1	**0.0**	31
M9	17.9	17.9	18.0	17.9	0.1	18.5	19.2	21.6	19.8	1.6	**-1.8**	31
M10	16.6	16.8	16.6	16.7	0.1	15.4	15.3	15.3	15.3	0.1	**1.3**	31
N1	19.7	19.7	19.8	19.7	0.1	19.6	19.4	19.3	19.4	0.2	**0.3**	30
N2	19.0	19.2	19.1	19.1	0.1	19.1	19.2	19.4	19.2	0.2	**-0.1**	30
N3	17.4	17.4	17.2	17.3	0.1	21.7	21.6	21.4	21.6	0.2	**-4.2**	30
N4	18.2	18.1	18.3	18.2	0.1	22.2	22.1	22.5	22.3	0.2	**-4.1**	30
N5	18.8	19.1	18.9	18.9	0.2	20.6	20.8	20.8	20.7	0.1	**-1.8**	30
N6	18.0	18.4	18.2	18.2	0.2	18.1	17.9	18.1	18.0	0.1	**0.2**	30
N7	17.4	17.2	17.1	17.2	0.2	18.1	18.1	17.9	18.0	0.1	**-0.8**	30
N8	18.6	18.7	18.7	18.7	0.1	19.8	19.2	18.7	19.2	0.6	**-0.6**	29
N9	17.7	18.2	18.0	18.0	0.3	17.9	18.0	18.7	18.2	0.4	**-0.2**	29
N10	18.0	17.8	17.5	17.8	0.3	17.7	16.7	17.4	17.3	0.5	**0.5**	29

Appendix 4. Sample Site Sampling Date, Water Depth, and Location Details

Sample Site	Sampling Date	Water Depth	Located in Marsh	Longitude	Latitude
A1	17-May/ 3-Jun (height measurements only)	2	No	-123.09561	49.00907
A2	17-May/ 3-Jun (height measurements only)	14	No	-123.09791	49.00813
A3	17-May/ 3-Jun (height measurements only)	12	No	-123.10024	49.00725
A4	17-May/ 3-Jun (height measurements only)	6	No	-123.10273	49.0065
A5	17-May/ 3-Jun (height measurements only)	N/D	No	-123.10511	49.00562
B1	19-May	0	No (mud)	-123.13262	49.05258
B2	19-May	7	No	-123.13446	49.05125
B3	19-May	0	No	-123.13635	49.04997
B4	19-May	1	No	-123.13798	49.0489
B5	19-May	1	No	-123.13955	49.04791
B6	19-May	3	No	-123.14128	49.04688
B7	19-May	3	No	-123.14325	49.04565
B8	12-Jul	8	No	-123.14522	49.0444
B9	12-Jul	9	No	-123.14723	49.04316
B10	12-Jul	11	No	-123.1492	49.04192
C1	29-Jun	film	No (mud)	-123.14731	49.05878
C2	29-Jun	film	No (cracked muddy ridge)	-123.14932	49.05754
C3	29-Jun	0	No (cracked muddy ridge)	-123.15131	49.05631
C4	29-Jun	0	No (in channel of cracked muddy ridge)	-123.15344	49.05516
C5	29-Jun	1	No (mud/sand)	-123.15529	49.05384
C6	29-Jun	2	No (sand/mud)	-123.15733	49.05264

C7	29-Jun	1.5	No (sand)	-123.15931	49.0514
C8	29-Jun	film	No (sand)	-123.16135	49.0502
C9	29-Jun	1	No (sand)	-123.1634	49.049
C10	12-Jul	1	No (sand)	-123.16542	49.04778
D0	16-Jun	N/D	Yes (grasses)	No Waypoint Collected	
D1	16-Jun	N/D	Yes (cattail, grasses)	-123.16166	49.06188
D2	16-Jun	N/D	Yes (grasses)	-123.16376	49.0607
D3	16-Jun	0	Yes (site in mud surrounded by grass)	-123.16561	49.05937
D4	16-Jun	0	Yes	-123.16758	49.05812
D5	16-Jun	0	Yes	-123.16956	49.05687
D6	16-Jun	2	No (mud)	-123.17153	49.05561
D7	16-Jun	1	No (sand ripples)	-123.17349	49.05437
D8	16-Jun	1	No (sand)	-123.17547	49.05313
D9	16-Jun	1	No	-123.17744	49.05188
F0	28-Jun	N/D	Yes (grass/sedge)	No Waypoint Collected	
F1	28-Jun	N/D	Yes (rush, sedge, grass)	-123.17784	49.08005
F2	28-Jun	N/D	Yes (rush, sedge, grass)	-123.18048	49.07955
F3	28-Jun	2	Yes (bulrush)	-123.18306	49.07895
F4	28-Jun	4	Yes (bulrush)	-123.18574	49.07849
F5	28-Jun	N/D	No (close to marsh)	-123.18812	49.07794
F6	18-Jul	film	No	-123.19074	49.07741
F7	18-Jul	film	No (mud, near vegetated mounds)	-123.19332	49.0768
F8	18-Jul	film	No (silty sand)	-123.19587	49.07614
F9	18-Jul	5	No (sand ripples)	No Waypoint Collected	

E1	30-Jun	0	Yes (sedge)	-123.18244	49.0903
E2	30-Jun	film	Yes (sedge/rush)	-123.1852	49.09029
E3	30-Jun	N/D	No (near the bulrush)	-123.18793	49.09013
E4	30-Jun	N/D	No	-123.19068	49.09007
E5	30-Jun	N/D	Yes (bulrush)	-123.19344	49.09001
E6	30-Jun	N/D	Yes (bulrush)	-123.19619	49.08994
E7	30-Jun	film	No (mud)	-123.19893	49.08989
E8	30-Jun	1	No (mud/sand)	-123.20165	49.08979
E9	30-Jun	1	No (sand/mud)	-123.20441	49.08974
E10	30-Jun	N/D	No (sand)	-123.20714	49.08964
G1	17-Jun	3	Yes (cattail)	-123.19002	49.09958
G2	17-Jun	1	Yes (grasses)	-123.19273	49.09987
G3	17-Jun	0	Yes (knobby hills with vegetation)	-123.19545	49.1002
G4	17-Jun	2	Yes (rushes)	-123.19816	49.10043
Z1	31-May	N/D	Yes	-123.1971	49.13293
Z2	31-May	N/D	Yes	-123.19983	49.13319
Z3	31-May	film	Yes	-123.20252	49.13349
Z4	31-May	film	No (marsh close to the east)	-123.20525	49.13376
Z5	31-May	N/D	No (mud)	-123.20799	49.13409
Z6	31-May	film	No (mud)	-123.21071	49.13435
H1	30-May	N/D	Yes	-123.19741	49.14147
H2	30-May	N/D	Yes	-123.20015	49.14163
H3	30-May	N/D	No (mud with some mounds)	-123.20284	49.142
H4	30-May	1	No (some vegetation)	-123.20554	49.1423
H5	30-May	0	No (mud/sand)	-123.20826	49.14256

H6	30-May	0	No (mud/sand)	-123.21101	49.14278
H7	30-May	1	No (mud/sand)	-123.21374	49.14306
H8	30-May	0	No (sand/mud)	-123.21643	49.14348
H9	30-May	1	No (sand)	-123.21913	49.14373
I1	19-May	0	Yes (salt grass)	-123.19803	49.14845
I2	19-May		No	-123.20082	49.14838
I3	19-May		No	-123.20358	49.14836
I4	19-May		No	-123.20633	49.14823
I5	19-May		No	-123.2091	49.14824
I6	19-May		No	-123.21183	49.14827
I7	19-May	2.5	No	-123.21461	49.1482
I8	15-Jun	0	No	-123.21738	49.1482
I9	15-Jun	1	No (trace vegetation)	-123.22012	49.14818
I10	15-Jun	5	No (trace vegetation)	-123.22285	49.14812
J0	1-Jun	0	Yes (grasses, sedge)	-123.19886	49.15565
J1	1-Jun	4	Yes (40% rush)	-123.20162	49.15564
J2	1-Jun	film	No (trace vegetation)	-123.20436	49.15574
J3	1-Jun	film	No (trace vegetation)	-123.20713	49.15574
J4	1-Jun	0	No (sand)	-123.20991	49.15578
J5	1-Jun	film	No (sand)	-123.21268	49.15585
J6	1-Jun	N/D	No (sand/mud, some vegetation)	-123.21543	49.15591
J7	1-Jun	N/D	No (sand/mud)	-123.21817	49.156
J8	1-Jun	film	No (sand/mud)	-123.22092	49.15606
J9	1-Jun	N/D	No (sand/mud)	-123.22368	49.15614
K0	3-Jun	0	Yes (grasses)	-123.19926	49.16306
K1	3-Jun	0	Yes (grass and rush)	-123.20201	49.16284

K2	3-Jun	film	No (mud)	-123.20476	49.1626
K3	15-Jun	4	No	-123.20751	49.16239
K4	15-Jun	N/D	No (sandy)	-123.21026	49.16218
K5	15-Jun	N/D	No (trace vegetation)	-123.21301	49.16197
K6	15-Jun	film	No (trace vegetation)	-123.21573	49.16175
K7	15-Jun	0	No	-123.21846	49.16155
K8	15-Jun	0	No	-123.22121	49.16135
K9	15-Jun	6	No	-123.22394	49.16115
L0	2-Jun	N/D	Yes (grasses)	-123.20156	49.17009
L1	2-Jun	film	Yes (grasses/ rushes)	-123.20433	49.17014
L2	2-Jun	film	No (mud/sand with some mounds)	-123.20708	49.17005
L3	2-Jun	1	Yes (edge of bulrush)	-123.20993	49.16996
L4	2-Jun	3	No (near the bulrush)	-123.21268	49.16989
L5	2-Jun	1	No (mud)	-123.21543	49.16983
L6	2-Jun	1.5	No (mud)	-123.21819	49.16974
L7	2-Jun	film	No (mud)	-123.22094	49.16968
L8	2-Jun	1	No (sand/mud)	-123.22371	49.1696
L9	2-Jun	1	no (mud)	-123.22646	49.16954
M1	14-Jun	N/D	Yes (browsed vegetation, anoxic subsurface conditions)	-123.20548	49.20726
M2	14-Jun	film	No	-123.20792	49.20643
M3	14-Jun	0	No (silty mud)	-123.21031	49.20553
M4	14-Jun	0	No	-123.21276	49.20471
M5	14-Jun	0	No	-123.21521	49.20386
M6	14-Jun	film	No (silty mud, 7% vegetation)	-123.21767	49.20307

M7	14-Jun	0	No (approx 20% vegetation, 10 cm height)	-123.2201	49.20223
M8	14-Jun	film	No (approx 20% vegetation, 10 cm height)	-123.22259	49.20143
M9	14-Jun	0	No (sandy mud, 10% vegetation)	-123.22505	49.20062
M10	14-Jun	2	No (sand, trace vegetation)	-123.22754	49.19984
N1	13-Jun	film	No (mud)	-123.21706	49.21875
N2	13-Jun	film	No (silty mud)	-123.2198	49.21863
N3	13-Jun	N/D	No (silty mud)	-123.22252	49.2186
N4	13-Jun	N/D	No (silty mud)	-123.22524	49.21843
N5	13-Jun	N/D	No (sandy/ silty mud)	-123.22797	49.21822
N6	13-Jun	N/D	No	-123.23067	49.2181
N7	13-Jun/ 14-Jun (invertebrate samples)	0.5	No (muddy, thicker)	-123.23409	49.21793
N8	14-Jun	1	No (sandy)	-123.23686	49.21779
N9	14-Jun	0	No (muddy)	-123.23961	49.21765
N10	14-Jun	0	No (sand/ silt)	-123.24235	49.2175

Sediment Quality Parameters, Methods, and Recommendations

Introduction

The purpose of this document is to guide FREMP on the sediment quality component of the Roberts and Sturgeon Banks Habitat Inventory. Sediment quality parameters will depend on the study objectives and management implications.

As much research has taken place on Roberts Bank, the study area will focus on Sturgeon Bank. Possible sources of contaminants affecting sediment quality on Sturgeon Bank are: nutrient runoff from Richmond agricultural lands, YVR airport, sewage outfalls, urban runoff, boat traffic, as well as others. Parameters can be linked to potential sources of concern and sampled for.

The Possible Relevant Parameters section of this document is based on previous sampling studies in the area and input from the following sources:

- Ken Hall, UBC
- Chris Garrett, formerly with EC
- Peter Ross, DFO

Peter Ross also provided an article written by Grant, Paul B.C. et al of DFO entitled *Environmental Fraction of PCBS and PBDES During Particle Transport as Recorded by Sediments in Coastal Waters* which outlines parameters relevant to the Sturgeon Bank study area.

Sampling Size and Location, and Sampling Methods sections also include recommendations from sources with knowledge and experience in sediment quality sampling including:

- Chris Garrett
- Ken Hall, UBC
- Hans Schreier, UBC
- Puget Sound sediment sampling guidelines (US Environmental Protection Agency)

The Recommendations section combines relevant recommendations from the above sources and has been developed to fit the environmental conditions of the area, as well as objectives and budget constraints of the project.

1. Objectives

Sampling for sediment quality will assist FREMP in assessing the environmental health of Sturgeon Bank. This information will be used to monitor the health of salmon and seabird populations, their habitat and food sources.

2. Possible Relevant Parameters

Nutrients

Total Kjeldahl Nitrogen - A measure of total organic nitrogen and ammonia nitrogen. It is the sum of organic nitrogen, ammonia, and ammonium ($NH4+$).

Total Nitrogen - The sum of kjeldahl nitrogen (organic and reduced nitrogen), ammonia, nitrate, and nitrite.

Ammonia - Toxic and a common cause of fish deaths.

Phosphorous - Naturally occurs as phosphate which promotes algae growth and could result in a reduction of light and oxygen levels in the water.

Heavy metals

Heavy metals accumulate in sediment and have strong toxicity for organisms. They also accumulate up the food chain. ALS Laboratories will analyze heavy metals as a single test.

Organic Contaminants

Polychlorinated biphenyls (PCB's) - This organic contaminant is of concern because it is widely distributed, of high persistence, of high potential for bioaccumulation and biomagnifications, and can cause adverse health effects on wildlife. The top 6 PCB congeners found in the *Environmental Fraction of PCBS and PBDES During Particle Transport as Recorded by Sediments in Coastal Waters* study were PCB-118, PCB-138, PCB-101, PCB-95, and PCB-153.

Polybrominated diphenyl ethers (PBDE's) - This organic contaminant is used or has been used as a flame retardant and as a dielectric fluid. Like PCB's, it is of concern because it is widely distributed, of high persistence, of high potential for bioaccumulation and biomagnifications, and can cause adverse health effects on wildlife. The top 6 PBDE congeners found in the *Environmental Fraction of PCBS and PBDES During Particle Transport as Recorded by Sediments in Coastal Waters* study were BDE 209, BDE-47, BDE-99, BDE-49, BDE-100, and BDE-17.

Nonylphenol ethoxylates - This organic contaminant is used as a detergent.

Polyaromatic hydrocarbons (PAHs) - Hydrocarbons come from sources such as motor oils and gasoline. They enter the estuary mainly through stormwater discharges.

Note: Metro Vancouver has conducted sampling along a north-south transect from the Iona STP outfall at 80m depth. Organic contaminants PBDEs, nonylphenol ethoxylates, and PAHs were found.

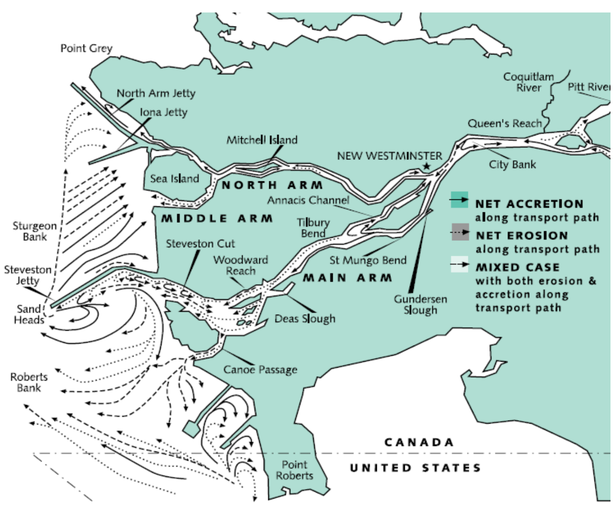
Tributyltin (TBT) - TBT is very toxic at low concentrations.

Hydrogen sulfide (H_2S)
Studies have been conducted on sea urchins, which are sediment dwelling invertebrates. Small concentrations were found to have caused reduced gonad production, wet weight, and increased death at higher concentrations. H_2S is often measured in higher concentrations around sewage outfalls due to the higher concentrations of organic matter causing bacteria to create anoxic conditions. However, low concentrations can kill also fish under certain environmental conditions (anoxic conditions). The EPA has set 0.002ppm as the acceptable level of H_2S in sediment.

3. Sampling size and location

Sample size
According to Chris Garrett, the number of samples can be decreased by compositing samples. At each site, 5-10 subsamples can be collected and then mixed together to form a single representative sample of the site. Sampling can be done on a grid system if this is appropriate for the area. When choosing areas in which composite samples can be taken, an understanding of the environmental conditions of the area should be taken into account. Areas with similar environmental conditions should be used as the composite sampling location. Environmental conditions to take into account include current patterns, contaminant sources, sediment types, etc.

Sample Location
According to Hans Schreier, important sampling locations can be located along transects from the Fraser River North and South arm but the current patterns should be researched before sampling locations are chosen. 30 samples would provide a sufficient number for statistical analysis. Samples can be taken at low tide near the shore and off shore in the intertidal zone under water at low tide.



This diagram taken from the study *Sediment Transport Patterns in the Lower Fraser River and Fraser Delta* shows net accretion and erosion patterns for sand at Roberts and Sturgeon Banks. This can be used to determine where sampling sites are located and where sediments sampled are coming from.

4. Sampling Method

According to Chris Garrett sediments should be collected at the same depth from each site because there are differences in the concentrations of contaminants with sediment depth. For surface sediments, the top 1-5cm or 1-10cm should be consistently collected for each sample. If the purpose is to compare new data with previous data, samples should be collected at the same depth. When sampling for chemical contaminants the sampling apparatus and containers must be appropriate for the contaminants to be sampled for.

According to Hans Schreier, the time period after the freshet is not optimal to sample for sediment quality because new sediment has just been deposited. However, a core can be taken and recently deposited sediments can be compared to older sediments.

According to Ken Hall, no more than the top 5 cm of sediment should be sampled. Also, the percent clay and silt fraction and the organic matter content should be determined for the sediments as these parameters can determine how contaminants bind to sediments.

The Puget Sound sediment sampling guidelines recommend that samples collected be placed in a stainless steel bowl and homogenized (mixed) with a Teflon spoon and placed into containers for the lab. A phosphate free detergent and brush should be used for cleaning sampling equipment. The equipment should be rinsed with in situ water and then a second rinse with analyte free water (Alconox, Liquinox, Detergent 8).

5. Recommendations

Due to the localized input of run-off from agricultural, urban, and industrial sources, many different parameters should be measured to develop an indicator of Sturgeon Bank sediment health.

Metals

Analyzing for metals is one of the best options because the analysis includes 31 different chemicals, many of which can have toxic affects on wildlife.

Polyaromatic Hydrocarbons

Polyaromatic Hydrocarbons are also very important due to the large urban influence in the Fraser River Estuary. Hydrocarbons will only be found in sediment underneath standing bodies of water, which are exempt from tidal influences (hydrocarbons were observed in Sturgeon Bank marshes by FREMP field technicians during summer 2011). Therefore, it is recommended that samples along the marsh be analyzed for polyaromatic hydrocarbons (other samples, taken farther out in the intertidal zone, can be analyzed as well to confirm the hypothesis of localized concentrations).

Persistent Organic Pollutants (POPs)

Persistent Organic Pollutants are environmentally damaging due to their high toxicity, persistence in the sediment and in an organism's tissue, bioaccumulation potential, and wide distribution. They are often found near urban areas and are especially common near sewage outfalls. Therefore, it is recommended that sampling for POPs be conducted throughout the

Sturgeon Bank intertidal zone. Recommended POPs to be analyzed are: PCBs, PBDE's, nonylphenol ethoxylates, TBT, and organochlorine pesticides.

Nutrients

Nutrient parameters, such as phosphate and total nitrogen, are considered lower priority because eutrophication is unlikely to occur along Sturgeon Bank due to of high tidal influence. Also, nutrients found in sediment require agitation in order to liberate many of the chemicals into the water body. Sampling for nutrients may be more appropriate for a water quality sampling project.

Ammonia

Low concentrations of ammonia are found naturally throughout the area. However, high concentrations are considered toxic and have been located near the sewage outfall. Therefore, it is recommended that samples near the sewage outfall be analyzed for ammonia.

Sediment Grain Size

It is also recommended that sediment grain size (percent silt and clay), and organic matter content be evaluated in conjunction with the results of sediment quality as they have a strong influence on the levels of certain parameters in sediment. PH, conductivity, and salinity are water quality measurements which can be measured along with sediment quality. These measurements could provide greater understanding of the environmental health of the region. The 2011 FREMP Habitat Inventory will have sediment grain size and salinity data which can be used if sediment quality samples are collected near the 2011 sample sites. Salinity may have to be re-sampled because it is highly variable throughout the year. The variability of salinity will affect conductivity levels as well.

Comparative Studies

Analyzing for PBDE's, nonylphenol ethoxylates, and PAH's will allow FREMP to compare results with Metro Vancouver's studies.

Sampling Method

The recommended sampling method for this project is to use a 5.5 cm diameter corer placed into the sediment at a depth of 5 cm. The bottom of the core will be cut and the sample will be placed into a bowl, mixed and then placed into a jar. Multiple samples can be taken in each area and composited. However, it is recommended that 30 samples should be taken for statistical analysis so compositing may not be necessary.

Limitations

The system outlined above may work for sampling heavy metals, nutrients, and organic contaminants, however it would not be appropriate work for hydrogen sulfide because it can not be mixed and exposed to oxygen. Also, in many places sediment has been stirred up and 5 cm may not be deep enough to sample.

Core Method vs. Grab Sampling

The core method is preferable for this project vs. grab sampling from a boat because a core sample taken during low tide will ensure a 5cm depth. Sampling on land is achievable because the study area is in the intertidal zone. Other advantages include easier navigation for a grid system, more comprehensive observations, and lower costs.

The following page shows a map of the Sturgeon Bank sampling area. Possible sediment quality sampling sites are shown as white circles. The 2011 FREMP Habitat Inventory transect lines and sampling sites are shown as blue dots. The approximate marsh edge is outlined in green. There are 24 sites off of Lulu Island and 6 sites off of Sea Island. Included in these areas are a total of 6 sites within the vegetated marsh. There may be different relevant parameters depending on the location of the sample site. Sample sites were chosen to reflect the variations of environmental conditions, sediment deposition or erosion conditions, and concerns of the study area. They are also located along the 2011 Habitat Inventory transects so that data from that study can be complimentary to the sediment quality study.

6. Cost estimates

Costs For Lab Analysis for all Parameters per Sample

Parameter	ALS Group Cost per Sample	AXYS Analytical Services Cost per Sample
Total Kjeldahl Nitrogen	$62.91	
Total nitrogen	$27.00	
Ammonia		
Phosphorous	$36.45	
Heavy Metals	$72.00	
Polychlorinated biphenyls (PCB's)		$900 for all 209 congeners, $625 for WHO toxic list of 12 analytes
Polybrominated diphenyl ethers (PBDE's)		$875 for 46 congeners
Nonylphenol ethoxylates		
Polyaromatic hydrocarbons (PAH's)	$135	$450-$625
Tributyltin (TBT)		
Hydrogen sulfide (H_2S)	$117.00	
Total Costs		

Costs for Lab Analysis for Recommended Parameters for Lulu Island

Parameter	ALS Group Cost per Sample	AXYS Analytical Services Cost per Sample
Ammonia		
Heavy Metals	$72.00	
Polychlorinated biphenyls (PCB's)		$900 for all 209 congeners, $625 for WHO toxic list of 12 analytes
Polybrominated diphenyl ethers (PBDE's)		$875 for 46 congeners
Nonylphenol ethoxylates		
Polyaromatic hydrocarbons (PAH's)	$135	$450-$625
Tributyltin (TBT)		
Total Costs		

There are 24 sample sites on Lulu Island

Costs for Lab analysis for Recommended Parameters for Sea Island

Parameter	ALS Group Cost per Sample	AXYS Analytical Services Cost per Sample
Ammonia		
Heavy Metals	$72.00	
Polychlorinated biphenyls (PCB's)		$900 for all 209 congeners, $625 for WHO toxic list of 12 analytes
Tributyltin (TBT)		
Total Costs		

There are 6 sample sites off of Sea Island

Costs for labour and Transportation

The field sampling portion of this project is estimated to take 3 days (9 hours per day)

Workers	Days	Total Hours	Cost
1	3	9 hours/day x 3 days = 27 hours	27 hours x $16/hour = **$432**
2	3	9 hours/day x 3 days x 2 people = 54 hours	54 hours x $16/hour = **$864**

The total labour cost for the field portion of this project is $432 per person.
If 2 people are required for this project for logistical or safety reasons, the costs will double to $864 total.

Driving distances range from 40 to 50 km round trip. Compensation for transportation is $0.30/km.

Distance per Day	Total Days	Total Cost
45km/day	3	45km/day x $0.30 x 3 days = **$40.50**

Dry ice may be required for this project. Cost for dry ice is around $20 for the 3 days.

The field costs may range between $472.5 (for one person and transportation compensation) and $924.5 (for 2 people, transportation compensation, and dry ice).

7. Conclusion

An understanding of the sediment quality parameters outlined in this document is essential to assess the environmental health and conditions of the Fraser River estuary at Sturgeon Bank. Information gathered through this study will be complimented with data obtained from the 2011 FREMP Habitat Inventory. For example, sediment grain size analysis and salinity results will be useful in determining conditions favourable for the prevalence of contaminants within the sediment. Sediment deposition and erosion measurements will help to determine the levels of sediment which are deposited at the site which may carry contaminants. The parameters to be analyzed in the laboratory will be costly; therefore there must be clear objectives when deciding which parameters to analyze and where to take them. The recommendations of this document are based on relevant sources and available knowledge, however other studies exist which can guide management decisions based on the health of the estuary. The study entitled *Linking Sediment Geochemistry in the Fraser River Intertidal Region to Metal Bioaccumulation in Macoma Balteica* written by Thomas, Christine, A. is an example of a source of information linking heavy metal contaminants to important food source organisms of the Fraser River estuary. The study entitled *Sediment Transport Patterns in the Lower Fraser River and Fraser Delta* written by McLaren, P. and Tuominen, T. includes diagrams which show sediment transport patterns for sand and mud in the Sturgeon Bank area. These studies as well as others can be used to further understand the results of sediment quality analysis and the affects these metals, nutrients, and chemical contaminants have on specified objectives. The Sturgeon Bank area is a relatively small study size but it contains many different habitats, environmental conditions, and development pressures. A vegetated marsh habitat may have different management objectives from a sand flat. Some contaminants may affect certain organisms more than others. Experts in this field may have to be contacted to develop a causal relationship between certain organisms and some of the parameters outlined in this document such as chemical contaminants and heavy metals. The results of the benthic invertebrate samples taken in the 2011 FREMP Habitat Inventory will be useful in determining which invertebrates are most prevalent at the sample locations where sediment quality samples can also be taken. Those invertebrates identified as important food sources can be used to correlate relationships. The relationship between biofilm on the surface sediments and such parameters as polyaromatic hydrocarbons may also be a useful part of this study. During the Habitat inventory, hydrocarbons were observed in close proximity to biofilm in some areas such as within marsh pools in the study area.

An intertidal system is very open to outside influences and is constantly changing and conditions will be changing throughout the year as well. These are all factors which must be taken into account when deciding the final parameters, sampling locations, and methodology for sediment quality analysis.

Eelgrass Sampling Methodology

The methodology for sampling eelgrass summarized in this document was developed by Precision Identification Biological Consultants in 2002. The full methodology and background are described in a report entitled *Methods for Mapping and Monitoring Eelgrass Habitat in British Columbia*.

The purpose of the eelgrass survey is to get a representation of the amount of eelgrass in a studied area. To start, the sample area is defined. This may be, for example, a defined stretch of coastline at the low tide mark. The extent of eelgrass present in the area (the eelgrass beds) is then mapped using a GPS and polygons of the areas are recorded. An eelgrass bed is defined as an area having a minimum of 1 shoot per m^3. Patches are included within beds and the outermost boundaries of the patches are the boundaries of the beds. Within the polygons, the sampling procedure takes place to the level of detail which is determined to be necessary for the study.

The sampling procedure is as follows:
A set distance (ex. 60 metres) is laid out with a measuring tape within the polygon area. The start of the set distance is chosen to cover an eelgrass community and usually starts at one edge of the community. Quadrats are then placed along and off of the sample distance (measuring tape) over eelgrass communities at random locations. The random locations are determined by tossing the quadrats. The location of the quadrat landing spot is the sample location. The size of the quadrat used for the native eelgrass (Zostera marina) is ¼ of a square metre. The size of the quadrat used for the introduced eelgrass, Japanese eelgrass (Zostera japonica) is 1/16 of a square metre. The difference in quadrat sample sizes is due to the larger size and fewer stems per area of Zostera marina compared with Zostera japonica. A representative eelgrass leaf is chosen for each quadrat. The width and length of the leaf is measured and recorded and multiplied to find the leaf area. Within the area of the quadrat, eelgrass stems are counted. Eelgrass stems which originate outside of the quadrat but have leaves that fall within the quadrat location are not counted in the survey and are removed from the area before counting takes place. Also recorded for Zostera marina only is the number of stems that are flowering. 30 quadrat sample counts are recorded for a 60 metre transect. The eelgrass polygons are visually split into densities if noticeable differences in densities are observed and an estimation of percent cover of each density is recorded. For example: 11-25% eelgrass cover for the community in which the transect takes place, and 0-10% cover for the community within the same polygon closer to the shoreline. The polygon is also mapped as a continuous community or as patches of eelgrass. If a patch is measured as being greater than 10 square metres, it is classified as a separate polygon and mapped as a polygon with the GPS. Substrates are recorded on order of dominance. The number of stems for the sample area, determined by the quadrats, is taken as a representation of the polygon area. The number of stems per square metre can then be multiplied by the area of the polygon as an estimation of the amount of eelgrass present in the polygon. These estimations of the number of eelgrass stems can be added with other polygon estimations in the study area to give an estimation of the amount of eelgrass stems present within the sample area. Photos are

taken at each site and show the overall site view and close up views of eelgrass with scales such as rulers included in the photos. Each year the photos must be taken in the same location.

Eelgrass mapping for the Sturgeon Bank study area

The Sturgeon Bank study area falls entirely within the intertidal zone. Therefore only the parameters which are possible within this zone can be assessed. For a level 2 survey all that is required is mapping the location of eelgrass meadows, overview of intertidal habitat, and delineation of meadows (with GPS). During the Roberts and Sturgeon Banks 2011 Habitat Inventory, locations of eelgrass beds and approximate percentages of eelgrass was mapped along survey transects at Sturgeon Bank. An overview of intertidal habitat was also taken. To complete the level 2 survey, eelgrass beds will have to be mapped using a GPS to create polygons. For a level 3 survey the parameters which are possible are: location of eelgrass meadows, overview of intertidal habitat, delineation of meadows (with GPS), distribution (degree of patchiness: continuous or patchy), shoot density including sexual status, and leaf area index (LAI). Overview of subtidal habitat, maximum and minimum depth, and turbidity are not possible without a boat and are parameters for the subtidal zone. Environmental water quality monitoring can be achieved through increasing the parameter level to level 4 by including salinity measurements in parts per thousand (ppt) with a refractometer, measuring the Total Suspended Solids (TSS), and measuring chlorophyll A. The samples for Total Suspended Solids and chlorophyll A are collected through water samples and are analyzed by a lab. The lab will give the sampling procedure and storage methods.

The Sturgeon Bank study area can be mapped and monitored using the parameters in a level 2 survey over the entire area and with more detail in a level 3 or 4 survey for environmentally sensitive areas with disturbance potential due to development. The level 3 or 4 survey must also include a protected area with optimal eelgrass habitat potential for a reference area to compare with other areas. The coastal area off of Sea Island is an area which includes a proposed future airport runway expansion development. This could be sampled with the level 3 or 4 parameters.

Appendix 7. Field Equipment List

Equipment list

Equipment	Quantity	Purchased at: (included if specific equipment)
4 Nimh AA rechargeable batteries with charger	1 set	
“Write in the rain” ringed book	1 set	
“Write in the rain” paper	150 pages	
Mallet	2 (1 metal, 1 rubber)	
WIRL-PAK bags, 60ml/2oz. (B01064WA)	870 bags	Dynamic Aqua Supply
Large, 50L or greater cooler with good insulation for sample storage with dry ice	1	
Small cooler for field work	1	
Gel Ice Packs	10	
Square- Combination Square ruler	1	Rona
183 cm metal pole	1	
Dry ice	2 blocks (for each sample week)	Iceberg Dry Ice
Large backpack for stakes	1	
Hip waders	1 (per person)	Dynamic Aqua Supply
Wood stakes	266 (3 foot pieces cut from 12 foot 2 x 2 inch wood)	Standard Lumber
Orange flagging tape	1	
Duct tape	1	
4 mm corrugated plastic sheet	1	
Refractometer: American Optical Corp. (Keene, N.H.) handheld refractometer (catalog # 10419)	1	Borrowed from Sean Boyd
60 cc syringe	15	Dynamic Aqua Supply
Ziploc bags	266	
Aluminum muffin trays for drying sediment	133 individual spots (trays in groups of 6)	
Mixing spoons	2 (large and small)	