The K'ómoks and Squamish Estuaries:
A Blue Carbon Pilot Project

Final Report to North American Partnership for Environmental Community Action (NAPECA) Grant 2014-1362

Comox Valley Project Watershed Society

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Executive Summary

The Comox Valley Project Watershed Society (CVPW) and the Squamish River Watershed Society (SRWS) received funding from NAPECA to work on developing a community-based initiative for carbon assessment in estuaries.

CVPW conducted research with the goal to develop a protocol suitable for coastal communities on the Pacific coast to identify rates of carbon sequestration in estuaries and to restore eelgrass and salt marsh habitats lost due to human activities. It is hoped community-based projects will be recognized for the carbon they sequester and store.

The protocol included four components: mapping, estimating carbon stores and estimating carbon sequestration rates. CVPW developed field methods that could be easily followed by other community groups.

Mapping Eelgrass & Saltmarsh

The area covered by saltmarsh and eelgrass can be estimated from air photos or satellite imagery. However, the cost associated with these types of imagery can be prohibitive to a small community group. CVPW tested several methods to obtain accurate area estimates of eelgrass and saltmarsh. Using a handheld GPS unit and walking the perimeter of a saltmarsh bed or the upper limit of the eelgrass bed was determined to be the simplest and least expensive option. This method proved to be very accurate when compared with air photo interpretation.

Tracing the lower limit of subtidal eelgrass is challenging. Most air photos and satellite imagery have difficulty providing accurate information. Again, the use of a handheld GPS unit proved to be the most efficient and reliable. A SCUBA diver 'walked' the lower boundary while dragging a float line with a GPS strapped to the float.

Estimating Carbon Stores & Sequestration Rates

CVPW tested several methods to collect sediment cores and determined the easiest and most inexpensive method is to use an open-ended acrylic cylinder. The sediment core was sampled and sectioned using a home-built coring stand. All samples from the initial cores were sent to a commercial lab and analyzed for total Carbon and C/N ratios as well as radioisotope analysis ($^{210}Pb/^{226}Ra$) to determine rate of sedimentation and age of sediments. Once representative cores have been analyzed, additional cores can be collected and analyzed for Carbon only.

Our Results

The K'ómoks Estuary contains 23 ha. saltmarsh and 164ha. eelgrass. The estimated carbon sequestration rate for the Estuary is 22.8 g C/m^2/yr. Based on 71% of eelgrass coverage, the K'ómoks Estuary has the capacity to store 42.5t C/yr. If extrapolated to the entire eelgrass area, the Estuary could store as much as 58t C/yr.

We hypothesized that carbon sequestration is influenced by local geography and hydrology so that different areas of the Estuary sequesters carbon at different rates and much of the carbon associated with eelgrass plant material is carried out of the Estuary and deposited elsewhere. These factors should be considered when selecting an area to carry out Blue Carbon projects and eelgrass habitat restoration.

Eelgrass & Saltmarsh Habitat Restoration

This project also involved habitat restoration of both eelgrass and saltmarsh beds. Eelgrass habitat restoration methods developed by Precision Environmental Ltd. were found to be cost-effective and suitable for community groups. The methods were modified for this project and achieved a success rate as high as 95% survival. Over the past 5 years, CVPW planted 6,300 m^2 eelgrass, 700m^2 of which was directly related to the NAPECA project.

Saltmarsh also acts as a carbon sink. CVPW developed a method to restore saltmarsh habitat in the K'ómoks Estuary. In summer 2015, two 'islands' were constructed by installing fill and the front edge was armoured with large boulders to protect from wave action during storm events. The areas were allowed to settle for one year and then were planted with 6 species of native saltmarsh vegetation. Over 500m^2 new saltmarsh area was created.

Opportunity for other Coastal Communities

The methods developed by CVPW to collect the baseline information are simple, cost-effective, and don't require advanced technical skills. It is hoped that once shared by NAPECA and CVPW, other community organizations will take advantage of this protocol to assess their local estuary and identify opportunities for habitat restoration with Blue Carbon benefits.

Chapter 1 - Introduction

The Comox Valley Project Watershed Society (CVPW) and the Squamish River Watershed Society (SRWS) received a two-year grant from the North American Partnership for Environmental Community Action (NAPECA). The purpose of the NAPECA grant was to carry out a study in the K'ómoks Estuary to measure the amount of carbon stored and carbon sequestration rates. In addition, CVPW would develop a protocol suitable for coastal communities on the Pacific coast to identify rates of carbon sequestration in estuaries and to restore eelgrass and salt marsh habitats lost due to human activities. It is hoped that future community-based projects will be recognized for the carbon they sequester and store while at the same time supporting habitat restoration.

Blue Carbon

The term Blue Carbon refers to the carbon captured by the world's ocean and coastal ecosystems into carbon sinks. Just as in terrestrial systems, the carbon is captured from the atmosphere and fixed via photosynthesis. The Blue Carbon in coastal vegetated habitats is stored in organic-rich sediments underlying the vegetation and, if left undisturbed, may be stored for millennia.

Saltmarshes and eelgrass meadows play two important roles:

1. they grow rapidly each year and capture carbon dioxide from the atmosphere each year (carbon sequestration);
2. because the sediments are waterlogged, they tend to be anaerobic and limit any biological activity, thus they store carbon in the sediments (carbon storage).

Not only does human activity add more carbon to the atmosphere by burning fossil fuels, a carbon source, but we are also destroying carbon sinks by human activities near coastlines. When these habitats are damaged, they change from a carbon sink to a carbon source, sort of a double jeopardy. Therefore restoring and protecting existing eelgrass habitats should be a priority.

Comox Valley Project Watershed

CVPW is a non-profit society whose mission is to promote community stewardship in the Comox Valley watershed through education, information and action. With over 20 years of habitat restoration experience, CVPW has worked on salmon enhancement in the local rivers and fostered the establishment of Stream Keepers organizations for many of the fish-bearing streams in the watershed.

Salt marsh riparian areas and eelgrass meadows are important habitats for fishes and other marine species, providing refuge, food, protection, and shelter from high temperatures. One of the goals of CVPW is to restore and protect saltmarsh and eelgrass habitats in the K'ómoks Estuary.

The local K'ómoks First Nations provided their support for eelgrass restoration projects through the signing of a Memorandum of Agreement (MOA) with CVPW in 2012, providing permission for CVPW to work in their traditional territory on projects that help protect and restore the estuary. With their support, the K'ómoks Estuary was chosen as the pilot project site for the development of Blue Carbon protocols. In 2012, CVPW formed a Blue Carbon Team comprised of professional and volunteers, led by Dr. Paul Horgen, Professor Emeritus, University of Toronto. Preliminary mapping data was collected in 2012-2013 and over 3000m^2 of eelgrass was planted in the estuary. In May 2015, CVPW signed a Memorandum of Understanding (MOU) with North Island College to cooperate on environmental stewardship projects.

The Project

The project supported by NAPECA had four main goals:

1. Map eelgrass and saltmarsh coverage in K'ómoks Estuary
2. Determine the amount of carbon stored in the sediments underlying eelgrass and saltmarsh habitats and estimate rate of carbon sequestration.
3. Carry out eelgrass and saltmarsh habitat restoration projects.
4. Develop a protocol suitable for community groups interested in identifying Blue Carbon benefits in their estuary.

The project spanned two years, from April 2014 to May 2016. The project lead was Christine Hodgson with technical expertise provided by Angela Spooner. In total, over 1,000 hours volunteer time was contributed to this project.

The activities carried out by CVPW were supported by other funding agencies in addition to NAPECA, including:

- Pacific Institute for Climate Solutions (PICS)
- Pacific Salmon Foundation
- BC Hydro Fish & Wildlife Compensation Program
- Fisheries and Oceans Canada, Recreational Fisheries Conservation Partnerships Program (RFCPP)
- Natural Sciences & Engineering Research Council of Canada (NSERC), College and Community Innovation Program

We feel privileged that as a community organization we are able to contribute to baseline research that will further our understanding of Blue Carbon. This project has already generated one M.Sc. thesis and it is anticipated at least two peer-reviewed publications will be produced.

Our Results

The following chapters summarize the work completed by CVPW under this project. It covers the work we accomplished on mapping, collecting and analyzing sediment cores, and eelgrass and saltmarsh habitat restoration methods.

In addition to this work, CVPW also undertook research on developing a DNA fingerprint for *Z. marina* with Dr. Will Hintz at University of Victoria. Samples throughout the estuary and in the sediment cores were analyzed and *Z. marina* DNA was found in all sediment samples, as well as in samples collected at 25, 35, and 165m depths in the Strait of Georgia.

Furthermore, CVPW conducted a short survey of eelgrass debris piles located at the upper intertidal area in two locations in the Estuary. It was determined that 0.4 -150 t organic C is captured along 500 m of the low sloped foreshore above the high tide line where mass amounts of eelgrass detritus are deposited and buried. Eelgrass DNA and observational evidence suggests eelgrass detritus is anchored in place by actively growing saltmarsh vegetation.

CVPW organized or participated in several meetings and conferences to disseminate the information gathered. These include:

- 2014 Salish Sea Ecosystem Conference, April 30-May 2, Seattle, Washington
- Pacific Estuarine Research Society (PERS), 37th Annual Meeting, April 3-5, 2014, Newport, Oregon.
- Restore America's Estuaries (RAE) 7th National Summit, November 1-6, 2014, National Harbor, Maryland.
- Commission for Environmental Cooperation (CEC), Joint Public Advisory Committee Regular Session 14-03: North America's Coasts in a Changing Climate, November 6-7, 2014, Arlington, Virginia.
- Climate Change Solutions & Habitat Restoration at the Community Level: Projects Completed by Comox Valley Project Watershed Society in 2014-15, March 14, 2015, Courtenay, British Columbia
- CVPW AGM, June 4, 2015, Courtenay, British Columbia
- Pacific Institute for Climate Solutions (PICS) special lecture, October 15, 2015, Victoria, British Columbia
- Coastal & Estuarine Research Federation (CERF) 2015 Conference, November 8-12, Portland Oregon
- Blue Carbon Workshop, organized by CVPW, April 11, 2016, Courtenay, British Columbia
- 2016 Salish Sea Ecosystem Conference, April 13-15, Vancouver, British Columbia
- plus several guest lectures to college classes, general public

SWRS conducted a scoping study of their estuary to identify areas suitable for eelgrass habitat restoration and develop relationships with regional governments. The work by SRWS was completed in 2014 (Appendix 1).

Chapter 2 - NAPECA Study Sites

The project was undertaken in the K'ómoks Estuary located on the east side of Vancouver Island (Figure 1). The 20.79 km^2 is bordered by the communities of Comox, Royston, and Courtenay, BC. The Puntledge and Tsolum Rivers merge into the very short Courtenay

River that flows into the Estuary. This is a dynamic Estuary with hydrologic influence from the outflow of the Courtenay River, Trent River, several smaller creeks, surface wind waves, and tidal inflow from Baynes Sound. The marine climate and surrounding topography result in dry summers and wet winters with average seasonal surface temperature variations from 7.4˚C to 17.4˚C. The annual average air temperatures range from 0.9˚C to 22.8˚C and there is annual average precipitation of 1153 mm.

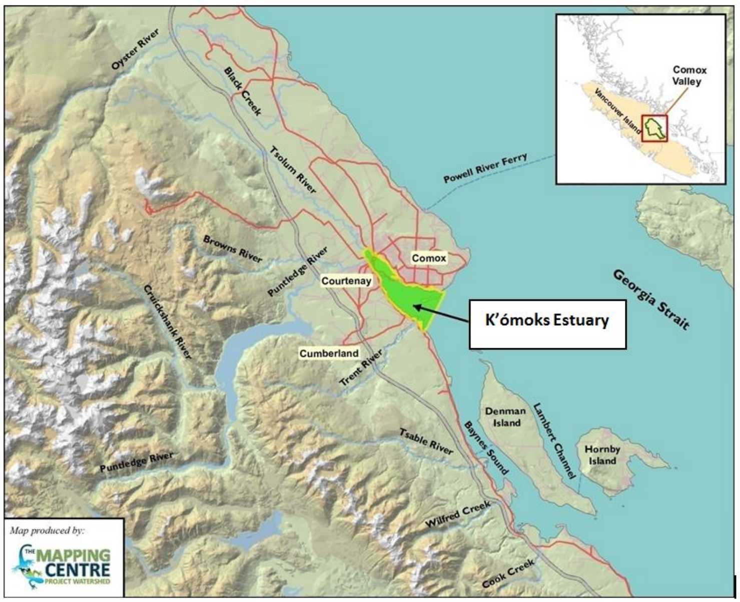


Figure 1. Location of the K'ómoks Estuary on the east coast of Vancouver Island, BC, Canada.

Historically, the K'ómoks Estuary was affected by log dumps and booms, a lumber mill, dredging, and upstream mining of copper and coal (Figure 2). Contemporary influences include storm drainage and several marinas.

Figure 2. Historic and current effects on the K'ómoks Estuary.

Location of Study Sites

Site locations were selected by evaluating areas within the estuary that were suitable candidates for future *Z. marina* restoration. Past studies identify the importance of physical habitat characteristics such as bathymetry, water quality, sediment distribution, exposure and proximity to other eelgrass beds. With these parameters and considerations in mind, study plots were located at the same or similar elevation/bathymetry and within similar aspect, slope, and substratum type.

The intertidal and subtidal study plots were easily accessible, monospecific beds of *Z. marina* paired with bare areas at approximately the same bathymetry within the K'ómoks Estuary. In May of 2014, six paired study plots were established in the K'ómoks Estuary; three intertidal and three subtidal (n=12) (Figure 3). Each site had one vegetated and one barren 50 m x 10 m plot (Figure 4). One barren plot in the Brooklyn Creek Site was later abandoned as it was deemed unsuitable for future successful *Z. marina* transplantation and was not replaced.

Figure 3. Location of Study Sites in K'ómoks Estuary. The plots on the east side of the Estuary (right in photo) were called Brooklyn Basin sites. The plots near the mouth of the Puntledge River (upper in photo) were called Hospital sites. The plots on the west side of the Estuary (left in photo) were called Royston sites.

a) b) c)

Figure 4. Close-up of Study Sites. a) Brooklyn Basin sites; b) Hospital sites; c) Royston sites. Eelgrass transplants occurred on one-half of the area (250 m²) at the sites as indicated. (See chapter 8 for further details.)

Chapter 3 - Mapping Eelgrass and Saltmarsh Habitats

The area covered by saltmarsh and eelgrass can be estimated from air photos or satellite imagery. However, the cost associated with these types of imagery can be prohibitive to a small community group.

Some challenges with the mapping eelgrass included:

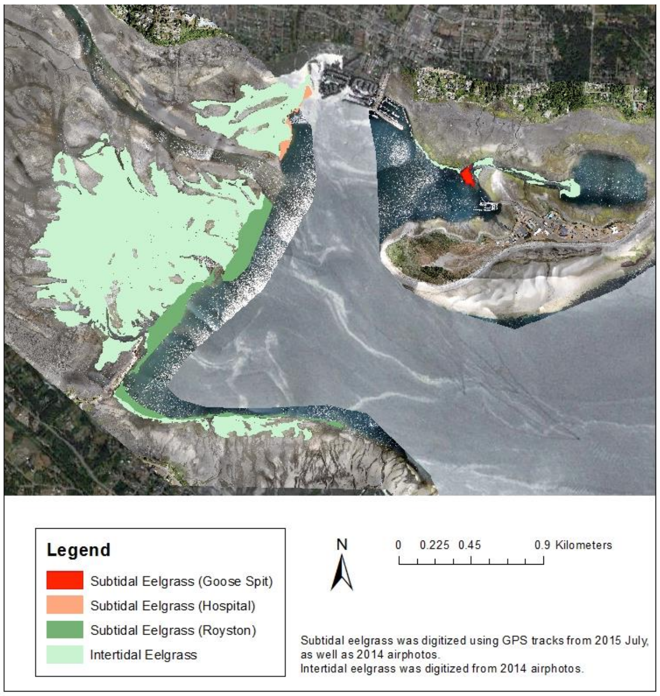
- Eelgrass is only exposed at very low tides and some is always subtidal
- It's known the distribution of eelgrass ranges from +1 to -1m depth and so this could be used to predict where it will be located based on this information.
- The zero tide line can be interpreted from air photos taken during a known low tide.
- The lower edge of subtidal eelgrass is difficult to ascertain

Interpreting Digital Air Photos for Eelgrass Coverage

For the purpose of this study, air photos of the K'ómoks Estuary were taken June 13, 2014, at a 0.4m tide. This allowed for maximal exposure of intertidal eelgrass meadows. The images were compiled into large data files that were then interpreted by technicians skilled in using ArcView.

The images were analyzed in ESRI ArcMap 10.2.2. (2014). The two aerial photos were mosaicked together into one data layer. Gaps between images were filled in using an ArcGIS base map. Eelgrass was digitized at 1:250 scale, and attributes for Coverage and Tidal Zone were filled in appropriately (Figure 5).

Figure 5. Map of K'ómoks Estuary showing distribution of eelgrass. A base map of the Estuary was overlain by the actual air photo images.



Coverage refers to the density of eelgrass cover. Eelgrass beds with greater than or equal to 75% coverage were identified as "Dense" and eelgrass beds with less than 75% coverage were identified as "Sparse."

Tidal Zone refers to the location of the eelgrass bed compared to the Canadian Hydrographic Service (CHS) Low Water Mark (accessed from DataBC). Eelgrass beds above the CHS line were identified as intertidal, and eelgrass beds located below the CHS line were identified as subtidal (Figure 6).

Figure 6. Map of K'ómoks Estuary showing distribution of dense and patchy eelgrass as interpreted from digital air photos analyzed using ArcMap.

Because this method requires interpretation by a skilled technician viewing air photos, the procedure was repeated three times by three different technicians. All technicians were students who had received training in ArcMap. Figure 7 shows some the different results recorded by three different students. This provides an indication of the level of accuracy of this mapping method.

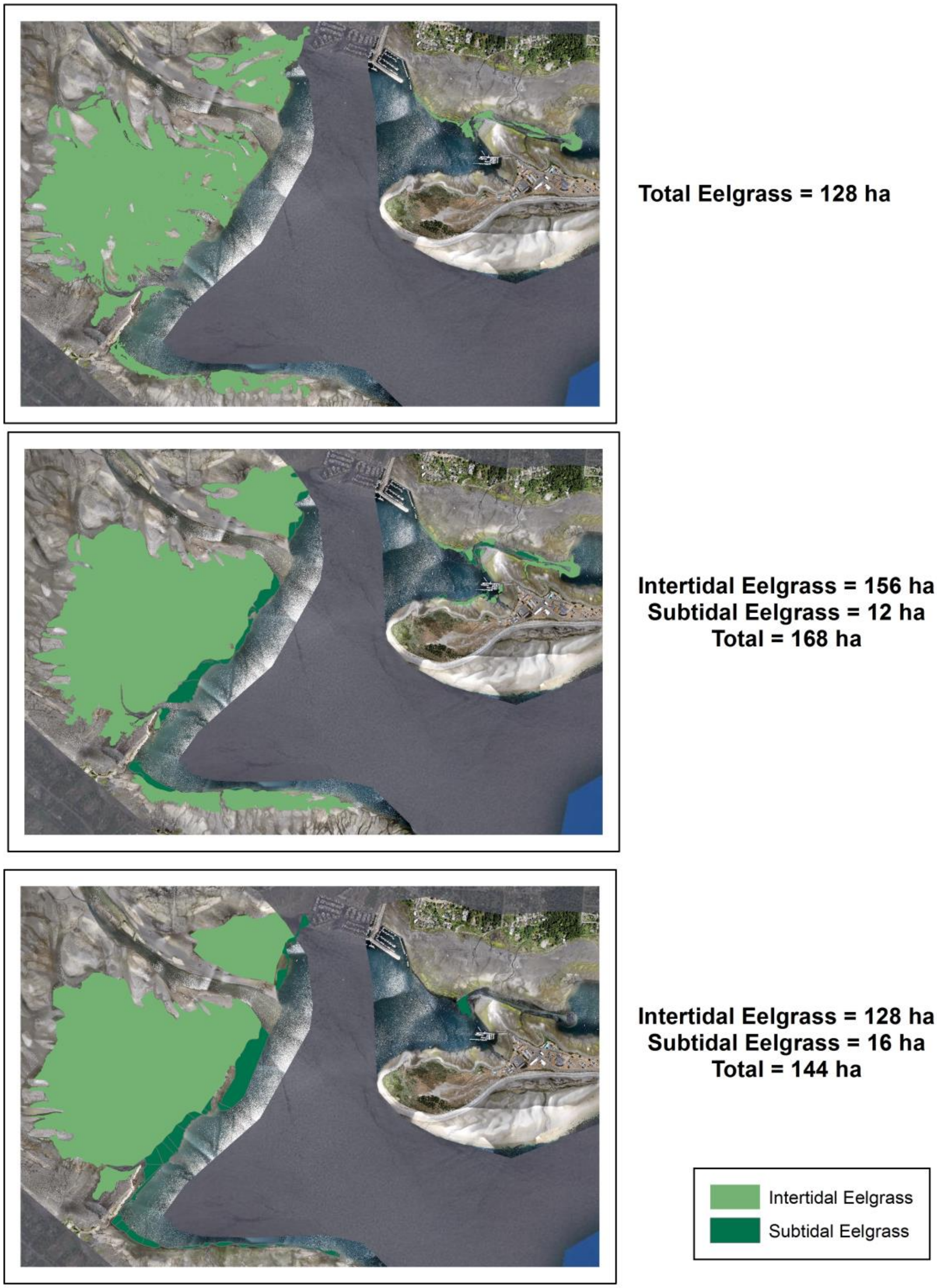


Figure 7. Comparison of results obtained by three different assessments of digital air photos. The area estimates for eelgrass ranged from 128 ha to 168 ha.

Using GPS Tracks to Verify Air Photo Interpretation

In order to verify the accuracy of the mapping, we conducted ground-truth surveys by walking the upper limit of the eelgrass bed. Figure 8 compares the results of GPS tracks with the mapping data. This provided a measure of comfort in the skills of the mapping technicians.

a)

b)

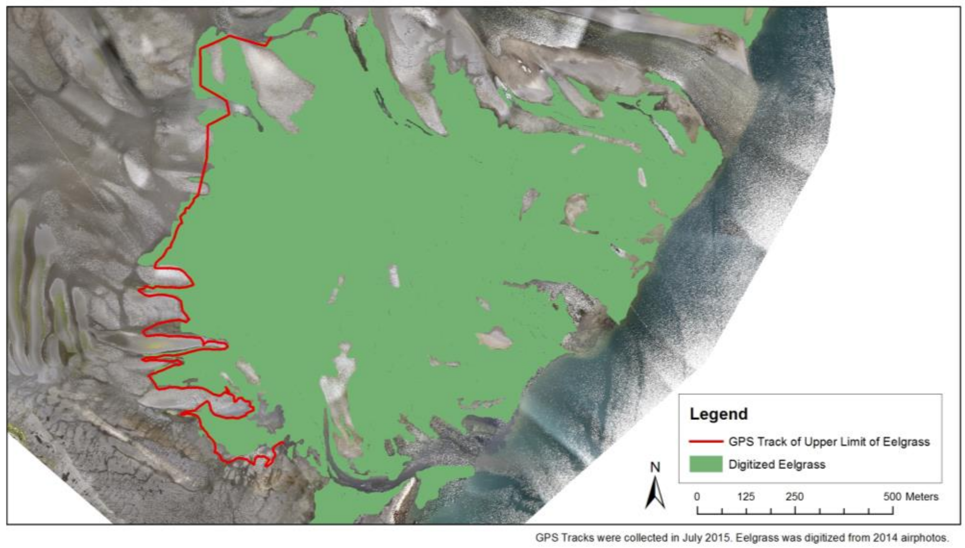


Figure 8. Comparison of results obtained using GPS tracking and aerial photography in the identification of the upper limit of eelgrass in the K'ómoks Estuary, BC. a) tracks along Goose Spit, b) tracks along southwest section of the Estuary.

Because the cost of air photos and subsequent analyses by a skilled mapping technician can be prohibitive to a small community organization, and the fact that GPS tracking seemed to provide similar results, we determined that GPS tracking could be an accurate and simple method to map upper limits of eelgrass meadows. So, although the GPS tracking was done to ground-truth the results of the mapping, it demonstrated that GPS tracking alone is sufficient.

Furthermore, we determined that maps with GPS tracks could be produced using Google Maps, thus eliminating the requirement for a skilled mapping technician. This is discussed further later in this chapter.

Mapping Saltmarsh Coverage using Air Photos

In 2013, CVPW mapped saltmarsh coverage in the K'ómoks Estuary using air photos and digital interpretation. Figure 9 shows the final estimated distribution of saltmarsh. Much of the saltmarsh in the Estuary is fringing fragments, with only one intact 10-12 ha section near the mouth of the Puntledge River.

Figure 9. Map of saltmarsh areas in K'ómoks Estuary. Air photos were taken in 2013.

Although not tested for this project, we believe that most saltmarsh areas can be mapped by community organizations using handheld GPS units and then produce maps using Google Earth, similar to the method proposed for mapping eelgrass meadows.

Mapping Subtidal Eelgrass

Mapping the distribution of subtidal eelgrass is challenging at best. Most air photos and satellite imagery have difficulty providing accurate information.

Given that we were seeking a method that could be accomplished by a citizen-science organization, we wanted to find a method that didn't require specialized skill sets. We attempted several other methods to map subtidal eelgrass:

- We tried running transects perpendicular to the lower boundary of the eelgrass bed and then determine presence/absence. A kayak or other vessel tracked along a compass bearing and then marked GPS points using a handheld GPS unit, plus presence/absence. There was difficulty in viewing through the water column, even when attempted at different times of the year. Also, it proved difficult to 'pause' and record data without losing the compass bearing. Table 1 shows an example of the data sheet used for mapping.
- We dragged a snorkeler behind a motorized boat or kayak to visually identify presence/absence of eelgrass (Figure 10). This proved problematic as the snorkeler had to continually signal presence or absence and a second technician recorded the data. It proved difficult to track along the lower edge of the eelgrass meadow and was time-consuming, taking as long as 30 minutes to map less than 50m linear distance of the lower edge.

The method that was deemed most suitable used SCUBA, where the diver 'ran' along the lower edge of the eelgrass meadow dragging a line attached to a surface float with a hand-held GPS unit contained in a waterproof bag (Figure 11). The GPS unit recorded the track of the diver. A second diver followed the path dragging a line with a float only. At every 200m, the diver pulled on the line, signaling individuals on the vessel to mark that point using handheld GPS units. This doubling of recording was used to ensure the data was not lost.

Table 1. Data sheet for Mapping Subtidal Eelgrass

Deepwater Eelgrass data sheet						
Vessel follows a bearing, from known intertidal to subtidal. Observer identifies presence/absence of eelgrass as specified waypoints. Typical transect						
Date:			Time:			Weather: Overall site name:
Compass Bearing:						
Collect waypoints every 5m.						
Data collectors:						Snorkler: Transect length:
Time	Waypoint	Coordinates	Depth (m)	Eelgrass present(Y) / absent (N)	Visibility (m)	Comments
Additional Comments:						

Figure 10. Methods to map subtidal distribution of eelgrass in K'ómoks Estuary. a) a snorkeler was dragged by a herring skiff; b,c) our summer intern, Maya Guttman, was transported and then dragged behind a kayak.

Figure 11. Use of SCUBA to map lower edge of eelgrass meadows in K'ómoks Estuary. A line attached to a surface float and handheld GPS unit contained in a waterproof bag was dragged by a diver as they 'ran' along the lower edge of the eelgrass meadow. The GPS unit recorded the track of the diver.

Using GPS Tracks to Map Eelgrass

As mentioned above, it was determined that accurate mapping of eelgrass meadows could be accomplished with the use of a handheld GPS unit. For this project, we used Garmin 64S units. The tracks were uploaded to Garmin Basecamp and edited before transferring to Google Maps. This represents a significant cost saving to a community group or agency unable to have access to imagery data.

Basic GPS skills for mapping are provided in the following section as well as methods to transfer the files to Google Maps and produce figures. These documents were used to train K'ómoks First Nations Guardians as part of a NSERC-funded project.

How to Collect Mapping Data using a Handheld GPS Unit

The following information was created as a handout and used to train K'ómoks First Nations Guardians.

Terminology:
GPS: Global Positioning System is a satellite- based navigation system. By comparing the signals transmitted by different satellites, the GPS receiver can determine the user's position and display it on an electronic map at any time of day and during any weather.
WAYPOINT: Essentially locations or landmarks that are stored in your GPS unit. These are useful for marking ground features or other notable checkpoints.
TRACKS: These are points automatically stored while the GPS is moving or during particular time increments. The points are shown strung together like a track.

General remarks:
By using the arrow keys in the middle of the device and the "enter" button you can navigate and explore the different abilities of your GPS unit.

Setting up your device:
It is important that the setting on your device are consistent so that they can be compared and uploaded to google earth later.
Select- Page>main menu>set up>position format
Under postion format make sure your format is the following:

<u>Position format</u>: hddd'mm.mmm'
<u>Map Datum</u>: NAD83
<u>Map Spheroid</u>: GRS 80

Units: Make sure that if several GPS units are working on a project together, that the units are the same. You can also manipulate how frequently tracks are taken and whether they are taken in space or in time.

Out in the field
Marking waypoints:

- Hit the power button on the side of the GPS unit
- Hit "Mark" on the lower left hand side of the unit (You have now taken a waypoint)
- By using the arrow keys in the middle of the device, you can scroll and select different fields if you wish to modify them. To select a field, highlight it with the arrow key and then press "enter". When you have finished, scroll down to "done" and hit "enter"
- If you wish to go back and look at previously marked waypoints on your GPS unit: Hit page until "main menu" has been selected. Under "main menu" select "waypoint manager". Once you have selected "waypoint manager", you have the option of selecting previously marked waypoints. You can now do a variety of things such as looking at the waypoints on the map on your GPS, or asking your GPS to take you to a

particular waypoint.

Marking tracks:

- Press the page button, cycling through the pages until you come to the page titled "Main Menu". It will have a bunch of icons
- The top left icon titled "set up" will be highlighted. Press the enter key. Scroll down until "tracks" is selected and hit "enter". Now you are in the tracks menu. To turn tracks on: select "track log" and then scroll to select whether or not you would like to record tracks or not.
- Note: if only marking waypoints, it is important to ensure that tracks are not recording
- Go to the "Main Menu" again, but this time select "Track Manager". Select "current track" and "clear current track".
- Walk your track taking Waypoints as you wish
- When you have finished, enter "Track Manager" and select "Save Track". You can now name the track as you would like
- Make sure to turn tracking off when you leave what you would like to mark. If you forget, the system will create a track wherever you take your GPS. This is not the end of the world, it is possible to delete this data, just confusing.

Practice:

- ✓ Make sure your GPS is under the correct settings
- ✓ Collect a waypoint at a random location and label it "Test 1"
- ✓ Collect a track at a random location and label is "Track Test"
- ✓ Ask your GPS to take you back to your original waypoint and make sure you can find it.

How to Transfer GPS data to Google Maps

The following information was created as a handout and used to train K'ómoks First Nations Guardians.

Programs needed:
Basecamp: We will use this software to clean up tracks and waypoints. We will also use this to convert the file type from GPX to KML so it can be used in google earth.

Download basecamp here:
https://docs.google.com/document/d/1FSzzBDf1JvDyXSin4nk3EfCGg2NJAZTrbzZL5h7yib4/edit

Google earth: We will use this as our background map and it will allow us to view our tracks and waypoints in relation to each other and to other landmarks.
Basecamp is not critical, but it makes the process easier especially if you are dealing with lots of waypoints and tracks

Uploading your data (2 methods)

1. **Using Basecamp**
   - Plug in device and wait for computer to recognize it
   - Open basecamp
   - Your GPS files should automatically come up in the left hand window (They are in GPX format)
   - Select the files you wish to view
   - Here, you can clean tracks up if necessary, create new points as well as new tracks
   - To clean tracks up: right click on track> select "split track here". You can now delete whichever segment of the track you would like.
   - If you have lots of different tracks, it is helpful to assign them different colours so that it is easier to identify what you are working with.
   - When you are finished you can select file> export selection> kml format and save the file to your location of choice.
2. **Using website:**
   - Plug in GPS
   - Go to: http://gpx2kml.com/
   - To choose your file, go to Garmin>GPX> Choose whichever file you like
   - Save your file
   - Open google earth
   - Select File>open and then navigate to the file that you just converted
   - Open this file. Hurrah, your file is now loaded onto google earth
   - Make sure to "Save place as" to a location that you can find again later.

Google earth: Select File>Open

- You will now be prompted to open your file of choice.
- Navigate to the Kml file you created above and open this. Your file will pop up under "my places" on the left hand side of your screen.
- When you select the file (clicking the small box in front of the file name) you will see your selected tracks and waypoints on google earth.

Modifying your tracks and waypoints… (Playing in google earth)

- To edit and feature in Google Earth, right-click on the feature in the 3D viewer or the Places panel and choose Properties
- Your cursor will now be a little box with which you can select segments of the tracks, delete parts of it and move things around as you would like. To save any changes you make, make sure to click 'ok' and not simply close the "edit tracks" box
- To add a new "placemark" select the yellow tack at the top right corner of the screen. You can now place and label your placemark as you would like.
- To add a polygon select the tool beside the yellow tack and follow a similar process to above. You can always modify your polygon by right clicking and selecting "properties".
- Under "my places" on the left hand side of the screen, you can choose whether you would like to view the polygon by checking the small box.

- Follow the same process if you wish to add tracks

Uploading another map layer
Tools>image overlay

Saving your map
It is useful to save any waypoint or track you are working with to your computer and not only to your map. This way, if data is saved in an organized way, your tracks and waypoints can be easily added to future maps. When you are finished with your map, select file> Save> Save as image

Trouble shooting?

1. Plug in GPS
2. Go to: http://gpx2kml.com/
3. To choose your file, go to Garmin>GPX> Choose whichever file you like
4. Save your file
5. Open google earth
6. Select File>open and then navigate to the file that you just converted
7. Open this file. Hurrah, your file is now loaded onto google earth
8. Make sure to “Save place as” to a location that you can find again later.

Chapter 4 - Methods for Carbon Sequestration in Aquatic Sediments - Literature Review

Introduction

There is global interest in learning the role of estuarine habitats in mitigating climate change through carbon sequestration. Before an economic value of estuarine habitats and subsequent habitat restoration can be determined, a better understanding is required on the amounts of carbon stored in these habitats and rates of carbon sequestration. Most research to date has focused on tropical estuarine habitats and with the emphasis on assessing total carbon stocks. The rate of carbon accumulation is another important piece of information necessary to quantify carbon sequestration. Methods to measure this are diverse and complex.

The Comox Valley Project Watershed (CVPW) received funding from the North American Partnership for Environmental Community Action (NAPECA) to quantify the amount of carbon stored and sequestered by estuarine habitats with the goal to identify an economic value to habitat restoration. The project focuses on two estuarine habitats typical of British Columbia coastal areas, eelgrass meadows and emergent salt marsh habitats.

Along with any habitat restoration project, community involvement and better understanding of the environment should be included in the overall objective.
Our goal is to develop a protocol suitable for other community groups to assess carbon stores and rate of carbon sequestration in estuarine habitats. Therefore, emphasis is placed on methods best suited for local community groups or citizen scientists.

The recently published Verified Carbon Standard (VCS) Methodology for Tidal Wetlands and Seagrass Restoration now allows coastal wetland restoration projects to apply for carbon financing, a significant step forward (Emmer *et al.*, 2015). It is hoped the Province of British Columbia will recognize estuarine habitat restoration projects verifiable for Blue Carbon offsets for the carbon sinks they produce, thus providing a community-based solution to climate adaptation.

The Blue Carbon Initiative recently published a document that provides methods to measure *carbon stores* in marine aquatic systems (Howard *et al*., 2014). The purpose of this literature review is to add to the information provided by outlining the various methods that can be used to measure *carbon sequestration* in estuarine sediments.

Background

Role of Coastal Ecosystems in Mitigating Global Climate Change

The Fifth Climate Assessment Report by the United Nations Intergovernmental Panel on Climate Change (IPCC) confirmed that recent anthropogenic emissions of atmospheric greenhouse gases (GHGs), a significant cause of global climate change, are the highest in history (Intergovernmental Panel on Climate Change (IPCC) AR5 SYR, 2014). The most significant GHG is carbon dioxide (CO_2) and its increase is primarily driven by the burning of fossil fuels and changes in land use (Solomon *et al*., 2007). A global agreement signed in late 2015 set a goal to limit warming to no more than 2 degrees Celsius above pre-industrial levels (UNFCCC, 2015).

One of the ways to achieve this goal is to reduce anthropogenic carbon emissions. However, further steps can be taken to identify and protect natural ecosystems that remove carbon from the atmosphere (Macreadie *et al*., 2013; Lavery *et al*., 2013). Any increase in carbon sequestration of natural ecosystems will mitigate global climate change. Reduction of deforestation readily comes to mind, but coastal ecosystems can also contribute to climate change mitigation by sequestering and storing significant amounts of *blue carbon* from the atmosphere and oceans (Conservation International, 2014).

Globally, coastal mangrove stands, salt marshes, and seagrass beds play a significant role in maintaining human wellbeing and climate stability. It has been suggested that together, healthy estuaries containing mangroves, salt marshes, or seagrass beds, can sequester and store (stock) more GHG associated carbon than terrestrial ecosystems, including forests (Campbell, 2010; Conservation International, 2014; Duarte *et al*., 2010; Fourqurean *et al*., 2012; Macreadie *et al.*, 2014; Pendleton *et al*., 2012). Just as in terrestrial systems, the carbon is captured from the atmosphere and fixed via photosynthesis. However, whereas in terrestrial forests the carbon is stored in vegetative biomass/necromass for many decades or centuries, the blue carbon in coastal vegetated habitats is stored in organic-rich, oxygen-deprived sediments and, if left undisturbed, may be stored for millennia (Campbell, 2010; Duarte *et al.*, 2013; Fourqurean *et al*., 2012; Macreadie *et al*., 2014).

However, not only does human activity add more carbon to the atmosphere by burning fossil fuels, a carbon source, but we are also destroying carbon sinks. Coastal habitats are being destroyed due to anthropogenic activities near coastlines. When these habitats are damaged, they change from a carbon sink to a carbon source, in a form of "double jeopardy". For example, the IPCC reports that seagrass meadows are experiencing a global loss of between 0.4 and 2.5% per year in area and some authors report rates as high as 7% per year (Duarte *et al*., 2013; IPCC, 2014; Orth *et al*., 2006; Waycott *et al*., 2009). For saltmarsh, it is estimated that as much as 50% of saltmarsh habitat has been lost in North America since European settlement (Gedan *et al*., 2009). With an estimated 44% of the global population living within 150 km of an ocean in 2010, this decline is expected to increase (Nganyi & Akrofi, 2010).

A recent study from Duke University suggests that restoration and reclamation of lost ecosystems, such as eelgrass meadows and saltmarsh, are best considered an investment in the future of a community rather than a cost, as they enhance carbon sequestration and avoid GHG emissions, but also provide co-benefits to local communities and biodiversity (Herr *et al*., 2015). Furthermore, Restore America's Estuaries recently produced a methods manual so that coastal wetland restoration activities are eligible for carbon offsets by the Verified Carbon Standard for verification (VM0033), thus providing opportunities for carbon finance (Emmer *et al*., 2015).

Carbon Stores in Aquatic Habitats

Carbon stores can be divided into four components:

1. living above-ground biomass, including herbaceous vegetation and associated organisms;
2. non-living above-ground biomass, such as leaf litter;
3. below-ground biomass, including roots and rhizomes;
4. carbon stored in sediments (Howard *et al*., 2014).

In general, the amount of carbon stored in biomass is much less than that contained in the sediments. For example Elsey-Quirk *et al*. (2011) report that between 65-95% of the total carbon stock in salt marsh habitat is contained in the sediments and below-ground biomass (roots and rhizomes). This is different from what has been found in Green Carbon, carbon storage in terrestrial habitats.

Furthermore, one may divide carbon storage into total carbon or the amount of buried carbon; that is, the amount of carbon permanently stored and unavailable for biogeochemical processes. If one were interested in knowing the amount of carbon that is permanently buried at a particular site, one would need to do an analysis to determine the depth of the sediment mixing layer (SML) in the sediments. Anything below the SML would be considered permanently buried, whereas any carbon found in sediment in the SML has the opportunity to re-enter the atmosphere through biogeochemical processes.

Given that the above-ground biomass of saltmarsh and eelgrass habitats is ephemeral, with as much as 80-95% lost each winter, it would be unwise to include the biomass estimates for anything other than identifying the total carbon stored in an estuary at a particular time of year.

More recently, there is interest in learning where the above-ground biomass is deposited or whether it is returned to the atmosphere through biogeochemical processes. Both eelgrass and marsh plant species are vascular plants and the lignin contained in the tissues is not easily broken down by micro-organisms in marine environments. This is different from what is observed in terrestrial habitats, where soil bacteria and fungi are able to digest lignin. Therefore, biomass from eelgrass and saltmarsh habitats that is deposited into the estuary may persist for extended periods of time. Recent research indicates this biomass could be deposited on land in tidal windrows and buried by layers of gravel and sand due to wave action. Therefore, it's possible to identify the amount of above-ground biomass that may be permanently buried. Dr. R. Petrell is investigating a way to model this process so it may be possible to quantify what portion of above-ground biomass is permanently buried (pers. comm., 2016).

Seagrass Meadows in British Columbia

While not true grasses, seagrasses are a small, diverse group of submerged marine monocotyledenous angiosperms that grow in water depths that receive periodic light limitations due to seasonal sedimentation loading or algal blooms. They are descended from terrestrial plants that returned to the sea by evolving the osmoregulatory capacity to thrive in highly saline environments (Green & Short, 2003; Touchette & Burkholder, 2000). Most seagrasses grow in nutrient-rich estuarine and marine sediments that may be muddy, sandy or rocky, where the water column sustains periodic increased turbidity from sediment loading or re-suspension, phytoplankton blooms or microalgae growth. Seagrasses may grow in monospecific or mixed species stands called beds or meadows, which can persist for decades (Green & Short, 2003).

Eight species of seagrass are recognized from the Pacific Coast of North America; of these, six occur in the Pacific Northwest. *Zostera marina* L. is the dominant seagrass in terms of biomass and areal extent with a range from Baja California (Mexico) to Southeastern Alaska and the Arctic (Figure 12). It is one of the most widespread seagrasses, found circumglobally in the northern hemisphere's Pacific and Atlantic oceans and in the Mediterranean and Black Seas (Short *et al*., 2010). Despite the broad distributional range and the ecological importance of eelgrasses, there are relatively few published studies on the biology and ecology of *Z. marina* in Pacific Northwest estuaries (Kaldy, 2006).

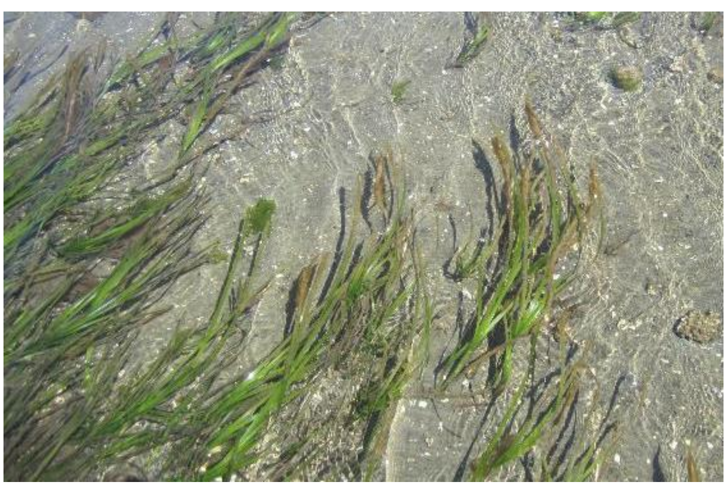


Figure 12. Zostera marina L., eelgrass. Photo taken at K'ómoks Estuary 2015.

Protection and policy development in support of the restoration and conservation of seagrass meadows is crucial because these beds combat environmental change through carbon sequestration (Curado *et al.,* 2013). However, to date, the development of such management plans and policies has been thwarted by limited knowledge of the mechanisms creating conditions for high carbon sink capacity, as well as carbon burial rates (Duarte *et al*., 2013).

Carbon Storage Capability

In the last decade, our understanding of the role of seagrass meadows as carbon sinks has improved; however, substantial uncertainties and gaps remain (Duarte *et al*., 2010). The actions required to address some of these uncertainties include:

- a need for improved estimates of global seagrass cover, revised regularly to account for net change;
- more comprehensive investigation of carbon stocks and burial rates over different time scales, including estimates of thickness of sediment deposits under extant seagrass meadows;
- understanding the fate of the carbon exported (sediment and biomass) from seagrass meadows;
- identification of the factors responsible for variability in seagrass carbon sink capacity;
- development of improved models to identify suitable areas for seagrass growth; and
- assessments of seagrass meadow area loss and the fate of the accumulated carbon in their bared or disturbed sediments (Duarte *et al*., 2013).

The tracking of carbon stock changes by the IPCC protocols are equally important to understand as the role of carbon sequestration globally and the loss of habitat concerns relating to seagrasses (IPCC, 2014). Many governments, industries, private and not-for-profit groups are interested in developing a voluntary wetland carbon stock and storage (the sequestration of carbon on an additionality measurement scale) or expanding on methodologies such as those available through the Verified Carbon Standard (VCS) (Louisiana Coastal Protection and Restoration Society, CH2M Hill, & EcoPartners, 2014). In late 2015, the Methodology for Tidal Wetlands and Seagrass Restoration was approved by the Verified Carbon Standard, thus allowing seagrass meadow restoration projects to apply for carbon financing (Emmer *et al*., 2015).

Seagrass meadows are estimated to be responsible for 10-20% (27.4 Tg C/yr) of the global carbon sequestration in marine sediments, while covering <0.2% of the ocean surface (Duarte *et al*., 2005; Fourqurean *et al*., 2012; Kennedy *et al*., 2010). However, their global organic carbon stores have not yet been adequately assessed (Campbell, 2010; Fourqurean *et al*., 2012) and most of the assessments that have been done used outdated techniques (Conservation International, 2014) or are considered rudimentary by terrestrial standards (Macreadie *et al*., 2014).

Emergent Tidal Marshes in British Columbia

Emergent tidal marshes occur along the tidal, typically in areas with low wave action. Several species comprise these habitats in coastal areas of British Columbia (Table 2).

Table 2. Common Species found in Emergent Tidal Wetlands in British Columbia

Species	**Common Name**	**General habitat characteristics**	**Illustration**
Carex lyngbyei	Lyngby's sedge	Prefers fresh water influence and finer sediments and occurs in patches across the higher parts of the marsh.	
Distichilis spicata	Seashore saltgrass	Occurs across the elevation range and tolerates coarse substrate	
Grindelia stricta	Oregon gumweed	Occurs as scattered individuals in the middle to upper salt marsh elevations	
Plantago maritima	Sea plantain	Occurs as scattered individuals in the lower and middle elevations	

Species	**Common Name**	**General habitat characteristics**	**Illustration**
Salicornia depressa	Sea asparagus	Colonizes the lowest elevations and coarse substrates and is also scattered through middle elevations	
Schoenoplectus pungens	Common three-square	Depends on fresh water influence and prefers fine sediments	
Triglochin maritimum	Sea arrow grass	Can colonize the lowest elevations in pure patches in fine sediments; also occurs scattered through middle elevations	
Phalaris arundinacea	reed canarygrass	Non-native species	

In the past, salt marsh ecosystems were not regarded as important habitat, resulting in considerable losses as coastal salt marshes were diked to convert the land to agricultural uses, or used for industrial, recreational or urban activities. Today it is acknowledged that salt marshes are among the most important marine habitats in the world. Salt marshes also provide many benefits to human populations, including coastal shoreline protection, water quality improvement, fishery support, carbon sequestration, recreational materials, and provision of raw materials and food. However, the majority of salt marsh habitat has already been lost, and what remains is threatened by ongoing human activities. When salt marshes are degraded or lost, the ecosystem services provided by those habitats are lost as well, thus creating a negative socioeconomic impact to coastal communities.

Carbon Storage Capability

Emergent tidal marshes have tremendous capacity for carbon sequestration, mainly in the soils beneath. Marsh vegetation produces large quantities of biomass each year, much of which decomposes and accumulates in the sediments beneath. Furthermore, entrained sediments from freshwater outflow tend to settle in salt marsh areas due to the dampening effect on water velocity. Because the sediments in tidal marshes are waterlogged, they tend to be anaerobic and limit any biological activity, thus retaining the organic material in the soils.

Considerably more research has been done on the carbon stores and sequestration rates of emergent tidal wetlands than seagrass meadows. In 2014, Restore America's Estuaries estimated carbon sequestration rates of saltmarshes in the Pacific Northwest to range from 0.9-3.52 tonne C/ha/yr, and a potential to store as much at 1.2 million tons C (Crooks *et al*., 2014).

Freshwater wetlands tend to produce methane, a GHG more potent than CO_2. Release of methane could counter any positive effects of carbon sequestration. However, the higher salinity (>18ppm) in saltmarsh inhibits the production of methane, thus generating a greater capacity for carbon storage (Poffenbarger *et al.,* 2011).

Published carbon sequestration rates for emergent tidal marshes range from 0.16 to 17.0 tonnes C/ha/year (Commission for Environmental Cooperation, 2013). The values were obtained from studies done in Louisiana, NE Canada, New England and San Francisco Bay (Commission for Environmental Cooperation, 2013).

Total carbon stores in saltmarsh range from 46 to 2160 t C/ha. Global estimates of carbon in tidal marshes show ranges of between 400 to 2010 Tg C (Quintana-Alcantara, 2014)

Methods for Estimating Carbon Sequestration

Obtaining an estimate of total carbon stores in an estuarine habitat does not provide adequate information to know whether the carbon stock is increasing, declining or stable. It is known that estuarine habitats can act as either a carbon sink or a carbon source, depending on its productivity and stability (Macreadie *et al*., 2014). An estimate of carbon sequestration provides the necessary information to determine whether a habitat is accumulating and storing carbon over time and thus having an impact on global climate change. The historic sediment carbon sequestration rates can then be used to predict the amount of carbon that could be stored by the habitat in future years. It can also provide baseline values to evaluate the benefit of habitat restoration; specifically, how much carbon can be sequestered through habitat protection and restoration efforts.

Only the carbon stored in the sediments is used to calculate sequestration rates and depends on two variables, the amount of carbon stored in the sediment and the sediment accumulation rate. The organic carbon may originate from the eelgrass itself or from terrestrial or other marine sources. A recent study in Maine USA used lipid biomarker concentrations and isotope composition to determine that within estuary sediment cores of *Z. marina* (33%), phytoplankton (41%), bacteria (14%), and other C3 plants (12%) all contributed to the carbon stored in the sediments (Sonshine, 2012).

a) Estimation of sediment accumulation rate

Several methods are available to determine the age of sediments and rate of accumulation, summarized in Table 3. Thomas and Ridd (2004) provide an excellent summary of methods for measuring short-term sediment accumulation. As well, additional information can be found on the website managed by USGS Western Ecological Research Center (http://www.tidalmarshmonitoring.org).

Table 3. Available methods to estimate sediment accumulation rate

Method	**General Description**	**Utility in Marine sediments**	**References**
Cs-137	Use of radioisotope deposited due to atmospheric nuclear tests. Initial detection in 1952, peak in 1963. Can be used to date sediments of recent history.	Because of mixing in surface sediments, may not provide accurate results (Johannessen & Macdonald, 2012)	Ritchie and McHenry (1990)
Sediment pins	Poles installed within a study site. Height of pole is measured through time to show sediment gain or loss.	Easy to install and measure underwater or on land. Sedimentation rates limited to where pin is installed, cm resolution	Thomas and Ridd (2004)
Sediment plates	Install a hard plate on sediment surface. Measure sediment accumulation on top of plate.	Suitable for soft sediments. Has ability to measure both accumulation and erosion, can be used to calculate sediment volume.	Thomas and Ridd (2004)
Surface Elevation Table	Portable mechanical leveling device for measuring relative sediment elevation changes. Is often paired with marker horizon to explain processes behind elevation increases or decreases.	Accurate and precise as measurements are always taken in the exact location, mm resolution	Thomas and Ridd (2004)
Marker horizon	A thick marker layer (usually white in color, i.e. feldspar clay) placed on top sediment surface.	Bioturbation by invertebrates or erosion can affect results. In unvegetated	Thomas and Ridd (2004)

Method	General Description	Utility in Marine sediments	References
	Sediment cores are later taken to measure sediment accumulation.	area, use of plastic grid or sediment plate is recommended). May be difficult to measure in areas of standing water (use liquid nitrogen to freeze sediment core).	
Radioisotope dating	A sediment core (5-10cm diameter and up to 1m depth) is collected and sectioned. Lead ($_{210}$Pb), with a half-life of 22.3 yrs, can be used to estimate accumulation rate over a period of 100 - 200 years. From the accumulation rate, the age of sediment from a particular depth in the sediment column can be estimated.	Analysis can only be analyzed by specialized laboratories and is very expensive.	Szmytkiewicz and Zalewska (2014); Flett Research Ltd. (www. http://www.flettresearch.ca)
C-14 dating	A sediment core (5-10cm diameter and up to 1m depth) is collected and sectioned. Sediment accumulation rates are calculated for each section by plotting the natural logarithm of the $_{14}$C activity versus sample depth and compare against the decay constant of $_{14}$C.	Analysis can only be analyzed by specialized laboratories.	Walker *et al*. (2007)

Methods that require the collection of a sediment core provide information on historic sediment accumulation rates and then future rates can be predicted. Methods that require the installation of a measuring device, such as a marker layer, sediment pins, plates or surface elevation table, provide information on subsequent accumulation from time of installation. However, several years may be required before a reasonable estimate of sediment accumulation can be made. Since a sediment core is required to estimate carbon content in the sediments and research projects may not have the luxury of time, researchers often opt for methods to measure historic sediment accumulation rates.

b) Collecting and Handling Sediment Samples

To determine sediment accumulation rates using a sediment core, a vertical profile of the sediment is required. In eelgrass meadows and emergent tidal marshes, a 5-10 cm diameter core to the depth of up to 1m typically is collected. The core tube may be constructed of metal or some form of plastic. Insertion of the core tube can be done by manually tamping the tube into the sediments, or using a variety of devices, such as a Russian peat corer, Eijkelkamp gouge auger, or a piston corer (Howard *et al*., 2014).

Soils that contain an abundance of coarse plant fibers may impede the penetration of the core into the sediments. This can be overcome by fashioning the bottom edge of the core tube into a sharp or serrated edge. Careful tamping of the core into the soil will allow it to penetrate the soil with minimal vertical compression of the sample within the tube.

Extraction of the core from the sediments can be difficult. If an open-ended tube is used to collect the core, it may be possible to cap the top and then extract the tube and sample. However, the sample may fall out of the core as it is pulled out of the ground if the sediments are loosely consolidated. Another option is to excavate the core by removing the surrounding sediments and capping the lower end of the tube before extracting from the soil. In areas that are above the waterline this can be accomplished with shovels and very long arms to reach down and cap the tube. For samples collected in submerged sediments, divers may use a pressurized water hose to excavate the core.

Once the sediment core sample is extracted from the sediments, it should be capped at both ends and stored upright in a cool environment until it can be sectioned. If sectioning of the core cannot be done within a few hours of collection, it can be frozen.

Because variations in carbon content are most significant in the upper 20-50cm of soil, most sampling methods recommend detailed sampling in the upper sections of the core (Choi and Wang, 2004; Johnson *et al*., 2007; Fourqurean *et al*., 2012). Howard *et al* (2014) provides information on several sampling strategies.

For each section obtained, care must be taken to remove the outer edge of the sample that was in contact with the coring tube, about 1-2mm. This is to ensure there is no contamination due to the side of the core passing through the many layers of sediment. Samples can be stored and frozen and analyzed at a later date.

c) Estimation of Soil Carbon Content

Howard *et al*. (2014) provide an excellent explanation of methods required to estimate soil carbon content. Below is a summary from their description.

Analysis of the carbon contained in sediment requires two variables: soil dry bulk density and organic carbon content (C_{org}). Bulk density (gm/cm^3) is determined by dividing the dry weight by the wet volume:

Dry Bulk Density (g/cm^3) = mass (dry) (g)/volume (wet) cm^3)

Determining Dry Bulk Density

Once the volume of the wet soil sample has been calculated, it is then dried to obtain mass. A common method is to dry the sample at 60°C for 24-48 hours, or until a constant weight is obtained. Care should be taken to not exceed 60°C as higher temperatures could cause the loss of organic matter, thus resulting in an under-estimate of organic carbon.

Determining Organic Carbon Content (%C_{org})

Two reliable methods are available to quantitatively estimate C_{org}: using an automated elemental analyzer or Loss on Ignition (LOI) method to differentiate between organic carbon and organic matter. Another method that uses wet chemistry techniques to oxidize and digest organic carbon is not recommended as it produces toxic wastes that require proper disposal and provides only a qualitative measure of C_{org}. Table 4 summarizes the benefits of each method.

Table 4. Comparison of Laboratory Techniques to Determine Percent Organic Carbon (from Howard et al., 2014).

Dry Combustion Method			**Wet Combustion Method**
	Elemental Analyzer	Loss on Ignition (LOI)	H_2O_2 & Dichromate Digestion (Walkley-Black method)
Pros	Quantitative measure of carbon content	Semi-quantitative measure of C_{org}; requires a muffle furnace	Semi-quantitative measure of organic carbon content; simple chemistry
Cons	Requires special instrumentation and lab to run equipment	Indirect estimate of C_{org}; requires calibration of %LOI to % C_{org}.	Not as accurate as other methods; produces hazardous waste
Cost	Expensive	Low cost	Low cost

Sediments from seagrass meadows often contain shell fragments from molluscs. These fragments represent a form of inorganic carbon, calcium carbonate ($CaCO_3$), but are also converted to CO_2 in an elemental analyzer along with the C_{org}. Although $CaCO_3$ contains carbon, it's not included in determining carbon stocks and so must to be subtracted from the C_{org} values obtained. If samples are processed using an elemental analyzer, a separate subsample is heated to 500°C to burn off C_{org} and leaving inorganic carbon in the ash. The amount of inorganic carbon is then determined using an elemental analyzer.

It is recommended that carbon analysis be conducted by a commercial laboratory to ensure accuracy.

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Chapter 5 - Collecting Sediment Cores

CVPW tested several methods to collect sediment cores and determined the easiest and most inexpensive method is to use an open-ended acrylic cylinder. The sediment core was sampled and sectioned using a home-built coring stand. All samples from the initial cores were sent to a commercial lab and analyzed for total Carbon and C/N ratios as well as radioisotope analysis ($^{210}Pb/^{226}Ra$) to determine rate of sedimentation and age of sediments. Once representative cores have been analyzed, additional cores can be collected and analyzed for Carbon only.

Details on the methods used are summarized below.

Equipment Required for Collecting Sediment Cores

We used 11.5cm (4.5") diameter clear acrylic tubing, cut into 80-100 cm lengths using a fine-tooth hacksaw (Figure 13). A clear tube makes it easier to observe and measure compaction of the sample during collection due to friction alongside the tube walls. The larger diameter tube size helps to minimize compaction and aid in the penetration of the core in the coarse sediments. Other transparent materials that could be used include polycarbonate and lexan. However, these materials are very expensive.

Figure 13. Open-ended acrylic tubing cut into 80-100cm lengths were used to collect sediment cores.

The lower edge of the tube was shaped into a bevel edge using a dremel tool, hand file, or mechanical sander (Figure 14). This allows easier penetration through the sediments.

Figure 14. Detail of lower edge of acrylic tube to facilitate penetration through sediments.

Other equipment included plastic end caps, discs to fit within the core tubes, a block of 2x4 wood and mallet or equivalent (Figure 15). It is important to stress that the logistics and time effort for collecting sediment cores is high. Therefore this work should be planned carefully and ensure there is duplication of equipment to avoid a lost opportunity.

Figure 15. Equipment required for collecting sediment cores.

For each core, a single plastic disc is placed inside the end cap before it was positioned at the bottom of the core. When the end cap is removed, the disc remains in position and provides a platform at the end of the core. This is critical for positioning the core onto the coring stand. The discs can be manufactured from any type of plastic. We used high-density polyethylene butcher-block scraps from a local plastics store. Table 5 provides a list of materials and typical costs.

Table 5. Costs for Core Tubes and Materials

Item	Purpose	Typical costs
10 cm diameter tubing	To manufacture coring tubes. Need a material that is not too brittle and can withstand some flexing.	$15/ft for acrylic $27/ft for polycarbonate >$100/ft for lexan
Plastic plumbing caps	To protect sediment cores	$2-4/cap
Plastic discs	To protect lower end of sediment core	$2-4/disc, constructed from high-density polyethylene (HDPE) butcher block scraps, 0.5-1 cm thickness
Rubber mallet	To push the core into the sediments	$12-15
Wood block	To protect edge of core tube from mallet when collecting intertidal samples	2 x 4 Wood scraps, no cost
Plastic board	To protect edge of core tube from mallet when collecting subtidal samples	$10-15, HDPE butcher block scraps, drilled with 5 mm holes

Constructing a Coring Stand

Because all sediment cores were sectioned within 2 hours of collection, Project Watershed custom-manufactured a coring stand suitable for use in the field (Figure 16). The stand allowed for the sediment sample to be extruded from the coring tube at a controlled rate to allow for sectioning. The vice grips were used to ensure the tube didn't drop down on its own if the sediment core was loosely consolidated.

The examples provided here are based on using an 11.5cm diameter coring tube. The coring stand can be modified to match the dimension of the coring tubes used.

Figure 16. Coring stand. The three aluminum rods, approximately 90 cm long, are bolted into a plywood base for support. The upper section is designed to help guide the core vertically. The distance between the two white discs is approximately 15 cm apart.

Table 6 provides a list of materials required to manufacture the coring stand illustrated.

Table 6. Costs for Manufacturing a Coring Stand

Supplies	**Approximate Cost**
High-density polyethylene plastic (HDPE), 1 cm thick for custom-made plates	125
Aluminum rods	30
316 Stainless Steel Bolts	35
Wood base	25
Vice grip pliers or other device to grip aluminum rods	20
Labour costs and shop supplies	285
Total	$520

Collecting Sediment Cores

Once a sample location is identified, position the core vertically at the sample site. Press down as much as possible and then gently hammer the core using the rubber mallet and wood block. Be careful to avoid fracturing the core. If the sediments have a lot of shell or gravel, there is potential for the tube to crack. Compaction can be minimized by hammering gently and slowly.

Figure 17. The coring tube is inserted in the sediments and then gently hammered to the required depth.

Collecting samples from subtidal locations requires the use of contract divers. The same method is used but the wooden block is replaced with a HDPE board with 5 mm holes drilled into it for water passage (Figure 18).

Figure 18. Collecting subtidal sediment cores.

Excavating the sediment core is accomplished by excavating the sediments adjacent to the core (Figures 19 & 20). On land, the core can be dug out with a small shovel. Underwater, the contract divers can use a "stinger", a high-pressure underwater hose that is typically used for shellfish harvesting. Before the sediment core is lifted out of the excavation hole, a flat disc HDPE insert and plastic plumbing cap are placed on the deep end of the tube to prevent any sediment from falling out.

Figure 19. Excavating sediments around core tube to facilitate removal. A plastic disc and plumbing end cap are positioned over the lower end of coring tube.

Figure 20. The yellow arrows point to the plastic disc and plumbing end cap that needs to be inserted at the bottom end of the tube. Accomplishing this task can be challenging.

Sediment cores should to be kept cool, shaded from sun, and in the shade, and any overlying water be left in the tube to help keep the sample as wet as possible. As well, they should remain upright to minimize any sediment disturbance or mixing (Figure 21).

Figure 21. Sediment cores are stored upright and kept cool before processing. Any water overlying the sediment in the core tube is left until ready to process.

Sectioning a Sediment Core

When ready to section a sediment core, ensure all equipment is handy. Table 7 provides a checklist of materials needed. Processing sediment cores is messy work so make sure you have an ample water supply for rinsing.

Figure 22. A typical work station. Keep sediment samples shaded (on right) until ready to process.

Table 7. Checklist of materials required for sectioning a sediment core

Item	Purpose
Coring stand	To help guide the core vertically
Vice grip pliers	To help keep sediment core from falling down on coring stand
Siphon hose	To remove overlying water in sediment core sample
Water source	For rinsing work station and sampling equipment
Distilled water	For final rinse of sampling equipment between samples
cooler	Keep samples cool until they can be transferred to a freezer
Work table	Not necessary but very handy
Field notebook, pencil and camera	Record observations during sampling
Sterile sample collection vessels	Collect sediment samples for analysis. May require 2-3 samples per sediment wafer.
Labeling tape and permanent marker	Label all samples as they are collected

When ready to process, cores are dewatered if necessary by siphoning off any overlying water and then mounted on the coring stand (Figure 23).

Figure 23. Siphon off overlying water before mounting the sediment core on the coring stand.

The lower plumber end cap is removed but the plastic disc is kept in position to prevent any of the sediments from falling out the bottom of the tube as it is positioned on the coring stand. Care must be taken to ensure the core tube is in a vertical position and tracking down the coring stand properly (Figure 24).

Figure 24. Positioning the sediment core on the coring stand and subsequent sampling.

If the sediments are too coarse to allow the tube to be manually slide down the extracting stand, then the core tubes were tapped down using a soft mallet and a piece of 2x4 lumber on their top edge in order to move the tube down the desired length of the sample. Vice grip pliers were positioned on the aluminum rods to prevent the tube from slipping downward too quickly.

Subsamples are collected based on a specific sampling protocol. We used a method where the core was sectioned at 1 cm intervals for the uppermost 10cm, then 2cm intervals for the next 20 cm, and 5 cm intervals for the remainder of the core.

The outer 1 cm of each sediment wafer is removed to avoid the core smearing. The remainder is transferred to a collecting vessel, such as a stainless steel bowl, and homogenized with a plastic or metal spatula (Figure 25). Note any large pieces of cobble, shell or other debris in the sample. These are not included in the subsamples sent for analysis (Figure 26).

Figure 25. Collecting a sample, 1cm thick. The outer 1cm of the sediment sample is removed and discarded.

Figure 26. The sample is transferred to a clean collecting vessel and well mixed. Any large pieces of shell or cobble are noted but not included in the sample sent for analysis.

Subsamples are collected and transferred to labeled, sterile sample containers (Figure 26). They can be stored in a 10 ˚C cooler for up to 4 hours before they are transferred to a freezer. Ideally, samples should be stored at -20 ˚C, in the dark, until they were sent for analysis.

Before the next sample is collected, all utensils and mixing bowls are rinsed at least twice, with the final rinse of distilled water (Figure 27). This prevents cross-contamination between samples.

Figure 27. A subsample is transferred and stored in sterile sample containers. All sampling equipment is rinsed between each sample collection.

Chapter 6 - Sediment Collection & Analyses Methodology

Sediment Cores and Subsurface Samples

Sediment cores (n=9, 5 intertidal and 4 subtidal) were collected throughout the Estuary between June/August, 2014 and May/July 2015. Six of these cores were paired to selected paired (barren and vegetated) study plots (Figures 30 & 31). Subsamples from the cores were collected for analysis of ^{210}Pb and ^{226}Ra, C_{org}, and N. The cores were used to calculate rates of sedimentation and carbon accumulation in the K'ómoks Estuary (Chapter 7).

For information on how to build the sediment coring tube and stand used in these methods and how to collect the cores and prepare the samples for analysis, please refer to Chapter 5.

Thirty-three additional subsurface sediment samples were collected from the study plots using the same coring tube and method, but only the 30-35 cm interval was kept for C:N analysis. We anticipated that this depth would be within the burial zone for organic carbon, based on experience with sediments in the nearby Strait of Georgia (Dr. Sophia Johannessen, personal communication.)

Figure 28. Location of radioisotope analysis sediment core locations (N = 9) (labeled: IHV, SBB, IBV, IBB, IRV, SBV, IRV2, SCV, SDV) within the K'ómoks Estuary. Each 2014 core site had shallow cores collected for C:N analysis paired to it (Figure 29).

a)

b)

c)

Figure 29. Study sites with paired vegetated / barren plots and transplanted areas: a) Royston Site (IRV& SBV cores), b) Basin Site (IBV & IBV cores) and c) Hospital Site (IHV & SBB cores).

Analysis of Samples

From each sediment core, one set of subsamples was analyzed for 210Pb and 226Ra activity by Flett Research Ltd., Winnipeg, Manitoba. This lab also salt corrected the samples and measured wet volume / dry weight. A set of subsamples from each sediment core and the sediment samples were analyzed for total carbon (TC), total inorganic carbon (C_{inorg}), N, and salt titration (C_{org} was calculated as TC - C_{inorg}) at the University of British Columbia's laboratories. A second set of subsamples was kept frozen for stable isotope analysis and sent to the National Research Program laboratories of the US Geological Survey Department, Menlo Park CA where the analysis was graciously donated.

Analytical Methods

Radioisotope analysis

^{210}Pb was measured in all sections of each core except the intertidal basin barren (IBB) core where only every second section was analyzed due to a miscommunication with the lab. The analysis of ^{210}Pb at Flett Research Ltd. was through measurement of the ^{210}Po granddaughter that is in secular equilibrium within two years of ^{210}Pb deposition, a modified methodology from Eakins and Morrison (1978). The method detection limit (MDL) is dependent on the amount of sample analyzed. The MDL for a 0.25 - 0.5 g (dry wt.) sample is between 0.1 - 0.2 dpm ^{210}Po g^{-1} (disintegrations per minute per gram) dry sample at a 95% confidence level for 60,000 second counting time and the estimated uncertainty for samples analyzed by this method (acid extraction) has been determined to be ± 11% at concentrations between 0.6 and 40 dpm/g at 95% confidence (Flett, n.d.).

^{226}Ra activity was determined as an average of three ^{226}Ra depth points approximating the top, middle and bottom of each core. The activity of ^{226}Ra in the sediment samples was calculated from the associated ^{222}Rn emanation following a modified methodology from Mathieu, Biscaye, Lupton, and Hammond (1998). As for ^{210}Po, the MDL of ^{226}Ra is dependent on the amount of sample analyzed. For a 60,000 second counting time the MDL at 95% confidence for 2 g of dry sample is 0.1 dpm/g and for 0.5 g of dry sample is 0.5 dpm/g, and the estimate of uncertainty of measurement for this method, at the Flett laboratory, is approximately ±12% at 95% confidence level (approximately 40,000 counts in 60,000 seconds) (Flett, n.d.).

The radioisotope activities and dry weight / wet volume values (g cm^{-3}) were salt corrected by Flett Research Ltd. based on the measured salinity of local bottom water (27 ppt). The calculation of salt correction was verified by the method described by the International Atomic Energy Agency (2003).

Organic carbon and total nitrogen

Profiles of organic carbon in sediment were derived from measurements made at UBC using established methods (Calvert, Pedersen, Naidu, & von Stackelberg, 1995). The concentration of C_{org} was calculated as the difference between the concentrations of TC and C_{inorg}. TC and N were measured by combustion and gas chromatography in a carbonhydrogen-nitrogen-sulfur analyzer, and the carbonate carbon was measured in a CO_2 coulometer with a precision of ±1.6%; as described by Johannessen *et al*., (2003). These samples were not salt corrected in this analysis.

Stable isotope analysis

The samples supplied for the stable isotope analysis were small for the levels of nitrogen detected resulting in a lack of confidence in the results for d15N. This supported the choice of plotting C: N elemental ratios against d13C to indicate the source of organic carbon at the sediment sample core sites. The USGS laboratory also provided C: N ratio data but again due to the small N levels these ratios were not included in the analysis data sets.

Sediment Mixing Layer

In many marine sediment cores there is a surface mixed layer (SML) in which the sediment is mixed relatively quickly, moving particles both up and down the sediment column through bioturbation and wave action. Below the SML, the sediment is mixed more slowly, if at all (Lavelle, Massoth, & Crecelius, 1986). This difference is diffusive versus advection mixing. For each core the bottom of the SML layer was located by eye as the depth at which the slope of the ^{210}Pb profile changed as per Johannessen et al. (2003).

Calculation of Sedimentation Rate

The radioisotope ^{226}Ra occurs naturally in the sediments and through decay emits ^{210}Pb; therefore this quantity of ^{210}Pb supported by ^{226}Ra was subtracted from the total ^{210}Pb found in the sample which provided the excess, $^{210}Pb_{EX}$ associated with particles sinking at the site, assuming a constant flux of ^{210}Pb to the sediment surface (Robbins, 1978).

Sedimentation velocity (w_s) was determined from the slope of the plot of ln($^{210}Pb_{EX}$) versus depth, below the SML, using the radioactive decay equation:

> $N = N_0 e^{-kt}$ where, for the decay of ^{210}Pb, k = -0.03114 yr, N = sample size, t = time (Lavelle *et al.,* 1986).

In three of the sediment cores, total ^{210}Pb values were below detection limits, resulting in negative values that could not be applied to the decay rate model. For any cores where deep $^{210}Pb_{total} < {}^{226}Ra$, the ^{210}Pb value was used as the background value instead of ^{226}Ra activity. Where all the values of ^{210}Pb in the core were under ≤ the limit of detection, the core was considered non-depositional and no sediment velocity was calculated.

Sediment velocity was then converted into sediment accumulation rate using porosity (ϕ) where, the salt corrected dry weight / wet volume values (g cm^{-3}) from Flett Research Ltd. and the assumed sediment particle density ρ_s of 2.65 g cm^{-3} (solid density of sand – used based on the sediment texture observations in the K'ómoks Estuary) were used to calculate ϕ below the SML of each sample as per Robbins (1978):

$$\varphi = 1 - \frac{\text{Dry weight/wet volume}}{\rho_s}$$

Next, the mass accumulation rate *r* (g $cm^{-2}yr^{-1}$) was calculated from the sedimentation velocity w_s (cm yr^{-1}), average porosity ϕ_{avg} (dimensionless), and density of particles ρ_s (g cm^{-3}) also, as per Robbins (1978):

$$r = w_s(1 - \varphi_{avg})\rho_s .$$

Minimizing the mean sum of squares between measured and modelled ^{210}Pb activities was done through testing a range of SMLs by varying parameters until the measured excess ^{210}Pb ($^{210}Pb_{EX}$) matched the modelled plot (Johannessen *et al.,* 2003; Lavelle *et al.,* 1986). The model returns the calculated value of $^{210}Pb_{EX}$ at every depth. This natural log of the modelled activity was then plotted as an overlay on the natural log of the measured $^{210}Pb_{EX}$.

Standard deviation was calculated for sedimentation velocities, accumulation rates, and average porosity using propagation of error formulae, beginning with analytical uncertainties in the measured values.

C: N Ratio as an Organic Matter Source Indicator

In the absence of stable isotope analysis, the ratio of C to N can be used as a rough index of the source of the C_{org} from terrestrial or marine vegetation sources by comparing the calculated C:N ratio to:

- the Redfield ratio of 6.6 for marine source phytoplankton (Redfield, Ketchum, B. A., & Richards, F. A., 1963);
- the C:N ratio of 19.7 (leaf biomass) to 31-62 (root-rhizome biomass) for *Z. marina* (Duarte, 1990; Fourqurean, Moore, Fry, & Hollibaugh, 1997; Pedersen & Borum, 1992); and
- a ratio range of 43-66 for terrestrial plants (McGroddy, Daufresne, & Hedin, 2004). The C: N ratios were calculated from the UBC laboratory results in order to determine the approximate source of the carbon in the K'ómoks Estuary sediments. Nonetheless, it is important to note that the use of C: N ratios is constrained by the ability of measured ratios to accurately reflect source characteristics even though the ratios of terrestrial and marine organic matter are relatively distinct (>12 and 6-9) (Thornton & McManus, 1994).

Stable Isotopes

In order to examine possible origins of the C_{org} present in the K'ómoks Estuary, sediment samples were analyzed for d13C and d15N. The organic carbon that accumulates in seagrass beds is from both seagrass production and the trapping of other particles. Therefore, in order to estimate the seagrass contribution to the K'ómoks Estuary carbon burial, it is necessary to understand the proportion of eelgrass C_{org} and other sources, terrestrial and marine (Kennedy *et al.,* 2010). Organic C: N ratios have been similarly used as source indicators of marine sedimentary particulate matter relying on the gross differences between respective organic matter sources in d13C, d15N and elemental N relative to terrigenous sources (Thornton & McManus, 1994).

Since C: N (as discussed previously) and d15N are often considered a less reliable indicator, because they record not only organic matter but also the degree of diagenetic alteration, which gives results of an organic matter breakdown with different compositional makeup than that of the original material. Of the three organic tracers, only d13C ratios are best able to record the original source of organic depositional matter in aquatic sedimentary environments (Thornton & McManus, 1994). However, the use of C: N and d13C ratios combined can increases information on the source, quality and history of particulate organic matter in marine environments even in poorly mixed estuaries (Andrews, Greenaway, & Dennis, 1998).

Calculation of Carbon Sequestration Rate

For the four cores with a measurable sediment accumulation rate, the sequestration rate of C_{org} (gC cm^{-2} yr^{-1}) was determined by multiplying C_{org} % below the burial depth by the sediment accumulation rate (g cm^{-2} yr^{-1}). The amount of gC yr^{-1} in the K'ómoks Estuary was determined by multiplying the calculated sequestration rates by the area (cm^{-2}) of *Z. marina* bed coverage estimated to be represented by the associated core. The area associated with each core was determined by considering the intertidal or subtidal limit surrounding the core location and the current patterns observed by sand ripple direction and pattern, a polygon was drawn by hand on Google Earth Pro to obtain the approximate area associated with each core sediment accumulation rate. Results are provided in Chapter 7.

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Chapter 7 - Results of Sediment Analyses

Sediment Core Measures

The locations, core length, and observed vertical compression of the six K'ómoks Estuary cores are summarized in Table 8. Eelgrass coverage is shown in Figure 28 and the associated eelgrass bed areas for each core are shown in Figure 29. Core length can be adjusted for vertical compaction according to a nonlinear compression factor applied to each core. However, due to time constraints related to incoming tides and divers' bottom times, the compaction difference was not measured at every cm of penetration so a linear length correction cannot be applied (Morton & White, 1997). When known, the total vertical compaction (cm, %) was recorded to demonstrate that compaction was small overall (≤ 5%).

Sediment Velocity

Table 9 summarizes the data used to derive sediment velocity and the final area assessment sediment accumulation rate for each core collected.

Figure 30 shows the profiles of $\ln^{210}Pb_{ex}$ activity from K'ómoks Estuary sediment cores, with model fit overlain, as determined through the interpretation and calculations of the radioisotope results.

Table 8. Estuary cores descriptive summary (n = 9).

Core Name	Latitude (˚N)	Longitude (˚W)	Core length (cm)	Core compression (cm) (%)	Bathymetry (m) ±mean zero tide	Date collected
Intertidal n=5						
IBV	49˚ 39.933'	124˚ 54.770'	44	2.5 (5.3)	+0.41	June 14 2014
IBB	49˚ 39.963'	124˚ 54.613'	54	1.5 (2.5)	+0.30	June 16, 2014
IHV	49˚ 40.203'	124˚ 56.312'	58.5	2.5 (4.2)	+0.67	June 13, 2014
IRV	49˚ 39.501'	124˚ 57.239'	50	2 (3.9)	+1.15	June 15, 2014
IRV2	49˚ 39.614'	124˚ 56.634'	56	2 (3.4)	+0.30~	July 30, 2015
Subtidal n=4						
SBB	49˚ 40.008'	124˚ 56.087'	47	2 (4.3)	-1.18	July 3, 2014
SBV	49˚ 39.519'	124˚ 56.538'	47	2 (4.3)	-1.40	July 3, 2014
SCV	49 ˚39.908'	124˚ 55.180'	49	unknown	-1.07	May 21, 2015
SDV	49˚ 39.097'	124˚ 55.945'	58	unknown	-1.00^	July 30, 2015

~ Calculated using estimated depth at time of sampling, is possible site is shallower but not deeper.

^ Calculated using estimated depth at time of sampling, is possible site is deeper but not shallower.

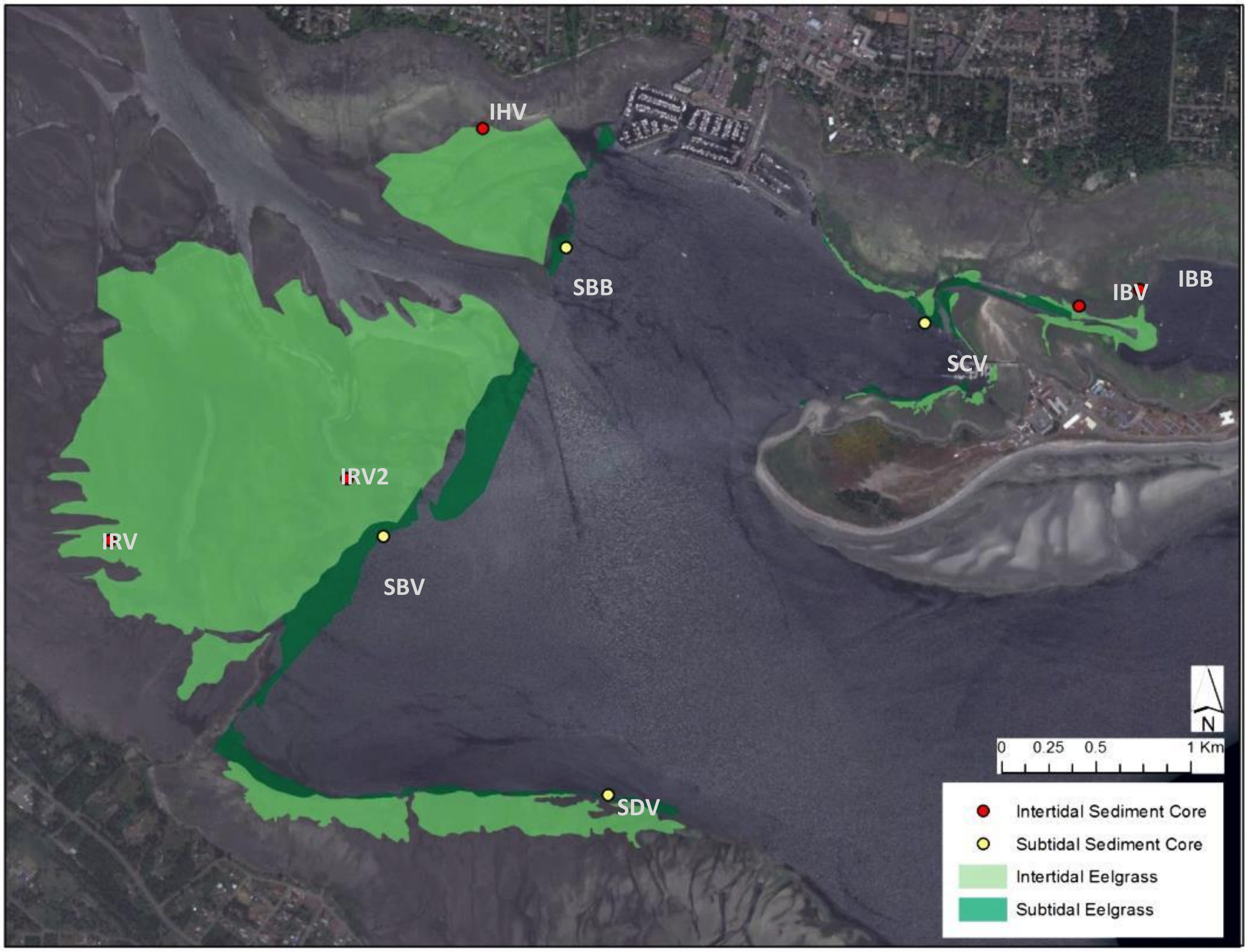


Figure 30. K'ómoks Estuary eelgrass bed area coverage showing core locations. Copyright 2015 by Comox Valley Project Watershed.

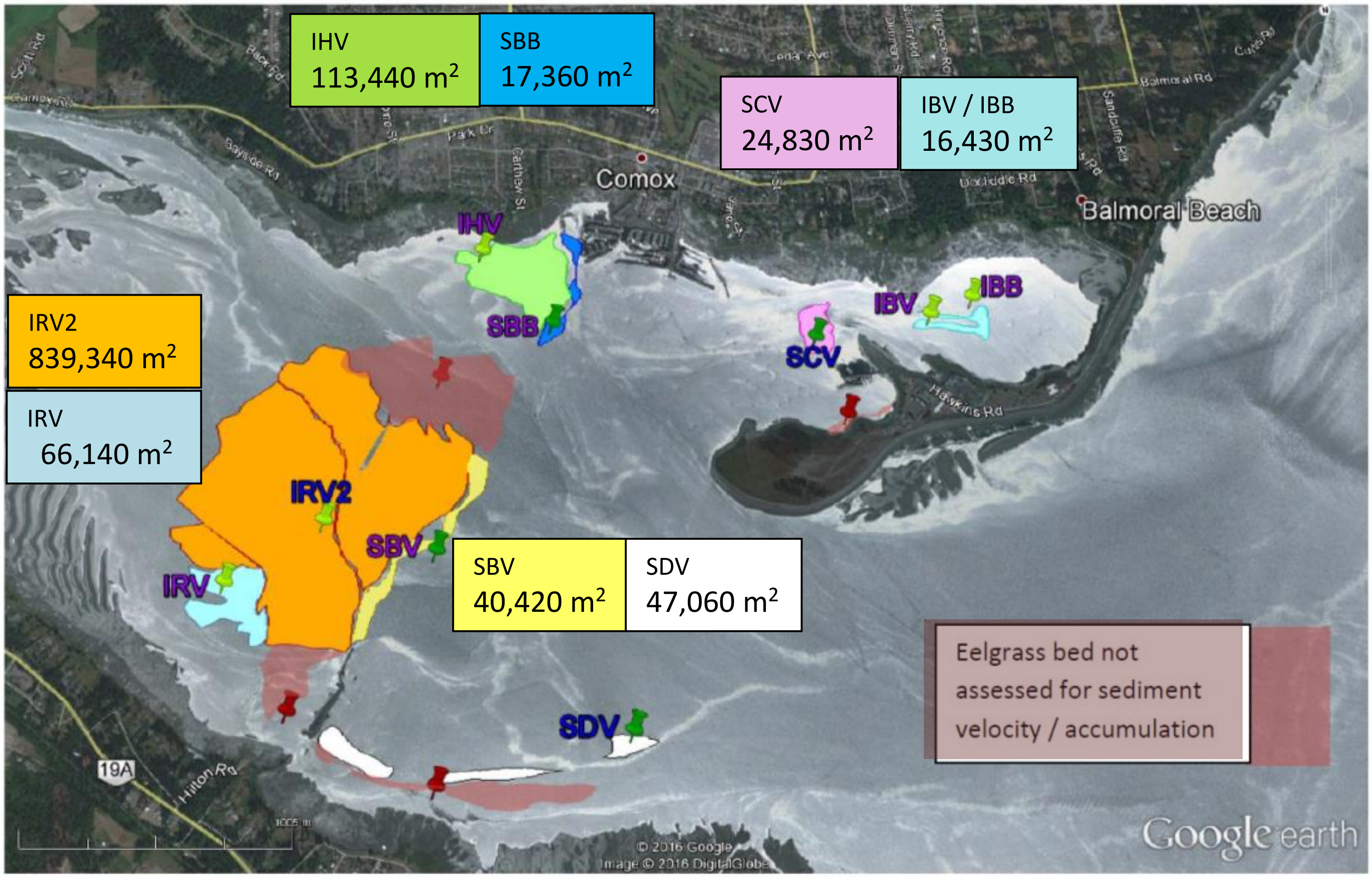


Figure 31. Estimated eelgrass bed area associated with individual sediment cores (Table 9). Approximately 71% of total eelgrass bed area has been assessed.

Two cores were collected from one area (IBV and IBB); calculated rates were presented as a range for the single area. Red shaded areas represent eelgrass beds not yet assessed for sediment velocity and accumulation rate. Blue labels are 2015 cores – purple labels are 2014.
Light green pins are intertidal, dark green are subtidal.

Table 9. Summary of the calculated values of sediment velocity, accumulation rate, and SML depth for the K'ómoks Estuary.

Core Name	Core length (cm)	SML Depth (cm)	Supported ^{210}Pb (dpm g^{-1})	Sedimentation velocity (cm yr^{-1})	Average porosity below mixed layer	Accumulation rate (g cm^{-2} yr^{-1})	Associated eelgrass bed area (m^2) (Figure 2)
K'ómoks Estuary Cores							
Core IBV	44	5	0.16±0.06	0.36±0.20	0.36±0.01	0.61±0.12	16,430 (cores IBV & IBB)
Core IBB	54	5	**0.12±0.06**	ƚ0.47±0.79	0.37±0.02	0.78±0.55	
Core IHV	58.5	0	0.13±0.07	0	0.40±0.01	na	113,440
Core IRV	50	0	**0.11±0.06**	0	0.41±0.01	na	66,140
Cove IRV2	56	0	**0.09**±0.05	0	0.37±0.002	na	839,340
Core SBB	47	3	**0.11±0.0**	0.13±0.04	0.36±0.01	0.23±0.01	17,360
Core SBV	47	0	0.18±0.05	0	0.38±0.01	na	40,420
Core SCV	49	20	**0.13**±0.05	0.16±0.04	0.37±0.11	0.26±0.02	24,830
Core SDV	58	0	0.38±0.02	0	0.36±0.11	na	47,060

Note: All cores have been salt corrected for *S*= 27, *T* = 16˚ C. Supported ^{210}Pb, sedimentation velocity, average porosity and accumulation rate are reported ±1 SD, as determined using propagation of error formulae. The SD of the accumulation rate includes errors in the sediment velocity, porosity, measured activity of ^{210}Pb and supported ^{210}Pb. Supported ^{210}Pb determined from ^{226}Ra activity (Johannessen *et al.,* 2003). Where ^{210}Pb was below detection limits error formulae were limited. Error calculated for estuary cores from raw data.

ƚ = there was a range of w_s possible, from 0.08 to 0.46 cm yr^{-1} considered for this core, best fit is shown in Figure 31
na = no accumulation
Bold = used lowest ^{210}Pb value instead of ^{226}Ra values since supported ^{210}Pb values were below limits of detection

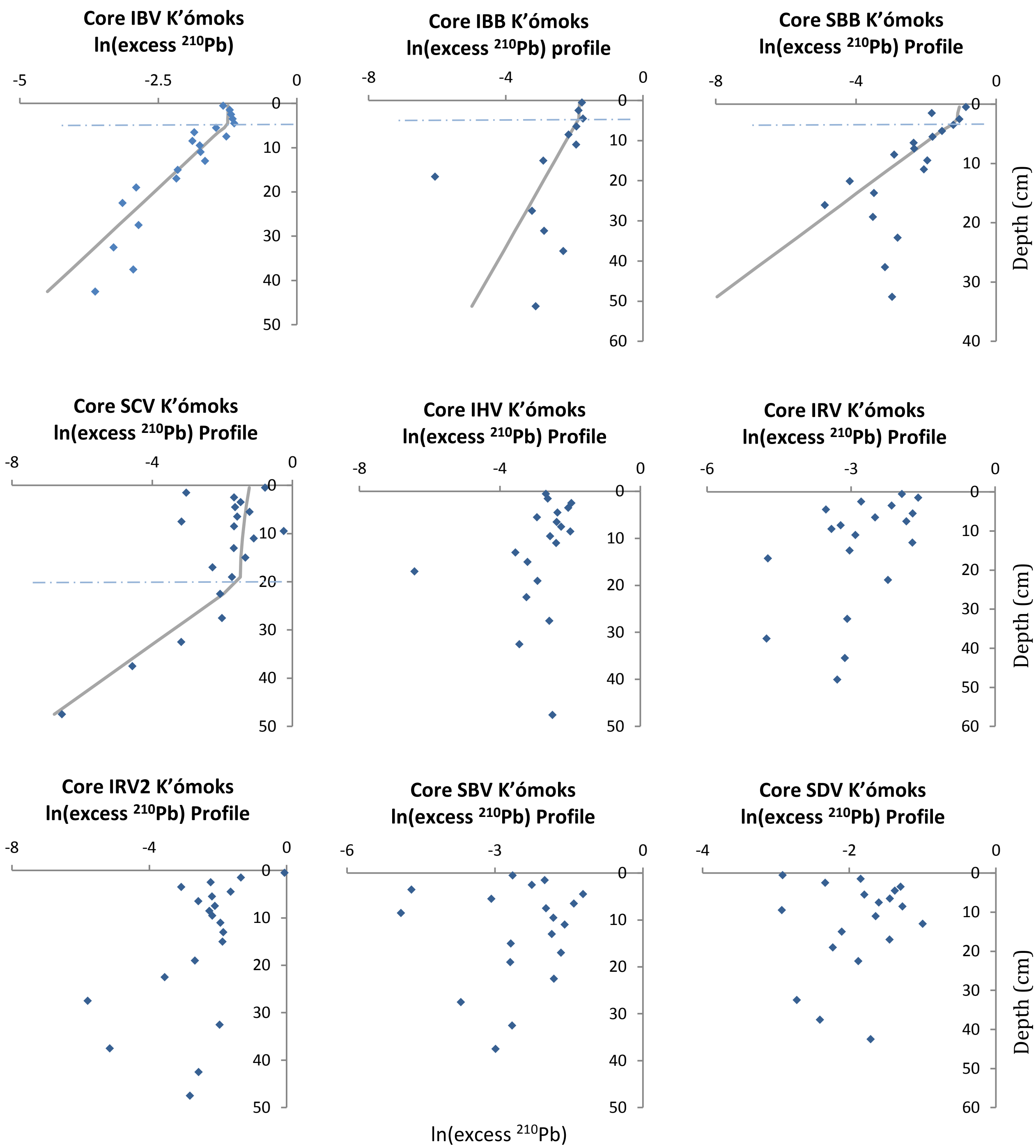


Figure 32. ln(excess ^{210}Pb) activity from K'ómoks Estuary cores profiles.

$^{210}Pb_{ex}$ points represent measured values with the background subtracted. The grey model profile lines note where the cores were assessed as fitting the model and measurable accumulation rates were calculated (Table 9). IBB core had only every second subsample analyzed and both IBB and SBB cores showed recent sediment accumulation where subsamples with sediment disturbed at depth. The line slope change point is the depth of the SML, represented by the dashed line.

Core IBV. The ln(excess ^{210}Pb) plot had the best model fit of the nine cores analyzed. With a sedimentation rate of 0.4 cm yr^{-1} and a core depth of 45 cm the approximate time this core represents was 112 years. However, due to the half-life period of ^{210}Pb, dates over 100 years are not captured by this method.

Core IBB. Due to miscommunication with the analyzing laboratory, only every second sample was analyzed. The SML was difficult to accurately determine by the standard approach. Therefore, a sensitivity analysis was done and examined the range of SMLs and the best fit was selected. Field notes indicate this core was anoxic below 4 cm. Many points were below ^{210}Pb limits of detection. The lack of data points made the analysis at depth more challenging, but it appeared that the core was disturbed at depth. At the sedimentation velocity of 0.47 cm yr^{-1} and a core depth of 52.5 cm this core represents sediment age at depth of approximately 111 years.

Core SBB. The SML was difficult to accurately determination by the standard approach. Therefore, a sensitivity analysis was done and examined the range of SMLs and the best fit was selected. Many points were below 210Pb limits of detection. The core appeared to be disturbed at depth. At the sedimentation velocity of 0.13 cm yr-1 and a core depth of 35 cm this core is approximately 269 years at depth, a time period that should be regarded with caution as it is well over the 100 year dating limit of 210Pb decay.

Core SCV. At 20 cm, the SML of this core was the deepest discovered in the cores from the K'ómoks Estuary. Many points were below ^{210}Pb limits of detection. The core was less consolidated than the other cores sampled. At the sedimentation rate of 0.16 cm yr^{-1} and a core depth of 49 cm this core represents sediment age at depth of approximately 325 years; again this time period should be regarded with caution as it is also well over the 100 year dating limit of ^{210}Pb.

Cores IHV, IRV, IRV2, SBV and SDV. For each of these cores, the ln(excess ^{210}Pb) plot did not fit the model and sediment velocity was zero. Interpretation options often were; 1) there was no accumulation, 2) there was a very short accumulation with too few points to interpret confidently, or 3) there were layers resulting from human related disturbance or slumping. In each case, there was no measurable SML depth, likely due to the upper disturbance layer. Interpretation best supported option 3; an upper, active, more recent layer and older layers with inactive ^{210}Pb levels.

In cores IHV and IRV many points were below ^{210}Pb limits of detection. Core IRV2 had two very different sediment densities above and below 30 cm depth. However, the average porosity of each core was similar throughout the estuary (Table 9). All intertidal sites were disturbed historically and core IHV and IRV2 had frequent dredging effects nearby until recently. Core SDV was very similar to Core SBV, and both cores were situated on the upper slope of a marine drop-off. It is possible there have been numerous slumping events with a large slump evident at the top of the core. There are strong tidal currents at these sites.

Sediment Accumulation Rate

Only 3 of 8 areas sampled of the estuary had a measurable sediment accumulation rate (Table 9). Sediment accumulation was most rapid at the K'ómoks Estuary IBB and IBV core site. These two cores were taken from the same eelgrass bed so represent a range of 0.61 - 0.78 g cm^{-2} yr^{-1} and cores SCV and SBB had lower rates of 0.26 and 0.23 g cm^{-2} yr^{-1} respectively. Overall, sediment accumulation rates in the K'ómoks Estuary were low compared to values found in literature.

Sediment SML Depth

Estuary SML depths ranged from 0 to 20 cm. In the accumulating areas of the estuary, the SML depths were used to estimate the length of time before C_{org} (accumulation) would be sequestered, for example after restoration efforts. In the IBB / IBV eelgrass bed the approximate time was 11-14 years and in the SBB eelgrass bed the approximate time was 23 years. The slower accumulating SCV site may take approximately 125 years before C_{org} accumulation values would be sequestered below the SML at the transplant site.

Organic Carbon and Nitrogen

Carbon Burial Percent

Carbon analysis of the sediment core subsamples and sediment samples yielded C_{org} profiles (Figures 33 & 34) that were interpreted to help understand the history of disturbances in the K'ómoks Estuary. The variability of C_{org}% through depth differed with each core and rate the profile of decay was atypical in non-accumulating cores. The blue carbon stored in sediments is measured as carbon burial percent (C_b%), at depths when both microbial and bacterial activity has slowed and there is no appreciable decay in C_{org}%.

The blue lines (Figure 33) indicate plots where carbon accumulation was recorded and %C_{org} decayed with depth steeply through the SML via benthic organism activity then via bacterial activity as oxidation decreased, and then levelled off to the mean C_b% range indicated by a red horizontal bar in each plot. The orange lines (Figure 34) indicate sediment cores that had no measurable sediment accumulation and had atypical carbon decay profiles. Note: no decay rate could be determined for core SBV and SDV. As noted in the figure, peaks in the plot can be reconciled at the same depth as field notes of woody debris and annelids observations. When a sample containing annelid remains and woody debris is analyzed, the carbon value will not be of the sediment and will be artificially high.

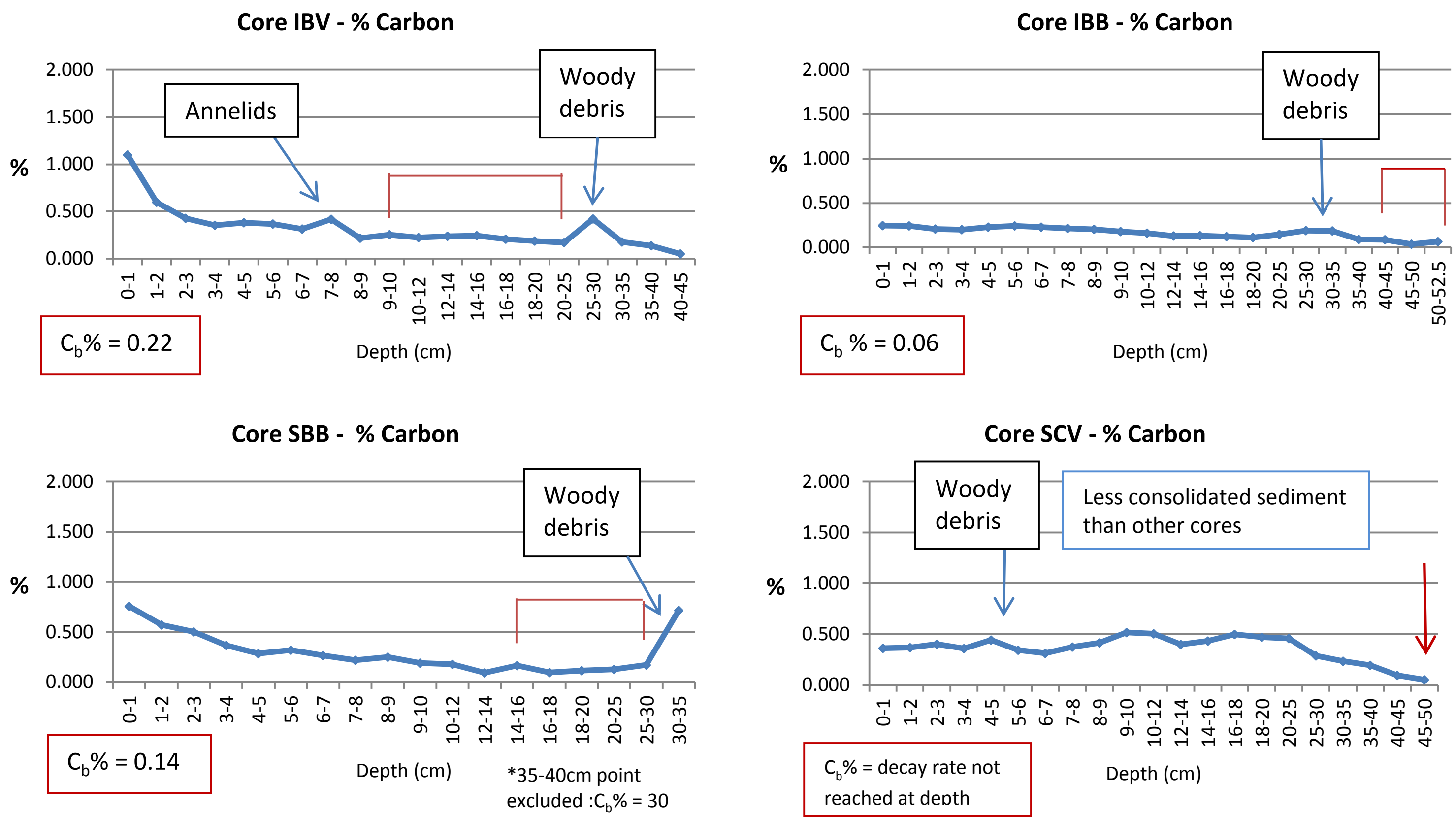
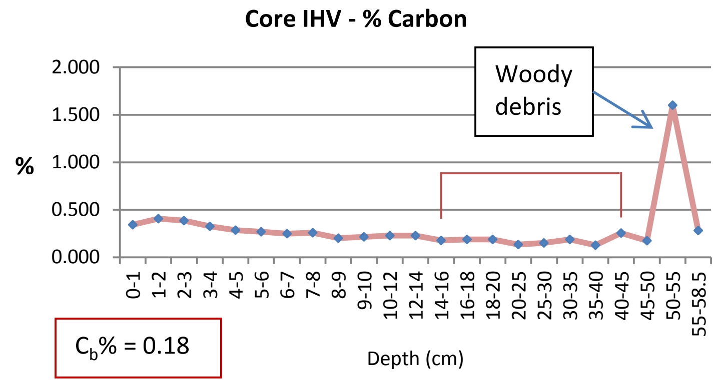
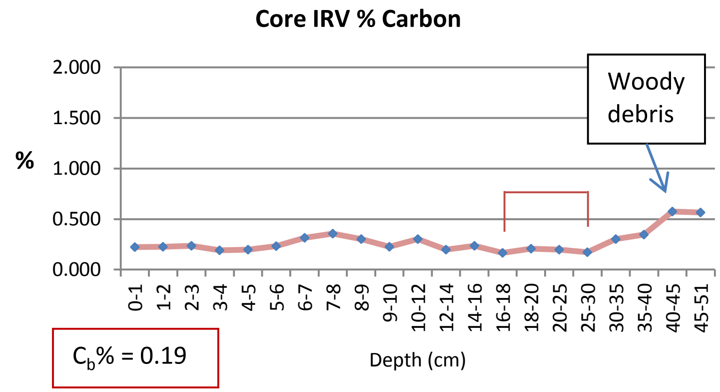
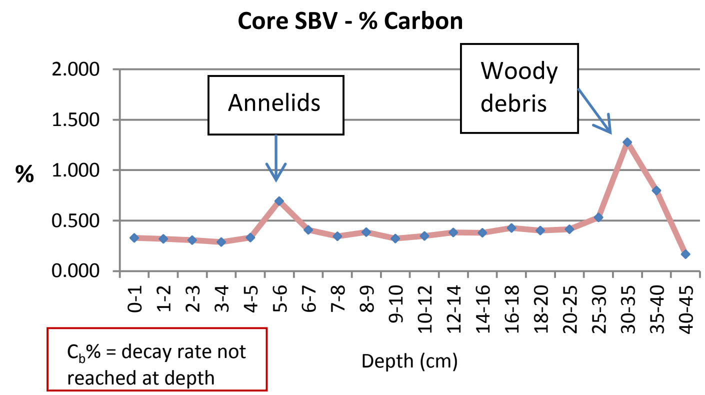
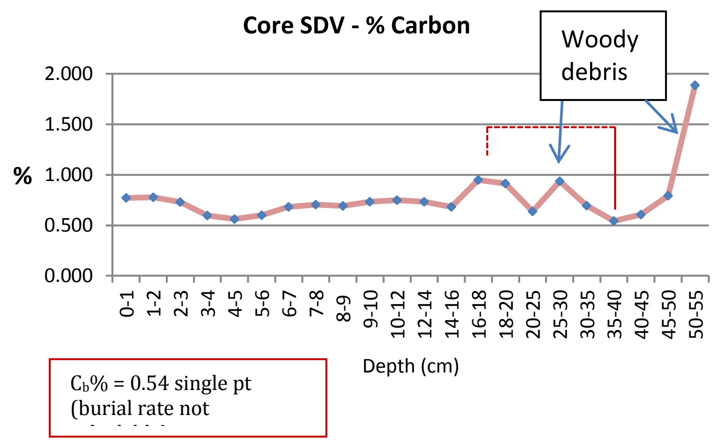


Figure 33. Plots of %C$_{org}$ profiles of the 4 accumulating site sediment cores.









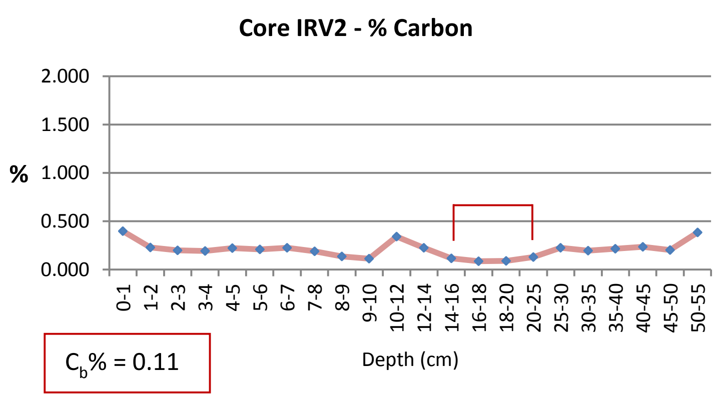


Figure 34. Plots of %C_{org} profiles of the 5 non-accumulating site sediment cores.

Figures 33 & 34 show the degree of variability in Cb% of the sediment cores. The estuary Cb% ranged from 0.06 to 0.69% with an average of 0.24 % (n = 8). C_{org} burial percent was greatest at the SDV study plot; on the edge of a drop off fringed with *Z. marina* and, in contrast, was lowest at the IBB study plot which was inside the lagoon basin. The K'ómoks Estuary Cb% are likely lower than expected from literature because as observed in the field, the estuary sediments were predominantly consolidated sand. It is wet, soupy, silty-mud, or sandy/silty, sediment types, which act as a better C_{org} binding material.

C_{org} Sources

Table 10. Summary of results from carbon and nitrogen analysis of sediment core samples (buried present organic carbon) at 30-35cm depth.

Core Name	Sample Mass (mg)	Nitrogen (µg)	Total Nitrogen (%)	Carbon (µg)	Total Carbon (%)	Carbonate Carbon (% C_{inorg})	Organic carbon (C_b%)	C_{org} :N
K'ómoks Estuary Cores (n=6)								
IBV	37.02	11.00	0.03	194.50	0.53	0.35	0.22	7.33
IBB	31.23	6.49	0.02	238.96	0.77	0.58	0.06	3.00
IHV	30.32	8.27	0.03	70.21	0.23	0.04	0.18	6.00
IRV	29.06	7.6	0.03	102.22	0.35	0.05	0.19	6.33
IRV2	31.42	*9.4*	0.03	*100.5*	0.32	0.12	0.20	6.67
SBB	35.23	10.40	0.03	408.14	1.16	0.44	0.14	4.67
SBV	28.95	12.94	0.05	436.89	1.51	0.23	1.28ᵻ	25.60ᵻ
SCV	47.30	*14.2*	0.03	*113.5*	0.24	0.001^	0.23	7.67
SDV	37.08	*18.5*	0.05	*378.2*	1.02	0.32	0.69	13.80

^ sample analysis was repeated to verify low value

ᵻ value elevated due to predominance of woody debris in sample, sample excluded from average C_b%

italics denote where C and N mass were derived from our total dry mass of samples sent for analysis and % C and N results as lab analysis did not provide these mass values.

Table 10 provides the summaries of the carbon and nitrogen analysis results from the sediment cores and sediment samples collected in the K'ómoks Estuary in 2014-15, including %C_{org} at 30-35 cm sample depth, C_b%, and C_{org}: N ratios.

Stable isotope analysis (Table 11) of d13C yielded reliable results; however the nitrogen content in our small sample volume analyzed was often below reliable detection limits of the d15N analysis. In this case, plotting C_{org}: N vs d13C (Figure 35) was the most reliable interpretation to represent the source, character and turnover of organic matter in a contrasting sedimentary environment such as is found in estuaries.

The upper C_{org}: N ratio range (Figure 35) suggests there was a mixture of C_{org} sources and independent DNA analysis of these cores has confirmed eelgrass sourced carbon buried in these sediments (Dr. Will Hintz, personal communication, March 2016).

Table 11. Summary of results from stable isotope analysis of sediment core samples (n=6) at 30-35cm depth.

Core Name	Sample Mass (mg)	Carbon (mg)	Nitrogen^ (mg)	C/N*	d13C	d15N^
IBV	12.316	0.042	0.005	7.33	-17.64	5.72
IBB	12.331	0.043	0.003	3.00	-16.12	7.19
IRV	12.643	0.028	0.002	6.33	-18.88	2.71
SBB	12.170	0.037	0.003	4.67	-17.90	2.72
SCV	12.699	0.047	0.006	7.67	-19.39	6.53
SDV	12.217	0.076	0.006	13.8	-19.58	4.51

All values are an average of three replicate analyses, except IRV had four replicates.
IBB had only two replicates as the third N values was less than detectible limits.
^All N values were small making dN15 results low confidence.
*C/N values from Table 10.

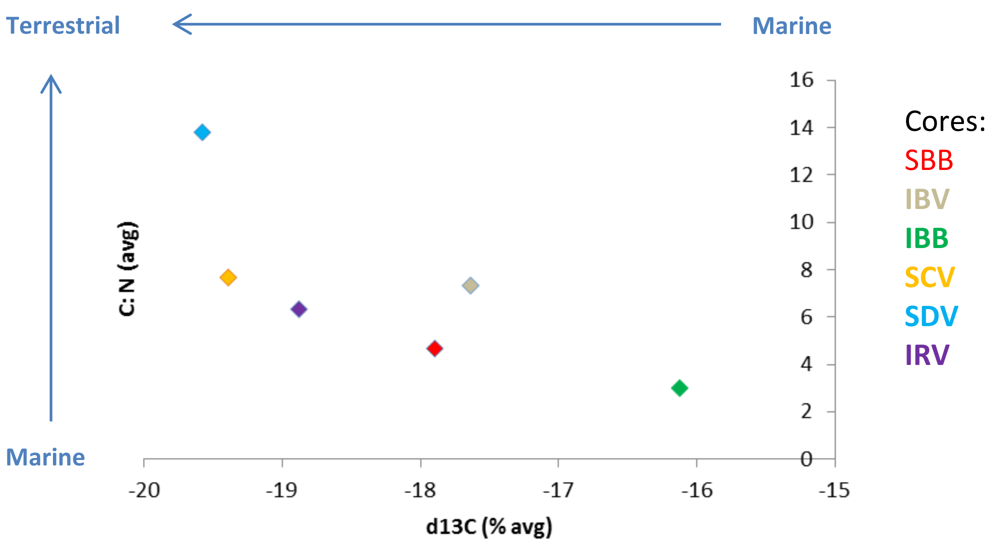


Figure 35. Composition of K'ómoks Estuary sediment core particular matter based on plots of elemental and isotopic data (Corg: N ratio vs d13C), n=6. The marine to terrestrial organic material source gradients intend to show trend not empirical data.

Globally, the range of natural d13C values in seagrasses is varied, ranging from -19.6 to -4.8 with a mean of -10.3 with a sediment d13C range of -26.6 to -7.3 and mean of -16.3. Specifically for *Z. marina* there was a mean calculated of -10.3 within a sediment d13C mean of -18.4 (Kennedy, et al. 2010). Reference *Z. marina* samples from five beds in the K'ómoks Estuary had a mean d13c value of -9.42(%.avg). Therefore, these results indicate that *Z. marina* is contributing at least part of the C_{org} in the sediments; the remainder was from terrestrial plant, marine and fresh water phytoplankton and anthropogenic sources (fertilizer, sewage, etc.) but we were unable to determine what percent at this time. Nonetheless, the composition results were typical of those found for estuaries in literature (Hemminga & Mateo, 1996; Kennedy *et al.*, 2010; Thayer, Parker, LaCroix, & Fry, 1978; Thornton & McManus, 1994).

In the estuary there is a large variation where the upper quartile is greater than the Redfield ratio of 6.6 for marine source phytoplankton, (mean = 6.78, upper quartile range 7.11 – 12.46). This mean is lower than the mean C_{org}: N ratio of 19.7 (leaf biomass) and 31-62 (root-rhizome biomass) for *Z. marina* and yet, not as high as the terrestrial source range of 43-66 (Duarte, 1990; James W. Fourqurean, Moore, Fry, & Hollibaugh, 1997; Pedersen & Borum, 1992).

Carbon Accumulation and Stored Carbon

The C_{org} accumulation rates and the area associated to those cores (Table 12) gave an approximation of the tonnes of carbon that can be stored in the associated area of eelgrass bed substrate per year. C_{org} accumulation rates in each assessed areas ranged between 0 and 0.13 gC cm^{-2} yr^{-1}. Over the whole of the assessed areas in the Estuary (n = 8 areas, 1,165,020 m^2) the carbon sequestration rate (C_{seq}) was 2.28 x 10^{-5} tC m^{-2} yr^{-1}. This value is much lower than the global seagrass long term rate of 8.3x 10^{-3} tC m^{-2} yr^{-1} (n= 5) estimated by Duarte *et al.* (2005) and the global carbon sequestration rate of 1.4x 10^{-2} tC m^{-2} yr^{-1} estimated by Pendleton *et al.* (2012). Yet the K'ómoks Estuary estimate is far greater than the recent range of -2.09x 10^{-8} to 2.05x 10^{-8} tC m^{-2} yr^{-1} (mean 1.38x 10^{-9}, n= 49) (Duarte, Kennedy, Marbà, & Hendriks, 2013; Kennedy *et al.*, 2010).

Table 12. Summary of the values derived from all radioisotope and carbon analysis required to determine the C_{org} accumulation rate for the associated eelgrass bed area of the cores in the K'ómoks Estuary.

Core Name	Associated Area (m^2)	Sedimentation Velocity (cm yr^{-1})	Sediment Accumulation rate (g cm^{-2} yr^{-1})	Burial Carbon (%)	C_{org} accumulation rate (gC cm^{-2} yr^{-1})	Area C_{org} Accumulation (tC yr^{-1})
IBV^	16,430	0.36	0.61	0.22	$1.3x10^{-3}$	^21.36
IBB^	16,430	0.47	0.78	0.06	$5.0x10^{-4}$	^8.22
IHV	113,440	0.0	na	0.18	0.00	0.00
IRV	66,140	0.0	na	0.19	0.00	0.00
IRV2	839,340	0.0	na	0.12	0.00	0.00
SBB	17,360	0.13	0.23	0.14	$3.0x10^{-4}$	3.41
SBV	40,420	0.0	na	unk	0.00	0.00
SCV	24,830	0.16	0.26	0.23	$6.0x10^{-4}$	14.90
SDV	47,060	0.0	na	0.69	0.00	0.00

na = no accumulation, used 0 value for calculations.

^ Cores IBV and IBB accumulation rates represent a range as they were sampled from the same associated area of the estuary (16,430 m^2) therefore a mean was used in calculations except C_{org} accumulation rate where IBB was excluded as a non-viable Z. marina site.

The area of eelgrass bed in the K'ómoks Estuary with a measured accumulation rate was approximately 58,620 m^2 which represents roughly 3.5% of the total eelgrass bed area of 1,640,000 m^2 (Figure 31). Note that cores IBV and IBB were associated with the same eelgrass bed area but had different C_{org} accumulation rates. The lower rate of 0.05 gC cm^{-2} yr^{-1} and higher rate of 0.13 gC cm^{-2} yr^{-1} represent the range of the rate within the same eelgrass bed. Therefore, in all calculations a mean was used for this bed. The area associated with non-accumulating cores IHV, IRV IRV2, SBV and SDV (1,106,400 m^2 with 0 gC cm^{-2} yr^{-1}) was approximately 67.5% of the total estimated eelgrass bed area. At this time, approximately 71% of the Estuary's eelgrass beds have been assessed.

Based on the assessed areas to date, the K'ómoks Estuary has the capacity to store 42.5 tC yr^{-1}. However, extrapolating to include the unassessed areas (29%), the Estuary could have the capacity to store as much as 58 tC yr^{-1} over 100% of the area assuming accumulation rates were in a similar range. Considering only 30-50% of the net community production of seagrass meadow is buried in situ (Kennedy *et al.,* 2010), supported by the elemental and stable isotope analysis, potentially 19 – 29 tC yr^{-1} originated from the eelgrass production in the K'ómoks Estuary.

Discussion

The K'ómoks Estuary has a long history of use dating to pre-European contact where local First Nation oral history tells of the rich resources of the estuary. However, as was evident in the sediment cores, the more recent historic anthropogenic activities on and around the estuary have resulted in both large particle and small particulate level influences as seen in the sediment cores. The greatest disturbance seems to have been related to the log dump and booming practices between 1911 and the 1950s and to log storage practices that ended only in 2005.

The earlier activities layered the estuary bottom with woody debris. These events and time periods were evident visually in the collected cores as well as by corresponding C_{org} and C: N spikes in the core profiles. Other disturbances, at sites where the ^{210}Pb plots were noisy, may have been due to the history of a saw mill and of dredging in the estuary, primarily upstream in the Courtenay River channel that flows directly into the estuary. There were anthropogenic sources of particles such as fine sediment, sewage, pulp mill effluent, and land based non-point-source chemical and nutrient run-off (Dan Bowen, personal communication, August 2014).

Natural disturbances in the estuary include high energy hydrology from rivers and streams, strong tidal currents and wind waves. Natural slumping events would occur along the steep drop off of the alluvial fan which is the subtidal limit of *Z. marina* in the K'ómoks Estuary.

The sites within the K'ómoks Estuary that had disturbed cores and no measurable accumulation rate have perhaps been the most affected by the past physical disturbances. Those cores that had a measurable accumulation rate could still be seen to have $^{210}Pb_{EX}$ values that did not fit the model at depths that roughly correspond to when the log dump and booming practices were at peak activity. C_{org} is not sequestered until it is buried and there cannot be any ongoing sequestration without sediment accumulation (e.g. a site with very high C_{org}% and no sediment accumulation will not sequester carbon).

Current estimates of global carbon sequestration rates are cited as being up to 35 times higher in marine ecosystems than tropical rainforests (Mcleod *et al.,* 2011) and up to twice the global average storage per hectare of terrestrial soils (139.7 Mg C_{org} ha^{-1}) (Fourqurean *et al.,* 2012). These estimates far exceed those measured in the K'ómoks Estuary. However, this study has outlined the accumulation rates and carbon sequestration levels for a damaged and recovering estuary, a situation that is unfortunately occurring along coastlines worldwide. With this information, we can now determine how much C_{org} can be projected to accumulate as additional C_{org} stock, as a result of protection and restoration activities in temperate Northwest Pacific estuaries similar to the K'ómoks Estuary.

Further study is necessary to determine how much of the K'ómoks Estuary C_{org} is exported to Baynes Sound or further to the Strait of Georgia and of that, what portion of C_{org} is from *Z. marina.* Also, further study in this area of research is recommended globally, and specifically along the Pacific Northwest Coast of North America, in order to better understand sedimentation velocity, sediment accumulation, and carbon sequestration; and narrow the uncertainties in regional and global rates.

Restoration and protection of estuarine ecosystems and *Z. marina* beds also provides ecological benefits and ecosystem services: a recent report by the David Suzuki Foundation values the services provided by the Howe Sound, BC *Z. marina* beds at between $23,504 and $87,203 ha^{-1} yr^{-1} (Molnar, 2015). It is recommended these secondary benefits should not be overlooked.

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Chapter 8 - Eelgrass Transplant Methods

Eelgrass reproduction in British Columbia occurs primarily through lateral rhizome spread, approximately 10-20 cm/yr. Eelgrass produces flowers and seeds, but seed dispersal does not appear to be the primary mechanism for colonizing new habitats. Because rhizome spread is slow and occurs only in areas immediately adjacent to existing eelgrass beds, areas that have been disturbed by human activities are often slow to recover naturally. Therefore, the transplanting of eelgrass to new locations has been determined to be a suitable method to increase eelgrass habitat.

CVPW has undertaken several eelgrass transplant projects since 2012. In the spring of 2011, Cynthia Durance of Precision Identification Ltd. was hired to give a workshop in the Comox Valley. At that time a small transplant, 77m^2, was planted. Over the following years it was monitored and results indicated the transplant method worked well in the Estuary and the plantings survived.

The method devised by Precision Environmental is called the SAFE method: **S**ite selected, **A**nchored with **F**e, using appropriate **E**cotype. It has been used successfully throughout British Columbia since 1994.

The following information describes the methods used by CVPW to undertake eelgrass transplants. For this project, over 1000m^2 was transplanted in 2014-2015. Figure 38 shows all transplant sites in the K'ómoks Estuary.

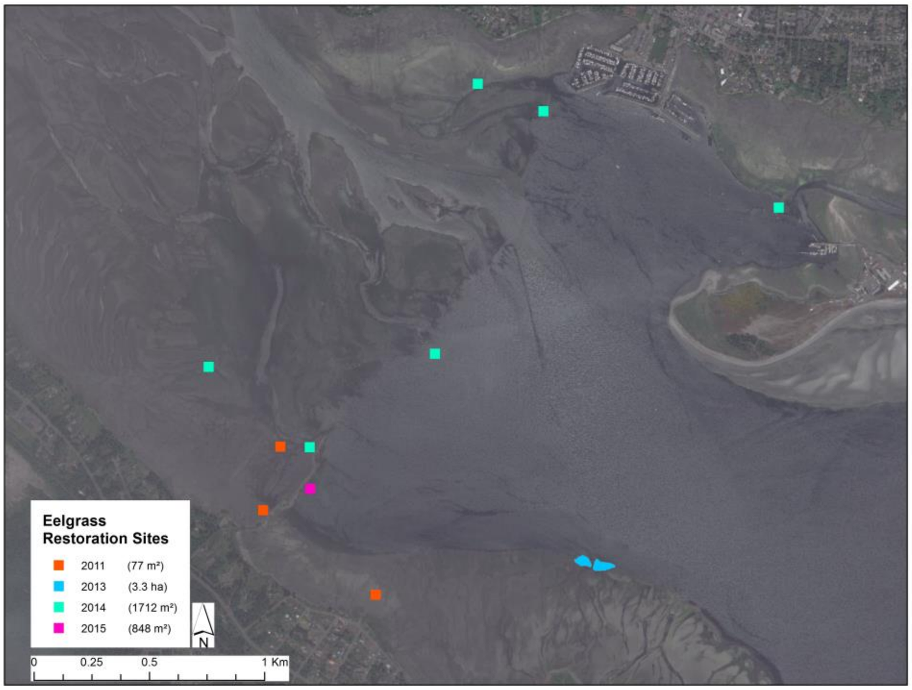


Figure 36. Eelgrass transplant sites in the K'ómoks Estuary and year of transplant.

Identify Transplant & Donor Sites

Transplant areas can be identified through visual surveys of the Estuary, either by diving or by walking during low tide. Transplant sites for this project were identified with the establishment of the NAPECA Study sites (see Chapter 2).

For each transplant site a suitable donor site must be identified and used only once. Characteristics of the donor areas should match those of the site to be transplanted, such as similar tidal elevation and proximity, and should have a density of at least 20 shoots/m^2.

Both transplant and donor sites can be marked using flagging tape on rebar pins pushed into the sediment. The coordinates for each site should be recorded using a handheld GPS unit. Figure 37 shows the location of the transplant sites used in the NAPECA project.

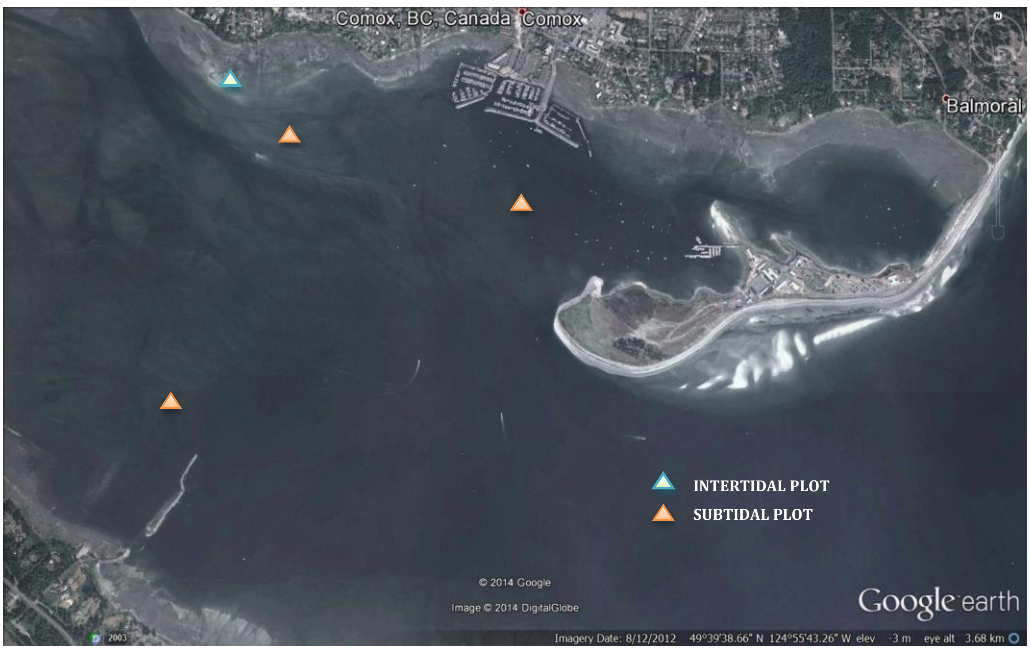


Figure 37. Locations of the four 250 m^2 eelgrass transplant plots in the K'ómoks Estuary. These sites are part of the NAPECA study sites identified in Chapter 2.

Collecting Donor Stock

Collection of intertidal eelgrass shoots can be accomplished during low tide. Harvesters wade into the donor site and collect no more than 10% of the donor site. A simple way to facilitate harvesting is to have each individual walk along a compass bearing, collecting 3-4 shoots for every 5 steps. The plants are placed into a collecting basket, such as a plastic tote or bucket. This activity can be accomplished by volunteers (Figure 38).

Figure 38. Volunteers harvesting intertidal eelgrass from donor bed.

The rhizome length of each shoot should be at least 8 cm long and have at least 3 nodes (root growth points) (Figure 39).

Figure 39. Each eelgrass shoot should have a rhizome length of at least 8 cm and have at least 3 growth nodes.

Collection of subtidal eelgrass requires the services of contract divers and a dive boat. A biologist should be present to ensure quality control on locating the subtidal plots and harvesting. Divers can use large mesh laundry bags and typically collect 100 shoots per bag per dive. After each collection, the boat should be repositioned 50 m away from the previous collection site to ensure harvesting is distributed over the donor bed.

Figure 40. Diver harvesting subtidal eelgrass from donor bed.

Given that planting will occur at 10 shoots/m^2, a total of 2,500 eelgrass shoots are required to plant an area of 250m^2.

Harvested shoots can be stored with high viability for several days if kept immersed, oxygenated and cool. For example, shoots can be stored in plastic laundry baskets contained within a large mesh bag and then weighted and hung off a dock (Figure 41). If a dock is not available, another method is to store all harvested shoots in a shallow subtidal area that is easily accessible and marked with a float. Divers can then retrieve harvested shoots as needed. It is important to note that during all stages of the transplant, harvest, tying and planting, eelgrass shoots should be kept submerged in seawater.

Figure 41. Short-term storage of harvested and bundled subtidal eelgrass baskets.

Preparing Eelgrass for Planting

Only shoots assessed to have healthy blades and roots should be used as transplant stems. All eelgrass should be examined for eelgrass wasting disease – a disease that has been found in eelgrass elsewhere but not yet in the K'ómoks Estuary.

When setting up a workstation for tying eelgrass, one needs to consider the proximity to the planting site, supply of fresh seawater, shade and comfort for the workers. Tying and bundling eelgrass is work that can be accomplished by volunteers. At all times, the eelgrass shoots should be kept cool and moist. CVPW found that working with eelgrass contained in plastic laundry baskets that are kept submerged in seawater within large totes worked well (Figure 42).

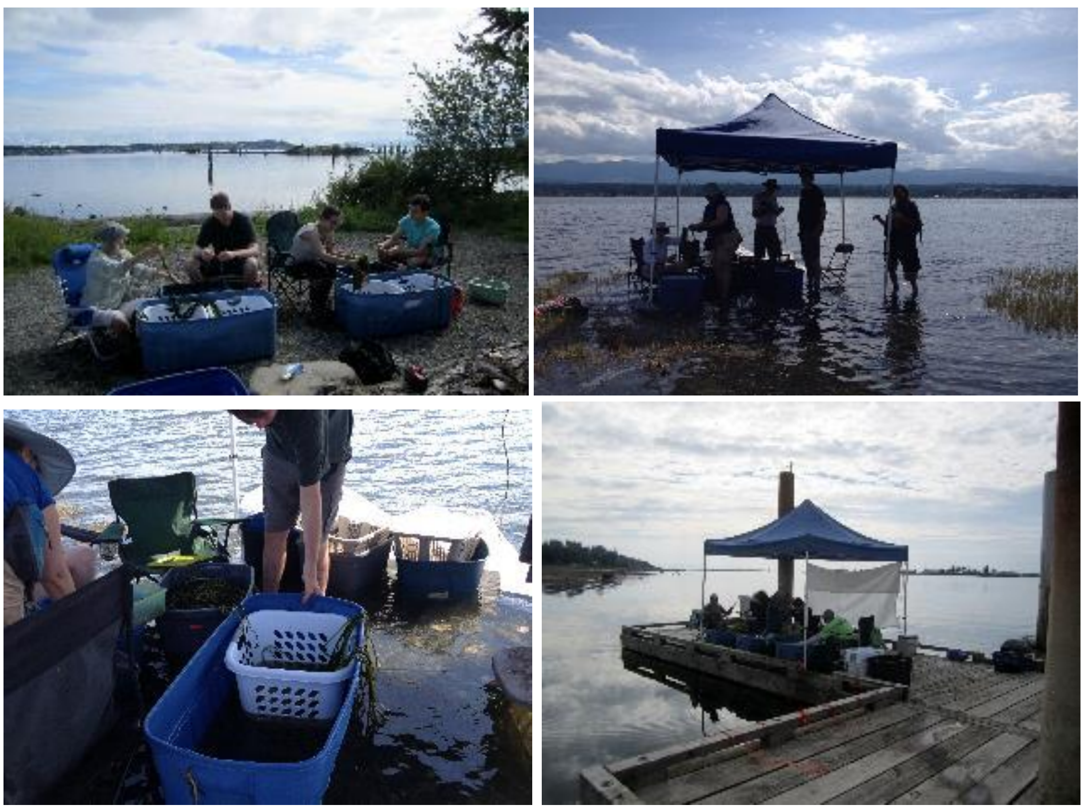
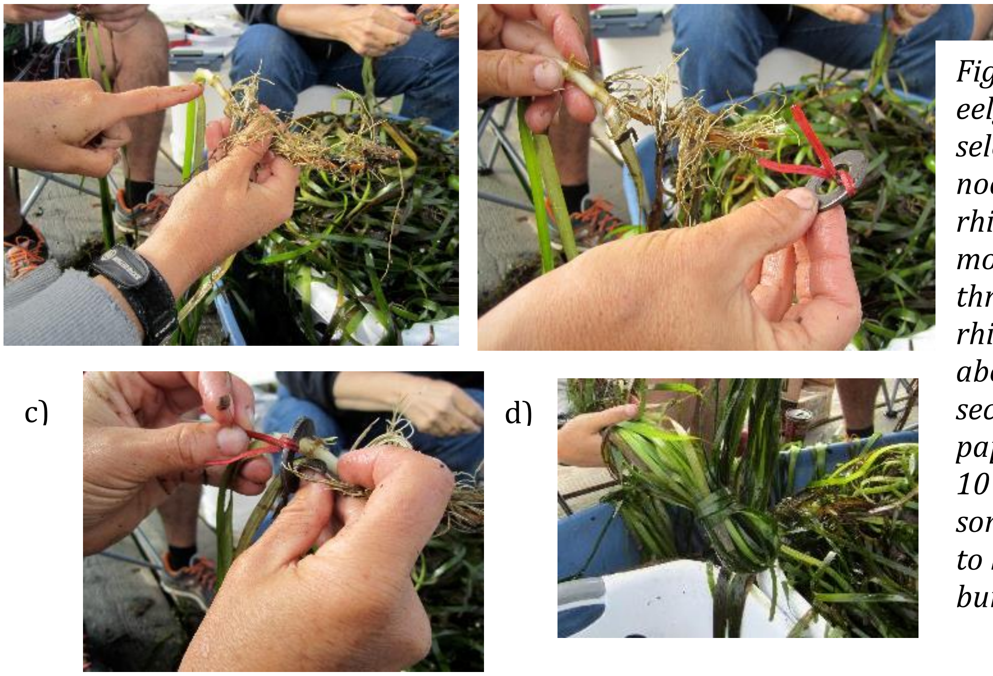


Figure 42. Examples of a workstation and volunteers tying washers and bundling intertidal eelgrass. Eelgrass is kept cool and moist at all times. Even though it's best to be close to the transplant site, one needs to be aware of tidal cycles.

Each eelgrass stem is weighted with a 5/8" steel washer positioned just above the first note. The washer is secured with a paper twist-tie (Figure 43). The weighting of the each eelgrass shoot allows it to remain in position and not be dragged easily by tidal action.



a) b) c) d)

Figure 43. Threading an eelgrass shoot. a) only select shoots with at least 3 nodes. Break off the rhizome so there are no more than 5 nodes; b) thread the washer up the rhizome and position just above the first node; c) secure the washer with the paper twist-tie' d) bundle 10 shoots together using some of the longer blades to loosely secure the bundle.

The materials are intentionally selected to ensure they will disintegrate in seawater over time. The paper twist-tie will break within a few weeks but will provide the necessary attachment to the steel washer while the roots of the plant get established in the sediments. The steel washer should not be stainless steel as it will provide iron to the eelgrass as it rusts away.

The weighted shoots are then bundled into groups of 10 by folding the blades over and then wrapping a few eelgrass blades around, holding it together to facilitate planting. For transplanting, each basket is prepared with 10 bundles per basket.

CVPW has found through experience that 2,000 plants may easily be tied and bundled per day. Harvesting and planting can go more quickly but must keep pace with the tying and bundling.

Planting Methods

Planting intertidal eelgrass can be accomplished with volunteers. The area to be transplanted should be delineated with measuring tapes, rebar pins and lead lines. Planters can meter sticks to work systematically and plant a bundle of 10 shoots roughly in the center of each square meter. One simple method is to have each planter carry a basket of 10 bundles and plant, then step forward, then plant again (Figure 44). Planting should occur during a rising tide to minimize the length of time the eelgrass shoots are exposed. Coordination of planting with the rising tide is an art.

Planting in subtidal plots requires the use of commercial divers. Again, each bundle of 10 shoots is planted in a grid pattern $1m^2$ apart.

Figure 44. Volunteers planting intertidal eelgrass bundles in transplant site. One bundle of 10 shoots is planted every square metre.

Monitoring of Transplant Sites

Once a bed has been transplanted, it's important to monitor its success over time. However, there is sometimes a challenge to cover the costs of monitoring as most granting agencies don't regard this as a valid activity. Therefore, each community organization should consider long-term monitoring options for a transplanted site.

A monitoring program should revisit the transplant site at least yearly and measure survival rate. Because the transplanted area is planted in a $1m^2$ grid pattern, it is relatively easy to note whether the bundles survived and whether there has been any infilling through rhizome spread.

A simple monitoring protocol could include setting up permanent transects that run through the transplant area and then survey the number of eelgrass bundles present along the length of the transect. Subsequent monitoring along the same transect will provide information on whether eelgrass coverage is increasing.

An eelgrass transplant conducted by CVPW in 2013 was monitored the following year and was determined to have 95% survival rate and infilling through rhizome spread. Information such as this is comforting to know the methods used to transplant eelgrass works well.

Figure 45. A transect line is positioned through a transplant site and the number of bundles present are recorded.

Chapter 9 - Saltmarsh Restoration Methods

Saltmarsh habitats are vulnerable to human disturbance. In the K'ómoks Estuary, the most significant loss of saltmarsh has been due to diking for agriculture, construction of structures in the intertidal area, and changes to shoreline process due to infrastructure installations. Along much of the shoreline, saltmarsh habitat consists of small fringing fragments along the upper tide line. Changes to local hydrology have exacerbated erosion processes in some areas, causing undermining of the sediments underlying the saltmarsh areas. This results in the formation of small hummocks that eventually get washed away during winter storm events.

Saltmarsh restoration is an evolving practice and there are limited examples of successful restoration projects to guide CVPW's plans. Most saltmarsh restoration projects involve the breaching of a dike to restore water flow. However, in the K'ómoks Estuary the challenge is that the front edges of the saltmarsh beds are being eroded.

In 2013, CVPW tested a method to create islands for saltmarsh habitat. This first attempt was used to gain expertise and experience to make larger saltmarsh restoration plans for the Estuary.

The following provides information on the methods used to construct the saltmarsh islands and subsequent planting.

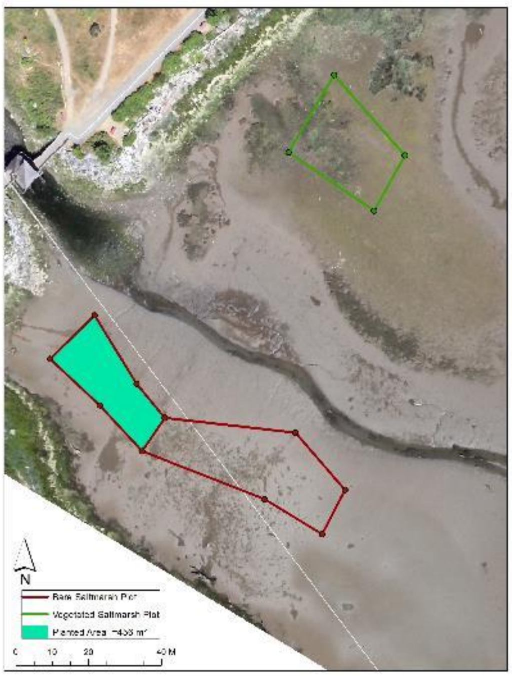
Site Selection

A survey conducted in 2013 identified potential areas for saltmarsh restoration. They were identified by proximity to existing saltmarsh, relative protection from storm action, and low sloping contours. Figure 46 shows the saltmarsh distribution in K'ómoks Estuary.

Figure 46. Saltmarsh distribution in K'ómoks Estuary. Air photos were collected in 2013. Data interpretation was done in 2014.

In 2014, the area adjacent to the outflow of the old sewage lagoons was selected as the saltmarsh study area (Figure 47). This area was initially modified in the 1950's with the establishment of dikes to create the sewage lagoons. They were operated by the City of Courtenay between 1963 and finally decommissioned in the 1980's. Subsequent rehabilitation of the area occurred in 1992 and the area was turned into a municipal park with walking trails installed on the berms of the old lagoons. This area was selected because of its relative protection from winter storms and high visibility to the public.

a)



b)

Figure 47. Survey of saltmarsh study site. a) The green area represents the area where the saltmarsh islands were constructed; b) volunteers assisting the surveyor with mapping of the study site.

The study area was surveyed to determine elevations and geo-referenced using GPS coordinates. In addition to the study site, two other sites were mapped: an adjacent area that would remain barren and a vegetated saltmarsh area in the same area. In the original proposal for NAPECA, the researchers proposed to monitor the amount of carbon sequestered in the new saltmarsh and compare it with an existing saltmarsh area and a barren site. It was later determined the approach was not feasible given that the saltmarsh habitat in the K'ómoks Estuary is highly disturbed and doesn't represent a 'typical' saltmarsh habitat. As well, considerable work had been completed by Restore America's Estuaries in the Snohomish Estuary, Washington State. Therefore this project focused primarily on methods to create saltmarsh habitat.

Species Composition of Saltmarsh

To determine which saltmarsh species would be most suitable for each planting elevation, a survey of adjacent saltmarsh areas is recommended.

For this project, the saltmarsh vegetation in the neighbouring areas was inventoried to identify species and species abundance for upper and lower elevations. In total 14 native species and 3 exotics were identified in adjacent saltmarsh areas (Table 13).

Table 13. List of Saltmarsh species in K'ómoks Estuary near mouth of Puntledge River.

Scientific Name	**Common Name (Invasive marked with *)**
Atriplex patula	Orache
Cakile edulenta	American searocket
Carex lyngbyei	Lyngy's sedge
Deschampia cespitosa sp.	Tufted hairgrass
Distichilis spicata	Seashore saltgrass
Elymus mollis	Dunegrass/dune wildrye
Fucus vesiculosis	Rockweed
Grindela integrifolia	Entire-leaved gumweed
Hierochloe odorata	Sweetgrass
Lathyrus japonicus	Beach pea
Plantago maritime	Sea plantain
Potentilla anserina	Silverweed
Salicornia virginica	Pickleweed; sea asparagus; glasswort
Triglochin maritimum	Sea arrow grass
Asparagus officinalis	Asparagus (escaped garden vegetable) *
Spartina patens	Salt meadow cordgrass (invasive exotic) *
Daucus carota	Wild carrot (invasive exotic) *

A survey of which species inhabited each zone in the marsh zone was identified (Table 14). This information then formed the basis for a planting plan.

Table 14. Saltmarsh species classified by relative elevation. Bolded names are species that are most abundant in the elevation band.

Lower Marsh	***Salicornia depressa, Triglochin maritimum, Distichilis spicata, Juncus gerardii,*** *Fucus spp, Glaux maritima, Suaeda calceoliformis, Schoenoplectus pungens, Plantago maritima, Puccinellisa pumila*
Middle/Upper Marsh	***Juncus gerardii, Spartina patens****, Distichilis spicata, Salicornia virginica, Carex lyngbyei, Triglochin maritimum, Grindelia stricta*
Upper Marsh	***Carex lyngbyei****, Deschampia cespitosa sp. Beringensis, Distichilis spicata, Grindelia stricta, Juncus gerardii, Ambrosia chamissonis, Cakile edulenta, Melilotus alba, Atriplex patula*
Fringe and Upland	***Leymus mollis****, Lathyrus japonicas, Malus domestica, Malus fusca, Crataegus douglasii, Daucus carota, Rosa nutkana, Melilotus alba*

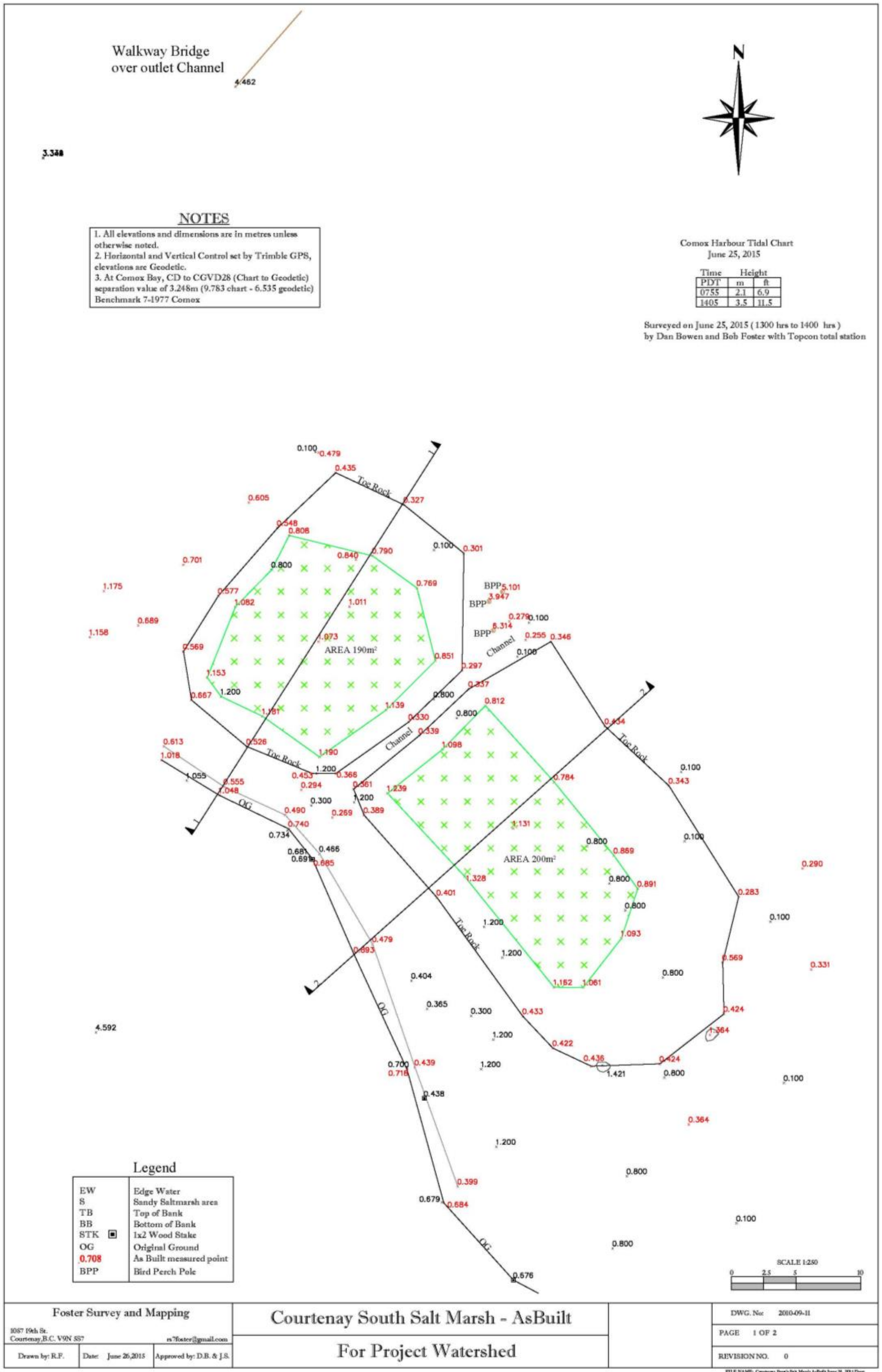
This planting plan is informed by the native species at the site as well as salt marsh planting done by Project Watershed on constructed salt marsh islands in 2015. In the native salt marsh, *Bolboshoenus maritimus* (saltmarsh bulrush) and *Schoenoplectus pungens* (common three-square) are dominant in the lower elevations alongside the new islands and in the airpark lagoon. *Juncus arcticus* (arctic rush) is prevalent in the lower to middle elevations at the island site and is also present in some areas in the lagoon. *Carex lyngbyei* (Lyngby's sedge) is abundant in the lower to middle salt marsh elevations in the lagoon and scattered throughout the island site as well. The species chosen for the planting plan are those that are suitable for the lower to middle salt marsh elevations—approximately 0.8 to 1.2 meters in elevation, as per the elevation of the constructed sites.

Saltmarsh Construction

Any activity occurring in the intertidal area must be approved by local fisheries and habitat agencies. In British Columbia, permitting is done through Fisheries and Oceans Canada and requires inspection by the local fisheries officer before any work can be done. As well, a window of time will be approved and all activities must be completed within that time. We found that saltmarsh construction was best done in late Spring to early Summer.

An engineering firm was hired to provide a construction plan for the saltmarsh islands. The planting platforms for each island were designed to be sloping between 0.8-1.2m in elevation with a bench slope of 4%. These specifications were derived from native saltmarsh in K'ómoks Estuary.

The design was planned as two 'islands', totaling approximately 390m^2, adjacent to the existing marsh. This was so that the existing salt marsh edges would not have to be disturbed, and to create a greater amount of edge habitat. The island design included armouring along the seaward edge of the planting platforms to ensure the imported sediment would persist through winter storms. An additional 285 m^2 of saltmarsh was planted in an area adjacent to a large culvert that was installed to breach the dyke and allow for water flow through the lagoon.



Time	Height	
PDT	m	ft
0755	2.1	6.9
1405	3.5	11.5

Figure 48. Engineering sketch of saltmarsh islands. Elevations are indicated.

Material of suitable size and composition was excavated from the nearby breach site and used to create saltmarsh benches in the estuary at the south end of the lagoon, near the original outlet. Specifications for sediment size and composition were based on the biological requirements for the plants and stable sediment sizes for the location.

Larger rock was imported and used to armour the benches due to their greater southeasterly exposure. Large woody debris (logs) at the site were salvaged and used to provide roosting perches for birds to increase habitat complexing at the site.

The constructed islands were allowed to go through a winter season un-vegetated so that any settling or erosion would occur before plants were installed.   In March 2016, the islands showed no noticeable damage from the winter storms.

a) b)

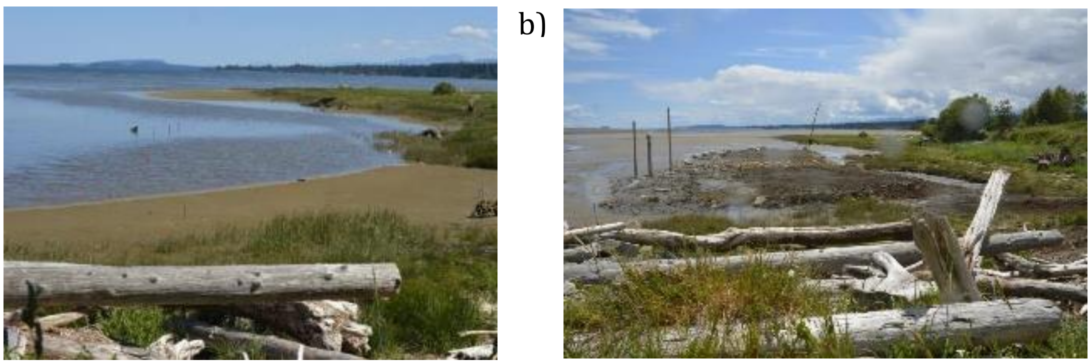


Figure 49. a) Location of saltmarsh bench restoration in K'ómoks Estuary, adjacent to lagoon outlet; b) completed saltmarsh bench at low tide.

a) b) c) d)

Figure 50. Construction of saltmarsh islands. a) Fill was added to allow movement of heavy equipment onto the mudflat; b) larger rock was incorporated at the front edge of each island; c) construction of the second island; d) detail of the front toe of the second island.

Figure 51. Constructed saltmarsh islands at medium tide.

Saltmarsh Planting

Based on the native species found in adjacent saltmarsh areas, a professional biologist created a planting plan using 4 of the local native species (Table 15; Figure 52). While natural salt marsh in the K'ómoks Estuary contains many more species, these were determined to be the most important species based on their coverage in the natural salt marsh. As well, these species are more likely to create dense cover and have establish root systems to stabilize the sediments. Other species are anticipated to colonize the site over time.

Table 15. Saltmarsh species in the planting plan for the Lagoon saltmarsh site.

Species	Common Name	Planting Notes
Carex lyngbyei	Lyngby's sedge	Prefers fresh water influence and finer sediments and occurs in patches across the higher parts of the marsh.
Juncus arcticus	Arctic rush	Occurs at middle elevations.
Bolboschoenus maritimus	Saltmarsh bulrush	Occurs throughout lower and middle elevations.
Schoenoplectus pungens	Common three-square	Depends on fresh water influence and prefers fine sediments

For the study site, a planting plan included over 3,500 nursery plants and 1,000 transplants. CVPW selected a 35 cm spacing for planting density based on communications with other professionals and past experience.

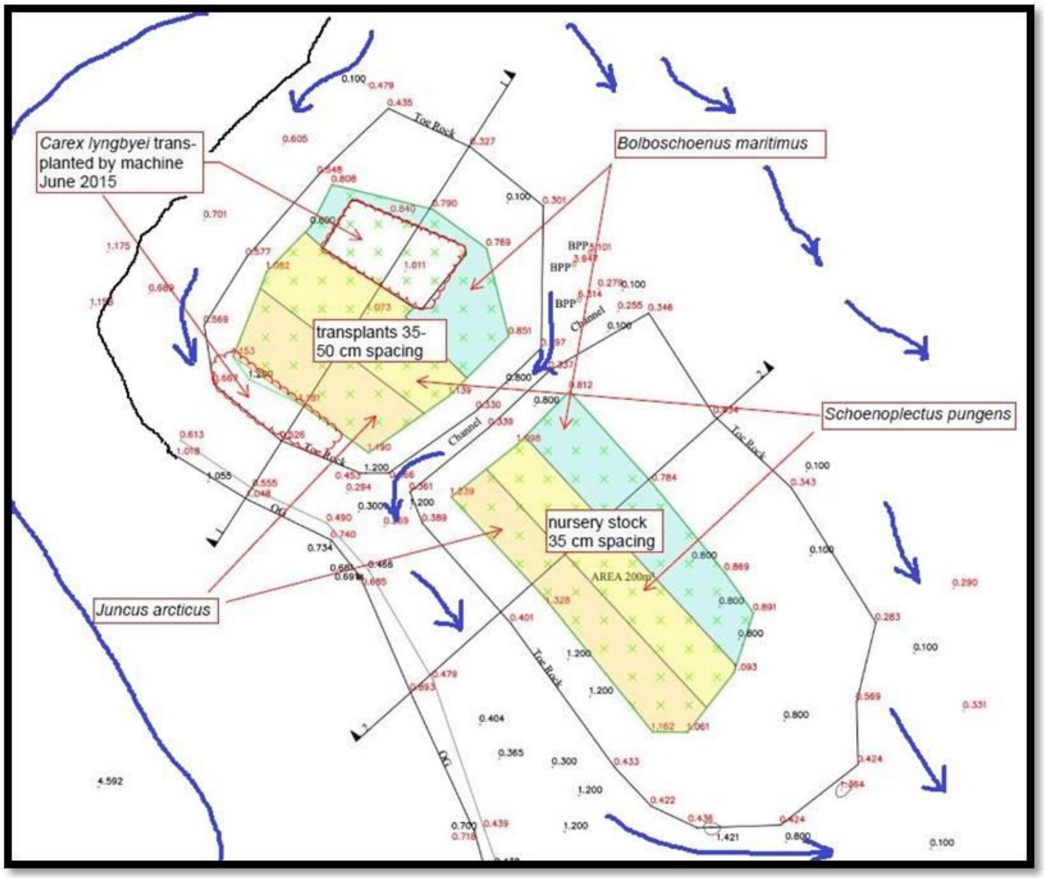


Figure 52. Planting plan for constructed saltmarsh islands.

Transplant stock was carefully obtained from nearby salt marshes. Stock was collected from small patches, no more than 10% of total stock, in such a manner that the vegetation cover will regrow within one growing season (Figure 53). Both nursery stock and transplants were installed in April 2016 during suitable tidal conditions. Fertilizer (a custom mix used by Project Watershed in the past) was used for both nursery stock and transplants. Due to the time-consuming nature of this work, the installation occurred over several days to ensure volunteers did not get too tired in a single day.

Figure 53. Collecting transplant stock from adjacent saltmarsh. All collection should be carried out to minimize impact on natural saltmarsh beds.

All planting should be carried out in the spring, to coincide with the start of the growing season and suitable tides. For both nursery stock and transplants a custom fertilizer mix should be used to facilitate root establishment. Volunteers are keen to assist in this type of activity (Figure 54).

Figure 54. a) Elementary school students assisting with the planting of saltmarsh benches in 2015; b) & c) planting with saltmarsh transplants.

Monitoring

As with any restoration project, a monitoring plan should be included in the project design. CVPW has now constructed saltmarsh islands in two areas in the K'ómoks Estuary. Because the planting plan and density are known, future monitoring can track the survival and recruitment of species.

This methodology is new and there are several unknowns. CVPW is working on determining the most suitable planting density for site, whether a lower planting density is equally successful. A lower planting density would reduce costs significantly. A spacing of 30 cm is a standard that is commonly used for planting salt marsh species grown from nursery stock. At CVPW's Royston site in 2015, experimental spacing was done at 30, 40, 50 and 60 cm. Early results suggest 30 cm spacing provides the best survival and coverage in the first growing season. However for some plants, 40 cm spacing was also effective. Based on this experience and the available budget, a spacing of 35 cm was chosen.

Based on the information in this report, Project Watershed will be able to track the survival and coverage of the different plant species in future years, as well as compare the success of nursery stock to transplants from donor stock.

Figure 55. One saltmarsh island planted with transplant stock collected from neighbouring saltmarsh areas.

Appendix 1

Squamish River Watershed Society Blue Carbon Project
Phase One Background Report
June 2014

Squamish River Watershed Society Blue Carbon Project

Phase One Background Report

June 2014

Estuaries are *where fresh water meets salt water and life flourishes. A mosaic of interconnected habitat types including eel grass beds, salt marshes, mud flats, sedge meadows, and tidal channels providing food, and shelter to an abundance of organisms. Estuaries also provide flood, erosion control, water filtration and carbon sequestration services.*

The Squamish River Watershed Society is *a registered, charitable environmental non-profit organization focused on watershed restoration since incorporation in 1998. The SRWS is a project based group that applies a collaborative science based approach towards watershed management within the Sea to Sky Corridor. Through our projects we:*

- *Promote environmental sustainability in the Squamish and surrounding watersheds;*
- *Conserve, protect and enhance the natural environment;*
- *Provide connection to the natural environment through education and outreach;*
- *Facilitate technical, academic and citizen science stewardship opportunities.*

Skwelwil'em Squamish Wildlife Management Area, Squamish River Estuary, 2011

Upper Mamquam Blind Channel estuary habitat, Squamish, 2014

Blue Carbon is *carbon that is sequestered in the soils, sediments and vegetative biomass found in estuaries.*

The Blue Carbon Project is *a community based climate change mitigation project to better understand the amount and potential value of carbon stored in estuary habitat in Squamish, B.C.*

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This report has been written by Kimberley Armour, SRWS Blue Carbon Project Manager. For more information on the blue carbon project email bluecarbon@squamishwaterhsed.com

Funding for phase one of the SRWS Blue Carbon Project has been provided by the Council of the Commission for Environmental Cooperation's North American Partnership for Environmental Community Action Program.

Summary

Estuaries can store more atmospheric carbon per unit area for a longer period of time then mature tropical rainforests, yet these hotspots of biodiversity are being in-filled, transformed from soft to hardened shorelines and developed at a rate unmatched to any other ecosystem worldwide. Estuary habitats provide an abundant, long term safe carbon storage opportunity. Through the conservation and restoration of estuary ecosystems there is great opportunity to foster greenhouse gas sinks needed to mitigate global climate change, while continued development of estuary ecosystems is proving to be a significant source of greenhouse gas, further driving global climate change (Grimsditch & Chung, 2012). Emission reductions, re-naturalization of developed habitats and conservation of existing habitat is necessary if we are to avoid an increase in the detrimental impacts associated with a global mean temperature increase (IPCC, 2014).

Carbon policies to position habitat restoration and conservation projects into economic internalities based on their ability to absorb atmospheric carbon dioxide, and mitigate the impacts of climate change are fast evolving internationally. Voluntary and compliance based carbon markets that support carbon off-set projects through emission trading are showing rapid economic growth. Blue carbon, or carbon that is sequestered in estuary habitats, does not currently trade in volunteer or compliance carbon markets however, protocol to certify blue carbon off-set projects is being developed to facilitate this.

Estuary habitat in Squamish, British Columbia has been impacted over the past century through infilling, development and urban expansion, and holds opportunity for restoration, and conservation from further development. The Squamish River Watershed Society (SRWS) has been leading estuary restoration projects in the area since 1998. Through the Blue Carbon Project the SRWS will identify estuary habitat restoration and conservation opportunities in Squamish, B.C. to establish a blue carbon monitoring study. Results from the blue carbon monitoring study will be used to support British Columbia Climate Action Secretariat's effort to develop Blue Carbon off-set protocol in British Columbia. In phase one of the Blue Carbon Project the SRWS is looking to develop policy, research, academic, land owner, community, and funding partnerships, and a collaborative action plan will be developed to direct phase two field work. This report kick-starts phase one of the Blue Carbon Project, sharing what we have learned about blue carbon research and policy so far. This report is an invitation to prospective partners to learn, engage and support this community based climate change mitigation effort to restore and conserve estuary habitat in Squamish, B.C.

Squamish aerial photo showing estuary habitat in 1954

Squamish aerial photo showing estuary habitat in 2010

Estuary Stewardship and Climate Change

INTRODUCTION

The International Panel on Climate Change (IPCC) is scheduled to deliver its fifth climate change assessment report in October 2014. This report is a synthesis of the organization three working group reports focused on:

- The physical evidence of climate change;
- Impacts adaptation and vulnerably due to climate change; and
- The pathway for climate change mitigation and adaptation.

Sections of this report have been released clearly indicating that the extraction of hydrocarbons from deep in the earth's lithosphere and subsequent burning of fossil fuels is loading our atmosphere with greenhouse gasses and driving global climate change. Atmospheric greenhouses gasses such as carbon dioxide, methane, and nitrous oxide have increased by 40% since pre-industrial times, reaching the highest concentrations in the past 800,000 years (IPCC, 2013). Excess greenhouse gas acts as a blanket in the atmosphere, capturing reflected sun rays that warm the earth's surface and ocean. Greenhouse gasses can be fixated in vegetation and begin the slow process back into fossil fuels, however, ongoing habitat destruction counters the earth's natural ability to fixate atmospheric greenhouse gases.

Globally the average combined land and ocean surface temperature shows a 0.85^0C increase since 1850 and each of the last three decades has been successively warmer than any other preceding decades. In the absence of change temperatures are anticipated to increase 1.5^0C relative to pre-industrial temperatures by the end of this century (IPCC, 2013).

Measuring spawning channel temperature at Mamquam River Reunion Site, Squamish B.C. 2014

Risks associated with climate change such as increased extinction of terrestrial and aquatic species and ecosystems, global food security, access to freshwater, ocean acidification, coastal flooding, and erosion are predicted to have considerable impact with a 1-2^{0}C global mean temperature increase, and high to very high impact if the global mean temperature increases 4^{0}C or more above pre-industrial levels (IPCC, 2014). Climate change impacts such as sea level rise is already impacting low elevation communities globally and adaptation to new realities is necessary. To mitigate further risk associated with an increase in global mean temperature, beyond adaptation we need to also focus efforts on reducing greenhouse gas emissions, restoring and preserving natural habitats.

Coastal erosion at Squamish Oceanfront Peninsula, 2014

Riparian planting, Upper Mamquam Blind Channel, Squamish, B.C., 2012

Mamquam River Reunion Channel, Squamish B.C., 2014

BLUE CARBON

Blue carbon is carbon dioxide that is sequestered in estuary biomass, sediment and soil. Through photosynthesis estuary vegetation fixates and stores atmospheric carbon dioxide in above (vegetation) and below (roots) ground biomass. Through ongoing sedimentation that occurs in estuaries, vegetation and benthic organisms become isolated in estuary sediments and soils where they undergo a slow anaerobic digestion decomposition process. Carbon dioxide emitted in the anaerobic decomposition process is captured in the sediment. If left undisturbed this captured carbon will be pushed down through dense soil and sediment layers and eventually transform back into fossil fuels deep within the earth's lithosphere (Campbell, 2010).

Estuary sediment layering, Cattermole Slough Squamish, B.C., 2014

Total blue carbon stored in one hectare of estuary habitat can be measured by adding the carbon stored in vegetative biomass, with the carbon stored in annual accretion sediment, and carbon stored in soils below the annual accretion layer (Sifleet, Pendleton, & Murray, 2011). Blue carbon research is being applied to develop carbon off-set protocol for mangrove, salt marsh and sea grass habitats. Coastal habitats such as mangroves can store up to five times more carbon per unit area annually than a tropical rainforest, 1 hectare of salt marsh can off-set the emissions produced by 488 cars in the US annually, and 1 hectare of sea grass can store up to 2 times the amount of carbon stored in 2 hectares of tropical rainforest (Murray et al., 2011). If, however, coastal ecosystems are degraded or destroyed they shift from an abundant carbon sink, to an abundant carbon source. Carbon sinks is habitat that mitigates global climate change by storing more carbon then it emits mitigate. When estuary soil is disturbed stored carbon is oxidized and emitted into the atmosphere further driving global climate change. Through the Blue Carbon Project the SRWS will identify estuary habitat restoration and conservation opportunities in Squamish, B.C., and establish a blue carbon restoration and monitoring plan to supports the development of blue carbon off-set protocol in British Columbia.

MITIGATING CLIMATE CHANGE AND VALUING NATURAL CAPITAL

Climate policies have evolved from concept to reality in the past decade and are transforming rapidly as leaders recognize the need to mitigate and adapt to global climate change. Under climate change agreements like the Kyoto Protocol, signing countries are subject to greenhouse gas emission caps. To realize emission caps countries agree to develop national carbon policies, such as, carbon tax incentive programs, and emissions cap and trade schemes, to transform the private sector in their respective countries toward clean energy technology. Emission trading and carbon tax incentive programs place emission efficiency in a company's profit margin competitively driving private sector reductions in greenhouse gas emissions. Countries unable to meet their emissions cap under the Kyoto Protocol are required to purchase carbon off-set credits from projects in developing nations certified under the UN Clean Development Mechanism.

Certification for a carbon off-set project is established in a given carbon policy or emission reduction agreement and defined by off-set protocol. The off-set project is required to be a project that offers reduced emissions through off-set investment, then emission levels had there been no off-set investment. In some instances Carbon off-set project protocol focuses on energy efficiencies, in other instances it can focus on habitat restoration or conservation. Under the UN Cancun Agreement, which is the successor to the UN Kyoto Protocol, signatories can get carbon credit through the conservation and management of forest carbon stocks under the UN REDD+ program (reduced emissions from deforestation and degradation). In British Columbia, under the Greenhouse Gas Reduction Targets Act (2007) the Provincial government is required to be carbon neutral in public sector emissions. To off-set emissions the Province funded various emission off-set projects including the conservation of old growth forest.

Carbon policy drives compliance carbon markets that now exist in the European Union, United States and New Zealand. These compliance markets traded 140 billion dollars for 5 gigatones of emissions in 2011, and forecasts anticipate international compliance carbon market trading to increase to 2-3 trillion dollars by 2020 (Calel, 2011). Voluntary carbon markets is also an emerging carbon market trend where parties, with a sense of corporate citizenship choose to be responsible for their emissions, and purchase offset credits. In 2012 voluntary carbon market traded 101 million tonnes of carbon and current suppliers anticipate that trading could reach 1.6 – 2.3 billion dollars by 2020 (Stanley & Yin, 2013).

Emissions stored through blue carbon off-set projects does not currently trade in compliance or voluntary carbon markets. Under the UN Cancun Agreement the inclusion of blue carbon in carbon policy continues to be researched (Murray, Linwood, Jenkins, &

Sifleet, 2011). Voluntary carbon market regulators such as the Verified Carbon Standard in the past year have started to pilot off-set certification standards for salt marshes. SRWS Blue Carbon Project partners, Project Watershed, in a Memorandum of Understanding with the B.C. Ministry of Environment Climate Action Secretariat has been working on the development of blue carbon off-set protocol for British Columbia, and the SRWS will be working to support these efforts.

CARBON POLICY AND ESTUARY RESTORATION IN SQUAMISH

Estuary restoration, and blue carbon research, that supports the development of Provincial blue carbon off-set protocol, is the current focus of the Blue Carbon Project. Generating off-set funding for estuary restoration and conservation in Squamish, B.C. is a longer term goal of the Blue Carbon Project. To accomplish this longer term goal we will be looking to identify opportunities to integrate blue carbon off-set work into existing and evolving local, regional, provincial and national carbon policies.

At the local and regional level, the District of Squamish and the Squamish Lillooet Regional District are signatories of the Climate Action Charter. The Climate Action Charter is a voluntary emission reduction agreement signed in 2009 by the majority of municipal and regional governments in British Columbia. Under the Climate Action Charter signatories commit to be carbon neutral in their corporate emissions by 2012. Signatories are required to publicly report their corporate emissions annually, and in exchange receive an annual carbon tax rebate to support their emission reduction efforts. If a signatory is unable to meet their goal of carbon neutrality they are expected to purchase emission off-set credits. The Squamish Lillooet Regional District reports to be building their corporate emissions inventory (LaFrance, 2014), and has yet to publicly report their corporate emissions. The District of Squamish reports an annual emissions rate of 1179 tonnes of greenhouse gas in 2012, and no off-set credits were purchased as expected under the Climate Action Charter (Armour, 2012). With the development of blue carbon off-set protocol, blue carbon off-set

SRWS Education Program monitoring Squamish River Estuary, 2010

projects could be funded through municipal and regional government signatories of the Climate Action Charter needing to off-set emissions.

The Province of British Columbia set legally binding legislation under the Greenhouse Gas Reduction Targets Act (2007) that includes a commitment to a carbon neutral public sector by 2010. The public sector includes provincial government offices, crown corporations, health authorities, schools, and post-secondary institutions. This commitment to carbon neutrality is to be achieved through efficiency upgrades and purchasing of off-sets credits where needed. The Climate Investment Branch of the Climate Action Secretariat, formally the Pacific Carbon Trust, certifies carbon off-set projects, and purchases credits from projects to off-set public sector emissions. When blue carbon off-set protocol is developed estuary restoration and conservation efforts in Squamish may be eligible for funding. British Columbia is also working with Pacific Coast regional governments under the Western Trade Initiative to establish an emission cap and trade agreements for private sector large scale greenhouse gas emitters. A cap and trade agreement of this nature could generate private sector support for blue carbon off-set projects.

Federally, Canada was a major contributor to the development of the UN Kyoto Accord, the first legally binding international climate change agreement to meet greenhouse gas emission reduction targets. Canada signed the accord, however, measures to meet first round emission reduction targets were insufficient. Facing an emissions off-set debt, and claims that Kyoto's success was limited as two major global emitters, China and the United States, were not participating, Canada withdrew support for the Kyoto Accord. As of 2011, Canada shifted climate change focus to supporting the UN Durban Platform that focuses on inclusion of all global emitters, including China and the United States. Under the Durban platform parties agree to develop legally binding reduction targets by 2015 that will take effect by 2020. When federal emission reduction target policies are more clearly defined the SRWS will explore opportunities to work with the Federal Government to support blue carbon climate change mitigation opportunities through estuary conservation and restoration.

The Squamish River Watershed Society Blue Carbon Project

INTRODUCTION

Habitat, land use plans, and relevant carbon policies will guide the SRWS Blue Carbon Project. Phase one of the Blue Carbon Project will focus on partnership formation and information gathering to enable blue carbon field research. Funding for phase one has been provided by the North American Partnership for Environmental Community Action (NAPECA) grant. NAPECA grants are a program of the Commission for Environmental Cooperation under the North American Free Trade Agreement. Canada's Environment Minister is the current chair of the Commission for Environmental Cooperation who in a letter to the SRWS articulated that the Blue Carbon Project, and community based climate change mitigation work is an essential part of Canada's environmental agenda. The SRWS has partnered with Project Watershed, a stewardship group also undertaking a blue carbon pilot project in Courtney-Comox K'omoks Estuary. Through the Blue Carbon Project the SRWS will identify estuary habitat restoration and conservation opportunities in Squamish, B.C., and establish a blue carbon restoration and monitoring plan to supports the development of blue carbon off-set protocol in British Columbia.

Great blue heron (*Ardea Herodias*), Squamish Oceanfront, 2014

IMPACTS, EFFORTS, AND OPPORTUNITIES FOR BLUE CARBON RESTORATION

Squamish is located in the Sea to Sky Corridor northwest of Vancouver, in the traditional territory of the Squamish First Nation at the northern end of the Howe Sound, a fjordal inlet of the Pacific Ocean. The valley is defined by high mountains and flowing rivers, the Squamish River and the smaller Stawamus River are the primary watercourses that discharge into the Howe Sound. The Squamish River extends for over 115 km with numerous branching tributaries. Downtown Squamish, and Squamish's North Yards, and Dentville areas are located on traditional estuary habitat in the valley flood plain.

Under the Blue Carbon Project the SRWS plans to map remaining estuary habitat in Squamish B.C., and identify restoration sites to study blue carbon storage. Impact to estuary habitat in Squamish, past SRWS estuary restoration efforts and opportunities to integrate blue carbon restoration and research is summarized by estuary habitat areas shown in Figure 1 below:

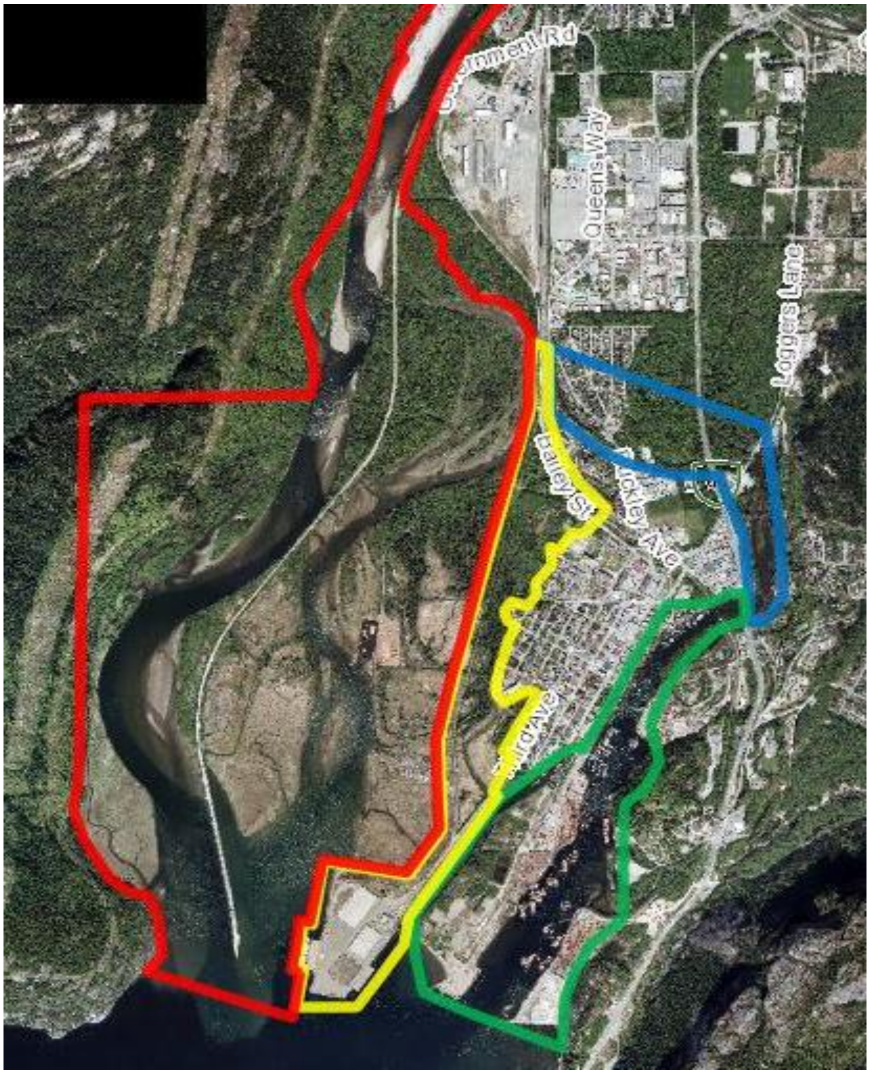


Figure 1: Estuary habitat areas, Squamish B.C., 2013

Colour	Estuary habitat area
Blue	Upper Mamquam Blind Channel & Dentville
Green	The Squamish Oceanfront Development Land & Lower Mamquam Blind
Yellow	The Bridge Pond
Red	Skwelwil'em Squamish Wildlife Management Area, Site A, west side of Squamish River

Upper Mamquam Blind Channel & Dentville

The Mamquam River is second order tributary of the Squamish River that drains 5 kilometers upstream of the Squamish River Estuary. The Mamquam River traditionally flowed down the east side of the valley into where the Mamquam Blind Channel exists today, with an arm extending west across what is now known as Dentville, and into the Squamish River Estuary. To accommodate development in the south east area of the Squamish flood plain the lower portion of the Mamquam River was dyked in 1921 and re-routed west to drain into the Squamish River. The Mamquam River dyke facilitated industrial, commercial, and residential development in Squamish's North Yards, Dentville, and Downtown Squamish.

Monitoring Mamquam River reunion spawning channels, 2007

The traditional flood plain of the Mamquam River supported a large complex of wetlands and watercourses that were interconnected through tidally influenced sloughs and channels. In 2005 the SRWS, in partnership with landowners, regulators, funders, and community volunteers led the Mamquam Reunion Project. A flood gate installed through the Mamquam River dyke now allows a controlled flow into 50,000 m^2 of developed channels, wetlands, and ponds that serve to re-water traditional estuary habitat in the lower portion of the Mamquam River flood plain. In 2008 the SRWS in partnership with The Land Conservancy, and the District of Squamish purchased District Lot 4625 (right) located where the Mamquam reunion channels drain into the Mamquam Blind Channel, and west toward the Squamish River Estuary. The Land Conservancy now holds a conservation covenant on this property protecting it from development. With certainty that restoration

Rewatered Mamquam River estuary habitat, Blind Channel-Dentville east/west connector, District Lot 4625 Squamish B.C., 2014

works will not be disturbed, DL4625 maybe an option for blue carbon restoration and research.

Squamish in their Official Community Plan makes a policy commitment to implement Green Shores wherever possible. The Green Shores policy however, is not legislated in land use zoning or development permits. Portions of estuary habitat in the Upper Mamquam Blind Channel is protected under Squamish's Official Community Plan development permit for protection of the natural environment, the guidelines of this development permit area are however, subjective offering limited protection. With fresh water flowing again into the Lower Mamquam River flood plain there is great opportunity for estuary vegetation restoration in the area. Squamish is planning an Official Community Plan review for 2016, and is currently undertaking a marine planning process and integrated flood hazard management plan to identify costal flood hazard mitigation opportunities. Opportunities to develop protected blue carbon sites may be found through these land use planning process in the Upper Mamquam Blind Channel and Dentville area.

Skwelwil'em Squamish Estuary WMA, Site A & West Side of Squamish River

The Squamish River discharges through the Squamish River Estuary and into the Howe Sound. In 1970 the Squamish River Training Dyke was constructed by B.C. Rail to move the Squamish River to the far west side of the valley, and dry out the Squamish River Estuary for development of a deep sea coal port. A 13ha pile of dredge material from the Squamish River was placed to infill the estuary in preparation for development.

In 1972 the Department of Fisheries and Oceans Canada (DFO) stopped the coal port from proceeding further but the training dyke was completed effectively isolating the Squamish River Estuary off from the Squamish River. In response to the proposed coal port and other development proposals in Squamish's marine foreshore, DFO, and the Provincial Ministry of Environment commissioned the Squamish Estuary Management Planning process in 1979 to balance industrial, commercial and conservation land uses on the Squamish waterfront. Between 1979 and 1999 a government, community and industry based stakeholder committee known as the Squamish Estuary Management Committee worked together to develop the regions first marine land use plan. Key land uses in the plan included a conservation area, industrial/commercial area, a planning assessment area for further study, and a transportation corridor that could be developed in existing estuary habitat if and when needed to service the Squamish Terminals (Squamish Estuary Management Committee, 1999). The Squamish Estuary Management Plan (1999) is a land use agreement intended to guide land use decisions, and is to be reviewed by the Squamish

Estuary Management Committee every five years. An interim review of this plan took place in 2005, a full review of the plan is overdue.

Upon completion of the Squamish Estuary Management Plan (1999) efforts to designate the conservation plan area as Provincial Wildlife Management (WMA) commenced. WMAs are designated under section 4(2) of the Provincial Wildlife Act for the benefit of regionally to internationally significant fish and wildlife species or their habitats.

> *Wildlife Act, R.S.B.C. 1996, c.488 section 4(2) Power to designate wildlife management areas*
>
> *(1) In this section, "park", "conservancy" and "recreation area" have the same meanings as in the Park Act*
>
> *(2) With the consent of the Lieutenant Governor in Council, the minister may, by regulation, designate as a wildlife management area land that is under the minister's administration and is not in a park, a conservancy or a recreation area*
>
> *(3) The designation of land under subsection (2) does not affect any rights granted before the designation.*
>
> *(4) Despite any other enactment, a person may not use land or resources in a wildlife management area without the written permission of the regional manager of the recreational fisheries and wildlife programs.*

A land exchange between the Province, BC Rail and the Squamish Nation along with a management agreement between the Ministry of Environment and Squamish Nation pertaining to the management and planning of the WMA and Site A (Squamish Nation WMA) facilitated the designation of the WMA that took place in 2007 (Figure 2).

Figure 2: Skwelwil'em Squamish Estuary Wildlife Management Area and Site A (Squamish Nation WMA)

Squamish River Estuary pre-restoration showing river dredge pile in background, 2002

Tidal channel restoration Squamish River Estuary, 2005

From 1998 onwards the SRWS, in partnership with DFO restored portions of the Squamish River Estuary impacted by the Squamish River training dyke and river dredge pile. The restoration work included reconnection of traditional tidal channels in the Squamish River Estuary to the Squamish River via 10 culverts installed through the Squamish River training dyke, removal of the infill dredge pile, and significant vegetation restoration works. Under the Skwelwil'em Squamish WMA Management Plan (2007), the industrial log sort in the WMA is scheduled to be decommissioned in October 2014 and returned to functioning estuary. Restoration of the decommissioned log sort may be a unique opportunity to collect successive blue carbon data as the land transforms from an industrial site through to functioning estuary. The Sqwelwil'em Squamish Estuary WMA is not inclusive of all estuary habitat on the west side of the Squamish River. Land on the West Side of the Squamish River is largely untouched however, in the past year has seen some recreation pressure from the growing wind sport community that currently operates off of the Squamish River Training Dyke. Further examination of this area is needed to determine if there is estuary habitat suitable for blue carbon research.

Community volunteers revegitating the former dredge pile site, Squamish River Estuary, 2004

Squamish River Estuary, 2011

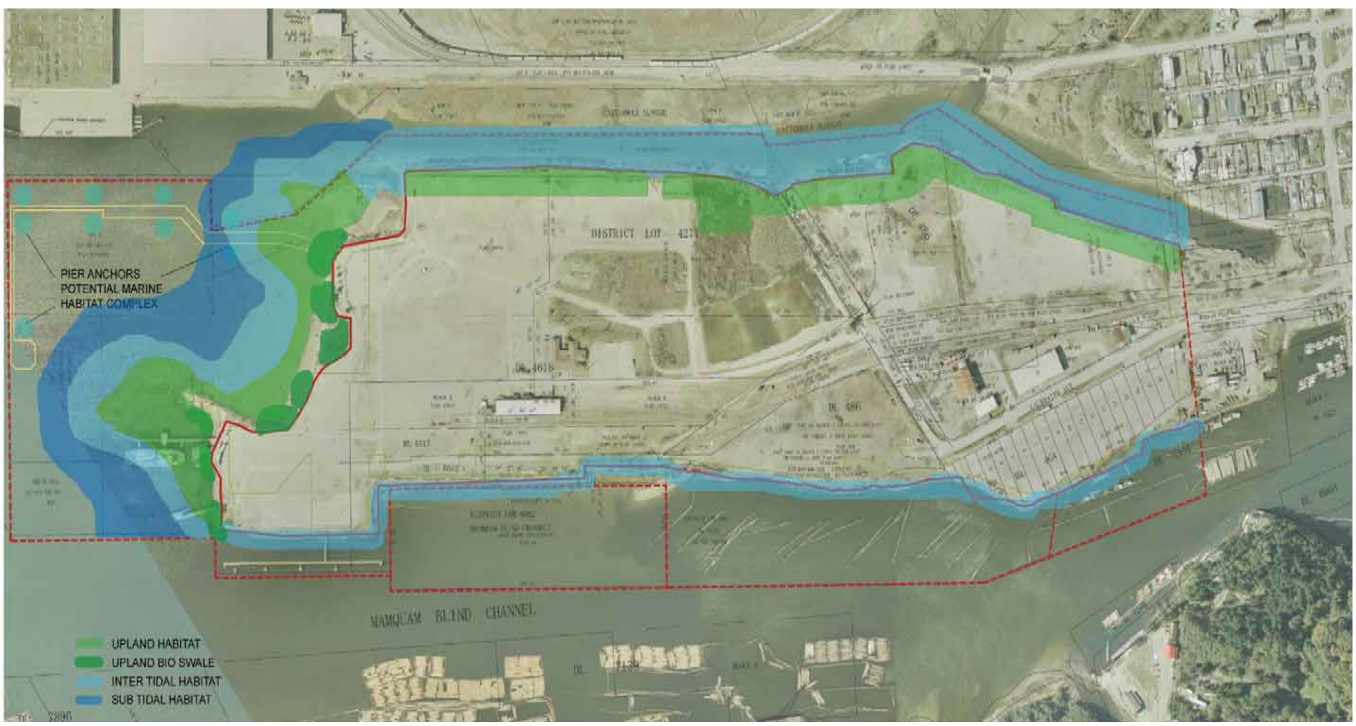
The Bridge Pond

Estuary habitat east of the Skwelwil'em Squamish Estuary WMA and Site A, known known locally as the Bridge Pond area is bisected by a north-south rail line that services the Squamish Terminals Deep Sea Port. Estuary habitat in the Bridge Pond area is also bisected by an east-west decommissioned sewage outfall line. Residential development in the area drove the installation of floodgates along the north eastern edge where the bridge pond meets the Cattermole Slough; the development of a stormwater retention pond; and enhanced sea dyking in the area. The floodgates were to remain open to facilitate ongoing tidal inundation in the bridge pond area, and used to prevent flooding in high tide storm serge events. Current operation of these gates however, limits tidal flow into the bridge pond area and the salt marsh habitat in this area is currently undergoing a forest succession process. Ground water infiltration in the stormwater retention pond seems limited due to the high water table in this traditional estuary habiatat. The stormwater retention pond connects to tidal channels via a flap gate in the sea dyke. Water in the retention pond below the hieght of the flap gate seems to stagnate. The retention pond collects the majority of downtown Squamish's stormwater runoff, and was designed to include oil separator infrastructure that is yet to be installed. Stormwater drainage outfalls at the north east end of the bridge pond area was also designed to include oil sperators that have yet to be installed. Water quality out flowing from the stormwater retention pond, and the tributaries that feed into the bridge pond area is of noticeably poor water quality, which may be partially attributed to missing stormwater oil seperator infrastructure.

The proposed transportation corridor identified in the SEMP (1999), and recognized in the District's Official Community Plan (2010) and Multi-modal Transportation Plan (2011), may potentially impact estuary habitat in the Bridge Pond area if develop. In 2008 The Nature Trust of BC purchased a 5.6 ha parcel of land in the Bridge Pond area to conserve critical habiat adjacent to the Skwelwil'em Squamish Estuary WMA. If developed the proposed transportation corridor would bisect these sections of estuary habitat impacting the areas overall productivity. There is opportunity to enhance estuary habitat in the Bridge Pond area by introducing more freshwater flow through the reconnection of tidal channels under the north-south rail line, removal of the east-west decommissioned sewarge outfall line that is no longer in use, and upgrades to the flood control infrastructure in this region to allow for a greater tidal exchange and improved stormwater quality. Through the Blue Carbon Project the SRWS will explore blue carbon restoration opportunities in the Bridge Pond area.

Lower Mamquam Blind Channel & Squamish Oceanfront Peninsula

Estuary habitat in the Squamish Oceanfront Peninsula and Lower Mamquam Blind Channel area has been largely in-filled for industrial development. Industry on Squamish's Oceanfront Peninsula has slowed since the days when the Woodfiber Pulp and Paper Mill was in operation. Industrial log sorts still operate on the west side of the lower Mamquam Blind channel. A new industrial log sort is being developed on Squamish Nation land on the west side of the Lower Mamquam Blind Channel just south of the mouth of the Stawamus River. The new log sort is where operations from, the soon to be decommissioned log sort in the central estuary, will move. Development of the new log sort was part of the Squamish Estuary Management and WMA planning process to move industrial activity out of the estuary conservation area and into an existing industrial/commercial area. Community consultation to re-define the Squamish Oceanfront Peninsula took place from 2005-2010 the outcome of which is defined in the Oceanfront Peninsula Sub-Area Plan (2010). The sub-area plan commits to Green Shores development and estuary habitat enhancements as shown in the blue and green highlighted areas of Figure 3. There are site contamination issues in this area, and site reclamation works are on-going as the community moves forward with a marine village vision for this space.



Figrure 3: Squamish Oceanfront Peninsula Sub-Area habitat enhancement plan, 2010

Since 2008 the SRWS, in partnership with the Sea Grass Conservation Working Group, has planted over 10,000 eel grass shoots in foreshore areas of the Squamish waterfront. Through the Blue Carbon Project the SRWS would like to explore further how eel grass, and estuary restoration works can support the implementation of Green Shores development policies in the Squamish Oceanfront Peninsula and Lower Mamquam Blind Channel.

Above water view, Lower Mamquam Blind ChannelSquamish B.C., 2014

Below water view, eel grass restoration Squamish, B.C., 2013

Community volunteers preparing eel grass shoots for transplant, Squamish , B.C., 2012

BLUE CARBON PROJECT GOALS

- Identify blue carbon restoration and conservation opportunities in Squamish, B.C. that supports local, regional, provincial and national climate change mitigation efforts;
- Conduct blue carbon research to support the development of blue carbon off-set protocol in British Columbia;
- Create carbon market support to restore and conserve estuary habitat in Squamish, B.C.
- Integrate ecosystem services planning into marine land use planning and development in Squamish, B.C.
- Share information with other community based organization engaged in estuary conservation and restoration activities.

PHASE 1 PROJECT OUTCOMES

1. Identify pilot study test sites for coastal blue carbon that:
   a. are protected from development under exiting land use plans
   b. Supports the development of a blue carbon off-set protocol in British Columbia
   c. Contributes to the advancement of international research efforts on blue carbon
2. Determine methodology for sampling blue carbon potential at identified pilot sites in partnership with Blue Carbon Project partners, Project Watershed
3. Summarize existing applicable information on the Squamish estuary habitat and identify information gaps to be addressed. Information may include:
   a. Estuary habitat mapping
   b. Vegetation surveys
   c. Sediment accretion rates
   d. Soil depth
   e. Eel grass mapping
   f. Tidal zone mapping and sea level rise modeling
   g. Salinity temperature and pH data
   h. Historical and traditional ecological knowledge of region
4. Climate change policy, planning and legislative review
5. Develop policy, research, academic, land owner, community, and funding partnerships to developed and implement blue carbon restoration and research field work.

BLUE CARBON PARTNERS AND PROSPECTIVE PARTNERS

- Project Watershed
- North American Partnership For Environmental Community Action
- Conservation International
- Sierra Club B.C.
- David Suzuki Foundation
- Pacific Salmon Foundation
- Sea Grass Conservation Working Group
- Sea to Sky Invasive Species Council
- Future of Howe Sound Society
- Sea to Sky Clean Air Society
- Verified Carbon Standard
- Squamish Nation
- District of Squamish
- Ministry of Forest Lands Natural Resources Fish and Wildlife Branch
- Skwelwil'em Squamish WMA Stewardship Working Group – yet to be formed
- Department of Fisheries and Oceans
- Environment Canada - Canadian Intermountain Joint Venture and Pacific Coast Joint Venture
- Squamish Estuary Management Committee
- Quest University
- BC Institute of Technology
- Capilano University
- University of British Columbia
- Simon Fraser University
- BC Climate Action Secretariat
- Pacific Institute for Climate Solutions

CONCLUSION

Through a collaborative approach to watershed management the Squamish River Watershed Society has successfully led estuary restoration projects for the past 15 years. Through the expertise in the SRWS network, and our on the ground work in the watershed we have developed strong understanding of the impacts to estuary habitat, and opportunities for estuary habitat enhancement in Squamish. Through the Blue Carbon Project the SRWS will identify estuary habitat restoration and conservation opportunities in Squamish, B.C. to establish a blue carbon monitoring study. The SRWS will work with project partners to advance blue carbon policy and research, continuing our estuary habitat stewardship work in Squamish, B.C.

Head of the Howe Sound, Squamish B.C., 2005

Orcas hunting in Howe Sound, 2014

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