Carbon Sequestration of Seagrass Meadows in Clayoquot Sound, BC:
An Identification of the Environmental Drivers of Sediment Carbon Variability

By

Jordan Prior
B.Sc., University of Victoria, 2021

A Thesis Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science
In the Department of Geography

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Abstract

Carbon storage mechanisms have seen increased attention to remove atmospheric carbon with the capability of seagrass meadows to sequester and store carbon becoming a key research objective within the Pacific Northwest (PNW). This study attempts to identify the environmental drivers of sediment carbon variability with a differentiation between allochthonous and autochthonous carbon. Seven seagrass meadows within Clayoquot Sound, BC were selected as determined by seagrass and morphological characteristics (tidal velocity, grainsize, slope, depth etc.). Carbon stocks varied among sites with five sites ranging between 21.1 ± 1.4 gC m^{-2} and 28.9 ± 1.6 gC m^{-2}. Two outliers were observed with 56.6 ± 2.8 gC m^{-2} and 15 ± 1.8 gC m^{-2} – resulting from a low D50 reflecting the propensity to sequester allochthonous carbon at the first site and a high velocity limiting deposition of allochthonous carbon at the other site. Average carbon stock (to 25 cm depth) throughout Clayoquot Sound for this study is 653.6 gC m^{-2} with a range of 366.3 to 1421 gC m^{-2}. Carbon accumulation aligns with previous studies with this study showing a range of 0.5 to 47 gC m^{-2} y^{-1}. Analysis of isotopic signatures, conducted via a Bayesian mixing model, show a strong allochthonous signal primarily from marine sources with terrestrial sources seen nearer to river mouths. Through the use of multivariate linear regression analysis, high tidal velocity is seen to be related to high autochthonous carbon due to suspension of sediment. In contrast, velocity and grainsize are seen to be related to marine carbon and terrestrial carbon is related to grainsize. This understanding shows that seagrass characteristics and spatial extent are not the only important variable to estimate carbon stocks and that there are definitive linkages between tidal velocity, grainsize, morphology (depth and slope) and carbon stocks. The extrapolation of carbon stocks beyond Clayoquot Sound could be better accounted for by using meadows, tidal measures, local bathymetry and local sediment characteristics. However, these variables are currently under-used in the modelling of carbon stocks for the PNW and around the world.

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Acknowledgments

First, I would like to acknowledge the Tla-o-qui-aht peoples, whose territory Clayoquot Sound resides in, and express my sincerest gratitude for allowing me and many others to research and learn within their lands. Thank you to Mary O'Connor, Matt Christensen and UBC's Biodiversity Research Centre for their support, resources and methodology. Thank you to the Hakai Institute and Parks Canada for their resources and access to data. A special thank you to Emie Woodburn and Matt Csordas for accompanying me under the water and providing their expertise during field collection.

Thank you to my supervisor, Dr. Eva Kwoll, for her guidance, support, and enthusiasm that made this research possible. Thanks to the past and present GECOS lab members, Wyatt Maddox, Bryn Forrest, Felipe Gomez, Narges Raee, and Keagan Patterson for your support in the field and in the lab. Finally, thank you to my friends and family for their continued and ongoing support.

1 Thesis introduction and objectives

Carbon sequestration has become a topical issue as the climate crisis persists and the eventuality of its dynamic impacts further erodes our coastlines, disrupts our global food production and creates water scarcity (International Panel on Climate Change, 2021). Carbon storage mechanisms have seen increased attention as a method to remove atmospheric carbon and maintain underground carbon stocks through conservation and restoration efforts (Depro et al., 2008; Fourqurean et al., 2012; Peng et al., 2014; Prentice, et al., 2019). In the public view, carbon sequestration primarily focuses on terrestrial carbon sinks, such as forests and bogs; however, terrestrial and marine carbon sequestration is riddled with disturbance regimes related to droughts, forest fire, storms surges and anthropocentric influences (Mckinley et al., 2011; Depro et al., 2008; Mazarrasa et al., 2018; Fourqurean et al., 2012). As such, a growing number of studies are looking at the carbon sequestration potential of sub and intertidal ecosystems, commonly known as 'blue carbon', to better understand how environmental (such as wave and tidal erosion) and human caused disturbances (via dredging, fishing and anchoring), impact marine landscapes, with a vast majority of these studies focusing on tropical ecosystems, such as coral reefs and mangroves (Fourqurean et al., 2012; Duarte et al., 2013).

This focus on tropical ecosystems has led to a large swath of the world's coastlines having limited research on their carbon storage potential (Kennedy et al., 2010). Tropical seagrass meadows are noted as an important ecosystem to accumulate and store carbon (Fourqurean et al., 2012); yet, geospatial data on temperate seagrass's extent and comprehensive analysis of carbon storage mechanisms continues to lag behind and is notably limited throughout the Pacific Northwest (PNW) (Postlethwaite et al., 2018; Prentice, et al., 2020). This lack of geospatial data has been identified recently by Fisheries and Oceans Canada as a high priority for seagrass mapping and carbon sequestration research to better understand the extent, storage, and carbon dynamics of seagrass meadows along the PNW (Gomez et al., 2021; Prentice et al., 2020). This is due, in part, to human impacts, such as agriculture, forestry, and commercial developments, which have destroyed substantial amounts of seagrass habitat and impacted carbon sequestration in BC (Duarte et al., 2013; Postlethwaite et al., 2018). It is understood that both terrestrial and marine ecosystems are impacted by anthropocentric activities which threatens habitat productivity and carbon stock accumulation; yet, limited research within the PNW leaves gaps in knowledge that disables effective comparisons and conservation efforts (Peng et al., 2014; Mazarrasa et al., 2018).

Numerous studies have shown that seagrass meadows enable the sequestration of carbon while, also, protecting coastlines from wave and tidal energy (Koch et al., 2006, Postlethwaite et al., 2018, Prentice et al., 2020). As such, determining the sources and environmental drivers, which impact carbon accumulation within seagrass meadows, has become a key limitation in providing robust predictions of carbon stocks within BC and beyond. This thesis seeks to detail the geomorphic processes that impact meadow and landscape scale seagrass carbon sequestration with a specific focus on separating the sources of carbon in seagrass (*Zostera marina)* meadows in the PNW.

1.1 Literature review

1.1.1 Principles of carbon sequestration in seagrass meadows

In northern latitudes, seagrass meadows provide essential habitat for a plethora of species while the morpho-dynamic setting, relating to interaction and adjustments of the seafloor to sediment movement and hydrodynamics, enables the capture of carbon (Lutz, 2018). The morpho-dynamic setting of seagrass meadows impacts and is impacted by, both, biological and environmental factors (Mazarrasa et al., 2018; Hansen & Reidenbach, 2013; Hendrik et al., 2008). Seagrass meadows impact the water column via its protruding leaves, which are known to reduce tidal velocity near the seabed (Koch et al., 2006). This reduced water velocity leads to suspended sediment being deposited within a meadow. The impact and growth of seagrass meadows' biological characteristics are impacted by its morpho-dynamic setting with tidal currents and wave energy known to impact the amount of sediment and the nutrients that are brought into a meadow (Lacy & Wyllie-Echeverria, 2011; Ricart et al., 2016).

Additionally, a meadow's capability to sequester carbon is dependant on the sourcing of its sediment and the biological productivity of the meadows (Novak et al., 2020). This is broken down into allochthonous and autochthonous carbon sources. Sediments that are deposited in a meadow from outside sources, allochthonous sourcing, contain a percentage of carbon from terrestrial or marine sources, and as this sediment accumulates, carbon stock increases (Prentice et al., 2019; Greiner et al., 2016). In a similar way, autochthonous sourcing results from the productivity of a meadow increasing the amount of carbon stored via its above and below ground biomass (*Figure 1*, Postlethwaite et al., 2018). By understanding the interaction between a meadow's biological and environmental characteristics, we can better understand the storage mechanisms of seagrass carbon sequestration in the PNW. Below we discuss how seagrass interacts with the hydrodynamic regime, observed carbon stocks throughout the PNW and the processes that enhance carbon sequestration.

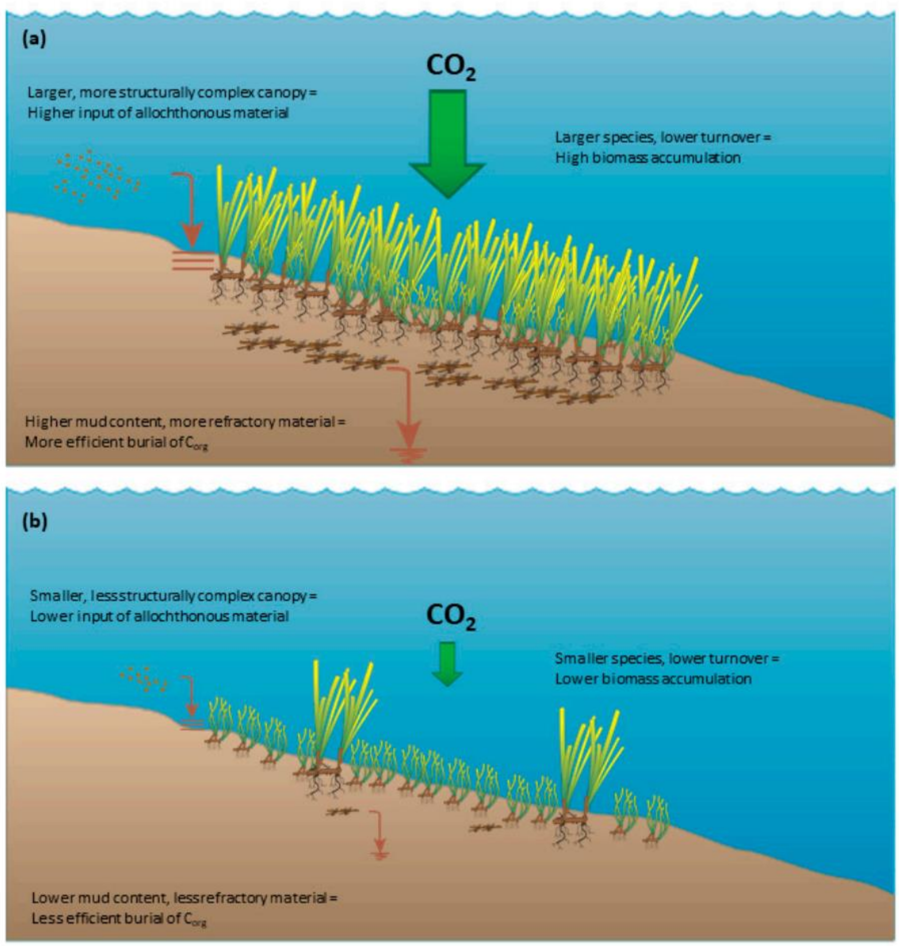


Figure 1: Three key processes in accumulation of seagrass carbon stock: biomass accumulation, input of allochthonous material, and efficient burial of Corg, and examples of the biophysical characteristics which drive higher (a) and lower (b) carbon stocks. (Figure from Simpson et al., 2022)

1.1.2 Seagrass interaction with the hydrodynamic regime and resultant sediment transport

The geomorphology of areas with seagrass meadows is irrevocably tied to a number of biological and physical forces. As such, it is important to understand how seagrass meadows interact with tide and wave regimes and how this energy is distributed throughout the water column and throughout the meadow. The hydrodynamics of seagrass meadows provide necessary context of the flow of sediment within and out of the meadow. This affects the ratio of autochthonous to allochthonous carbon entering long-term storage (Prentice et al., 2020).

Seagrass meadows induce drag throughout the height of the seagrass canopy which reduces water velocity through flow diversion (Hansen & Reidenbach, 2013). As such, meadows act as a shelter from hydrodynamic shear stress and reduce resuspension of sediments creating depositional environments (Hendriks et al., 2008). Two types of flow diversion have been identified: horizontal flow diversion (around individual shoots), causing scouring around individual shoots; and vertical flow diversion (above meadow), reducing water velocities and turbulence adjacent to the bed within high density seagrass canopies (Koch et al., 2006). In this manner, dense vegetation shields the bed from turbulence and bed-shear stresses that are capable of resuspending sediment (Nepf, 2012).

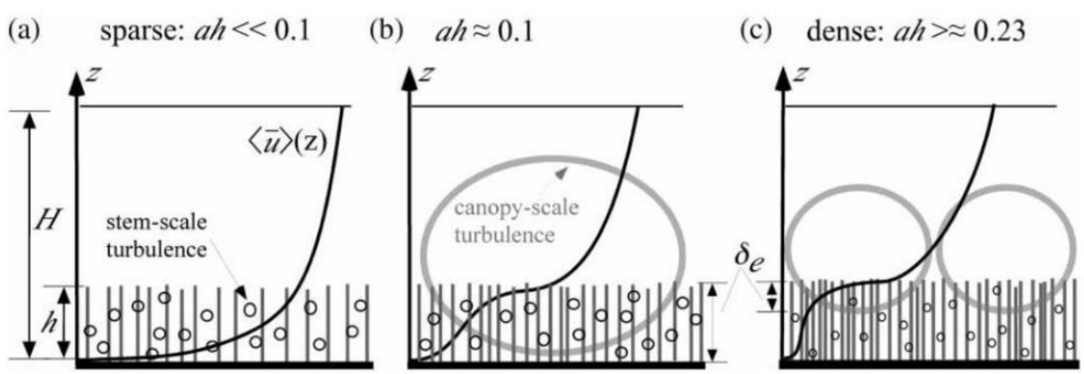


Figure *2: Mean velocity profiles of flow through submerged seagrass at the sparse and dense canopy limits. Here, H is water depth, h is canopy height. (a) Rough boundary-layer profile of a sparse canopy, where ah < 0.1. (b) Canopy-scale turbulence generated at densities between the sparse and dense limit, where ah ≥ 0.1. (c) Flow profile through a dense canopy (ah > 0.23), where the bed is shielded from canopy-scale turbulence (*Figure *from Nepf, 2012).*

This sheltering effect of seagrass meadows creates a positive feedback loop that enhances rhizome colonization and reduces sediment suspension increasing the amount of incident light radiation that can reach the meadow, thus increasing seagrass growth (Fonseca & Bell, 1998; Hansen & Reidenbach, 2013). Due to this feedback loop, it would be expected that increased accumulation of autochthonous and allochthonous carbon will occur within meadows where the sheltering effect and density is highest; however, spatial and temporal variability in the characteristics of seagrasses may increase or decrease local resuspension and transport causing variability in carbon sequestration (Hansen & Reidenbach, 2013).

Spatial variability is introduced when flow will accelerate or decelerate, due to changes in seagrass density, while passing from high to low or low to high density portions of a meadow, such as on the edge of a meadow or within a patchy meadow (Hansen & Reidenbach, 2013). Resuspension of sediment is then greatest within less dense canopies creating local scouring, while deposition may be confined to denser portions of the meadow (Hansen and Reidenbach, 2013). Moreover, seagrass edges are noted to store less carbon than the innermost parts of a meadow with seagrass landscapes increasing carbon storage inside the innermost portion of seagrass patches and in the adjacent bare sediments due to the edge effects. This suggests that patchy meadows' carbon stocks can often be over estimated due to a larger surface area of edges (Colomer & Serra, 2021; Ricart et al., 2015)

Annual life cycles of seagrass meadows define the temporal variability of deposition and resuspension accompanied by seasonal variation of energy regimes (Alcoverro et al., 1995). In temperate climates, seagrass flowering, leaf production and vegetative spreading begins in early spring. As such, the meadow reaches its maximum vegetative coverage midsummer, begins senescence in late summer, typically germinates in the fall, between mid-October to November, and has sparse coverage over the winter (Hansen & Reidenbach, 2013). The sloughing of leaves in the seagrass meadow thins the meadow's vegetative cover and shortens the canopy height. These seasonal changes impact fluid velocities within meadows and alters the rates of sediment erosion and deposition by increasing flow over a meadow in the winter when the meadow has the lowest vegetative coverage (Hansen & Reidenbach, 2013; Alcoverro et al., 1995).

Not only do seagrass meadows modulate flow, but tide and wave regimes also influence the characteristics of seagrass meadows. Several studies have shown that species composition and biomass of aquatic ecosystems are strongly related to wave exposure (Fonseca & Bell, 1998; Coops et al., 1991; Duarte & Kalff, 1990). Higher wave exposure is linked to increasing mechanical disturbances, with increased disturbances resulting in reduced seagrass spread and prevention of seedling colonization (Koch, 2001). In the absence of strong, sediment-moving tidal currents, wave exposure may therefore be the primary mechanism for the orderings of seagrass bed attributes (Fonseca & Bell, 1998). Using this relationship, prediction of time-averaged attributes of seagrass beds in a geographically enclosed setting is possible (Fonseca & Bell, 1998; Dahl et al., 2016), however, high temporal and spatial resolution of tide and wave regimes is required to provide quantitative linkages between meadow characteristics and the hydrodynamic setting on a landscape scale (Fonseca & Bell, 1998).

1.1.3 Carbon stocks of the Pacific Northwest

Overviewing carbon capture potential of past studies of seagrass meadows provides an important baseline for undertaking research and conservation of seagrass in the PNW. There have been five significant studies of carbon along the BC Coast: the first conducted in 2015-2016 by Postlethwaite et al. (2018) in Clayoquot Sound on Vancouver Island, the second completed in 2017 by Prentice et al. (2019) conducted near Culvert Island on the central coast, the third by Douglas et al. (2021) sought to determine nearshore carbon stocks of saltmarshes and eelgrass along the east coast of Vancouver island, the fourth by Prentice et al. (2020) which provides a synthesis of carbon stocks throughout the PNW between Washington state, BC and Alaska, and the fifth by Christensen & O'Connor (2023) who sought to provide updated estimates and modelling of Canada's carbon stocks including the PNW.

The highest carbon content in the PNW was found in Tsawwassen, BC with regional averages being highest in southeast Alaska and South Slough, Oregon, while the lowest values were found in the Southern Salish Sea in Washington (Christensen & O'Connor; Prentice et al., 2020); which reaffirms the low influence of latitude throughout the Pacific coast that was found in Röhr et al. (2018) who determined that latitude explained relatively little variation in carbon stocks in *Zostera marina* meadows across the Northern Hemisphere (Prentice et al., 2020). The information gathered through this analysis indicate that *Zostera marina* meadows are similar throughout the global north and carbon stocks in the PNW are notably lower than global seagrass averages. Refer to Appendix A for a detailed overview of carbon stocks.

This variation and accumulation of sediment carbon stock provides clear evidence for conservation and restoration policy along the coastlines of the PNW to ensure that carbon stocks remain in long-term storage. Otherwise, potential coastal degradation may transfer an evident carbon sink into a source of CO_2 emissions which will further erode our coastlines via increased wave and tidal regime combined with increased storm events that can further degrade these coastal environments (Prentice, et al., 2018). Predicting the extent and carbon potential of seagrass meadows along the PNW has become a necessity to encourage conservation and restoration of the meadows.

1.1.4 Processes that enhance carbon sequestration

The sources of sedimentary carbon are a notable factor in predicting carbon stock along the PNW due to seagrass meadows reducing velocity and causing deposition of suspended sediments. Yet, different regions are more suspectable to deposition of allochthonous carbon due to their location near riverine inflow or tidal conditions that transport sediment (Hendrik et al., 2008). Seagrass meadows throughout the global north are noted to store a large amount of carbon from allochthonous sources (between 50-72%) which are deposited preferentially in meadows due their propensity to trap sediment (Gacia et al., 2002; Koch et al. 2006; Hendriks et al., 2008). Along British Columbia's coastlines allochthonous carbon is a significant contributor to overall meadow carbon (Prentice et al., 2019; Postlethwaite et al., 2018); aligning with other studies, conducted outside of the PNW, which conclude that more than 50% of the carbon in meadows originates from non-seagrass sources, such as macroalgae, salt marsh vegetation, benthic microalgae, plankton, and/or terrestrial sources (Gacia et al., 2002; Kennedy et al., 2010; Novak et al., 2020). However, only one study in the PNW has shown the percentage of allochthonous versus autochthonous carbon due to limitations in data collection (Prentice et al., 2019).

The effect of core location – whether a core was taken from the meadow interior, edge, or adjacent unvegetated sediments – is an important factor in determining carbon stocks. A study of six vegetated sites near Calvert Island showed that carbon content varied 13-fold between sites and were significantly higher in vegetated than unvegetated locations (5-15 m from meadow sites) (Prentice et al., 2019). Within the study, three of the six meadows sampled followed hypothesized trends of higher carbon stocks in the interior followed by edge and unvegetated cores. Moreover, a second study found that carbon stocks within 2 of 3 meadows in Clayoquot sound were found to be significantly greater within the seagrass meadows as compared to non-vegetated reference sites (~250 m from meadow sites) (Postlethwaite et al., 2018).

Shallower depths are noted to have high accumulation rates of sedimentary carbon due to high primary production and increased biomass (Dahl et al., 2016). The study within Clayoquot Sound showed that the large mud flats support high-density intertidal seagrass that substantially out-contribute carbon storage compared to the subtidal portions of the meadows within that meadow (Postlethwaite et al., 2018); however, analysis of the two other meadows showed no notable difference between sub and intertidal portions of the meadow. It was concluded that the subtidal regions of the large mudflat may be limited by light, nutrient limitations and unsuitable sediment characteristics leading to the smaller size of subtidal meadows. A different study noted that sediment carbon storage capacity does not significantly change between intertidal and subtidal meadows; yet, sediment carbon appears to change with surface salinity and temperature (Koch, 2001). Variability along salinity and temperature gradients showed that the most saline and coolest meadows had the highest carbon content. This suggests that there is greater variation among separate sites than among locations within meadows (Postlethwaite et al., 2018)

Prentice et al. (2019) provides evidence that variation in biological drivers impacts sedimentation rates throughout the meadow and landscape scale. It is noted that lower wave heights, lower wave exposure and lower current velocities concurrently increase rates of carbon deposition and must also be considered when making carbon stock predictions (Hansen & Reidenbach, 2013). Accordingly, dense seagrass meadows are seen to stabilize sediment minimizing erosion while high seagrass canopies can trap suspended particles increasing the deposition of organic matter (Dahl et al., 2016). Yet, Alcoverro et al. (1995) found that the biological drivers commonly associated with increased sedimentation rates, such as a high canopy height, high shoot density and shallow water depths, have a minor influence on carbon sequestration. This implies that aboveground seagrass structure and water depth have a lower influence on overall carbon sequestration and that environmental conditions, such as wave and tide regimes, may have a much higher influence on sequestration due to their capability to bring allochthonous carbon into a meadow (Prentice et al., 2019).

Seagrass biomass and areal coverage are highly dynamic changing as a result of seasonality and current environmental conditions; thus, utilizing the current areal extent and density of a seagrass meadow may not be reflective of past carbon sequestration. As such, the estimates of present seagrass meadow properties may not be fully representative of carbon sequestration over decades or centuries (Dahl et al., 2016). Sediment characteristics can help reflect past conditions of carbon storage potential in *Zostera marina* meadows, and should be taking into consideration when evaluating high priority areas for protection and/or conservation of efficient carbon storage *Zostera marina* areas (Dahl et al., 2016). Furthermore, Duarte et al. (2013) furthers this by stating that increased research will be necessary to evaluate the expected carbon sequestration potential along decadal time-scales, which remains critical knowledge that is not yet available. As such, follow-up data collection at previously analysed sites may help to determine the viability and consistency of carbon accumulation, while consequently building upon the limited data available in the PNW.

To understand this variability, it is necessary to understand the factors that influence accumulation and preservation of carbon in seagrass sediments. Several environmental and seagrass-related factors (water, depth, meadow size, hydrodynamics and seagrass canopy complexity) are important to sediment carbon. Yet, sediment grain size and, in particular, fine sediment is often found to be the most important variable explaining carbon stock variability with allochthonous sediment significantly contributing to the sediment carbon stock (Dahl et al., 2016; Röhr et al., 2018). Additionally, fluid velocities within meadows play an important role in this transport as they alter the rates of sediment erosion and deposition caused by hydrodynamic forces within the meadow (Hansen & Reidenbach, 2013). Areas that have a larger portion of coarse sands are more likely to have higher autochthonous carbon via primary productivity of seagrass characteristics, such as above- and below-ground seagrass biomass, seagrass cover and shoot density, due to these regions often having higher flow velocity that inhibits silts and clays from being deposited within the meadow (Dahl et al., 2016).

1.2 Research objectives

The research objectives of this study focus on two scales of carbon sequestration in one of the previous study sites, Clayoquot Sound. Firstly, examining meadow-scale variability of sediment carbon, which focuses on the question: How does sediment carbon storage differ within a single meadow for different sediment and seagrass characteristics? Through this, the primary objective will be to quantify the variability of sediment carbon within their respective meadows as a function of meadow size and sediment and seagrass characteristics. Secondly, examining the landscape-scale variability of sediment carbon through understanding how sediment carbon storage (allochthonous and autochthonous) varies within Clayoquot Sound based on wave energy, seagrass characteristics (shoot density, height, width), bed characteristics (grainsize, slope depth), tidal flow characteristics (tidal velocity, turbidity, salinity, temperature) and proximity to river mouths. Through this, the primary objective will be to quantify the variability of carbon storage in seagrass meadows as a function of these parameters comparing how this variability impacts the distribution of allochthonous and autochthonous carbon within the region.

This study will focus on seven seagrass meadows within Clayoquot Sound, BC as determined by meadow size, past seagrass characteristics (shoot density, height, width), morphological characteristics (sediment type, abundance), distance to river mouths, and wave exposure. We hypothesize that environmental drivers of sediment carbon have a significant impact on deposition of allochthonous carbon and, thus, taking into consideration environmental variables will increase accuracy of predicted carbon stocks within seagrass meadows of the PNW. Utilizing meadow size, tidal velocity, local bathymetry and distance from riverine outflows, it may be possible to provide a better estimate of provincial and national carbon stocks within seagrass meadows than with traditional seagrass characteristic alone.

1.2.1 Predictions

(1) Meadow-scale variability of sediment carbon

Prediction: The amount of carbon variability within a single meadow depends on sediment and seagrass characteristics within the meadow and amount of allochthonous carbon within the sediment. Larger meadows with high density and largest blades alongside small grainsize are expected to have higher carbon content. Settling and accumulation of (allochthonous) carbon in the meadow interior is expected to be largest for large meadows and the largest blades as these meadows are expected to have the largest reduction in velocity over the meadow.

(2) Landscape-scale variability of sediment carbon

Prediction: Increased terrestrial sediment carbon is expected closer to river mouths in regions of higher turbidity; whereas, marine sediment carbon is expected to be high near more marine exposed sites. Sediment carbon is expected to be higher in less energetic and deposition-favouring environments; however, decreases in autochthonous carbon are expected to be associated with less productivity in turbid environments.

2 Key bio-geomorphological factors controlling carbon storage in (*Zostera marina)* meadows of the Pacific Northwest

2.1. Introduction:

Coastal habitats, including saltmarsh, kelp forests and seagrass, provide hotspots of biodiversity, protection from coastal erosion, and accumulate “blue carbon” leading governmental agencies and numerous studies to identify sub and intertidal ecosystems as a high priority for carbon stock and accumulation research (Gomez et al., 2021; Peng et al., 2014; Prentice et al., 2019, 2020; Postlethwaite et al., 2018; Daurte et al., 2013). Terrestrial and marine ecosystems are impacted by anthropocentric activities and climate driven disturbances (i.e., forest fires and storm events) which threatens habitat productivity and carbon stock accumulation; moreover, limited research within the coastal ecosystems of the Pacific Northwest (PNW) has left gaps in knowledge that inhibits conservation efforts and effective carbon storage modelling (Mazarrasa et al., 2018; Fourqurean et al., 2012; Mckinley et al., 2011; Depro et al., 2008).

Globally, carbon stocks within seagrass meadows vary between ~3493 gC m^{-2} (top 25 cm), in tropical regions, and ~1,752 gC m^{-2}, in the PNW (Fourqurean et al., 2012; Prentice et al., 2020; Röhr et al., 2016, 2018). Seagrass meadows of the PNW have a Carbon Accumulation Rate (CAR) ranging from 4.3 to 93.0 gC m^{-2} y^{-1} (Prentice et al., 2020), which is a broader range than reported from temperate meadows elsewhere (e.g., Miyajima et al., 2015; Jankowska et al., 2016; Greiner et al., 2013). In comparison, two studies in British Columbia show forested ecosystems and saltmarsh habitats of the PNW have CARs of 44 gC m^{-2} y^{-1} and 74 gC m^{-2} y^{-1}, respectively (Peng et al., 2014; Douglas et al., 2021), which are consistent with other studies in the PNW (e.g., Payne et al., 2019; Depro et al., 2008; Galis et al. 2021; Chastain et al., 2022). These values show that seagrass meadows of the PNW accumulates carbon similarly to terrestrial sources and other coastal habitats; however, more robust analysis on seagrass’ biological and environmental characteristics are important to determining regional and national carbon stocks.

The sources of carbon accumulation show an important dynamic between seagrass characteristics and the environmental conditions that bring carbon into a meadow. While some of the carbon sequestered derives from the plant itself (autochthonous), numerous studies conducted in tropical and temperate seagrass meadows conclude that more than 50% of the carbon in meadows originates from allochthonous sources (from outside the meadow), such as macroalgae, salt marsh vegetation, benthic microalgae, plankton, and terrestrial sources, due to the meadows propensity to trap sediment (Gacia et al., 2002; Kennedy et al., 2010; Koch et al., 2006; Hendriks et al., 2008; Novak et al., 2020).

This aligns with one study of the PNW, Prentice et al. (2019), which concluded that allochthonous carbon are a significant contributor to overall meadow carbon. Their study shows high terrestrial input (40%) and low seagrass carbon (25%). Building upon this understanding is nessacery to show the conditions that can bring carbon into a meadow and whether this carbon remains deposited within meadows of the PNW.

Carbon stocks of individual seagrass meadows vary depending on a meadow's geologic location and the morpho-dynamic setting (Dahl et al., 2016). The PNW has large variability in carbon stocks (13-fold) with higher carbon stocks in vegetated meadows than nearby unvegetated locations (Prentice et al., 2019; Postlethwaite et al., 2018). Vegetated meadows shield the seafloor from turbulence and bed-shear stresses that are capable of resuspending sedimentary carbon (Nepf, 2012). Therefore, a meadow's patchiness can impact carbon sequestration as the seagrass edges cause scouring around individual shoots increasing resuspension (Ricart et al., 2015; Fonseca & Bell, 1998; Hansen & Reidenbach, 2013). Higher CARs in intertidal meadows are theorized as shallower depths have higher incident light radiation which increases vegetative coverage and suggests increased deposition in the intertidal portion (Dahl et al., 2016; Alcoverro et al., 1995; Hansen & Reidenbach, 2013); however, studies within the PNW have noted that carbon storage capacity does not significantly change between sub and intertidal meadows (Koch, 2001; Postlethwaite et al., 2018). This suggests that there is greater variation among separate sites than locations within meadows; yet, only one study in the PNW has verified this (Postlethwaite et al., 2018).

The ecological components of seagrass meadows define the temporal scale at which deposition and resuspension occurs due to the thinning of the meadows' canopy and the seasonal variation of energy regimes (Alcoverro et al., 1995). As such resuspension of sediment is greatest with minimum canopy development of the winter months, while deposition occurs under maximum vegetative coverage (Hansen and Reidenbach, 2013). Despite this, the biological drivers commonly associated with increased sedimentation rates, such as high canopy height, high shoot density and shallow water depths, have a minor influence on carbon sequestration (Alcoverro et al., 1995). A stronger understanding of these variables' impact on carbon stock may create a more robust modelling of carbon in PNW.

Along with biological conditions, high tidal velocity and waves increase mechanical disturbances which reduces seagrass spread and seedling colonization (Fonseca & Bell, 1998, Coops et al., 1991; Duarte & Kalff, 1990). Environmental conditions are considered to have a higher influence on carbon sequestration due to their capability to bring allochthonous carbon into a meadow (Prentice et al., 2019). It is noted that lower wave heights, lower wave exposure and lower current velocities increase rates of carbon deposition (Lacy & Wyllie-Echeverria, 2011). Additionally, sediment abundance and the percentage of silts and clays are shown to correspond with increased carbon storage. In contrast, coarse sands are more likely to correspond to lower carbon storage due to higher tidal velocity that enable their deposition (Dahl et al., 2016).

Seagrass meadows throughout the PNW have lower carbon storage relative to the global average and high allochthonous carbon sourcing, which is likely controlled by the morpho-dynamic setting (Postlethwaite et al., 2018; Fourquean et al., 2012; Prentice et al., 2019). Furthermore, a seagrass meadow's hydrodynamic and biological conditions increase sediment deposition and enhance carbon sequestration throughout the meadow scale (Dahl et al., 2016; Hansen & Reidenbach, 2013; Fonseca & Bell, 1998). Yet, few studies combine this knowledge to quantify and predict carbon storage using both hydrodynamics and biological measurements to more accurately predict carbon stocks within the PNW. This study focuses on combining local knowledge of carbon stocks in the PNW with hydrodynamic qualities to more accurately extrapolate carbon storage throughout British Columbia's and Canada's coastlines using the knowledge from seven seagrass meadows in Clayoquot Sound, BC.

This paper seeks to answer the following research questions: How do sediment carbon stocks (allochthonous and autochthonous) differ within a single meadow (meadow-scale) and within a single bay (landscape-scale) for different seagrass characteristics and morpho-dynamic settings? How can this knowledge be used to estimate carbon stocks beyond Clayoquot Sound?

2.1.1. Study site and available data

Clayoquot Sound is located on the mid-west coast of Vancouver Island and within the Coastal Western Hemlock Biogeoclimatic zone (*Figure 3*; Dearden and Mitchell, 2016). The sound is a collection of several fjords formed from glacial valleys with steep walls and a sill located offshore at Browning Passage. Streamflow from local tributaries (Tofino Creek, Kennedy River and Cypres Creek) are an important input into the estuarine environment. The Insular Mountains to its west and the Pacific Ocean to its east create significant orographic precipitation (~3200 mm per year) (Ross, 2017). Summer discharges rates are low due to low precipitation and no significant icefields near Clayoquot Sound. Tofino Creek is expected to have high suspended sediment with coarser material, Cypres Creek is suspected to have moderate suspended sediment (limited information is available on this creek), and Kennedy River has low suspended sediment and fine sediments.

The westward coastline is primarily marsh or lagoon/gravel beach with abundant sediment; whereas, eastward coastal regions are primarily steep, forested walls with bedrock and large boulder beaches below the intertidal line with steep slopes seen to a depth >150 m (*Figure 3*). Tofino Creek has coarse sands and gravels, while Cannery cove has silts and clays. Shoals and protected bays are noted further west near Browning Passage with coarse sands and silty sediments making habitat for seagrass meadows (Shorezone).

Tidal characteristics of Clayoquot Sound are macrotidal with a total range > 4 m from high to low tide. Two tide stations, Tofino (live data) and Kennedy cove (predicted), are located within the bay (for locations see *Figure 3*) and have a ~1.5 hr lag between the stations. Average wind speeds and direction within Clayoquot Sound during 2015-2020 show ~10 km hr^{-1} from SSE with maximum windspeed of 67 km hr^{-1} (not including gusts) (Tofino Airport (1038210), Government of Canada). In terms of wave climate, the study area comprises mostly of protected areas with limited fetch, while some regions, namely the regions around Duffin Passage, are semi-exposed to wave energy.

This study focuses on seven seagrasses meadows in Clayoquot Sound, British Columbia. The sites were chosen based on wave exposure, sedimentary characteristics (based on ShoreZone BC, Appendix A) and proximity to river mouths. Monitoring data from Parks Canada (2008, 2018) was made available for this study, including seagrass characteristics and drone-based, low-tide meadow extents (Hakai Institute), which seeks to characterize the present state of 12 seagrass meadows within west Clayoquot Sound and provide early diagnosis of abnormal ecosystem structure. 2 813 340 m^2 of seagrass meadows have been mapped and are actively monitored by Parks Canada (Robinson & Yakimishyn, 2008; Reshitnyk 2018).

Out of the sites monitored by Parks Canada, Auseth, Beck, Calmus, Ducking and Mud Bay (*Figure 3*) were selected. Additionally, Cannery Cove was chosen as a previous study in, nearby, Kennedy Cove had carbon stock data enabling us to compare our data (Postlethwaite et al., 2018). The final site, Tofino Creek, was chosen due to its proximity to the mouth of Tofino Creek (BC Marine Conservation analysis). The majority of seagrass meadows are located in Tranquil Tribal Park and another three sites are located in Wah-nah-jus–Hilth-hoo-is Tribal Park which lies within traditional Tla-o-qui-aht territory.

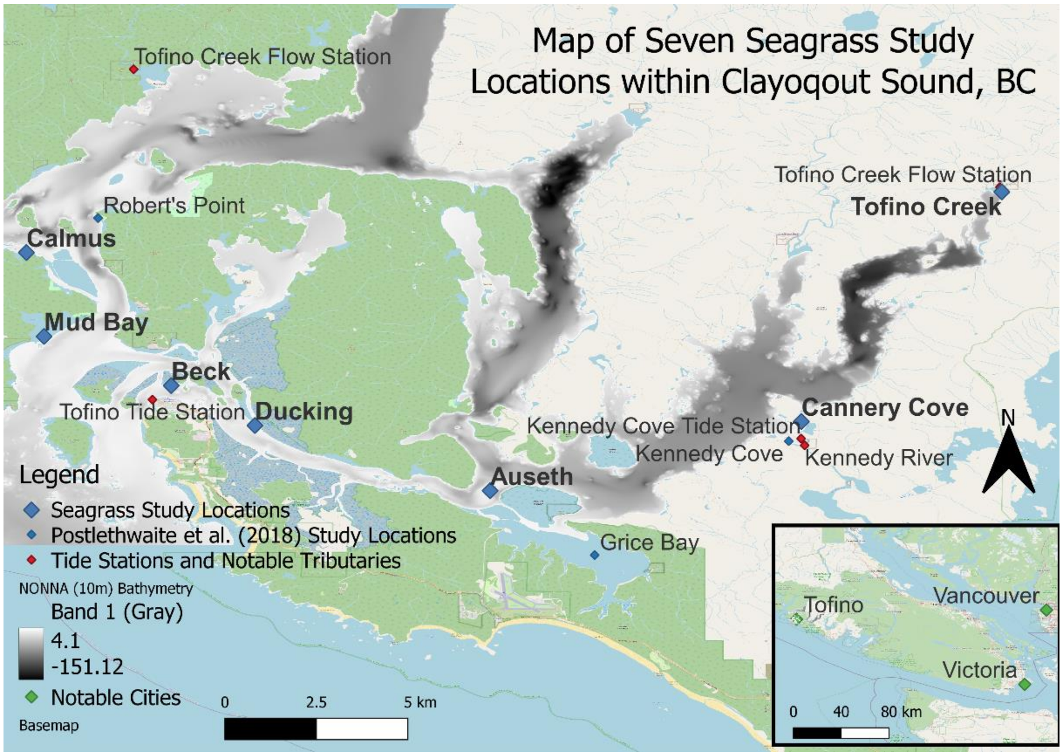


Figure 3: Site map of seven seagrass meadows within Clayoquot Sound. Meadow data was collected from Hakai Institute & Parks Canada (Auseth, Beck, Calmus, Ducking and Mud Bay meadow sites), Postlethwaite et al., (2018) (Kennedy Cove, Grice Bay and Roberts Point) and BCMCA (Tofino Creek). Tofino, Kennedy Cove tide stations and Tofino Creek River gauge provided by Government of Canada. NONNA 10 m subtidal bathymetry retrieved from Government of Canada

2.2. Methodology

2.2.1. Data collection

In optimal circumstances, three cores were collected per site along a 70 m transect starting from an unvegetated area surrounding the meadow over the subtidal portion toward the intertidal portion. The first core (reference core) was collected 10 m outside the meadow on an unvegetated surface and marked the beginning of the transect (Prentice et al., 2019). A subtidal core was collected 30 m from the subtidal boundary (depth of ~5m) and the intertidal cores was collected 30 m into the intertidal portion. Some meadows (Beck and Ducking) required modifications to the total length of transect due to meadow extent; however, these sub and intertidal cores were collected at their corresponding depths to ensure accuracy of results. Only a subtidal and reference core was collected from Tofino Creek due to the fringe nature of the meadow. For details on transect location refer to Appendix A.

Cores were collected at high tide via percussion coring by divers, whereby a 5 cm wide, and 60 cm long core tube with core catcher was inserted into the sediment using a sledge hammer. Cores were inserted up to maximum depth or the "depth of refusal" and a hand pump was used to keep sediment stable during extraction. It is noted that percussion coring can cause compaction as sediments shift during the coring process; thus, divers measured compaction once the core was fully inserted. Due to time constraints associated with remote sites and SCUBA diving, compaction was calculated as the distance (in centimeters) from the top of the core to the sediment surface outside of the core before core removal (core depth was marked with a Ziptie). Once the core was removed from the surrounding sediment, the total height of the core was measured again. During sample preparation, compaction was calculated to account for reduction in pore space as water was removed in the defrosting process. This value was added to the original compaction value to get total compaction.

Seagrass characteristics were determined via four to six 0.25 m^2 quadrats approximately every 10 m along the transect (at each coring site and in between cores) dependant on the length of the transect. The number of seagrass shoots within each quadrat were counted, and the length and width of five blades from five different shoots were measured to the nearest mm.

Alongside the seagrass characteristics, sediment samples (~1000g) of the seabed were collected via a scooper and Ziplock bags at each of the quadrat sites. Seagrass characteristics were not collected at Ducking due to unsafe tidal conditions.

A bottom-mounted, upward-looking Acoustic Doppler Current Profiler (ADCP, 1200 kHz Teledyne Workhorse) was used to collect information about tidal velocity changes throughout the seven seagrass meadows. This instrument measures 3-dimensional flow velocity and acoustic backscatter. The instrument was installed for a full tidal cycle (~12 hours) at each site within the subtidal portion of the meadow to enable the collection of tidal information during high and low tide and maximum flows without interruption. The cell size was 0.25 m, the time between ensembles was 1 s. No averaging was performed during acquisition. Due to the deployment on a frame and blanking distance, the lowest reading of the ADCP was located 0.8 m above the seabed. The beam angle of the ADCPs was 20°. The collected tidal properties are considered to be presenting average tidal conditions, though small fluctuations over the 7 survey days may be related to the spring/neap cycle.

2.2.2. Sample processing

Cores were extruded and sub-sectioned into 1 cm thick slices down the length of the core following best practices of recent seagrass coring studies in the PNW (Christensen & O'Connor, 2023; Postlethwaite et al., 2018; Prentice et al., 2020; Short et al., 2017). Occasionally the last, bottom section was a bit thicker (<2 cm). The samples were dried at 60°, and weighted with a 0.1 g precision scale every 24 hr until changes in weights were less than 4% of the mass of the previous day (Christensen & O'Connor, 2023). The final weight was noted as the mass of dry sediment (MDS) for each sample. Gravel particles (>1 mm) were removed from each sample via sieving using a 2 mm and 1 mm sieve and masses noted. The (< 1 mm) sediment of each sample was then homogenized into a fine powder using a mortar and pestle (Short et al., 2017). All visible living biomass (such as rhizomes, roots and seagrass leaves) were removed manually, while all non-living material was left in the sample (Prentice et al., 2020). It is acknowledged that very small pieces of living material may have remained within the sample, particularly in the surface samples.

Prior to laboratory analysis, ~4 g subsamples of each slice were burned in a furnace at 500° for 4 hours to remove all biomass from the samples and to determine the amount of organic matter (%OM) from loss of ignition (LOI) (Christensen & O'Connor, 2023). %LOI can give an indirect estimate of %C within a sample, though errors may occur due to LOI removing all organic matters (not solely carbon) and, thus, a relationship between %OM and %C must be determined for the local region (Howard et al., 2014). As samples were not treated prior to elemental analysis, additional error may occur because %C estimates may include small fractions of inorganic carbon. Since overall carbon content is low (<5%) the effect of removing inorganic carbon prior to analysis is believed to be negligible (Howard et al., 2014).

From these samples, 6.94-75.73 mg subsamples (dependent on predicted carbon content) were extracted for Elemental (%C and %N) and Isotopic (δ13C and δ15 N) analysis at sample depths: 1, 3, 5, 8, 12, 16 and 20cm, and were encapsulated to avoid leaching of the processed samples. Sample processing was conducted at the University of British Columbia's

Stable Isotope Facility via mass spectrometry (Short et al., 2017). A third 0.5g subsample, taken at the same sample depths, was sent for 210Pb analysis, via alpha spectrometry which measures the activity of polonium-210 (210Po), a high-energy alpha-emitting daughter product of 210Pb, to obtain radiometric dates at UQAM Geotop Radiochronology laboratory. The210Pb radiometric dates were used to construct age-depth relationships and determine mass accretion rates (MAR) (cm yr^{-1}) (as provided by UQAM using modelling by Aquino-López et al., 2018).

The seagrass characteristics, canopy height (cm), and width (mm)), and shoot density (scaled up to shoots per m^2), were averaged for each collection site. These characteristics were further split into sub and intertidal characteristics by averaging the sites collected before and after the subtidal core. Bed sediment samples were processed using a 15 min auto-sieve shaker with a range of 2 mm (#10 ASTM) to 0.07 5mm (#200 ASTM) following methodology of Kalra & Maynard (1991). The fine sediments left in the receiving pan were processed using hydrometry to determine %clays and %silts (Appendix C; Kalra & Maynard, 1991; ASTM, 2017). Sites that had less than 10% fine sediments in the receiving pan did not undergo hydrometry. Grainsize values as converted to D10, D50, and D90 were mathematically calculated using slope formulas to ensure precision. These values are representative of the size (in mm) of material finer than the numerical percentage value.

2.2.3. ADCP processing

ADCP flow velocities were corrected for pitch, roll, and heading, using data from the internal gyro compass [RD Instruments, 2008]. Due to the stationary ADCPs being oriented upward, the data was corrected for variations in water height across the tidal cycle using the backscatter signal and converted to height above the bed. The data was then clipped in the beginning and end of collection to remove errors associated with deployment and recollection of the ADCP. Depth-averaged velocity was calculated by averaging all valid velocity measurement per ping. Calculations were made to determine the max/min of depth-averaged velocity associated with flood and ebb tidal flow. From this, the visualization of depth averaged velocity, backscatter and direction was done in multiple plots (Appendix A).

2.2.4. %OM to %C conversion, carbon stock estimates and accumulation rates

An Ordinary Least Squares Regression was performed to compare the 124 %C measurements from Elemental Analysis to %OM measurements from the same sample. Refer to Appendix D for results of model selection. The resultant model generated an R^2 of 0.97 and compares well with previous models used in %C and %OM conversion (Table 2).

Table 1: Ordinary Least Squares Regression between %OM as derived from loss of ignition and %C from elemental analysis from this and other studies.

Model	N	Slope	Intercept	R^2
Prior et al., 2023 (This study)	**124**	**0.35**	**-0.15**	**0.97**
Postlethwaite et al., 2018	n/a	0.30	-0.26	0.73
Fourquean et al., 2012	1667	0.4	-0.21	0.87
Christensen & O'Connor, 2023	201	1.33	-1.57	0.88
Prentice et al., 2020	n/a*	0.31*	-0.11*	n/a*

*Estimate of %carbon for Southeast Alaska sites only with N and R^2 not provided

Utilizing the linear model, %C was then estimated for every 1 cm sample from %OM measurements to create a consistent curve downcore. Dry Bulk Density (DBD) (g cm^{-3}) for each 1 cm section was determined by dividing the MDS measurements by the compacted volume of the sample:

$$DBD = \frac{MDS}{\pi * r^2 * h}$$

Where r is the radius of the core (5 cm), h is the thickness of the slices (1 cm). Soil carbon density (g m^{-3}) was then determined by multiplying the DBD with the %C/100 and carbon content in each core section (gC m^{-2}) was derived by multiplying the carbon density with the section thickness (here: 1 cm). Core compaction was accounted for by multiplying the carbon content in each core section with the individual compression factor to produce plots of carbon content downcore. Carbon stocks of the first 25 cm were then estimated by summing the carbon content of each uncompacted core section down to the depth of 25 cm. Carbon stocks of the first 1 m were determined by averaging all carbon contents from each section and by multiplying this average by the number of uncompacted sections contained in a 1 m core segment (N = 100 cm/ (1 cm*compression factor)) for each particular core.

Sediment mass accumulation rates (SAR) (g $m^{-2}y^{-1}$) and Carbon accumulation rates (CAR) (gC $m^{-2}y^{-1}$) were estimated at depth intervals based on the sediment dry bulk densities (DBD) and the mass accretion rates (MAR) provided by UQUAM:

$$SAR = \left(\frac{MAR}{DBD}\right) * 10$$

$$CAR = \left(\frac{SAR}{\%C}\right) * 10\ 000$$

2.2.5. Statistical analysis

The δ13C and δ15N signatures of sediment samples were used to determine the distribution of autochthonous versus allochthonous carbon within the meadows. We utilized a three-source Bayesian mixing model in the SMMR package of RStudio (Parnell & Inger, 2021, R Core Team, 2022, Prentice, 2020). Isotopic source signatures of terrestrial (consisting of trees, shrubs and riverine particulate organic matter), oceanic (consisting of kelps, planktons and marine particulate organic matter) and seagrass (*Zostera marina*) sources were collected from past literature and averaged (Table 2). All isotopic ratios are expressed relative to Vienna Pee Dee Belemnite for carbon, and atmospheric air for nitrogen, in per mil notation (‰).

Table 2: Table shows isotopic ranges, averages and sources of δ13C and δ15N signatures of sediment samples throughout the West Coast of North America

Source	AVG. *δ13C*	Range *δ13C*	AVG. *δ13C*	Range *δ15N*	Sources
Seagrass	6	4.22 to 8.92	-9.72	-8.08 to -11.1	Olson 2015, Howe 2012, Dethier 2013
Marine	3.87	3.37 to 6.3	-21.91	-19.04 to -25.83	Olson 2015, Howe 2012
Terrestrial	7.45	1.95 to 21.5	-27.27	-24.7 to -28.3	Howe 2012, Cloern et al., 2002

Multiple independent variables were utilized for inter and intra-site statistics. These variables were compared against average carbon content and allochthonous versus autochthonous carbon using multivariate linear regression. After Shapiro-Wilks normality and

Levene's variance tests, the multivariate linear regression was performed to identify relationships between the environmental variables and the average gram Carbon (Avg. C), average gram Carbon from marine sources (Cmar), average gram Carbon from terrestrial sources (Cterr), and average gram Carbon from eelgrass (Cgrass) sources. As a first step, a number of model combinations were tried and Variance Inflation Factor (VIF), significance of coefficients and absolute value of coefficients (i.e., how much larger/smaller than 0) examined. Using the R Code dredge (MuMIn Package), automatic model building was performed to identify the most significant variables for each response variable. The candidate models were grouped by AICc and delta value and the highest-ranking models were examined.

2.3. Results

2.3.1. Site characteristics

General trends of the study area show small to moderately sized meadows with a range in area between 15 000 m^2 (Tofino Creek) to 407 000 m^2 (Mud Bay) (Table 5). The deepest and steeper meadows occur generally more seaward (exception is Mud Bay); whereas, shallow locations occur further inland in protected bays with possible fluvial input. Detailed maps and descriptions of the meadows can be found in Appendix A. Most meadows occur on the mud/sand flats connected to the land, while Auseth and Beck are located on shoals within in the Sound. Fringe meadows were noted at Ducking (patchy subtidal meadow near tidal channel, continuous meadow in the intertidal section) and Tofino creek (small patchy meadow spread along the northwest side fjord head). The remaining meadows were continuous following depth and topography in their bays or on shoals. Changes in the meadows since the 2018 survey by Hakai were observed when diving with Auseth increasing in size in the intertidal and Calmus, Ducking and Beck notably decreasing in the subtidal. The region had low to moderate seagrass density, height and width; moreover, qualitative analysis showed shallow roots systems throughout the study area. Results are noted within Table 3 from the west to east.

Table 3: Averaged values for 14 independent variables (maximum velocity, average velocity, seagrass density, height, width, D50, sound velocity (proxy for salinity), average slope, average depth, and turbidity (2 m and 5 m)) for seven seagrass meadows throughout Clayoquot Sound,

BC (from west to east). Yellow shading indicates maximum values, while green indicates minimum values.

Variables	Calmus	M. Bay	Beck	Ducking	Auseth	C. Cove	T. Creek
Max. Velocity (m s^{-1})	0.17	0.16	0.47	0.61	0.1	0.05	0.04[1]
Avg. Velocity	0.09	0.07	0.27	0.44	0.04	0.03	0.01[1]
Seagrass density (shoots m^{-2}) this study / Hakai Institute (2008)	168 /	180 /	442.7 /	---[2] / 200	308 /	99.2 /	136 /
Seagrass height (cm)	76.7	85	46.9	---[2]	82.2	96	42
Seagrass width (mm)	9.5	7	6.3	---[2]	8.7	7.9	5.1
D50 (mm)	0.128	0.141	0.15	0.145	0.14	0.086	1.212
Sound velocity (m s^{-1})	1485.82	1485.76	1483.14	1483.52	1478.94	1475.71	1469.8
Avg. Slope (°)	1.641	0.642	6.151	1.613	0.408	2.611	5.373
Avg. Depth (m)	6.65	4.332	8.015	5.895	3.609	6.011	5.726
Meadow Area (m^2) Hakai Institute (2008)	49,000	407,000	40,000	139,000	35,000	70,000[3]	15,000[3]
Turbidity 2 m (NTU)	0.045	0.018	0.021	0.018	0.021	0.04	0.032
Turbidity 5 m (NTU)	0.019	0.081	0.018	0.02	0.055	0.355	0.067
Temperature (°C)	14[4]	13[4]	13[4]	13[4]	13[4]	13[4]	12[4]
Distance to River (km)	8.88	13.41	15.6	18.22	10.22	1.34	0.21

[1]Estimated from faulty ADCP data
[2]Meadow characteristics were not collected due to unsafe tidal conditions
[3] Approximated meadow size based on transect length and observed meadow distribution via diving
[4] Shallow water temperature data in May 2022 from dive watch temperature sensors

2.3.2. Downcore variation in *gC m*$^{-2}$

Downcore variation in carbon content per uncompacted section (*Figure 4*) was consistent among six of the study sites with little variation between surface and depth and among cores of one meadow, with values ranging between 0 – 50 gC m^{-2}. The notable exception is Cannery Cove with carbon content reaching above 100 gC m^{-2} at meadow sites and a notable difference in carbon content between reference core and meadow cores, and, at depth, between subtidal and intertidal cores (*Figure 4e*). The only other site that showed carbon content up to 100 gC m^{-2} was Tofino Creek (*Figure 4g*), though carbon content decreased rapidly with depth.

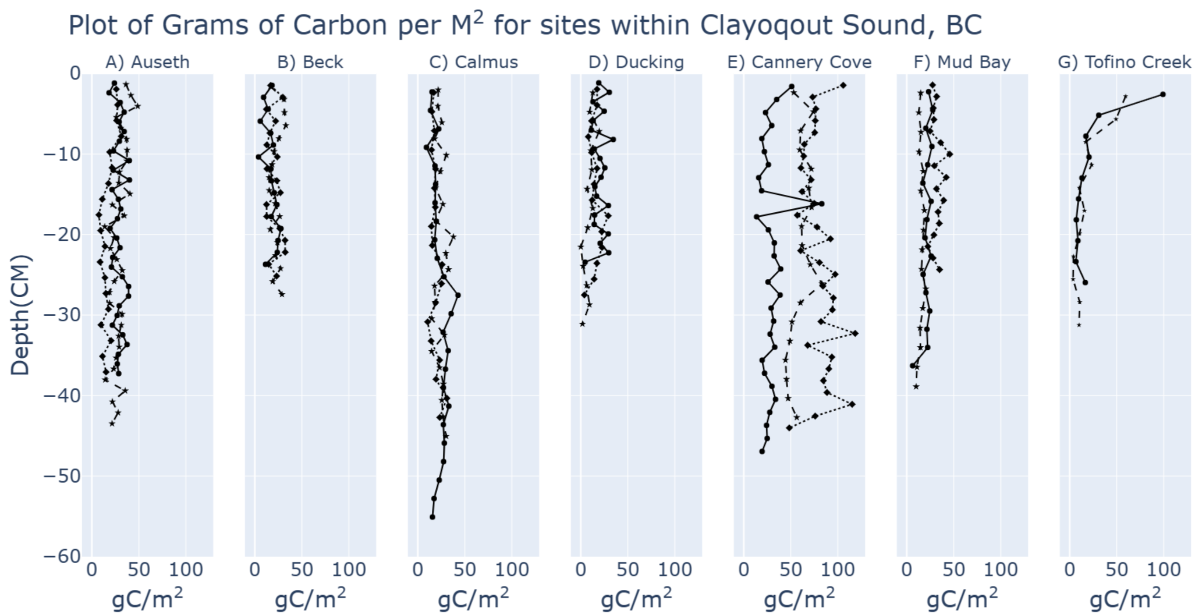


Figure 4: Down core variation in carbon content per uncompacted section (gC m^{-2}) at seven meadow sites within Clayoquot Sound (reference core = straight, subtidal = dashed, intertidal = dotted).

Statistical summaries of carbon content for each core are provided in Table 4. Notable differences among cores of one meadow were observed at four of the seven sites. Tofino Creek, Beck, and Calmus had differences between cores that were within the standard deviation (between 5-7 gC m^{-2} for most sites) and thus considered not significant. Out of the four sites with significant differences, the unvegetated, reference core had lower carbon content than both meadow cores at Cannery Cove and lower than at least one meadow core at Mud Bay. Highest average carbon occurred in the subtidal core at Cannery Cove and at the intertidal core in Mud Bay. Auseth had similarly high average carbon content at the reference site compared to the intertidal core, while Ducking had highest average carbon content at the reference site, but within the range of one standard deviation compared to the intertidal site. At these locations, lowest average carbon content is found at the intertidal core.

The within meadow average gC m^{-2} varied between 11.9 gC m^{-2} (Ducking) and a maximum of 70.5 gC m^{-2} (Cannery Cove). All other sites ranged between 19-24 gC m^{-2}. Carbon stocks (per core to 25 cm and 1 m depth) for in-meadow cores varied with the highest carbon content observed at Cannery Cove (1421.4 gC m^{-2}, 5685.6 gC m^{-2}) and lowest at Ducking (366.3 gC m^{-2}, 1465.2 gC m^{-2}). Taking into account meadow area, highest total carbon stock occurred at Mud Bay (934.2 MgC m^{-2}) and lowest at Beck (81 MgC m^{-2}). Using our estimate of meadow area at Tofino Creek, carbon stock was even lower with 31.7 MgC m^{-2}.

Average CAR were highest at Cannery Cove (16.11 gC m^{-2} y^{-1}) and lowest at Ducking (2.6 gC m^{-2} y^{-1}). CAR had a non-averaged range of 47 gC m^{-2} y^{-1} at Cannery Cove and 0.5 gC m^{-2} y^{-1} at Ducking. Four of the sites had consistent downcore carbon accumulation rates; however, Calmus, Cannery Cove and Tofino Creek had high accumulation between 0-5 cm depth (maximum of 24.8, 47 and 37.9 gC m^{-2} y^{-1}, respectively). After this depth, accumulation decreased to a minimum of 3.2, 5.6, 2.8 gC m^{-2} y^{-1}, respectively. This change occurred approximately 40 years ago (~1985). Cannery Cove had an increase in CAR at depth between 15-18 cm increasing to 15.3 gC m^{-2} y^{-1}. The average core represented 105.96 years of total accumulation. Cannery Cove (167.9 years) covered the longest period of accumulation; whereas, Tofino Creek (64.2 years) covered the lowest period of accumulation (refer to appendix E for results of age-depth models). Moreover, the core lengths and depth of refusal had a notable impact on periods of accumulation with shortest cores having the shortest periods of accumulation.

Table 4: Statistics of average variation of gC m^{-2} for reference, subtidal, intertidal meadow sites, meadow cores, all cores combined, top 25 cm and top 1 m, Carbon stock per m^2 and Carbon Accumulation rates for seven selected meadow sites within Clayoquot Sound

		Auseth	Beck	Calmus	Ducking	Cannery Cove	Mud Bay	Tofino Creek
Reference core	Avg. *gC m^{-2}*	28.851	17.008	23.632	20.115	29.52	21.403	22.914
	Std *gC m^{-2}*	6.189	6.746	7.856	7.898	12.932	5.109	27.834
Subtidal core	Avg. *gC m^{-2}*	17.001	23.113	24.223	8.237	80.373	15.25	19.405
	Std *gC m^{-2}*	7.01	5.936	6.059	5.944	16.783	2.759	18.309
Intertidal core	Avg. *gC m^{-2}*	28.709	20.642	18.947	15.603	60.677	32.208	-[5]
	Std *gC m^{-2}*	8.15	7.302	5.085	6.421	11.102	6.113	-[5]
Meadow cores combined	Avg. *gC m^{-2}*	22.855	21.878	21.585	11.92	70.525	23.729	19.405
	Std *gC m^{-2}*	7.58	6.619	5.572	6.182	13.943	4.436	18.309
All cores combined	Avg. *gC m^{-2}*	24.853	20.255	22.267	14.652	56.856	22.954	21.16
	Std *gC m^{-2}*	7.116	6.661	6.333	6.754	13.606	4.66	23.072
Avg. carbon Stock (25 cm)	*gC m^{-2}*	621.336	506.364	556.68	366.294	1421.411	573.842	528.991
Avg. carbon Stock (1 m)	*gC m^{-2}*	2485.346	2025.454	2226.72	1465.177	5685.646	2295.369	2115.963
Total carbon stock (1 m)	*MgC m^{-2}*	87.0	81.0	109.1	203.7	398.0[6]	934.2	31.7[6]

Carbon Accumulation	*gC $m^{-2}y^{-1}$*	3.51	5.1	11.07	2.55	16.11	5.09	12.88

[5]*Due to Tofino Creek being a fringe meadow only a reference and subtidal core was collected*

[6]Approximated meadow size based on transect length and observed meadow distribution via diving

2.3.3. Autochthonous versus allochthonous carbon

The results of the Bayesian mixing model for the entire isotopic dataset (*Figure 5a*) showed that marine sources were the largest contributor to carbon sequestered within the meadows (average 76.8%, *Figure 5b*). Seagrass sources (on average 14.3%) accounted for a slightly higher amount of carbon than terrestrial material (on average 8.9%); however, given the spread, the difference was not statistically significant. Results per site show that marine sourcing was most dominant at Auseth (88.5%), Mud Bay (86.4%), and Cannery Cove (83.8%) and lowest at Beck (72% and Ducking (62.1%) (Table 5). Although overall much lower, terrestrial sources showed highest contributions at Tofino Creek (25.6%) followed by Cannery Cove (13.1%) with differences between other sites being low (<7.5%). Looking at seagrass sources, Ducking (32.7%), Calmus (23.5%), and Beck (19.9%) had the highest proportion, while all other sites had low contributions (<10.6%) (Refer to appendix F for expanded results).

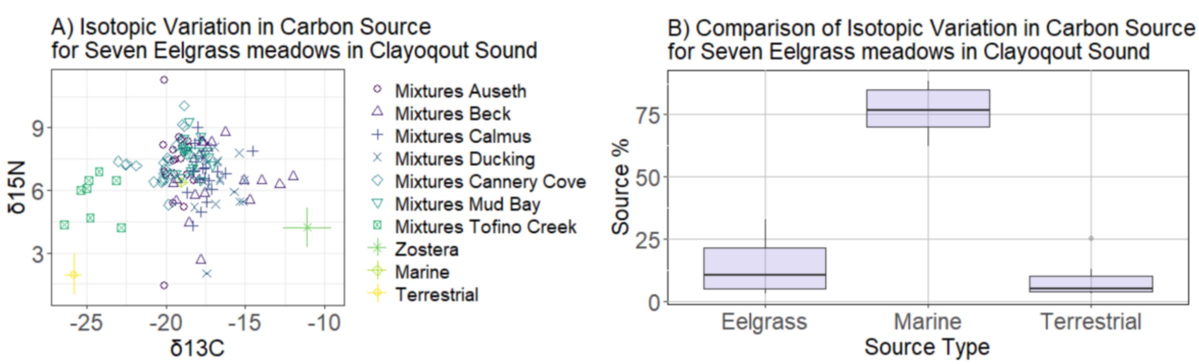


Figure 5: *A)* Observed distribution of δ13C and δ15N for all core samples of seven meadow sites in Clayoquot Sound. Also shown are typical isotopic signatures of seagrass (*Z. marina*, Olson 2015, Howe 2012, Dethier 2013), marine (Olson 2015, Howe 2012), and terrestrial (Howe 2012, Cloern et al., 2002) source material. *B)* Results of *Bayesian* mixing model of *isotopic* signatures of meadow core samples using known seagrass, marine, and terrestrial source endmembers

Table 5: Results of Bayesian mixing model of isotopic signatures of meadow core samples for seven seagrass meadows throughout Clayoquot Sound, BC using known seagrass, marine, and terrestrial source endmembers. Table shows average percent variation in relative proportion of the three endmembers at each site. Yellow shading indicates maximum values, while green indicates minimum values.

	Auseth	Beck	Calmus	Ducking	C. Cove	M. Bay	T. Creek
%marine	88.5	72.0	76.6	62.1	83.8	86.4	68.0
%terrestrial	7.5	4.5	3.5	5.2	13.1	3.1	25.6
%eelgrass	3.9	23.5	19.9	32.7	3.1	10.6	6.4

2.3.4. Multivariate linear regression

Out of all environmental variables, area, slope, and density, showed an improved normal distribution after log transfer, utilizing a Shapiro-wilks normality test and assessing visually. It was found, using Cook's distance, that Tofino Creek formed such an outlier that model performance was reduced and no significant variable combinations could be found. Upon removal of the site Tofino Creek, the explanatory variables of seagrass width, height, and log (Area) could further be eliminated from the model based on high VIF and low significance of coefficients, leaving the D50, the average velocity (Avgvel), log (Density) (Denslog), and a combination of log(Slope)+Depth (SDlog) as the explanatory variables (Table 8). Using the D50, 87% of the variability in marine and terrestrial carbon was explained with significant coefficients and low p-value. This was not the case for seagrass carbon and the dominant variable in this case is the Depth-Slope combination, explaining 76% of the variability. When using a second variable, the R^2 generally improved, while the p-value increased and the significance level of the coefficients decreased (Table 8). An exception occurs for seagrass carbon, where adding the second variable (average velocity) improved the R^2, the p-value and the significance levels. In *Figure 6*, those 2-variable models are included that have the highest significance level for the model coefficients. Where the levels were similar, the model with the highest significance level for the dominant variable was chosen. For marine carbon this variable is average velocity, while it is the Depth-Slope combination for terrestrial carbon (refer to appendix B for expanded results).

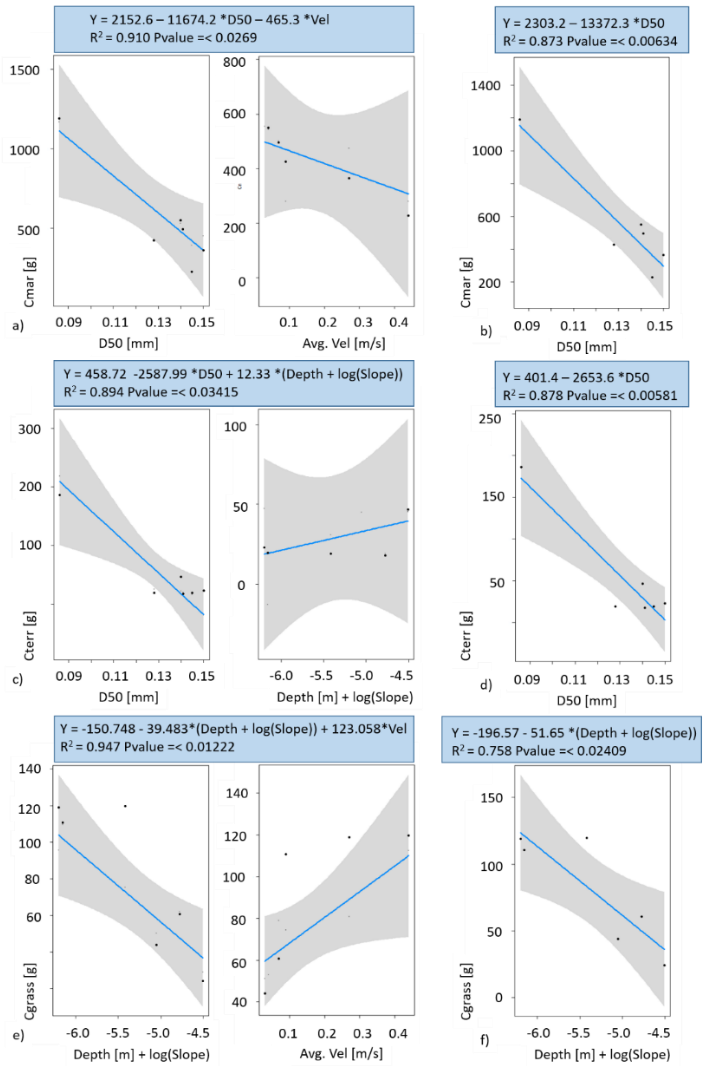


Figure 6. Results from multivariate linear Regression for response variables marine (a + b), terrestrial (c+d), and seagrass carbon (e+f). Shown are model predictions for two (left) or one (right) environmental variable with highest confidence in estimated coefficients.

Examining the model performance for 1- variable, and 2-variable for average carbon showed that similarly to marine and terrestrial carbon, the D50 holds the highest explanatory power, yielding and R^2 of 0.911 (*Table 8* and *Figure 7*). Adding Average velocity only marginally increases the R^2, while raising the p-value and lowering the significance level of the D50 coefficient (*Table 8* and *Figure 7*)

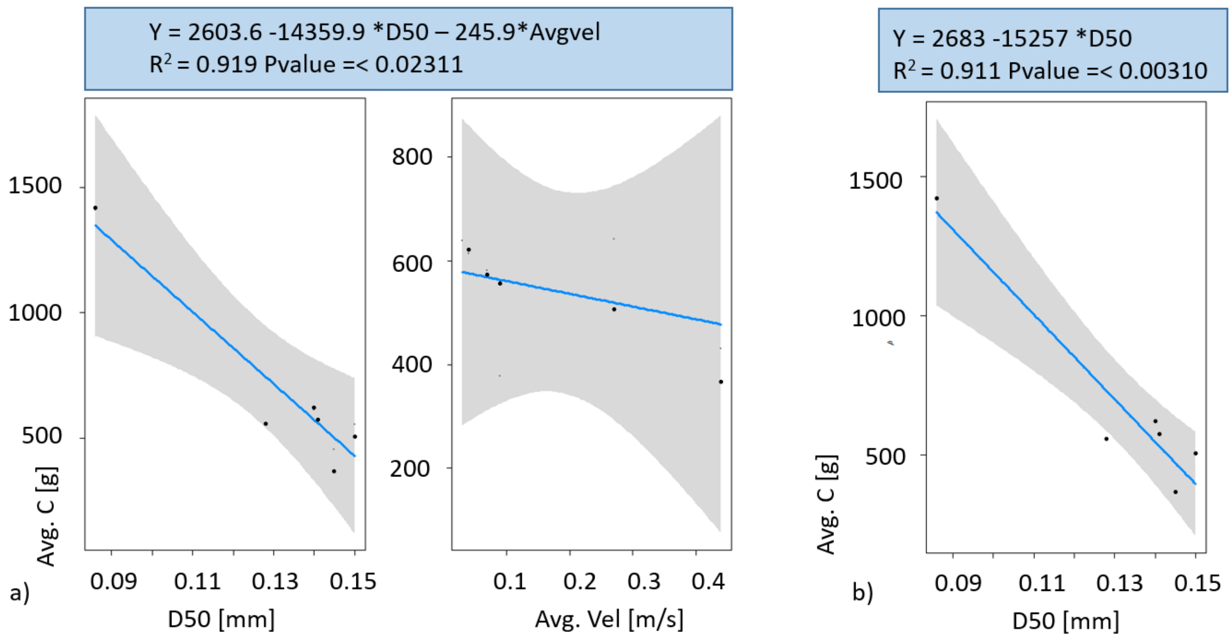


Figure 7. Results from multivariate linear Regression for response variable Avg C. Shown are model predictions for two (a) or one (b) environmental variable with highest confidence in estimated coefficients.

2.4. Discussion

2.4.1. Carbon sequestration in Clayoquot Sound in context

The average carbon stock (to 25 cm depth), determined in this study, throughout Clayoquot Sound is 653.6 gC m^{-2} with a range of 366.3 to 1,421 gC m^{-2}. This carbon stock is fives time less than the global average of 3,493 gC m^{-2} (Fourqurean et al., 2012), three times less than the PNW average of 1,752 gC m^{-2} (Prentice et al., 2020), and within the range of a previous study in Clayoquot Sound (average 957g C m^{-2} with a range from 820 to 2106 gC m^{-2}) (Postlethwaite et al., 2018). This is suspected to be caused, in part, by shallower roots than observed in other meadow of the PNW leading to limited ability to trap sediment, coarse sands with limited silts and clays and shallow depths of accumulation related to significant shell layers and isostatic rebound of the post-glacial sound (Postlethwaite et al., 2018; Cabello-Pasini et al., 2003; Mazzotti et al., 2008). The variability in CAR aligns with previous studies with an average of 8.8 gC m^{-2} y^{-1} and a range of 0.5 to 47.0 gC m^{-2} y^{-1}. The overall average of this study is notably lower than the PNW average of 24.2 gC m^{-2} y^{-1} (Prentice et al., 2020); however, the average is similar to a previous study in Clayoquot Sound (3.9–22.3 gC m^{-2} y^{-1}; Postlethwaite et al., 2018), and other temperate measurements from Japan (3–10 gC m^{-2} y^{-1}; Miyajima et al., 2015) and Poland (0.8–41 gC m^{-2} y^{-1}; Jankowska et al., 2016). Low CARs in temperate environments have been shown to be caused by limited terrestrial input related to local environmental settings such as local hydrodynamic regimes, geographic variability in grainsize, and the minor contribution of seagrass-derived carbon (Postlethwaite et al., 2018; Jankowska et al., 2016; Miyajima et al., 2015).

2.4.2 Meadow-scale variability

Our results show that carbon content at reference sites were not consistently lower than their within-meadow sites, and that sub and intertidal sites did not differ consistently. Only Cannery Cove had a notable difference between reference and meadow sites. The past study in Clayoquot Sound found a significant difference in carbon storage for two out of the three meadows surveyed (Kennedy Cove and Robert's Point) compared to their unvegetated sites which aligns with a number of studies that showed increased carbon stored within the sediments of seagrass meadows when compared to reference sites (Prentice et al., 2020; Lutz, 2018; Christensen & O'Connor, 2023; Postlethwaite et al., 2018). One reason behind the lack of significantly lower carbon between the within-meadow reference sites may be related to our selection of the reference core sites. Due to safety requirements for the divers in the strong tidal currents, our cores were located on average only 10 m outside the meadow. The reference cores of Postlethwaite et al. (2018) were located approximately 250 m outside the meadow where carbon was significantly lower. However, a different study in the PNW found significantly lower carbon content in reference cores 5-15 m away from the nearest meadow (Prentice et al., 2018, 2020); however, this may be tied to underground carbon transport being enabled by shallow root depth (Röhr et al., 2018; Postlethwaite et al., 2018). Additionally, significant differences may not have been observed because i) the current extent of the meadow may not be reflective of past extents, as meadow sizes globally are known to decrease (Fourqurean et al., 2012; Fonseca and Bell, 1998). As such, the reference cores may be more reflective of carbon storage within the meadow than serve as a true reference core; or ii) the area in vicinity of the meadow may still be influenced by the reduced flow velocities caused by drag over the nearby meadow (Ricart et al., 2016), which may lead to similar amounts of carbon sequestration.

Postlethwaite et al. (2018) differentiated between subtidal and intertidal carbon sequestration, showing that two out of three sites (Robert's Point and Kennedy Cove) had higher carbon in the subtidal cores. In contrast, we found that three of our sites had lower carbon content (greater than one standard deviation) in the subtidal than the intertidal site and three sites had higher subtidal carbon content. A possible reason behind this variability could be the proportions and characteristics of a meadow located in the sub and intertidal area varying throughout Clayoquot Sound. Postlethwaite et al. (2018) noted that Robert's point had higher carbon in the subtidal, and had a smaller portion of the meadow in the intertidal range. This effect was similarly noted with Beck, Calmus, and Cannery Cove having lower intertidal carbon and smaller intertidal meadows. Thus, differentiating between subtidal portions of a meadow in the PNW may be less important than the environmental conditions impacting the meadow and gathering information on meadow extent in the subtidal zone will be important for determining overall carbon stock; however, differentiation does not seem to be nessacery in the PNW. Gathering information on subtidal extent is similarly important because current subtidal drone-based mapping is limited by turbidity above the meadow leading to underestimates of subtidal extent. Future studies mapping eelgrass extents should ensure subtidal mapping is included too effectively determine carbon stocks within the PNW.

2.4.3 Landscape-scale variability

Our statistical analysis reveals that the environmental variables pertaining to the geomorphological setting (median seabed grain size, bathymetry, and tidal current speed) exert the largest control on average carbon content and each carbon sourcing component. Generally, high canopy height, high shoot density and shallow depths are considered to accumulate finer grainsizes promoting carbon deposition (Peralta et al., 2008; Alcoverro et al., 1995); however, recent studies state that the primary factors that increased carbon storage were related to sediment type and the percentage of silts and clays which aligns with our observed results (Postlethwatie et al., 2018; Dahl et al., 2016).

The median bed grain size exerts the most dominant control on the amount of carbon found from marine and terrestrial sources with marine carbon nearly doubling with a decrease in median grain size by 0.04 mm (from fine sand to very fine sand), while terrestrial carbon, though overall much lower, almost triples. As a result, the average amount of carbon sequestered in a meadow increases by 1.87x over the same grain size range. The presence of silts and clays are noted to have a strong impact on carbon sequestration due to the reduced flow dynamics that enable their deposition (Fonseca & Bell, 1998, Coops et al., 1991; Duarte & Kalff, 1990; Kennedy et al., 2010; Rohr et al., 2016).

Despite this, no clear relationship between average tidal velocity and median grain size was observed in this study, indicating that although the relation between bed grain size exists, lower flow may not be the best indicator of trapping potential. This is observed in Clayoquot Sound where the D50 does not describe the variability in autochthonous (seagrass) carbon well, suggesting that the link between overall carbon content and grain size found here results from the D50 reflecting the propensity of the environment to trap allochthonous carbon (analogous to Fonseca & Bell, 1998, Coops et al., 1991; Duarte & Kalff, 1990) rather than habitat suitability for eelgrass (Dahl et al., 2016; Rohr et al., 2016). In Clayoquot Sound, these favourable environments occur landward of our gradients at Calmus and Cannery Cove, while all meadows seaward tend to have similar range of fine sand.

The most dominant variable describing the variability in autochthonous carbon is a combination of water depth and bed slope, mirroring variations in bathymetry around the meadow. Meadows that are located in a deep and steep to moderately steep setting (Beck and Calmus) were found to sequester ~1.6x more autochthonous carbon than moderately deep, moderately steep meadows (Ducking and Cannery Cove). The lowest amount of autochthonous carbon was found in the shallowest meadows with lowest slopes (Auseth and Mud Bay). This result coincides with results showing limited differences for average carbon at depth (Postlethwaite et al., 2018; Miyajima et al., 2015); however, shows there are differences in sourcing based on depth and slope. The average carbon result differs from other studies which showed a decrease in carbon with depth (Serrano et al., 2014; Dahl et al., 2016). This difference could be attributed to our in-meadow core collection reaching a maximum depth of 6.3 m at

Mud Bay; thus, lower carbon related to a decrease in irradiance may not have had a strong influence on carbon deposition (Alcoverro et al., 1995). Additionally, we show that there is no clear relationship between bathymetry and meadow characteristics (Area, Width, Height, Density). Many of the deepest and steeper meadows occur generally for more seaward meadows (exception is Mud Bay), reflecting adaptation to wave exposure and a general increase in water depth towards the open ocean.

The combination of depth and slope also served as a secondary variable to explain the variability in terrestrial carbon, with opposing effect. Shallow, less steep meadows sequestered more terrestrial carbon, than deep and steep to moderately steep meadows. This relationship is believed to reflect differences in the morpho- dynamic origin of the shallow water habitats. Shallow shoals further inland or in protected bays are likely formed from fluvial input, while the seaward flats are formed through adaptation towards wave exposure and tidal currents. The decrease in terrestrial carbon with depth and slope can not compensate for the effect of increasing seagrass carbon with increasing slope and depth, however.

Average tidal flow velocity was able to explain some variability in marine carbon, seagrass carbon, and average carbon overall. While the amount of marine carbon decreases under faster flow, seagrass carbon increases. This is likely due to high velocities limiting deposition and enhancing resuspension leading to eelgrass biomass becoming more pronounced (Hansen and Reidenbach, 2013; Hendriks et al., 2008). We found no significant link however, between the D50 of a studied meadow and the average tidal velocity. This may be related to our selection of monitoring velocity, but also follows several other studies that found that seabed grain size does not necessarily reflect current hydrodynamic flow, but may be influenced by glacial lag deposits or episodic events such as landslides or storms (Hansen and Reidenbach, 2013; Koch et al., 2006). Our statistical analysis revealed that the amount of average carbon is predominately controlled by the same explanatory variables that control marine carbon. This is not surprising given that marine carbon is the largest contributor to overall carbon at all sites.

The high allochthonous sourcing throughout Clayoquot Sound concurs with a number of other studies of seagrass meadows throughout the global north, which state that a large amount (40-72%) of carbon stored in seagrass sediments stems from allochthonous sources and are deposited preferentially in meadows due their propensity to trap sediment (Prentice et al., 2018; Gacia et al., 2002; Koch et al., 2006; Hendriks et al., 2008). Terrestrial sourcing is largest for those landward meadows closest to riverine outflow, though always a fraction of the marine component. Interestingly, marine carbon is largest in the landward meadows of Auseth and Cannery Cove, combined with low velocities and very fine to fine sandy bed sediment. Cannery Cove, Calmus, and Tofino Creek have the highest accumulation rates, lowest flow velocity and the finest grainsizes, this shows a pattern of protected bays offering the most hydrodynamic relief leading to fine sediments being deposited within the meadow instead of terrestrial carbon being transported to other meadows. The tidal flow and depth of the inlet may limit the amount of sediment brought into the meadows as there is a larger depression to a depth of >200 m between Tofino Creek and Auseth (Duarte et al., 2001). As such, low current speeds throughout this region may cause fine sediments to be deposited at a greater depth while low velocities are able to bring fine sediment containing marine carbon landward. Future analysis of turbidity at depth >15 m may provide clearer understanding of terrestrial carbon movement.

2.4.4 Extrapolation and future steps

This study shows the impact of environmental variables on carbon storage, carbon sourcing and carbon accumulation rates within the sub and intertidal portions of seven seagrass meadows within Clayoquot Sound, BC. The gC m^{-2} collected within these meadows align with results of regional studies on seagrass carbon storage. Carbon storage values are lower than the average for the PNW and lower than the global average; yet, these lower carbon stocks were expected due to the environmental conditions that these meadows are exposed too (Prentice et al., 2020, Fourquean et al., 2012). These meadows were not chosen due to predicted high carbon content; but to show that carbon stock variation is dynamic and is related to the environmental conditions that surround them. The data shows this dynamic range of carbon values with Auseth, Beck, Calmus and Mud Bay seen to have lower carbon values than the PNW as shown in Prentice et al. (2020).

Carbon content was consistent between four moderate flow, marine meadows (Auseth, Beck, Calmus, Mud Bay), with Cannery Cove, Ducking and Tofino Creek having significantly different carbon contents. These values are shown to be dependant, primarily, on the environmental conditions observed. This consistency among four meadows with similar environmental characteristics and the difference between meadows that had dynamic environmental characteristics show that extrapolation of carbon storage can be effectively updated using environmental drivers. However, a larger number of sites are required to verify the quantitative link created within this study. This is due to a common issue within regression analysis; namely, correlation versus causation. The number of study sites and number of cores collected per site are a limiting factor in this analysis. Utilizing the multivariate linear regression shows that there are significant differences between sites, environmental variables and the carbon stocks. The limited sites and data available along the PNW may indicate that observed variation in regression models are strongly impacted by meadows with high or low carbon storage due to their more varied environmental characteristics.

Variation in tidal velocity in considered to be consistent over years and decades due to the consistency of tides (Fonseca & Bell, 1998). As such, marine carbon can be deposited during low flow at slack tides enabling marine sediments to be deposited (Hansen & Reidenbach, 2013; Hendriks et al., 2008). With this known, significant resuspension events can still occur due to storm events; however, majority of seagrass meadows within Clayoquot Sound are within protected bays or semi-exposed. Terrestrial carbon is dependent on high flow variability related to riverine outflows which bring large grainsizes reducing carbon due to resuspension or flow consistency can lead to high carbon due to the deposition of small grain sizes (Dahl et al., 2016; Ricart et al., 2016). Whereas, high autochthonous is noted in absences of strong marine or terrestrial carbon deposition.

This understanding shows that seagrass characteristics and spatial extent are not the only important variable to estimate carbon stocks. Environmental variables are currently under-used in the modelling of carbon stocks for the PNW and around the world. More research must be conducted on sites that have predicted high and low flow characteristics. Moreover, one model may not be sufficient to more accurately predict carbon stocks in the PNW. More marine and moderate flow sites showed similar carbon stock variation; yet, high flow and near river sites had much larger variation. Taking into account this variability would increase accuracy in predictive models by specifying the environmental characteristics along with biological factors. By doing this, we reduce the possibility of outlying meadows skewing the predicted carbon stocks throughout the PNW and Canada.

2.5. Conclusion

This study shows that seagrass characteristics and spatial extent are not the only important variables to estimate carbon stocks. The extrapolation of carbon stocks beyond Clayoquot Sound could be better accounted for by using meadows extents (including, both sub and intertidal), tidal measures, local bathymetry and local sediment characteristics (i.e., ShoreZone). These variables are currently under-used in the modelling of carbon stocks for the PNW and around the world; however, one model may not be sufficient to more accurately predict carbon stocks. More marine and moderate flow sites showed similar carbon stock variation; yet, high flow and near river sites had much larger variation. Taking into account this variability would increase accuracy in predictive models by specifying the environmental characteristics along with biological factors.

Overall, the capability of seagrass meadows within the PNW is seen to be lower than tropical seagrass; however, seagrass's biological and environmental characteristics promote sediment deposition. As such, conservation efforts may be effective in increasing carbon stocks along the PNW and throughout Canada's Coastlines (Lavery et al., 2013; Howard et al., 2014). This study has shown that continued research and modelling of sub and intertidal carbon stocks should remain as a key research objective and continued research into meadows with high and low flow characteristic should be prioritized to create a comprehensive understanding of seagrass's ability to store carbon.

3 Thesis Conclusion

This study examined meadow and landscape-scale variability of sediment carbon, its sources and how this knowledge can be used to extrapolate carbon stocks beyond Clayoquot Sound. This was completed by identifying the environmental drivers of sediment carbon variability with a differentiation between allochthonous and autochthonous carbon. Seven seagrass meadows within Clayoquot Sound, BC were selected based on seagrass characteristics and morpho- dynamic setting (tidal velocity, grainsize, turbidity, wave exposure, distance to river mouths).

3.1 Meadow-scale

Within the meadow scale, our prediction was rejected. The amount of carbon variability within a single meadow was not notably dependant on sediment and seagrass characteristics within the meadow. The total amount of carbon (*M*gC m^{-2}) was noted to be higher in sub or intertidal portions that had notably larger extents; however, higher density and/or larger blades in the sub or intertidal portions were not seen to cause significant variation in carbon. Small grainsizes were noted to be related to higher carbon content in the landscape scale but the relationship between sub and intertidal portions was not significant. This suggests that variation in meadow characteristics and grainsize may have a lower impact than the size of the meadow and its morphodynamical setting.

3.2 Landscape-scale

From the landscape scale, our predictions were generally accepted with increased allochthonous sediment carbon seen closer to river mouths. Analysis of Isotopic signatures, conducted via a Bayesian Mixing Model, high allochthonous carbon was observed at all sites. As such, allochthonous carbon was broken down into terrestrial and marine carbon to identify if specific carbon sourcing was more pronounced at different sites. Higher percentages of terrestrial carbon were observed near river mouths with high marine carbon throughout the entire study site. However, our analysis showed that decreased autochthonous carbon was associated with high velocities rather than low productivity related to turbid environments. Autochthonous carbon was highest in regions of high flow and high expected resuspension, which limited allochthonous material from being deposited. As such, turbidity was observed to have smaller impact on carbon deposition with average velocity, D50 and Slope/depth having the greatest impact on the multivariate linear regression model.

From this model, it is noted that high tidal velocity is seen to be related to high autochthonous carbon due to suspension of sediment. In contrast, velocity and grainsize are seen to be related to marine carbon and terrestrial carbon is related to grainsize and slope-depth. The environmental drivers were shown to be statistically different between separate sites, with Ducking and Cannery Cove having the highest and lowest velocities of the sites within Clayoquot Sound. Sediment carbon was observed to be notably higher in less energetic and deposition-favouring environments such as Cannery Cove; however, seagrass characteristics were observed to have low influence on carbon deposition.

This aligns with the geomorphic and hydrodynamic observations seen within the PNW and around the world. This study provides further evidence of seagrass' morphological impact on flow characteristics and its capability to act as carbon storage by reducing flow conditions and enhancing deposition of carbon.

These understandings shows that seagrass characteristics and spatial extent are not the only important variable to estimate carbon stocks. The extrapolation of carbon stocks beyond Clayoquot Sound could be better accounted for by using meadows, tidal measures, local bathymetry and local sediment characteristics (i.e., ShoreZone). However, recent studies have not sought to combine this understanding to better align our carbon stocks to be more accurate. This study shows definitive linkages between tidal velocity, grainsize and carbon stocks. These variables are currently under-used in the modelling of carbon stocks for the PNW and around the world. However, one model may not be sufficient to more accurately predict carbon stocks. More marine and moderate flow sites showed similar carbon stock variation; yet, high flow and near river sites had much larger variation. Taking into account this variability would increase accuracy in predictive models by specifying the environmental characteristics along with biophysical factors.

Overall, the capability of seagrass meadows within the PNW is seen to be lower than tropical seagrass; however, seagrass's biophysical and environmental characteristics promote sediment deposition and conservation efforts may be effective in increasing Corg stocks along the PNW and throughout Canada's Coastlines (Lavery et al., 2013; Howard et al., 2014). Carbon storage mechanisms have seen increased attention as a method to remove atmospheric carbon and maintain underground carbon stocks through conservation and restoration efforts. This study has shown that continued research and modelling of sub and intertidal carbon stocks should remain as a key research objective and continued research into meadows with high and low flow characteristic should be prioritized to create a comprehensive understanding of seagrass's ability to store carbon.

3.3 Potential additional research

3.3.1 Seagrass conservation versus restoration

The ongoing demise of seagrass meadows prevents carbon sequestration and enhances the risk of re-emission of stored carbon from the affected habitats (Postlethwaite et al., 2018). As such, it will be important to utilize knowledge gained in ongoing carbon sequestration research in national and global efforts to conserve and restore seagrass meadows in combination with on-going monitoring of seagrass meadow health. Duarte et al. (2013) have shown that focus must be placed on the conservation of marine vegetated ecosystems as meadows clonally spread in a self-accelerating, exponential process. Accordingly, due to this clonal spread, conservation has been shown to result in greater carbon storage capacity than the restoration of degraded habitats.

In contrast, the effectiveness of restoration projects must focus on the long-term impact as seagrass colonization requires years to centuries to establish meadows due to its patchy growth (Duarte et al., 2013). This is due to numerous environmental factors, planting densities and grazing pressures that have been seen to directly affect the success of seagrass restoration projects (quotes). Moreover, regions of the PNW provide limited access to establish effective restoration programmes as a majority of coastal landscapes exist in remote stretches that are only accessible by plane or boat (Prentice et al., 2020). This is combined with high labour costs that reduce the financial impact and limit the spatial and temporal scope of restoration (Duarte et al., 2013).

It is noted that smaller fringe meadows found in Tofino Inlet (e.g., Kennedy Cove and Tofino Creek; and elsewhere on the BC coast) have lower carbon content due to increased potential for resuspension in smaller meadows (this study; Postlethwaite et al, 2018). Hence, larger intertidal flats of seagrass in the more saline and colder end of the environmental spectrum should be clearly targeted in conservation initiatives as they are seen to have a stronger impact on carbon storage in Tofino Inlet and PNW (Postlethwaite et al., 2016).

Despite its remoteness, the PNW should be targeted by conservation initiatives as the coastline supports thousands of kilometres of semi-pristine pre-established meadows that have received little direct anthropocentric impacts. These meadows can be protected with primarily regulatory oversight to act as catalysts for fish nurseries and as a sink for atmospheric carbon (Gacia et al., 2006).

3.3.2 Seagrass modelling for BC and Canada

An important end goal for advancing understanding seagrasses' capability to sequester carbon requires going beyond the landscape and meadows scale by creating regional, provincial, and national carbon estimates of carbon sequestration by this ecosystem. By understanding the local scale, we hope to extrapolate environmental parameters to represent productive and non-productive zones for carbon storage along Canada's coast. Further analysis from this study can be used develop simple parametrizations to allow scaling-up of the findings to estimate carbon stocks using only readily available environmental data (basin geometry, proximity to river mouth, bathymetry, wind, and tidal constituents) and mapped seagrass extents.

This is predicted to be possible via investigatory studies by computing the fetch and wave climate from the dominant wind directions and model tidal current velocities using Government of Canada tide station (Mariotti and Fagherazzi, 2012) using the USGS GIS algorithm (Rohweder et al., 2012). Field measurements, such as the data collected within Clayoquot sound, can be used to validate these models using sediment carbon content, sediment characteristics and seagrass characteristics (shoot density, leaf area index) along transects. Moreover, the turbidity gradient for the regional scale can be determined from satellite imagery and ground-truthing data of field measurements.

3.3.3 Historical drivers of sediment carbon

Understanding the present-day environmental conditions allow us to understand how seagrass meadows may be impacting coastal carbon sequestration right now; however, when looking into future predictions of seagrass carbon sequestration it becomes necessary to look beyond the short term and understand how climatic variation has impacted seagrass meadows. As such an additional focus on the historical drivers of sediment carbon within Clayoquot Sound should be a priority for future research. This research would look to how past environmental conditions in the bay may have impacted the carbon sequestration potential of seagrass meadows and how might we qualify/quantify historical sediment carbon accumulation rates and drivers taking into account past anthropocentric impacts (Logging, dredging)? This research would also look to understanding the long-term climatic variation in seagrass extent and density from traditional ecological knowledge of the Tla-o-qui-aht First nation and throughout the remainder of BC.

4 References

Alcoverro T, Duarte CM, and J Romero (1995). Annual growth dynamics of Posidonia oceanica: Contribution of large-scale versus local factors to seasonality, Marine Ecology Progress *Series*, 120: 203–210.

Aquino-López MA, Blaauw M, Christen JA, et al. (2018) Bayesian analysis of 210Pb dating. Journal of Agricultural Biological and Environmental Statistics 23: 317–333.

ASTM, A. (2017). D7928: Standard test method for particle-size distribution (gradation) of fine-grained soil using the sedimentation (hydrometer) analysis. ASTM International: West Conshohocken (PA).

Cabello-Pasini, A., Muñiz-Salazar, R., & Ward, D. H. (2003). Annual variations of biomass and photosynthesis in Zostera marina at its southern end of distribution in the North Pacific. *Aquatic Botany*, *76*(1), 31–47. https://doi.org/10.1016/S0304-3770(03)00012-3

Chastain, S. G., Kohfeld, K. E., Pellatt, M. G., Olid, C., & Gailis, M. (2022). Quantification of blue carbon in salt marshes of the Pacific coast of Canada. Biogeosciences, 19(24), 5751–5777. https://doi.org/10.5194/bg-19-5751-2022

Christensen M. & O'Connor M. (2023). Estimating blue carbon storage capacity of Canada's eelgrass beds. University of British Columbia

Colomer, J.; Serra, T. (2021). The World of Edges in Submerged Vegetated Marine Canopies: From Patch to Canopy Scale. Water, 13, 2430. https://doi.org/10.3390/ w13172430

Coops, H., Boeters, R., & Smit, H. (1991). Direct and indirect effects of wave attack on helophytes. Aquatic Botany, 41(4), 333-352. https://doi.org/10.1016/0304-3770(91)90052-7

Dahl M, Deyanova D, Gütschow S, Asplund ME, Lyimo LD, Karamfilov V, Santos R, Björk M, and M Gullström (2016). Sediment properties as important predictors of carbon storage in Zostera marina meadows: a comparison of four European areas. PLOS One, 11(12) e0167493. doi: 10.1371/journal.pone.0167493.

Dearden, P, & Mitchell, B. (2016). Environmental Change & Challenge: A Canadian Perspective. Oxford University Press. Ontario: CA

Deines, K. L. (1999). Backscatter estimation using Broadband acoustic Doppler current profilers. Proceedings of the IEEE Sixth Working Conference on Current Measurement (Cat. No.99CH36331), 249–253. https://doi.org/10.1109/CCM.1999.755249

Depro, B. M., Murray, B. C., Alig, R. J., & Shanks, A. (2008). Public land, timber harvests, and climate mitigation: Quantifying carbon sequestration potential on U.S. public timberlands. Forest Ecology and Management, 255(3), 1122-1134. https://doi.org/10.1016/j.foreco.2007.10.036

Douglas T., Juniper S. K., Dower J., Costa, M, & Schuerholz G. (2021). Blue Carbon Storage in the Cowichan Estuary, British Columbia. University of Victoria

Duarte C. M., & Kirkman H. (2001). Methods for the measurement of seagrass abundance and depth distribution. In: Short FT, Coles RG, editors. Global seagrass research methods. Netherlands: Elsevier Science; 141–153.

Duarte C. M., Sintes T, and N Marbà (2013). Assessing the CO2 capture potential of seagrass restoration projects. Journal of Applied Ecology, 50(6):1341-1349.

Dunn, C., Lopez, F., & Garcia, M. (1996). Mean flow and turbulence structure induced by vegetation: Experiments. Hydraulic engineering series, 51.

Fonseca, M. and Bell, S. (1998). Influence of physical setting on seagrass landscapes near Beaufort, North Carolina, USA. Marine Ecology Progress Series, 171:109. doi:10.3354/meps171109.

Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbà, N., Holmer, M., Mateo, M. A., Apostolaki, E. T., Kendrick, G. A., Krause-Jensen, D., McGlathery, K. J., & Serrano, O. (2012). Seagrass ecosystems as a globally significant carbon stock. Nature Geoscience, 5(7), 505-509. https://doi.org/10.1038/ngeo1477

Gacia E, Duarte CM, and JJ Middelburg (2002). Carbon and nutrient deposition in a Mediterranean seagrass (Posidonia oceanica) meadow. Limnology and Oceanography, 47: 23–32. doi:10.4319/lo.2002.47.1.0023.

Gailis, M., Kohfeld, K. E., Pellatt, M. G., & Carlson, D. (2021). Quantifying blue carbon for the largest salt marsh in southern British Columbia: implications for regional coastal management. Coastal Engineering Journal, 63(3), 275–309. https://doi.org/10.1080/21664250.2021.1894815

Gomez, C. Guijarro-Sabanie, J. Wong, M. (2021). National Eelgrass Task (NET) Force: engagement in support of a dynamic map of eelgrass distribution in Canada to support monitoring, research and decision making. Fisheries and Oceans Canada

Gartner, J. W. (2004). Estimating suspended solids concentrations from backscatter intensity measured by acoustic Doppler current profiler in San Francisco Bay, California. Marine Geology, 211(3–4), 169–187. https://doi.org/10.1016/j.margeo.2004.07.001

Gordon, R. L. (1996). Acoustic Doppler current profiler-Principles of operation: A practical primer. RD Instruments.

Greiner, J. & Wilkinson, Grace & McGlathery, KJ & Emery, Kyle. (2016). Sources of sediment carbon sequestered in restored seagrass meadows. Marine Ecology Progress Series. 551. 10.3354/meps11722.

Hansen, J. C. R., & Reidenbach, M. A. (2013). Seasonal growth and senescence of a zostera marina seagrass meadow alters wave-dominated flow and sediment suspension within a coastal bay. Estuaries and Coasts, 36(6), 1099-1114. https://doi.org/10.1007/s12237-013-9620-5

Hendriks IE, Sintes T, Bouma TJ, and CM Duarte (2008). Experimental assessment and modeling evaluation of the effects of seagrass Posidonia oceanica on flow and particle trapping. Marine Ecology Progress Series, 356: 163–173. doi:10.3354/meps07316.

Howard, J., Hoyt, S., Isensee, K., Telszewski, M. and Pidgeon, E. (2014). Coastal Blue Carbon: Methods for assessing carbon stocks and emission factors in mangroves, tidal salt marshes and seagrasses. Conservation International, Intergovernmental Oceanographic Commission of UNESCO, International Union for Conservation of Nature. In: Conservation International. Arlington, Virginia, USA. 99–107.

IPCC, (2021). Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. In Press

Jankowska, E., Michel, L. N., Zaborska, A., & Włodarska-Kowalczuk, M. (2016). Sediment carbon sink in low-density temperate eelgrass meadows (baltic sea). Journal of Geophysical Research. Biogeosciences, 121(12), 2918-2934. https://doi.org/10.1002/2016JG003424

Kaldy JE. (2014) Effect of temperature and nutrient manipulations on eelgrass Zostera marina from the Pacific Northwest, USA. J.Exp Mar Bio Ecol.; 453:108–115.

Kalra, Y. P., & Maynard, D. G. (1991). Methods manual for forest soil and plant analysis (Vol. 319)

Kennedy H, Beggins J, Duarte CM, Fourqurean JW, Holmer M, Marba N, and JJ Middelburg (2010). Seagrass sediments as a global carbon sink: Isotopic constraints. Global Biogeochemical Cycles, 24: GB4026. doi:10.1029/2010GB003848.

Koch E (2001). Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. Estuaries, 24: 1–17. doi:10.2307/1352808.

Koch E, Ackerman J, Verduin J, and M Keulen (2006). Fluid dynamics in seagrass ecology: From molecules to ecosystems, p. 193–225. In AWD Larkum, RJ Orth, and CM Duarte [eds.], Biology, ecology and conservation. Springer.

Lacy, J. R., & Wyllie-Echeverria, S. (2011). The influence of current speed and vegetation density on flow structure in two macrotidal eelgrass canopies: A field study of eelgrass hydrodynamics. Limnology and Oceanography: Fluids and Environments, 1(1), 38–55. https://doi.org/10.1215/21573698-1152489

Lavery, P. S., Mateo, M., Serrano, O., & Rozaimi, M. (2013). Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. PloS One, 8(9), e73748-e73748. https://doi.org/10.1371/journal.pone.0073748

Lutz M (2018). A Search for Blue Carbon in Central Salish Sea Eelgrass Meadows. MSc Thesis, Western Washington University.

Mazarrasa, I., Samper-Villarreal, J., Serrano, O., Lavery, P. S., Lovelock, C. E., Marbà N., Duarte. C. M., Cortés, J. (2018). Habitat characteristics provide insights of carbon storage in seagrass meadows, Marine Pollution Bulletin, 134, 106-117, https://doi.org/10.1016/j.marpolbul.2018.01.059.

Mazzotti, S., Jones, C., & Thomson, R. E. (2008). Relative and absolute sea level rise in western Canada and northwestern United States from a combined tide gauge-GPS analysis. *Journal of Geophysical Research*, *113*(C11), C11019–n/a. https://doi.org/10.1029/2008JC004835

McKinley, D. C., Ryan, M. G., Birdsey, R. A., Giardina, C. P., Harmon, M. E., Heath, L. S., Houghton, R. A., Jackson, R. B., Morrison, J. F., Murray, B. C., Pataki, D. E., & Skog, K. E. (2011). A synthesis of current knowledge on forests and carbon storage in the United States. *Ecological Applications*, *21*(6), 1902–1924. https://doi.org/10.1890/10-0697.1

Miyajima, T., Hori, M., Hamaguchi, M., Shimabukuro, H., Adachi, H., Yamano, H., & Nakaoka, M. (2015). Geographic variability in organic carbon stock and accumulation rate in sediments of east and southeast asian seagrass meadows. Global Biogeochemical Cycles, 29(4), 397-415. https://doi.org/10.1002/2014GB004979

Nepf, H. M. (2012) Hydrodynamics of vegetated channels, Journal of Hydraulic Research, 50:3, 262-279, DOI: 10.1080/00221686.2012.696559

Novak, A.B., Pelletier, M.C., Colarusso, P. *et al. (*(2020). Factors Influencing Carbon Stocks and Accumulation Rates in Eelgrass Meadows Across New England, USA. *Estuaries and Coasts* 43, 2076–2091. https://doi-org.ezproxy.library.uvic.ca/10.1007/s12237-020-00754-9

Payne, N.J., Allan Cameron, D., Leblanc, JD. *et al.* (2019). Carbon storage and net primary productivity in Canadian boreal mixed wood stands. *J. For. Res.* **30**, 1667–1678 (2019). https://doi-org.ezproxy.library.uvic.ca/10.1007/s11676-019-00886-0

Peng, Y., Arora, V. K., Kurz, W. A., Hember, R. A., Hawkins, B. J., Fyfe, J. C., & Werner, A. T. (2014). Climate and atmospheric drivers of historical terrestrial carbon uptake in the province of British Columbia, Canada. Biogeosciences, 11(3), 635–649. https://doi.org/10.5194/bg-11-635-2014

Peralta G, Van Duren LA, Morris EP, Bouma TJ (2008) Consequences of shoot density and stiffness for ecosystem engineering by benthic macrophytes inflow dominated areas: A hydrodynamic flume study. Mar Ecol Prog Ser 368: 103–115.

Postlethwaite, V. R., McGowan, A. E., Kohfeld, K. E., Robinson, C. L. K., & Pellatt, M. G. (2018). Low blue carbon storage in eelgrass (zostera marina) meadows on the pacific coast of canada. PloS One, 13(6), e0198348-e0198348. https://doi.org/10.1371/journal.pone.0198348

Prentice, C. I., Hessing-Lewis, M., Sanders-Smith, R. & Salomon, A. K (2019). Reduced water motion enhances organic carbon stocks in temperate eelgrass meadows. Limnology and Oceanography 64, 2389-2404. https://doi-org.ezproxy.library.uvic.ca/10.1002/lno.11191

Prentice, C. et al. (2020). A synthesis of blue carbon stocks, sources and accumulation rates in eelgrass (Zostera marina) meadows in the Northeast Pacific. Global Biogeochemical. Cycles. 34 (2), https://doi-org.ezproxy.library.uvic.ca/10.1029/2019GB006345

Reshitnyk, L. (2018). Mapping eelgrass with remotely piloted aerial systems within the Long Beach unit of Pacific Rim National Park reserve. Hakai Institute.

Ricart, A. M., York, P. H., Rasheed, M. A., Perez, M., Romero, J., Bryant, C. V., & Macreadie, P. I. (2015). Variability of sedimentary organic carbon in patchy seagrass landscapes. *Marine Pollution Bulletin*, *100*(1), 476–482. https://doi.org/10.1016/j.marpolbul.2015.09.032

Ricart, A. M., Pérez, M., & Romero, J. (2016). Landscape configuration modulates carbon storage in seagrass sediments. Estuarine, Coastal and Shelf Science, 185, https://doi.org/10.1016/j.ecss.2016.12.011.

Robinson, C. & Yakimishyn, J. (2008). Monitoring of the ecological integrity of eelgrass beds (Zostera marina) in Canada's national parks of British Columbia. Parks Canada.

Röhr, ME, Holmer M., Baum, JK, Björk M, Chin D, Chalifour L, et al. (2018). Blue carbon storage capacity of temperate eelgrass (Zostera marina) meadows. Global Biogeochemical Cycles, 32, 1457–1475. https://doi.org/10.1029/2018GB005941

Ross, S. L. (2017) Weather and Climate: An Introduction. Oxford University Press. Ontario: CA

Salo T, Pedersen MF, Boström C. (2014) Population specific salinity tolerance in eelgrass (Zostera marina). JExp Mar Biol Ecol.; 461:425–429

Short, F. T., Hessing-Lewis, M., Prentice, C., Sanders-Smith, R., Gaeckle, J., & Helms, A. (2017). Seagrass Sediment Sampling Protocol and Field Study: British Columbia, Washington and Oregon. 12 Pp. Montreal, Canada: Commission for Environmental Cooperation.

Simpson, J., Bruce, E., Davies, K. P., & Barber, P. (2022). A Blueprint for the Estimation of Seagrass Carbon Stock Using Remote Sensing-Enabled Proxies. Remote Sensing, 14(15), 3572. MDPI AG. Retrieved from http://dx.doi.org/10.3390/rs14153572

Thom RM, Borde AB, Rumrill S, Woodruff DL, Williams GD, Southar dJA, et al.(2003) Factors influencing spatial and annual variability ineelgrass (Zostera marina L.) meadows in Willapa Bay, Washingtonand Coos Bay, Oregon, Estuaries. Estuaries; 26: 1117–1129.

Thorne, P. D., Hardcastle, P. J., Flatt, D., & Humphery, J. D. (1994). On the use of acoustics for measuring shallow water suspended sediment processes. IEEE journal of oceanic engineering, 19(1), 48-57.

5 Appendices

5.1 Appendix A: Regional and site characteristics

5.1.1 Regional estimates of carbon from previous studies

Five studies show how carbon varies throughout the PNW and Canada:

The first study conducted by Postlethwaite et al. (2018) at Clayoquot Sound showed carbon stocks up to 25 cm depth averaged 1343 ± 482 g C/m^2 in the three study sites (Robert Point, Grice Bay, and Kennedy Cove). Carbon stocks ranged from 802-2519 g C/m^2 in Clayoquot Sound's seagrass meadows. Moreover, the study showed that accumulation rates range from 3.9–22.3 g C m^{-2}in Clayoquot Sound (Postlethwaite et al., 2018). These three sites had significantly lower carbon storage than previous estimates from global studies (~3493 g C m^{-2}, Fourqurean et al., 2012). As such, seagrass meadows contribute to carbon storage in Clayoquot Sound and the BC coastline; however, total carbon stocks and accumulation rates are lower what has been identified for tropical seagrass meadows (Fourqurean et al., 2012).

The second study by Prentice et al. (2018) solidified this result by showing that carbon sequestration rates in seagrass meadows are highly variable (13-fold over 54 cores) within the central coastal region of BC. The range seen on the central coast was from 83 g C m^{-2}in Choked Pass to 1089 g C m^{-2} at McMullins North. This study showed annual accumulation and carbon content over depth via 210^{Pb} isotopes in the sediments at four meadows. Two sites were excluded due to insufficient 210 Pb at Goose SW and high levels of mixing and erosion impacted results skewing results in Ko-eye Estuary. The remaining four meadows had carbon accumulation rates ranging from 4.6 g C $m^{-2}y^{-1}$ ± 1.5 (SE) in Choked Pass to 33.1 g C $m^{-2}y^{-1}$ ± 4.5 (SE) in Triquet Bay with an averaged of 22.4 g $C/m^2/y$. Moreover, the estimated age of the top 20 cm of sediment ranged from 71 to 88 years (average = 76.8 years). Meadows with higher carbon accumulation rates also tended to have higher carbon stocks in the top 50 cm showing that seagrass's biological characteristic can limit resuspension and move allochthonous carbon into long-term storage.

The third study by Douglas et al. (2021) showed how eelgrass meadows compared to other intertidal carbon stocks, namely saltmarsh and mudflats, by overviewing total carbon stock throughout the Cowichan estuary. The results showed that seagrass extent is an important determinant when researching carbon stock accumulation with saltmarsh accumulating 256.7 Mg CO_2e yr^{-1} in 94.6 hectares (ha), the mudflat accumulating 349.7 ± 239.3 Mg CO2e/yr in 251 ha, and eelgrass accumulating 25.1 ± 17.2 Mg CO2e yr^{-1} in 18 ha. Taking into account size differences, carbon accumulation rates in the eelgrass meadow were similar to those of the mudflats and the seagrass carbon accumulation rates (38 ± 26 g C/m^2/y) were lower than global averages but consistent with those recently reported in seagrass meadows of the PNW.

Moreover, the fourth study, undertaken by Prentice et al. (2020), put these accumulation rates for *Zostera marina* in a global perspective by stating that the carbon accumulation rates in the meadows sampled along the central BC ranged from 5 to 33 g C/m^2/y, which are similar to estimates from *Zostera marina* meadows in Japan (3–10 g C/m^2/y; Miyajima et al., 2015), in Virginia (37 g C/m^2/y; Greiner et al., 2013), and Postlethwaite et al. (2018)'s study further south on the BC coast in Clayoquot Sound (10.8 ± 5.2 g C/m^2/y) and Cowichan estuary (38 ± 26 g C/m^2/y. The sites from the central coast of BC and Vancouver Island were higher than those reported by Jankowska et al. (2016) in Baltic Sea seagrass meadows (1–4 g C/m^2/y).

As stated by Prentice et al. (2020), the average carbon stocks in the top 25 cm on the central Coast (1482 g C/m^2), assuming a relatively consistent carbon profile to 1 m (~ 5928 g C/m^2), are approximately three times lower than the global median for 1m carbon stocks in seagrass meadows (19,420 g C/m^2) reported by Fourqurean et al. (2012). These carbon stocks, provided via Prentice et al. (2018), align similarly with other temperate *Zostera marina* meadows. This averaged carbon stock (to 25 cm depth) from the central coast of BC aligned similarly to seagrass meadows across all temperate latitudes (2,721 g C/m^2) as reported by Röhr et al. (2018) and is marginally similar to the PNW average of 1,752 g C/m^2. Additionally, BC's central coast aligns with similar studies in the upper 25 cm of Australian seagrass meadows which had an average 1,262 g C/m^2 (Lavery et al., 2013).

The fifth study by Christensen & O'Connor (2023) sought to provide updated estimates of carbon stock within 22 meadows throughout three regions of Canada: Pacific, Atlantic and Central (Gulf of St. Lawrence) Coasts. From this analysis, the study found within meadow carbon stocks for the top 25cm varied between 121.35 and 4767.71 g C/$m^2$with averages of the Pacific coast (1637.66 gC/m^2), the Atlantic Coast (2369.95 g C/m^2), and the central coast (846.31 g C/m^2). Moreover, the models created for this study identified substrate cover type, coast, sediment silt content, exposure, and sediment depth as key variables to explain variation in carbon stock.

5.1.2 Clayoquot Sound overview

Real-Time Hydrometric Data Graph for Tofino Creek near the mouth (08HB086) [BC]

Table 6: Basic information for each of the seven meadow sites as pertinent to this study. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018, BCMCA, and ShoreZone

Site	Meadow size(m^2)	Depth (m)	Waves Exposure	Substrate (shoretype, sediment abundance)	River exposure
Auseth	35 000	-3.8	Protected, no waves	Rock w sand beach/rock cliff, Abundant	low
Beck	40 000	-11.2	Semi-exposed	Rock, sand and Gravel Beach, Abundant	low
Calmus	49 000	-9.7	Protected/Semi-protected	Rock, sand and Gravel Beach/Rock Cliff, Moderate/Abundant	low
Ducking	139 000	-6.6	Protected	Estuary, Marsh or lagoon/Gravel Beach, Abundant	low
Cannery Cove	70 000	-7.3	Protected	Estuary, Marsh or lagoon/abundant	High
Mud Bay	407 000	-4.6	Sem-exposed/semi-protected, no waves	Estuary, Marsh or lagoon/Rock, sand and Gravel Beach/Rock with Sand Beach, Abundant	low
Tofino Creek	15 000	-7.2	protected	Estuary, Marsh or lagoon/abundant	High

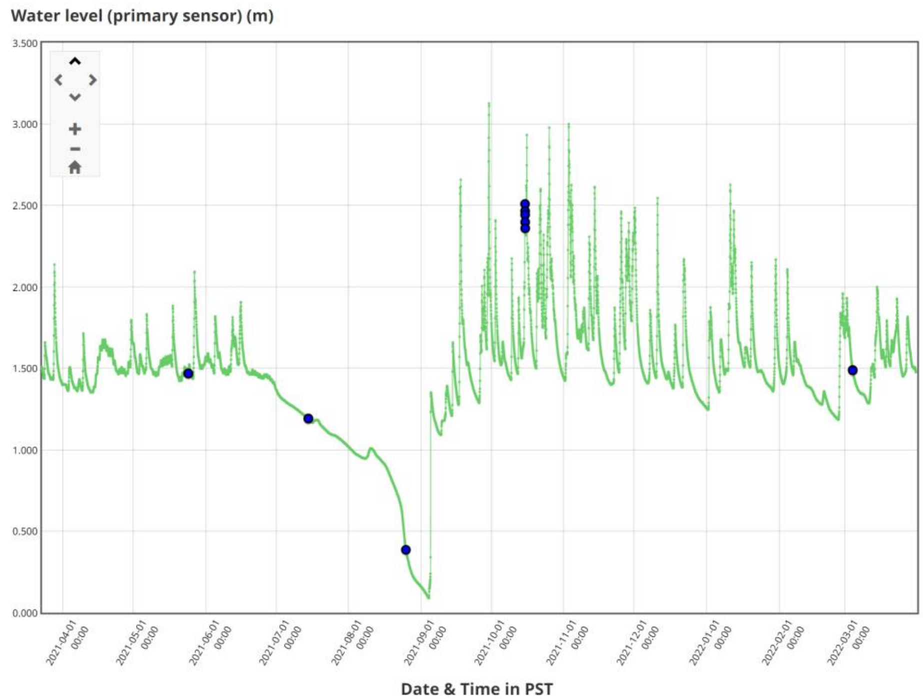
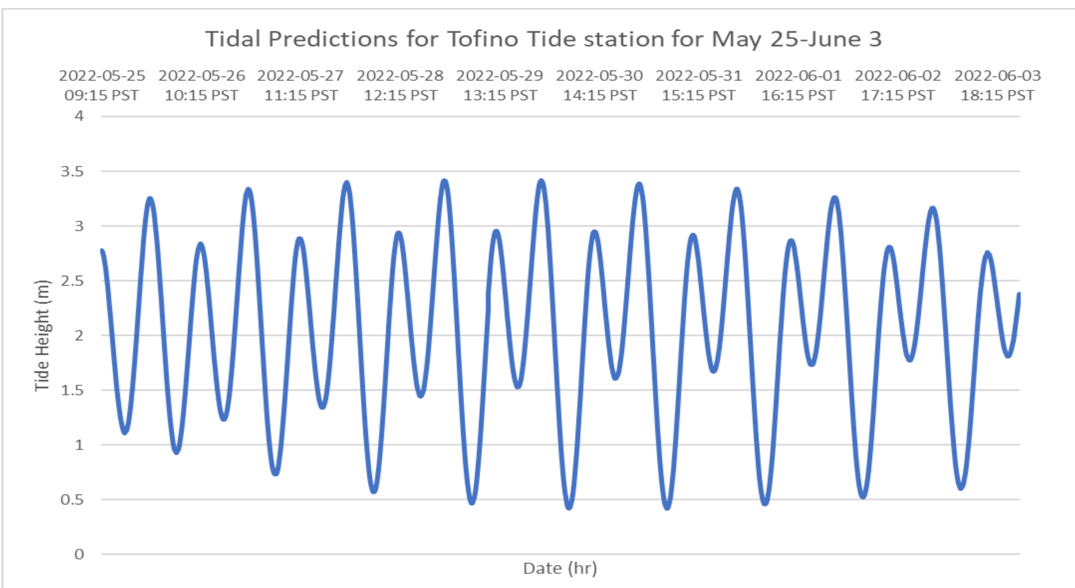


Figure 8: Real-Time Hydrometric Data Graph for TOFINO CREEK near the mouth (08HB086) [BC] from March 24, 2021 to March 24, 2022. Data collected from Government of Canada



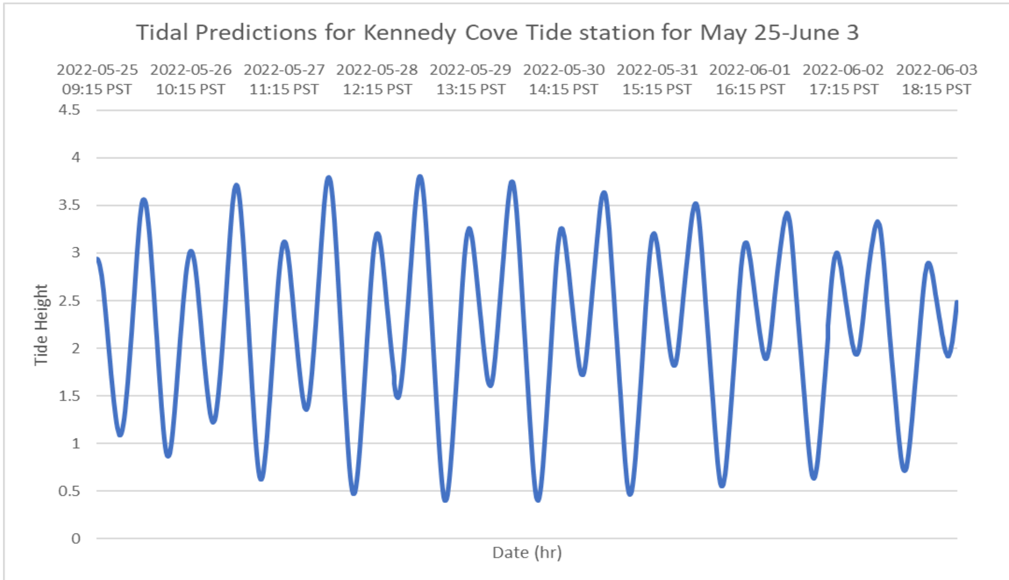


Figure 9: Predicted tidal variation for May 25, 2022 to June 3, 2022 at the Tofino tide station and Kennedy Cove prediction station. Data collected from Tides Canada.

5.1.3 Seagrass study site results

Site specific results are noted below from the west to east:

Calmus is located on the north side of Vargas Island near Calmus Passage. This site is closest to Roberts Point, a site previously examined by Postlethwaite et al. (2018). Compared to 26 Mud Bay, this meadow is located in a slightly deeper and steeper area, with similar density though much smaller extent. Tidal velocity is similar to Mud Bay and the seabed slightly finer.

Mud Bay is located ~5 km east of Calmus within a shallow, gently sloped bay of a lowgradient portion of Varges Island. Mud Bay holds the largest meadow area (407,000 m2) with generally longer and thick blades, and moderate density. A small creek drains into the meadow, but it is far from the main freshwater sources. Tidal velocity is low-moderate and the seabed consists of fine sand with mixed turbidity.

Beck is the most seaward, deepest (8.015m), and steepest (6.151°) location on a shoal formed in the lee of a group of islands. This is reflected in a large distance to the nearest river, high tidal velocity, coarsest bed (though still fine sand) after Tofino Creek, and low turbidity. Interestingly, this meadow is the densest meadow out of the 7 with short, slimmer blades

Ducking is a fringy, long meadow situated adjacent to Browning Passage, a narrow tidal channel between the Esowista peninsula and steeply sloped Meares island. This results in a steep drop off and highest tidal velocity (0.61 m/s) over this meadow. Yet, the meadow is the second largest out of the 7 with a slightly higher average density than the Varges Island meadows. The meadow is located the furthest from the major freshwater sources, though small drainage channels are visible landward of the meadow.

Auseth is located surrounding an isolated shoal between Meares island to the west and Indian island, where Browning passage veers to the north and splits into Tofino Inlet and Fortune Channel. This is the shallowest (3.609m) and least steep (0.408°) location with low tidal velocity and turbidity, yet the seabed is similarly grained than Beck, Ducking, and Mud Bay. The small meadow is dense and fringes the shoal towards the north.

Cannery cove is located far into Tofino Inlet, away from the mudflats around Browning Passage and Grice Bay and close to the Kennedy River outflow. The meadow grows on the finest seabed, away from high tidal velocities and with the longest blades, but has the lowest density (99.2 shoots/m^2).

Tofino Creek is located at the head of Tofino Inlet on a shallow likely formed from the outflow of Tofino Creek. The meadow is the smallest meadow out of the 7 with short and thin blades and low density. Tidal velocity fluctuations are minimal.

5.1.4 Seagrass transect locations

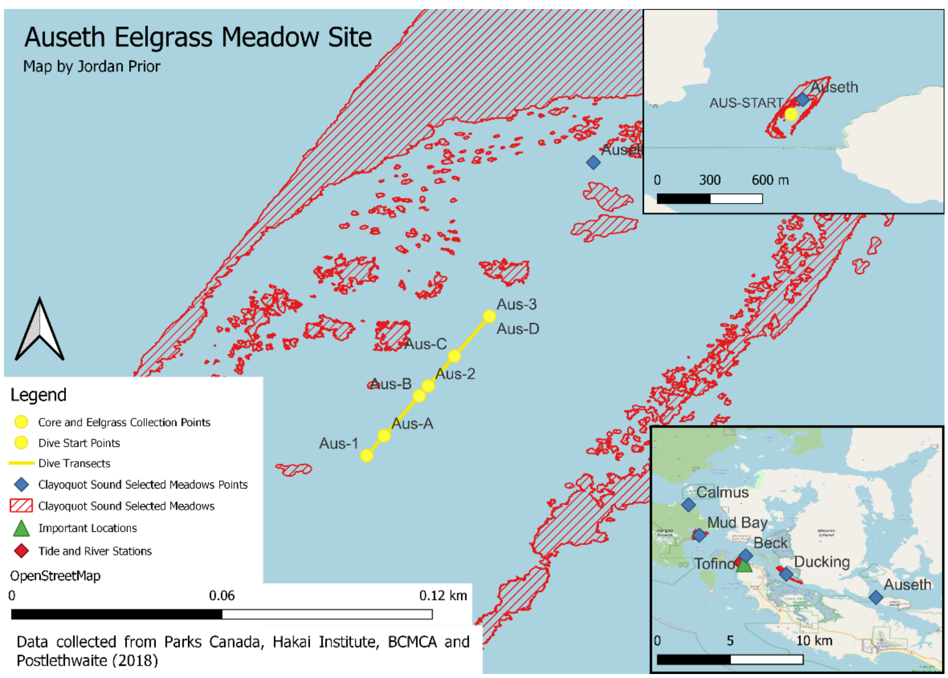


Figure 10: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Auseth eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

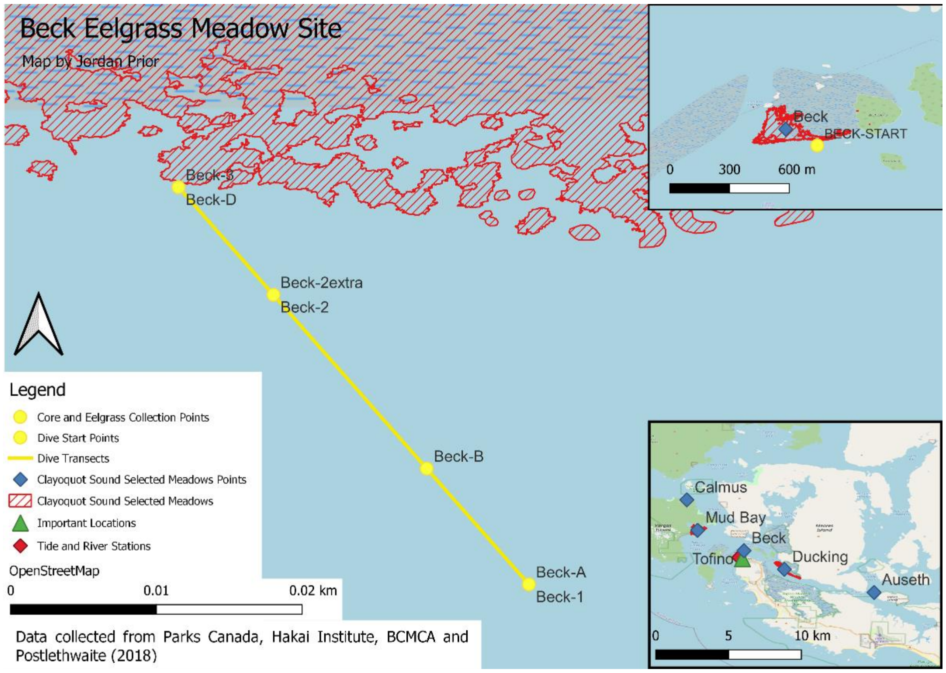


Figure 11: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Beck eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

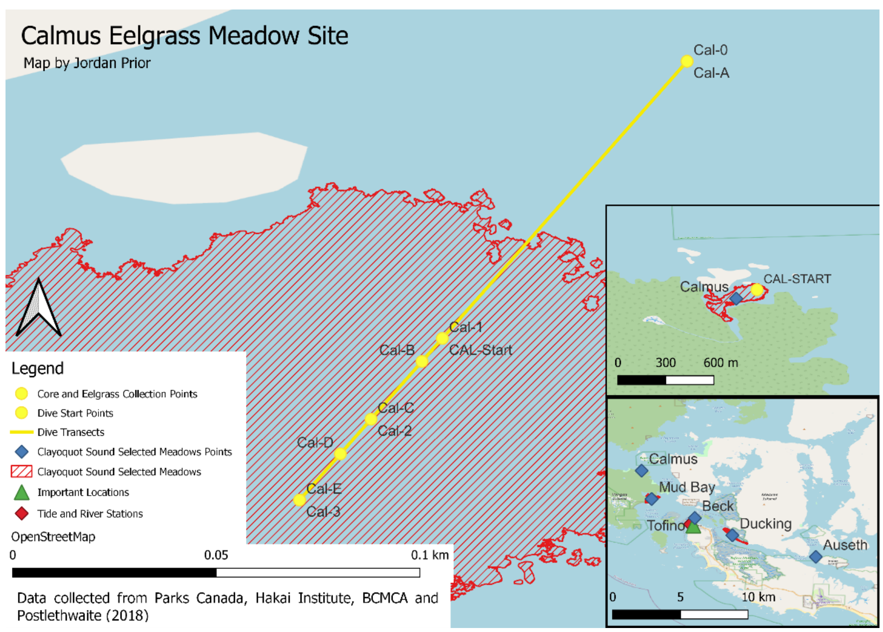


Figure 12: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Calmus eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

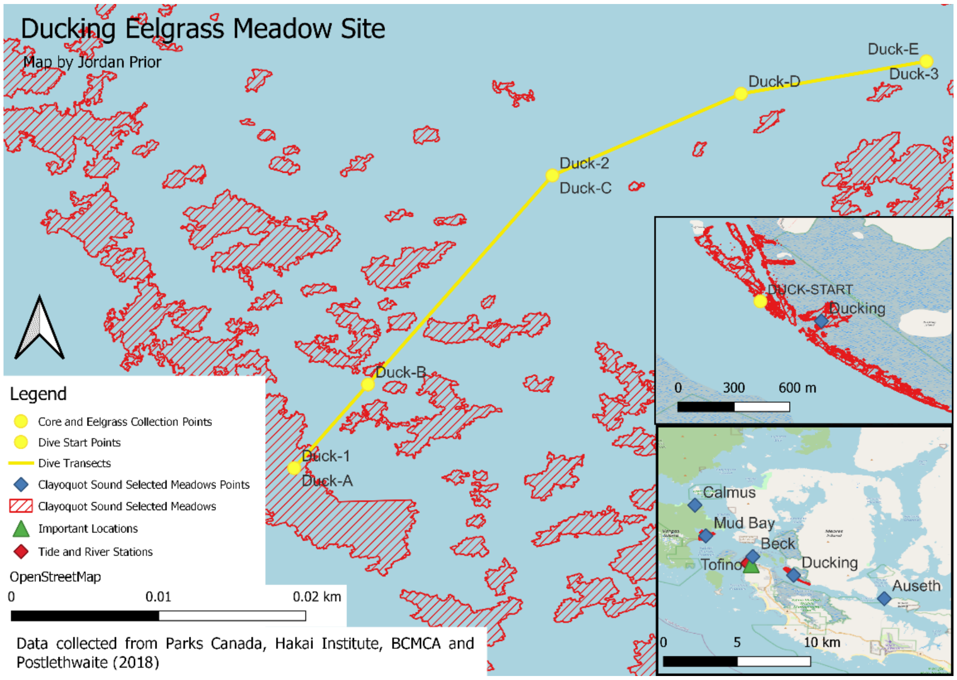


Figure 13: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Auseth eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

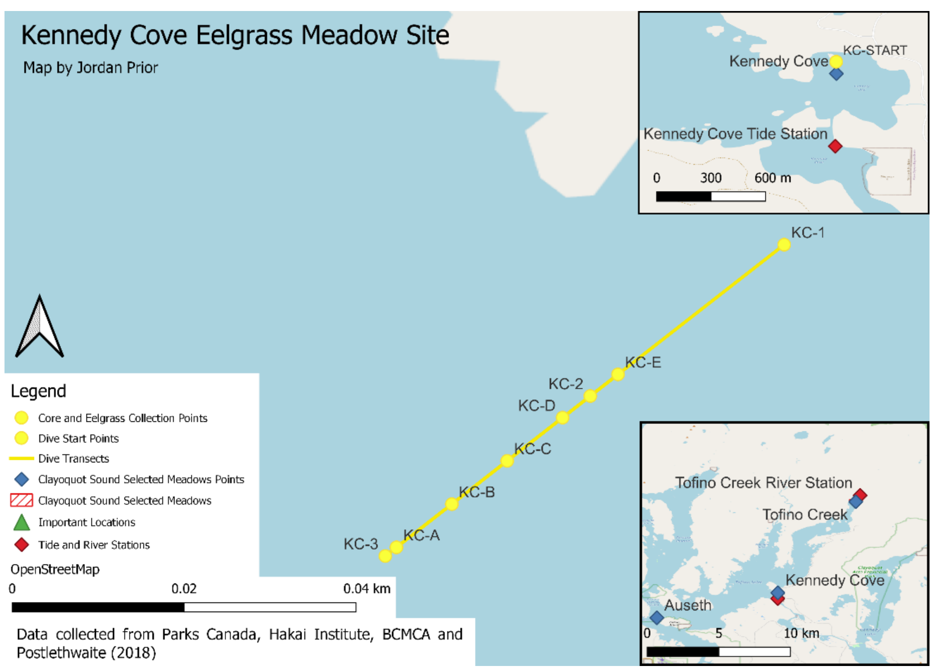


Figure 14: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Kennedy Cove (AKA Cannery Cove) eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

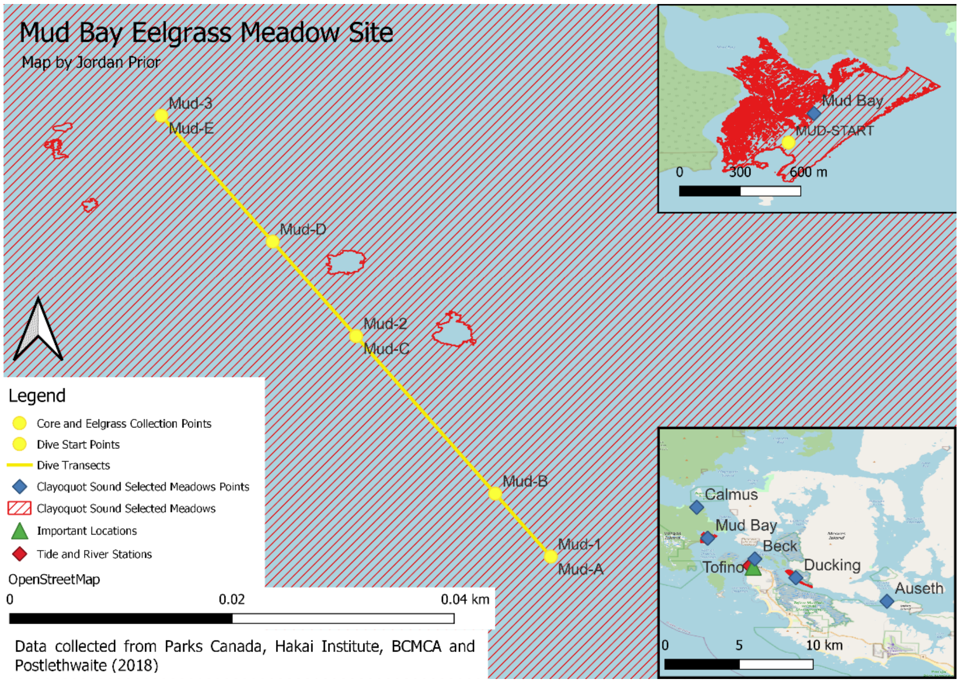


Figure 15: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Mud Bay eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

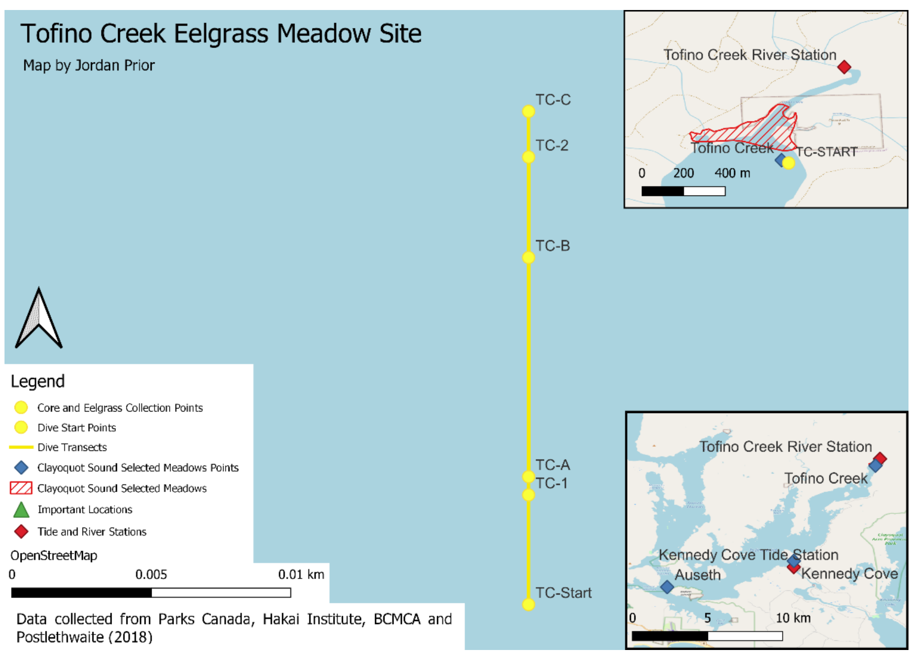


Figure 16: Sediment core and biophysical characteristic collection points as compared to historical mapping of eelgrass extents at Tofino Creek eelgrass meadow site. Data collected from Hakai Institute, Parks Canada, Postlethwaite et al., 2018 and BCMCA (Intertidal and Subtidal cores were within current eelgrass extent)

5.1.5 Velocity measurements at study sites

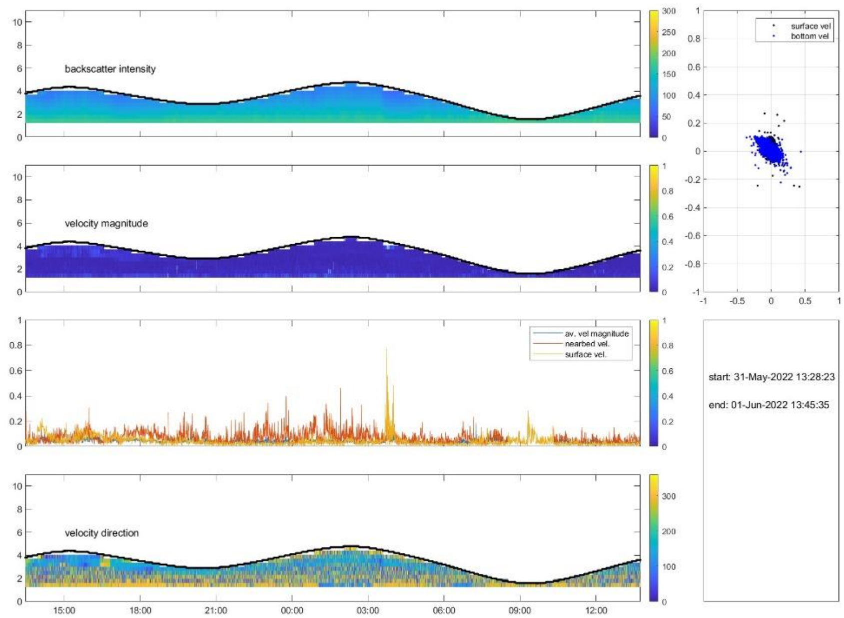


Figure 17: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Auseth eelgrass site

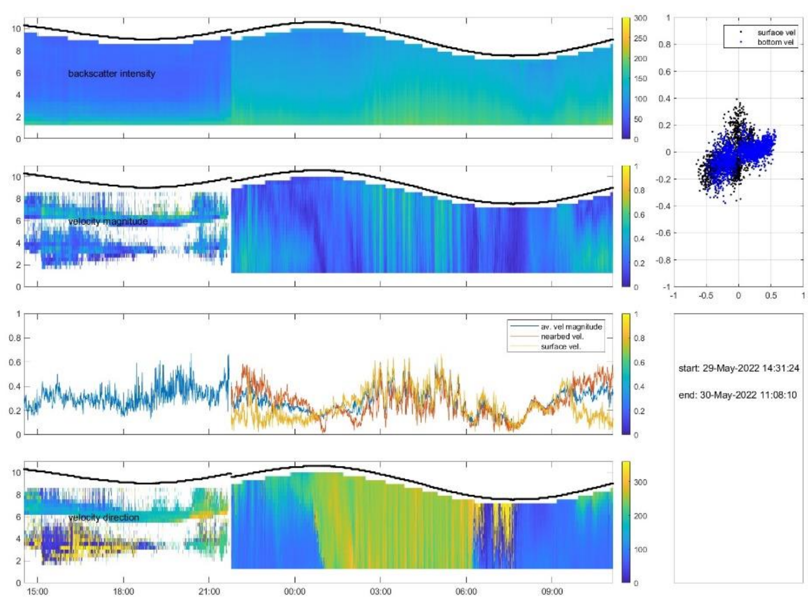


Figure 18: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Beck eelgrass site

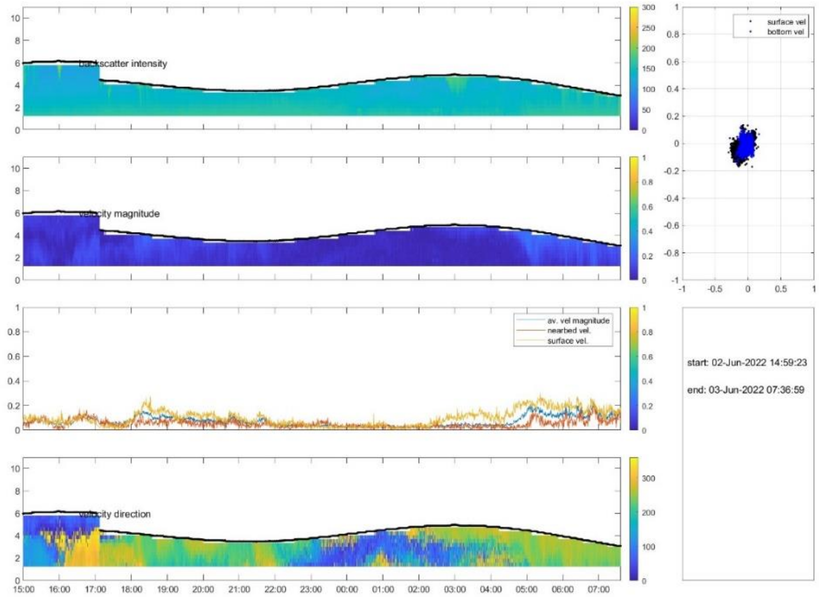


Figure 19: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Calmus eelgrass site

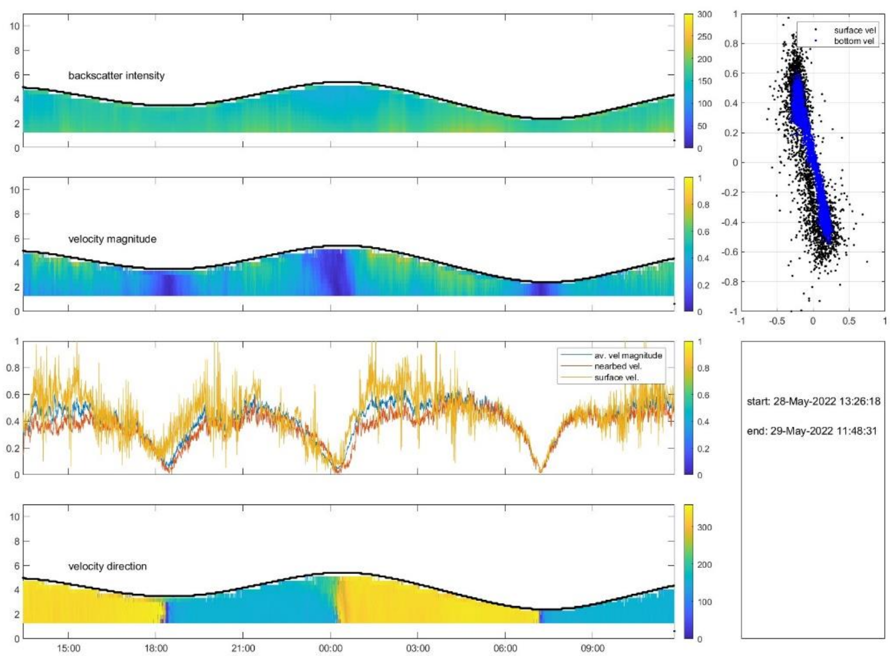


Figure 20: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Ducking eelgrass site

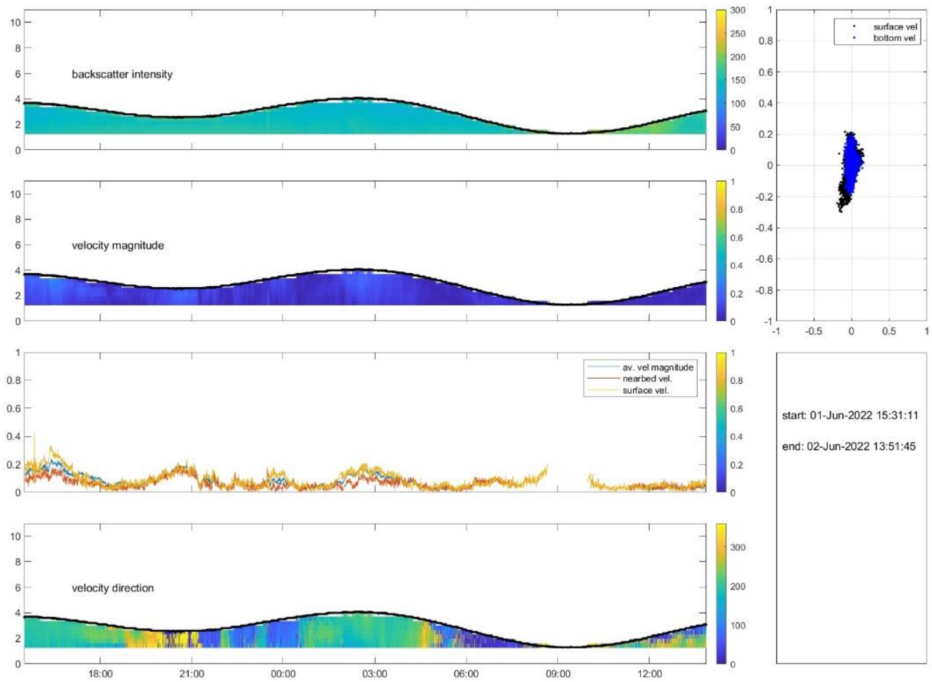


Figure 21: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Cannery cove eelgrass site

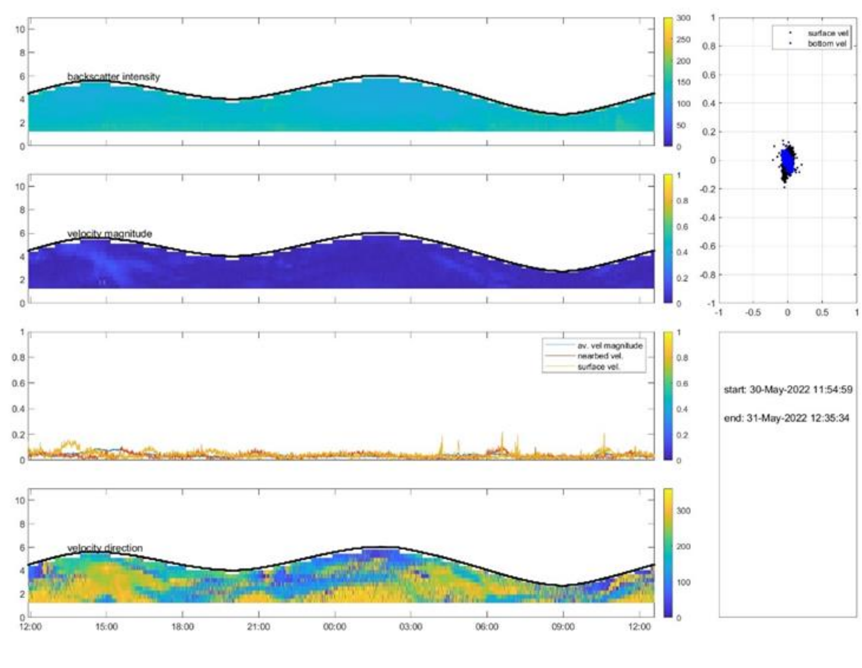


Figure 22: Backscatter intensity, velocity magnitude, Velocity magnitude (average, Nearbed and surface), and velocity direction at Mud Bay eelgrass site

5.1.6 Grainsize analysis results

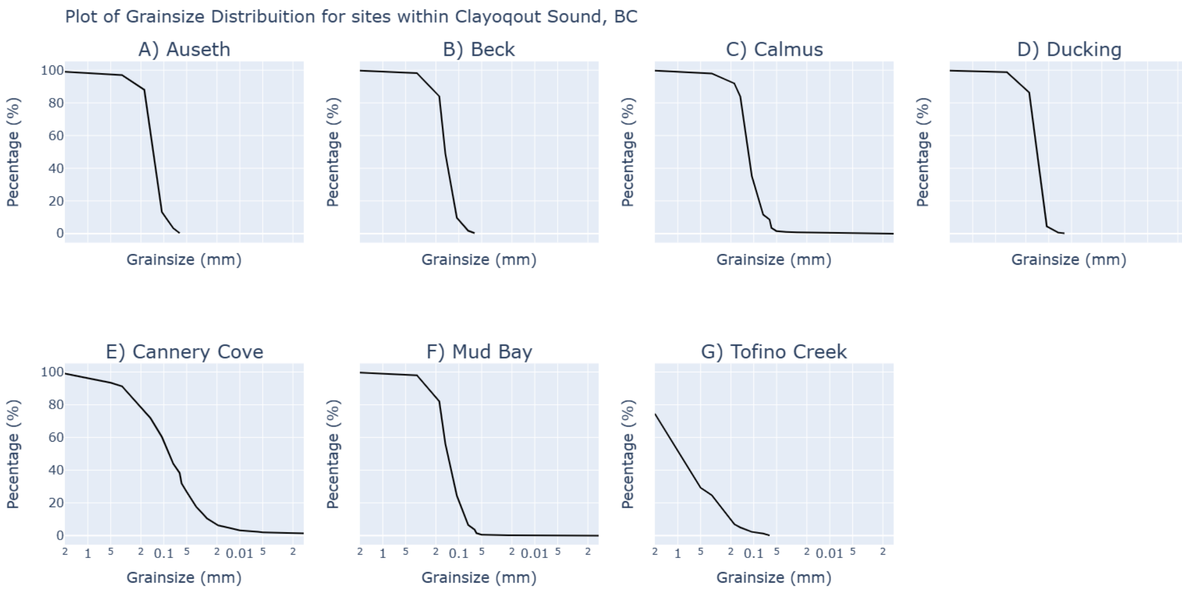
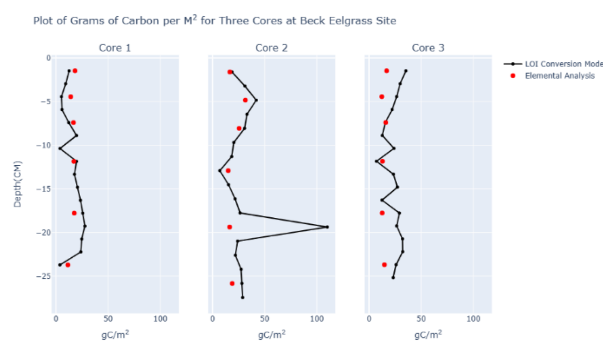
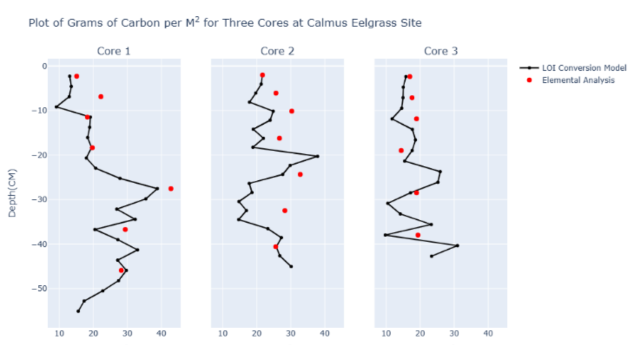
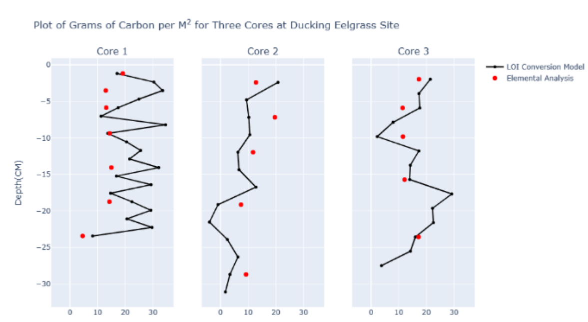


Figure 23: Average grainsize distribution for seven sites within Clayoquot Sound, BC

5.1.7 Downcore carbon stock variation







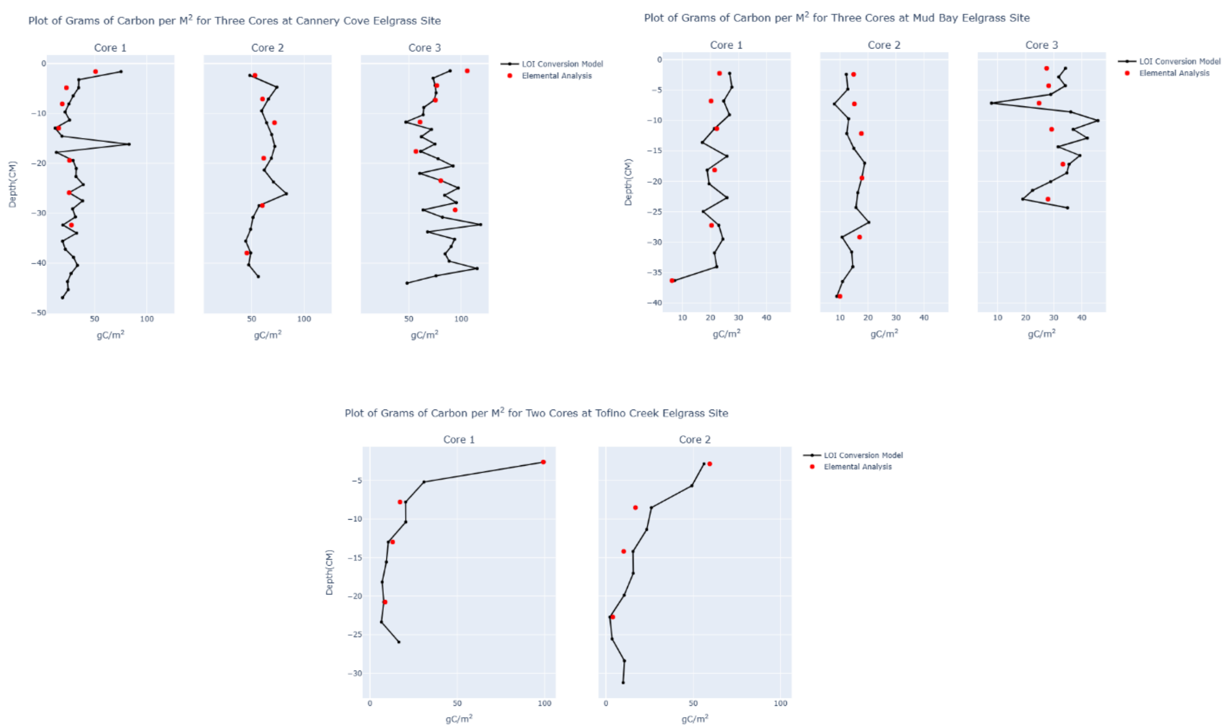


Figure 24: Downcore variation of carbon (gC m^{-2}) for reference, subtidal and Intertidal sediment cores for seven eelgrass meadows in Clayoquot Sound (Black = OLS regression, Red = elemental analysis)

5.2 Appendix B: Results of statistical Analysis

Table 7: Outputs of Kruskal-Wallis ANOVA tests on dependant variables on inter-sites and intra-sites variation for seven selected sites within Clayoquot Sound, BC.

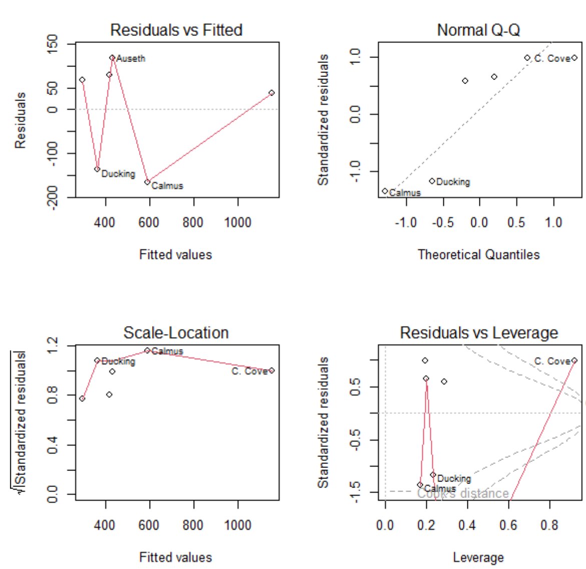
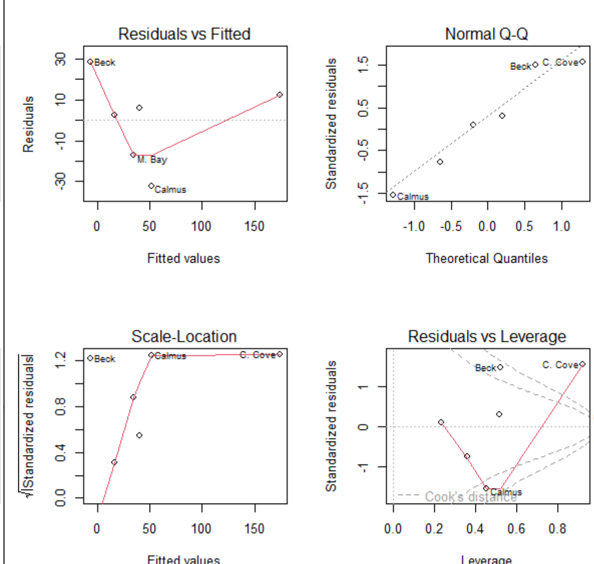
Inter-site	N	P-Value	Significance
gC m^{-2}	385	p= 2.2e-16	significant difference
Intra-site	N	P-Value	Significance
gC m^{-2}	385	p= 0.4271	no significant difference

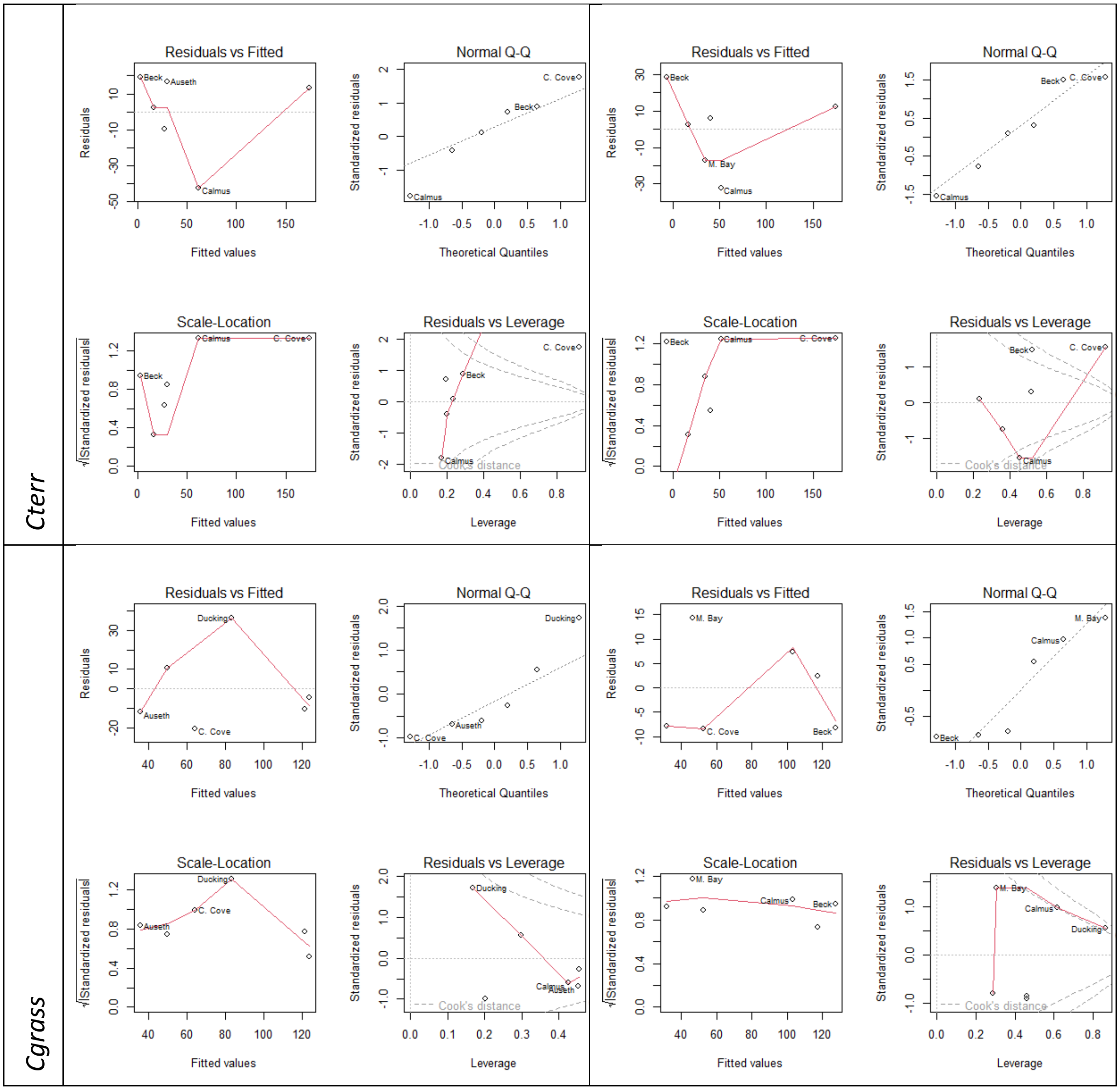
Table 8: Model Parameters for all model runs with p-value <0.05. Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1. Bolded model runs are considered to be the best model runs for response variables

	Expl. Var.	Coeff. Estimate	Std. Error	t value	Pr(>|t|)	Sig.	AICc	Res. Std. err.	Multiple R^2
C	Intcpt	2057.49	515.76	3.989	0.0575	.	Inf.	91.97	0.9702

	D50	-17578.23	3039.47	-5.783	0.0286	*			
	Denslog	268.82	140.03	1.92	0.1949				
	DSlog	118.83	59.89	1.984	0.1857				
	Intcpt	2152.6	356.8	6.033	0.00913	**	119.31	130.3	0.9102
	D50	-11674.2	2905.2	-4.018	0.02767	*			
	Avgvel	-465.4	416.5	-1.117	0.34522				
	Intcpt	1643.2	663.4	2.477	0.0895	.	119.22	129.4	0.9115
	D50	-17372.5	4273.1	-4.066	0.0268	*			
	Denslog	222.3	194.2	1.145	0.3354				
	Intcpt	2766.16	495.86	5.579	0.0114	*	118.96	126.6	0.9152
	D50	-12842.56	2444.52	-5.254	0.0134	*			
	DSlog	99.56	81.28	1.225	0.308				
	Intcpt	**2303.2**	**340.5**	**6.765**	**0.00249**	**	91.39	**134.3**	**0.8728**
	D50	**-13372.3**	**2552**	**-5.24**	**0.00634**	**			
Cterr [g]	Intcpt	411.05	80.9	5.081	0.0147	*	101.5	29.55	0.8821
	D50	-2762.68	658.76	-4.194	0.0247	*			
	Avgvel	29.9	94.44	0.317	0.7723				
	Intcpt	458.72	109.32	4.196	0.0247	*	100.82	27.91	0.8947
	D50	-2587.99	538.94	-4.802	0.0172	*			
	DSlog	12.33	17.92	0.688	0.5408				
	Intcpt	254.91	119.4	2.135	0.1224		98.64	23.29	0.9267
	D50	-3541.31	769.11	-4.604	0.0193	*			
	Denslog	49.32	34.95	1.411	0.253				
	Intcpt	**401.38**	**65.94**	**6.087**	**0.00368**	**	71.7	**26.01**	**0.8781**
	D50	**-2653.6**	**494.3**	**-5.368**	**0.00581**	**			
Cgrass [g]	**Intcpt**	**-150.748**	**44.767**	**-3.367**	**0.0435**	*	91.16	**12.49**	**0.947**
	DSlog	**-39.483**	**8.722**	**-4.527**	**0.0202**	*			
	Avgvel	**123.058**	**37.607**	**3.272**	**0.0467**	*			
	Intcpt	-196.57	78.71	-2.497	0.067	.	70.28	23.12	0.7577

	DSlog	-51.65	14.61	-3.536	0.0241	*			
AvgC [g]	Intcpt	2229.8	545.37	4.089	0.0549	.	Inf.	97.25	0.9733
	D50	-19916.91	3213.95	-6.197	0.0251	*			
	Denslog	283.65	148.07	1.916	0.1955				
	DSlog	83.66	63.33	1.321	0.3174				
	Intcpt	2603.6	378.9	6.872	0.00631	**	120.03	138.4	0.9189
	D50	-14359.9	3085	-4.655	0.0187	*			
	Avgvel	-245.9	442.3	-0.556	0.61706				
	Intcpt	2977.58	523.6	5.687	0.0108	*	119.62	133.7	0.9243
	D50	-14919.95	2581.31	-5.78	0.0103	*			
	DSlog	63.32	85.83	0.738	0.5141				
	Intcpt	1938.2	557.2	3.479	0.0401	*	117.13	108.7	0.95
	D50	-19772	3588.7	-5.509	0.0118	*			
	Denslog	250.9	163.1	1.538	0.2216				
	Intcpt	**2683**	**319**	**8.41**	**0.00109**	**	90.62	**125.9**	**0.9105**
	D50	**-15257**	**2392**	**-6.38**	**0.0031**	**			

	1-variable model	*2-variable model*
Cmar		


Cterr
Cgrass
Residuals vs Fitted
Normal Q-Q
Scale-Location
Residuals vs Leverage
Residuals
Standardized residuals
√|Standardized residuals|
Fitted values
Theoretical Quantiles
Leverage
Cook's distance
Beck
Auseth
Calmus
C. Cove
M. Bay
Ducking

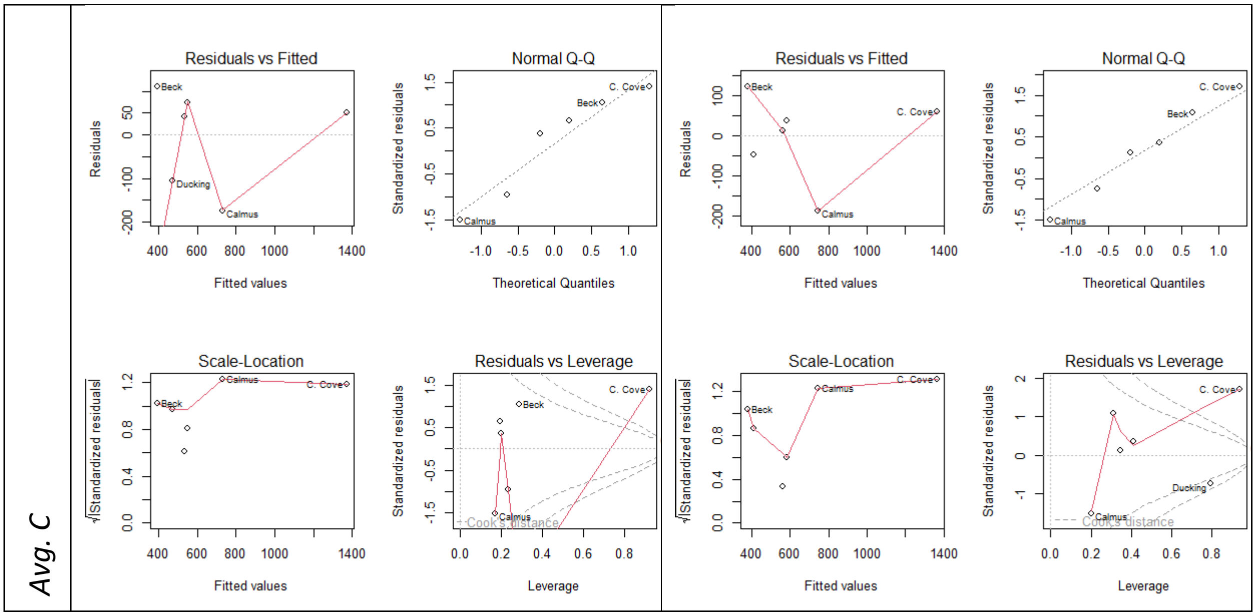


Figure 25: Model Quality plot from multivariate linear regression for response variable Cmar, Cterr, Cgrass and Avg C. Shown are model predictions for (a) one (b) two environmental variables

5.3 Appendix C: Modified grainsize analysis from Peterson (2022)

Thirty-five sediment samples were collected along sediment core transects by divers from the seabed of seven eelgrass meadows of Clayoquot Sound in June 2022 (Figure 1). Samples were retrieved by hand and stored in Ziploc bags. Samples were immediately frozen and transported to the University of Victoria. Once in the lab, the frozen samples were thawed at room temperature for 24 hrs, and then oven dried at 110°C for 24hrs. Large pieces of organic material (e.g., macro-algae, invertebrates) were removed from the sample prior to drying.

Approximately 500 g of each sample were collected for sieve grain analysis (Table 1). Each sieve was cleaned for residues from prior usage. The weight of each sieve and pan were recorded prior to shaking. Sieves were assembled in ascending order (Table 7). The sample was poured into the top sieve and the lid was placed over the stack. Finally, the stack was placed into the sieve shaker for 15 minutes. Once finished, the stack was removed, and each sieve and the receiving pan were weighed.

Table 9: Sieve number and size (mm) used in grain size analysis of particles greater than 0.075mm

Sieve Number	Sieve Size (mm)
10	2
35	0.5
40	0.355
80	0.18
100	0.15
140	0.106
200	0.075

The finest grain sediments within the receiving pan were collected for hydrometer analysis of fine sands, silts and clays (ASTM, 2017; Hossain et al., 2021; Kalra and Manard, 1991). Due to the small proportion of fine grains within each sample, only 15 of the samples from 3 sites (Calmus, Cannery Cove and Mud Bay) had 40-50 g of the fine grains that is recommended for hydrometer analysis (Kalra and Manard, 1991; Hossain et al., 2021). Therefore, only those samples that had more than more than 10% mass of fine sediments were used for hydrometer analysis. A 152H hydrometer was used for this part of the analysis. The fines were placed in a beaker with 125 mL of a [40 g/L] Sodium hexametaphosphate (NaPO3) solution. The mixture was stirred until mixed and let rest for 10 minutes. While resting, a control sample was prepared in a 1000 mL graduate cylinder with 125 mL of the a [40 g/L] Sodium hexametaphosphate (NaPO3) solution and 875 mL of distilled. The control sample was mixed thoroughly, and the hydrometer and thermometer were inserted into the control to measure the zero correction, meniscus correction, and the temperature. The zero correction is where the meniscus formed on the hydrometer stem by the control solution. Values less than zero are negative corrections, while values between zero and sixty are positive corrections. The meniscus correction is determined by the difference from the top of the meniscus and the level of control solution graduated cylinder. The hydrometer readings are corrected with the meniscus correction value and either subtracted or added to the original reading depending on the sign of the zero connection.

After the 10-minute rest period, the soil slurry sample was mixed with distilled water for an additional two minutes, then transferred into a graduated cylinder and filled with distilled water up to create a 1000 mL soil slurry solution. The final solution was inverted 30 times, and the timer began. Once recording, the hydrometer was carefully placed in the sample. Measurements were collected at the top of the meniscus, then removed from the soil slurry solution and placed in the control sample until the next reading. Hydrometer readings and temperature to the nearest 0.5°C were recorded at 10 15 secs, 20 secs, 40 secs, 1 min, 2 min, 4 min, 6 min, 8 min, 15 min, 30 min, 1.5 hr, 2 hrs, and 24 hrs. After 48 hrs, the meniscus correction was applied to all readings. From the corrected meniscus readings, the effective hydrometer depth (L) was determined using the values in Table 3. To determine the K value at specific temperatures, the specific gravity of the soil was assumed to be 2.65 (Table 4). The equivalent particle diameter was calculated for each reading using this formula:

$$D = L \times \sqrt{} \; L \; t \tag{8}$$

In equation 1, t is time in minutes, L is effective hydrometer depth, and D is particle diameter in mm. Table 5 was used to determine the temperature correction factor (CT). Then, Table 6 was used to determine the correction factor a for the specific unit weight of solids (g cm^{-3}). The corrected hydrometer readings were calculated by the following formula:

$$Rc = Ractual - Zero\ Correction + Ct \tag{9}$$

Using Rc, the percent finer were calculated using the following equation:

$$P = Rc \times a \; Ws \times 100 \tag{10}$$

In equation 3, Ws is the initial sample weight in grams. Finally, the percent fines is adjusted with the following equation:

$$PA = P \times F200 \; 100 \tag{11}$$

In equation 4, F200 is the percent finer of the #200 sieve as a percentage.

Table 10: Values of effective depth based on hydrometer and sedimentation cylinders of specific sizes for corrections for the Hydrometer 152H (Table 4.1; Hossain et al., 2021).

Corrected Hydrometer Reading	Effective Depth, L (cm)	Corrected Hydrometer Reading	Effective Depth, L (cm)
0	16.3	31	11.2
1	16.1	32	11.1
2	16.0	33	10.9
3	15.8	34	10.7
4	15.6	35	10.6
5	15.5	36	10.4
6	15.3	37	10.2
7	15.2	38	10.1
8	15.0	39	9.9
9	14.8	40	9.7
10	14.7	41	9.6
11	14.5	42	9.4
12	14.3	43	9.2
13	14.2	44	9.1
14	14.0	45	8.9
15	13.8	46	8.8
16	13.7	47	8.6
17	13.5	48	8.4
18	13.3	49	8.3
19	13.2	50	8.1
20	13.0	51	7.9
21	12.9	52	7.8
22	12.7	53	7.6
23	12.5	54	7.4
24	12.4	55	7.3
25	12.2	56	7.1
26	12.0	57	7.0
27	11.9	58	6.8
28	11.7	59	6.6
29	11.5	60	6.5
30	11.4		

Table 11: Values of K to determine particle diameter in hydrometer analysis. If the specific gravity is not known assume that it is 2.65 (Table 4.2; Hossain et al., 2021).

Temperature	Specific Gravity of Soil Particles								
	2.45	2.5	2.55	2.6	2.65	2.7	2.75	2.8	2.85
16	0.0151	0.01505	0.01481	0.01457	0.01435	0.01414	0.01394	0.01374	0.01356
17	0.01511	0.01486	0.01462	0.01439	0.01417	0.01396	0.01376	0.01356	0.01338
18	0.01492	0.01467	0.01443	0.01421	0.01399	0.01378	0.01359	0.01339	0.01321
19	0.01474	0.01449	0.01425	0.01403	0.01382	0.01361	0.01342	0.01323	0.01305
20	0.01456	0.01431	0.01408	0.01386	0.01365	0.01344	0.01325	0.01307	0.01289
21	0.01438	0.01414	0.01391	0.01369	0.01348	0.01328	0.01309	0.01291	0.01273
22	0.01421	0.01397	0.01374	0.01353	0.01332	0.01312	0.01294	0.01276	0.01258
23	0.01404	0.01381	0.01358	0.01337	0.01317	0.01297	0.01279	0.01261	0.01243
24	0.01388	0.01365	0.01342	0.01321	0.01301	0.01282	0.01264	0.01246	0.01229
25	0.01372	0.01349	0.01327	0.01306	0.01286	0.01267	0.01249	0.01232	0.01215
26	0.01357	0.01334	0.01312	0.01291	0.01272	0.01253	0.01235	0.01218	0.01201
27	0.01342	0.01319	0.01297	0.01277	0.01258	0.01239	0.01221	0.01204	0.01188
28	0.01327	0.01304	0.01283	0.01264	0.01244	0.01255	0.01208	0.01191	0.01175
29	0.01312	0.0129	0.01269	0.01249	0.0123	0.01212	0.01195	0.01178	0.01162
30	0.01298	0.01276	0.01256	0.01236	0.01217	0.01199	0.01182	0.01165	0.01149

Table 12: Temperature correction factors, CT (Table 4.3; Hossain et al., 2021).

Temperature (C)	factor (CT)
15	1.10
16	-0.90
17	-0.70
18	-0.50
19	-0.30
20	0.00
21	0.20
22	0.40
23	0.70
24	1.00
25	1.30
26	1.65
27	2.00
28	2.50
29	3.05
30	3.80

Table 13: Correction factors, a, for unit weight of solids (g cm^{-3}) (Table 4.4; Hossain et al.,2021).

Unit Weight of Soil Solids, g/cm3	Correction factor, a
2.85	0.96
2.8	0.97
2.75	0.98
2.7	0.99
2.65	1
2.6	1.01
2.55	1.02
2.5	1.04

5.4 Appendix D: Results of model selection and LOI to gC m^{-2} conversion

A Loss on Ignition fit is the first step required to begin overall analysis of the carbon data. The % LOI values must be converted to a standardized version of carbon (namely, gC cm^{-3}). To do this a statistical model must be created to discern %LOI to %C – which can then be mathematically converted gC cm^{-3}. This will be done to take our known %C carbon values from the Elemental analysis and use a linear regression model to provide a carbon value for all un-analysed samples. A linear model was used because it's fit accounted for the largest amount of %LOI values; yet, seemed to overestimate values for smaller %LOI values. A R^2 value of 0.9645 was attained from this model within the entire dataset which is very good; however, this may be skewed by high values which match the linearity. To further check this fit, a linear model was performed on each of the seven sites and the results were varied with the highest R^2 values in TOFC of 0.9957 and lowest in Beck of 0.051776. Despite this variation, it is shown that the linear model shows the best fit as compared to the non-linear regressions. Namely, log transformed, Locally Weighted Scatterplot Smoothing (LOWESS), and Exponentially-weighted moving average (half-life of 2 point). Using this simple linear regression, the measurements of %C from elemental analysis (EA) were related to measurements of %LOI from the same subset of samples (Figure 27a). It is noted that a larger dataset with higher %LOI values would improve this model to better show a continuous fit; yet, the current dataset of 124 samples is adequate to show fit.

Utilizing the linear model, %C was then estimated for every 1 cm sample from %OM measurements to create a consistent curve downcore. Dry Bulk Density (DBD) (g cm^{-3}) for each 1 cm section was determined by dividing the MDS measurements by the compacted volume of the sample:

$$DBD = \frac{MDS}{\pi * r^2 * h}$$

Where r is the radius of the core (5 cm), h is the thickness of the slices (1 cm). Soil carbon density (C g m^{-3}) was then determined by multiplying the DBD with the %C/100 and carbon content in each core section (C g m^{-2}) was derived by multiplying the carbon density with the section thickness (here: 1 cm). Core compaction was accounted for by multiplying the carbon content in each core section with the individual compression factor to produce plots of carbon content downcore. Carbon stocks of the first 25 cm were then estimated by summing the carbon content of each uncompacted core section down to the depth of 25 cm. Carbon stocks of the first 1 m were determined by averaging all carbon contents from each section and by multiplying this average by the number of uncompacted sections contained in a 1 m core segment (N = 100 cm/ (1 cm*compression factor)) for each particular core.

Sediment mass accumulation rates (SAR) (g m^{-2} y^{-1}) and Carbon accumulation rates (CAR) (gC m^{-2} y^{-1}) were estimated at depth intervals based on the sediment dry bulk densities and the Pb-age data:

$$SAR = \left(\frac{MAR}{DBD}\right) * 10$$

$$CAR = \left(\frac{SAR}{\%C}\right) * 10\ 000$$

Table 14: Ordinary Least Squares Regression between %OM as derived from loss of ignition and %C from elemental analysis from this and other studies.

Model	N	Slope	Intercept	R^2
Prior et al., 2023 (This study)	**124**	**0.35**	**-0.15**	**0.97**
Postlethwaite et al., 2018	n/a	0.30	-0.26	0.73
Fourquean et al., 2012	1667	0.4	-0.21	0.87
Christensen & O'Connor, 2022	201	1.33	-1.57	0.88
Prentice et al., 2020	n/a*	0.31*	-0.11*	n/a*

*Estimate of %carbon for Southeast Alaska sites only with N and R^2 not provided

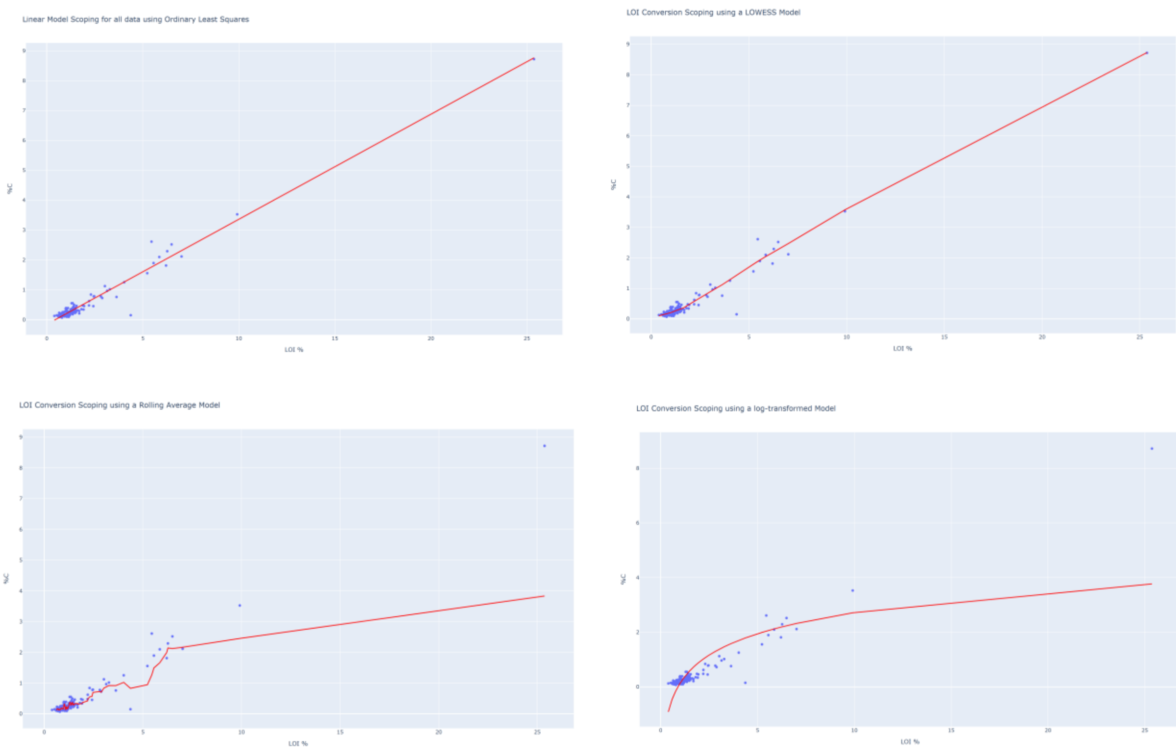


Figure 26: Linear (Ordinary least squares) and Non-Linear (LOWESS, Rolling average and Logarithmic) regression for %C versus %LOI to interpolate carbon for samples without elemental analysis

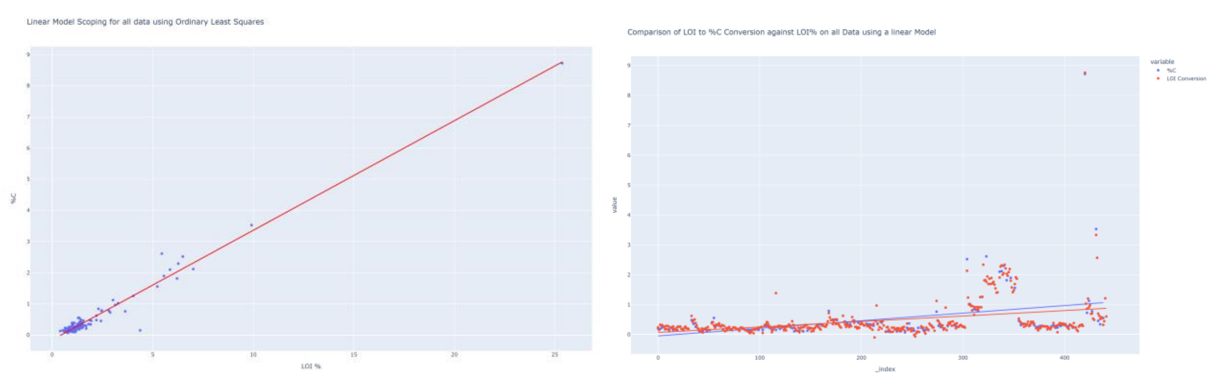


Figure 27: A) Ordinary least squares regression model of the 124 Elemental Analysis samples (%C) to create a conversion model for %LOI to %C. B) models behavior after extrapolated to the remainder of %LOI (red= Calculated %C, Blue= model from 1A)

5.5 Appendix E: Outputs of 210Pb age-modeling methodology from Sanderson (2023) and Aquino-López et al. (2018)

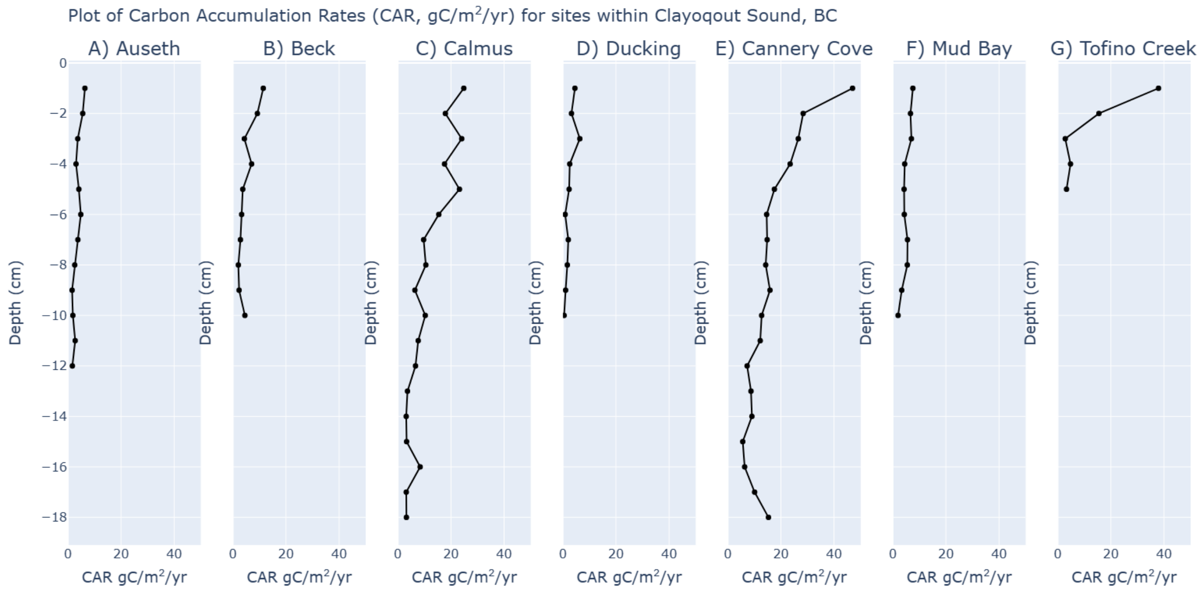


Figure 28: Outputs of 210Pb age-modeling methodology using alpha-spectrometry for Carbon accumulation rates variation at seven meadow sites within Clayoquot Sound

Table 15: Outputs of 210Pb age-modeling methodology using alpha-spectrometry for average year between sample depth at the subtidal core for seven meadow sites in Clayoquot Sound

Depth (Cm)	Auseth	Beck	Calmus	Ducking	C. Cove	M. Bay	T. Creek
1	2014.5	2020.2	2020.8	2015.7	2019.1	2017.8	2018.1
2	2004.8	2014.7	2018.3	2008.6	2015	2013.1	2009
3	1990.6	2002.6	2016.1	2001.2	2010.5	2007.8	1988.8
4	1970.5	1994.8	2014	1991.4	2005.5	2000.7	1969.3
5	1961.4	1983.6	2011.3	1979.5	1999.1	1990.6	1953.9
6	1952.6	1973.5	2008.1	1961.1	1992.5	1982.2	
7	1943.4	1963	2004.1	1946.3	1985.9	1973.9	
8	1934.9	1951.1	1998.9	1935.9	1979.5	1965.9	
9	1925.7	1940.5	1992.9	1924.7	1972.7	1954.1	
10	1915.8	1932.7	1985.2	1912.6	1965.2	1935	
11	1905.9		1977.1		1956		
12	1895.8		1966.9		1944		
13			1956.8		1930.5		
14			1944.7		1914.4		
15			1935.2		1896.9		
16			1928		1876.5		
17			1918.3		1860.6		
18			1903.3		1851.2		

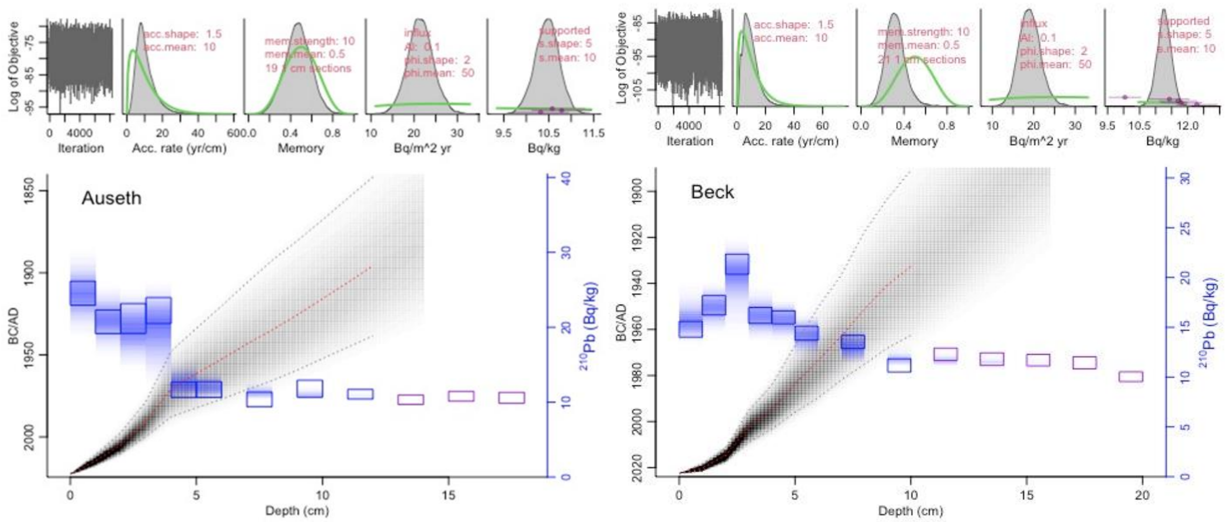


Figure 29: Age-depth models for the Auseth and Beck Meadow sites modelled using the R package rplum v0.2.2 (Aquino-López et al., 2018). The 210Pb activity (Bq/kg1) is represented by the blue rectangles and 14C dates are shown in purple. The red line represents the mean model, grey dashed lines are the 95% confidence intervals. The prior (green lines) and posterior (grey plots) distributions of each model are shown in the mini plots.

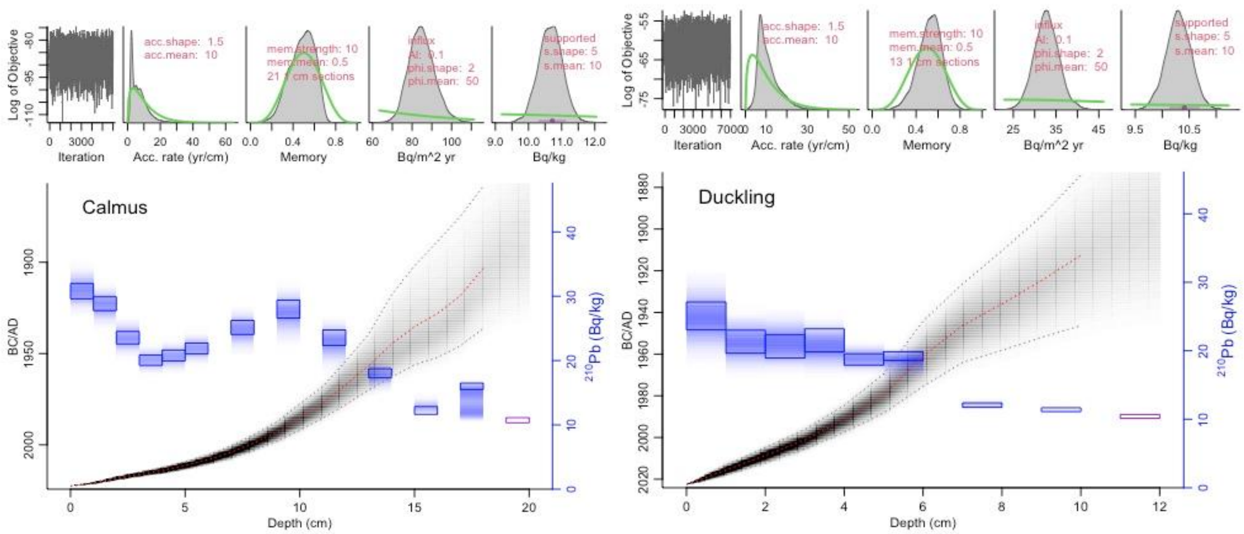


Figure 30: Age-depth models for the Calmus and Ducking Meadow sites modelled using the R package rplum v0.2.2 (Aquino-López et al., 2018). The 210Pb activity (Bq/kg) is represented by the blue rectangles and 14C dates are shown in purple. The red line represents the mean model, grey dashed lines are the 95% confidence intervals. The prior (green lines) and posterior (grey plots) distributions of each model are shown in the mini plots.

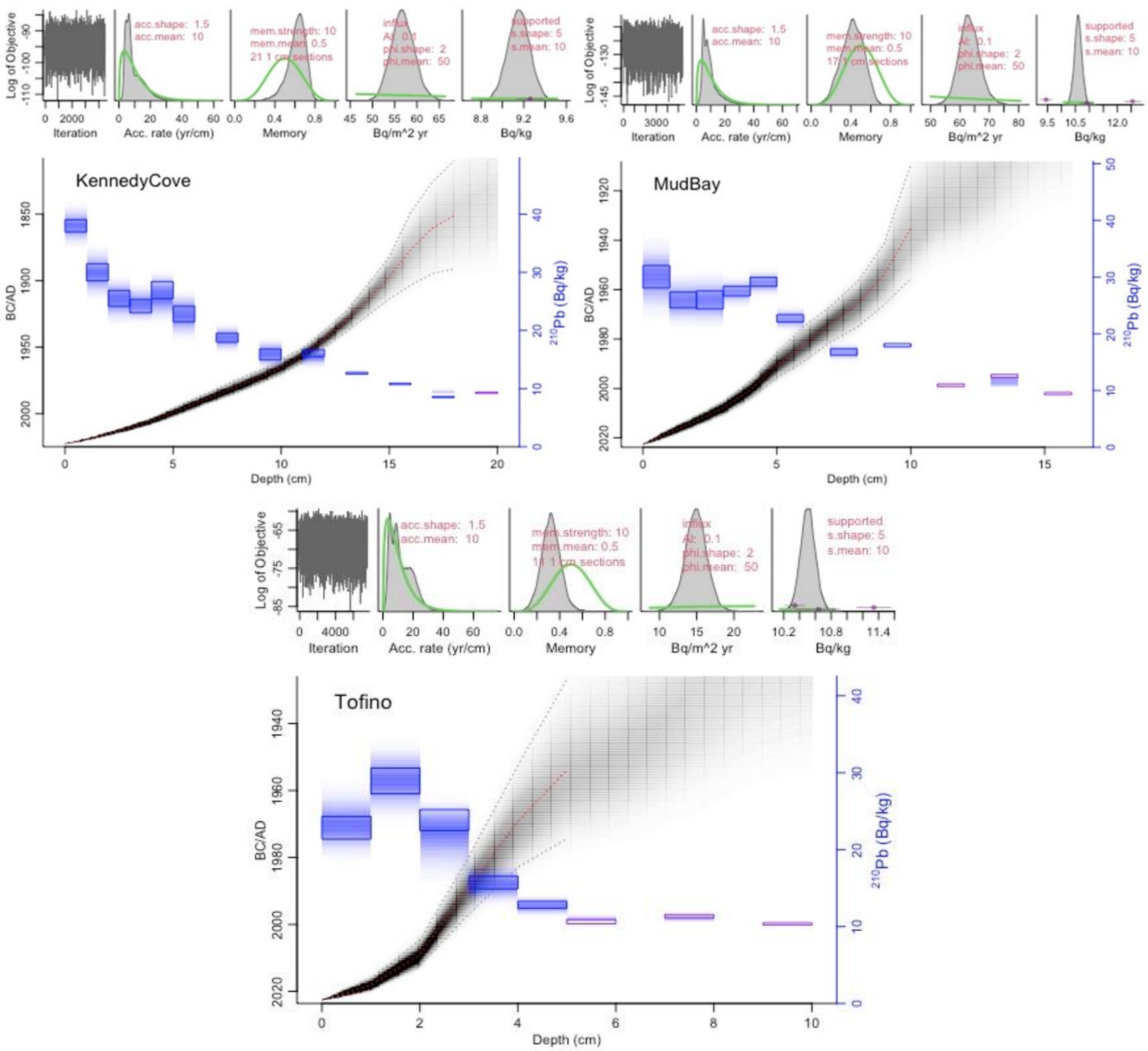


Figure 31: Age-depth models for the Cannery Cove (aka Kennedy Cove, Mud Bay and Tofino Creek Meadow sites modelled using the R package rplum v0.2.2 (Aquino-López et al., 2018). The 210Pb activity (Bq/kg) is represented by the blue rectangles and 14C dates are shown in purple. The red line represents the mean model, grey dashed lines are the 95% confidence intervals. The prior (green lines) and posterior (grey plots) distributions of each model are shown in the mini plots.

5.6 Appendix F: Autochthonous versus allochthonous carbon sources

Determining the sources of sedimentary carbon was done by utilizing the δ13C/ δ15N ratio enabling the differentiation of autochthonous versus allochthonous sediment sourcing. Lower δ13C values indicated a higher contribution from allochthonous sources.

To determine the distribution of autochthonous versus allochthonous carbon within the meadows, we followed a three-source Bayesian mixing model as conducted by a number of other recent studies. The most recent and closest example of this method is from Prentice et al. (2020). These averages along with the methodology used provides a succinct method to perform a Bayesian mixing model utilizing local variables (Terrestrial, Oceanic and Eelgrass) (Table 16).

Table 16: Isotopic ranges, averages and sources of δ13C and δ15N signatures of sediment samples throughout the West Coast of North America. Data from Supporting information of Prentice et al. (2020)

Source	AVG. *δ13C*	Range *δ13C*	AVG. *δ13C*	Range *δ15N*	Sources
Zostera	6	4.22 to 8.92	-9.72	-8.08 to -11.1	Olson 2015, Howe 2012, Dethier 2013
Marine	3.87	3.37 to 6.3	-21.91	-19.04 to -25.83	Olson 2015, Howe 2012
Terrestrial	7.45	1.95 to 21.5	-27.27	-24.7 to -28.3	Howe 2012, Cloern et al., 2002

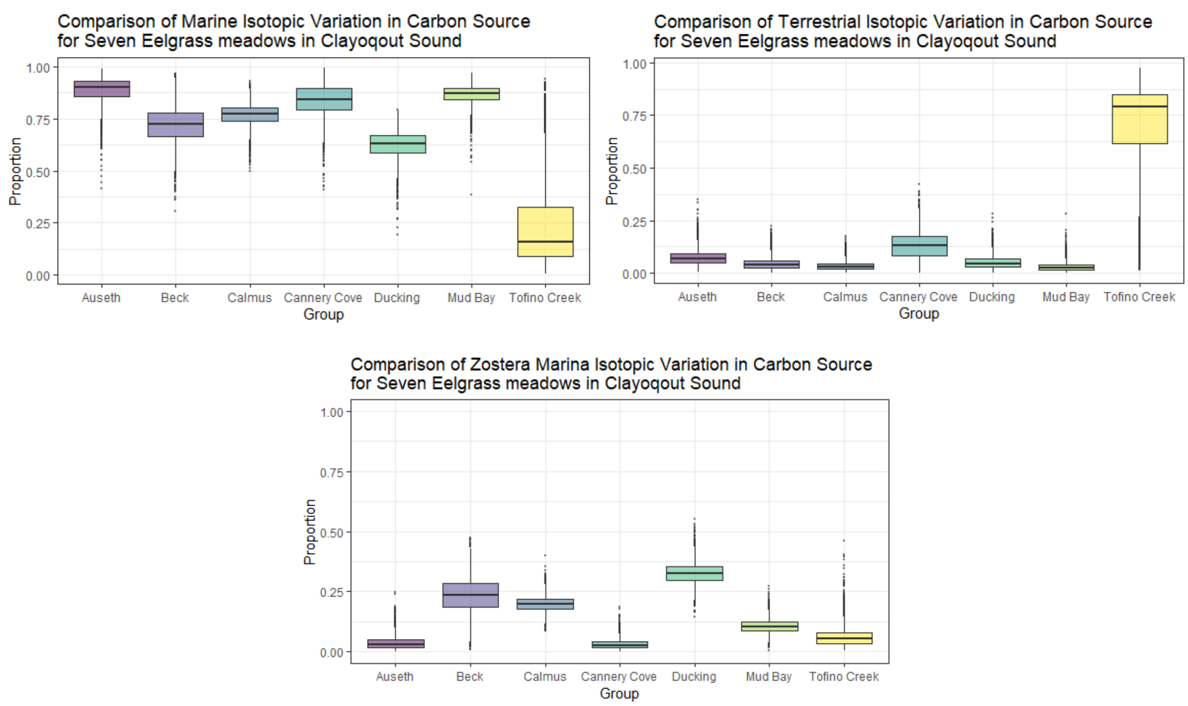


Figure 32: Isotopic variation in autochthonous carbon (Zostera Marina) and allochthonous carbon (Marine and Terrestrial) sourcing throughout seven seagrass meadows throughout Clayoquot Sound, BC with high marine carbon sourcing observed in moderate flow

environments, high terrestrial carbon sourcing in low flow sites and near-river sites, and high autochthonous sourcing in high flow sites.

5.7 Appendix Bibliography

ASTM, A. (2017). D7928: Standard test method for particle-size distribution (gradation) of fine-grained soil using the sedimentation (hydrometer) analysis. ASTM International: West Conshohocken (PA).

Kalra, Y. P., & Maynard, D. G. (1991). Methods manual for forest soil and plant analysis (Vol. 319)