



Blue Carbon Storage Variability in Eelgrass Meadows on the Pacific Coast of Canada



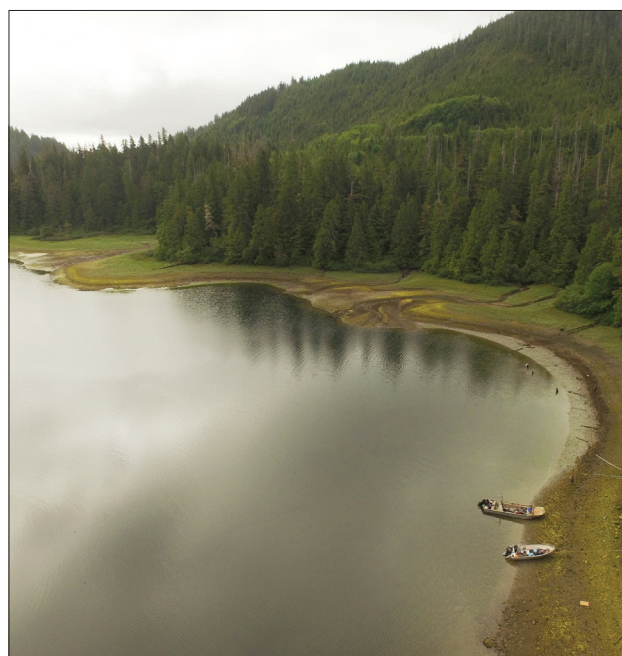
An Assessment of the Variability Between and Within Subtidal and Intertidal Portions of Three Meadows in the Southern Clayoquot Sound, BC

This research was carried out by
A. McGowan, V. Postlethwaite and
Professor K. Kohfeld (Simon Fraser University);
J. Yakimishyn (Parks Canada); and
Dr. C. Robinson (University of Victoria)

With support from the **Commission for Environmental Cooperation's** (CEC's) 2015–2016 project, *North American Blue Carbon: Next Steps in Science for Policy*.

Eelgrass along the Northern North American Pacific Coast

Coastal marine ecosystems are recognized as highly productive systems, but their potential to store and sequester organic carbon, known as blue carbon, has largely been overlooked on the Pacific Coast of North America (Nellemann et al. 2009; McLeod et al. 2011). Vegetated coastal ecosystems, such as mangroves, salt marshes, seagrass meadows, and kelp forests are estimated to store carbon up to 12 times faster than terrestrial forests (Fourqurean et al. 2012). Recent estimates suggest that seagrasses, some of the most productive aquatic vegetative plants on the globe, are highly efficient carbon sinks, storing a disproportionate amount of carbon for their relatively small area (Duarte 2002; Pendleton et al. 2012; Duarte et al. 2013). These blue carbon habitats occupy approximately 0.2% of the global ocean area but have been estimated to account for more than 15% of global marine carbon sequestration (Duarte et al. 2010). Recent assessments suggest that 300,000–600,000 km² of Earth's total area is covered in seagrass habitats, potentially storing as much as 19.9 Pg C (Fourqurean et al. 2012).



Kennedy Cove, British Columbia.

Photo: Courtesy of Cliff Robinson

Along the Pacific Coast of Canada and the United States, eelgrass (*Zostera marina*) is a commonly distributed genus of seagrass located in the shallow areas of temperate estuaries (Raposa and Bradley 2009; Lavery et al. 2013). In addition to its role in ecosystem function, sediment deposition, and substrate stabilization, *Z. marina* acts as an important carbon sink (Raposa and Bradley 2009). This carbon is stored in the sediment and accumulates mainly from *in situ* production and precipitation out of the water column (Greiner et al. 2013).

Unfortunately, seagrass meadows are also among the most threatened coastal ecosystems, due to anthropogenic activities and developments (Orth et al. 2006; Waycott et al. 2009). Approximately 0.4 to 2.6% of seagrass meadows are lost worldwide each year, potentially releasing 0.15-1.02 Pg of carbon dioxide into the atmosphere annually (Pendleton et al. 2012). Increased loss of these ecosystems weakens their ability to sequester and store carbon. In some regions around the globe, the destruction of these habitats can lead to the release of up to 8,000 years of carbon accumulation (Campbell 2010; CEC 2016). A lack of knowledge about eelgrass as a carbon sink hinders blue carbon conservation planning and comprehensive policy development regarding coastal carbon management on the Pacific Coast of North America (Sutton-Grier and Moore 2016). Given the lack of geospatial information on the spatial coverage of seagrass, as well as the major generalizations of blue carbon stocks, the Pacific Coast of North America was recently identified as a high priority location for seagrass mapping and carbon sequestration research (CEC 2016).

Research Summary

This study estimates carbon storage and accumulation variability in eelgrass meadows found along a 25 km gradient of freshwater input in Clayoquot Sound, British Columbia. Specifically, it quantitatively assesses the spatial variability in above/below ground eelgrass biomass, carbon storage, and carbon accumulation rates within the intertidal and subtidal zones of three meadows in southern Clayoquot Sound, British Columbia (Figure 1). This research addressed several questions:

- What is the geospatial extent and area of the intertidal and subtidal portions of eelgrass meadows?
- What is the variability in eelgrass shoot density and biomass within and among meadows?

- What is the variability within and among eelgrass meadow sediments for storing and sequestering carbon compared to non vegetated intertidal sites?
- Overall, how does the variability in the above conditions influence estimates of total organic carbon storage and accumulation in eelgrass?

The three study meadows are located within Tofino Inlet, southern Clayoquot Sound, on the southwestern coast of Vancouver Island, British Columbia. One meadow, Grice Bay, is situated in the Long Beach Unit of the Pacific Rim National Park Reserve of Canada, and all three meadows occur within the UNESCO Clayoquot Biosphere Reserve. The three meadows are distributed within Tofino Inlet along a gradient in water temperature and surface salinity, due to the freshwater discharge from the Lower Kennedy River (Robinson and Yakimishyn 2008).

The areal extent of the intertidal and subtidal regions of each meadow was estimated using the following approaches: a) GPS coordinates were collected in the field during low tide to demarcate the boundaries of the intertidal and subtidal meadows (Figure 2); b) video from an underwater HD camera was viewed to characterize eelgrass density and boundaries of the subtidal portion of each meadow, and c) aerial images were used to synthesize field measurements into large-scale, regional maps of each meadow.

Living eelgrass shoot density and biomass was determined at each meadow during low tide; three 50m-long transects, each containing 0.25 m² quadrats, were sampled

Figure 1. Location of the three meadows sampled in Clayoquot Sound, British Columbia, Canada

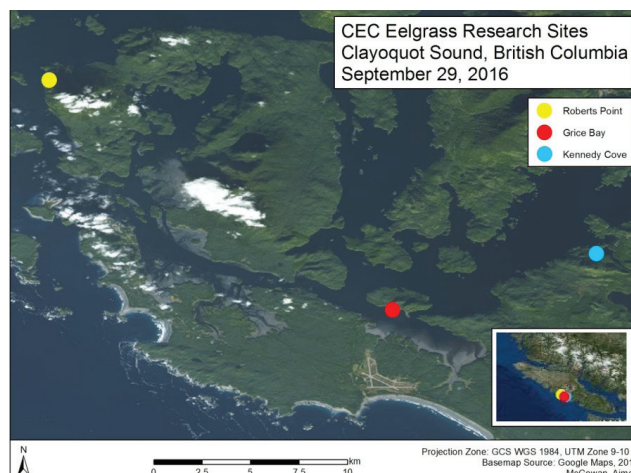


Figure 2. Collecting GPS coordinates along landward boundary of Grice Bay



Photo: Courtesy of Jennifer Yakimishyn

for aboveground and belowground eelgrass properties; 24 quadrats were representative of the intertidal and 12 quadrats were representative of the shallow subtidal. At each meadow, six sediment cores were also taken to depth of refusal using a simple push method (Figure 3); an additional core was collected from a nearby non-vegetated site, to act as a reference.

Cores were extracted in the field into one cm increments, and then analyzed in the laboratory for dry bulk density. A detailed grain-size analysis was also conducted on sediments from one core per meadow. To estimate carbon, loss-on-ignition was used as a proxy measure for % organic carbon, by pairing it with estimates of organic carbon made from elemental analysis of total carbon and coulometric analysis of inorganic carbon contents. Subsamples from nine cores, including the three reference cores, were sent for ^{210}Pb analysis, to obtain radiometric dates for determining sediment accretion and carbon accumulation rates.

The most marine eelgrass meadow, furthest away from the lower Kennedy River, Robert Point, had a total surface area estimate of 31,900 m² (3.19 ha) (Figure 4). The intertidal component of the meadow was estimated at 22,400 m² (2.24 ha, 70%) while the subtidal portion was 9,470 m² (0.95 ha, 30%). The eelgrass meadow midway from the lower Kennedy River, Grice Bay, had a total surface area estimate of 262,000 m² (26.20 ha); the intertidal component of the meadow was estimated at 186,000 m² (18.60 ha, 71%) while the subtidal portion was 75,171 m² (7.51 ha, 29%). The eelgrass meadow closest to the lower Kennedy River, Kennedy Cove, had a total surface area of 5,340 m² (0.53 ha). The intertidal component of the meadow was estimated at 1,025 m² (0.10 ha, 19%) while the subtidal portion was 4,318 m² (0.43 ha, 81%).

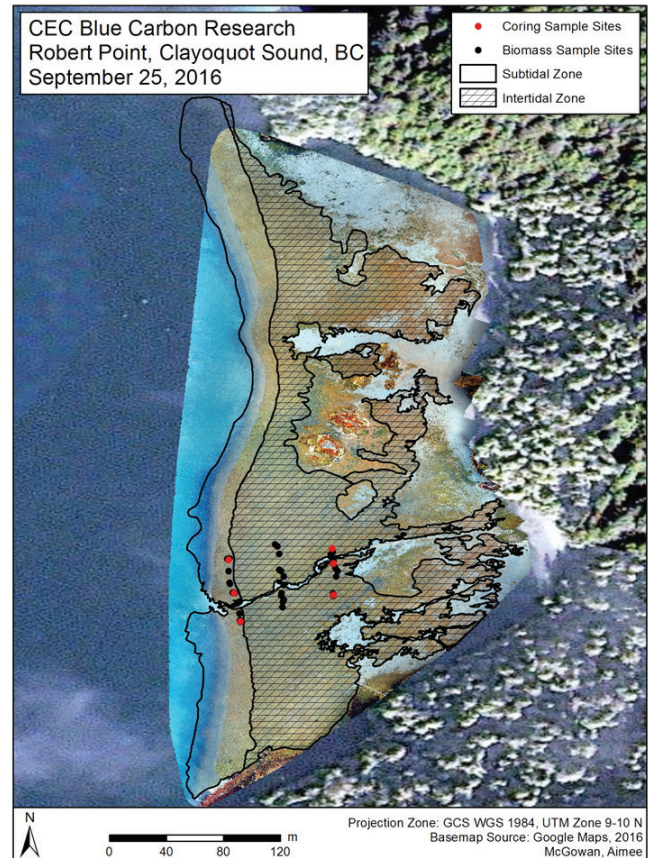
Figure 3. Collecting sediment cores from the intertidal meadow at Robert Point



Photo: Courtesy of Cliff Robinson

The study data collected on eelgrass shoot densities and biomass were used to generate estimates of eelgrass biomass aboveground and belowground. Estimates of aboveground eelgrass biomass in the intertidal and subtidal zones of Robert Point, Grice Bay and Kennedy Cove were consistent with values found in literature, ranging from 5 to 96 g dry weight (DW) m⁻².

Figure 4. Map of Robert Point eelgrass meadow as a hatched polygon (intertidal) and clear polygon (subtidal)



Note: Black dots indicate quadrats for biomass collection (3 cross-transsects) and red dots indicate the six sediment core collection sites.

In the intertidal zone, Robert Point and Grice Bay shared mean belowground biomass estimates (20 ± 6 g DW m^{-2}), which were two-fold higher than the mean belowground biomass of Kennedy Cove. Subtidal belowground biomass levels were also higher at Robert Point (26 ± 20 g DW m^{-2}); these estimates were 1.5 times higher than Grice Bay (15 ± 8 g DW m^{-2}) and 5 times greater than in Kennedy Cove (5 ± 4 g DW m^{-2}). Overall, though, Clayoquot Sound belowground biomass estimates in the intertidal and subtidal zones of each meadow were much lower than values found in the literature, which typically range between 49 and 244 g DW m^{-2} .

The ratio of aboveground to belowground biomass (AGB:BGB) calculated for the intertidal and subtidal portions of the meadows averaged 3.1 (ranging 1.7–4.3): about an order of magnitude higher than ratios reported in the literature. We speculate that the low belowground biomass estimates of eelgrass in Clayoquot Sound are likely due to environmental conditions, such as reduced light availability and relatively poor belowground sediment conditions.

The laboratory analysis of the sediment cores indicated that the percent sediment carbon (C_{org}) was <1.30% at all meadows and was moderately variable. Specifically, the percent C_{org} was <1% at Robert Point, with an average value of 0.22 ± 0.13 % C_{org} . There was no significant difference between the subtidal and intertidal portion of the Robert Point meadow ($p=0.055$). In addition, the non-vegetated reference core had significantly lower % C_{org} than the Robert Point meadow ($p<0.001$).

Percent C_{org} for Grice Bay was <1%, with an average value of 0.30 ± 0.12 % C_{org} . The percent C_{org} values in the intertidal meadow (0.24 ± 0.04 % C_{org}) were significantly lower than that of the subtidal meadow ($p<0.001$). Further, the non-vegetated reference core had significantly lower % C_{org} values than the Grice Bay meadow ($p<0.001$).

Percent C_{org} in Kennedy Cove was the highest of the three meadows, with an average value of 0.47 ± 0.26 % C_{org} . There was no significant difference in percent C_{org} between the intertidal and subtidal portions of the Kennedy Cove meadow ($p=0.532$). The non-vegetated reference core had a significantly lower percent C_{org} than the intertidal ($p=0.002$) and subtidal ($p<0.001$) portions of Kennedy Cove meadow.

Analysis of ^{210}Pb was used to calculate carbon accumulation rates (sequestration) and showed lower sequestration rates each year that significantly decline below the first ~10–20 cm depth at all meadows. Sediment accretion rates at Robert Point meadow ranged from 10.36–36.74 g $m^{-2}\cdot yr^{-1}$ and carbon accumulation rates ranged from 0.03–0.16 g- C_{org} $m^{-2}\cdot yr^{-1}$. Sediment accretion rates at Grice Bay meadow ranged from 25.53–49.08 g $m^{-2}\cdot yr^{-1}$ and carbon accumulation rates ranged from 0.06–0.15 g- C_{org} $m^{-2}\cdot yr^{-1}$, with an average rate of 0.12 ± 0.02 g- C_{org} $m^{-2}\cdot yr^{-1}$. Sediment accretion rates at Kennedy Cove meadow ranged from 8.41–40.74 g $m^{-2}\cdot yr^{-1}$ and carbon accumulation rates ranged from 0.03–0.47 g-C $m^{-2}\cdot yr^{-1}$.

When the living eelgrass biomass estimates were combined with aerial estimates for each of the study meadows, Grice



Seagrass, Tofino, British Columbia.

Figure 5. Carbon stocks in the intertidal meadows at Robert Point (RP), Grice Bay (GB), and Kennedy Cove (KC) ($\text{g-C}_{\text{org}} \text{m}^{-2}$)

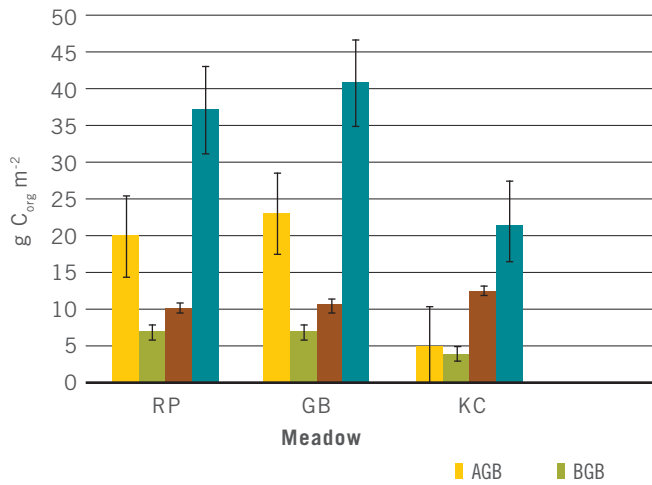
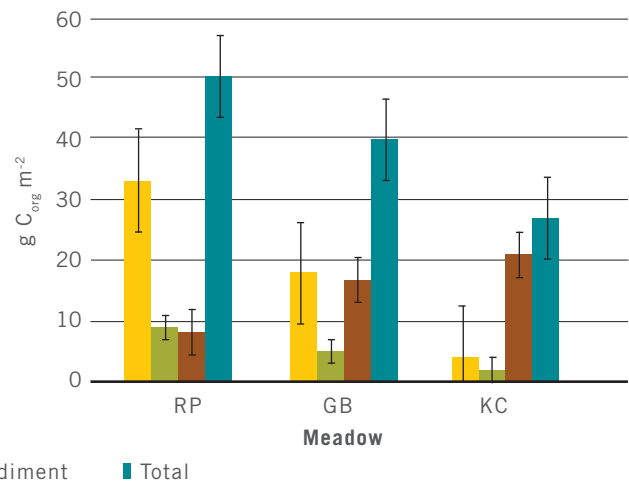


Figure 6. Carbon stocks in the subtidal meadows at Robert Point, Grice Bay, and Kennedy Cove ($\text{g-C}_{\text{org}} \text{m}^{-2}$)



Bay had the greatest total eelgrass biomass, followed by Robert Point and Kennedy Cove. Grice Bay has a total aboveground biomass of $15.80 \pm 10.27 \text{ Mt DW m}^{-2}$ and total belowground biomass of $6.06 \pm 3.77 \text{ Mt DW m}^{-2}$. Robert Point has a total aboveground biomass of $2.06 \pm 1.04 \text{ Mt DW m}^{-2}$ and total belowground biomass $0.69 \pm 0.50 \text{ Mt DW m}^{-2}$. Kennedy Cove has the lowest total above- and belowground biomasses, with $0.06 \pm 0.03 \text{ Mt DW m}^{-2}$ and $0.03 \pm 0.02 \text{ Mt DW m}^{-2}$, respectively.

Biomass estimates above- (AGB) and belowground (BGB) were converted to C_{org} using a standard conversion factor of 36%. Grice Bay had the highest estimated C_{org} storage levels of aboveground intertidal biomass, with a mean value of $23 \pm 17 \text{ g-C}_{\text{org}} \text{m}^{-2}$. Kennedy Cove had the lowest aboveground intertidal biomass C_{org} stock, with an average value of $5 \pm 3 \text{ g-C}_{\text{org}} \text{m}^{-2}$. However, in the subtidal meadows, Robert Point had the highest AGB carbon stock ($33 \pm 18 \text{ g-C}_{\text{org}} \text{m}^{-2}$), with Kennedy Cove having the lowest values ($4 \pm 1 \text{ g-C}_{\text{org}} \text{m}^{-2}$). The highest average BGB carbon stocks in the intertidal zone were found at Robert Point ($7 \pm 5 \text{ g-C}_{\text{org}} \text{m}^{-2}$) and Grice Bay ($7 \pm 6 \text{ g-C}_{\text{org}} \text{m}^{-2}$). The lowest BGB was again at Kennedy Cove ($4 \pm 3 \text{ g-C}_{\text{org}} \text{m}^{-2}$). In the subtidal meadows, Robert Point has the highest BGB C_{org} stock ($9 \pm 7 \text{ g-C}_{\text{org}} \text{m}^{-2}$), and the lowest values were again found at Kennedy Cove ($2 \pm 1 \text{ g-C}_{\text{org}} \text{m}^{-2}$).

Total Organic Carbon Pool

Total organic carbon is the sum of living carbon in the eelgrass, both above and below ground, and the carbon stored

in the sediments. In this study, intertidal sediment carbon stores and belowground carbon stocks were similar among meadows. The sediment carbon was estimated to be highest at Kennedy Cove on a square meter basis but when values are scaled to the total meadow area, Grice Bay had the highest sediment content due to the meadow's large surface area (26.10 ha, as compared to 3.19 ha at Robert Point and 0.53 ha at Kennedy Cove). Overall, the total sediment and living carbon biomass was highest in Grice Bay, closely followed by Robert Point, with about half as much carbon in the Kennedy Cove meadow. These results are graphed in Figure 5. On an aerial basis, Grice Bay's intertidal meadow had 10 to 20 times the carbon storage capacity of Kennedy Cove or Robert Point because of the size of the meadow.

In the subtidal portion of the meadows studied, the amount of sediment C_{org} decreased by about half, with an increase of 23 ppt salinity and decrease of 5°C moving seaward. Further, aboveground and belowground living C_{org} was about 8 and 2 times greater in the subtidal area of Robert Point, respectively, compared to the Kennedy Cove meadow which was subjected to warmer, fresher water. Although sediment C_{org} stocks were greatest at the fresher Kennedy Cove meadow on a square meter basis, the aerial estimates indicate that Grice Bay had 6 to 10 times more carbon storage in the subtidal portion of the meadow. (See graphs in Figure 6.) Overall, our study results indicate that there is a clear inverse relationship between the amount of carbon in living eelgrass and that contained in sediment stocks along the salinity and temperature gradients observed in Clayoquot Sound.

Key Findings

Key findings of this study include:

- Shoot density was found to be greatest in the lower intertidal portions of the Clayoquot Sound meadows.
- The variability of shoot density in the upper intertidal portion of each meadow was about twice that of the lower intertidal and shallow subtidal portions.
- Belowground eelgrass root biomass did not differ appreciably among the intertidal or subtidal portions of each study meadow but the estimates were about 2.5 to 10 times lower than literature values for other seagrasses. The estimated aboveground to belowground eelgrass biomass ratio, which averaged 3.1 for intertidal and subtidal components of all three study meadows, is about an order of magnitude greater than reported for other seagrass regions
- Carbon accumulation (sequestration) rates in this study averaged about 0.1-0.3 g-C m⁻²•yr⁻¹ and were very low compared to literature values.
- The estimated percent C_{org} stored in the sediments of all three meadows did not exceed 1.30% organic carbon, which is substantially lower than estimates for other seagrasses and regions.
- Intertidal and subtidal sediment C_{org} showed limited variability among the Clayoquot Sound meadows and between 50 and 70% of the sediment content below each eelgrass meadow was found to consist of fine-to-medium sand, which does not promote carbon adsorption.
- Intertidal sediment carbon stores and belowground living carbon levels were similar among the three study meadows; intertidal aboveground carbon increased 2 to 3 times with increasing salinity and decreasing water temperature.
- In the subtidal portion of the study meadows, as one moves seaward the amount of sediment C_{org} decreased by about half with an increase of 23 ppt in salinity and a temperature decrease of 5°C; belowground carbon was relatively stable while aboveground subtidal carbon decreased almost 7-fold with increasing temperature and decreasing salinity.
- Overall, the Grice Bay meadow was estimated to have the highest total living and sediment C_{org} stock of the three study meadows, and was about 10 times greater than Robert Point and about 77 times greater than Kennedy Cove. Grice Bay meadow has 8 times and 49 times the surface area of these two meadows, respectively.
- Lead 210 (²¹⁰Pb) profiles indicated that the surface mixing in the sediments below each meadow occurred at a depth of about 10–15 cm.

Conclusion

While the Clayoquot Sound eelgrass meadows appear to have low C_{org} values, carbon stocks were significantly greater in the eelgrass meadows compared to the non-vegetated reference sites. This indicates that eelgrass still contributes to carbon storage in Clayoquot Sound but not at the higher rates identified for more tropical seagrasses. Further, this research noted that while most literature studies do not distinguish between intertidal and subtidal portions of eelgrass meadows (because of a lack of tidal range), important differences between intertidal and subtidal carbon storage properties were found in this study. The large mud flats of Tofino Inlet support large surface areas of relatively high density intertidal eelgrass (e.g., Grice Bay) that substantially out-contribute carbon storage compared to the subtidal portions of the meadows and to the typically smaller fringe meadows found in Tofino Inlet (e.g., Kennedy Cove; and elsewhere on the BC coast). The subtidal regions of most Tofino Inlet eelgrass meadows are likely small because of light or nutrient limitation, or a lack of suitable carbon-adsorbing sub-surface sediments. This research also highlights that while the sediment carbon storage capacity does not change markedly between intertidal and subtidal portions within or among meadows, it does appear to be linked to changes in surface salinity and temperature. Hence, it might be expected that larger intertidal flats of eelgrass located toward the more saline and cooler end of the environmental spectrum are the more important contributors to aboveground carbon storage in Tofino Inlet, and should be clearly targeted in conservation initiatives.

Acknowledgments

We would like to thank Dr. M. Pellatt (Parks Canada) who assisted with access to field sites, field work (coring), and providing laboratory infrastructure for sediment analysis. S. Chastain and C. Barlow (Simon Fraser University) provided valuable field assistance and guidance. The field work could also not have been completed without the assistance of D. Harrison (Raincoast Education Society), who served as guide and field assistant. We are also grateful to M. Soon (University of British Columbia), who assisted with Elemental Analysis and to H. Jensen, who helped with laboratory work. Finally, we are grateful to the CEC for funding this important study, and to Dr. K. Richardson for her important guidance.

References

- Campbell, C.R. 2010. *Blue Carbon-British Columbia: The case for the conservation and enhancement of estuarine processes and sediments in B.C. B.C.*, Canada: Sierra Club. Available online: <<http://sierraclub.bc.ca/wp-content/uploads/2015/08/Blue-Carbon-British-Columbia-Report.pdf>>.
- CEC. 2016. North America's Blue Carbon: Assessing Seagrass, Salt Marsh and Mangrove Distribution and Carbon Sinks. Montreal, Canada: Commission for Environmental Cooperation. 54pp. Available at: <www.cec.org/islandora/es/item/11664-north-america-s-blue-carbon-assessing-seagrass-salt-marsh-and-mangrove>.
- Duarte, C.M. 2002. The future of seagrass meadows. *Environmental Conservation* 29(2):192-206.
- Duarte, C.M., N. Marbà, E.Gacia, J. W. Fourqurean, J. Begins, C. Barron, and E.T. Apostolaki. 2010. Seagrass community metabolism: assessing the carbon sink capacity of seagrass meadows. *Global Biogeochemical Cycles* 24.
- Duarte, C.M., H. Kennedy, N. Marbà, and I. Hendriks. 2013. Assessing the capacity of seagrass meadows for carbon burial: current limitations and future strategies. *Ocean and Coastal Management* 83:32–38.
- Fourqurean, J.W., C.M. Duarte, H. Kennedy, N. Marbà, M. Holmer, M.A. Mateo, and O. Serrano. 2012. Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* 5:505– 509.
- Greiner, J.T., K.J. McGlathery, J. Gunnell, and B.A. McKee. 2013. Seagrass restoration enhances blue carbon sequestration in coastal waters. *PLoS ONE* 8(8).
- Lavery, P.S, M.A. Mateo, O. Serrano, and M. Rozaimi. 2013. Variability in the carbon storage of seagrass habitats and its implications for global estimates of blue carbon ecosystem service. *PLoS ONE* 8(9).
- McLeod, E., G.L. Chmura, S. Bouillon, R. Salm, M. Björk, C.M. Duarte, and B.R. Silliman. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO₂. *Frontiers in Ecology and the Environment* 10: 552–560.
- Nellemann, C., E. Corcoran, C.M. Duarte, L. Valdes, C. DeYoung, L. Fonseca, and G. Grimsditch. 2009. *Blue Carbon: The Role of Healthy Oceans in Binding Carbon*. Norway: BirkelandTrykkeri AS. Available online: <http://www.grida.no/files/publications/blue-carbon/BlueCarbon_screen.pdf>.
- Orth, R.J., T.J.B. Carruthers, W.C. Dennison, C.M. Duarte, J.W. Fourqurean, K.L. Heck Jr., A. Randall-Hughes, G.A. Kendrick, W. Judson-Kenworthy, S. Olyarnik, F.T. Short, M. Waycott, and S.L. Williams. 2006. A global crisis for seagrass ecosystems. *BioScience* 56(12): 987-996.
- Pendleton, L., D.C. Donato, B.C. Murray, S. Crooks, W.A. Jenkins, S. Sifleet, and A. Baldera. 2012. Estimating global “blue carbon” emissions from conversion and degradation of vegetated coastal ecosystems. *PLoS ONE* 7(9).
- Raposa, K., and M. Bradley. 2009. *Methods and protocols for eelgrass mapping in Rhode Island: recommendations from the Rhode Island eelgrass mapping task force*. Rhode Island, USA: Narragansett Bay Research Reserve. Available online: <http://www.nbnerr.org/Content/Series/TechSeries_2009_5_EelgrassMapping_report.pdf>.
- Robinson, C. and J. Yakimishyn. 2008. Monitoring for the ecological integrity of eelgrass beds (*Zostera marina*) in Canada's coastal national parks of British Columbia. 2007 Edition. Parks Canada. WNSC Resource Conservation Technical Report. 115 pp.
- Sutton-Grier, A., and A. Moore. 2016. Leveraging carbon services of coastal ecosystems for habitat protection and restoration. *Coastal Management* 44(3). <http://dx.doi.org/10.1080/08920753.2016.1160206>.
- Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrick, W.J. Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences in the United States of America* 106(30):12377-12381.