



Blue Carbon Seagrass Mapping in Canada and the United States: British Columbia, Washington and Oregon



Developing an Algorithm and Quantifying Eelgrass Extent

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Eelgrass Carbon Stocks

Eelgrass (*Zostera marina*) is a seagrass and the primary rooted marine plant found in the coastal waters of the Pacific Northwest (which, for this study, will be taken as comprising the US states of Oregon and Washington, and the Canadian province of British Columbia). Unlike algae, it is a rooted plant and it traps, accumulates and stores carbon in the sediments where it grows. In the nearshore zone, distribution of eelgrass habitats can vary from vast flats and beds, to patchy areas or narrow fringe habitats along the shoreline. Eelgrass habitat provides a wide array of ecological functions in coastal ecosystems, including essential habitat for commercially and recreationally important invertebrate and fish species and baffling the coastline from storms by decreasing currents and wave action. Eelgrass beds also filter runoff and suspended sediments, taking up and storing nutrients and carbon from both water and the sediments in which they are rooted. Finally, eelgrass habitat plays a vital role in facilitating the accumulation of organic matter in sediments, ultimately acting as a carbon sink.



Eelgrass, Pruth Bay, British Columbia.

Photo: Carolyn Prentice

Carbon stored in coastal and marine ecosystems is referred to as blue carbon. Blue carbon stocks have only recently been acknowledged as globally significant (Fourqurean et al. 2012). Meta-analyses reveal that blue carbon ecosystems, in particular mangroves, seagrass beds and salt marshes, play a disproportionately large role in carbon sequestration relative to their global areal extent, making them “hot spots” for carbon storage (Duarte et al. 2005, McLeod et al. 2011, Fourqurean et al. 2012). For example, one hectare of eelgrass, despite its much smaller living biomass, may hold as much carbon as a hectare of tropical rainforest due to high accumulation of carbon in sediments and belowground biomass (Pendleton et al. 2012).

Despite the recently recognized importance of these ecosystems in the global carbon budget, there is a much poorer understanding of the dynamics of blue carbon stocks relative to terrestrial carbon stocks (McLeod et al. 2011), and this lack of understanding currently limits our ability to include blue carbon stocks in climate change mitigation strategies (Macreadie et al. 2014, Hejnowicz et al. 2015). Further, the destruction and degradation of blue carbon ecosystems is concerning, as it has the potential to exacerbate the impacts of climate change, as well as to limit the other ecosystem services associated with these important marine habitats (Barbier et al. 2011, Hejnowicz et al. 2015). Blue carbon ecosystems are being lost worldwide; 29% of seagrass beds, 50% of salt marshes and 35% of mangrove forests are either degraded or destroyed (Barbier et al. 2011).

Filling Knowledge Gaps along the Pacific Northwest Coastline

The goal of this work was to develop new blue carbon information for eelgrass beds along the Pacific Northwest of North America to fill a major and identified gap in knowledge. To do this, a protocol was created for estimating eelgrass distribution in coastal British Columbia, Puget Sound, Washington, and Oregon using existing geographical datasets of linear eelgrass extent and bathymetry data and employing a newly-developed algorithm. Carbon sequestration and storage estimates were also made for eelgrass beds through field sampling and analysis of samples from all three areas. Prior to this work, only limited data were available on the extent of eelgrass area, including incomplete records of mapped polygons, particularly for British Columbia, but also for Washington and, to some extent, Oregon. However, for all three areas, data for eelgrass locations existed in the form of observational line data collected using the ShoreZone mapping methodology (Berry et al. 2004). “ShoreZone” is a habitat classification and mapping method (Howes 2001) that represents the most complete geographical dataset of geomorphological and biological characteristics of the coastline of the Pacific Northwest, including British Columbia (BC), Canada, as well as the states of Washington and Oregon in the USA. The current BC ShoreZone dataset was created from georeferenced video and photographs collected at low tide between the late 1980s and 2004. These georeferenced images were used to map the presence and absence of eelgrass and the linear distribution of biological communities (including eelgrass) along sections of coastline.

Additionally, eelgrass biomass data were available from existing SeagrassNet information for sites in Oregon and Washington, with some biomass measurements existing for British Columbia. Almost no pre-existing data were available on measures of sedimentary carbon storage or sequestration for any of these locations, requiring original fieldwork to make these determinations. To more completely map eelgrass, an algorithm was developed that enabled extrapolations from ShoreZone line data to eelgrass area, using bathymetry information in a Geographic Information System (GIS) framework.

British Columbia Eelgrass Mapping

Data used to develop the algorithm for estimating area of eelgrass beds in British Columbia included:

1. ShoreZone dataset provided by the province of British Columbia;
2. Bathymetric datasets from the Canadian Hydrographic Service for most of mainland BC and Vancouver Island, excluding Haida Gwaii, and bathymetry data for Haida Gwaii from Parks Canada Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site; and
3. Existing mapped eelgrass beds from the British Columbia Marine Conservation Analysis (BCMCA) online database and the Hakai Institute for the Central Coast and Haida Gwaii. In addition, the depth

distribution of eelgrass beds in the eelgrass dataset was examined for two geographical regions: (1) Strait of Georgia and (2) the rest of BC. The division was made to account for potential regional variation in eelgrass depth distribution across British Columbia.

The ShoreZone lines were converted to polygons in order to estimate eelgrass bed area using a tool (the “Gegrator”) developed in ArcGIS (v 10.4), based on methods from the bottom patch model developed by Gregr et al. (2013) (see Figure 1 for steps).

The accuracy assessment was calculated for instances where eelgrass dataset polygons (n = 2807) overlapped with the derived ShoreZone eelgrass presence polygons. Data were not available, however, to determine how well ShoreZone predicted the absence of eelgrass.

Results showed the average maximum depth (eelgrass’ deep edge) was 3 meters for the Strait of Georgia and 5 meters for the rest of British Columbia. The eelgrass polygons

Figure 1. Graphical representation of converting ShoreZone eelgrass “lines” to polygons

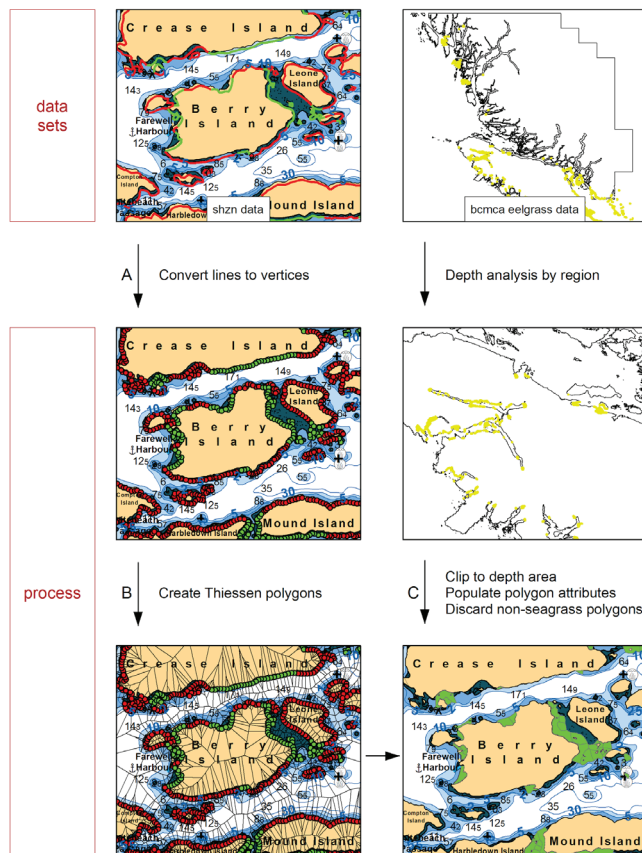
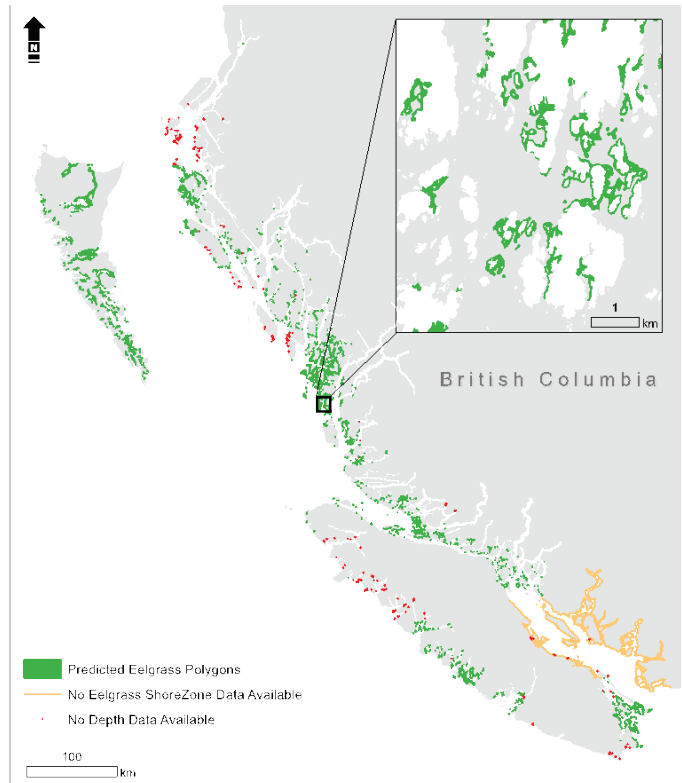


Figure 2. Predicted eelgrass polygons created from ShoreZone data, and areas where ShoreZone and depth data were not available



generated from the ShoreZone eelgrass line data are shown in Figure 2. Total estimated eelgrass area was 416.12 km². The accuracy assessment showed that 60% of the generated eelgrass polygons overlapped with the ShoreZone dataset.

In summary, in British Columbia, where the coastline extends over 35,000 km, the ability to map eelgrass at this scale depends directly on the only dataset, ShoreZone, that covers this geographic extent. The algorithm developed here to estimate eelgrass area from an extrapolation of the species’ present linear extent most likely underestimates eelgrass presence on the British Columbia coastline because ShoreZone line data have been shown, in verification, to underestimate the presence of eelgrass (Harper and Morris 2008). In addition, the dataset used to assess the accuracy of the ShoreZone analysis represents a conglomeration of eelgrass datasets from various sources collected over multiple decades by various methods. These data revealed that ShoreZone tended to miss classifying smaller eelgrass beds.

Since eelgrass beds in British Columbia represent a large potential for carbon storage that is important for climate change policy, as well as for the management and conservation of coastal ecosystems, these results are only a first step in obtaining estimates of the carbon storage potential across this region. When combined with extent and carbon estimates of eelgrass beds for Puget Sound, Washington, and the coast of Oregon, they provide the first spatial description of eelgrass-associated carbon along the coast of the Pacific Northwest.

Puget Sound, Washington, Eelgrass Mapping

The algorithm developed to estimate and map eelgrass beds from vector line data and bathymetry in British Columbia was implemented with a few modifications to map eelgrass beds in Puget Sound, Washington. Line data, high-resolution topo-bathymetry and a combination of minimum and maximum depth values were used in the algorithm. The Washington State ShoreZone Inventory (ShoreZone 2016) was used, along with an eelgrass dataset constructed of polygons from the Submerged Vegetation Monitoring Program (SVMP 2012). Topo-bathymetric data were used to determine lower and upper limits of eelgrass based on the SVMP depth ranges (Finlayson et al. 2000).

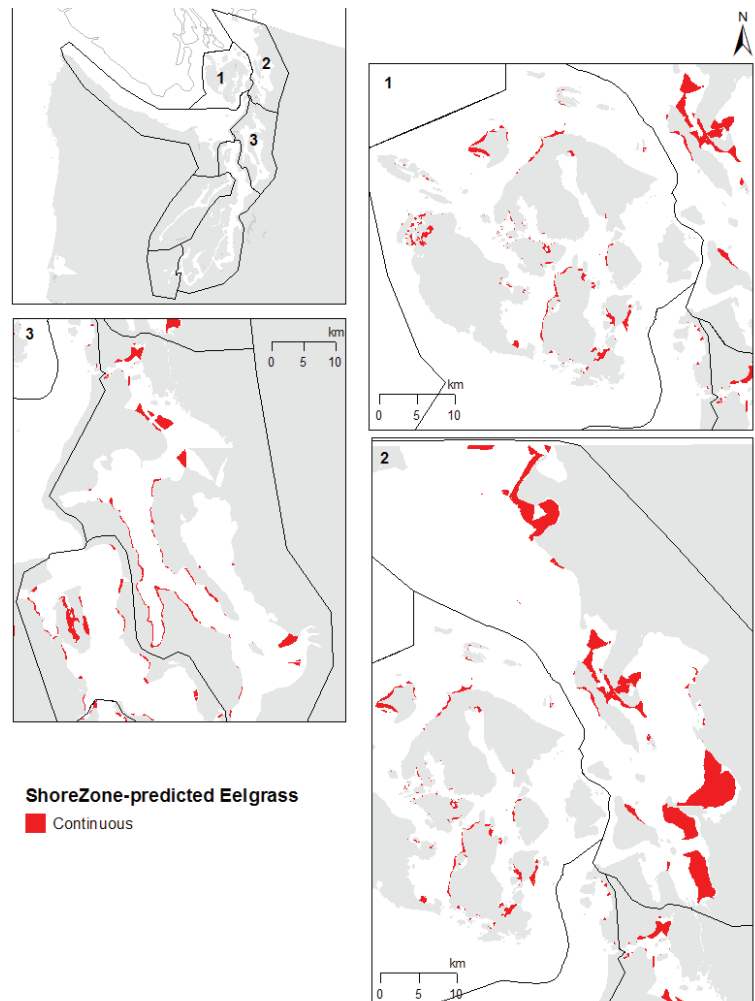
ShoreZone eelgrass line data were converted to eelgrass polygons using the algorithm for British Columbia, with the following modifications: a) a raster layer with a value of 1 representing suitable eelgrass depths was created using a conditional thresholding technique and a combination of lower and upper eelgrass depth statistics; and b) the resulting raster was converted to a vector polygon and used to clip ShoreZone-derived Thiessen polygons. The accuracy of eelgrass prediction was assessed by calculating the number and area of SVMP polygons overlapping with ShoreZone-predicted polygons.

Results showed that Puget Sound eelgrass beds occur at variable depths, ranging from +2.33 to -12.40 m. The algorithm produced 1,047 polygons covering 227 km² of eelgrass area based

on the continuous ShoreZone line data for Puget Sound (Figure 3). The smallest eelgrass beds were found in the Strait of Juan de Fuca and San Juan Islands regions and the largest were found in northern Puget Sound. The accuracy assessment showed that 83% of Submerged Vegetation Monitoring Program polygons overlapped with the predicted polygons.

Overall, for Puget Sound, the algorithm was robust in predicting the extent of eelgrass beds from ShoreZone line data. The algorithm estimated 227 km² of eelgrass, slightly greater than the area, 218 km², inventoried by SVMP to date. There were some inconsistencies that re-

Figure 3. Eelgrass polygons predicted by algorithm, based on 1994–2000 Washington State ShoreZone data. Insets show regions with smallest and largest continuous eelgrass beds (San Juan Islands [Inset 1], North Puget Sound [Inset 2])



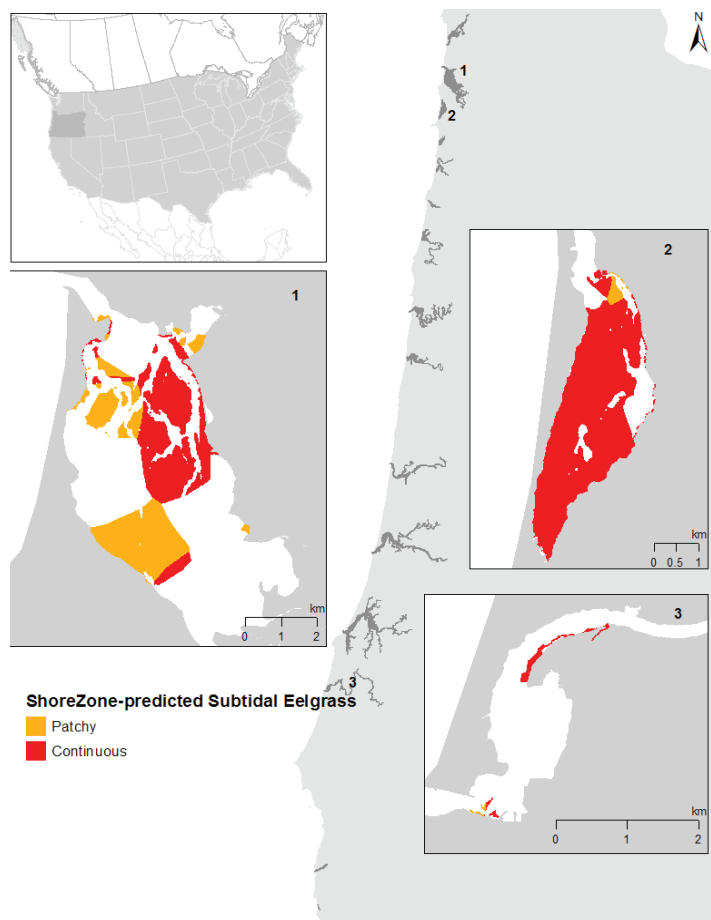
quire further investigation—especially for seagrass beds in deep or murky waters.

Eelgrass Mapping along Coastal Oregon

The algorithm developed for British Columbia was also used to estimate eelgrass distribution in coastal Oregon relative to the 2014 statewide ShoreZone data (ShoreZone 2014a). Coastal Oregon differs in topography, hydrology, and bathymetry from British Columbia, and the estuaries where eelgrass is found are discontinuous and variable in size, depth, and tidal restriction. Topo-bathymetric data from the NOAA Center for Tsunami Research, Pacific Marine Environmental Laboratory (NOAA 2016) and 2003 United States Geological Survey data (NGDC 2003) were used. Two sets of eelgrass polygons were used to validate the results of the model: the Pacific State Fishery Management Commission Essential Fish Habitats (PSFMC) (PSFMC 2004) polygons and the US EPA eelgrass distribution polygons in selected Oregon estuaries (Young et al. 2009; Young et al. 2012). Neither the ShoreZone nor the PSFMC eelgrass polygon dataset contained information on depth ranges for eelgrass, so depth ranges were obtained from published literature: -0.5 to -2.25 m Mean Sea Level (MSL) on average (Boese et al. 2009).

Data from the ShoreZone eelgrass lines were converted to polygons, following the algorithm developed in this study, and then applied both to subtidal line segments and also to line segments (subtidal+intertidal) that combined all eelgrass data. Accuracy was assessed by calculating the percent polygon and percent area overlap between the EPA polygon dataset and eelgrass polygons predicted by the algorithm. The algorithm produced 1,611 polygons of subtidal eelgrass, covering 31.5 km² in Oregon (Figure 4), slightly more than the area inventoried by PSFMC. In terms of accuracy, the subtidal eelgrass polygons predicted by the algorithm had 43% overlap with EPA and PSFMC validation polygons. In most of the bays, prediction was less than 50% accurate. When all the ShoreZone line segment eelgrass data (intertidal and sub-

Figure 4. Subtidal eelgrass polygons in Oregon, as predicted by the algorithm. Insets show estuaries with largest (Tillamook Bay [Inset 1] and Netarts Bay [Inset 2]) and smallest (Coquille River [Inset 3]) predicted eelgrass areas



tidal) were used, however, the algorithm was 63% accurate for estuaries with EPA validation polygons.

In summary, most eelgrass in Oregon is likely to be found at an optimum depth of -0.5 to -2.25 m MSL. This depth range is close to the values reported by Young et al. (2012) and Boese et al. (2009) for upper and lower depth limits of eelgrass in selected Oregon estuaries. At this depth range, the predicted intertidal and subtidal eelgrass polygons were fairly well represented in most Oregon estuaries. The algorithm predicted a total area of 43.68 km² of intertidal and subtidal eelgrass for Oregon.

Carbon Stocks of Eelgrass Beds on the Coast of the Pacific Northwest

British Columbia had the largest area of eelgrass beds, with 361.6 km² of eelgrass predicted by the algorithm, which totals 1004.4 km² when combined with already documented eelgrass (CEC 2016), 56% more than previously estimated. In Puget Sound, Washington, the estimated area predicted by our algorithm was about 24% greater than the area previously estimated by SVMP. In Oregon's coastal estuaries, the eelgrass area predicted by the algorithm was also much greater than previous estimates, at 823%. The overall accuracy provided information about the robustness and applicability of our method at the site

level, while subregional accuracies showed the importance of good data as inputs and highlighted the limitations of regional data.

Using location-specific rates of CO₂ sequestration by eelgrass at these three locations (CEC 2017), we were able to conclude that eelgrass in British Columbia absorbs up to 23,403 tons of CO₂ annually; that in Puget Sound, Washington, eelgrass absorbs 11,722 tons of CO₂ annually; and in Oregon, 4,217 tons of CO₂ are absorbed annually.

Future Work

The algorithm developed for this project provides a GIS tool for other ShoreZone and bathymetry datasets. The algorithm was developed for coastal British Columbia and adapted for use in Washington and Oregon where similar datasets exist. It is now a tool that can be applied easily to new areas. The maps and analytical output generated from this work are intended as a starting point to inform stakeholders of the coastal blue carbon storage potential of eelgrass habitats.

Datasets compiled for this work, together with the map products and analyses, lay the foundation for identifying: 1) specific, subregional areas where ground-truthed data are lacking or where data are too old to be useful; 2) regional differences in accuracy of the ShoreZone dataset; 3) appropriate methods for handling regional eelgrass data, including trade-offs of different imagery acquisition technologies; 4) areas where inadequate bathymetry information exists; and 5) areas with inadequate eelgrass depth-range data. Seagrass mapping is a necessity in the coastal Pacific Northwest, as well as globally for coastal assessment of carbon stocks and storage. Maps will also benefit many other marine planning initiatives, including marine protected area network designation and design, fisheries and invertebrate management, and assessment of changes resulting from application for, and creation of, new coastal developments.

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