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ATTACHMENT B

INCORPORATING COASTAL BLUE CARBON DATA AND APPROACHES IN OREGON'S FIRST GENERATION NATURAL AND WORKING LANDS PROPOSAL

South Slough, Oregon (Photo courtesy of Craig Cornu)

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1 Overview

On March 10, 2020, Governor Kate Brown issued Executive Order 20-04 (EO 20-04)[1], which sets new science-based emissions reduction goals for Oregon, calls for specific actions to reduce emissions and mitigate the impacts of climate change, and provides overarching direction to state agencies to help achieve Oregon's climate goals. The EO also calls on the Oregon Global Warming Commission to submit a proposal to the Governor articulating the possible adoption of state goals for carbon sequestration and storage by Oregon's natural and working lands. Natural and working lands (NWL) can include forests, farms, rangelands, and wetlands.[2]

In response to the EO, an informal working group came together to assess the particular role that tidally-influenced coastal wetlands could play relative to carbon sequestration and storage. The group included representatives from the Oregon Coastal Management Program, the Pacific Northwest Blue Carbon Working Group, Silvestrum Climate Associates, and The Pew Charitable Trusts. This white paper reflects the collective input of the group for consideration by the Oregon Global Warming Commission and Governor.

Oregon's tidally-influenced coastal wetland ecosystems, the focus of this analysis, are carbon rich and function as important natural carbon sinks, comparable to the Pacific Northwest's old growth forests (Kauffman et al. 2020). This important ecosystem service is referred to as "blue carbon." Oregon's tidal wetlands (referred to interchangeably in this document as coastal wetlands) include marshes, seagrass beds, scrub-shrub wetlands, and forested tidal wetlands (tidal swamps).

Over the last hundred years, Oregon's coastal wetlands have shrunk to a fraction of historic levels due to diking, draining and other forms of conversion, as indicated in Table 1 (Marco and Pilson 2017; Brophy 2019). Along Oregon's coast, 95% of tidal forested wetlands have been lost (Brophy 2019)

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[1] See: https://www.oregon.gov/gov/Pages/carbonpolicy_climatechange.aspx
[2] See: http://www.usclimatealliance.org/nwlchallenge

Table 1: Historical and current tidal wetland areas in Oregon.

	Historical Tidal Wetlands+		**Current Tidal Wetlands**†	
Wetland Type	**area (acres)**	**% historical area**	**area (acres)**	**% area lost**
Tidal Emergent Wetland	61,423	54.4	25,763	58.1
Tidal Forested Wetland*	51,530	45.6	15,431	70.0
Total	112,954		41,194	

+ historical refers to 1850 to 1870; Sources: Marcoe and Pilson 2017; Brophy 2019; † current area estimates are based on C-CAP land cover data; current study; * area contains scrub/shrub wetlands

Degradation and loss of coastal wetlands result in emissions from carbon sinks that in some instances have been accumulating and storing carbon over centuries. This loss also shrinks Oregon's natural carbon capacity for future sequestration and storage. In recent decades, however, coastal wetland conservation has been robust, and the rates of loss have been very low due to protective measures put in place by the state and by federal laws. Accordingly, conservation and management of these ecosystems through restoration, preservation, policy, and regulatory mechanisms are essential to maintain and expand this rich carbon pool.

In 2019, as described in detail in Section 4, **Oregon's remaining coastal wetlands provided a net annual sink of 0.051 metric tonnes[3] (t) CO_2 equivalent[4] (CO_2e).**[5] **Current carbon stocks in Oregon's coastal wetlands amount to at least 83.7 million metric tonnes CO_2e, largely driven by substantial soil carbon stocks accumulated over centuries to millennia.** As described in Section 5.1, identifying opportunities for restoring these carbon rich habitats would provide important contributions to an overall NWL climate mitigation strategy for Oregon, as well as offer significant co-benefits. For example, **focusing on opportunities to restore forested tidal wetlands could yield an additional 7.9 metric tonnes CO_2e.[6]**

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[3] One metric tonne is equivalent to 2,204.6 pounds.

[4] Carbon dioxide equivalents are used to compare or summarize the emissions of greenhouse gases based on their global-warming potential by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential. For example, 1 metric tonnes CH_4 is equal to 25 metric tonnes CO_2e.

[5] The reporting period for National GHG inventory published in 2021 is between 1990 and 2019 and this report mirrors that.

[6] This value represents the carbon sequestered annually for mature Sitka spruce forests; the amount of carbon sequestered increases as restored forests mature.

Forested Tidal Wetlands

Because of their ability to sequester significant quantities of C and offer other important ecosystem services, the conservation and restoration of Oregon's forested tidal wetlands should be a high priority for policy makers developing Oregon's emissions mitigation goals for natural and working lands. Although forested tidal wetlands historically comprised over half of Oregon's total tidal wetland area (60%), nearly all these unique wetlands (95%) have been lost along the Pacific coast of Oregon (not including the Columbia River estuary) due to past land use practices (Brophy 2019). Efforts to conserve and restore forested tidal wetlands in the Pacific Northwest have gained momentum due to their ecological importance especially for juvenile salmonids (Davis et al. 2019, Woo et al. 2019), their ability to attenuate flooding and protect shorelines, and because of the exceptional amounts of C they store (Kauffman et al. 2020). Forested tidal wetlands store two and three times more C than Pacific Northwest tidal marshes and eelgrass communities, and on a per-acre basis, they store more than Pacific Northwest coast range forests and almost as much as old growth forests (Kauffman et al. 2020). Efforts to conserve and restore these important and now rare ecosystems can also play an important role in state and regional natural and working lands strategies to advance GHG reduction targets.

Targeting attention and resources towards restoring forested tidal wetlands would represent another important strategy to help the state grow its carbon pool while also promoting coastal resiliency. Looking forward, implementing measures that account for sea level rise and other impacts to ensure the persistence of these habitats into the future, including protecting coastal lands to allow wetlands to migrate inland, should be incorporated into climate strategies focusing both on mitigation and adaptation.

In addition, the blue carbon sequestration and storage estimates provided in this white paper are likely conservative in that they do not account for carbon pools where mapping is sparse (e.g., eelgrass) or where research is not yet available to quantify carbon contributions (e.g., kelp, nearshore sediments). Better understanding the role submerged aquatic vegetation, including eelgrass and kelp forests, plays in addressing Oregon's climate challenges represents an important next step. Kelp forests and other nearshore ecosystems are the focus of a growing body of research around carbon sequestration potential, and as the science develops, Oregon may be able to include these ocean ecosystems as an additional component of the NWL proposal in the future.


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***Eelgrass beds** are common in the lower intertidal and subtidal portions of Pacific Northwest estuaries. These habitats provide food and refuge for a wide variety of fish and shellfish, protect shorelines by stabilizing sediments and reducing wave energy, and provide a "halo" of local pH improvements in estuarine waters, combating the deleterious effects of ocean acidification that threaten both wild and commercially grown shellfish populations (e.g., Beheshti and Ward 2021; Ricart et al. 2021).*

Eelgrass beds store carbon as above and belowground biomass (leaves and roots) and in their sediments, and like other coastal wetlands, have an Intergovernmental Panel on Climate Change (IPCC) approved carbon accounting methodology. Some sediment carbon is imported to eelgrass beds from elsewhere in the estuary when suspended sediments, often rich in organic matter, settle out as tidal currents flow through eelgrass beds (Grenier et al. 2013). Although research suggests that they may not store as much carbon as other estuarine wetland types – a recent Pacific Northwest regional study found the mean total ecosystem carbon stocks (TECS) in eelgrass beds to be 87.1 metric tonnes C acre^{-1} compared with TECS means of 430.6 metric tonnes C acre^{-1} for forested tidal wetlands, 222.9 metric tonnes C acre^{-1} for high emergent marshes and 168.4 metric tonnes C acre^{-1} for low emergent marshes (Kauffman et al. 2020) – they are integral to healthy coastal ecosystems. More than other tidal wetland types, eelgrass beds are essential for providing critical juvenile rearing habitat for important and valuable commercial and recreational fish and shellfish (e.g., salmon, California halibut, English sole, Dungeness crab; Phillips 1984; Blackmon et al. 2006). These critical ecosystem services combined with the documented losses of Oregon's eelgrass beds over the past several decades (Sherman and DeBruyckere 2018; Anderson 2020) suggest that efforts to conserve existing and restore lost eelgrass habitats, as well as research to identify the causes for eelgrass declines, should receive the same attention from land managers and policy makers as the management of other tidal wetland types for offsetting greenhouse gas emissions in the state.

Robert Schwemmer/NOAA National Marine Sanctuaries

***Kelp forests** provide important ecosystem services in nearshore ocean environments. They reduce the frequency and duration of harmful algal blooms and hypoxia events by mitigating local eutrophication, reduce coastal erosion by attenuating wave energy, and provide complex nursery and refuge habitats for a wide variety of commercial and recreational fish and shellfish species (Steneck et al. 2002; Christie et al. 2003; Gundersen et al. 2016). Like eelgrass meadows, kelp forests can help ameliorate the local effects of ocean acidification (Silbiger and Sorte 2018). Research is ongoing to quantify the potential carbon benefits of improved management of seaweeds, both conservation and restoration of wild resources as well as farmed (Krause-Jensen et al. 2018). While seaweeds do not store carbon in the rocky location to which they attach, they shed carbon into the environment, a portion of which eventually deposit in soft sediments or deep ocean waters. Farmed seaweed may also provide a marine carbon sequestration benefit as a portion of the biomass is shed into the water column during the growth phase. Seaweed aquaculture is of particular interest because of the promising applications for cattle feed to reduce methane emissions, human consumption, and biofuel.*

Including blue carbon ecosystems into the NWL Greenhouse Gas (GHG) inventory, associated goals and subsequent policies, as well as integration into existing policy frameworks, will help the state highlight the role of coastal wetlands as particularly effective natural carbon sinks while reinforcing the importance of maintaining and expanding their carbon sequestration services over time. Such actions would also deliver significant co-benefits in terms of coastal adaptation and resilience, biodiversity, and economically important fisheries. These efforts would position Oregon as a national leader in recognizing the important role coastal ecosystems play in climate action.

2 Background: The National GHG Inventory and Coastal Wetlands

Greenhouse gas inventories provide standardized tracking of GHG emissions (emissions) and GHG sequestration and storage (removals) resulting from socioeconomic activities. Inventories of natural and human-driven emissions and removals help policy makers develop and assess strategies for emissions reductions against an established, transparent baseline. Scientists use inventories to support climate modeling. Private land-owners, business entities and other interested groups may apply inventories to understand and reduce emissions or improve removals of GHGs. Finally, because they are intended to be updated regularly, inventories can help illuminate data gaps and prioritize needs to guide future research initiatives designed to inform policy and management decisions related to climate mitigation.

In the NWL sector (also known as the “Agriculture, Forestry and Other Land Use” category by the Intergovernmental Panel on Climate Change, or IPCC[7]and referred to in the U.S. Inventory as Land Use, Land Use Change, and Forestry), inventories of natural GHG emissions and removals allow for comprehensive tracking of carbon stocks, GHG emissions, and removals related to land use. This information can support the establishment of forward-looking land management approaches to maintain and increase carbon storage, as well as reduce GHG emissions that may result from natural resource degradation.

At the national level, the Inventory of U.S. Greenhouse Gas Emissions and Sinks (or “National Greenhouse Gas Inventory” / NGGI) annually reports GHG emissions and removals resulting from US socioeconomic activity, inclusive of NWL, following the IPCC good practice principles.[8] According to the NGGI, only the NWL sector of the US economy provides net GHG removals.

Since 2017, the NGGI has included coastal wetlands following guidance from the 2013 IPCC Wetland Supplement (Wetlands Supplement; IPCC 2014; Crooks et al. 2018). As noted in the NGGI, the Wetlands Supplement accounts for the important role of coastal wetlands in sequestering CO_2 within living biomass (plants), dead organic material (DOM, including litter and dead wood stocks) and soils, and provides specific guidance on quantifying emissions, specifically methane and nitrous oxide, and removals from these ecosystems.[9]

The NGGI quantifies GHG emissions and removals from US coastal wetlands by: (1) defining the coastal, tidally-influenced land base, recognized as land below the elevation of the highest tides and estuarine open water bodies; (2) identifying land cover types within the coastal land area; (3) quantifying annual change in land-cover between 1990 and 2019;[10] (4) assigning carbon (C) stocks, carbon accumulation rates, and methane (CH_4) or Nitrous Oxide (N_2O) emissions, as appropriate, to wetland classes to quantify GHG emissions and removals related to the land-cover change; and (5) summing to the respective subcategories of coastal wetlands that remained coastal wetlands and land that was converted to coastal wetlands to determine total emissions and removals (Crooks et al. 2018). According to the most recent national report released by the U.S. Environmental Protection Agency (EPA) in April 2021, coastal wetlands in the lower 48 states sequestered 4.8 metric tonnes of CO_2e in 2019 and store 2.9 billion of CO_2e in their soils.

In 2021, the U.S. government is releasing a breakdown of state level NGGI data, creating the first opportunity for states to incorporate this information into their own inventories. This development is

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[7] https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter11.pdf

[8] See: https://unfccc.int/resource/docs/2013/cop19/eng/10a03.pdf#page=2

[9] Coastal wetlands defined as coastal ecosystems with organic and mineral soils that are covered or saturated for part of the year by tidal freshwater, brackish or saline water and are vegetated by vascular plants and may extend seawards to the maximum depth of vascular plant vegetation (Crooks et al. 2018)

[10] The NGGI is published annually. The reporting period begins in 1990 and includes all years since then up until two years prior to the publishing date (i.e. 2019 is the most recent year included in the 2021 report).

particularly important for states that want to recognize the role of coastal wetlands in their inventories and lack resources and/or robust state level data. For coastal counties, a time-series of land use change data, including for tidal wetlands and tidal forests, is provided by the NOAA Coastal Change Analysis Program (C-CAP)[11] and forms the basis of the NGGI. This NGGI information can create a starting point for states to include coastal wetlands into NWL inventories. As additional data become available in the future, states can continue to improve GHG emissions and removal estimates from these ecosystems via inventory updates.

The Oregon coastal wetlands GHG inventory (OGGI) that follows is modeled closely on the NGGI approach and uses the newly available datasets described above. This approach will help ensure consistency with national GHG reporting and ideally enable inclusion of improved, Oregon-specific data in future NGGI updates.

3 Approach and Key Information for Calculating GHG Emissions and Removals from Coastal Wetlands

In this analysis, the team - led by blue carbon experts Lisa Beers and Steve Crooks from Silvestrum Climate Associates - worked with the U.S. Environmental Protection Agency (EPA) to develop estimates of GHG Emissions and Removals for Oregon's Coastal Wetlands, applying datasets and approaches that meet national and IPCC level reporting requirements for 1) Transparency, 2) Consistency, 3) Comparability, 4) Completeness, and 5) Accuracy.

The IPCC has provided three methodological tiers for estimating GHG emissions and removals. Tier 1 represents the minimum set of information needed to complete inventories based on default values from global literature reviews, while Tiers 2 and 3 represent marked improvements over Tier 1 estimates in terms of certainty and sophistication through the use of national, regional and localized data sets. Tiers represent options for national and state entities to incorporate coastal wetlands into GHG inventories without the need to wait for all key data gaps to be filled. As more complete data become available, these entities can work to achieve greater certainty in GHG emissions and removals estimates.

The analysis presented here for Oregon's coastal wetlands spans all three Tiers, relying on validated modeling of Oregon's estuary extents from Oregon's Coastal and Marine Ecological Classification Standard (CMECS) mapping (Lanier et al. 2014; Lanier et al. 2018) and state-specific biomass and soil carbon data (Tier 3); regional tidal forested wetland biomass and DOM stocks (Tier 2); and the Tier 1 default value for CH_4 emissions (though ongoing research on local CH_4 emissions will soon be

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[11] See: https://coast.noaa.gov/digitalcoast/data/ccapregional.html

completed to provide Tier 3 emissions factors). Oregon is fortunate to have some of the most robust blue carbon data in the nation because of the efforts of the Pacific Northwest Blue Carbon Working Group.[12]

As described in Section 2, calculating GHG emissions and removals from coastal wetlands follows a process that includes: (1) determining the total coastal land area and wetland types, (2) analyzing how the "land cover" (including subtidal lands) has changed since 1990, and (3) applying emissions factors to these land cover types based on default values or more regionally specific information to calculate yearly estimates on emissions and removals based on (1) and (2). The following subsections describe the use of Oregon-specific information to calculate the GHG estimates presented in Section 4.

3.1 Determination of Coastal Wetland Area and Types

The OGGI is based on the total coastal land area and wetland types[13] used in the NGGI: estuarine emergent wetland, estuarine scrub-shrub wetland, palustrine emergent wetland, palustrine scrub/shrub wetland, and palustrine forested wetland.[14] Only areas that are currently tidal are included within the analyses; former tidal wetland habitat is not included because its emissions and removals are tracked under a different land use (e.g. Cropland, Settlement, Forest, etc.) and would only be included if restored to tidal flow. Estimated coastal wetland areas in 2019 are presented in Table 2.

Table 2: Area of coastal wetland types in 2019.

Wetland Type	Area (acres)
Palustrine Forested Wetland	11,782
Palustrine Scrub/Shrub Wetland	10,481
Palustrine Emergent Wetland	33,236
Estuarine Emergent Wetland	10,149
Eelgrass*	3,551
Total	**69,199**

* area represents estimate of maximum extent contained in the CMECS dataset

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[12] See: https://www.pnwbluecarbon.org/

[13] The OGGI recognizes wetlands as a "land-use that includes land covered or saturated for all or part of the year, in addition to areas of lakes, reservoirs, and rivers. Consistent with ecological definitions of wetlands, the United States has historically included under the category of wetlands those coastal shallow water areas of estuaries and bays that lie within the extent of the Land Representation." https://www.epa.gov/sites/production/files/2020-02/documents/us-ghg-inventory-2020-chapter-6-land-use-land-use-change-and-forestry.pdf

[14] Estuarine forested wetlands and estuarine scrub/shrub wetlands are classified in the C-CAP datasets; however, no area was documented within Oregon for the image dates. Although there are C-CAP land cover classes for palustrine and estuarine aquatic beds, under which eelgrass beds are classified, they are often difficult to detect and properly classify using remote sensing due to their submergence in water; however, the estimated maximum current extent from Lanier et al. (2014, 2018) is included. Palustrine wetlands are freshwater wetlands with salinities less than 0.5 PSU. Estuarine wetlands are saline or brackish, covering a range of salinities starting at 0.5 PSU and greater.

3.2 Determining Change Over Time

Like the NGGI, the OGGI calculates emissions and removals based upon the stock change methodologies for soil carbon and the gain-loss method for above- and below-ground biomass and DOM. This analysis uses information from the NGGI (specifically the C-CAP data sets[15]) in conjunction with the detailed coastal wetland mapping and maximum tidal extent (Lanier et al. 2014; Lanier et al. 2018; Brophy et al. 2019) to determine coastal wetland change since 1990 as the basis for calculating these GHG fluxes (Table 3). Consistent with the NGGI, the OGGI recognizes both Vegetated Wetlands and Unvegetated Open Water as Coastal Wetlands.

Table 3: Area of Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands, Vegetated Coastal Wetlands Converted to Open Water, and Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands (acres).

Year	1990	2005	2015	2016	2017	2018	2019
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	66,038	65,122	65,353	65,412	65,471	65,530	65,589
Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands	0	91	10	10	10	10	10
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	0	3	62	62	62	62	62

In addition to the above categories, Lands Converted to Vegetated Coastal Wetlands are also tracked in the OGGI. This category includes low-lying coastal areas that have been inundated as a result of gradual sea-level rise (e.g., flooding of previously drained land behind failing hydrological barriers) or coastal wetlands that have been restored through removal of hydrological barriers.[16] Assessed land cover types are: Settlement (sparse to dense urban areas), Grasslands, Croplands (agriculture and pastureland), Forest (deciduous, evergreen, and mixed), and Other (bare, unconsolidated shoreline, and scrub-shrub).

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[15] The C-CAP datasets provide coastal land cover data from 1996, 2001, 2006, 2010 and 2016 at a resolution of 30m. More detailed data are available in select locations and a 2019 data set is currently being produced.

[16] See: https://www.epa.gov/sites/production/files/2021-04/documents/us-ghg-inventory-2021-chapter-6-land-use-land-use-change-and-forestry.pdf

Our analyses show that between 1990 and 2019 the rate of annual transition for the Land Converted to Vegetated Coastal Wetlands category ranged from 10 to 47 acres per year, depending on the type of land converted. There was no documented land conversion from Settlement, Cultivated or Grassland classes to coastal wetlands during the Inventory period. Conversion from Other Land represented the majority of change over time, ranging from 7 to 47 acres per year.

3.3 Determining Carbon Stocks and Fluxes

Under the Coastal Wetlands Remaining Coastal Wetlands category, the following emissions and removals are quantified:

1. C stock changes and CH_4 emissions on Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands,
2. C stock changes on Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands,
3. C stock changes on Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands
4. C stock changes and CH_4 emissions on Lands Converted to Vegetated Coastal Wetlands

Following the guidance provided by the IPCC Wetlands Supplement, the OGGI accounts for carbon sequestration only in the Vegetated Coastal Wetlands category. Vegetated Coastal Wetlands are net carbon sinks since they sequester carbon under anaerobic soil conditions and in plant biomass. The OGGI also accounts for emissions that occur when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands from impacts like subsidence, channel cutting, or erosion. These carbon stock losses resulting from conversion to Unvegetated Open Water Coastal Wetlands can result in the release of centuries to millennia of accumulated soil C, as well as the standing biomass carbon stock. Conversion of Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands through restoration restarts the building of carbon stocks within soils and biomass.

In applying the Wetlands Supplement methodologies for CH_4 emissions, coastal wetlands in salinity conditions less than half that of sea water (i.e., <18 Practical Salinity Units [PSU]) are sources of CH_4 as a result of slow decomposition of organic matter under lower salinity brackish and freshwater, anaerobic conditions. Conversion of Vegetated Coastal Wetlands to or from Unvegetated Open Water Coastal Wetlands does not result in a change in salinity condition and is assumed to have no impact on CH_4 emissions (Crooks et al. 2018).

Lands Converted to Vegetated Coastal Wetlands occur when land is flooded by coastal waters. The land categories include: Cropland (pastureland and agriculture), Forest Land (evergreen, deciduous and mixed), Grassland, Settlement (sparse to dense developed land), and Other (bare, scrub-shrub, and unconsolidated shore). Soil carbon accumulation is initiated once coastal wetland biomass becomes established. Flooding of freshwater initiates CH_4 emissions when lands are inundated, which is accounted for in the OGGI[17]. Additionally, carbon stock changes that occur because of conversion to coastal wetlands are accounted for, specifically the loss of aboveground biomass in forests (including forest DOM), croplands, and grasslands.[18]

Although nitrous oxide (N_2O) emissions are not currently included in the OGGI, the Wetlands Supplement provides methodologies to estimate N_2O emissions from aquaculture production. The U.S. provides national level area estimates of aquaculture that are reported in the NGGI.

Analysis of stocks and fluxes associated with Oregon's coastal wetlands are based on research from the Pacific Northwest Blue Carbon Working Group, NGGI data, IPCC default values and the Smithsonian Environmental Research Center's Coastal Carbon Atlas.[19]

4 Estimates of GHG Emissions and Removals in Oregon's Coastal Wetlands

The carbon fluxes for all four wetland categories described above are summarized in Tables 4 and 5. Across the entire reporting period, Coastal Wetlands Remaining Coastal Wetlands are a net carbon sink, with removals ranging from -11.8 to -63.0 kiloton[20] (kt) CO_2e across most of the time series (consistent with the NGGI, ***removals are expressed as negative numbers***). The majority of removals range between -50.2 and -54.4 kt CO_2e. In 2019, Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands are a net sink of -51.9 kt CO_2e, driven largely by tidal forested wetland biomass and DOM production offsetting CH_4 emissions from palustrine tidal wetlands. In contrast, loss of coastal wetlands to open water, recognized as Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands, drives an emission of 4.5 kt CO_2e, with the majority of that, 3.5 kt CO_2e, from soils (consistent with the NGGI, ***emissions are expressed as positive numbers***). Converting open water to new tidal wetlands, recognized as Unvegetated Coastal Wetlands Converted to Vegetated

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[17] Methane is produced under brackish conditions; however, the estuarine class in C-CAP includes areas with salinity greater than 0.5 PSU and therefore CH_4 emissions cannot be included in the analysis due to the broad range of salinities included in this class.

[18] As noted in chapter 6 of the NGGI (see https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks), estimates of emissions and removals are based on emission factor data that have been applied to assess changes in each respective flux for Land Converted to Vegetated Coastal Wetlands. Converted lands are held in this land category for 20 years and the assumption is that the carbon stock losses from biomass and DOM all occur in the year of conversion. There are no soil carbon losses assumed from land use conversion. Carbon stock increases in coastal wetlands as a result of gains in plant biomass and DOM on these converted lands are also included during the first year of transition, even though the entire carbon stock accrual takes many years to occur. Soil carbon accumulation and CH4 emissions are quantified using an annual rate and thus are occurring over the period under which lands are held in this category. Therefore, the soil carbon removals and CH_4 emissions presented for a given year include the cumulative removals/emissions for the newly converted area during that year and the area held in this category for the prior 19 years.

[19] https://ccrcn.shinyapps.io/CoastalCarbonAtlas/

[20] One metric ton is equivalent to 1,000 kilotons. This unit is used here and below for ease of reading and formatting tables.

Coastal, results each year in removals of 0.006 to 3.5 kt CO_2e. **In all, Coastal Wetlands were a net sink of -50.9 kt CO_2e in 2019**.

Table 4: Emissions and Removals from Coastal Wetlands Remaining Coastal Wetlands (kt CO_2e).

Land Use/Carbon Pool	1990	2005	2015	2016	2017	2018	2019
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	**(63.0)**	**(56.7)**	**(52.2)**	**(51.1)**	**(51.1)**	**(52.0)**	**(51.9)**
Biomass Carbon Flux	(76.4)	(70.5)	(67.6)	(67.6)	(67.6)	(67.5)	(67.5)
Dead Organic Matter Carbon Flux	(15.3)	(14.3)	(13.3)	(13.3)	(13.3)	(13.3)	(13.3)
Soil Carbon Flux	(80.8)	(79.6)	(79.5)	(79.5)	(79.6)	(79.7)	(79.7)
Net CH_4 Flux	109.5	107.7	108.2	108.3	108.4	108.5	108.6
Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal	**0**	**45.0**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**
Biomass Carbon Flux	0	7.9	0.7	0.7	0.7	0.7	0.7
Dead Organic Matter Carbon Flux	0	3.2	0.2	0.2	0.2	0.2	0.2
Soil Carbon Flux	0	33.9	3.5	3.5	3.5	3.5	3.5
Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands	**(0.01)**	**(0.1)**	**(2.7)**	**(2.9)**	**(3.0)**	**(3.2)**	**(3.5)**
Biomass Carbon Flux	(+)	(0.06)	(1.5)	(1.6)	(1.7)	(1.8)	(1.9)
Dead Organic Matter Carbon Flux	0	(0.02)	(0.2)	(0.3)	(0.3)	(0.4)	(0.4)
Soil Carbon Flux	(+)	(0.02)	(0.9)	(1.0)	(1.0)	(1.1)	(1.2)
Net N_2O Flux from Aquaculture in Coastal Wetlands	ND	ND	ND	ND	ND	ND	ND
Total Biomass Carbon Flux	**(76.4)**	**(62.6)**	**(68.5)**	**(68.5)**	**(68.6)**	**(68.7)**	**(68.7)**
Total Dead Organic Matter Carbon Flux	**(15.3)**	**(11.1)**	**(13.3)**	**(13.3)**	**(13.4)**	**(13.4)**	**(13.5)**
Total Soil Carbon Flux	**(80.8)**	**(45.7)**	**(76.8)**	**(77.0)**	**(77.1)**	**(77.2)**	**(77.3)**
Total CH_4 Flux	**109.5**	**107.7**	**108.2**	**108.3**	**108.4**	**108.5**	**108.6**
Total N_2O Flux	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
Total Flux	**(63.0)**	**(11.8)**	**(50.4)**	**(50.5)**	**(50.6)**	**(50.8)**	**(50.9)**

Note: Parentheses indicate net sequestration; ND = no data; Totals may not sum due to independent rounding.
+ Absolute value does not exceed 0.005 kt CO_2e.

Between the C-CAP mapping years of 2001 and 2006, there was an increase in area of Vegetated Coastal Wetlands converted Unvegetated Open Water Coastal Wetlands that resulted in a spike in emissions compared to other periods (see data for 2005 in Table 4). This loss is likely due to the hydrologic reconnection (restoration) of a series of sites within the Columbia River estuary that resulted in increased flooding and thus reclassification of vegetated coastal wetland to open water.

Nitrous oxide emissions, specifically those created through aquaculture, should also be included in the OGGI. However, data on the extent and type of aquaculture within Oregon are currently not available, and therefore N_2O is not included.

Presently, neither the OGGI nor the NGGI calculate the lateral flux of carbon to or from any land use. Research is underway to better understand carbon flows to coastal wetlands and to marine sediments in coastal waters. In future inventory updates, Oregon can apply this research to improve carbon accounting in coastal wetlands.

Lands Converted to Vegetated Coastal Wetlands, which represent a relatively small portion of GHG removals in the OGGI due to few area changes, resulted in CO_2 removals of -0.1 kt CO_2e (-0.03 kt C) in 2019 (Table 5). Conversion of land to tidal palustrine ecosystems (forested and emergent) resulted in CH_4 emissions that nearly matched removals: 0.7 kt CO_2e (0.02 kt C). Loss of forest biomass through conversion of Forest Lands to Vegetated Coastal Wetlands resulted in biomass emissions.[21] Combined with CH_4 emissions, conversion of Forest Land to Vegetated Coastal Wetlands is currently a net emission; however, over the long term, conversion to coastal wetlands results in net carbon removals. Conversion of Other Lands results in net removals across the reporting period, driven by increases in tidal wetland biomass and soil carbon accumulation. Removals from palustrine forested wetlands DOM accrual occurred throughout the majority of the reporting period and ranged from -0.01 to -0.07 kt CO_2e. Once Tier 1 or 2 DOM values are collated and accounted for in estuarine and palustrine scrub shrub coastal wetlands, there will be additional carbon removals. **Across all time periods, soil carbon accumulation resulting from Lands Converted to Vegetated Coastal Wetlands is a carbon sink and has ranged between -0.2 and -0.4 kt CO_2e (-0.05 and -0.11 kt C; Table 5).**

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[21] Current research is investigating the preservation of woody debris with conversion to tidal wetlands ('ghost forests') and could ultimately be a carbon sink rather than a source.

Table 5: Net CO_2 Flux from Carbon Stock Changes in Land Converted to Vegetated Coastal Wetlands (kt CO_2e).

Land Use/Carbon Pool	1990	2005	2015	2016	2017	2018	2019
Cropland Converted to Vegetated Coastal Wetlands	**0**	**(+)**	**+**	**+**	**+**	**+**	**+**
Biomass Carbon Stock	0	(+)	0	0	0	0	0
Dead Organic Matter Carbon Flux	0	0	0	0	0	0	0
Soil Carbon Stock	0	(+)	(+)	(+)	(+)	(+)	(+)
Net CH_4 Flux		0	+	+	+	+	+
Forest Land Converted to Vegetated Coastal Wetlands	**1.2**	**0.1**	**0.04**	**0.04**	**0.03**	**0.02**	**0.01**
Biomass Carbon Stock	0.9	0.01	0.005	0.005	0.005	0.005	0.005
Dead Organic Matter Carbon Flux	0.1	+	+	+	+	+	+
Soil Carbon Stock	(0.2)	(0.1)	(0.05)	(0.04)	(0.03)	(0.02)	(0.01)
Net CH_4 Flux	0.3	0.3	0.09	0.07	0.05	0.04	0.02
Grassland Converted to Vegetated Coastal Wetlands	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Biomass Carbon Stock	0	0	0	0	0	0	0
Dead Organic Matter Carbon Flux	0	0	0	0	0	0	0
Soil Carbon Stock	0	0	0	0	0	0	0
Net CH_4 Flux	0	0	0	0	0	0	0
Other Land Converted to Vegetated Coastal Wetlands	**(+)**	**(0.1)**	**(0.06)**	**(0.08)**	**(0.09)**	**(0.1)**	**(0.1)**
Biomass Carbon Stock	(0.01)	(0.1)	(0.3)	(0.3)	(0.3)	(0.3)	(0.3)
Dead Organic Matter Carbon Flux	0	(0.01)	(0.05)	(0.06)	(0.07)	(0.08)	(0.09)
Soil Carbon Stock	(0.01)	(0.04)	(0.4)	(0.4)	(0.4)	(0.4)	(0.4)
Net CH_4 Flux	0.01	0.06	0.6	0.6	0.6	0.7	0.7
Settlements Converted to Vegetated Coastal Wetlands	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Biomass Carbon Stock	0	0	0	0	0	0	0
Dead Organic Matter Carbon Flux	0	0	0	0	0	0	0
Soil Carbon Stock	0	0	0	0	0	0	0
Net CH_4 Flux	0	0	0	0	0	0	0
Total Biomass Flux	**0.9**	**(0.1)**	**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**	**(0.3)**
Total Dead Organic Matter Flux	**0.1**	**(0.01)**	**(0.05)**	**(0.06)**	**(0.07)**	**(0.08)**	**(0.09)**
Total Soil Carbon Flux	**(0.2)**	**(0.2)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**	**(0.4)**
Total CH_4 Flux	**0.4**	**0.3**	**0.7**	**0.7**	**0.7**	**0.7**	**0.7**
Total Flux	**1.2**	**(0.01)**	**(0.02)**	**(0.04)**	**(0.06)**	**(0.09)**	**(0.1)**

Note: Totals may not sum due to independent rounding. Parentheses indicate net sequestration.

\+ Absolute value does not exceed 0.005 kt CO2e.

5 Looking Forward

As described in Section 4, Oregon's coastal wetlands are net carbon sinks. Tracking and ensuring the conservation of those important ecosystems to maintain this carbon sink through continued or strengthened regulatory protections will be an important part of the state's NWL climate mitigation strategies. In addition, continued or accelerated restoration of coastal wetlands historically converted to other land uses offers critical prospects for expanding baseline rates of carbon sequestration in Oregon's coastal watersheds. As blue carbon data gaps in the PNW continue to be filled and Oregon's coastal mapping becomes more refined and targeted to address specific questions raised by the OGGI, Oregon policymakers will have access to increasingly powerful tools to guide the development and implementation of effective coastal management strategies that help Oregonians mitigate the local effects of climate change.

5.1 Restoration Opportunities to Expand Coastal Wetland Carbon Sinks

Based on current knowledge of blue carbon ecosystems, Oregon's coastal wetlands historically sequestered approximately 6.1 tons CO_2e in the biomass, DOM and top meter of soil for emergent and 16.8 million tons CO_2e in forested tidal wetlands before European settlement.[22] Though restoring this carbon pool in its entirety is not feasible due to current uses, community needs, and infrastructure, identifying opportunities for restoring these carbon rich habitats would represent important contributions to an overall NWL climate mitigation strategy for Oregon, as well as offer significant co-benefits as described in Section 6. Focusing on forested tidal wetland restoration could yield 7.9 metric tonnes CO_2e[23] per acre in carbon benefits. As such, restoring 2,470 acres of forested tidal wetlands today would yield approximately 525 kt CO_2e in increased carbon storage by 2050.

As previously mentioned, coastal wetlands converted to other land cover types are not included in this inventory since they are represented within each respective land cover's inventory. It is worth noting, however, the importance of accounting for potential ongoing CO_2 emissions from the soil that could still be occurring. Diking and draining of coastal wetlands cause large emissions through oxidation of organic matter held within the soil and can occur for many decades, if not longer, before stabilizing. The wetland conversions in Oregon happened some time ago and so have likely stabilized; however, ongoing CH_4 emissions from impounded waters and saturated land can still occur. Approximately 55

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[22] Estimates are based on emissions factors used in this analysis.

[23] This value represents the carbon sequestered annually for mature Sitka spruce forests; the amount of carbon sequestered increases as restored forests mature.

metric tonnes CH_4 (1,375 metric tonnes CO_2e) are emitted annually from these impounded waters.[24] Tidal restoration as a blue carbon strategy to reduce methane emissions is an area of active research (see Kroeger et al. 2017).

Additionally, approximately 13,000 acres of formerly tidal area is classified as a palustrine wetland within the C-CAP dataset. While the seasonal timing and duration of inundation of these lands are not known, there are likely CH_4 emissions occurring. Restoring these lands to tidal wetlands gradually brings back the soil, biomass, and DOM carbon stocks and rebuilds these carbon sinks in the long term. Although short term climate mitigation benefits associated with restoring these palustrine wetlands may not occur in the near term due to CH_4 emissions, other benefits associated with fish habitat, biodiversity and flood storage/attenuation could accrue.

5.2. Planning for a Blue Carbon Future

Conserving and managing existing blue carbon stocks and capitalizing on restoration opportunities (as described above) will require broad-based efforts inclusive of agencies, sovereign Tribal Nations, watershed councils, and the public. In addition to continued work to halt coastal wetland loss, the state should bolster efforts focusing on planning for sea level rise. Recent studies indicate that Oregon's tidal wetlands may be more resilient to sea level rise than some other coastal regions of the U.S., but they remain vulnerable to this threat (Brophy 2019). Accordingly, it will be important to allow for landward migration of these habitats to ensure their persistence into the future.

Fortunately, the state has a foundation of knowledge to help refine understanding of the extent to which Oregon’s coastal wetlands are keeping pace with sea level rise that can help inform state and estuary-level planning. Brophy and Ewald (2017) mapped potential areas for landward migration under several sea-level rise scenarios and identified key next steps, including more detailed spatial analyses within estuaries and shorelands, better understanding of changes in salinity with sea-level rise since salinity drives species composition and CH_4 emissions, analysis of land ownership patterns, and the potential for partnerships and collaborations. The latter is essential to identify priority lands for local jurisdictions to consider protecting as the basis for discussions with local communities on possible collaborations, funding opportunities, and conflicts with zoning and how both state and local efforts can address them.

One possible area of focus for planning efforts could be coastal lands that are becoming marginalized due to sea-level rise and aging infrastructure wherein financial assistance could incentivize

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[24] Using the CMECS dataset, the area of impounded water, either as reservoirs or managed channels (e.g. controlled by tide gates), within former coastal wetland areas is estimated to be 284 ha. Using the IPCC default CH4 emission value of 193.7 kg ha^{-1} yr^{-1}, approximately 55 metric tonnes CH_4 (1,375 metric tonnes CO_2e) are emitted annually from these impounded waters.

conservation and restoration. Such efforts would focus on the ability of healthy estuarine areas to provide vital benefits to the community, ecosystem, and economy while performing long-term carbon storage and sequestration of GHGs and ameliorating other climate-related threats such as flooding.

5.3 Leveraging existing policy frameworks

Landscape level assessments of opportunities to address climate mitigation could be accomplished through existing policy frameworks, such as Oregon's Natural Resources planning, Estuary Management Planning, and Shorelands Planning, which are guided by the state's umbrella land use planning goals (see text box below). The Department of Land Conservation and Development (DLCD) – through the Oregon Coastal Management Program (OCMP) – as well as coastal communities are currently prioritizing updates to estuary management plans (EMPs), most of which are decades old and based on outdated science and mapping. These updates provide an opportunity for agencies and communities to elevate protection and enhancement of estuarine ecosystem services and advance adaptation, resilience, and greenhouse gas mitigation goals. EMP updates could apply this climate lens to assess land and water use planning, policy and management, regulatory requirements, government incentives and voluntary programs, and funding mechanisms.

The OCMP, which is facilitating EMP updates, is well positioned to help implement blue carbon-focused strategies such as targeted restoration and planning for sea-level rise. These are complex efforts involving a mosaic of local, state, and federal authorities and requiring extensive coordination and strategic planning for implementation. As a "networked" program,[25] the OCMP consists of multiple agencies with authority in the coastal zone. The OCMP is composed of eleven state agencies, thirty-three cities, and seven counties. This unified structure could help reduce duplication of effort, create efficiencies, and leverage federal funding opportunities through the National Oceanic and Atmospheric Administration (NOAA), National Fish and Wildlife Foundation, and other funders.

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[25] See: https://www.oregon.gov/lcd/OCMP/Pages/About.aspx

Land Use Planning Goals and Estuaries

Oregon has existing Land Use Planning Goals[26] that can provide the policy framework for developing and implementing blue carbon strategies in the state's estuaries. The Goals for Natural Resources (Goal 5), Estuarine Resources (Goal 16), and Coastal Shorelands (Goal 17) provide official guidance for the management of Oregon's estuaries.

*The aim of **Goal 16** is "to recognize and protect the unique environmental, economic and social values of each estuary and associated wetlands; and to protect, maintain, where appropriate develop, and where appropriate restore the long term environmental, economic and social values, diversity and benefits of Oregon's estuaries." The goal sets specific requirements for plans and review of development projects and requires coordinated management by local, state, and federal agencies that regulate or have an interest in Oregon estuary activity. Goal 16 requirements are generally implemented through local estuary plans, but some are applied through state permit review. Goal 16 mandates estuary plans to designate uses for different areas within each estuary based on biological and physical characteristics and features. Estuarine alterations must be reviewed to assure they are consistent with management objectives and that adverse impacts are minimized. The specific, but flexible, requirements of Goal 16 provide a framework for implementation of carbon sequestration goals and planning for sea level rise.*

*Statewide **Planning Goal 17** provides management requirements for lands bordering estuaries and the ocean shore. Goal 17 focuses on the protection and management of resources of shoreland areas; and can include designation of significant shoreland habitat, as well as lands suited for water-dependent uses, public access, potential restoration areas, and potential compensatory mitigation sites required by state and federal environmental regulatory permitting processes. The requirement to identify areas for restoration or compensatory mitigation projects provides an opportunity to consider high potential carbon storage areas to meet state sequestration goals. The goal prioritizes uses and alterations to be compatible with adjacent coastal water uses and characteristics. Goal 17 is usually implemented through local plans and zoning regulations.*

5.4 Exploring Markets

To date, market-based financing mechanisms to fund blue carbon projects have remained largely out of reach due to the low cost of carbon, the relatively complex process to secure accreditation and its underlying knowledge gaps, and the scale needed for projects be viable. However, research and pilot projects are underway across the country to better quantify carbon benefits and secure private funding that may inform the development of market-related opportunities.[27] The Pacific Northwest

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[26] https://www.oregon.gov/lcd/op/pages/goals.aspx

[27] See: https://coast.noaa.gov/states/stories/first-carbon-market-guidance-for-wetlands.html

Blue Carbon Working Group completed a "Feasibility Planning for Pacific Northwest Blue Carbon Finance Projects" in 2019 that could serve as a starting point[28] for Oregon-based efforts in this arena.

Blue carbon accreditation methodologies for the carbon markets are in place for conservation and restoration of tidal wetlands and seagrass.[29] The science remains in development, but there is growing interest in linking the blue economy to improved management of a range of ocean ecosystems that may provide blue carbon services. To this end, a coalition of partners including Verra and Silvestrum Climate Associates are exploring the potential to connect these wider blue carbon ecosystems to the carbon market. This work would create a 'Seascape Carbon Crediting Framework' to map out how carbon management practices could be applied to generate carbon benefits in a variety of marine ecosystems. Developing this framework aims to stimulate more science, and greater regulatory and policy review on this topic, and to increase understanding of the enabling conditions required to potentially connect these ecosystems to the carbon market.

6 Co-Benefits

Oregon's coastal wetlands, including tidal marshes, scrub-shrub, forested tidal wetlands, and eelgrass meadows, provide human, plant and animal communities with a suite of important ecosystem services in addition to carbon sequestration. As described in Table 6 below, these ecosystems improve water quality; provide coastal shoreline protection; help reduce coastal flooding and ameliorate the local effects of ocean acidification; provide a wide array of wildlife habitats, including critical rearing habitat for juvenile salmonids (e.g., endangered Coho salmon); and have long provided cultural services and food provisioning for Tribal Nations. Coastal ecosystems also provide valuable economic benefits that support Oregon's coastal communities and natural resource dependent economies. For example, in 2019, visitors to Tillamook County alone spent $240 million.[30]

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[28] See: https://www.pnwbluecarbon.org/projects and https://ceff240a-b12a-47ec-aa5a-52c962fe647b.filesusr.com/ugd/43d666_076d61dcf0ad48ac8c8c138372324a70.pdf

[29] See: https://e360.yale.edu/features/why-the-market-for-blue-carbon-credits-may-be-poised-to-take-off

[30] Dean Runyan Associates. 2019. Oregon Travel Impacts, 1992-2018. Prepared for the Oregon Tourism Commission.

Table 6: Ecosystem services in Pacific Northwest Coastal Wetlands (see full table with citations in Appendix 2).

Ecosystem Services	***Cross-cutting***	***Tidal salt marsh***	***Forested tidal wetlands***	***Eelgrass***
Water quality	Nutrient cycling and transport, sediment retention and stabilization, and temperature regulation	Salinity and temperature buffer zone, trap sediments and improve water quality.	Salinity buffer zone, nutrient regulation and removal	Temperature regulation, localized amelioration of ocean acidification and hypoxia, nutrient cycling and pH balance.
Coastal shoreline protection	Erosion prevention	Storm wave attenuation, flooding mediation	Storm wave attenuation, flooding mediation	Non-storm wave attenuation and sediment stabilization.
Wildlife habitat and ecological support	Directly and indirectly benefit keystone and ecologically significant terrestrial and marine species, including the Endangered Coho salmon. Many are designated as Important Bird Areas.	Habitat for numerous insects, fish, small and large mammals, migratory and resident shorebirds, and waterfowl prized by hunters.	Support salmon population genetic diversity and growth and are highly productive to all trophic levels. Habitat for mammals and sensitive migratory birds.	Important feeding grounds and sheltering habitat for pelagic and coastal fish, resident and sensitive migratory shorebirds (black brant rely almost entirely on eelgrass), and the food webs they rely on.

Ecosystem Services	***Cross-cutting***	***Tidal salt marsh***	***Forested tidal wetlands***	***Eelgrass***
Natural resource dependent economies	High primary productivity supports a variety of economically important species. Coastal ecosystem fisheries comprise 75% of all PNW commercial fishery landings: crabs, clams, oysters, and fish. Ecotourism/ recreation: kayaking, bird watching, whale watching, etc.	Highly productive juvenile salmon feeding and nursery ground, shellfish fishery, oyster rearing grounds, and recreational fishing.	Highly productive juvenile salmon feeding grounds, supports salmon fishery resilience and many other fish and shellfish industries	Designated by the Pacific Fishery Management Council as Essential Fish Habitat. Directly or indirectly supports important crab, salmon, bivalves (wild and aquaculture), and other fisheries as nursery and feeding grounds.
Cultural Services	Coastal Tribal Nation ancestral territories and sustained cultural identity	Tribal Nation fisheries: salmon, eulachon, and lamprey. Materials for basket-making.	Support Tribal Nation fishery species' juvenile stages. Materials for basket-making.	Tribal Nation use of eelgrass plant material for cooking, housing materials, and hunting grounds.

7 Next Steps

This analysis describes Oregon's blue carbon baseline inventory and potential opportunities for carbon sequestration and storage in the context of the state's first Natural and Working Lands proposal. The document is based on a growing body of research with opportunities for improvements as science evolves. There is also likely significant alignment and leverage potential between the blue carbon-focused climate mitigation strategies described in this report and other sectors included in the NWL proposal, as well as the state's adaptation, infrastructure, and conservation goals. Taking a comprehensive, landscape-level approach for implementing Natural and Working Lands goals, inclusive of blue carbon, will help the state capitalize on opportunities to maintain and enhance these multiple benefits.

Specific near-term next steps to jump start action on blue carbon include:

- Creation of a broad-based coastal carbon planning group charged with developing a blue carbon implementation plan. The OCMP, which includes a network of agencies and localities, Oregon's Climate Change Research Institute (OCCRI), and the Pacific Northwest Blue Carbon Working Group, are well situated to take the lead on this effort.
- Assessment of existing state and federal level funding resources (including grants and other incentives) available to support blue carbon strategies and additional needs.
- Development of a priority list of "shovel ready" restoration projects and land use planning efforts in the state's estuaries. Given federal-level interest in supporting climate and infrastructure-related policies and projects, there may be opportunities to secure federal funding in the near-term to support these efforts.
- Identification of key blue carbon management questions and associated research needs. An initial list is included in Appendix 2.

Though the above is not a complete list of key actions needed to maintain and enhance coastal carbon in Oregon's estuaries, these initial steps could help the state build an initial foundation of knowledge, support and management actions that will grow and improve over time.

As one of the first states in the U.S. to develop a blue carbon inventory and strategies in the context of climate mitigation, Oregon is poised to be a national leader in this effort. As the state begins implementation of blue carbon strategies, it can build on its extensive science capacity and policy infrastructure to become a model for other coastal states (including neighboring California and Washington) to follow.

Appendix 1: Detailed Information/Analyses Related to the Blue Carbon Inventory

Note: much of the information included below is derived from the EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 – 2019 (EPA 430-R-21-005) as it pertains to the Oregon GHG inventory.

A1.1 Detailed Information/Analyses Related to the Blue Carbon Inventory

Historic habitat extent

Unlike most other states, Oregon has detailed coastwide historic estuary extent data, which helps illuminate losses in habitat types and associated carbon storage. Marcoe and Pilson (2017) estimated the area of tidal wetlands in the Columbia River Estuary and Brophy (2019) estimated tidal wetland extent along coastal Oregon (see Table 1 in main report). While there has been a reduction by nearly half of the total area of coastal wetlands in Oregon, the loss of forested tidal wetlands has been greater than for emergent wetlands with over 95% of habitat lost along coastal Oregon (not including the Columbia River estuary).

Recent Habitat Extent and Change Over Time

Combining habitat extent data from different years creates habitat change (land change) datasets that demonstrate gains or losses in the landscape over time, allowing for estimates of carbon storage and emissions. The EPA NGGI coastal wetlands component was determined using 1990 as the base year reference point (i.e., the first year of the national GHG Inventory estimation) with data from the NOAA Coastal Change Analysis Program[31] (C-CAP) land cover atlas. The same methods used for the NGGI were applied for the inclusion of coastal wetlands into the OGGI. The C-CAP datasets, which provide land cover classifications at a resolution of 30 meters for coastal states within the United States, were used in conjunction with the detailed regional coastal wetland mapping (Lanier et al. 2014; Lanier et al. 2018; Brophy et al. 2019). Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands on land below the elevation of high tides (taken to be the 50% exceedance water elevation from NOAA's Extreme Water Levels) and as far seawards as the extent of intertidal vascular plants according to the Pacific coast estuary extent data (Brophy et al. 2019) and land use histories recorded in the 1996, 2001, 2006, 2010, and 2016 NOAA C-CAP surveys (NOAA OCM 2020). The C-CAP areas were clipped to include only area within Oregon and, based on Brophy et al. (2019), only areas that are tidal within that boundary were used, meaning that former tidal wetlands that are now diked or impounded are not included in the analyses (representing an opportunity for future improvements as the inventory is updated). Federal and non-federal lands are represented. Changes in area between C-

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[31] https://coast.noaa.gov/digitalcoast/data/ccapregional.html

CAP image dates were interpolated. For years that are between two C-CAP image dates, the area change for each category was divided by five and that value was applied to each year. For example, the area changes between 2001 and 2006 for each land use change category was divided by five and that average change value was used for years 2001, 2002, 2003, 2004 and 2005. For years 1990 to 1995, the yearly trend between 1996 and 2001 was used and for years 2017 to 2019, the yearly trend between 2010 and 2016 were used. Based upon NOAA C-CAP, coastal wetlands are subdivided into palustrine and estuarine classes and further subdivided into emergent marsh, scrub shrub and forest classes.

The Institute for Applied Ecology has conducted research that has led to significant improvements in knowledge of the current and historic extent of tidal wetlands along the Pacific coast of the U.S. The Biotic Component Layer of NOAA's Coastal and Marine Ecological Classification Standard[32] (CMECS) spatial dataset was used to compare against the C-CAP classifications as well as to identify areas that are no longer tidal but classified as estuarine or palustrine wetlands within C-CAP. The only modification made to the tidal portion of the C-CAP dataset was to remove the erroneous classification of palustrine wetlands within the open waters of Coos Bay.

Eelgrass beds are an integral blue carbon ecosystem; however, due to the current lack of extent data over time, eelgrass is not included in the inventory calculations at this time (although as a recognized carbon sink, this should not preclude protection and restoration of eelgrass in the context of climate mitigation strategies). There are estimates of extent for each of Oregon's 17 major estuaries dating as far back as 1987, which have been incorporated as GIS layers on the Oregon Coastal Atlas website.[33]

Carbon Stocks and Fluxes

Gathering information on the amount of carbon stored in coastal habitats (stocks) and how these stocks change over time (fluxes), is necessary for creating an emissions factor. Emission factors are the loss or gain of carbon as a result in changes in land coverage and use. Positive values indicate loss of carbon from the biomass/soil to the atmosphere and CH_4 and N_2O emissions, while negative values indicate removal of carbon from the atmosphere. Combined with information on habitat extent and change over time, this information will allow for a baseline estimate of blue carbon GHG emissions for the OGGI. Where stock data are not available, the Wetlands Supplement (including all currently quantifiable blue carbon ecosystems — mangrove forests, tidal marshes and seagrass meadows) provides emissions factors and methodologies for coastal habitats and associated land uses including mangrove forest management practices, rewetting, revegetation and creation, aquaculture and drainage. These default values can be utilized for a Tier 1 estimate (i.e., globally averaged estimated

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[32] https://www.pacificfishhabitat.org/data/estuarine-biotic-habitat/

[33] https://www.coastalatlas.net/index.php/tools/planners/63-estuary-data-viewer

based on current literature and with a high degree of uncertainty; IPCC 2014). Whenever possible, state and local data should be used in place of default values.

The carbon pools in tidal forested, scrub-shrub, and emergent tidal wetlands, and eelgrass beds are found within the:

- living aboveground biomass (leaves, branches, stems)
- living belowground biomass (roots)
- soil
- dead organic matter (both litter and dead wood)

"Vegetated Coastal Wetlands" are net accumulators of carbon as soils accumulate what can be substantial carbon stocks under anaerobic soil conditions and in plant biomass. Emissions from soil carbon and biomass stocks occur when Vegetated Coastal Wetlands are converted to Unvegetated Open Water Coastal Wetlands (e.g., due to subsidence, erosion or channel cutting), but are still recognized as Coastal Wetlands in the OGGI. These carbon stock losses resulting from conversion to Unvegetated Open Water Coastal Wetlands can release of many years of accumulated soil C, as well as the standing stock of biomass C. Conversion of Unvegetated Open Water Coastal Wetlands to Vegetated Coastal Wetlands restarts the building of carbon stocks within soils and biomass.

Coastal wetlands are also natural sources of GHGs, specifically CH_4 and N_2O, and both need to be accounted for where relevant. In applying the Wetlands Supplement methodologies for CH_4 emissions, coastal wetlands in salinity conditions less than half that of sea water are sources of CH_4 as result of slow decomposition of organic matter under lower salinity brackish and freshwater, anaerobic conditions. Conversion of Vegetated Coastal Wetlands to or from Unvegetated Open Water Coastal Wetlands do not result in a change in salinity condition and are assumed to have no impact on CH_4 emissions. Although N_2O emissions are not currently included in the OGGI, the Wetlands Supplement provides methodologies to estimate N_2O emissions from coastal wetlands that occur due to aquaculture.

Biomass Carbon Stock Changes

Tier 3 level estimates of above- and below ground biomass carbon stocks for palustrine (freshwater, 0 – 0.5 PSU) and estuarine (salinity greater than 0.5 PSU) marshes are estimated for Vegetated Coastal Wetlands on land below the elevation of high tides (taken to be the 50% exceedance of extreme water levels) and as far seawards as the extent of intertidal vascular plants according to the Pacific coast estuary extent data (Brophy et al. 2019) and land use histories recorded in the 1996, 2001, 2006, 2010, and 2016 NOAA C-CAP surveys (NOAA OCM 2020). Based upon NOAA C-CAP, coastal wetlands are subdivided into palustrine and estuarine classes and further subdivided into emergent marsh, scrub shrub and forest classes (Table A1). Biomass is not sensitive to soil organic content but is differentiated based on vegetation type. Aboveground biomass carbon stocks for non-forested wetlands data are derived from ten tidal emergent wetlands, spanning both low and high marshes, and three eelgrass beds within Oregon (Kauffman et al. 2020). The standing stock for palustrine forested wetlands[34] was estimated from three forests within Oregon (Kauffman et al. 2020). Root to shoot ratios for non-forested wetlands from the Wetlands Supplement were used to account for belowground biomass (Table A2; IPCC 2014), which were multiplied by the aboveground carbon stock. Above- and belowground values were summed to obtain total biomass carbon stocks. For palustrine forested wetlands, the annual growth rate for a mature Sitka spruce forest in the coastal region of the Pacific Northwest, 1.53 tonnes C acre^{-1} yr^{-1}, was derived from Smith et al. (2006) and standing tree stock was derived from Kauffman et al. (2020). The Sitka spruce biomass carbon stock growth curve was derived from Smith et al. (2006; Figure A1). Biomass carbon stock changes per year for non-forested Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands were determined by calculating the difference in area between that year and the previous year to calculate gain/loss of area for each wetland type, which was multiplied by the mean biomass for that wetland type. For forested tidal wetlands, the annual growth rate was multiplied by the area for that year.

Table A1. Aboveground Biomass Carbon Stocks for Vegetated Coastal Wetlands

Wetland Type	t C acre^{-1}
Palustrine Forested Wetland	112.24
Palustrine Scrub/Shrub Wetland	2.53
Palustrine Emergent Wetland	2.53
Estuarine Forested Wetland	112.24
Estuarine Scrub/Shrub Wetland	2.53
Estuarine Emergent Wetland	2.53
Eelgrass	0.29

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[34] According to the C-CAP land cover data, no estuarine forested wetlands are within Oregon across the years examined for the inventory.

Table A2. Root to Shoot Ratios for Vegetated Coastal Wetlands

Wetland Type	Root to shoot ratio
Palustrine Scrub/Shrub Wetland	1.15
Palustrine Emergent Wetland	1.15
Estuarine Scrub/Shrub Wetland	2.11
Estuarine Emergent Wetland	2.11
Eelgrass	1.3

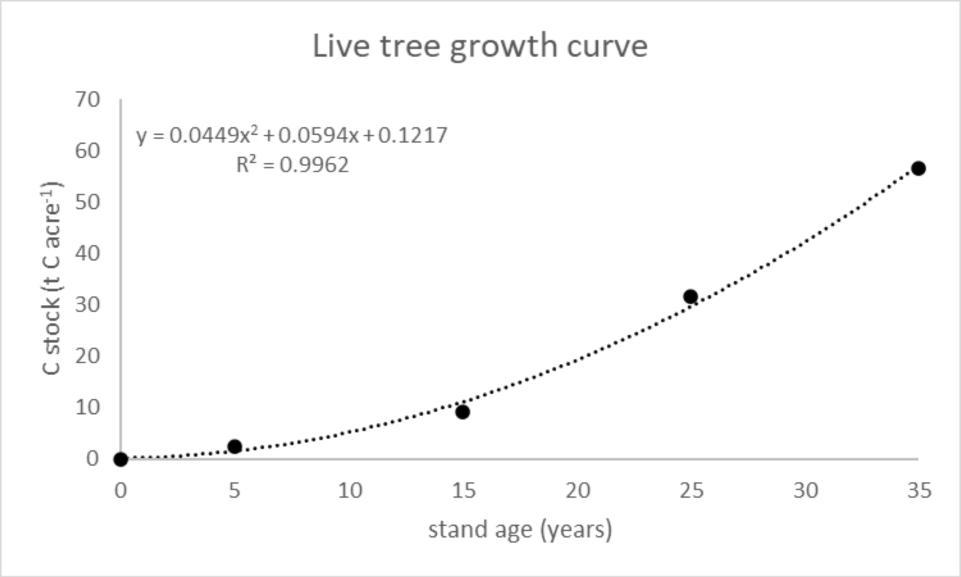

Figure A1. Estimates of Sitka spruce live tree biomass carbon stocks modeled over a 40-year period.

Soil Carbon Stock Changes

As described in the NGGI, soil carbon stock changes are estimated for Vegetated Coastal Wetlands for both mineral and organic soils although they are not differentiated. Soil carbon accumulation rates were derived for each wetland type from several regional datasets (Table A3; Crooks et al. 2014; Buffington 2017; Peck et al. 2019; Prentice et al. 2020). Scrub shrub wetlands were assumed to be high marsh. Soil carbon stocks to one meter, stratified by wetland class, are derived from Kauffman et al.

(2020; Table A3). The stock data were queried and downloaded from the Smithsonian Environmental Research Center (SERC) Coastal Carbon Atlas.[35]

As described in the NGGI, Tier 3 estimates of soil carbon removals associated with annual soil carbon accumulation on managed Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands, Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands, and Lands Converted to Vegetated Coastal Wetlands were developed with state-specific soil carbon removal factors multiplied by activity data of land area for each change class, respectively (Table A3). The methodology follows Eq. 4.7, Chapter 4 of the Wetlands Supplement, and is applied to the area of each change class on an annual basis. To estimate soil carbon stock loss to one meter due to Vegetated Coastal Wetlands Converted to Open Water Coastal Wetlands, no differentiation is made between organic and mineral soils since currently no statistical evidence supports disaggregation (Holmquist et al. 2018; Table A3).

Table A3. Annual Soil Carbon Accumulation Rates and Soil Carbon Stocks for Vegetated Coastal Wetlands

	Accumulation rate	**Stock (1 m)**
Wetland Type	**t C acre^{-1} yr^{-1}**	**t C acre^{-1}**
Palustrine Forested Wetland	0.41	142.4
Palustrine Scrub/Shrub Wetland	0.36	93.9
Palustrine Emergent Wetland	0.30	93.9
Estuarine Forested Wetland	0.41	142.4
Estuarine Scrub/Shrub Wetland	0.36	93.9
Estuarine Emergent Wetland	0.30	93.9
Eelgrass	0.11	41.5

Dead Organic Matter

As described in the NGGI, dead organic matter (DOM) carbon stocks, which include litter and dead wood stocks for palustrine forested wetlands, are estimated using Tier 2 estimates presented in Smith et al. (2006). Data on DOM carbon stocks are not currently available for either palustrine or estuarine scrub/shrub wetlands but will be included in future Inventory iterations when data are available. Annual rates of accumulation for mature tidal forests in Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands – 0.15, 0.08, and 0.08 tonnes C acre^{-1} yr^{-1} for down dead wood, standing dead trees, and forest floor carbon accumulation rates, respectively – were derived from Smith et al.

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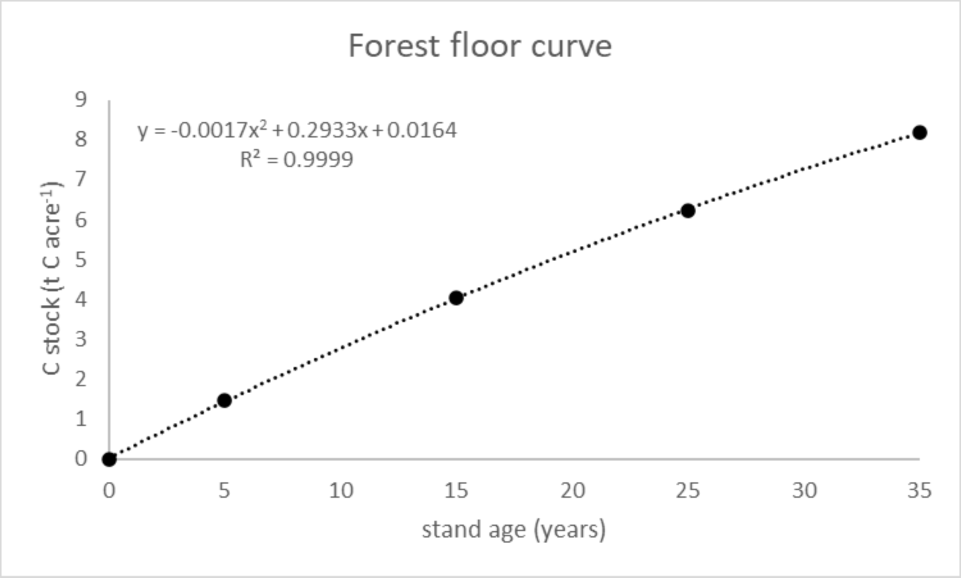
[35] https://serc.si.edu/coastalcarbon/data; accessed April 2021

(2006). Carbon stocks for down dead wood, standing dead trees and forest floor litter were estimated for mature stands – 22.8, 20.0, and 18.3 tonnes C acre^{-1} yr^{-1}, respectively (assuming 125 year old stand) – to account for loss when tidal forested wetlands are converted to open water. Down dead wood, forest floor litter accumulation, and standing dead tree curves were created from data in Smith et al. (2006) to estimate DOM carbon accumulation with conversion of open water to tidal forested wetlands (Figure A2 through Figure A4). Trends in land cover change are derived from the NOAA C-CAP dataset and extrapolated to cover the entire 1990 to 2019 time series. Conversion to open water results in emissions of all DOM carbon stocks during the year of conversion; therefore, emissions are calculated by multiplying the C-CAP derived area of vegetated coastal wetlands lost that year by its Tier 2 DOM carbon stock.

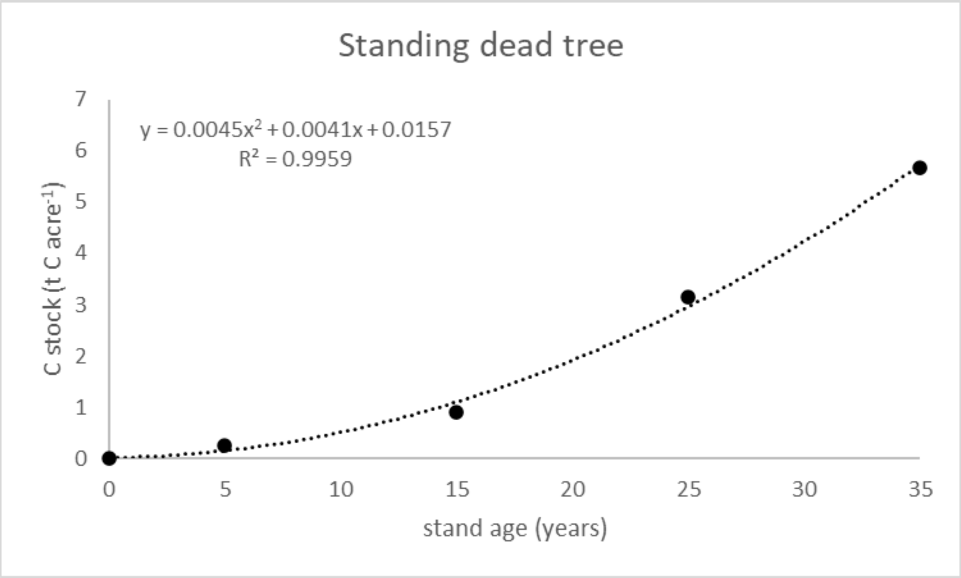
Source: Smith et al. 2006

Figure A2. Estimates of Sitka spruce down dead wood biomass carbon stocks modeled over a 40-year period.



Source: Smith et al. 2006

Figure A3. Estimates of Sitka spruce forest floor (litter) biomass carbon stocks modeled over a 40-year period.



Source: Smith et al. 2006

Figure A4. Estimates of Sitka spruce standing dead tree biomass carbon stocks modeled over a 40-year period.

Soil Methane Emissions

As described in the NGGI, Tier 1 estimates of CH_4 emissions for Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands and Lands Converted to Vegetated Coastal Wetlands are derived from the same wetland map used in the analysis of wetland soil carbon fluxes in combination with default CH_4 emission factors provided in Table 4.14 of the Wetlands Supplement. The methodology follows Equation 4.9, Chapter 4 of the Wetlands Supplement; the Tier 1 emissions factor, 78.4 kg CH_4 acre^{-1} yr^{-1}, is multiplied by the area of palustrine coastal wetlands for each change class. The CH_4 fluxes applied are determined based on salinity; only palustrine wetlands are assumed to emit CH_4. Estuarine coastal wetlands in the C-CAP classification include wetlands with salinity less than 18 PSU, a threshold at which methanogenesis begins to occur (Poffenbarger et al. 2011), but the dataset currently does not differentiate estuarine wetlands based on their salinities and as a result CH_4 emissions from estuarine wetlands are not included at this time.

A1.2 Calculation of GHG emissions and removals estimates

Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands

Across the entire reporting period, Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands are a net sink of CO_2 (Table A4). In 2019, coastal wetlands sequestered -51.9 kt CO_2e, largely driven by biomass and DOM accumulation in palustrine forested wetlands. Since the majority of tidal wetlands within Oregon are palustrine, CH_4 emissions were significant.

Table A4. Net CO_2 Flux from Carbon Stock Changes in Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands (kt CO_2e)

Year	1990	2005	2015	2016	2017	2018	2019
Biomass Carbon Flux	(76.4)	(70.5)	(67.6)	(67.6)	(67.6)	(67.5)	(67.5)
Dead Organic Matter Carbon Flux	(15.3)	(14.3)	(13.3)	(13.3)	(13.3)	(13.3)	(13.3)
Soil Carbon Flux	(80.8)	(79.6)	(79.5)	(79.5)	(79.6)	(79.7)	(79.7)
Net CH_4 Flux	109.5	107.7	108.2	108.3	108.4	108.5	108.6
Total Carbon Stock Change	**(63.0)**	**(56.7)**	**(52.2**	**(51.1)**	**(51.1)**	**(52.0)**	**(51.9)**

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Emissions from Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands

Loss of coastal wetlands to open water, recognized as Vegetated Coastal Wetlands Converted to Unvegetated Coastal Wetlands, drives an emission of 4.5 kt CO_2e over recent years, with the majority of that, 3.5 kt CO_2e, from soils.

Table A5. Net CO_2 Flux from Carbon Stock Changes in Vegetated Coastal Wetlands Converted to Unvegetated Open Water Coastal Wetlands (kt CO_2e)

Year	1990	2005	2015	2016	2017	2018	2019
Biomass Carbon Flux	0	7.9	0.7	0.7	0.7	0.7	0.7
Dead Organic Matter Carbon Flux	0	3.2	0.2	0.2	0.2	0.2	0.2
Soil Carbon Flux	0	33.9	3.5	3.5	3.5	3.5	3.5
Total Carbon Stock Change	**0**	**45.0**	**4.5**	**4.5**	**4.5**	**4.5**	**4.5**

Note: Totals may not sum due to independent rounding.

Removals from Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands

Building of new wetlands from open water, recognized as Unvegetated Coastal Wetlands Converted to Vegetated Coastal, results each year in removal of 0.006 to 3.5 kt CO_2e. The increase over time can be attributed to restoration efforts within Oregon.

Table A6. Net CO_2 Flux from Carbon Stock Changes from Unvegetated Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands (kt CO_2e)

Year	1990	2005	2015	2016	2017	2018	2019
Biomass Carbon Flux	(+)	(0.06)	(1.5)	(1.6)	(1.7)	(1.8)	(1.9)
Dead Organic Matter Carbon Flux	0	(0.02)	(0.2)	(0.3)	(0.3)	(0.4)	(0.4)
Soil Carbon Flux	(+)	(0.02)	(0.9)	(1.0)	(1.0)	(1.1)	(1.2)
Total Carbon Stock Change	**(0.006)**	**(0.1)**	**(2.7)**	**(2.9)**	**(3.0)**	**(3.2)**	**(3.5)**

+ Absolute value does not exceed 0.005 kt CO_2e.

Note: Parentheses indicate net sequestration. Totals may not sum due to independent rounding.

Emissions and Removals from Lands Converted to Vegetated Coastal Wetlands

Since 1990, very little conversion from lands to vegetated coastal wetlands has occurred (see Table 5 in main report). Conversion of land to tidal palustrine ecosystems (forested and emergent) resulted in CH_4 emissions that nearly matched removals: 0.7 kt CO_2e (0.02 kt C). Loss of forest biomass through conversion of Forest Lands to Vegetated Coastal Wetlands resulted in biomass emissions. Combined with CH_4 emissions, conversion of Forest Land to Vegetated Coastal Wetlands is a net emission. Conversion of Other Lands results in net removals across the reporting period, driven by increases in tidal wetland biomass and soil carbon accumulation. Removals from palustrine forested wetlands DOM accrual occurred throughout the majority of the reporting period and ranged from -0.01 to -

0.07 kt CO_2e. Once any DOM values are collated and accounted for in estuarine and palustrine scrub shrub coastal wetlands, there will be additional carbon removals. Across all time periods, soil carbon accumulation resulting from Lands Converted to Vegetated Coastal Wetlands is a carbon sink and has ranged between -0.2 and -0.4 kt CO_2e (-0.05 and -0.11 kt C).

A1.3 Uncertainty and Time-Series Consistency

As described in the NGGI, estimates of uncertainty around all emissions factors need to be calculated to assess the potential range of values that could occur given variations in the source data. Underlying uncertainties in the estimates of soil and biomass carbon stock changes and CH_4 emissions include uncertainties associated with Tiers 1, 2 and 3 literature values of soil carbon stocks, biomass carbon stocks and CH_4 flux, assumptions that underlie the methodological approaches applied and uncertainties linked to interpretation of remote sensing data. Uncertainty includes differentiation of palustrine and estuarine community classes, which determines the soil carbon stock and CH_4 flux applied. Uncertainties for soil and biomass carbon stock data for all subcategories are not available and thus assumptions were applied using expert judgment about the most appropriate assignment of a carbon stock to a disaggregation of a community class. Because mean soil and biomass carbon stocks for each available community class are in a fairly narrow range, the same overall uncertainty was assigned to each, respectively (i.e., applying approach for asymmetrical errors, where the largest uncertainty for any one soil carbon stock referenced using published literature values for a community class; uncertainty approaches provide that if multiple values are available for a single parameter, the highest uncertainty value should be applied to the propagation of errors; IPCC 2000). Uncertainty for root to shoot ratios, which are used for quantifying belowground biomass, are derived from the Wetlands Supplement. Uncertainties for CH_4 flux are the Tier 1 default values reported in the Wetlands Supplement. Overall uncertainty of the NOAA C-CAP remote sensing product is 15%. This is in the range of remote sensing methods (±10-15%; IPCC 2003). However, there is significant uncertainty in salinity ranges for tidal and non-tidal estuarine wetlands and activity data used to apply CH_4 flux emission factors (delineation of an 18 PSU boundary) that will need significant improvement to reduce uncertainties. Current research conducted by the Pacific Northwest Blue Carbon Working Group on CH_4 emissions on both tidal and degraded wetlands should reduce this uncertainty in future updates of the OGGI. Details on the emission/removal trends and methodologies through time are described in more detail above. The combined uncertainty was calculated using the IPCC Approach 1 method of summing the squared uncertainty for each individual source (C-CAP, soil, biomass, DOM and CH_4) and taking the square root of that total.

Uncertainty estimates for Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands are presented in Tables A5 and A6 for each subsource (i.e., soil C, biomass C, DOM, and CH_4 emissions). The combined uncertainty across all subsources is +/-41.6%, which is primarily driven by the uncertainty in the CH_4 estimates because there is high variability in CH_4 emissions when the salinity is less than 18 PSU. In 1990, the total flux was -63.0 kt CO_2e, with lower and upper estimates of -36.8 and -89.2 kt CO_2e. In 2019, the total flux was -51.9 kt CO_2e, with lower and upper estimates of -30.3 and -73.5 kt CO_2e.

Table A7. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands in 1990 (kt CO_2e and Percent)

Source	1990 Estimate (kt CO_2 Eq.)	Uncertainty Range Relative to Estimate (kt CO_2 Eq.)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	(76.4)	(56.9)	(95.9)	-25.5	25.5
Dead Organic Matter Carbon Flux	(15.3)	(11.8)	(18.8)	-22.8	22.8
Soil Carbon Stock Change	(80.8)	(65.8)	(95.7)	-18.5	18.5
CH_4 emissions	109.5	76.8	142.1	-29.9	29.9
Total Flux	(63.0)	(36.8)	(89.2)	-41.6	41.6

Table A8. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands in 2019 (kt CO_2e and Percent)

Source	2019 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	(67.5)	(50.3)	(84.8)	-25.5	25.5
Dead Organic Matter Carbon Flux	(13.3)	(10.3)	(16.3)	-22.8	22.8
Soil Carbon Stock Change	(79.7)	(65.0)	(94.5)	-18.5	18.5
CH_4 emissions	108.6	76.2	141.1	-29.9	29.9
Total Flux	(51.9)	(30.3)	(73.5)	-41.6	41.6

Uncertainty estimates for Vegetated Coastal Wetlands Converted to Open Water Coastal Wetlands are presented in Tables A8 and A9 for each subsource. The combined uncertainty across all subsources is +/-26.6%. In 1990, the total flux was 0 kt CO_2e, with lower and upper estimates of 0 and 0 kt CO_2e. In 2019, the total flux was -4.5 kt CO_2e, with lower and upper estimates of 3.3 and 5.6 kt CO_2e.

Table A9. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes occurring within Vegetated Coastal Wetlands Converted to Open Water Coastal Wetlands in 1990 (kt CO_2e and Percent)

Source	1990 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	0	0	0	-25.5	25.5
Dead Organic Matter Carbon Flux	0	0	0	-22.8	22.8
Soil Carbon Stock Change	0	0	0	-17.0	17.0
Total Flux	0	0	0	-26.6	26.6

Table A10. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes occurring within Vegetated Coastal Wetlands Converted to Open Water Coastal Wetlands in 2019 (kt CO_2e and Percent)

Source	2019 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	0.7	0.5	0.8	-25.5	25.5
Dead Organic Matter Carbon Flux	0.2	0.2	0.3	-22.8	22.8
Soil Carbon Stock Change	3.5	2.9	4.1	-17.0	17.0
Total Flux	4.5	3.3	5.6	-26.6	26.6

Uncertainty estimates for Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands are presented in Tables A11 and A12 for each subsource. The combined uncertainty across all subsources is +/-32.6%. In 1990, the total flux was -0.006 kt CO_2e, with lower and upper estimates of -0.004 and -0.007 kt CO_2e. In 2019, the total flux was -3.4 kt CO_2e, with lower and upper estimates of -2.3 and -4.6 kt CO_2e.

Table A11. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands in 1990 (kt CO_2e and Percent)

Source	1990 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	(0.003)	(0.002)	(0.003)	-25.5	25.5
Dead Organic Matter Carbon Flux	0	0	0	-22.8	22.8
Soil Carbon Stock Change	(0.003)	(0.002)	(0.004)	-18.5	18.5
Total Flux	(0.006)	(0.004)	(0.007)	-32.6	32.6

Table A12. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Open Water Coastal Wetlands Converted to Vegetated Coastal Wetlands in 2019 (kt CO_2e and Percent)

Source	2019 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	(1.9)	(1.4)	(2.3)	-25.5	25.5
Dead Organic Matter Carbon Flux	(0.4)	(0.3)	(0.5)	-22.8	22.8
Soil Carbon Stock Change	(1.2)	(1.0)	(1.4)	-18.5	18.5
Total Flux	(3.5)	(2.3)	(4.6)	-32.6	32.6

Uncertainty estimates for Land Converted to Vegetated Coastal Wetlands are presented in Tables A13 and A14 for each subsource. The combined uncertainty across all subsources is +/-41.6%, which is primarily driven by the uncertainty in the CH_4 estimates because there is high variability in CH_4 emissions when the salinity is less than 18 PSU. In 1990, the total flux was 1.2 kt CO_2e, with lower and upper estimates of 0.7 and 1.7 kt CO_2e. In 2019, the total flux was -0.1 kt CO_2e, with lower and upper estimates of -0.06 and -0.15 kt CO_2e.

Table A13. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Land Converted to Vegetated Coastal Wetlands in 1990 (kt CO_2e and Percent)

Source	1990 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	0.9	0.7	1.1	-25.5	25.5
Dead Organic Matter Carbon Flux	0.1	0.10	0.16	-22.8	22.8
Soil Carbon Stock Change	(0.2)	(0.17)	(0.24)	-18.5	18.5
CH_4 emissions	0.4	0.3	0.5	-29.9	29.9
Total Flux	1.2	0.7	1.7	-41.6	41.6

Table A14. IPCC Approach 1 Quantitative Uncertainty Estimates for Carbon Stock Changes and CH_4 Emissions occurring within Land Converted to Vegetated Coastal Wetlands in 2019 (kt CO_2e and Percent)

Source	2019 Estimate (kt CO_2e)	Uncertainty Range Relative to Estimate (kt CO_2e)		Uncertainty Range Relative to Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass Carbon Stock Change	(0.3)	(0.2)	(0.4)	-25.5	25.5
Dead Organic Matter Carbon Flux	(0.09)	(0.07)	(0.1)	-22.8	22.8
Soil Carbon Stock Change	(0.4)	(0.3)	(0.5)	-18.5	18.5
CH_4 emissions	0.7	0.5	0.9	-29.9	29.9
Total Flux	(0.1)	(0.07)	(0.17)	-41.6	41.6

A1.4 QA/QC and Verification

As described in the NGGI, NOAA provided C-CAP land cover and land cover change mapping, all of which are subject to agency internal QA/QC assessment. Acceptance of final datasets into archive and dissemination are contingent upon the product compilation being compliant with mandatory QA/QC requirements (McCombs et al. 2016). Soil carbon stocks are derived from peer-reviewed literature and have been provided by Silvestrum Climate Associates and SERC’s Coastal Carbon Research

Coordination Network who reviewed summary tables against reviewed sources. Biomass carbon stocks are derived from peer-review literature and reviewed by Silvestrum Climate Associates prior to publishing and by the peer-review process during publishing. A team of two evaluated and verified there were no computational errors within the calculation worksheets. Soil and biomass carbon stock change data are based upon peer-reviewed literature and CH_4 emission factors derived from the Wetlands Supplement.

A1.5 Planned Improvements

Administered by the Smithsonian Environmental Research Center, the Coastal Carbon Research Coordination Network has established an international database of soil carbon stock and biomass estimates for coastal wetlands.[36] This dataset is updated periodically. Refined error analysis combining land cover change and carbon stock estimates will be provided as new data are incorporated. Through this work, a model is in development to represent updated changes in soil carbon stocks for tidal wetlands.

Work is currently underway to examine the feasibility of incorporating eelgrass sediments and biomass carbon stocks into all Vegetated Coastal Wetlands estimates. Additionally, investigation into quantifying the distribution, area, and emissions resulting from impounded waters (i.e., coastal wetlands where tidal connection to the ocean has been restricted or eliminated completely) is underway.

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[36] https://serc.si.edu/coastalcarbon

Appendix 2: Initial Compilation of Data Needs

The following table is an initial, non-exhaustive list of research needs, resources, and estimated costs (where information is available). This table can be a starting point for a blue carbon research prioritization plan.

Data Categories	**Needs/Opportunities**	**Existing Resources**	**Enhancements/costs (where estimates are available)**
Comprehensive inventory of restoration opportunities for Oregon estuaries	Comprehensive mapping of restored (passively or actively), restorable and least disturbed tidal wetlands to help refine future OGGI assessments and facilitate tidal wetland protection and restoration work of local and regional planners, watershed councils and restoration practitioners. Mapping would include additional spatial data layers that define relevant landscape scale attributes e.g., salinity (where available), sea level rise extent and landward migration zones, and (where available) spatial data layer quantifying blue carbon values (C sequestration rates, carbon stocks values, GHG emissions)	Coastal and Marine Ecological Classification Standard (CMECS) Biotic Component layer https://appliedeco.org/wp-content/uploads/ Brophy_2019_Oregon_tidal_swamp_and_marsh_losses_FINAL_Dec2019.pdf NOAA's Coastal Change Analysis Program (C-CAP) and http://arcg.is/1LSSeT;	Higher resolution C-CAP mapping (Pilot 1 meter resolution C-CAP data for coastal areas (approx. $650,000 for entire state)
Comprehensive mapping of submerged aquatic vegetation (eelgrass, kelp)	Consistent mapping of submerged aquatic vegetation in all (42) Oregon estuaries to help improve knowledge of the contribution of these habitats for climate mitigation (including incorporating eelgrass into the OGGI baseline), resiliency (localized ocean acidification amelioration), and	Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) Current eelgrass extent from ODFW's SEACOR effort has been incorporated into the Biotic Component Layer of CMECS.	Cost estimates (based on personal communication with ODFW staff) to expand mapping to all estuaries in the state to support multiple policy priorities (fisheries, resilience, etc.): 3

	SAV habitat changes due to sea level rise.	The U.S. EPA also collected data from 2004-2007 for seven estuaries in Oregon. The data layer displays both native and non-native eelgrass beds. Oregon Coastal Atlas website.	years/9 staff/ $3.3 million total
Carbon science	GHG emissions data and additional carbon sequestration rate data for least disturbed, restored, and disturbed (converted to agriculture lands) tidal wetlands in the Pacific Northwest (PNW). Collection of continuously recording gas flux data at select sites to refine GHG emissions dynamics in least disturbed, restored, and disturbed tidal wetlands in the PNW to improve measurements of net ecosystem carbon balance and annual methane fluxes. Quantification of lateral movement of carbon in least disturbed, restored, and disturbed tidal wetland sites in the PNW under a range of site conditions and including carbon exported from wetland biomass and soils, fate of eroded carbon, and fate of allochthonous carbon passing through estuary.	Pacific Northwest Blue Carbon Working Group (PNWBCWG) projects: *Funding secured from the National Estuarine Research Reserve System Science Collaborative and the National Oceanic and Atmospheric Administration (NOAA) Ecological Effects of Sea Level Rise (ESLR) program and include sampling gas flux using static chambers at replicate sites within multiple PNW estuaries (330 total gas flux sample locations at 55 sites in 7 PNW estuaries).* *Funding pending from National Science Foundation* Smithsonian Environmental Research Center (SERC) Coastal Carbon Atlas https://serc.si.edu/coastalcarbon/data	
Funding (private, public)	Assessment of financing opportunities related to restoration	PNWBCWG's Scoping Assessment for Pacific	Expertise related to assessing financing

	of forested and scrub shrub tidal wetlands. Inventory of existing government programs and incentives (e.g., tax credits, tax deferrals, grants, etc.) that can be applied to blue carbon enhancement (state and federal levels) or could be modified to do so. Assessment of knowledge gaps, barriers, and enabling conditions required for public and private funding opportunities based on experiences to date in other states, internationally.	Northwest Blue Carbon Finance Projects (Crooks et al. 2020)	potential & preparing applications: approx. $200,000

Literature Cited

Beheshti, K. and M. Ward (2021) Eelgrass Restoration on the U.S. West Coast: A Comprehensive Assessment of Restoration Techniques and Their Outcomes. Prepared for the Pacific Marine and Estuarine Fish Habitat Partnership.

Blackmon, D., T. Wyllie-Echeverria, and D.J. Shafer (2006) The role of seagrasses and kelps in marine fish support. *Wetland Regulatory Assistance Program*, 1–22.

Brophy, L.S. and M.J. Ewald (2017) Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future. Prepared for: MidCoast Watersheds Council, Newport, OR.

Brophy, L.S., C.M. Greene, V.C. Hare, B. Holycross, A. Lanier, W.N. Heady, K. O'Connor, H. Imaki, T. Haddad, and R. Dana (2019) Insights into estuary habitat loss in the western United States using a new method for mapping maximum extent of tidal wetlands. *PloS one* 14(8): p.e0218558.

Brophy, L.S. (2019) Comparing historical losses of forested, scrub-shrub, and emergent tidal wetlands on the Oregon coast, USA: A paradigm shift for estuary restoration and conservation. Prepared for the Pacific States Marine Fisheries Commission and the Pacific Marine and Estuarine Fish Habitat Partnership. Estuary Technical Group, Institute for Applied Ecology, Corvallis, OR, USA.

Buffington, K. (2017) Improving projections of tidal marsh persistence under climate change with remote sensing and site-specific data. Dissertation. Oregon State University.

Calloway, M., D. Oster, H. Berry, T. Mumford, N. Naar, B. Peabody, L. Hart, D. Tonnes, S. Copps, J. Selleck, B. Allen, and J. Toft (2020) Puget Sound kelp conservation and recovery plan. Prepared for NOAA-NMFS, Seattle, WA. 52 pages plus appendices. Available at: https://nwstraits.org/our-work/kelp/.

Christie H, N.M. Jorgensen, K.M. Norderhaug, and E. Waage-Nielsen (2003) Species distribution and habitat exploitation of fauna associated with kelp (Laminaria hyperborea) along the Norwegian coast. J Mar Biol Assoc UK 83:687–699.

Crooks, S., J. Rybczyk, K. O'Connell, D. Devier, K. Poppe, and S. Emmett-Mattox (2014) Coastal blue carbon opportunity assessment for the Snohomish Estuary: The climate benefits of estuary restoration. Report by Environmental Science Associates, Western Washington University, EarthCorps, and Restore America's Estuaries.

Crooks, S., A.E. Sutton-Grier, T.G. Troxler, N. Herold, B. Bernal, L. Schile-Beers, and T. Wirth (2018) Coastal wetland management as a contribution to the US National Greenhouse Gas Inventory. *Nature Climate Change* 8(12): 1109-1112.

Crooks, S., L. Beers, S. Settelmyer, E. Swails, S. Emmett-Mattox, and C. Cornu (2020) Scoping Assessment for Pacific Northwest Blue Carbon Finance Projects. A report by Silvestrum Climate Associates, TerraCarbon LLC, Strategic Solutions LLC and the Institute for Applied Ecology.

Davis, M. J., I. Woo, C.S. Ellings, S. Hodgson, D.A. Beauchamp, G. Nakai, and S.E. De La Cruz (2019) Freshwater tidal forests and estuarine wetlands may confer early life growth advantages for delta-reared chinook salmon. *Transactions of the American Fisheries Society* 148(2): 289-307.

EPA (2021) Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990 - 2019. EPA 430-R-21-005.

Filbee-Dexter, K. And T. Wernberg (2020) Substantial blue carbon in overlooked Australian kelp forests. *Scientific Reports* 10: 12341.

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): e72469.

Gundersen, H., T. Bryan, W. Chen, and F.E. Moy (2016) Ecosystem Services: In the Coastal Zone of the Nordic Countries. Nordic Council of Ministers.

Holmquist, J. R., L. Windham-Myers, N. Bliss, S. Crooks, J.T. Morris, J.P. Megonigal, J. Callaway, J. Drexler, M.C. Ferner, M.E. Gonneea, K.D. Kroeger, L. Schile-Beers, I. Woo, K. Buffington, J. Breithaupt, B.M. Boyd, L.N. Brown, N. Dix, L. Hice, B. P. Horton, G.M. MacDonald, R.P. Moyer, W. Reay, T. Shaw, E. Smith, J.M. Smoak, C. Sommerfield, K. Thorne, D. Velinsky, E. Watson, K. Wilson Grimes and M. Woodrey (2018) Accuracy and Precision of Tidal Wetland Soil Carbon Mapping in the Conterminous United States. *Scientific Reports* 8(1): 9478.

IPCC (2000) Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Quantifying Uncertainties in Practice, Chapter 6. Penman, J., D. Kruger, I. Galbally, T. Hiraishi, B. Nyenzi, S. Emmanuel, L. Buendia, R. Hoppaus, T. Martinsen, J. Meijer, K. Miwa and K. Tanabe (eds). Institute of Global Environmental Strategies (IGES), on behalf of the Intergovernmental Panel on Climate Change (IPCC): Hayama, Japan.

IPCC (2003) Good Practice Guidance for Land Use, Land-Use Change and Forestry. LUCF Sector Good Practice Guidance, Chapter 3. Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner (eds). Institute of Global Environmental Strategies (IGES), on behalf of the Intergovernmental Panel on Climate Change (IPCC): Hayama, Japan.

IPCC (2014) 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. Hiraishi, T., T. Krug, K. Tanabe, N. Srivastava, J. Baasansuren, M. Fukuda, and T.G. Troxler (eds.). Published: IPCC, Switzerland.

Kauffman, J.B., L. Giovanonni, J. Kelly, N. Dunstan, A. Borde, H. Diefenderfer, C. Cornu, C. Janousek, J. Apple, and L. Brophy (2020) Total ecosystem carbon stocks at the marine-terrestrial interface: blue carbon of the Pacific Northwest Coast, United States. *Global Change Biology* 26(10): 5679-5692.

Krause-Jensen, D., P. Lavery, O. Serrano, N. Marbà, P. Masque and C.M. Duarte (2018) Sequestration of macroalgal carbon: the elephant in the Blue Carbon room. *Biology Letters* 14(6): 20180236.

Kroeger, K., S. Crooks, S. Moseman-Valtierra, and J. Tang (2017) Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. *Scientific Reports* 7:10.1038/s41598-017-12138-4.

Lanier, A., T. Haddad, L. Mattison, and L. Brophy (2014) Core CMECS GIS Processing Methods - Oregon Estuary Project of Special Merit. Oregon Coastal Management Program, Oregon Dept. of Land Conservation and Development, Salem, OR.

Lanier, A., T. Haddad, L. Brophy, and A. D'Andrea (2018) Core CMECS GIS Processing Methods, Phase II - Oregon Estuary Project of Special Merit. Oregon Coastal Management Program, Oregon Dept. of Land Conservation and Development, Salem, OR.

Marcoe, K. and S. Pilson (2017) Habitat change in the lower Columbia River estuary, 1870–2009. *Journal of Coastal Conservation* 21(4): 505-525.

McCombs, J.W., N.D. Herold, S.G. Burkhalter, and C.J. Robinson. (2016) Accuracy Assessment of NOAA Coastal Change Analysis Program 2006-2010 Land Cover and Land Cover Change Data. *Photogrammetric Engineering & Remote Sensing* 82: 711-718.

National Oceanic and Atmospheric Administration, Office for Coastal Management (2020) Coastal Change Analysis Program (C-CAP) Regional Land Cover. Charleston, SC: NOAA Office for Coastal Management. Accessed May 2021 at https://coast.noaa.gov/dataviewer/#/landcover/search/.

Peck, E.K., R.A. Wheatcroft, and L.S. Brophy (2020) Controls on sediment accretion and blue carbon burial in tidal saline wetlands: Insights from the Oregon coast, USA. *Journal of Geophysical Research: Biogeosciences* 125(2): e2019JG005464.

Pendleton, L (ed). (2009) The economic and market value of coasts and estuaries: what's at stake. Produced by: Restore America's Estuaries. Arlington VA.

Phillips, R. (1984) Ecology of eelgrass meadows in the Pacific Northwest: A community profile. *Fish Wildlife*. vol. FWS/OBS-84. 85pp.

Poffenbarger, H. J., B.A. Needelman, and J.P. Megonigal (2011) Salinity influence on methane emissions from tidal marshes. *Wetlands* 31(5): 831-842.

Prentice, C., K.L. Poppe, M. Lutz, E. Murray, T.A. Stephens, A. Spooner, M. Hessing-Lewis, R. Sanders-Smith, J.M. Rybczyk, J. Apple, and F.T. Short (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): p.e2019GB006345.

Richart, A.M., M. Ward, T.M. Hill, E. Sanford, K.J. Kroeker, Y. Takeshita, S. Merolla, P. Shukla, A.T. Ninokawa, K. Elsmore, B. Gaylord (2021) Coast-Wide Evidence of Low Ph Amelioration by Seagrass Ecosystems. *Global Change Biology* 27(11): 2580-2591.

Roque BM, M. Venegas, R.D. Kinley, R. de Nys, T.L Duarte et al. (2021) Red seaweed (*Asparagopsis taxiformis*) supplementation reduces enteric methane by over 80 percent in beef steers. PLOS ONE 16(3): e0247820.

Sala, E., J. Mayorga, D. Bradley, R.B. Cabral, T.B. Atwood, A. Auber, W. Cheung, C. Costello, F. Ferretti, A.M. Friedlander, and S.D. Gaines (2021) Protecting the global ocean for biodiversity, food and climate. *Nature* 592(7854): 397-402.

Sherman, K., and L.A. DeBruyckere (2018) Eelgrass habitats on the U.S. West Coast. State of the Knowledge of Eelgrass Ecosystem Services and Eelgrass Extent. A publication prepared by the Pacific Marine and Estuarine Fish Habitat Partnership for The Nature Conservancy. 67pp

Silbiger, N. J., and C.J.B. Sorte (2018) Biophysical feedbacks mediate carbonate chemistry in coastal ecosystems across spatiotemporal gradients. *Scientific Reports* 8:796.

Smith, J.E., L.S. Heath, K.E. Skog, and R.A. Birdsey (2006) Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Gen. Tech. Rep. NE-343. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 216 p. 343.

Steneck RS, M.H. Graham, B.J. Bourque, D. Corbett, J.M. Erlandson, J.A. Estes, et al. (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. *Environmental Conservation* 29: 436-459.

Wang, Z.A., K. Kroeger, N.K. Ganju, M.E. Gonneea, and S.N. Chu (2016) Intertidal Salt Marshes Serve as an Important Source of Inorganic Carbon to the Coastal Ocean. *Limnology and Oceanography* 16: 1916-1931.

Woo, I., M.J. Davis, C.S. Ellings, S. Hodgson, J.Y. Takekawa, G. Nakai, and S.E. De La Cruz (2019) A mosaic of estuarine habitat types with prey resources from multiple environmental strata supports a diversified foraging portfolio for juvenile Chinook salmon. *Estuaries and Coasts* 42(7): 1938-1954.

Appendix 3: Pacific Northwest Coastal Wetlands - Co-Benefits

Ecosystem service co-benefits of including coastal blue carbon in Natural and Working Lands strategies	**Critical services common to marshland, tidal forested wetlands, and eelgrass meadows**	**Critical services provided by tidal salt marsh**	**Critical services provided by tidal forested wetlands (Sitka spruce-dominated swamps)**	**Critical services provided by eelgrass meadows**	**Supporting Oregon State Agency Plans and Policy**
Water quality	Nutrient cycling and transport, sediment retention and stabilization, and temperature regulation [1-6]	Salinity and temperature buffer zone [7], trap sediments and improve water quality before entry into fully marine systems [8]	Salinity buffer zone [4, 9], nutrient regulation and removal [10]	Temperature regulation [6], localized amelioration of ocean acidification and hypoxia [11-13], nutrient cycling [13, 14] and pH balance [13].	Ocean Acidification and Hypoxia Action Plan [15], Climate Change Adaptation Framework and Equity Blueprint [16]
Coastal shoreline protection	Erosion prevention [6, 17-19]	Storm wave attenuation [5, 17], flooding mediation [5, 6, 17]	Storm wave attenuation [5], flooding mediation [6, 10, 18]	Non-storm wave attenuation and sediment stabilization [5, 14, 19, 20].	Climate Change Adaptation Framework and Equity Blueprint [16]
Wildlife habitat and ecological support	Directly and indirectly numerous keystone and ecologically significant terrestrial and marine species [5, 6, 21], including the Endangered Coho salmon [8, 22]. Many are designated as Important Bird Areas [8].	Habitat for numerous insects, fish, small and large mammals, and migratory and resident shorebirds [5, 7, 8], including migrating tundra swans [1].	Support salmon population genetic diversity [22] and growth [4] and are highly productive to all trophic levels [8]. Habitat for mammals and sensitive migratory birds [8].	Important feeding grounds and sheltering habitat for pelagic and coastal fish [6, 23], resident [20] and sensitive migratory shorebirds (black brant rely almost entirely on eelgrass) [24], and the food chains they rely on [25, 26].	ODFW Climate and Ocean Change Policy [27], Climate Change Adaptation Framework and Equity Blueprint [16]
Natural resource dependent economies: commercial fisheries, recreational fisheries, recreation, wildlife viewing, on-water recreation	High primary productivity supports a variety of economically important species [8, 17, 21]. Coastal ecosystem fisheries make up ¾ of all Pacific Northwest commercial fishery landings: crabs, clams, oysters, and fish [8, 21]. Ecotourism/recreation: kayaking, bird watching, whale watching, etc. [8, 17, 25]	Highly productive juvenile salmon feeding and nursery ground [2, 5, 8, 9, 28], shellfish fishery [1, 21], oyster rearing grounds, and recreational fishing [8].	Highly productive juvenile salmon feeding ground [2, 8, 9], supports salmon fishery resilience and many other fish and shellfish industries [8]	Designated by the Pacific Fishery Management Council as Essential Fish Habitat [29]. Directly or indirectly supports important crab [20, 21, 23, 25], salmon [5, 20, 23, 25], bivalves (wild and aquaculture) [5, 20, 25], and other fisheries as nursery and feeding grounds [5, 6, 20, 21, 25].	Climate Change Adaptation Framework and Equity Blueprint [16]
Cultural Services	Coastal Tribal Nation ancestral territories and sustained cultural identity	Tribal Nation fisheries: salmon, eulachon, and lamprey [5, 10, 21]	Support Tribal Nation fishery species' juvenile stages [10].	Tribal Nation use of eelgrass plant material for cooking, housing materials [19, 20], and hunting grounds [20].	Climate Change Adaptation Framework and Equity Blueprint [16]

Citations (co-benefits)

1. Brophy, L.S. and K. So (2005) *Tidal Wetland Prioritization for the Umpqua River Estuary*. Green Point Consulting.
2. Brophy, L.S. and K. So (2005) *Tidal Wetland Prioritization for the Nehalem River Estuary*. Green Point Consulting.
3. Brophy, L.S. (2005) *Tidal wetland prioritization for the Siuslaw River Estuary*. Green Point Consulting.
4. Brophy, L.S. (2009) *Effectiveness Monitoring at Tidal Wetland Restoration and Reference Sites in the Siuslaw River Estuary: A Tidal Swamp Focus*. Green Point Consulting.
5. Swedeen, P., et al. (2008) *Understanding Oregon's Coastal Economy and Environment*. Audubon Society of Portland.
6. Hodgson, C. and A. Spooner (2016) *The K'ómoks and Squamish Estuaries: A Blue Carbon Pilot Project; Final Report to North American Partnership for Environmental Community Action (NAPECA)*. Comox Valley Project Watershed Society.
7. Brophy, L.S. and S. van de Wetering (2012) *Ni-les'tun Tidal Wetland Restoration Effectiveness Monitoring: Baseline: 2010-2011*. Corvallis, Oregon: Green Point Consulting, the Institute for Applied Ecology, and the Confederated Tribes of Siletz Indians.
8. Brophy, L.S. and M.J. Ewald (2017) *Modeling sea level rise impacts to Oregon's tidal wetlands: Maps and prioritization tools to help plan for habitat conservation into the future*. MidCoast Watersheds Council.
9. David, A.T., et al. (2015) Wetland Loss, Juvenile Salmon Foraging Performance, and Density Dependence in Pacific Northwest Estuaries. *Estuaries and Coasts* 39(3): 767-780.
10. Janousek, C., et al. (2019) *EESLR 2019 Ecohydrological impacts of sea-level rise on flood protection and blue carbon sequestration in Pacific Northwest tidal wetlands*. Oregon State University, Pacific Northwest National Laboratories; University of Oregon, Institute for Applied Ecology.
11. Oregon's Coordinating Council on Ocean Acidification and Hypoxia (2019) *Oregon Acidification and Hypoxia Species Spotlight*.
12. Shishido, C.M. (2013) *Carbon draw-down potential by the native eelgrass Zostera marina in Puget Sound and implications for ocean acidification management*. University of Washington.

13. Khangaonkar, T., et al. (2021) Projections of algae, eelgrass, and zooplankton ecological interactions in the inner Salish Sea – for future climate, and altered oceanic states. *Ecological Modelling* 441: 109420.
14. Hejnowicz, A.P., et al. (2015) Harnessing the climate mitigation, conservation and poverty alleviation potential of seagrasses: prospects for developing blue carbon initiatives and payment for ecosystem service programmes. *Frontiers in Marine Science* 2: 32.
15. Oregon's Coordinating Council on Ocean Acidification and Hypoxia (2018) *Ocean Acidification & Hypoxia Action Plan 2019-2025*. The Oregon Department of Land Conservation and Development.
16. State of Oregon (2021) *Oregon Climate Change Adaptation Framework*. Department of Land Conservation and Development.
17. Chastain, S.G., K. Kohfeld, and M.G. Pellatt (2018) Carbon Stocks and Accumulation Rates in Salt Marshes of the Pacific Coast of Canada. *Biogeosciences Discuss.* p. 1-45.
18. Crooks, S., et al. (2014) *Coastal Blue Carbon Opportunity Assessment for the Snohomish Estuary: The Climate Benefits of Estuary Restoration*.
19. United States Department of Agriculture (2011) *Plant Fact Sheet: Eelgrass (Zostera marina Linnaeus)*.
20. Mumford Jr., T.F. (2007) *Kelp and Eelgrass in Puget Sound*. Washington Department of Natural Resources, Aquatic Resources Division.
21. Lellis-Dibble, K.A., K.E. McGlynn, and T.E. Bigford (2008) *Estuarine fish and shellfish species in U.S. commercial and recreational fisheries : economic value as an incentive to protect and restore estuarine habitat.*
22. Brophy, L.S. (2019) *Comparing historical losses of forested, scrub-shrub, and emergent tidal wetlands on the Oregon coast, USA: A paradigm shift for estuary restoration and conservation*. Institute for Applied Ecology, Corvallis, Oregon, USA.
23. Thom, R.M., et al. (2003) Factors influencing spatial and annual variability in eelgrass (Zostera marina L.) meadows in Willapa Bay, Washington, and Coos Bay, Oregon, estuaries. *Estuaries* 26(4): 1117-1129.
24. Moore, J.E., et al. (2004) Staging of Pacific flyway brant in relation to eelgrass abundance and site isolation, with special consideration of Humboldt Bay, California. *Biological Conservation* 115(3): 475-486.

25. Plummer, M.L., et al. (2013) The Role of Eelgrass in Marine Community Interactions and Ecosystem Services: Results from Ecosystem-Scale Food Web Models. *Ecosystems* 16(2): 237-251.

26. Muething, K.A., et al. (2020) On the edge: assessing fish habitat use across the boundary between Pacific oyster aquaculture and eelgrass in Willapa Bay, Washington, USA. *Aquaculture Environment Interactions* 12: 541-557.

27. State of Oregon (2020) *ODFW Climate and Ocean Change Policy*. Oregon Department of Fish and Wildlife.

28. Hering, D.K., et al. (2010) Tidal movements and residency of subyearling Chinook salmon (*Oncorhynchus tshawytscha*) in an Oregon salt marsh channel. *Canadian Journal of Fisheries and Aquatic Sciences* 67(3): 524-533.

29. Pacific Fishery Management Council. *Fact sheet: Habitat and essential fish habitat*. 1/20/21 [cited 3/16/21; Available from: https://www.pcouncil.org/fact-sheet-habitat-and-essential-fish-habitat/.