Coastal Wetland Greenhouse Gas Inventory for the San Francisco Bay Estuary

Lisa Beers and Steve Crooks
Silvestrum Climate Associates

silvestrum
CLIMATE ASSOCIATES

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1 Overview

This report, conducted by Silvestrum Climate Associates, applies methods that adhere to the Intergovernmental Panel on Climate Change (IPCC) guidance from the 2013 IPCC Wetlands Supplement (IPCC 2014) to calculate greenhouse gas (GHG) emissions and removals from the approximately 59,000 acres of tidal coastal wetlands that occur within the San Francisco Bay Estuary (Figure 1). The report lays out the data, approaches, and steps for developing the GHG inventory. This analysis was the first to consider a refinement of the estuarine salinity class to better account for methane (CH_4) emissions – a potent GHG - in low salinity brackish wetlands. It also provides recommendations for improvements that could occur within the context of inventory updates.

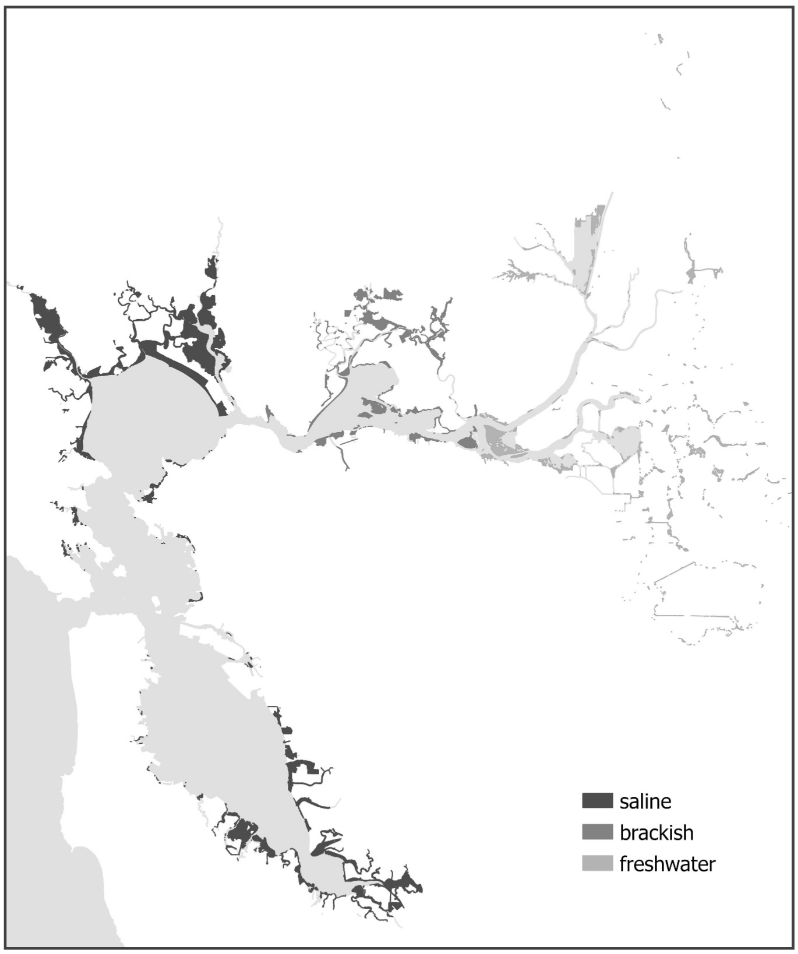

Figure 1. Map of coastal wetland salinity zones used for application of CH_4 emissions.

The analysis shows that from the period of 1990 to 2020, coastal wetlands in the San Francisco Estuary were a net carbon sink, with GHG removals increasing over the years because of significant coastal wetland restoration efforts occurring in the Bay. In 2020, these habitats sequestered approximately 43,600 metric tons CO_2 equivalent (CO_2e).

This analysis can serve as an example of how the methods could be applied to California for improving estimates of GHG emissions and removals from coastal wetlands in the state's Natural and Working Lands' greenhouse gas inventory (CGGI), as well as provide guidance for the California Air Resources Board (CARB), Natural Resources Agency and other agencies and states interested in incorporating "blue carbon" landscapes into GHG inventories and climate mitigation efforts.

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2 Methods

Below are high-level descriptions of elements that went into the creation of the coastal wetland GHG inventory for San Francisco Bay. More detailed methods are included in Appendix 1.

2.1 Coastal Wetland Ecosystems

The following land cover categories were tracked under the coastal wetlands: Vegetated Coastal Wetlands remaining Vegetated Coastal Wetlands; Vegetated Coastal Wetlands converted to Open Water; Open Water converted to Vegetated Coastal Wetlands; and Lands converted to Vegetated Coastal Wetlands[1]. Vegetated coastal wetlands converted to open water occurs when wetlands drown or are eroded. Open water converted to vegetated coastal wetlands occurs most commonly when coastal wetlands are restored but can occur through lateral expansion due to sedimentation. Lands converted to vegetated coastal wetlands occurs either through restoration or when non-tidal land is inundated due to sea-level rise.

Coastal wetlands were classified by wetland type and salinity. Wetland types follow the classification scheme used in NOAA's Coastal Change Analysis Program (C-CAP[2]) coastal area change datasets that

[1] 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 dead organic matter (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 because 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.

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

cover coastal regions of the conterminous United States, with some modifications discussed below. They include shrub/scrub and emergent wetlands. Tidal forested wetlands are included in the forest landcover category and as such are not included in this analysis. Another important coastal wetland ecosystem is seagrass, and eelgrass beds are present within San Francisco Bay. However, insufficient activity data are available currently to track changes over time.

C-CAP includes two salinity classes: palustrine (salinity range: 0 – 0.5 parts per thousand (ppt)) and estuarine (salinity range: > 0.5 ppt). In this analysis, the brackish salinity class was added to better estimate methane (CH_4) emissions from low salinity tidal wetlands. Methane production is inhibited at salinities greater than 18 ppt (Poffenbarger et al. 2011) and the C-CAP estuarine category is too broad to properly address this CH_4 threshold; therefore, CH_4 production has not been fully accounted for in the NGGI due to insufficient data on mapping salinity at a finer resolution. The salinity data for San Francisco Bay draw from many sources and the expert judgement of Lisa Beers, who has studied coastal wetlands in the San Francisco Bay Estuary since 2004 (Figure 1). To date, no spatial dataset has delineated estuarine from brackish or oligohaline tidal wetlands. Neither the fine-scale California Aquatic Resource Inventory (CARI[3]) or the Coastal and Marine Ecological Classification Standard (CMECS[4]) spatial datasets contain refined data on brackish wetland distributions.

2.2 Activity Data

Activity data refer to land use cover classification and change over time. The C-CAP coastal land cover change dataset was used to estimate coastal wetland change over time using all available image dates: 1996, 2001, 2006, 2010, and 2016. See Appendix 1 for the details on how the activity data were prepared. The tidal boundary for the Pacific coast of the conterminous Unites States developed by Brophy et al. (2019) was used, which delineates the spring higher high water tidal boundary based on tidal and elevation data and includes areas that were once tidally influenced. This includes the tidally influenced areas of the Sacramento San Joaquin Delta. The C-CAP rasters were clipped using this tidal spatial dataset. Since only five image dates are currently available for the C-CAP dataset, areas were interpolated by taking the area difference between each C-CAP year for each coastal wetland type, dividing by the number of years between the C-CAP image dates, and adding that value to areas for all years between those image dates. For the period between 1990 and 1995, we assumed the same yearly change determined between 1996 and 2001. For the period between 2017 and 2021, we used the same yearly change determined between 2010 and 2016. Data on coastal wetland restoration

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[3] San Francisco Estuary Institute (SFEI). 2017. "California Aquatic Resource Inventory (CARI) version 0.3." Accessed September 2021. http://www.sfei.org/data/ california-aquatic-resource-inventory-cari-version-03-gis-data

[4] Pacific Marine and Estuarine Fish Habitat Partnership, PSMFC GIS, Oregon Coastal Management Program (Department of Land Conservation and Development), NOAA-NWFSC, PC Trask. Accessed on January 21, 2022. https://www.pacificfishhabitat.org/data/estuarine-biotic-habitat/

locations and dates were collated to better delineate conversion of land and open water to coastal wetlands. Using a combination of the CARI and CMECS datasets, the nontidal areas for each C-CAP image date were mapped, while accounting for the timing of tidal wetland restorations that have occurred between 1996 and 2016. The area of nontidal wetlands is summarized throughout the reporting period (see Section 5.2 for more details). Areas for coastal wetlands remaining coastal wetlands, coastal wetlands converted to open water, and open water converted to coastal wetlands are in Tables 1 through 3; land converted to coastal wetland areas are found in Appendix 2.

Table 1: Area in acres of vegetated coastal wetlands remaining coastal wetlands.

Wetland Type	1990		2005		2016	2017	2018	2019	2020
Palustrine Scrub/Shrub Wetland	2,136		2,136		2,209	2,219	2,229	2,238	2,248
Palustrine Emergent Wetland	10,620		10,879		13,486	13,620	13,755	13,889	14,023
Brackish Scrub/Shrub Wetland	18		15		14	14	14	15	15
Brackish Emergent Wetland	12,171		13,782		14,046	14,046	14,046	14,046	14,045
Estuarine Scrub/Shrub Wetland	56		36		34	34	35	35	36
Estuarine Emergent Wetland	25,559		26,608		28,569	28,597	28,626	28,654	28,683

Table 2: Area in acres of vegetated coastal wetlands converted to open water.

Wetland Type	1990		2005		2016	2017	2018	2019	2020
Palustrine Scrub/Shrub Wetland	0		0		1	1	1	1	1
Palustrine Emergent Wetland	6		56		11	11	11	11	11
Brackish Scrub/Shrub Wetland	0		0		0	0	0	0	0
Oligo. Emergent Wetland	0		2		0	0	0	0	0
Estuarine Scrub/Shrub Wetland	0		0		0	0	0	0	0
Estuarine Emergent Wetland	3		3		0	0	0	0	0

Table 3: Area in acres of open water converted to vegetated coastal wetlands.

Wetland Type	1990		2005		2016	2017	2018	2019	2020
Palustrine Scrub/Shrub Wetland	0		2		11	11	11	11	11
Palustrine Emergent Wetland	1		92		120	120	120	120	120
Brackish Scrub/Shrub Wetland	0		0		0	0	0	0	0
Brackish Emergent Wetland	1		17		0	0	0	0	0
Estuarine Scrub/Shrub Wetland	0		0		0	0	0	0	0
Estuarine Emergent Wetland	3		13		29	29	29	29	29

2.3 Emissions Factors

An emissions factor, also known as a stock change factor, is a representative value that relates the quantity of a GHG source or sink with an activity associated with the release to or removal of that gas from the atmosphere. The following emissions factors were calculated and are, when possible, specific to San Francisco Bay:

- Soil carbon accumulation rates by habitat type (t C $acre^{-1}$ yr^{-1})
- Soil carbon lost with conversion to open water (t C $acre^{-1}$)
- Aboveground biomass by habitat type (t C $acre^{-1}$)
- Belowground biomass by habitat type (t C $acre^{-1}$)
- Methane (CH_4) emissions (t CO_2e $acre^{-1}$ yr^{-1})

Dead organic matter, which includes standing dead biomass and litter, should be included for scrub/shrub wetlands but no data were available at the time of this analysis. Table 4 includes all emissions factors used in this analysis and details of their calculations are included below. Following IPCC conventions, **positive values reflect a carbon sources** and **negative values reflect carbon removal.**

Table 4: Emissions factors for all coastal wetland carbon pools included in the inventory. Negative values represent carbon removal and positive values represent carbon sources.

		t C $acre^{-1}$ yr^{-1}	t C $acre^{-1}$				kg $acre^{-1}$ yr^{-1}
Wetland Type	**salinity**	**soil C accum.**	**soil C, 1m depth**	**AGB C**	**BGB C**	**Total C**	**CH_4**
Palustrine Scrub/Shrub	freshwater	-0.31	105.7	-1.90	-6.89	-8.79	78.39
Palustrine Emergent	freshwater	-0.31	105.7	-1.90	-6.89	-8.79	78.39
Estuarine Scrub/Shrub	brackish	-0.31	105.7	-1.39	-5.05	-6.45	0.53
Estuarine Emergent	brackish	-0.31	105.7	-1.39	-5.05	-6.45	0.53
Estuarine Scrub/Shrub	saline	-0.31	105.7	-1.39	-5.05	-6.45	0
Estuarine Emergent	saline	-0.31	105.7	-1.39	-5.05	-6.45	0

Where accum. = accumulation, AGB = aboveground biomass, BGB = belowground biomass, Total = total biomass

2.3.1 Soil Carbon Emissions Factors

Rates of soil carbon accumulation were collated from citations provided within the Smithsonian's Coastal Carbon Research Coordination Network's (CCRCN) Carbon Atlas, which is a user-generated international hub for soil carbon datasets, that included soil cores that had been radiometrically dated (Callaway et al. 2012, Drexler 2011). Rates were conservatively assumed to be the same across salinity ranges. Scrub/scrub wetlands were not represented within the available accumulation data; therefore, rates from emergent tidal wetlands were used.

Carbon stocks in the top one meter of soil were calculated using individual core data downloaded from the CCRCN Carbon Atlas (data sources: Watson and Byrne 2013, Callaway et al. 2012, Drexler et al. 2009; Schile-Beers et al, unpublished data). As with soil carbon accumulation rates, values for wetland types that were not represented within the dataset were derived from emergent wetland values and conservatively assumed to not vary with salinity[5]. The amount of soil carbon that is lost with conversion to open water conservatively was assumed to be 1 m deep and 100% of the carbon is assumed to be emitted to the atmosphere; this occurs when wetlands are eroded and is considered a conservative estimate since the amount of carbon emitted is highly variable and dependent on site-level hydrologic conditions. A refinement in this analysis was made when tidal wetlands were restored and converted to open water in that no soil carbon loss was assumed to occur.

2.3.2 Biomass Emissions Factors

Aboveground biomass stocks were derived from published data specific to San Francisco Bay (Byrd et al. 2018, 2020). Belowground biomass was estimated using the default root to shoot ratio for Mediterranean wetlands (3.63) in the 2013 IPCC Wetlands Supplement (IPCC 2014). When data for a given wetland type were not available, expert judgement was used to apply an appropriate value.

2.3.3 Methane and Nitrous Oxide Emissions

Methane emissions from tidal wetlands within a given watershed are roughly predictable as a function of porewater salinity, with a very precipitous drop off in CH_4 production with supply of marine-based sulfate. As such, coastal wetlands with salinities greater than 18 ppt are considered to have negligible CH_4. Methane emissions from low salinity brackish marshes were derived from unpublished data collected over eight years using an eddy covariance tower at Rush Ranch Open Space Preserve along Suisun Bay. The IPCC default CH_4 emissions factor, 78.39 kg CH_4 acre^{-1} yr^{-1}, was used for palustrine wetland types. Following IPCC guidance, a global warming potential of 25 was applied to convert CH_4 to CO_2e[6].

In the NGGI, nitrous oxide (N_2O) emissions are included for aquaculture within the United States and the data are based on a nationally aggregated summary. Since data are not state-based and there is

[5] This is supported by findings from Holmquist et al. (2018) who did not find statistical differences with salinity, wetland type, or soil type (mineral and organic) among soil carbon stocks in the top meter of nearly 2,000 cores collected within the conterminous United States.

[6] While the sustained global warming potential from Neubauer and Megonigal (2015) is considered to be a more accurate representation of the residency time of CH_4 in the atmosphere, IPCC guidance has not been updated since 2006.

no known aquaculture production with San Francisco Bay, N_2O emissions are not included in this analysis.

2.4 Calculation of Emissions and Removals

Emissions and removals were calculated by taking each respective emissions factor (Table 4) and multiplying that by the landcover area for each wetland type under each land use change scenario for every year. Values were converted to carbon dioxide equivalents and summed by year to produce estimates of the emissions and removals of coastal wetlands within the San Francisco Bay estuary. Like with the NGGI, simplifying assumptions were made that all biomass removals are accounted for during the first year of transition and that soil carbon accumulation rates are the same as for mature vegetated coastal wetlands[7] for open water and lands converted to vegetated coastal wetlands.

3 Results

Tidal coastal wetlands occupy approximately 59,000 acres within San Francisco Bay estuary, comprised of 16,271, 14,060, and 28,718 acres of palustrine, brackish, and saline wetlands, respectively, and are a net carbon sink. The carbon fluxes for all four wetland categories described above are summarized in Tables 5 and 6. The presentation of the combined emissions and removals in the tables for select years follows the reporting format for the NGGI. Across the entire reporting period, Coastal Wetlands Remaining Coastal Wetlands are a net carbon sink, with removals ranging from -35.6 to -56.2 kiloton (kt) CO_2e across the time series (consistent with the NGGI, removals are expressed as negative numbers). The majority of removals range between -35.6 and -40.4 kt CO_2e. In 2020 Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands are a net sink of -39.7 kt CO_2e, driven largely by soil carbon accumulation offsetting CH_4 emissions from palustrine and brackish 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 5.1 kt CO_2e, with the majority of that, 4.7 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 Coastal, results each year in removals of -0.3 in 1990 to 9.1 kt CO_2e. Removals have increased over the years due to the concerted restoration efforts within South San Francisco Bay and within the Napa Sonoma salt pond complexes. In all, Coastal Wetlands were a net sink of -43.6 kt CO_2e in 2020.

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[7] Soil carbon accumulation rates in restoring sites are highly variable and depend on geomorphic features, hydrology, and sediment supply and source. Furthermore, it is not known when accumulation rates change to match those of a mature tidal wetland. Therefore, it is challenging to apply a different rate specifically for this landcover change class.

Lands Converted to Vegetated Coastal Wetlands, which represent a relatively small portion of GHG removals due to few area changes, resulted in CO_2e removals of -0.5 kt CO_2e in 2020 (Table 5). Conversion of land classified as other (which includes bare, unconsolidated shoreline and scrub/shrub) to tidal wetlands resulted in greatest CO_2e removals: -0.6 kt CO_2e. The majority of conversion to coastal wetlands occurred within the palustrine emergent wetland category, which resulted in 1.5 kt CO_2e in CH_4 emissions.

Table 5: CO_2 Flux across all Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands (kt CO_2e; ND = no data).

Land Use/Carbon Pool	1990	2005	2016	2017	2018	2019	2020
Vegetated Coastal Wetlands Remaining Vegetated Coastal Wetlands	**(35.6)**	**(41.5)**	**(40.1)**	**(40.0)**	**(39.9)**	**(39.8)**	**(39.7)**
Biomass C Flux	(3.9)	(7.1)	(5.3)	(5.3)	(5.3)	(5.3)	(5.3)
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Flux	(56.9)	(60.2)	(65.7)	(65.9)	(66.1)	(66.3)	(66.5)
Net CH_4 flux	25.2	25.7	30.9	31.2	31.5	31.8	32.1
Vegetated Coastal Wetlands Converted to Unvegetated Open Water	**4.1**	**25.6**	**5.1**	**5.1**	**5.1**	**5.1**	**5.1**
Biomass C Flux	0.3	1.9	0.4	0.4	0.4	0.4	0.4
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Flux	3.8	23.7	4.7	4.7	4.7	4.7	4.7
Unvegetated Open Water Converted to Vegetated Coastal Wetlands	**(0.3)**	**(4.5)**	**(8.4)**	**(8.5)**	**(8.7)**	**(8.9)**	**(9.1)**
Biomass C Flux	(0.1)	(3.7)	(4.9)	(4.9)	(4.9)	(4.9)	(4.9)
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Flux	(0.1)	(0.8)	(3.5)	(3.6)	(3.8)	(4.0)	(4.2)
Net N_2O Flux from Aquaculture in Coastal Wetlands (MMT CO_2 Eq.)	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**
Total Biomass C Flux	(3.7)	(8.9)	(9.8)	(9.8)	(9.8)	(9.8)	(9.8)
Total Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Total Soil C Flux	(53.2)	(37.3)	(64.4)	(64.8)	(65.1)	(65.5)	(65.9)
Total CH_4 Flux	25.2	25.7	30.9	31.2	31.5	31.8	32.1
Total N_2O Flux	ND	ND	ND	ND	ND	ND	ND
Total C Flux (CO_2e)	(31.8)	(20.5)	(43.3)	(43.4)	(43.5)	(43.6)	(43.6)

Table 6: CO_2 Flux from C Stock Changes in Land Converted to Vegetated Coastal Wetlands (kt CO_2e).

Land Use/Carbon Pool	1990	2005	2016	2017	2018	2019	2020
Cropland Converted to Vegetated Coastal Wetlands	**4.5**	**4.2**	**1.13**	**0.86**	**0.58**	**0.31**	**0.03**
Biomass C Stock	(1.0)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Stock	(1.7)	(1.3)	(0.3)	(0.3)	(0.2)	(0.1)	(0.01)
Net CH_4 Flux	7.2	5.5	1.5	1.1	0.8	0.4	0.05
Forest Land Converted to Vegetated Coastal Wetlands	**0.1**	**0.001**	**0.0006**	**0.0006**	**0.0006**	**0.0006**	**0.0006**
Biomass C Stock	0	0	0	0	0	0	0
Dead Organic Matter C Flux	0.1	0.001	0.0006	0.0006	0.0006	0.0006	0.0006
Soil C Stock	0	0	0	0	0	0	0
Net CH_4 Flux	0	0	0	0	0	0	0
Grassland Converted to Vegetated Coastal Wetlands	**0**	**0.006**	**0.08**	**0.08**	**0.09**	**0.09**	**0.09**
Biomass C Stock	0	(0.005)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Stock	0	(0.00)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
Net CH_4 Flux	0	0.01	0.1	0.1	0.1	0.1	0.1
Other Land Converted to Vegetated Coastal Wetlands	**(5.5)**	**(5.2)**	**(1.4)**	**(1.2)**	**(1.0)**	**(0.8)**	**(0.6)**
Biomass C Stock	(3.8)	(3.2)	(0.8)	(0.8)	(0.8)	(0.8)	(0.8)
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Stock	(3.5)	(3.4)	(1.7)	(1.6)	(1.4)	(1.3)	(1.1)
Net CH_4 Flux	1.8	1.4	1.2	1.2	1.3	1.3	1.3
Settlements Converted to Vegetated Coastal Wetlands	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Biomass C Stock	0	0	0	0	0	0	0
Dead Organic Matter C Flux	ND	ND	ND	ND	ND	ND	ND
Soil C Stock	0	0	0	0	0	0	0
Net CH_4 Flux	0	0	0	0	0	0	0
Total Biomass Flux	**(4.9)**	**(3.2)**	**(0.9)**	**(0.9)**	**(0.9)**	**(0.9)**	**(0.9)**
Total Dead Organic Matter Flux	**0.1**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
Total Soil C Flux	**(5.2)**	**(4.6)**	**(2.1)**	**(1.9)**	**(1.6)**	**(1.4)**	**(1.2)**
Total CH_4 Flux	**9.0**	**6.9**	**2.8**	**2.5**	**2.2**	**1.8**	**1.5**
Total Flux	**(0.9)**	**(1.0)**	**(0.2)**	**(0.2)**	**(0.3)**	**(0.4)**	**(0.5)**

4 Uncertainty

Underlying uncertainties in the emissions factor estimates include uncertainties associated with literature values of soil, biomass and dead organic matter carbon stocks and CH_4 flux and uncertainties linked to interpretation of the C-CAP data. Mean soil and biomass carbon stocks for each available wetland class are in a fairly narrow range and the same overall uncertainty was assigned to each, respectively. Uncertainty for the root to shoot ratio and CH_4 flux are derived from the 2013 Wetlands Supplement (IPCC 2014) and that for dead organic matter of forest land converted to coastal wetlands is derived from IPCC (2003). Overall uncertainty of the NOAA C-CAP remote sensing product is 15%. The combined uncertainty was calculated using the IPCC Approach 1 method of summing the squared uncertainty for each individual source (C-CAP, soil, biomass, CH_4, and DOM) and taking the square root of that total.

Detailed uncertainty estimates are presented in Appendix 3 and are shown for each subsource (i.e., soil, biomass and CH_4 emissions) for years 1990 and 2020. The combined uncertainty across all subsources for each land use category are included in Table 7.

Table 7. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring in each land use category in 2020.

Source	2020 (kt CO_2e)	Uncertainty Range Relative to Land Use Category (kt CO_2e)		Uncertainty Range Relative to Land Use Category (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Coastal Wetlands Remaining Coastal Wetlands	(39.7)	(27.2)	(52.2)	-31.4	31.4
Coastal Wetlands converted to Open Water	5.1	6.0	4.3	-16.7	16.7
Open Water converted to Coastal Wetlands	(9.1)	(7.4)	(10.7)	-17.9	17.9
Land converted to Coastal Wetlands	(0.5)	(0.3)	(0.7)	-33.8	33.8

5 Recommendations for Future Improvements

While this GHG inventory for coastal wetlands of San Francisco Bay estuary follows the same methods employed for the national GHG inventory, there are improvements that can be made for a more comprehensive analysis.

5.1 Seagrass

Seagrass meadows, specifically eelgrass, are a coastal wetland ecosystem that is not currently included in this inventory or in the U.S. inventory. Carbon stock data are available for eelgrass beds within California, in addition to Tier 1 values provided within the 2013 Wetlands Supplement. However, there is not a comprehensive activity dataset that allows for quantifying seagrass area change over time. This is largely due to the inherent difficulty in mapping subaquatic vegetation. Once a spatial dataset is available that tracks area changes over time, eelgrass can be incorporated into the inventory.

5.2 Impounded Waters

The U.S. NGGI is exploring the inclusion of impounded waters with the release of the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The estimated area of impounded coastal wetlands, defined as palustrine and estuarine wetlands found in non-tidal or muted areas, in 2020 is 72,703 acres (Table 8). In a 2022 analysis conducted by Hydrofocus, San Francisco Estuary Institute and Silvestrum Climate Associates to quantify emissions and removals of impounded wetlands, among other ecosystems, within Suisun Bay and the Delta for CARB, it was estimated that the combined emissions and removals from CH_4 and soils for brackish and freshwater systems was 3.8 t CO_2e acre^{-1} yr^{-1} and 1.35 t CO_2e acre^{-1} yr^{-1}, respectively[8]. While these emissions were not calculated using the same methods as in this current analysis and there are not estimates for impounded saline wetlands, it is estimated that approximately 156 kt CO_2e was released from impounded brackish and freshwater wetlands in 2020. This is approximately four times greater than the combined CO_2e removals from vegetated coastal wetlands in the current analysis and points to the potential emissions reductions of reintroducing tidal connects. Further research needs to be conducted to improve the emissions and removals estimates for impounded wetlands in San Francisco Bay.

Table 8: Area and emissions estimates of impounded coastal wetlands within the San Francisco Bay estuary in 2020.

Salinity	**Area (acres)**	**Estimated emissions (kt CO_2e)**
saline	28,223	No data
brackish	39,223	149.0
freshwater	5,256	7.1

5.3 Restored Coastal Wetlands

The data availability of the location, size, and year of restored wetlands in San Francisco Bay estuary improved the estimates of CO_2e removals and emissions for areas that could be classified under the 'open water to vegetated coastal wetlands', 'land converted to vegetated coastal wetlands' and

[8] Data were summarized from eddy covariance flux towers and modeled soil emissions using SUBCALC (Deverel et al. 2016). https://ww2.arb.ca.gov/sites/default/files/2022-05/2022-draft-sp-appendix-i-nwl-modeling.pdf

'vegetated coastal wetlands converted to open water[9]' categories. Depending on antecedent conditions, site elevation, sediment supply, and location in the estuary, among many other factors, soil carbon accumulation rates in restoring sites can either be higher or lower than in mature ecosystems and can be quite variable (Callaway et al. 2012b[10]; Crooks et al. 2014). The same applies to CH_4 emissions. Therefore, it is challenging to determine an appropriate emissions factor and to decide a time after which rates are comparable to mature sites. There currently is not guidance within the 2013 IPCC Wetlands supplement to address this. More research is needed to understand these GHG dynamics in restoring sites to determine more appropriate emissions factors.

5.4 Salinity

This analysis was the first to consider a refinement of the estuarine salinity class to better account for CH_4 emissions in low salinity brackish wetlands. This delineation relied mostly upon expert judgement and species presence/absence. More work is needed to further refine the salinity mapping within the San Francisco Bay estuary and California writ large so that the emissions from this impactful GHG can be more accurately quantified.

6 Literature Cited

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[9] As noted previously, sometimes impounded wetlands are located in sites prior to restoration of tidal activity. This is often results in a land change classification of vegetated wetlands converted to open water and includes a corresponding loss of soil carbon stocks since the soils are assumed to be eroded.

[10] http://www.adaptingtorisingtides.org/project/corte-madera-baylands-conceptual-sea-level-rise-adaptation-strategy/marsh-sediment-accumulation-rates-callaway-et-al-2012/

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Appendix 1: Detailed GHG Inventory Methods

Software Used

- ArcPro version 2.9
- Microsoft Excel 365

Data Sources

Coastal Change Analysis Program (C-CAP)

- https://coast.noaa.gov/digitalcoast/data/ccapregional.html
- Citation: National Oceanic and Atmospheric Administration, Office for Coastal Management. “Name of Data Set.” Coastal Change Analysis Program (C-CAP) Regional Land Cover. Charleston, SC: NOAA Office for Coastal Management. Accessed March 2022 at www.coast.noaa.gov/htdata/raster1/landcover/bulkdownload/30m_lc/.

Coastal and Marine Ecological Classification Standard (CMECS) [11]

- https://www.pacificfishhabitat.org/data/estuarine-biotic-habitat/
  - Citation: Pacific Marine and Estuarine Fish Habitat Partnership, Pacific States Marine Fisheries Commission, Oregon Coastal Management Program, PC Trask. Accessed on January 21, 2022
  - Geodatabase used: PMEP_West_Coast_USA_Estuarine_Biotic_Habitat_V1
- https://www.pacificfishhabitat.org/data/estuary-extents
  - Pacific Marine and Estuarine Fish Habitat Partnership, PSMFC GIS, Oregon Coastal Management Program (Department of Land Conservation and Development), NOAA-NWFSC, PC Trask. Accessed on January 21, 2022
  - Geodatabase used: PMEP_West_Coast_USA_Estuary_Extent_V1

California Aquatic Resources Inventory (CARI)

- https://www.sfei.org/cari
- Citation: San Francisco Estuary Institute (SFEI). 2017. "California Aquatic Resource Inventory (CARI) version 0.3." Accessed January 21, 2022. http://www.sfei.org/data/ california-aquatic-resource-inventory-cari-version-03-gis-data
- An updated draft dataset that is not yet available to the public was shared by SFEI.

San Francisco Bay Salinity Zones

- Rationale: The C-CAP datasets define the class ‘estuarine’ as encompassing all salinities greater than 0.5 parts per thousand (ppt). To most accurately account for methane emissions, this salinity range should be separated into two ranges – 0.5 to 18 ppt (hereafter ‘mesohaline’) and

[11] Note that CMECS and PMEP (Pacific Marine and Estuarine Fish Habitat Partnership) are used interchangeably and refer to the same dataset. Depending on the layer used within geodatabase, either name is used.

>18 ppt (hereafter 'saline') – because methane production is inhibited at salinities greater than 18 ppt[12].

- Saline, oligohaline and freshwater zones were based on work by Schile (2012)[13] and further supported by Parker et al. (2011)[14] and Vasey et al. (2012)[15]. Neither the CMECS biotic nor CARI datasets differentiate saline from oligohaline/brackish areas so a new later was created for this analysis. The data sources are too many to list, but this salinity classification is back by at least 2 years of pore-water and channel water salinity data (measured every 15 minutes) collected as part of Schile (2012) and by vegetation classes that are representative of the salinities. I also have been working in San Francisco Bay tidal wetlands since 2004 and have a very strong knowledge based on field work experience. Figure 1 in Chapter 1 of Schile (2012) has been adopted by many in the Bay.

Emission Factor Determination

- Soil carbon accumulation rates for San Francisco Bay were derived from sources downloaded from the Coastal Carbon Atlas[16], which contains the most up to date references for soil carbon data. The papers that present results were accessed, and their calculated accumulation rates were used in lieu of recalculating them.
- Data on soil carbon stocks within the top meter were downloaded from the Coastal Caron Atlas and supplemented by unpublished data by Schile-Beers. Raw data were synthesized into carbon stock data.
- Aboveground biomass emission factors were obtained with Byrd et al. (2018,2020[17]). These papers contain the most comprehensive dataset for tidal wetland biomass to date and therefore no other data were compiled. Belowground biomass was determined using Tier 1 root to shoot ratios from the 2013 Wetlands Supplement[18].
- Dead organic matter and litter (cumulatively referred to as DOM) production are to be calculated for scrub/shrub and forested lands. Due to lack of DOM data on scrub/shrub habitats in California and an appropriate Tier 1 default value in the 2013 Wetlands Supplement, this carbon pool is not included in the inventory.

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[12] In the National GHG Inventory, any wetland classified as estuarine has no methane emissions because there is no further spatial refinement at the 18 ppt threshold in C-CAP. Therefore, we underestimate methane production in the Inventory. At the finer scale of San Francisco Bay, we can tease this out and this exercise is the first attempt to do so.

[13] Schile, L.M. (2012) Tidal Wetland Vegetation in the San Francisco Bay Estuary: Modeling Species Distributions with Sea-Level Rise. Dissertation. University of California, Berkeley.

[14] Parker, V.T, L.M. Schile, M.C. Vasey, and J.C. Callaway (2011) Efficiency in assessment and monitoring methods: scaling down gradient-directed transects. *Ecosphere* 2(9): 1-11.

[15] Vasey, M.C., V.T. Parker, J.C. Callaway, E.R. Herbert, and L.M. Schile (2012) Tidal wetland vegetation in the San Francisco Bay-Delta estuary. *San Francisco Estuary and Watershed Science* 10(2): 1-16.

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

[17] Byrd et al. 2018. ISPRS Journal of Photogrammetry and Remote Sensing, 139, 255-271; Byrd et al. 2020. ISPRS Journal of Photogrammetry and Remote Sensing, 166, 63-67.

[18] IPCC 2014. 2013 supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands. IPCC, Switzerland.

- The methane emission factor varied by salinity. Tidal wetlands with salinity greater than 18 ppt are assumed to have negligible emissions[8]. Annualized methane emission data collected from an eddy flux tower at Rush Ranch averaged over eight years were applied to tidal wetlands with salinity between 0.5 and 18 ppt[19]. The Tier 1 default value for freshwater tidal wetlands was applied[8].
- In the NGGI, nitrous oxide (N_2O) emissions are included for aquaculture within the United States and the data are based on a nationally aggregated summary. Since data are not state-based and there is no know aquaculture production with San Francisco Bay, N_2O emissions are not included in this analysis.

C-CAP layer processing and Determination of salinity zones

First, all C-CAP data layers were downloaded and clipped to only the tidal and formerly tidal extents of San Francisco Bay. Delineation of San Francisco Bay was accomplished manually by selecting polygons within the '*PMEP_West_Coast_USA_Estuary_Extent_V1'* feature class that were only within San Francisco Bay (Attribute: *Estuary Name*; polygons: *Sacramento-San Joaquin, Suisun-Grizzly Bays, San Pablo Bay, San Francisco Bay, South San Francisco Bay*) to create a new feature class. This feature class was used to clip each C-CAP raster using the *Extract by Mask* geoprocessing tool:

The C-CAP rasters have 24 values corresponding to landcover types, 22 of which are used in the GHG inventory. The table below shows the C-CAP values and corresponding classes and how they are grouped within the GHG Inventory:

Value	C-CAP class	Inventory Class	Value	C-CAP class	Inventory Class
2	Developed, high	settlement	14	Palustrine scrub shrub wetland	as is
3	Developed, medium	settlement	15	Palustrine emergent wetland	as is
4	Developed, low	settlement	16	Estuarine forested wetland	as is
5	Developed, open space	settlement	17	Estuarine scrub shrub wetland	as is
6	Cultivated crops	cultivated	18	Estuarine emergent wetland	as is
7	Pasture/hay	cultivated	19	Unconsolidated shore	other
8	Grassland	grassland	20	Bare land	other
9	Deciduous forest	forest	21	Open water	open water
10	Evergreen forest	forest	22	Palustrine aquatic bed[20]	open water
11	Mixed forest	forest	23	Estuarine aquatic bed	open water
12	Scrub/shrub	other	24	Tundra	N/A
13	Palustrine forested wetland	as is			

[19] Data provided by Lisamarie Windham-Myers.

[20] The resolution of both aquatic bed classes is not accurate enough to use for assessment of eelgrass in the inventory; therefore, they are grouped with open water as per guidance by C-CAP's Nate Herold.

To detect change in landcover classes between C-CAP image dates, the *Raster Calculator* tool was used to subtract one raster date from another (e.g. 1996 from 2001).

Next, the same process was used to extract the coverage of each C-CAP wetland type for each year. For each year and land cover classification, 'Raster Calculator' was used to extract only the area for that class (e.g. palustrine emergent wetland) using the SetNull expression.

These rasters are then used to extract areas within each C-CAP difference raster to determine the extent and nature of wetland landcover change. Starting with the differenced raster from 2001 to 1996, the '*Extract by Mask*' tool was used for all applicable wetland classes from each date to extract area that's only from those rasters. For example, the 1996 palustrine forested wetland raster (*SFB_1996_PFW*) was used to extract cells from the difference raster *SFB_01_min_96* to determine if anything that was palustrine forested wetland in 1996 changed to a different land cover type or remained the same in 2001. Additionally, the 2001 palustrine forested wetland raster (*SFB_2001_PFW*) was used to extract pixels from that same difference raster to determine if anything that was classified as palustrine forested wetland in 2001 was a different land cover type in 1996. This same process was repeated for all wetland types and difference rasters and all processes were done using Model Builder.

The next step is to extract areas by salinity zone to account for methane fluxes more accurately. The '*Extract by Mask*' process was used for all rasters above for each salinity zone. These processes were done using the Model Builder model. All attribute tables were opened and the data within each table was transcribed into Excel.

Determination of Nontidal Areas

To extract nontidal areas within San Francisco Bay, a combination of the CMECS and CARI datasets were used, as neither full encompassed impounded/managed areas or areas that are no longer tidal[21]. This was done because the emission factors calculated for this inventory apply specifically to tidal wetlands and it is uncertain whether they are appropriate to use in areas that are not tidal. But it is still very important to quantify the area of these muted/impounded/managed wetlands

The first step was to clip the CARI dataset to only include spatial data for San Francisco Bay. This was accomplished clipping "*CARI_OPC_Wetlands_Draft*" using the '*PMEP_SFBay*' layer discussed above.

Next, the CARI version 0.3[22] was used to create a tidal open water layer.. There was no non-manual way, such as 'Select by Attribute', to select specific attributes to create this layer since tidal flats (found

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[21] Note that CARI is has more detail in polygon classification than CMECS and would have been the preferred geodatabase to use if it fully covered the tidal extent.

[22] These open water polygons fully align with the updated CARI dataset so are interchangeable. I started all analyses with the 0.3 version, not knowing that there was an unreleased updated draft version, so whenever possible I kept the analyses with the older version to reduce duplicating processes that would result in the same data. Additionally, the older version was chosen so that there were fewer restored areas that would appear as open water. The aim was to have only open water bodies and rivers and nothing within current or former marsh habitat.

along river and bay margins) and marsh pannes (found within tidal wetlands) are combined under the same classification of 'Tidal Flat and Marsh Panne' under the attribute name 'leglabellevel1'. Therefore, manual selection of tidal flat areas to be included in the tidal open water was needed to accomplish this. This layer was used to remove tidal waters from the CARI dataset using the '*Pairwise Erase*' tool.

Next, all tidal vegetated wetlands were removed from the dataset created above. This was done by using the 'Select by Attribute' tool and deleting the following classes from the 'clicklabel' field to create a new shapefile[23]:

- Estuarine Saline Natural Intertidal Emergent
- Estuarine Saline Natural Subtidal Non-vegetated
- Estuarine Saline Natural Intertidal Non-vegetated
- Estuarine Non-saline Natural Intertidal Forested
- Estuarine Non-saline Natural Intertidal Non-vegetated
- Estuarine Non-saline Natural Intertidal Vegetated
- Riverine Natural Subtidal Non-vegetated
- Riverine Natural Subtidal Open Water
- Riverine Natural Tidal Emergent
- Riverine Unnatural Open Water

To fill in the areas that were not covered within the CARI dataset, the "*PMEP_West_Coast_USA_ Estuarine_Biotic_Habitat_V1*" layer was used. First, the 'Pairwise Erase' tool was used to remove the areas that the CARI dataset covered. There were remnants of tidal areas included with this clip and they were removed by using the 'Select by Attribute' tool and referencing the following values under the 'CMECS BC Name' field:

- Aquatic Vascular Vegetation
- Aquatic Vegetation Bed
- Brackish Emergent Tidal Marsh
- Brackish Tidal Scrub-shrub Wetland
- Emergent Tidal Marsh
- Tidal Forest/Woodland
- Tidal Scrub-shrub Wetland
- Unclassified (which equals water)

The nontidal areas of CARI and CMECS were merged using the '*Merge*' tool.

A shapefile was created to delineate tidal marsh restoration areas that have occurred between 1996 and 2016. This was done because some restored areas appear as restored and others are still classified

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The CMECS water body layer ('Unclassified') couldn't be used because there are many upland places that were erroneously categorized as water when it was urban and also included nontidal waterways within the open water classification.

[23] Note that there some iterations to accomplish the final feature class and these layers were not deleted in the process so that version control could be maintained. They are not included in the final geodatabase but the version control number is still included in the final product.

as not restored in both the CARI and CMECS data layers. The State of the Estuary reports for 2015[24] and 2019[25] list all restoration sites and dates and sites were hand-delineated. This shapefile was used to first erase any remnant polygons from the merging of the CMECS and CARI datasets for nontidal areas using the '*Pairwise Erase*' tool[26] and then this shapefile was merged with other shapefiles to create a layer that represents the extent of nontidal areas in 1996.

Next, nontidal feature classes need to be made for each C-CAP change period. To account for landcover changes that result from tidal restoration that has happened in San Francisco Bay between 2001 and 2016, a feature class was made for each C-CAP epoch (meaning 2001 to 2006 etc)[27].

Using the 'Pairwise Erase' tool, the relevant feature class was used to remove restorations that occurred between 2001 and 2006 from the nontidal layer. The same process was used for the remaining C-CAP change periods and restoration sites.

Each nontidal feature class was then used to extract those areas from each raster that was already differentiated by salinity class, wetland type, and year that was applicable to that restoration time period. These processes were completed using Model Builder. The attribute tables were opened and data were transcribed into Excel in the 'raw pixel counts nontidal' worksheet.

While working with the C-CAP rasters, a small area in the Napa/Sonoma salt pond complex was identified that was erroneously classified as palustrine emergent wetland when it was truly estuarine emergent wetland. There was no physical boundary separating these areas and was likely a result of different Landsat pixels used. This error is only present in the 1996 and 2001 C-CAP images. To correct for this, the error boundary was hand delineated '*Extract by Mask*' was used to isolate this area within the appropriate rasters containing C-CAP image differences following the same procedure as noted above. The attribute tables were opened and the data were transcribed into Excel

To determine the area of each wetland type that was converted to open water as a result of restoration, the same '*Extract by Mask*' process as described previously was followed using the restoration site feature classes above and the rasters containing the differenced C-CAP data for that same year combination for saline wetlands for each year. This was done up until the point where restoration occurred. The processes were completed using Model Builder. The attribute tables were opened and data were transcribed into Excel. These conversions due to restoration from wetland to open water are accounted for separately in the spreadsheets.

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[24] The State of the Estuary 2015, San Francisco Estuary Partnership.

[25] The State of the Estuary 2019, San Francisco Estuary Partnership.

[26] This was done to avoid duplicative and layered polygons

[27] This was done because, in many cases, restoration results in a landcover change from palustrine/estuarine emergent wetland (nontidal) to open water. In the inventory, it is assumed that the top meter of soil is lost when a wetland is converted to open water (e.g. erosion the Mississippi delta) but this is not the case in restoration sites. There might be some surface erosion or erosion through the development of channels but writ large this is not the case. Therefore it was important to specifically account for the areas that are restored and to not have conversions to water result in carbon emissions in this case.

Appendix 2: Area of Land converted to Coastal Wetlands

Table A2.1: Area in acres of land converted to vegetated coastal wetlands.

Land Type	Wetland Type	1990	2005	2016	2017	2018	2019	2020
Settlement	Palustrine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Settlement	Palustrine Emergent Wetland	0	0	0	0	0	0	0
Settlement	Oligo. Scrub/Shrub Wetland	0	0	0	0	0	0	0
Settlement	Oligo. Emergent Wetland	0	0	0	0	0	0	0
Settlement	Estuarine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Settlement	Estuarine Emergent Wetland	0	0	0	0	0	0	0
Cultivated	Palustrine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Cultivated	Palustrine Emergent Wetland	75	1	1	1	1	1	1
Cultivated	Oligo. Scrub/Shrub Wetland	0	0	0	0	0	0	0
Cultivated	Oligo. Emergent Wetland	0	0	0	0	0	0	0
Cultivated	Estuarine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Cultivated	Estuarine Emergent Wetland	0	0	0	0	0	0	0
Grassland	Palustrine Scrub/Shrub Wetland	0	1	0	0	0	0	0
Grassland	Palustrine Emergent Wetland	0	0	0	0	0	0	0
Grassland	Oligo. Scrub/Shrub Wetland	0	0	0	0	0	0	0
Grassland	Oligo. Emergent Wetland	0	0	0	0	0	0	0
Grassland	Estuarine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Grassland	Estuarine Emergent Wetland	0	0	0	0	0	0	0
Forest	Palustrine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Forest	Palustrine Emergent Wetland	0	0	0	0	0	0	0
Forest	Oligo. Scrub/Shrub Wetland	0	0	0	0	0	0	0
Forest	Oligo. Emergent Wetland	0	0	0	0	0	0	0
Forest	Estuarine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Forest	Estuarine Emergent Wetland	0	0	0	0	0	0	0
Other	Palustrine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Other	Palustrine Emergent Wetland	18	3	26	26	26	26	26
Other	Oligo. Scrub/Shrub Wetland	0	0	0	0	0	0	0
Other	Oligo. Emergent Wetland	129	5	0	0	0	0	0
Other	Estuarine Scrub/Shrub Wetland	0	0	0	0	0	0	0
Other	Estuarine Emergent Wetland	8	128	0	0	0	0	0

Appendix 3: Uncertainty Tables

Uncertainty estimates and greenhouse gas flux ranges for all landcover change classes are presented below for emissions and removals in 1990 and 2020. Parentheses indicate negative values, which represent CO_2e removals.

Table A3.1. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within vegetated coastal wetlands remaining vegetated coastal wetlands in 1990.

Source	1990 Flux Estimate (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2e)		Uncertainty Range Relative to Flux Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass C Stock Change	(3.9)	(3.2)	(4.5)	-16.4	16.4
Soil C Stock Change	(56.9)	(47.5)	(66.4)	-16.6	16.6
CH_4 emissions	25.2	17.6	32.7	-29.9	29.9
Total Wetland	**(35.6)**	**(24.4)**	**(46.8)**	**-31.4**	**31.4**

Table A3.2. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within vegetated coastal wetlands remaining vegetated coastal wetlands in 2020.

Source	2020 Flux Estimate (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2e)		Uncertainty Range Relative to Flux Estimate (%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass C Stock Change	(5.3)	(4.4)	(6.2)	-16.4	16.4
Soil C Stock Change	(66.5)	(55.4)	(77.5)	-16.6	16.6
CH_4 emissions	32.1	22.5	41.6	-29.9	29.9
Total Wetland	**(39.7)**	**(27.2)**	**(52.2)**	**-31.4**	**31.4**

Table A3.3. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within vegetated coastal wetlands converted to open water in 1990.

Source	1990 Flux Estimate (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2e)		Uncertainty Range Relative to Flux Estimate (%)	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Biomass C Stock Change	0.29	0.24	0.33	-16.4	16.4
Soil C Stock Change	3.8	3.2	4.4	-15.3	15.3
Total Wetland	**4.1**	**3.4**	**4.8**	**-16.7**	**16.7**

Table A3.4. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within vegetated coastal wetlands converted to open water in 2020.

Source	2020 Flux Estimate (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2e)		Uncertainty Range Relative to Flux Estimate (%)	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Biomass C Stock Change	0.4	0.3	0.5	-16.4	16.4
Soil C Stock Change	4.7	4.0	5.5	-15.3	15.3
Total Wetland	**5.1**	**4.3**	**6.0**	**-16.7**	**16.7**

Table A3.5. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within open water converted to vegetated coastal wetlands in 1990.

Source	1990 Flux Estimate (kt CO_2e)	Uncertainty Range Relative to Flux Estimate (kt CO_2e)		Uncertainty Range Relative to Flux Estimate (%)	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Biomass C Stock Change	(0.15)	(0.13)	(0.18)	-16.4	16.4
Soil C Stock Change	(0.13)	(0.11)	(0.16)	-16.6	16.6
Total Wetland	**(0.29)**	**(0.24)**	**(0.34)**	**-17.9**	**17.9**

Table A3.6. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within open water converted to vegetated coastal wetlands in 2020.

Source	**2020 Flux Estimate (kt CO_2e)**	**Uncertainty Range Relative to Flux Estimate (kt CO_2e)**		**(%)**	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Biomass C Stock Change	(4.9)	(4.1)	(5.7)	-16.4	16.4
Soil C Stock Change	(4.2)	(3.5)	(4.9)	-16.6	16.6
Total Wetland	**(9.1)**	**(7.4)**	**(10.7)**	**-17.9**	**17.9**

Table A3.7. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within land converted to vegetated coastal wetlands in 1990.

Source	**1990 Flux Estimate (kt CO_2e)**	**Uncertainty Range Relative to Flux (kt CO_2e)**		**(%)**	
		Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
Biomass C Stock Change	(4.9)	(4.1)	(5.7)	-16.4	16.4
Dead Organic Matter Flux	0.11	0.09	0.14	-19.5	19.5
Soil C Stock Change	(5.2)	(4.3)	(6.0)	-16.6	16.6
CH_4 emissions	9.0	6.3	11.7	-29.9	29.9
Total Wetland	**(0.9)**	**(0.6)**	**(1.2)**	**-33.8**	**33.8**

Table A3.8. Approach 1 quantitative combined uncertainty emissions estimates for carbon stock changes occurring within land converted to vegetated coastal wetlands in 2020.

Source	2020 Flux Estimate ($kt\ CO_2e$)	Uncertainty Range Relative to Flux Estimate ($kt\ CO_2e$)		(%)	
		Lower Bound	Upper Bound	Lower Bound	Upper Bound
Biomass C Stock Change	(0.9)	(0.7)	(1.0)	-16.4	16.4
Dead Organic Matter	0.0006	0.0005	0.0007	-19.5	19.5
Soil C Stock Change	(1.2)	(1.0)	(1.4)	-16.6	16.6
CH_4 emissions	1.5	1.1	2.0	-29.9	29.9
Total Wetland	**(0.5)**	**(0.3)**	**(0.7)**	**-33.8**	**33.8**