Maryland Blue Carbon Flux: Estuarine Wetlands and Submerged Aquatic Vegetation

Data and Methodology Documentation

as prepared for the

2020 Maryland Greenhouse Gas Inventory

Maryland Department of the Environment

Maryland Department of Natural Resources

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Maryland Greenhouse Gas Emissions Inventory

This report supports Maryland's 2020 greenhouse gas (GHG) emissions inventory and the revised historical inventories. The state's 2020 inventory was released on September 24, 2022.[1]

Blue Carbon Flux: Estuarine Wetlands and Submerged Aquatic Vegetation

Blue carbon is a term conventionally used to reference the carbon captured by the ocean and coastal ecosystems, including from mangroves, tidal and salt marshes, and seagrasses. For the Maryland GHG inventory, blue carbon stocks and fluxes comprise the state's estuarine wetlands and seagrasses, otherwise referred to as submerged aquatic vegetation. There are no mangrove ecosystems in Maryland.

An estuary is where freshwater from the land mixes with saltwater from the ocean, and the Chesapeake Bay is the largest estuary in North America. Maryland has ~220,000 acres of estuarine wetlands within its borders (NOAA 2022). All of these wetlands are either on the fringes of the Chesapeake Bay, its tributaries, or the Atlantic Coastal Bays and are important to both the culture and ecology of Maryland. Many of Maryland's iconic species, like the blue heron, striped bass, and blue crab spend at least a portion of their life cycles in estuarine wetlands. Estuarine wetlands provide essential ecosystem services - they protect coastlines from erosion and storm surge, absorb nutrients, provide habitat for numerous species, all while helping to mitigate climate change by storing carbon in their soils and plant biomass.

Submerged Aquatic Vegetation (SAV) is recognized as a global (Fourqurean et al. 2012) and regional (Moore et al. 2000) carbon sink, but is not currently included in the national greenhouse gas inventory due to uncertainty in national extent and the magnitude of associated carbon sequestration and methane emissions. Maryland, however, is fortunate to have long term monitoring of SAV extent and density through annual surveying towards Chesapeake Bay Program goals.

Maryland is taking advantage of recent advances in the understanding of both carbon sequestration and methane emissions associated with estuarine wetlands and SAV to add these carbon sinks to Maryland's 2020 greenhouse (GHG) inventory. The state's inventory does not include inland freshwater wetland systems nor estuarine wetlands in areas of the Bay with a salinity less than 5 parts per thousand. The uncertainty for both carbon sequestration and methane emissions in these systems was too high to be able to reliably report this flux. Forested wetlands, which comprise about 85% of inland freshwater (i.e. palustrine) wetlands, are included in the Forest Carbon Flux portion of Maryland's GHG Inventory.

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[1] The full emissions inventory, including all Land Use, Land-Use Change, and Forestry emissions and sequestration, can be found on Maryland Department of the Environment's website: mde.maryland.gov/programs/air/climatechange/pages/greenhousegasinventory.aspx

Method and Data Inputs

Core Method

Maryland's approach to quantifying the blue carbon flux for the state's coastal wetlands[2] builds on the work that Silvestrum (Troost et al. 2021) has led for the U.S. Environmental Protection Agency's (EPA) national GHG inventory and state inventory tool. Dr. Steve Crooks and Dr. Lisa Beers, blue carbon experts with Silvestrum, were consulted to better understand their approach to downscaling the national inventory results for individual states.

The following simplifying assumptions in the national inventory approach were identified as those that could be refined for Maryland's greenhouse gas inventory using state level data:

1. all estuarine wetlands were assumed to be saline (i.e. methane emissions were assumed to largely be inhibited);
2. the rate of carbon sequestration was a regional average for coastal wetlands;
3. the rate of methane emissions was a regional average for coastal wetlands; and
4. submerged aquatic vegetation was not included due to the lack of national data.

The data sources used by the state of Maryland to quantify and map ecosystem extent by salinity class and estimate related methane emission and carbon sequestration rates are summarized in Table 1 with more detailed methods described below.

Table 1. Data inputs for state level blue carbon flux analysis

Data Type	Data Source	Reference Link or Citation
Wetland Extent	NOAA Coastal Change and Analysis Program	coast.noaa.gov/digitalcoast/data/ccapregional.html
SAV Extent	Virginia Institute of Marine Science (VIMS) SAV Survey	vims.edu/research/units/programs/sav/index.php
Salinity Zones	VIMS SAV Survey	vims.edu/research/units/programs/sav/reports/2013/salinity_zones.php
Wetland Carbon Sequestration	Campbell et al. 2020	sciencedirect.com/science/article/abs/pii/S2212041620300358
SAV Carbon Sequestration	Campbell, unpublished literature review	Duarte et al. 2010, Duarte et al. 2013 Greiner et al. 2013, Heisey and Damman 1982, Hillman et al. 2020, Kennedy et al. 2010, Moore et al. 2000, Oreska et al. 2017, Oreska et

[2] The EPA defines coastal wetlands for the national greenhouse gas inventory as saltwater and freshwater wetlands located within coastal watersheds.

		al. 2020, Patel and Kanungo 2012, Van Wijik 1988, Vonk et al. 2015
Wetland Methane Emissions	Campbell et al. 2020	sciencedirect.com/science/article/abs/pii/S2212041620300358
SAV Methane Emissions	Campbell, unpublished literature review	Garcias-Bonet and Duarte 2017, Oreska et al. 2020, Rosentreter et al. 2021

Wetland and SAV Extent

For wetland extent, the same dataset was used as the EPA approach, the NOAA Coastal Change Analysis Program (C-CAP), mapped for 2006, 2010, and 2016 (Figure 1, Table 2). For the relevant years of triennial GHG inventory reporting, interval years are interpolated maintaining the observed trend, and future years are held at 2016 extent awaiting subsequent C-CAP data releases (Table 3). Overall, relatively little net-wetland change is observed in Maryland over this period. To refine this estimate, wetlands were further mapped by salinity zone (i.e., tidal fresh (0-2 ppt), oligohaline (2-5 ppt), mesohaline (5-18 ppt), and polyhaline (18 ppt+)) using a map of average salinity in the Bay, its tributaries, and the Maryland Coastal Bays produced by the Virginia Institute of Marine Science (VIMS). Wetlands in the categories below 5 ppt are not utilized further in the calculation due to uncertainty in sequestration and emissions rates as discussed further below. These areas represent 12% of the coastal wetland extent. Their exclusion is not expected to have a significant impact on the results as the sequestered carbon is generally balanced by methane emissions (Poffenbarger et al. 2011). This adjustment decreased the coastal wetland acreage being considered from ~220,000 acres to ~200,000 acres.

Figure 1: Wetland and SAV extent in Maryland

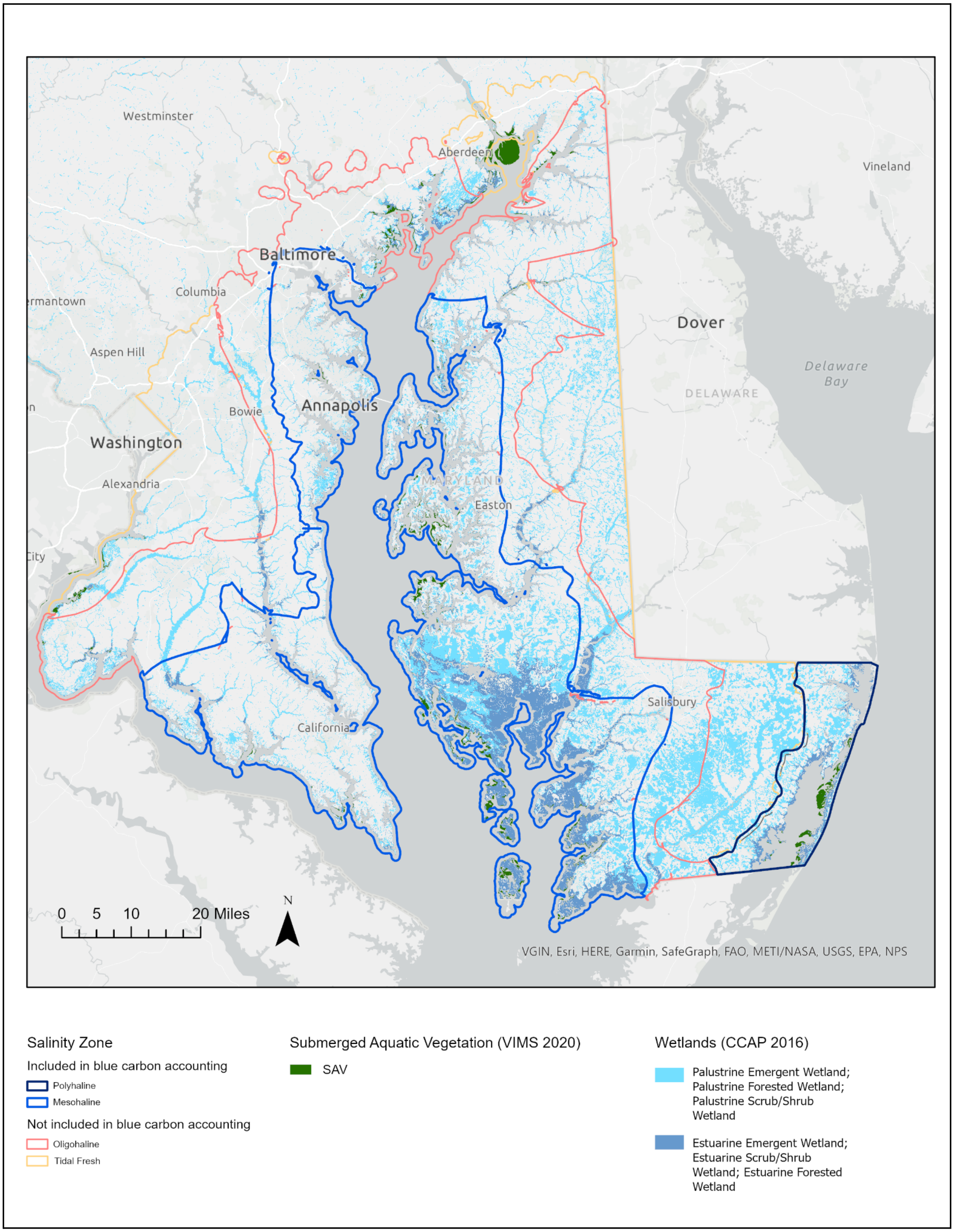

Table 2: Wetland extent as mapped from C-CAP (acres)

	2006	2010	2016
Tidal Fresh Wetlands	3,834	3,857	3,852
Oligohaline Wetlands	23,130	23,520	23,475
Mesohaline Estuarine Wetlands	181,365	182,983	182,884
Coastal Bays Estuarine Wetland (polyhaline)	16,413	16,421	16,405

Table 3: Wetland extent as utilized for the GHG inventory (acres)

	2006	2011	2014	2017	2020
Coastal Bays Estuarine Wetland (polyhaline)	16,413	16,418	16,409	16,405	16,405
Mesohaline Estuarine Wetlands	181,365	182,966	182,919	182,884	182,884

Spatial extent of SAV by salinity zone, as shown in Table 4, is tabulated annually by VIMS and used as an input to this analysis. The Chesapeake and Atlantic Coastal Bays have some of the best mapping of SAV globally, so confidence in the extent and density of SAV in the bay on a yearly basis is high.

Table 4: SAV extent as reported annually by VIMS and utilized in the GHG Inventory (acres)

	2006	2011	2014	2017	2020
Freshwater SAV	13,246	10,257	10,060	13,115	12,170
Oligohaline SAV	7,240	3,140	3,599	5,465	5,276
Mesohaline SAV	9,612	15,898	22,996	39,164	15,073
Coastal Bays SAV	7,368	5,673	6,492	5,642	5,264

Emission and Sequestration Rates

Wetlands remove carbon from the atmosphere through an annual cycle of plant growth removing CO2 from the atmosphere and storing carbon in the plants biomass and senescence following the growing season where a portion of the carbon accumulated in biomass enters long term storage in the soil of the wetland. As the amount of carbon entering long term storage can be quite variable, this analysis used an average soil carbon accumulation value for estuarine wetlands from across fifteen different studies. This value only represents soil carbon accumulation, and assumes that the remainder of annual plant biomass production reenters the atmosphere. State specific carbon sequestration and methane emission estimates for wetlands in different salinity zones were estimated through literature review (Campbell et al. 2020). Results from this work indicate that estuarine coastal wetlands in the Chesapeake Bay sequester 0.84 Mg C (3.07 Mg of CO_2e) per acre per year, on average (Table 5). In comparison, the national average used by the EPA is only 1.22 Mg CO_2e per acre per year for estuarine coastal wetlands. A significant difference was not observed between carbon sequestration rates in mesohaline and polyhaline wetlands so one rate was used for both categories.

Table 5: Soil carbon burial rates for estuarine wetlands

	Mg C acre-1 yr-1	Mg C as CO2e acre-1 yr-1
Coastal Bays Estuarine Wetland (polyhaline)	0.84	3.07
Mesohaline Estuarine Wetlands	0.84	3.07
Oligohaline	*[high uncertainty]*	
Tidal fresh		

Wetlands emit methane when methanogenic bacteria in the sediment process organic material in the absence of oxygen (i.e. anaerobic conditions). The rate of methane emissions tends to decrease as salinity increases because saltwater contains sulfur and sulfur reducing bacteria compete with the methanogenic bacterial community. Methane is a greenhouse gas, with a global warming potential between 28 and 84 times that of carbon dioxide, depending on the time over which the lifespan of CO_2 and CH_4 are being compared. CH_4 is more powerful over a shorter time frame so a higher potency (i.e. 84 times as potent as CO_2) reflects a 20 year comparison (used in Maryland's inventory) while a lower relative potency of 28 reflects a longer 100 year comparison (used by the EPA and IPCC).

The EPA approach assumes all wetlands mapped as estuarine do not emit methane, but prior work shows that mesohaline wetlands in the Chesapeake Bay have significant methane emissions, averaging 1.68 Mg CO_2e per acre per year[3] (Table 6). As such, estuarine wetlands in the mesohaline salinity are estimated to have a net GHG sink effect of 1.39 Mg CO_2e per acre per year. Methane emissions are very different between mesohaline and polyhaline wetlands, with polyhaline having much lower methane emissions, at a rate of 0.08 Mg CO_2e per acre per year; the net GHG sink for polyhaline wetlands is estimated to be 2.98 Mg CO_2e per acre per year. Only about 10% of estuarine coastal wetlands in Maryland fall into this category, all of which are in the Atlantic Coastal Bays.

[3] Using a 100-year global warming potential for methane

Table 6: Methane emission rates for estuarine wetlands

	Mg CH4 acre-1 yr-1	Mg CO2e acre-1 yr-1 (100-yr GWP, AR5)	Mg CO2e acre-1 yr-1 (20-yr GWP, AR5)
Coastal Bays Estuarine Wetland (polyhaline)	0.003	0.08	0.25
Mesohaline Estuarine Wetlands	0.060	1.68	5.03
Oligohaline	*[high uncertainty]*		
Tidal fresh			

The net greenhouse gas impact of submerged aquatic vegetation is less studied and understood in comparison to coastal wetlands or other natural lands like forests. Accordingly, new calculations were performed to estimate the carbon removal in these systems and a literature review was conducted to estimate methane emissions in these systems. It was found that carbon sequestration varies by the SAV species and density of growth and that the mix of species commonly occurring varies by salinity regime in the Bay (Table 7). The percentage of carbon that is buried varies in the literature; the median estimate of 50% of carbon content in SAV biomass production was assumed to be buried and enter long term storage in the sediment. A literature review of methane emissions revealed that methane emissions in SAV beds are highly variable and do not demonstrate a relationship with salinity. One average rate from the literature was used (0.09 Mg CO2e per acre per year, Table 8), which corresponded to the median of observations and was very similar to other rates observed in the Chesapeake Bay.

Table 7: Soil carbon burial rates for SAV

	Mg C acre-1 yr-1	Mg C as CO2 acre-1 yr-1
Freshwater SAV	0.123	0.45
Oligohaline SAV	0.123	0.45
Mesohaline SAV	0.042	0.15
Coastal Bays SAV	0.111	0.41

Table 8: Methane emission rates for SAV

	Mg CH4 acre-1 yr-1	Mg CO2e acre-1 yr-1 (100-yr GWP, AR5)	Mg CO2e acre-1 yr-1 (20-yr GWP, AR5)
SAV of all salinity zones	0.003	0.09	0.27

Reporting

Annual carbon sequestration and methane emissions estimates for Maryland blue carbon ecosystems can be found in Tables 9 and 10. These results are a product of multiplying wetland and SAV extent (Tables 2-4) by the relative sequestration and methane emissions rates. In these tables, negative values indicate net sequestration and positive values indicate net emission.

Table 9. Annual soil carbon burial

	Soil Carbon Burial, Mg CO2e				
Ecosystem Type	**2006**	**2011**	**2014**	**2017**	**2020**
Coastal Bays Estuarine Wetland	-50,340	-50,356	-50,328	-50,317	-50,317
Mesohaline Estuarine Wetlands	-556,268	-561,179	-561,033	-560,927	-560,927
Freshwater SAV	-5,956	-4,612	-4,523	-5,897	-5,472
Oligohaline SAV	-3,223	-1,398	-1,602	-2,433	-2,349
Mesohaline SAV	-1,478	-2,445	-3,536	-6,023	-2,318
Coastal Bays SAV	-3,011	-2,319	-2,653	-2,306	-2,152
Total, wetlands	-606,607	-611,535	-611,361	-611,244	-611,244
Total, SAV	-13,668	-10,773	-12,315	-16,658	-12,290

Table 10. Annual methane emissions

	Methane (CH4) Emissions, Mg CO2e (100-yr GWP)				
Ecosystem Type	**2006**	**2011**	**2014**	**2017**	**2020**
Coastal Bays Estuarine Wetland	1,390	1,390	1,390	1,389	1,389
Mesohaline Estuarine Wetlands	304,142	306,827	306,747	306,689	306,689
Freshwater SAV	1,201	930	912	1,189	1,103
Oligohaline SAV	656	285	326	495	478
Mesohaline SAV	871	1,441	2,085	3,550	1,366
Coastal Bays SAV	668	514	588	511	477
Total, wetlands	305,532	308,217	308,137	308,079	308,079
Total, SAV	3,396	3,170	3,911	5,746	3,425

The net greenhouse gas flux for each estuarine wetland and SAV class is annually calculated by subtracting the respective annual emissions total from the annual sequestration total (Table 11). The results are then summarized across classes to provide a single statewide estuarine wetlands and SAV net carbon flux estimate. While these results focus on the net GHG flux from wetlands which remain as such from year to year, the net emissions impact due to wetland loss due to drowning or land-use change and additional sequestration due to wetland addition through migration or restoration is reflected separately in a “land-use change” category. The estimated GHG impact of this land use change was taken directly from the GHG Data Explorer[4] and subsequently used to calculate an overall annual net blue carbon flux for the state. These results show that SAV is a relatively minor carbon sink at around ~0.01 Mg CO2e per year for the Maryland portion of the Bay. While the assumptions made for this SAV calculation are likely conservative, more generous assumptions would not change the relative magnitude of this sink.

Table 11. Annual Maryland blue carbon net greenhouse gas flux (Mg CO2e yr-1, 100-yr GWP)

Ecosystem Type	2006	2011	2014	2017	2020
Coastal Bays Estuarine Wetland	-48,950	-48,966	-48,939	-48,927	-48,927
Mesohaline Estuarine Wetlands	-252,126	-254,352	-254,286	-254,238	-254,238
Freshwater SAV	-4,755	-3,682	-3,611	-4,708	-4,369
Oligohaline SAV	-2,567	-1,113	-1,276	-1,937	-1,870
Mesohaline SAV	-607	-1,004	-1,452	-2,472	-952
Coastal Bays SAV	-2,344	-1,804	-2,065	-1,795	-1,674
Total, Wetlands	-301,076	-303,317	-303,224	-303,165	-303,165
Total, SAV	-10,272	-7,603	-8,404	-10,912	-8,865
Total, Land Use Change[4]	11,722	9,993	9,990	9,987	9,984
Net GHG Flux (Mg CO2e/yr)	-299,626	-300,927	-301,638	-304,090	-302,046
Net GHG Flux (MMTCO2e/yr)	**-0.2996**	**-0.3009**	**-0.3016**	**-0.3041**	**-0.3020**

Conclusions

After modifications with state level data, the annual blue carbon flux in Maryland is estimated to be higher than the estimate in the EPA inventory, at -0.300 to -0.304 MMT CO2e per year

[4] Methodology for the land use change calculation for wetlands can be found in Crooks et. al. 2018. These values for Maryland can be found at the EPA GHG Data Explorer, cfpub.epa.gov/ghgdata/inventoryexplorer

compared to -0.244 to -0.248 for the period considered, 2006-2020. Uncertainty was not assessed for the calculation and is not available for the state level estimates but was assessed at +/- 36.6% for the national scale inventory. Uncertainty for state level estimates would likely be similar, indicating that the two estimates are within the bounds of uncertainty estimates for each. It should be noted that the choice of a 100-year global warming potential for methane compared to a 20 year GWP is highly influential on the blue carbon sink. If a 20 year GWP was used these systems would represent a net source of greenhouse gas emissions.

An advantage of using this state level calculation is that specific wetland and SAV restoration or enhancement projects are likely to use more specific carbon and methane estimates offering an opportunity to maintain consistency in reporting across spatial scales. The incorporation of SAV, while a relatively minor component of the sink (~3%), is another advantage of this state modified approach. SAV is known to have many benefits in terms of water quality and habitat and is a priority for Bay restoration. Identifying the carbon sink benefits of SAV in our inventory perpetuates Maryland’s role as a leader in blue carbon accounting. While these estimates of Maryland’s blue carbon sinks reflect our best understanding at this time, these estimates can be refined in the future as the scientific understanding of blue carbon expands.

Future Improvements

Reducing uncertainties in low salinity environments

Inland freshwater wetland systems and estuarine wetlands in areas of the Bay with a salinity less than 5 parts per thousand were not included in this analysis due to high uncertainties about both carbon sequestration and methane emissions in these systems. More field work in these systems could help constrain current estimates and provide an avenue for future inclusion within the inventory.

Improving estimates of wetland extent

While wetlands are mapped on five-year increments through federal efforts, mapping change at more frequent intervals and at a finer spatial resolution would make the maps more useful to attribute changes to specific drivers. Better mapping of specific plant communities would potentially allow for community specific carbon and methane rates to be used in future inventory updates.

Relating wetland condition to productivity and carbon burial

It can be intuited that marsh condition and health relates to rates of productivity and carbon burial. However, this relationship has not been demonstrated in Maryland and a method is not available to relate spatial indicators of marsh health to carbon sequestration. There also may be a relationship between methane emissions and marsh health. Greater resolution on these relationships could be accomplished through a synthesis study of spatial data on marsh health and field data on carbon sequestration and methane emissions.

Reducing uncertainties in SAV systems

While Maryland has excellent longitudinal data on SAV extent in the Chesapeake Bay, the rates of carbon sequestration and methane emission associated with this ecosystem are highly uncertain. There is a need for additional studies and data points to improve the estimates used in this analysis. Additional studies would ideally focus on species assemblages present in different salinity zones of the Bay, improving estimates in each respective region.

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