Chapter 20: Blue Carbon Accounting for Carbon Markets

Brian A. Needelman[1], Igino M. Emmer[2], Matthew P. J. Oreska[3], J. Patrick Megonigal[4]

[1]University of Maryland, College Park, MD 20742

[2]Silvestrum Climate Associates, Dorpsstraat 4, 1546 LJ Jisp, The Netherlands

[3]University of Virginia, Department of Environmental Sciences, Charlottesville, VA 22904

[4]Smithsonian Environmental Research Center, Edgewater, MD 21037

20.1 Introduction

Coastal wetlands sequester carbon dioxide, and this greenhouse gas mitigation benefit has a financial value on carbon offset-credit markets. Offset markets~~, therefore,~~ ~~represent~~ are a potential source of funding for tidal wetland conservation and restoration projects; however, coastal managers must first quantify the magnitude of the greenhouse gas offset that results from the project in order to monetize this benefit. Several new standards provide greenhouse gas flux accounting rules for wetlands, which specify how projects can determine the net greenhouse gas benefit that results from conserving or restoring a coastal plant community. In both cases, this benefit equates to enhanced greenhouse gas sequestration or emissions reductions directly attributable to the project, relative to a baseline (i.e. business-as-usual) scenario over time. These new accounting procedures must be rigorous enough to generate credible offset-credits, yet flexible enough to be applied to a diverse range of coastal wetland habitat types and conditions. Estimating greenhouse gas fluxes and projecting the baseline scenario is a technically complex ~~part~~ step in a carbon project, and project developers need to rely on one or more approved methodologies to do so. In this chapter, we discuss ~~and explain~~ essential science and policy components of GHG accounting methodologies, captured in the VCS VM0033 Methodology for Tidal Wetland and Seagrass Restoration (Emmer et al. 2015a, Emmer et al. 2015b) and modules in the VM0007 REDD+ methodology Framework (Emmer et al. 2018 a, Emmer et al. 2018b). We provide a general outline of the methodology. See Needelman et al. (2018) for a more in-depth description and analysis of the restoration methodology. For project developers, we refer to Emmer et al (2015b), which answers questions on how to set-up, implement, and organize a blue carbon project on the ground.

The VM0033 Tidal Wetland and Seagrass Restoration Methodology is the first globally applicable methodology for coastal wetland restoration activities and provides project developers with the protocol needed to generate wetland carbon credits. It outlines procedures to estimate net greenhouse gas emission reductions and removals resulting from restoration of coastal wetlands along the entire salinity range. The scope of VM0033 is global and includes all tidal wetland systems, including mangroves, tidal marshes, tidal forested wetlands, and seagrass meadows. It incorporates best practices and principles in restoration and carbon management, while leaving the flexibility necessary to enable projects to emerge in diverse coastal settings. VM0033 has provided the basis for the tidal wetland~~s~~ greenhouse gas accounting modules (Emmer et al, 2018a; Emmer et al, 2018b) incorporated into the VCS VM0007 REDD+ Methodology Framework, which is a modular methodology covering both conservation and restoration in the land use sector.

We also address concerns about potential offset-credit misallocation in seagrass blue carbon projects, which may result from estimating long-term carbon accumulation by extrapolating sediment carbon burial rates (e.g. Johannessen and Macdonald, 2016, Oreska et al, 2018). Credit over-allocation to seagrass meadows or other blue carbon systems would devalue legitimate offset credits.

BOX

Since its launch in 2007, the VCS has become the largest standard in the agriculture, forestry and other land use (AFOLU) sector and has initiated projects and methodologies for forest conservation, improved forest management, and agricultural land management (VCS 2017, Hamrick et al. 2015). The Wetlands Restoration and Conservation (WRC) category is the most recent project category in the VCS (VCS 2017); it offers comprehensive guidance for how to account for greenhouse gas removals and emission reductions across 'blue carbon' ecosystems, guidance on eligible project categories, greenhouse gas sources and carbon pools, baseline determination, leakage calculation, and greenhouse gas emission reductions and removals calculation. To date, three methodologies have been approved under the VCS Wetlands Restoration and Conservation (WRC) category—the Methodology for Coastal Wetland Creation (VM0024), the Methodology for Tidal Wetland and Seagrass Restoration (VM0033) and the REDD+ Methodology Framework (VM0007).

20.2 Overview of the Accounting Procedures for Tidal Wetland and Seagrass Restoration and Conservation

The VCS methodologies for tidal wetland and seagrass restoration and conservation provide greenhouse gas accounting procedures for restoration, creation and conservation of marshes, mangroves, seagrasses, and forested tidal wetlands.

The methodologies consider emissions of CO_2 (including carbon stock changes), CH_4, and N_2O and fulfill the requirements for the VCS Wetland Restoration and Conservation and Afforestation, Reforestation and Revegetation project categories (VCS 2017). The restoration methodology covers the variety of restoration practices that may be used to restore degraded tidal wetland systems (Perillo et al. 2009). Restoration activities must have a net greenhouse gas

Commented [IE1]: Or refer to other chapter in this book benefit and fall under some combination of the following practices: creating, restoring and/or managing hydrological conditions; altering sediment supply; changing salinity characteristics; improving water quality; (re-)introducing native plant communities; and improving management practices. The procedures for conservation cover protecting at-risk wetlands (e.g., establishing conservation easements, establishing community supported management agreements, establishing protective government regulations, and preventing disruption of water and/ or sediment supply to wetland areas), improving water management on drained wetlands, maintaining or improving water quality for seagrass meadows, recharging sediment to avoid drowning of coastal wetlands, and creating accommodation space for wetlands to migrate with sea-level rise.

Greenhouse gas emissions are estimated for both a most-likely baseline scenario and a with-project scenario; accounting is then done by subtraction. This basic principle of project GHG accounting is shown in Figure 1. Therefore, ~~Mere~~ mere burial or sequestration rates of carbon ~~are, therefore, not the same as blue carbon benefits~~do not translat~~eing~~ directly in to carbon credits. Emissions may be either estimated or set to a conservative value. Accounting methods for each greenhouse gas include~~, amongst others,~~ measured data, default values, published values, or models.

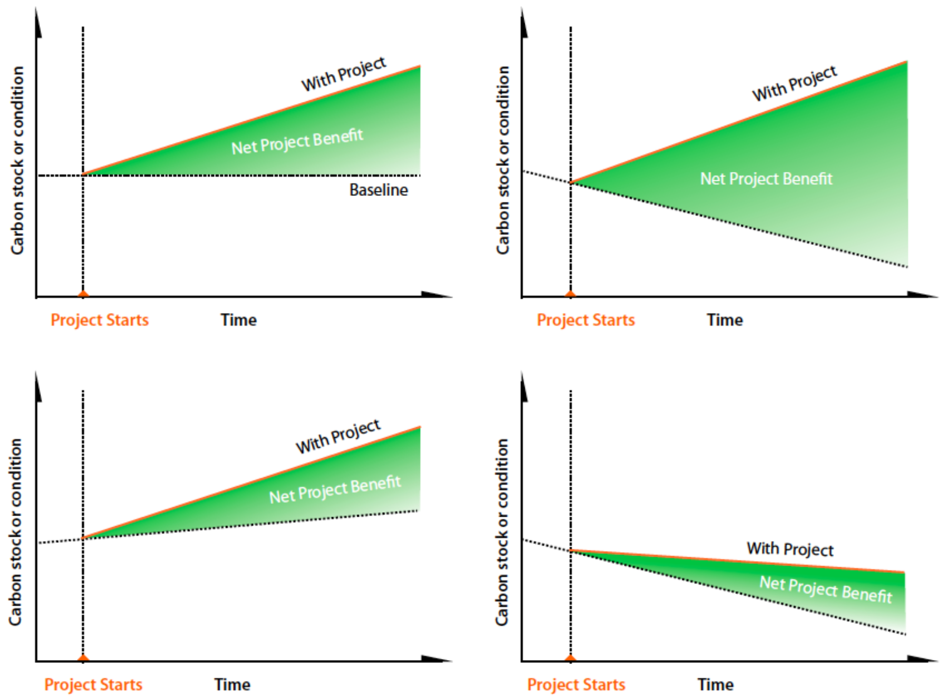

Figure 1: Various hypothetical scenarios for net project benefits of carbon projects, based on the difference between the baseline and the project scenario.1 For example, salt pond restoration may be represented by a flat baseline carbon stock and an increasing project carbon stock (top left). Restoration projects that accumulate carbon may have a declining baseline (top right) and therefore have an avoided emissions component as in conservation projects. A project may improve on both an increasing baseline and a declining baseline (bottom left and right, respectively). Conservation projects are typically represented by the bottom-right graph, where the project scenario may as well be flat or increasing.

[1] After: Olander and Ebeling (2011)

20.3 Key Scientific Components of the Accounting Procedures

Soil carbon sequestration default values

Allowing the project to use default values for soil carbon sequestration and other greenhouse gas flux rates greatly increases project feasibility but must be scientifically credible. There has been extensive data collection on soil carbon sequestration in marsh and mangrove systems; we derived a default value of 1.46 t C ha^{-1} yr^{-1} from Chmura et al. (2003). A single, general default value for soil carbon sequestration in seagrass systems cannot yet be justified, given continued uncertainty about long-term seagrass carbon sequestration (Belshe et al. 2017), but the procedures allow projects to justify the use of external emission factors, including the IPCC emission factor for seagrasses of 0.43 t C ha^{-1} yr^{-1} (IPCC 2014).

Commented [MP2]: This term will not be generally understood by many of the readers. Please define the term here where we use it first.

Accounting for allochthonous carbon

Allochthonous carbon is carbon that was removed from the atmosphere outside of the project area and transported into the project area. Such carbon may only be counted as a project benefit if it would have been returned to the atmosphere in the baseline scenario (VCS 2017). This can occur if the fate of the carbon in the baseline scenario (i.e. in the absence of the project) would be transport or deposition in a relatively aerobic environment compared to the project wetland. ~~A large percentage of allochthonous carbon is available to microbes for decomposition~~ Allochthonous carbon deposited on the soil surface of a given wetland should ~~and is likely to~~ be preserved as efficiently as authocthonous carbon (e.g. leaf litter) deposited in the same system compared to decomposition under more aerobic conditions. ~~returned to the atmosphere. Therefore, for reasons explained in Needelman et al. (2018), the methodologies assume that most~~

~~allochthonous carbon is returned the atmosphere in both the with-project and the baseline scenario.~~ However, a portion of the allochthonous carbon is equally resistant to decomposition in both aerobic and anaerobic conditions on project timescales (e.g. 100 years). Extremely slow rates of decomposition in aerobic environments are often due to a close association of carbon compounds with mineral particles (Shields et al., 2016). ~~and other ecosystem properties: this portion is defined as mineral-protected allochthonous carbon (herein “recalcitrant carbon”).~~ We ~~used the conservative assumption~~assumed that ~~all of~~ mineral-protected allochthonous carbon is equally retained in both ~~this recalcitrant material would be returned to the atmosphere in~~ the baseline scenario ~~but retained in the soil in~~and the with-project scenario. Therefore, projects are required to estimate the mineral-protected allochthonous ~~recalcitrant~~ soil carbon and subtract this from their carbon sequestration estimates. The methodologies provide procedures to estimate this mineral-protected allochthonous carbon ~~recalcitrant~~ fraction based on organic carbon percentage of tidal wetland soils and deposited sediments.

The methodologies do not currently account for possible seagrass wrack accumulation in certain regions where seagrass beds are abundant. Seagrass wrack is buoyant and often exported from the meadow area by hydrodynamics. Most seagrass projects will not count this carbon sequestration, unless the wrack becomes buried within the seagrass project area. However, regional hydrodynamics may cause this seagrass wrack to be exported to adjacent blue carbon habitats. In such situations, this allochthonous carbon may accumulate in the project area where it would also have accumulated in the baseline scenario, so that the above assumptions about recalcitrant carbon do not hold. This special case warrants validator discretion until both methodologies are updated to address such conditions.

Commented [MP3]: Shields, M. R., Bianchi, T. S., Gélinas, Y., Allison, M. A., Twilley, R. R. (2016). Enhanced terrestrial carbon preservation promoted by reactive iron in deltaic sediments. *Geophysical Research Letters*, *43*(3), 2015GL067388. doi:10.1002/2015GL067388

Soil carbon fate following erosion

Coastal wetland soil carbon pools are vulnerable to enhanced rates of oxidation to CO_2 when disturbed through erosion and conversion to open water. The possible fates of soil carbon following erosion or conversion to open water depend on the hydrological and geomorphic setting of the tidal wetland or seagrass system through its influence on integrated molecular oxygen exposure time (Blair and Aller 2012). Soil carbon oxidation rates are greatest when the soil is eroded into geomorphic systems that expose the carbon to aerobic conditions. This occurs when eroded carbon is entrained in river-estuary systems that transport materials seaward by continual resuspension; coastal margins and embayments with sufficient wave energy to continually resuspend sediments into an aerobic water column~~,~~; or subaquatic settings with low sediment organic carbon content and course-grained sediments that act to maintain aerobic conditions in the upper soil profile. Exposure to oxygen is far less when eroded soil carbon is deposited in a low-oxygen environment, or rapidly buried by sediment, separating it from aerobic overlying water. In cases where marshes are lost but there is no hydrologic connectivity between the site and a river-estuary system, soil carbon loss is minimal because it remains submerged and undisturbed in a low-oxygen environment (Lane et al. 2016).

Commented [MP4]: Lane, R.R., Mack, S.K., Day, J.W. et al. Wetlands (2016) 36: 1167. https://doi.org/10.1007/s13157-016-0834-8

The influence of hydrologic connectivity and depositional environment on preservation of eroded soil carbon was captured in the VCS conservation methodology (VM0007 REDD+ Methodology Framework and associated modules) by defining carbon preservation depositional environments (CPDEs), defined as *sub-aquatic sediment deposition environments that impact the amount of deposited organic carbon that is preserved. Carbon preservation is affected by mineral grain size, sediment accumulation and burial rates,* O_2 *availability in the overlying* *water column and sediment hydraulic conductivity*. The carbon preservation in each of four CPDEs (see Table 1) were based on a literature review by Blair and Aller (2012).

Table 1: Carbon preservation in each of four CPDEs.

Hydrologic Setting	Geomorphic Setting	Fraction Preserved	Fraction Lost
Hydrologic Connectivity	Normal Marine or Deltaic Fluidized Mud	20%	80%
Hydrologic Connectivity	Depleted O_2 at Sediment Surface	53%	47%
Hydrologic Connectivity	Transport in Small Mountainous Rivers	39%	61%
Hydrologic Connectivity	Extreme Sedimentation Rates	49%	51%
No Hydrologic Connectivity		100%	0%

Recent work has confirmed that erosion of subtidal seagrass beds also contributes to the loss of sediment organic carbon (Macreadie et al. 2015; Marbà et al. 2015).

Avoided losses in organic and mineral soils

Carbon in wetland soils is maintained due to anaerobic conditions, however rapid carbon loss to the atmosphere can occur when these soil materials are exposed to an aerobic environment. The term "avoided losses" refers to projects that avoid such soil organic matter oxidation in the baseline scenario; this benefit can be substantially larger than the other greenhouse gas benefits in many conservation and restoration projects. In the conservation methodology, procedures are available for projects that prevent the drainage of wetlands or the excavation of wetland soils and subsequent placement into aerobic conditions. A variety of methods are available to estimate these losses, including historical data collected from the project area or time series (chronosequence) data collected at similar sites. Estimates may be made directly based on changing soil volume, density, and carbon concentrations or indirectly based on initial carbon mass and projected oxidation rates.

Methane emissions

Accounting for methane emissions is critical for blue carbon projects because of the high potency of methane relative to carbon dioxide and the large variation in methane emissions rates. The primary means we have to narrow this variation is based on the general decrease in methane emissions with increased salinity such that tidal wetlands with salinities greater than 18 ppt consistently have very low emissions (Poffenbarger et al. 2011, Holm et al. 2016). The VCS methodologies include two default values for these emissions: 0.011 Mg CH_4 ha^{-1} yr^{-1} (0.374 Mg CO_2eq ha^{-1} yr^{-1}) for systems with salinity > 18 ppt and 0.0056 Mg CH_4 ha^{-1} yr^{-1} (0.19 Mg CO_2eq ha^{-1} yr^{-1}) for salinities > 20 ppt. Default values for tidal wetlands with salinities ~~below~~ < 18 ppt were not included due to limited data availability and the high variation that have been observed in these systems (Poffenbarger et al. 2011). Without a default value available for brackish and freshwater tidal wetlands, projects will need to use more expensive and labor-intensive quantification methods such as field-data collection, modeling, or proxies. The development of cost-effective methods to estimate methane emissions from brackish and freshwater tidal wetlands is among the greatest research needs in the field of blue carbon accounting.

An additional note is that ponded areas can act as methane emission hotspots even in high salinity systems, particularly if they are not tidal flushed regularly to replenish the sulfate in seawater. For this reason, the methodologies require that areas of ponds, ditches or similar bodies

Commented [MP5]: Holm, G.O., Perez, B.C., McWhorter, D.E. Krauss, K.W., Johnson, D.J., Raynie, R.C., Killebrew, C.J., 2016. Ecosystem Level Methane Fluxes from Tidal Freshwater and Brackish Marshes of the Mississippi River Delta: Implications for Coastal Wetland Carbon Projects. Wetlands. 36: 401. doi: 10.1007/s13157-016-0746-7 of water within the project area that do not have surface tidal water connectivity be treated as separate strata for the estimation of methane emissions.

Nitrous oxide emissions

Although nitrous oxide is a potent greenhouse gas, emissions are generally low from tidal wetland systems because of low oxygen availability in anaerobic saturated soils, which favors complete denitrification (reduction of NO_3^- and N_2O to N_2). However, some projects do involve the lowering of water levels, leading to increased oxygen availability and potentially increased nitrous oxide emissions—these projects are required to account for nitrous oxide emissions in the VCS methodologies. An example of such a project is an impoundment breaching in which the water level in a ponded system is lowered to create a wetland system. Projects that create wetlands from initially open water systems also function to lower water levels relative to the soil surface.

The methodologies provide for a full suite of methods to estimate nitrous oxide emissions including default values, proxies, field data collection, published data, and modeling. The default values were derived from a study in the Barataria Basin in the Gulf of Mexico in which nitrous oxide emissions from three marsh sites (fresh, brackish, and salt) and adjacent open water areas were compared (Smith et al. 1983). High nitrogen inputs can substantially increase nitrous oxide emissions; therefore, these default values may not be used in systems that receive direct inputs of nitrogen (Needelman et al. 2018).

In the methodologies, seagrass projects are not required to account for nitrous oxide emissions, because emissions from seagrasses are expected to be lower than the baseline scenario (Purvaja et al. 2008). This is partly due to the nitrogen limitation generally found in seagrass communities, such that nitrogen release is low (Welsh et al. 2000).

Soil profile sampling methods

Field sampling of soil carbon stocks over time is a widely used technique to estimate soil carbon sequestration rates. In the VCS methodologies, projects have several alternatives to direct measurement of soil carbon sequestration—including default values—but many will likely opt to use field values in order to capture potential high rates of sequestration. Field sampling of soil carbon stocks generally involves collection of soil cores and laboratory analysis for bulk density and either carbon or organic matter. The key additional step that must be taken to estimate carbon sequestration rates over time is to establish a consistent reference plane within the soil profile and then truncating soil cores at this plane. This is needed because the depth (volume) of tidal wetland soils often changes over time, such that samples collected to the same depth in different years are not directly comparable. The change in soil organic carbon content above the reference may be used to estimate carbon sequestration rates based either on the age of the reference plane or the start of project activities. There are many options to establish a reference plane including marker horizons (most commonly using feldspar) (Cahoon and Turner 1989), a strongly contrasting soil layer (such as the boundary between organic and mineral soil materials), an installed reference plane (such as the shallow marker in a surface elevation table) (Cahoon et al. 2002), a layer identified biogeochemically (such as through radionuclide, heavy metal, or biological tracers) (DeLaune et al. 1978), and a layer with soil organic carbon indistinguishable from the baseline SOC concentration, a method specifically included for seagrass projects (Greiner et al. 2013).

Most seagrass projects occur in dynamic, subtidal environments, where establishing a reference plane may not be possible. In the last permitted soil coring method, a seagrass soil core profile is compared with a depth-calibrated, background carbon concentration profile (e.g. the soil carbon profile prior to the project start date or at bare control sites). Subtracting the bare concentration from the meadow concentration along the calibrated cores down to the depth where the profiles intersect gives the sediment carbon pool enhancement attributable to the meadow. Repeated calibrated core comparisons can facilitate stock-change accounting in a seagrass bed over time, which should avoid issues with burial flux estimation that may over-estimate seagrass carbon sequestration rates (Oreska et al. 2018). Johannessen and Macdonald (2016) note that most seagrass studies simply extrapolate a single burial flux rate from a dated sediment core into the future to estimate carbon accumulation. This approach does not account for within-bed organic carbon remineralization over long time-scales, sediment mixing, lateral movement, and other factors that may diminish long-term carbon accumulation rates (Johannessen and Macdonald 2016).

Sample size

Collecting a sufficient number of field samples for laboratory analysis to achieve statistically confident estimates can be a significant project cost that may in some cases render a project infeasible. The methodologies include alternative estimation strategies that may be less expensive; in particular, default values were provided whenever they are scientifically valid. Nonetheless, field sampling may be necessary in some cases and may be preferable to alternative methods to achieve the maximum estimate of greenhouse gas benefits.

The methodologies use a dedicated VCS tool to determine sampling size requirements. The equations in this tool determine sample size requirements as a power function of the coefficient of variation of the quantity being estimated. Projects are instructed to target a confidence interval of 95% with a 30% allowable error (a 90% confidence interval with 20% allowable error is also allowed but requires a greater number of samples).

The sample size requirements in the methodologies should be reasonable for most projects for variables with moderate levels of variation such as soil carbon stocks. Most projects analyzed in the review by Chmura et al. (2003) had a coefficient of variation less than 0.5 for carbon sequestration rates, which would translate to a sample requirement of about 10 per stratum. However, variables with greater variation will require a substantially greater number of samples; for example, methane emissions could require about 40 samples per stratum per sampling event (Needelman et al. 2018). This represents a substantial burden to project implementation due to the high cost of methane flux sampling.

20.4 Policy Components of the Methodologies

Additionality

Carbon markets provide an incentive for new projects and activities that result in net greenhouse gas benefits. To demonstrate this incentive, a project must meet the additionality requirement in order to be awarded carbon offsets. The VCS established two approaches to demonstrating additionality: an individual approach at the project level and a standardized approach for a class of project activities. The VM0033 utilizes the standardized approach for projects within the US and the individual approach for projects outside of the US. The VM0007 REDD+ methodology utilizes the standardized approach as developed for the US; it has, however, been extended to a global scope. Using the standardized approach, it has been demonstrated that all tidal wetland and seagrass restoration and conservation projects are additional. For a further justification see Needelman et al. (2018). The standardized method removes the significant burden for projects to demonstrate additionality. VM0033 will be updated to apply the standardized approach globally.

Leakage

~~Leakage occurs when a project leads to~~ An increase in emissions or a decrease in removals of greenhouse gases outside of the project area as a result of the project intervention are called leakage. Leakage is traditionally broken down into a) ~~may occur by~~activity-shifting leakage related to shifting an activity such as agriculture from the project site to some other location~~, referred to as activity shifting~~; or b) market-effect leakage, when a project reduces the local supply of a product increasing production elsewhere ~~, referred to as market leakage~~ (Aukland et al. 2003). Specific to wetlands, an additional type of leakage is ecological leakage, ~~; or by causing~~i.e. an increase in emissions or decrease in removals in an ecosystem outside ~~of~~ the project boundary that is hydrologically connected to the project area~~, referred to as ecological leakage~~ (VCS 2017). ~~A greenhouse gas accounting methodology has two general ways to account for leakage: a) tracking leakage emissions in the with-project scenario; b)~~ VM0033 requires projects to avoid~~ing~~ leakage ~~altogether~~ by setting ~~strict~~ specific ~~applicability conditions including~~limitations to projects pertaining to the kind of pre-project land use permitted, and a careful establishment of project boundaries. ~~The restoration methodology only allows for the second option, avoiding leakage, because tracking leakage is a significant burden on project developers that may sometimes render the project unfeasible; e.g., when leakage emissions overwhelm project emission reductions or monitoring costs are high.~~

~~In order to a~~Avoiding activity~~-~~ shifting and market leakage~~, the methodology sets~~ can be achieved if one of the following conditions is met:

a) ~~applicability conditions that either a)~~ Demonstrate that prior to the start of the project the land is free of land use that could be displaced outside the project area

b) ~~, b)~~ Require that a land use that could be displaced outside the project area (e.g. timber harvesting) is not accounted for in the baseline scenario, or

c) ~~c)~~ Require a pre-project land use that will continue at a similar level of service or production during the project crediting period (e.g. reed or hay harvesting, collection of fuelwood, subsistence harvesting). ~~The focus is on avoiding situations where shifted activities cause the drainage or otherwise degradation of wetlands, which usually results in considerable greenhouse gas emissions.~~

For example, project developers may demonstrate that farmers have abandoned the project area prior to project start or that the land has already become unproductive (e.g. due to salinity intrusion). The methodologies do not currently allow projects to demonstrate the lack of activity-shifting leakage except through the absence of a displaceable land use. The methodology could be improved if it allowed projects to demonstrate the absence of activity shifting.~~.~~

VM0007, however, also allows for quantifying leakage emissions in the with-project scenario. It allows for a variety of approaches since it already includes leakage accounting modules developed for forest conservation projects as well as a module for ecological leakage originally developed for peatlands, where ecological connectivity is of similar importance as in tidal wetlands.

Ecological leakage in tidal wetland projects is avoided in both the restoration and conservation methodology by a ~~setting applicability conditions regarding~~ project design~~, ensuring that~~ which

Commented [IE6]: No need to depl because taken from methodology itself manages hydrological connectivity with adjacent areas ~~does not lead to~~so as to avoid a significant increase in net greenhouse gas emissions outside the project area,~~.~~ ~~The ecological leakage procedure was adapted from non-tidal systems where construction of a permeable dam can prevent changes in water levels outside the project boundary. However, in tidal systems, such dam construction is generally not feasible. This issue underscores the importance of~~for example by establishing a project boundary wide enough to capture expected water level changes that are linked to project activities. ~~The methodology provides the following ways for avoiding certain hydrologic alterations outside of the project area: maintaining wetland conditions (e.g., converting from impounded water to a wetland), which prevents soil carbon oxidation resulting from the lowering of the water table; not converting non-seagrass wetlands to open water, which prevents a lowering of the water table that may increase~~ ~~N_2O~~ ~~emissions; not converting non-wetland to wetland conditions, which prevents the raising of the water table that may cause increased~~ ~~CH_4~~ ~~emissions; or not converting vegetated to non-vegetated or poorly vegetated conditions, which prevents decreased plant productivity that may be caused by increased water tables.~~

20.5 Concluding Remarks

The VCS VM0033 Methodology for Tidal Wetland and Seagrass Restoration and the tidal wetlands modules in the VCS VM0007 REDD+ Methodology Framework allow the diversity of tidal wetland restoration and conservation projects to receive VCS-approved carbon credits. These and other reputable methodologies are designed to underestimate the net greenhouse gas benefit unless applicant projects take thorough, rigorous, direct measurements that convince validators that the actual project benefit is higher than the conservative, estimated benefit. The procedures are designed to be feasible to implement and highly flexible, while maintaining scientific rigor. The science and policy of greenhouse gas emissions and carbon storage in tidal wetlands is evolving—as evidenced by several innovative approaches in the methodologies—yet it remains limited by knowledge gaps. The accounting tools provided have a broader applicability and may be used to complement currently available systems of national to project-level greenhouse gas accounting for tidal wetland systems.

The existence of approved methodologies is one less barrier to market entry. Tidal wetlands restoration and conservation projects are now served with their own dedicated methodologies. However, appropriate greenhouse gas accounting is – under any carbon standard – a great burden for offset projects in any category, requiring a resourceful team and sufficient funding from the onset. Small-scale projects are unlikely to benefit from carbon finance, unless methodologies are further simplified or unless projects are grouped to realize economies of scale.

Isolated single-category restoration or conservation projects in the coastal zone are likely to face a significant risk of failure. This is because in most coastal settings, sea-level rise will require projects to accommodate a landward shift of coastal ecosystems. With GHG accounting methodologies now ready to assist, it is time to explore landscape-scale interventions including the entire sub to supra-tidal sequence, considering – where relevant – restoration or conservation of wetland and vegetation, or combinations of those. This would have to occur at an appropriate scale to become part of regional land-use planning and to reduce development and transaction costs.

Literature Cited

Aukland, L., P. Moura Costa, and S. Brown. 2003. A conceptual framework and its application for addressing leakage: the case of avoided deforestation. *Climate Policy* 3: 123-136.

Belshe, E. F., M. A. Mateo, L. Gillis, M. Zimmer, and M. Teichberg. 2017. Muddy waters: Unintentional consequences of blue carbon research obscure our understanding of organic carbon dynamics in seagrass ecosystems. *Frontiers in Marine Science* 4: 125.

Blair, N. E., and R. C. Aller. 2012. The fate of terrestrial organic carbon in the marine environment. *Annual Review of Marine Science* 4: 401-423.

Cahoon, D. R., J. C. Lynch, P. Hensel, R. Boumans, B. C. Perez, B. Segura, and J. W. Day. 2002. High-Precision Measurements of Wetland Sediment Elevation: I. Recent Improvements to the Sedimentation-Erosion Table. *Journal of Sedimentary Research* 72: 730-733.

Cahoon, D. R., and R. E. Turner. 1989. Accretion and canal impacts in a rapidly subsiding wetland II. Feldspar marker horizon technique. *Estuaries* 12: 260-268.

Chmura, G. L., S. C. Anisfeld, D. R. Cahoon, and J. C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. *Global Biogeochemical Cycles* 17: 1111.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. *Classification of Wetlands and Deepwater Habitats of the United States*. U. S. Government Printing Office, Washington, D.C.

Delaune, R. D., W. H. Patrick, and R. J. Buresh. 1978. Sedimentation rates determined by ^{137}Cs dating in a rapidly accreting salt marsh. *Nature* 275: 532-533.

Emmer, I. M., B. A. Needelman, S. Emmett-Mattox, S. Crooks, J. P. Megonigal, D. Myers, M. P. J. Oreska, K. J. McGlathery, and D. Shoch. 2015a. *Methodology for Tidal Wetland and*

Seagrass Restoration. VCS Methodology VM0033, v 1.0. Verified Carbon Standard, Washington, D.C.

Emmer, I. M., M. von Unger, B. A. Needelman, S. Crooks, and S. Emmett-Mattox. 2015b. *Coastal Blue Carbon in Practice: A Manual for Using the VCS Methodology for Tidal Wetland and Seagrass Restoration*. Restore America's Estuaries, Arlington, VA.

Emmer, I. M., B. A. Needelman, S. Emmett-Mattox, S. Crooks, J. P. Megonigal, D. Myers, M. P. J. Oreska, and K. J. McGlathery. 2018a. *Estimation of Baseline Carbon Stock Changes and Greenhouse Gas Emissions in Tidal Wetland Restoration and Conservation Project Activities (BL-TW). VCS Module, v 1.0*. Verified Carbon Standard, Washington, D.C.

Emmer, I. M., B. A. Needelman, S. Emmett-Mattox, S. Crooks, J. P. Megonigal, D. Myers, M. P. J. Oreska, and K. J. McGlathery. 2018b. *Methods for Monitoring of Carbon Stock Changes and Greenhouse Gas Emissions and Removals in Tidal Wetland Restoration and Conservation Project Activities (M-TW). VCS Module, v 1.0*. Verified Carbon Standard, Washington, D.C.

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: e72469.

Hamrick, K., and A. Goldstein. 2015. *Ahead of the Curve: State of the Voluntary Carbon Markets 2015*. Forest Trends, Washington, DC.

Johannessen, S. C., R. W. Macdonald. 2016. Geoengineering with seagrasses: is credit due where credit is given? *Environmental Research Letters* 11: 113001.

Macreadie, P. I., S. M. Trevathan-Tackett, C. G. Skilbeck, J. Sanderman, N. Curlevski, G. Jacobsen, and J.R. Seymour. 2015. Losses and recovery of organic carbon from a seagrass ecosystem following disturbance. *Proceedings of the Royal Society B* 282: 20151537.

Marbà N., A. Arias-Ortiz, P. Masqué, G. A. Kendrick, I. Mazarrasa, G. R. Bastyan, J. Garcia-Orellana, and C.M. Duarte. 2015. Impact of seagrass loss and subsequent revegetation on carbon sequestration and stocks. *Journal of Ecology* 103: 296-302

Mcleod, E., G. L. Chmura, S. Bouillon, R. Salm, M Björk, C. M. Duarte, C. E. Lovelock, W. H. Schlesinger, and B. R. Silliman. 2011. A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment* 9: 552-560.

Needelman, B.A., I.M. Emmer, S. Emmett-Mattox, S. Crooks, J.P. Megonigal, D. Myers, M.P. J. Oreska, and K. McGlathery. 2018. The science and policy of the Verified Carbon Standard Methodology for Tidal Wetland and Seagrass Restoration. *Estuaries and Coasts.* (In review)

Olander, J. and J. Ebeling. 2011. *Building Forest Carbon Projects: Step-by-Step Overview and Guide*. In Ebeling J. and Olander J. (eds.). Building Forest carbon Projects, Washington, DC: Forest Trends. Accessed 27 November 2014 http://www.foresttrends.org/documents/files/doc_2555.pdf

Oreska, M.P.J., K. McGlathery, I.M. Emmer, B.A. Needelman, S. Emmett-Mattox, S. Crooks, J.P. Megonigal, and D. Myers. 2018. Comment on ‘Geoengineering with seagrasses: is credit due where credit is given?’. *Environmental Research Letters*. (Accepted) DOI:10.1088/1748-9326/aaae72

Perillo, G. M. E., E. Wolanski, D. R. Cahoon, and M. M. Brinson. 2009. *Coastal Wetlands - An Integrated Ecosystem Approach*. 1st ed. Elsevier, Amsterdam.

Poffenbarger, H. J., B. A. Needelman, and J. P. Megonigal. 2011. Salinity Influence on Methane Emissions from Tidal Marshes. *Wetlands* 31: 831-842.

Purvaja, R., R. Ramesh, A. Shalini, and T. Rixen. 2008. Biogeochemistry of nitrogen in seagrass and oceanic systems. *Memoir Geological Society of India* 73 :435-460.

Smith, C. J., R. D. DeLaune, and W. H. Patrick, Jr. 1983. Nitrous oxide emission from Gulf Coast wetlands. *Geochimica et Cosmochimica Acta* 47: 1805-1814.

Verified Carbon Standard. 2017. *Agriculture, Forestry, and Other Land Use (AFOLU) Requirements. VCS Version 3 Requirements Document*. Verified Carbon Standard, Washington, D.C.

Welsh, D., M. Bartoli, D. Nizzoli, G. Castaldelli, S. A. Riou, and P. Viaroli. 2000. Denitrification, nitrogen fixation, community primary productivity and inorganic-N and oxygen fluxes in an intertidal Zostera noltii meadow. *Marine Ecology Progress Series* 208: 65-77.