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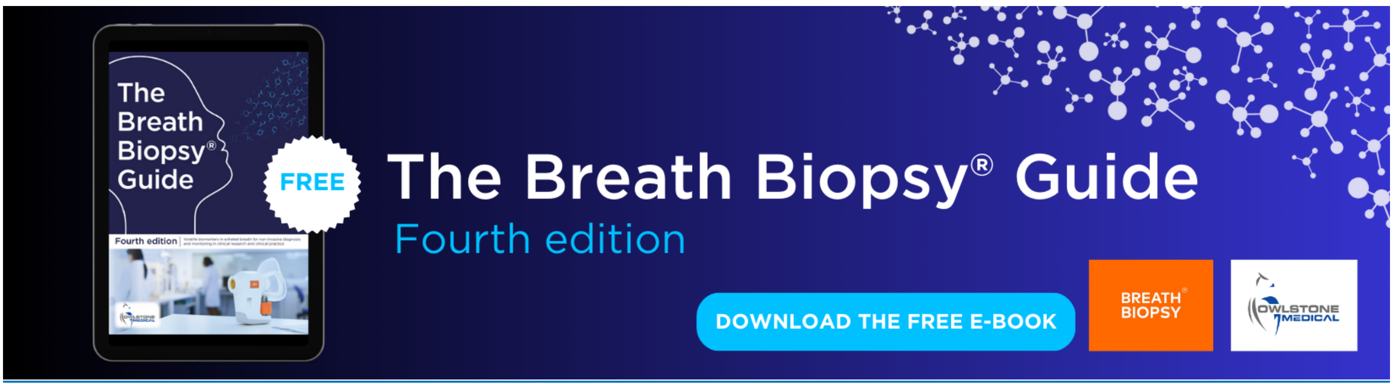

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REPLY

Reply to Oreska *et al* 'Comment on Geoengineering with seagrasses: is credit due where credit is given?'

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Abstract

In their comment on the review paper, 'Geoengineering with seagrasses: is credit due where credit is given?,' Oreska *et al* 2018 state that some of the concerns raised in the review 'warrant serious consideration by the seagrass research community,' but they argue that these concerns are either not relevant to the Voluntary Carbon Standard protocol, VM0033, or are already addressed by specific provisions in the protocol. The VM0033 protocol is a strong and detailed document that includes much of merit, but the methodology for determining carbon sequestration in sediment is flawed, both in the carbon stock change method and in the carbon burial method. The main problem with the carbon stock change method is that the labile carbon in the surface layer of sediments is vulnerable to remineralization and resuspension; it is not sequestered on the 100 year timescale required for carbon credits. The problem with the carbon burial method is chiefly in its application. The protocol does not explain how to apply ^{210}Pb-dating to a core, leaving project proponents to apply the inappropriate methods frequently reported in the blue carbon literature, which result in overestimated sediment accumulation rates. Finally, the default emission factors permitted by the protocol are based on literature values that are themselves too high. All of these problems can be addressed, which should result in clearer, more rigorous guidelines for awarding carbon credits for the protection or restoration of seagrass meadows.

1. Introduction

In their comment on our paper, 'Geoengineering with seagrasses: is credit due where credit is given?' (Johannessen and Macdonald 2016), Oreska *et al* 2018 state that some of the concerns raised by Johannessen and Macdonald 2016 'warrant serious consideration by the seagrass research community.' They then argue that these concerns are either not relevant to the Voluntary Carbon Standard protocol, VM0033 (Emmer *et al* 2015a, and its associated handbook, Emmer *et al* 2015b) or are already addressed by specific provisions in the protocol.

As noted by Oreska *et al* 2018, our concerns focussed on the methodologies approved for the estimation of carbon burial rates in marine sediment associated with seagrass beds. A reliable determination of carbon burial flux is the foundation upon which rests any estimate of the capacity of seagrass beds to sequester atmospheric CO_2 over the long-term (≥100 years). Accurate measurement of sedimentation rates in shallow-water sediments is challenging. Even more challenging is to estimate the associated flux of a substance like organic carbon, which is not conservatively buried, and then to estimate the difference in carbon burial flux before and after seagrass colonization. These difficulties require scrupulous attention to methodology. In this context, we identified six problems associated with methods sanctioned by protocols or used in published papers, which, taken together or independently, tend to overestimate carbon sequestration in seagrass sediments (Johannessen and Macdonald 2016).

These six problems were:

1. Confusing carbon inventories with fluxes
2. Extrapolating from Posidonia beds to all seagrass meadows globally
3. Neglecting mixing in surface sediments (e.g. bioturbation)

4. Neglecting organic carbon remineralization within surface and shallow sediments
5. Neglecting organic carbon export resulting from the high energy of the shallow ocean environment
6. Counting allochthonous as well as autochthonous organic carbon, since the allochthonous carbon would likely have been stored elsewhere.

It was not our intention to imply that all six of these problems applied to every international protocol. Our intention was, and still is, to point out that one or more of these problems occur within each of the international protocols that we cited, and all of them appear in the seagrass blue carbon literature, including peer-reviewed articles. Furthermore, we provided guidance on how these issues might be addressed in a revised protocol (Johannessen and Macdonald 2016).

In the case of the VM0033 protocol, we agree that there are many responsible provisions for making conservative estimates of greenhouse gas (GHG) emission reductions, including subtracting allochthonous organic carbon and accounting for non-CO_2 GHG emissions. The VM0033 protocol is extensive, and includes many considerations besides the calculation of carbon sequestration in marine sediments. Here and in Johannessen and Macdonald 2016, we focus only on the sequestration of carbon in seagrass sediments. The carbon stock change method described by VM0033 and in the literature cited by Oreska *et al* 2018 in support of that protocol, does not adequately account for the effects of sediment mixing (by bioturbation or physical processes) or remineralization of organic carbon within the sediments and will produce an overestimate of carbon sequestration whenever mixing or organic carbon metabolism occur. Our contention is that both of these processes are pervasive in coastal marine sediment.

2. Problems with the carbon stock change method

The main problem with the carbon stock change method is that organic carbon in the uppermost layer of sediment is not sequestered on the timescale of 100 years required by the protocol, because it remains vulnerable to remineralization or resuspension.

Oreska *et al* 2018 point out that VM0033 does account for remineralization, but what they refer to is the remineralization that occurs when a seagrass bed is degraded and the organic carbon returns to the water column (VM0033 section 8.2.4.1). In contrast, the remineralization that causes problems with the estimation of burial flux by the carbon stock change method occurs naturally within the sediments, whether or not a seagrass bed has been degraded. Microbial respiration occurs rapidly within the surface mixed layer of sediment, and may continue more slowly for some tens of cm below the sediment surface mixed layer (Stolpovsky *et al* 2015). Only the portion of carbon that is buried below the depth of microbial remineralization can be considered buried on a 100 year timescale (see cross-hatched portion of figure 4 in Johannessen and Macdonald 2016).

VM0033 requires proponents to quantify organic carbon inventory change down to 'a layer with soil organic carbon indistinguishable from the baseline SOC concentration' and to exclude that baseline concentration. By discounting the buried portion of organic carbon and including the labile portion that is respired within the surface sediment, VM0033 does exactly the opposite of what is required.

An argument could be made that, although labile organic carbon is respired within the shallow sediment, there is an ongoing supply of labile carbon from a living seagrass bed, such that a steady-state inventory is maintained over time. However, even in that case, the surface sediment reservoir is not permanent, because intertidal and shallow subtidal sediment is subject to erosion and resuspension. Bos *et al* (2007) illustrated the potentially transient nature of organic carbon in the surface sediments of a seagrass bed. They showed that sediment accreted faster within a newly-planted seagrass bed than at a nearby bare patch from summer to autumn, but then eroded faster than the bare sediment from autumn to winter. If a project proponent were to collect sediment cores only during summer, he/she could easily conclude that the seagrass bed was storing carbon rapidly, when, in fact, it was actually losing sediment and carbon over the course of a year. Even in subtidal, perennial seagrass beds, the surface sediment can be eroded rapidly. Miyajima *et al* (1998) found that the top 10 cm of sediment in a seagrass meadow on the Great Barrier Reef was turned over or resuspended on the timescale of 17–170 days.

If there were a consensus that the inventory of transient organic carbon in the surface layer should be included for crediting, it seems to us that it ought to be accounted for separately from the carbon buried more permanently ($\geq$100 years). The latter is sustainable over an indefinite time period, whereas the former ceases to store further amounts of organic carbon once steady state is reached. A conservative approach, as claimed by Oreska *et al* 2018 for VM0033, would require that only the portion of carbon that was buried below the depth of surface sediment mixing would be considered buried on the timescale required for carbon crediting. Even this approach might be less than conservative, depending on the vigour of metabolism occurring slowly over longer periods of time in deep sediments.

The VM0033 version of the carbon stock change method does not suffer from some of the problems apparent in other versions of the method, such as integrating the sum of organic carbon over a set depth. That and other limitations of the stock change method are discussed in more detail by Johannessen and Macdonald 2016 and in our Reply (Johannessen and Macdonald 2018) to the Macreadie *et al* 2018 Comment.

3. Problems with carbon burial flux calculation in VM0033

In addition to the carbon stock change method, as Oreska *et al* 2018 note, VM0033 permits the calculation of carbon burial using sediment accumulation rates determined from, for example, ^{210}Pb profiles in sediment cores. We agree that multiplying a sediment accumulation rate by the buried % organic carbon is an acceptable, direct way to determine carbon burial in seagrass bed sediment. However, the references cited in VM0033 and by Oreska *et al* 2018 do not present applications of this method that are suitable for determining organic carbon burial in seagrass beds.

The example profiles presented in figure 2 by Oreska *et al* 2018 were taken from observations by Greiner *et al* (2013) and Marbà *et al* (2015). We have addressed the shortcomings of the Greiner *et al* 2013 paper (Johannessen and Macdonald 2018). Briefly, the cores obtained by Greiner *et al* 2013 cannot be confidently dated using the ^{210}Pb profiles that they present. In addition, although they conclude that the sediments in these cores have been bioturbated, they assign dates to discrete depths, which has no meaning in a mixed core (Silverberg *et al* 1986). Then, without explanation, Greiner *et al* 2013 produce a series of different accumulation rates associated with those years, which they then multiply by the organic carbon concentration at each depth, even within the surface mixed layer. This is not a reliable approach upon which to build an international protocol.

The Marbà *et al* (2015) paper, although it determines the sediment accumulation rate below the surface mixed layer, also goes on to assign dates to specific layers in the core and to assign organic carbon accumulation rates to those years. Given the 0.1 cm yr^{-1} sedimentation velocity and 2–3 cm mixed layer depth reported by Marbà *et al* 2015, 20–30 years of sedimentation are blended together within the surface mixed layer. Sediment buried beneath the mixed layer contains a mixture of unknown proportions of organic carbon deposited during the previous 20–30 years. As already pointed out, discrete dates down a mixed core are meaningless and misleading, as are the variable carbon accumulation rates reported for the various depths in the core.

We do not argue that there was no additional carbon sequestered in the sediment observed by Marbà *et al* (2015) or Greiner *et al* (2013) following seagrass restoration, but only that their methodology does not permit a valid determination of the enhanced carbon sequestration rate.

The international protocols, including VM0033, are silent about how ^{210}Pb should be applied in marine sediment cores. Sediment accumulation rates can be determined from mixed cores, using an advective-diffusive model that explicitly accounts for the surface mixed layer (e.g. Lavelle *et al* 1986). However, these models cannot recover individual years (Johannessen and Macdonald 2012). It is misleading to cite ^{210}Pb dating methods appropriate for unmixed sediments, such as those found in lakes or deep, anoxic basins (e.g. Appleby 2001, Sanchez-Cabeza and Ruiz-Fernández 2012), without noting that those models generally do not apply in shallow, marine sediments.

Another problem not addressed by the protocols is that data are often provided from cores that are $\leq$ 10 cm in length. Conservatively, cores this short are likely collecting only mixed-layer material (Boudreau 1994). Under such circumstances, a log-linear ^{210}Pb profile might indicate radioactive decay and slow sedimentation, but more likely reflects radioactive decay and mixing. By itself, the ^{210}Pb profile cannot be used to produce a reliable sedimentation rate for such short cores.

4. Overestimated default emission values

Oreska *et al* 2018 state that problem #2 (extrapolating to seagrass beds globally from data collected only in Posidonia beds) does not apply to VM0033, because the credits are not awarded for existing seagrass carbon pools. However, the problem does apply implicitly, because the default Tier 1 emission factor for seagrass restoration permitted by VM0033 comes only from studies in Posidonia beds. Oreska *et al* 2018 state that this value is still conservative because it is comparable to the value determined by Greiner *et al* (2013), which we have already discussed, and falls at the low end of the range determined globally, citing McLeod *et al* (2011) (who were quoting Kennedy *et al* (2010)). However, as we have pointed out, the rates determined globally are overestimated as a result of the methodologies used to estimate carbon burial (Johannessen and Macdonald 2016, 2018) and, therefore, the default value is almost certainly too high.

5. A stronger protocol

In Johannessen and Macdonald 2016, we cited methodologies developed and published during the past four decades by the community of sedimentary geochemists that would provide the most reliable (and conservative) way to determine the contribution of a seagrass meadow to the sequestration of carbon. Such methodologies would have to include explicit consideration of surface sediment mixing and remineralization of organic carbon within the sediments. For almost all shallow-water sediments, recourse to modeling beyond a simple log-linear interpretation of

^{210}Pb profiles is necessary, as is consideration of the metabolism of organic carbon.

6. Conclusion

Our intention with the original paper (Johannessen and Macdonald 2016) and in our responses to the Comments is not to discount entirely protocols like VM0033, which contains much of merit. Rather, we have identified a specific topic—the methodology to produce acceptable measurements of burial rates of organic carbon in seagrass beds—that requires revision. We have described the problem and laid some groundwork toward redrafting this component of the protocols. The VM0033 protocol is a strong and detailed document that includes a comprehensive set of equations for calculating GHG-emission reductions, discounting allochthonous carbon, and including non-CO_2 GHGs. Nevertheless, the methodology described by VM0033 for determining carbon sequestration remains flawed with respect to the carbon stock change method and the carbon burial method. Both of these problems can, however, be addressed, which should result in stronger, more reliable guidelines for awarding carbon credits for the protection or restoration of seagrass meadows.

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References

Appleby P G 2001 Chronostratigraphic techniques in recent sediments *Tracking Environmental Change Using Lake Sediments* ed W M Last and J P Smol (Dordrecht: Klewer Academic) pp 171–203 ch 9

Bos A R, Bouma T J, de Kort G L J and van Katwijk M M 2007 Ecosystem engineering by annual intertidal seagrass beds: sediment accretion and modification *Estuar. Coast Shelf Sci.* **74** 344–8

Boudreau B P 1994 Is burial velocity a master parameter for bioturbation? *Geochim. Cosmochim. Acta* **58** 1243–9

Emmer I, Needelman B, Emmett-Mattox S, Crooks S, Megonigal P, Myers D, Oreska M, McGlathery K and Shoch D 2015a *Methodology for Tidal Wetland and Seagrass Restoration VM0033 Version 1.0 Verified Carbon Standard* (Washington, DC: University of Virginia)

Emmer I, von Unger M, Needelman B, Crooks S and Emmett-Mattox S 2015b *Coastal Blue Carbon in Practice: A Manual for Using the VCS Methodology for Tidal Wetland and Seagrass Restoration VM0033* ed S Simpson (Arlington: University of Virginia)

Greiner J T, McGlathery K J, Gunnell J and McKee B A 2013 Seagrass restoration enhances blue carbon sequestration in coastal waters *PLoS ONE* **8** e72469

Johannessen S C and Macdonald R W 2012 There is no 1954 in that core! Interpreting sedimentation rates and contaminant trends in marine sediment cores *Mar. Pollut. Bull.* **64** 675–8

Johannessen S C and Macdonald R W 2016 Geoengineering with seagrasses: is credit due where credit is given? *Environ. Res. Lett.* **11** 113001

Johannessen S C and Macdonald R W 2018 Reply to Macreadie, *et al* Comment on 'Geoengineering with seagrasses is credit due where credit is given?' *Environ. Res. Lett.* **13** 028001

Kennedy H, Beggins J, Duarte C M, Fourqurean J W, Holmer M, Marbà N and Middelburg J J 2010 Seagrass sediments as a global carbon sink: isotopic constraints *Glob. Biogeochem. Cycles* **24** GB4026

Lavelle J W, Massoth G J and Crecelius E A 1986 Accumulation rates of recent sediments in Puget Sound, Washington *Mar. Geol.* **72** 59–70

Macreadie P I, Ewers C, Whitt A, Ollivier Q, Trevathan-Tackett S, Carnell P, Thomson A and Serrano O 2018 Comment on Geoengineering with seagrasses: is credit due where credit is given? *Environ. Res. Lett.* **13** 028002

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

McLeod E, Chmura G L, Bouillon S, Salm R, Björk M, Duarte C M, Lovelock C E, Schlesinger W H and Silliman B R 2011 A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2 *Front. Ecol. Environ.* **9** 552–60

Miyajima T, Koike I, Yamano H and Iizumi H 1998 Accumulation and transport of seagrass-derived organic matter in a reef flat sediment of Green Island, Great Barrier Reef *Mar. Ecol. Prog. Ser.* **175** 251–9

Oreska M P J, McGlathery K J, Emmer I M, Needelman B A, Emmett-Mattox S, Crooks S, Megonigal P and Myers D 2018 Comment on Geoengineering with seagrasses: is credit due where credit is given? *Environ. Res. Lett.* this issue

Sanchez-Cabeza J A and Ruiz-Fernández A C 2012 ^{210}Pb sediment radiochronology: an integrated formulation and classification of dating models *Geochim. Cosmochim. Acta* **82** 183–200

Silverberg N, Nguyen H V, Delibrias G, Koide M, Sundby B, Yokoyama Y and Chesselet R 1986 Radionuclide profiles, sedimentation rates, and bioturbation in modern sediments of the Laurentian Trough, Gulf of St. *Lawrence Oceanol. Acta* **9** 285–90

Stolpovsky K, Dale A W and Wallmann K 2015 Towards a parameterization of global-scale organic carbon mineralization kinetics in surface marine sediments *Glob. Biogeochem. Cycles* **29** 812–29