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 ($\geq$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-CO₂ 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 sediments.

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 was 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 (≥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, 210Pb 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 210Pb 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 210Pb 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 210Pb 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 ≤ 10 cm in length. Conservatively, cores this short are likely collecting only mixed-layer material (Boudreau 1994). Under such circumstances, a log-linear 210Pb profile might indicate radioactive decay and slow sedimentation, but more likely reflects radioactive decay and mixing. By itself, the 210Pb 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...
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-CO₂ 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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