

## Quantifying the carbon benefits of ending bottom trawling

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1 Quantifying the carbon benefits of ending bottom trawling 2 3 Jan Geert Hiddink<sup>1</sup> 4 Sebastiaan J. van de Velde<sup>2,3</sup> 5 Robert A. McConnaughey<sup>4</sup> 6 Emil De Borger<sup>5</sup> 7 Justin Tiano<sup>5,6</sup> 8 Michel J. Kaiser<sup>7</sup> 9 Andrew Sweetman<sup>7</sup> 10 Marija Sciberras<sup>7</sup> 11 12 1. School of Ocean Sciences, Bangor University, United Kingdom, j.hiddink@bangor.ac.uk 13 2. Department of Geoscience, Environment & Society, Université Libre de Bruxelles, Brussels, 14 Belgium 15 3. Operational Directorate Natural Environment, Royal Belgian Institute of Natural Sciences, 16 1000 Brussels, Belgium 17 4. Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, Seattle, 18 Washington, USA 19 5. Royal Netherlands Institute of Sea Research, Department of Estuarine and Delta Systems, and 20 Utrecht University, Yerseke, The Netherlands 21 6. Wageningen Marine Research, Wageningen University and Research, IJmuiden, the 22 Netherlands 23 7. Lyell Centre, Heriot-Watt University, Edinburgh, United Kingdom. 24 Bottom trawling disrupts natural carbon flows in seabed ecosystems due to sediment mixing,

25 26 resuspension and changes in the biological community. Sala, et al. <sup>1</sup> suggest that seafloor disturbance by industrial trawlers and dredgers results in 0.58 to 1.47 Pg of aqueous CO<sub>2</sub> release annually 27 28 (equivalent to 0.16 to 0.4 Pg C per year), owing to increased organic carbon (OC) mineralisation that 29 occurs after trawling. We are concerned, however, that Sala et al. seriously overestimate trawl-30 induced  $CO_2$  release because their model uses a reactivity value (k, the first order decay rate) 31 estimated for highly reactive OC delivered recently to the sediment surface, and apply it to bulk 32 sediment (typically composed of labile, recalcitrant and refractory C) which is known to have a much 33 lower reactivity<sup>2</sup>. These issues result in an upward bias in the estimated CO<sub>2</sub> release by several orders 34 of magnitude, severely overestimating the impact of trawling on global organic carbon mineralisation 35 rates.

36 37 The Sala et al. important of parameter values in ignore the role 38 composition in driving OC mineralisation in marine sediments. Organic carbon that reaches the 39 sediment represents a mixture of different compounds that range from very reactive to very 40 unreactive molecules<sup>4</sup>. Typically, around 70% (represented by the fraction of reactive material p of 41 0.70 for muddy sediment in the model of Sala et al.) is very reactive and mineralised by micro-42 organisms within the first few centimetres of sediment, which translates into a high k-value (reactivity 43 of the OC pool, 1-10  $y^{-1}$ ). The remaining, less reactive, fractions are mineralised much slower, with typical k-values of < 0.1 y<sup>-1</sup> (<sup>5</sup>). Because of the preferential mineralisation of the more reactive 44 45 fractions, the k-value of the bulk OC decreases exponentially with sediment depth, generally from 1-46 10 y<sup>-1</sup> at the sediment-water interface to <0.01 y<sup>-1</sup> below 5 cm depth<sup>5,6</sup> (Figure 1). The standing stock of OC in the sediment thus typically exhibits a k-value of 0.01 - 0.1 y<sup>-1</sup>. Consequently, the approach 47 48 Sala et al. <sup>1</sup> have taken - using a k-value of 0.3-17 y<sup>-1</sup> and applying this to the bulk of the OC stock – 49 and may result in an overestimation of CO<sub>2</sub> release of historically-buried OC by two to three orders of 50 magnitude. We argue that incorporating the role of composition would require lowering the k value 51 to around 0.01 y<sup>-1</sup>, which is representative for sub-surface sediment<sup>6</sup>, and applying it to the bulk of the

sediment (fraction of reactive material p = 1), or alternatively using the original high k values (k = 0.3-17 y<sup>-1</sup>) and applying them to the fraction of reactive material p present in historically buried OC (p = 0.001-0.01). More importantly, the calculations in Sala, et al. <sup>1</sup> would only have given an estimate of OC remineralisation independent of trawling – since these k- and p-values are representative of OC mineralisation in marine sediments (Fig. 1 shows typical k-values relative to sediment depth for a range of North Sea sediments).

Furthermore, the OC model presented by Sala, et al. <sup>1</sup> does not differentiate between OC 58 59 mineralisation in undisturbed sediment, and OC mineralisation induced by sediment disturbance. 60 Instead, Sala et al. implicitly assume that the OC mineralisation rate calculated using their model 61 results from trawling disturbance alone. As a result, their model assumptions imply that OC in an area 62 protected from trawling is unreactive and will not be mineralised. The 'carbon model validation' in the 63 Methods section clearly illustrates this issue. Sala et al. compare the modelled CO<sub>2</sub> emissions that 64 derive only from the trawl disturbance of historically-buried OC with empirical estimates of CO<sub>2</sub> 65 emissions from natural-plus-trawling mineralisation of all sedimentary OC, and without comparisons 66 to untrawled control sites. These fundamentally incomparable measures are unsuitable for the model 67 validation. The fact that these measures are of the same order of magnitude illustrates that CO<sub>2</sub> emissions by trawling are likely to be small compared to emissions from natural mineralisation <sup>3</sup> and 68 69 much smaller than modelled by Sala, et al. <sup>1</sup>.

70 The ultimate question is whether the reactivity of the OC stock is increased by trawling disturbance 71 and resuspension, and thus if the k-value is higher after trawling. Unfortunately, this question is not 72 addressed by Sala et al.<sup>1</sup>. To date, our knowledge of the effects of trawling-induced disturbance and 73 resuspension on the reactivity of OC, and how this compares to those by natural resuspension events 74 (e.g., storms, waves) is extremely limited. A recent review of 49 studies investigating OC stocks after 75 trawling-induced disturbances demonstrated highly mixed results, with 61% of studies reporting no 76 significant effect, 29% reporting lower OC stocks, and 10% reporting higher stocks<sup>3</sup>. To robustly 77 estimate the global impact of bottom trawling on OC mineralisation, new experiments are needed 78 that quantify the reactivity of disturbed OC in the sediment and in resuspension.

79 In conclusion, we currently do not know enough about the impact of trawling on seabed carbon to 80 make robust global projections. Reliable estimates of sediment carbon loss should be based on models 81 that use parameter estimates for the change in OC reactivity and that are tested against empirical 82 measurements. Sala, et al.<sup>1</sup> suggest that reducing CO<sub>2</sub> release through reducing trawling effort could 83 generate carbon credits and provide an opportunity for financing Marine Protected Areas. While this 84 is certainly an idea worth considering, we argue that the Sala et al.'s CO<sub>2</sub> release estimates create 85 unrealistic expectations about the quantity of carbon credits that can be generated. Even initial plans 86 for the management of bottom trawling for carbon benefits require estimates that are of the correct 87 order of magnitude, and we argue that Sala et al. does not supply them.

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- sites in the North Sea, with varying organic carbon contents at the sediment surface ( $C_{org}$ , %).
- 129 Average rates stem from the degradation of OC consisting of a reactive and a less-reactive OC
- 130 fraction, where both fractions have a different degradation rate *k*. Data and modelling results from <sup>7</sup>.

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