

Interactive comment on “Effects of the arrival of fresh organic matter on eroded and nutrient-depleted trawling grounds (Gulf of Castellammare, SW Mediterranean)” by Sarah Paradis et al.

Sarah Paradis et al.

sarah.paradis@uab.cat

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We would like to thank Dr. Van de Velde for the time taken to read and review our manuscript, and for raising relevant aspects that need clarification in the text. Please find below our detailed responses to his comments.

1. I feel that the title does not really reflect the contents. Most of the paper deals with the impact of bottom trawling fishing on the sedimentary organic matter dynamics, of which the arrival of fresh organic matter is part. Perhaps something like ‘the impact of

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trawling on organic matter dynamics in sediments of the Gulf of Castellammare (SW Mediterranean)' would be more appropriate.

RESPONSE: We believe that the title emphasizes the novelty of our manuscript, since previous papers have already addressed the impacts of bottom trawling in sediment erosion and depletion of sedimentary organic matter, but not on the recent deposition of fresh sediment. Nevertheless, we have modified the title to “Organic matter contents and degradation in a highly trawled area during fresh particle inputs (Gulf of Castellammare, SW Mediterranean)” to englobe the different aspects studied in our manuscript.

2. I like that the paper is written very concisely and to the point. I do however feel that the abstract is a bit out of balance with the rest of the paper. If possible, I would try to shorten it somewhat.

RESPONSE: The abstract has been condensed in the revised manuscript.

3. Introduction: It might be relevant to mention the common depth range of the sediment that is resuspended after trawling, as it might be important when considering the impact of changing the frequency of trawling. For example, if your site has a sedimentation rate of 0.15 cm/yr, and you decrease trawling frequency to once every 10 years, and the trawl resuspends the upper 15 cm of sediment, the impact is still considerable.

RESPONSE: Indeed, knowing the depth-range of sediment that is resuspended by bottom trawlers would be crucial to understand the vulnerability of our study site to bottom trawling activities and establish efficient management strategies. There have been studies that model the amount of sediment resuspended by bottom trawlers, which indicate that type of trawling gear, sediment grain size, and hydrodynamic drag exerted by the trawling gear influence the mobilization of sediment (see O'Neill and Ivanovic, 2016, ICES Journal of Marine Systems; O'Neill and Summerbell, 2016, Journal of Marine Systems). These studies highlight that penetration depth of trawling gear on the seafloor and sediment resuspension do not always present an evident positive correlation, since some of this sediment is simply overturned and/or displaced laterally.

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Hence, providing a penetration depth of bottom trawling gear would not be indicative of the depth-range of sediment being resuspended, either. With our data, we cannot provide information on the amount of sediment being eroded per trawler. However, we have sufficient evidence, based on our results, that the overall erosion rate of trawlers is greater than the sedimentation rate in the Gulf of Castellammare. This is inferred due to the coincident penetration depths of both excess Th-234 and excess Pb-210, which have considerably different half-lives, indicating that the upper 2 cm of sediment was recently deposited, whereas sediment below these sections had been deposited more than a century prior to sampling. This highlights the vulnerability of bottom trawling in deep environments, where the sedimentation rate is lower than shallower continental shelves. Please see the response to your comment 6, which also deals on management strategies to mitigate this impact.

4. P10L14: Would you expect coarser sediment to be washed away following trawling induced resuspension? I would assume the inverse happens, that the finer-grained, OM rich material gets washed away, and the coarser material remains behind. Also, the grain size of the trawled site has near-identical values for its grain size. Unless you mean that the finest material does not settle as fast as the intermediate grain sizes (but that should then be explained a bit clearer).

RESPONSE: Indeed, we should observe the advection of fine sediment, and not coarse sediment, with a preferential deposition based on particle size. The untrawled core was collected approximately 1 km downcurrent from trawling grounds, where silty sediment will be preferentially deposited in comparison to finer sediment such as clay particles. Clay sediment, however, can remain in suspension and travel greater distances, eventually redepositing farther away. For instance, a study on the distribution of trawling-induced resuspension of sediment in the Koster Sea on the west coast of Sweden observed that silt particles can travel up to 7 km from trawling grounds, whereas finer clay particles can travel beyond 28 km (Linders et al., 2018, ICES Journal of Marine Systems). We acknowledge that this message may not have been clear

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due to poor word choice, referring to “silt” particles as “coarse” sediment. The amended manuscript now reads: “Provided the high capacity of bottom trawling gear to resuspend sediments (Martin et al., 2014a, 2014c; Oberle et al., 2018; Puig et al., 2012), the siltation of superficial sediments on the untrawled site could probably be explained by the preferential deposition of siltier particles resuspended from an adjacent trawling ground located ~ 1 km up-current from this sampled site (Fig.1). Finer clay particles resuspended by bottom trawlers can be advected at farther distances along the margin (Linders et al., 2018).”

5. P10L22-26: Another explanation could be that the resuspension and mixing stimulate the breakdown of organic matter that is already present, thus leading to lower concentrations. This is also what you allude to in P11L15-23, an increase in mineralization rates due to the mixing of refractory and fresh compounds. If it is noticeable after the deposition of fresh material, I assume it will play a role over the longer term too. Most likely the truth exists somewhere in the middle, and the impact of bottom trawling induced resuspension events is likely very dependent on the exact grain size. For example, we found recently that this mixing stimulates organic matter breakdown in a fine grained (63% clay) sediment in the North Sea (van de Velde et al., 2018, Scientific Reports), whereas Tiano et al. (2019, ICES Journal of Marine Science) found that sediment metabolism actually went down after trawling. The North Sea site of Tiano et al. (which is a reference you should include) was much however much sandier (30% silt, 40% fine sand). Maybe it would be worth expanding the discussion a bit, and considering both end-member scenarios.

RESPONSE: Diverse results have been found on the fate of OM in trawling grounds, some of them summarized in Martin et al., 2014, Anthropocene. As the reviewer mentions, one of the reasons of these contradictory results could be the type of sediment in each environment: whether trawling occurs on non-cohesive sandy seafloors or on cohesive muddy seafloors. We limited our study to comparing the effects of bottom trawling to other cohesive environments (including the results portrayed in van de

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Velde et al., 2018, Scientific Reports), and merely distinguishing between biogeochemical impacts in shallower and deeper trawling grounds. We agree with the reviewer that it would be worth exploring the influence of grain size, but it is not the scope of this paper. We believe that a proper review of the impacts of bottom trawling on the biogeochemistry of OM should be done to assess the influence of grain size, water depth, and other factors. Nevertheless, we have included the following sentences in the Introduction of the amended manuscript, which highlight the broad range of effects that bottom trawling can generate in different environments: “The effects that these perturbations generate on sedimentary OM can vary in cohesive (i.e. muddy sediment with high clay content) and non-cohesive (i.e. sandy seafloor) sediment. For instance, trawling on cohesive sediments can increase superficial concentrations of sedimentary OM (Palanques et al., 2014; Pusceddu et al., 2005a; Sciberras et al., 2016; Polymenakou et al., 2005), whereas trawling on coarse non-cohesive sediments can exert null or minimal effects on OM contents and benthic community metabolism (Hale et al., 2017; Tiano et al., 2019; Trimmer et al., 2005).”

6. P11L29: this is a nice section to end the discussion, maybe it would be worth expanding this a bit, maybe by being a bit more concrete in the potential mitigation effects? This could be related to my comment about the depth of the bottom trawling, how long would temporary need to be to really mitigate the effect?

RESPONSE: Our study suggests that the ephemeral deposition of fresh and nutritious sediment could be sustaining the otherwise starved benthic communities. Establishing temporal trawling closures would allow a longer-lived deposition of fresh sediment, temporarily restoring sedimentary OM in trawling grounds which could be beneficial to the benthic communities inhabiting this area. However, with the punctual information we have of the impacts of bottom trawling and the effect of the deposition of fresh sediment, we can not provide additional details of how a temporal trawling closure should be implemented (i.e. length or season of the trawling closure). Hence, we believe that further studies assessing the viability of these mitigation practices should be car-

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ried out. From the sedimentological perspective, a temporal trawling closure would not solve the issue of erosion in trawling grounds. For instance, assuming a regional sedimentation rate of 0.09 g/cm²/yr, or 0.15 cm/yr, a trawling closure of a decade would allow the accumulation of 0.9 g/cm², or 1.5 cm of “new” sediment. Such a long trawling closure isn’t feasible from a socioeconomic perspective, nor efficient. To solve this problem, other management strategies that reduce the rate of erosion would need to be studied, such as reducing the trawling frequency or changing their trawling gear to minimize sediment remobilization. This additional issue has been addressed in the revised manuscript by modifying the discussion’s closing paragraph from the original manuscript to the following: “These results confirm that actions aimed at mitigating the impacts of bottom trawling include the implementation of temporary fishing closures, allowing for a longer-lived deposition of fresh OM on the seafloor. However, such temporary trawling closures would most probably not allow the full restoration of fresh sediment from trawl-induced erosion, given the low sedimentation rates found on these deep environments. Further management strategies would need to be implemented to mitigate the impacts of bottom trawling erosion (Depestele et al., 2019), which would magnify the effect of temporary closures on the restoration of sedimentary OM in nutrient-deprived trawling grounds.”

Minor editorial suggestions: As a more general remark, you say you sliced cores in triplicate, but I only see one profile per figure and per site (and the captions says that the error bars represent the analytical error). What happened to the other 2 cores that were sliced?

RESPONSE: Triplicate cores were taken only for organic matter analyses (protein, carbohydrate, lipid, phytopigment, turnover rates), whereas the remaining analyses (dry bulk density, grain size, radiochemical analyses, and elemental analyses) were carried out in one sediment core from each site. We specified that error bars in Fig. 4, for instance, represent analytical errors, and we should have also specified that Figs. 5 and 7 represent mean and standard errors of triplicate samples. This has been clarified

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in the revised manuscript.

P2L13-15: 'concentrations of sedimentary organic matter in superficial sediments tend to increase' and later 'stimulate mineralization of buried and refractory organic matter' This seems contradictory to me, as stimulating mineralization would decrease organic matter.

RESPONSE: Indeed, this would seem contradictory and should be clarified. High OM concentrations initially lead to high remineralization, which eventually lower sedimentary OM concentrations. It is basically an issue of the time-scale of these processes. In Polymenakou et al., 2005, Continental Shelf Research and in Pusceddu et al., 2005, Continental Shelf Research, the onset of trawling activities initially led to higher sedimentary organic matter concentrations, possibly due to mixing, which was accompanied with higher OM degradation. However, re-sampling of these trawled sites a few months later indicated a decrease of sedimentary organic matter concentrations, attributed to the high degradation rates observed earlier. Nevertheless, this apparent contradictory sentence was removed to avoid confusions. See the response to your comment 5 for how this issue was clarified.

P3L17: move 'are' between 'sedimentary organic matter' and 'by'

RESPONSE: This grammatical correction has been included in the revised manuscript.

P4L13: you mention that you slice cores on deck, up to 9cm depth, but later you show figures with date up to 20 cm depth? (e.g. Fig.2)

RESPONSE: We sliced triplicate cores intended for organic matter analyses up to 9 cm, whereas the remaining cores, used to analyse the remaining parameters (dry bulk density, grain size fraction, radiochemical analyses), were completely sliced in 1 cm intervals.

P5L11: why did you limit measurements to the upper 5 cm? I assume that is because activities dropped below the detection limit, but it might be nice to mention that here.

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RESPONSE: Only the upper 5 cm were analysed for excess Th-234 since samples need to be measured within two half-lives (approximately 6 weeks), after which 75 % of excess Th-234 would have decayed, rendering its quantification unreliable and with a high uncertainty. Since we didn't find detectable concentrations of Cs-137 in the trawled site in these upper 5 cm, we considered unnecessary to analyse deeper samples of this core, whereas gamma measurements for Cs-137 in the untrawled core were conducted for deeper layers until concentrations were below detection limit. This has been clarified in the revised manuscript.

P8L8: Maybe it is not relevant for this paper, but why would the CaCO₃ contents differ?

RESPONSE: Trawled sites presented higher (~27 %) CaCO₃ concentrations than the untrawled site (~17 %) in the upper 10 cm, although the difference becomes smaller at deeper sections in the cores. This could be related to differences of (or proximity to) riverine sediment sources, or to a higher presence of broken shells or foraminifera. With the available information, we cannot explain the exact reasons for this phenomenon and we prefer not to speculate about this aspect in the paper.

P11L18: Aller (1994) is not an appropriate reference, this paper deals with bioturbation and redox oscillations, not self-priming.

RESPONSE: This reference was accordingly removed in the revised manuscript.

Figs 2 and 3 could be combined into 1

RESPONSE: We would rather keep these two figures separate, since combining them would make the figure too dense.

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