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Discussions

# *Interactive comment on* "Organic N and P in eutrophic fjord sediments – rates of mineralization and consequences for internal nutrient loading" *by* T. Valdemarsen et al.

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The authors thank Susanna Hietanen (Reviewer#1) for her constructive criticism of the manuscript. In the text below, the Reviewers original comments are indicated by the headline "REVIEWER COMMENT" and author responses are indicated by the headlines "REPLY" and "ACTION"

REVIEWER COMMENT: This MS discusses a topical, important and controversial aspect in aquatic ecosystem protection and restoration – the effect internal, independently of external, nutrient loading has on the water quality. While internal nutrient loading has traditionally been seen only as phosphorus release from iron hydroxides



under oxygen stress, these authors define it wider, as the release of inorganic nutrients by mineralization of organic matter. To quantify such a release they performed a two-year experiment in which they incubated different types of sediments from different areas of a eutrophied fjord in both oxic and anoxic conditions and followed the fluxes of inorganic nutrients in and out of the sediments, production of ammonium and phosphate in anoxic conditions and the concentrations of total nutrients in the sediments. The same authors have recently published the results of organic carbon mineralization in this same experiment in Marine Ecology Progress Series (503: 41-58; 2014), stating that organic carbon accumulates in sediments and it's degradation is a slow process that delays the recovery of the water ecosystem. In this discussion paper the authors present data on nitrogen and phosphorus mineralization, concluding that internal nitrogen loading ceases much faster than that of phosphorus, which can be seen as good news for nitrogen limited systems (although the authors fail to mention e.g. that low N:P ratio favors the growth of cyanobacteria that, in turn, may release plenty of freshly fixed nitrogen to the system).

REPLY: The same point was addressed by reviewer#2. The reviewers are right that we did not mention that decreasing internal nitrogen loading could lead to stimulation of cyanobacteria, which could potentially buffer the decreasing internal nitrogen loading through N-fixation. This was omitted because we thought it was too speculative. In our experiment we only looked at N coming from the sediment and neglected the external N-loading, which is still the dominating source of N in the studied system. Decreasing internal nutrient loading may therefore not necessarily lead to reduced DIN concentrations as long as external N-loading remains high. Therefore major changes in phytoplankton composition towards increased dominance of cyanobacteria will probably not occur.

ACTION: In the revised manuscript we will mention that the decreasing internal N-loading and stable internal P-loading could lead to increased dominance of cyanobacteria. However, a major shift in phytoplankton community can only occur in systems where decreased internal nutrient loading results in markedly lower DIN-concentrations, i.e. in systems where (1) internal nutrient sources dominate, or where (2) external N-loading is significantly reduced.

REVIEWER COMMENT: The experiment has been carefully conducted and the paper is well written, with good quality tables and figures. The authors show that they are quite well aware of the shortcomings of the experimental setup used and discuss the results mainly accordingly. While the paper does not present especially novel ideas, it strengthens theories on shallow-water ecosystem recovery processes. I have very few specific comments: Page 15114 row 5: The selected habitat types are said to have covered the whole fjord (100%) – still, for example the highest porosity found in these samples was 0.8 which is surprisingly low – are there no high-organic muddy areas in this estuary, with porosities well over 0.9?

REPLY: The 3 stations located in the outer fjord (St 6-8) were chosen to represent the most organic rich, muddy areas in the fjord. A previous survey of sediment characteristics in Odense fjord covering >100 stations, showed that the most fine grained sediments had porosities around 0.8. The absence of extremely muddy sites in Odense Fjord is probably due to wind driven resuspension events, which may affect even the deep parts of this shallow system (down to 10 m depth) and prevent accumulation of the finest sediment fractions.

ACTION: This comment will not lead to changes in the manuscript.

REVIEWER COMMENT: Page 15114 row 20 on; removing macrofauna from naturally permanently oxic system makes the interpretation and generalization of the results dubious. The authors mention this shortcoming briefly in discussion as a possible source of error, and probably this is the only way to study slow processes in laboratory conditions. However, the role of macrofauna in benthic mineralisation in shallow, oxic waterbodies is very large and excluding them from the experimental setup a very drastic manipulation of the system. This might merit a bit longer discussion about the



reliability of the results from this point of view.

REPLY: A similar point was raised by Reviewer#2. We agree with the reviewers that removing macrofauna was a major manipulation, which undoubtedly changed/stimulated mineralization rates and temporal patterns. However, the main goal of the experiment was to assess how much nutrients could be released from the organic matter that had accumulated in the sediments during eutrophication, and this could not have been accomplished if macrofauna had been included in the study. To keep macrofauna alive in a 2 year laboratory experiment is virtually impossible. Macrofauna would need a stable food source (addition of some source of organic matter, including organic N and P), and then we would not know how much of the generated nutrients were coming from the sediment and added organic matter, respectively. Furthermore, most benthic infauna has a life span of less than 2 years, meaning that they would eventually die out in the lab experiment since there was no recruitment. Finally, the infauna composition is highly variable at the different stations (i.e. some stations have large bioturbators and others not), and this variability would have disturbed the major patterns in sediment nutrient generation at the different stations.

ACTION: In the revised manuscript we will strengthen our discussion of the consequences of removing infauna at the beginning of the experiment. We will emphasize that our estimates of nutrient regeneration are probably conservative, since macrofauna would have stimulated the remineralization of organic matter and nutrients.

REVIEWER COMMENT: Similarly, some mention could be made about the annual oxygen and temperature conditions these sediments might be exposed to in contrast to fully oxic, 15 degree incubation used in the experiment.

REPLY: A similar comment was made by Reviewer#2. The incubation temperature of 15ËŽC was chosen to reflect the average annual temperature in Odense Fjord. Hypoxia/anoxia is no longer occurring in Odense Fjord, so the incubation condition of fully oxygenated water is fully representative for Odense Fjord. It is true that annual temperature variations occur in the system and that this will influence microbial reaction rates. However, the main goal of the experiment was to provide an estimate of the total nutrient release from Odense Fjord sediments and not to simulate seasonal changes in microbial reaction rates. We therefore choose to omit any temperature driven variation in microbial reaction rates, which would complicate the interpretation of results.

ACTION: The influence of temperature variations were briefly mentioned in the original manuscript (Page 15129, Line 23). In the revised manuscript we will strengthen the discussion of consequences of constant contra variable temperature for internal nutrient loading.

REVIEWER COMMENT: Page 15117 Jar experiments. These experiments were run fully anoxic to prevent oxidation of end products, and homogenized probably for minimizing variation between samples. Both cutting the contact with oxygen for the surface sediments and homogenizing across redox zones heavily changes conditions compared to core incubations.These effects are not discussed at all. Was oxygen penetration to the sediments so shallow that it merited the anoxic incubation in the top layer?

REPLY: It is true that the jar technique may underestimate the actual mineralization rates in oxidized sediments where O2 sensitive organic matter is degraded. However, most coastal and estuarine sediments are predominantly anoxic beneath a shallow (1-3 mm deep) oxidized sediment layer, i.e. conditions similar to the beginning of this experiment. We (and probably the Reviewer) expected the sediments to become more and more oxic as the experiment progressed and labile organic matter was depleted, but this did not occur. This was for instance shown by hydrogen sulfide (data not shown), which was present at all sediment depths at all stations throughout the experiment, suggesting that sediments remained predominantly anoxic except for the upper few mm. Anoxic sediment incubations was therefore an appropriate technique to measure microbial reaction rates throughout the experiment.



ACTION: In the revised manuscript we will mention that the sediments remained mostly anoxic throughout the experiment and that closed anoxic sediment incubations therefore was an appropriate technique to measure microbial reaction rates throughout the experiment.

REVIEWER COMMENT: Page 15117 row 25; you probably mean that the concentrations of Fe (III) were compared at the beginning (initial) and end (final) of the experiments using pairwise t-tests? the results are really surprising – according to table 3 there are no significant differences, despite increase or decrease by 2.5-3.4 times.

REPLY: True – we compared total pools of Fe(III) at the beginning and end by pairwise t-tests. We were also very surprised that 2 year incubation with no addition of new organic matter did not lead to significant changes in Fe(III)-pools, owing to large spatial heterogeneity between sediment cores. Unfortunately, intercore variability is one of the drawbacks of using non-manipulated sediment cores.

ACTION: We will rephrase the lines (Page 15117 row 25-26) according to the reviewer′s suggestion.

REVIEWER COMMENT: Page 15120 rows 18-25; there seems to be some words missing and some in excess in the text (check grammar).

ACTION: The indicated section will be rephrased to: "Surface NH+4 production decreased rapidly over time in sediments from shallow locations in the inner and outer fjord, by 96% of initial rates on St 1 and by 61–82% on St 2–5. The surface NH4+ production in the sediments sampled in the deep outer basin (St 6–8) decreased by 8–67% during the experiment. NH4+ production at 4–6 cm depth was initially 18–60 nmol cm−3 d−1 on all stations and temporal changes were also observed in this layer, especially in shallow silty sediments from the inner basin where NH4+ production decreased by 75–96% to 1.4–12 nmol cm−3 d−1 by the end (Fig. 3)."

REVIEWER COMMENT: Page 15123 general comment on all the discussion about the sandy site: Sandy sediments are usually permeable, which means they operate by advection, not by diffusion. Enclosing sand in a core, out of reach of advective flow, changes conditions in the porewater dramatically. Recent research has indicated sandy sediments as areas of extremely high mineralization despite the low organic content. The authors mention that the sandy sediment came from area affected by with wind driven waves, deeply burying macrofauna and intense microphytobenthic production. None of this could be reproduced in the experimental setup, which questions the interpretation of the results on this site.

REPLY: A similar comment was made by reviewer#2.We are aware that shallow sandy sediments may be highly reactive due to a very dynamic environment. As mentioned in previous comments the main purpose of the experiment was not to simulate in situ degradation rates, but to measure how much nutrients could actually be made available by degradation and efflux to the overlying water column in different sediment types. In this respect the omission of waves, light and microphytobenthos is critical to be able to compare the reactivity of sedimentary organic matter and nutrients at different sites.

ACTION: In the revised manuscript we will strengthen the paragraph concerning the sandy site (Page 15124, Lines 141-23) and underline that shallow sandy sediments are highly dynamic environments supporting a rapid cycling of nutrients and organic matter. We will also emphasize that we are not claiming to simulate in situ degradation rates.

REVIEWER COMMENT: Page 15124 row 25 typos- subscripts instead of superscripts in Mkg.

ACTION: This will be corrected.

REVIEWER COMMENT: Page 15128 Ecological implications – the first half of the chapter is very repetitive and could be pruned heavily.

ACTION: We will shorten this paragraph.



REVIEWER COMMENT: Page 15138 Table 2 should show “average TN:TP ratios” but it does not.

ACTION: This will be corrected.

REVIEWER COMMENT: Page 15146 Figure 5 DIN= NH4+ + NOx- in figure but DIN= NH4+ + NO3- in legend.

ACTION: This will be corrected.

REVIEWER COMMENT: Page 15147 Figure 6 I am not sure this figure is really needed, although it is nice. REPLY: Reviewer#2 had the same comment. The temporal trends in NH4+ and NOx- are described sufficiently in the text.

ACTION: Figure 6 will be deleted in the revised version of the manuscript.

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Interactive comment on Biogeosciences Discuss., 11, 15109, 2014.