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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.

T. Valdemarsen et al.

valdemarsen@biology.sdu.dk

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The authors thank the reviewer for his/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: The manuscript discusses the importance of internal nutrient loading in the recovery of eutrophic estuaries by examining the mineralisation of organic nitrogen (ON) and phosphorus (OP) buried in the sediment. The magnitude of the internal loading of ON and OP was investigated in a two year experiment span-

ning a number of different sediment types found within the Odense Fjord. Cores were kept oxic throughout the experimental phase in which sediment porewater profiles, dissolved nutrient fluxes and anaerobic jar experiments (anaerobic mineralisation rates) were periodically measured over the two year period. The authors concluded that internal nitrogen loading is of minor importance (6% external N) and DIN fluxes stabilised after 50-200 days, alternatively internal phosphorus loading is potentially a source of P (36% external P) and PO43- fluxes throughout the two year period were variable and P efflux could be sustained over years which may be important for the management of P. The principles within the manuscript are not necessarily novel, however, the authors do provide further understanding of internal nutrient loading which is an important measure in the management of these systems and the potential for a delayed response after reducing external inputs. The manuscript is generally well written some areas could be shortened. There are, however, some limitations in the experimental design, possibly unavoidable due to the required length of the experiment but they do raise the question as to how relevant long term laboratory experiments are to the natural environment. Some of these limitations have been discussed briefly in the discussion and more thoroughly in the partner paper on carbon mineralisation published in the Marine Ecology Progress Series (Vol. 503: 41–58, 2014) however these need to be addressed more thoroughly.

REPLY: Both reviewers indicate that sources of errors and uncertainties regarding experimental setup and estimates of internal nutrient loading should be emphasized more clearly in the text. We agree with both reviewers that variation in temperature, macrofauna and hydrodynamics/advection will impact nutrient regeneration and hence the magnitude of internal nutrient loading compared to our estimates.

ACTION: Where appropriate we will emphasize sources of errors and consequences of omitting different environmental variables in the experiment set-up. See our reply to specific comments for more details.

REVIEWER COMMENT: Page 15114 Line 1 – Station 5 represents sandy sediment

which has been collected in a closed core. Measuring fluxes in sediment within closed cores is based on diffusion principles, however in the natural environment processes within sandy sediments are not only governed by diffusion but also advective flow. This will likely alter the estimate of nutrient effluxes from the sediment depending on residence time of the porewaters etc. The difference of this site to the others is briefly touched on in the discussion (15124 – line 14) however it is not discussed in terms of an experimental limitation and how this influences the interpretation of the results at this site and requires further comment.

REPLY: A similar comment was made by reviewer#1.We are aware that shallow sandy sediments may be highly reactive due to a very dynamic environment. However, 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 15114 Line 20 – What was the density of the macrofauna at each of the sites? In the literature macrofauna play an important role in nutrient cycling in the Odense Fjord turning over large volumes of sediment annually if this also applies to these sites excluding them from your experiments (even though it would be challenging to include them in a long term experiment such as this) could drastically change your estimates ON and OP released from the sediment. This also changes the redox conditions at the sediment surface where burrowing macrofauna can increase the depth of oxygen penetration and nutrient transport into the sediment and in inturn

potentially influence your mineralisation rates. I am uncertain here how relevant to natural conditions your estimates of internal nutrient loadings are having excluded all macrofauna from your experiments. This requires further discussion.

REPLY: A similar point was raised by Reviewer#1. We agree with the reviewers that removing macrofauna was a major manipulation, which undoubtedly changed 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: Page 15114 Line 11/25 - The authors state that at the time of sampling the in situ temperature was 10 – 12oC, however the experimental conditions were set to 15oC I am uncertain why this temperature was chosen. Furthermore the authors then extrapolate annual ON and OP release under these conditions where on an annual cycle temperatures in the Odense Fjord range from _3 - 19oC. Bacterial populations could also vary throughout this time based on temperature differences.

The influence of temperature on mineralisation rates should be something that is considered and discussed further particularly when temperature regulation is quite easy to manipulate in an experimental setup.

REPLY: A similar comment was made by Reviewer#1. The incubation temperature of 15ËŽC was chosen to reflect the average annual temperature in 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 potential 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 Line 6 – Was there a control to compare the rate of aerobic and anaerobic mineralisation to confirm that anaerobic mineralisation measurements were representative of all mineralisation within the fjord? This would not be an issue for deep anaerobic sediments but in aerobic surface sediments an aerobic mineralisation measurement should have been considered.

REPLY: We have evidence (hydrogen sulfide concentrations in porewater) suggesting that sediments from all stations were predominantly anoxic throughout the experiment, indicating that anaerobic degradation was most important for organic matter degradation in this experiment. Furthermore, results obtained in anoxic jar experiments are evaluated against flux measurements, which include both anaerobic and aerobic processes. Hence both anaerobic and aerobic processes are actually accounted for in the manuscript.

ACTION: We will mention that sediments remained mostly anoxic throughout the experiment and that anaerobic degradation processes were most important in the present experiment.

REVIEWER COMMENT: Page 15126 Line 15 – The authors mention that the missing NH4+ could be lost due to nitrification-denitrification coupling. I do agree the missing NH4+ in the oxic fluxes is most likely accounted for by nitrification however in Figure 6 it does not appear that nitrification and denitrification are strongly coupled with most of the NO3- released from the sediment after _20 days. Possibly revise this statement.

REPLY: We are not sure we understand the reviewer′s argument. We measure much higher NH4+ production in the sediments than is released as DIN-efflux or accumulates as NH4+ in porewater. We argue that the deficit between NH4+ production and DIN efflux must be caused by closely coupled nitrification-denitrification (i.e. we do not see the produced NO3- as it is consumed as fast as it is produced). This is the only explanation for the observed deficit and we see no reason to revise this statement.

ACTION: This comment will not lead to major changes in the text. However, Fig. 6 will be deleted from the revised manuscript as requested by both reviewers.

REVIEWER COMMENT: Page 15128 Line 3 – The authors state in the discussion that the sandy sediments are the most important for the total fjord release of N (39%) I would note that this estimate probably has the most uncertainty out of all sites due to the absence of advective flow in these estimates. This statement is also made about P release (Line 16).

ACTION: As also mentioned for other comments, we will emphasize in the revised manuscript that our estimates of nutrient release should be extrapolated with caution because we have omitted important factors in our experimental setup (temperature variation, macrofauna and hydrodynamics/advection). The error by omitting these factors is probably largest for shallow sandy sediments, which are impacted by e.g. the largest temperature fluctuations and more intense hydrodynamics compared to the

other environments.

REVIEWER COMMENT: Page 15129 Line 17 – As mentioned by the previous referee (S. Hietanen) – the authors need to explore further how a change in the N:P ratio from high internal P loading could potentially result in N2 fixers dominating the system and be a long term management issue.

REPLY: The same point was addressed by reviewer#1. 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: Page 15120 Line 6 – This line is not essential. Why Fe(III) was measured is already mentioned in the introduction.

ACTION: The indicated section will be rephrased in the revised manuscript.

REVIEWER COMMENT: Page 15124 Line 25 subscript on numbers instead of superscript

ACTION: This will be corrected.

REVIEWER COMMENT: Page 15138 - Table 2 is missing the average TP:TN ratios

ACTION: This will be corrected.

REVIEWER COMMENT: Page 15147 - Figure 6 is not essential it is explained well in results.

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 manuscript.

REVIEWER COMMENT: Page 15125 Lines 1-2 are not necessary this is clear in the previous sentence and was set out in the introduction

ACTION: The indicated section will be rephrased in the revised manuscript.

REVIEWER COMMENT: Page 15141 - Table 5 should ON and OP degradation or any of the other measurements here be time integrated? the units are in mmol m-2

REPLY: Values in table 5 are time integrated – hence the unit mol m-2. This is clearly indicated in the table legend: “Total NH4+, NOx- and PO43- effluxes were calculated by time integration of effluxes over the entire experimental period.”

REVIEWER COMMENT: Page 15127 Line 13 – Normal text for N-1 should be superscript

ACTION: This will be corrected.

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