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Biogeosciences Discussions

Interactive comment on "The role of benthic foraminifera in the benthic nitrogen cycle of the Peruvian oxygen minimum zone" *by* N. Glock et al.

N. Glock et al.

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We thank the reviewer Patrick Grunert for his constructive comments and positive feedback. We acknowledge the great effort for crosschecking all the tables which definitely improved our manuscript substantially. Note that the response letter has also been added as a .pdf file in the supplementary. In the supplementary version it is probably easier to follow changes in the revised manuscript. Below we comment in detail the points of revision.

Patrick Grunert:

PG: General comments The manuscript of Glock et al. reports an ambitious study that aims to quantify the contribution of benthic foraminiferal nitrate storage and denitrifi-

cation to the nitrogen cycle of the Peruvian OMZ. The results of this study will be an important contribution to our understanding of the oceanic nitrogen cycle, and are worthy of being published in BG. However, there remain some concerns after reviewing the manuscript, specifically with respect to the calculation of foraminiferal denitrification rates (see Specific comments). These issues should be clarified and addressed in more detail by the authors in the revised version of the manuscript. The manuscript is well structured and, for the most part, well written. The Results section could be shortened to some extend as in many cases the text is a repetition of data shown in the tables.

Reply: Again we thank the reviewer for his positive feedback. As suggested by the reviewer we shortened the result section. The other concerns we addressed below directly after the particular specific comments.

PG: Specific comments

Abstract

Given the approximations applied in this study and the resulting uncertainities, I suggest to formulate some passages of the abstract more cautiously.This has been successfully done in the Conclusions and Implications section. Compare e.g. "... benthic foraminifera account for the total denitrification on the shelf..." (Abstract) to "at 79m to 248m water depth most likely the entire denitrification is performed by benthic foraminifera" (Conclusions and Implications).

Reply: As the reviewer suggested some passages of the abstract have been formulated more cautiously:

"A comparison with total benthic denitrification rates as inferred by biogeochemical models revealed that benthic foraminifera account for the total denitrification on the shelf between 80 and 250 m water depth. They are still important denitrifiers in the centre of the OMZ around 320 m (29-56% of the benthic denitrification) but play only

a minor role at the lower OMZ boundary and below the OMZ between 465 and 700 m (3-7% of total benthic denitrification). Furthermore, foraminiferal denitrification was compared to the total benthic nitrate loss measured during benthic chamber experiments. Foraminiferal denitrification contributes 1 to 50% to the total nitrate loss across a depth transect from 80 to 700 m, respectively."

Has been changed to: "A comparison with total benthic denitrification rates as inferred by biogeochemical models revealed that benthic foraminifera probably account for the total denitrification on the shelf between 80 and 250 m water depth. The estimations also imply that foraminifera are still important denitrifiers in the centre of the OMZ around 320 m (29-50% of the benthic denitrification) but play only a minor role at the lower OMZ boundary and below the OMZ between 465 and 700 m (2-6% of total benthic denitrification). Furthermore, foraminiferal denitrification was compared to the total benthic nitrate loss measured during benthic chamber experiments. The estimated foraminiferal denitrification rates contribute 2 to 46% to the total nitrate loss across a depth transect from 80 to 700 m, respectively."

PG: Material and methods

Please add a map of the study area indicating the sampled localities!

Reply: A map has been added as fig.1.

PG: Page 17781, lines 7-8: The authors should explain why they have not considered the B. argentea and F. cornuta in their calculations! Because other species of these genera show much lower denitrification rates? This is important to know given the approximations for the calculation of denitrification.

Reply: This is most probably a misunderstanding. The reviewer is right: We did not consider B. argentea and F. cornuta (both from the Santa Barbara Basin) in our calculations because these species show extremely high denitrification rates. To give an example: for B. argentea individual denitrification rates of 1976 pmol ind-1 d-1 (Bern-

hard et al., 2012) are reported. For other Bolivinidae from the Peruvian OMZ with a similar test size, denitrification rates are reported ranging from 79 to 216 pmol ind-1 d-1 (Pina-Ochoa et al., 2010). Thus, the individual denitrification rate of B. argentea is 9-25 times higher than the individual denitrfication rates reported from other locations than the Santa Barbara Basin. To use these rates for the Peruvian OMZ would most propably overestimate total foraminiferal denitrification, especially at location 540/MUC-49 where B. costata is the dominant species and assumption A has a strong influence, since no individual denitrification rates have been measured for B. costata, yet. To clarify this misunderstanding we added the following part to the methods section (2.3):

"Exceptionally high rates, that have been reported for B. argentea and F. cornuta from the Santa Barbara basin, are not taken into account (Bernhard et al., 2012a). The individual denitrification rate for B. argentea is 1976 pmol ind-1 d-1. For other Bolivinidae from the Peruvian OMZ with a similar test size, denitrification rates range from 79 to 216 pmol ind-1 d-1 (Pina-Ochoa et al., 2010a)."

PG: Page 17781, lines 16-17: Rephrase; this statement contradicts the Results section in which the authors discuss the strong impact on the calculations for the station at 697m (Page 17784, lines 24-26).

Reply: The reviewer is right. This sentence has been deleted in the revised manuscript.

PG: Page 17780, line 21 –Page 17781, line 3: This comment reflects my major concern about the study. Table A1 suggests that the cores have been sampled for benthic foraminifera down to very different depths at the individual stations (for example, 5cm at station M77-1 583-MUC-32; 50cm at station M77-1 540-MUC-49). Does that affect the calculations and has it been considered by the authors? Benthic foraminiferal abundance is a key-variable in their calculations, and neither from the text nor from Table A1 and Figure 1 it is clear to me which value they applied to the equation (total abundance down to the maximum sampling depth at each site or selective abundance down to the same sampling depth at all sites)! This should be addressed and clarified

in the methods, results and discussion sections! As it is now, there is a single, short reference on this topic (Page 17786, lines 7-8) – it's not clear to me if that implies denitrification rates consider only foraminiferal abundance in the upper 5 cm of all cores. In my opinion, this is the only way to compare calculated foraminiferal denitrification rates (5 cm being the maximum sampling depth at M77-1 473-MUC-32). The presentation of the results in the text, figures, and tables, however, suggests that total foraminiferal abundance regardless of the sampled depth at each station has been used. This has to be clarified and clearly stated in the methods section!

Reply: The main concern of the reviewer about that study is that the cores have been sampled for benthic foraminifera to different depths and if this has been considered by the authors. The sampling depths range from 5 mm at station M77-1 583-MUC-32 to 50 mm at station M77-1 540-MUC-49. The reviewer wrote 5 cm to 50 cm probably as typing error. He suggests that only the first 5 mm should be considered for the comparison of foraminiferal denitrification rates. In our manuscript we used the whole foraminiferal abundance at the single locations (cumulated by all sampling intervals) for the calculations of foraminiferal denitrification. The sampling scheme included all the depths where a sufficient amount of stained individuals could be found. Thus we tried to consider the entire living fauna despite habitat depth including all microhabitats (the deep infaunal as well). Since the denitrification and nitrate loss rates we used for comparison represent the whole denitrification or nitrate loss at these sites it is only possible that we also use the whole foraminiferal denitrification. For example: If we use only the top 5 mm at the site 540-MUC-49 we would only consider ∼30% of the entire living fauna which would substantially underestimate the foraminiferal contribution to denitrification at this site. We agree it is problematic that we only have data up to 5 mm for station 583-MUC-32. Nevertheless, a comparison to station 449-MUC-19 (which is essentially the same station sampled on a different day) shows that ∼90% of the living fauna can be found in the top 5 mm of this site. The number of living individuals often shows an exponential decay with sediment depth with a maximum in the top 5 mm (Lutze, 1987; Corliss, 1985). To clarify that the total abundance to the maximum sampling depth at

each site was used for the calculation of foraminiferal denitrification we changed the following part of the methodology (Part 2.3): "The abundances in each slice were integrated for the whole core studied." to "The abundances in each slice were integrated for the whole core studied regardless of sampling depth. Thus, we tried to consider the entire living fauna despite habitat, depth including all microhabitats." Furthermore, we changed the following part of the results chapter 3.2 to underline the problem that station 583-MUC-32 has only been sampled to 5 mm sediment depth: "It has to be emphasized that despite the high contribution of foraminiferal to total benthic denitrification at the shallower sites, our estimates only consider near surface sediments up to ∼50 mm depth." (Page 17786, lines 7-8 in the original manuscript) Has been moved to the discussion (Part 4.1) and changed to: "It has to be emphasized that despite the high contribution of foraminiferal to total benthic denitrification at the shallower sites, our estimates only consider near surface sediments up to ∼50 mm depth. For example our data for station M77/1 583-MUC-32 (317 m) might underestimate foraminiferal denitrification because the core has just been sampled to 5 mm sediment depth. Nevertheless, a comparison to station 449-MUC-19 (essentially the same station sampled on a different day) shows that ∼90% of the living fauna can be found in the top 5 mm of this site."

PG: Page 17782, line 4: Figs. 1 and 2 do not show the depth transect! However, as mentioned earlier I suggest to include such a figure in the manuscript.

Reply: The depth transect is now visible at the new map in figure 1.

PG: Results

Page 17784, line 6: According to Table A1, the second-most abundant species at 79m water depth is Nonionella stella (16.4%) and not Bolivina seminuda.

Reply: This is right.

"At 78 m water depth the dominant species was Bolivina costata (74%) followed by

Bolivina seminuda (5%)" (original manuscript Page 17784, line 6)

Has been changed to:

"At 79 m water depth the dominant species was Bolivina costata (74%) followed by Nonionella stella (16%) and Bolivina seminuda (5%)."

PG: Page 17785, lines 3-9: It's not clear to me where the calculated benthic foraminiferal denitrification rates come from. Table 4 is referenced by the authors but the respective table shows values different from the main text. See also Page 17776, Line 19, and Page 17792, line 12.

Reply: Thank you for that comment! Indeed there has been a mistake at the column for the foraminiferal denitrification rates. The denitrification rates discussed in the text were the right ones. All tables were checked again for mistakes and the errors have been corrected in the revised manuscript.

PG: Page 17785, lines 13-14: Explain in one or two sentences why you chose this specific denitrification rate!

Reply: To explain why we chose this specific rate we added the following part into the revised manuscript:

"We chose this rate instead of the turnover rate from NO2- to N2 because it reflects the decomposition of nitrate by denitrification and foraminifera are known to store nitrate for nitrate respiration (not nitrite)."

PG: Discussion My concerns about the calculation of foraminiferal denitrification rates should also be reflected in the Discussion chapter.

Reply: As already mentioned above we added a paragraph to the discussion (Part 4.1) regarding the problem that station M77-1 583-MUC-32 was just sampled for foraminifera to 5 mm depth:

"It has to be emphasized that despite the high contribution of foraminiferal to total ben-

thic denitrification at the shallower sites, our estimates only consider near surface sediments up to ∼50 mm depth. For example our data for station M77/1 583-MUC-32 (317 m) might underestimate foraminiferal denitrification because the core has just been sampled to 5 mm sediment depth. Nevertheless, a comparison to station 449-MUC-19 (essentially the same station sampled on a different day) shows that ∼90% of the living fauna can be found in the top 5 mm of this site."

PG: Otherwise the Discussion is fine and offers intriguing ideas, and I have only one minor comment. Page 17790, lines 16-18: The limitation of the Japanese material to size fraction > 125μm might additionally complicate a comparison.

Reply: To accentuate the complication of the comparisons due to the different size fractions used we changed the following part in the revised manuscript:

"In addition, the benthic foraminiferal abundance is with only 12 ind cm-2 (size fraction >125 ïA■m) rather low as compared to the OMZ off Peru (616 ind cm-2)."

was changed to:

"In addition, the benthic foraminiferal abundance is with only 12 ind cm-2 (size fraction >125 ïA■m) rather low as compared to the OMZ off Peru (616 ind cm-2), although the different size fractions used for the foraminiferal studies might complicate the comparison of the abundances."

PG: Tables

Table 2: After checking the listed values for denitrification rates and nitrate storage with literature I have several comments on this table:

âĂć After calculating the mean denitrification rate for the genus Bolivina based on Piña-Ochoa (2010a) the result was 124pmol#-1d-1instead of 135 pmol#-1d-1.

Reply: Thanks a lot for reading the manuscript this carefully. This is a very important comment. There has indeed been a mistake by the calculation of the mean value in

this case. We slipped a line in table 2 of Pina-Ochoa et al 2010 using the rate of Valvulineria cf. laevigata instead of the rate of Bolivina seminuda for calculation of the mean denitrification rate for the genus Bolivina. This value has now been recalculated and used for new calculations for foraminiferal denitrification rates. The changed rates have been included into the revised manuscript. Because the changes were relatively low this did neither change the interpretation of the results nor the discussion.

PG: âĂć Why did you apply the mean denitrification rate for the genus Uvigerina to U. striata but not to U. auberiana, U. canariensis, and U. peregrina?

Reply: We did apply mean denitrification rate for the genus Uvigerina also to U. auberiana, U. canariensis, and U. peregrina but forgot to list this in table 4. This has been changed in the revised manuscript and the values are now listed for all species from the Uvigerina genus.

PG: âĂć The value of 166 pmol#-1 is listed for nitrate storage of U. peregrina - a mean value for this species calculated based on values of 0 pmol#-1 and 332 pmol#-1 in Piña-Ochoa (2010a). Given the big range of these values as well as the significantly higher mean values applied to the other Uvigerina species - does it make sense to calculate a mean in this case?

Reply: In this case it indeed does not make sense to calculate a mean value based on the reported values of 0 pmol#-1 and 332 pmol#-1 because the value of 0 indicates that the specimens from the Bay of Biscay effectively do not store nitrate for denitrification. Thus, for the revised manuscript we just used the higher value (332 pmol#-1). Uvigerina peregrina has only been found at the location 459/MUC-25 (697 m). For this location the foraminiferal nitrate storage changed from 2.7 to 3.1 mmol.l-1. This does not change the interpration of the data and the discussion compared to the distinctively higher values at the other locations (62-705 mmol.l-1).

PG: Table 4: Foraminiferal abundance of M77/1 473-MUC-32 is indicated with 522.5 indcm-2 in Table A1. Please check which value you considered in your calculations for

this site!

Reply: The reviewer is right. The right value is now listed in table 4.

PG: Technical corrections

Page 17776, line 5: Rephrase this sentence

Reply: The sentence has been rephrased in the revised manuscript:

“Rate estimates of foraminiferal denitrification were very sparse on a regional scale.”

has been changed to:

“Rate estimates of foraminiferal denitrification were very sparse and are limited to specific regions in the oceans, not comparing stations along a transect of a certain region.”

PG: Page 17778, line 10: Fursenkoina

Reply: Done.

PG: Page 17779, line 9: The name of the cruises should be M77/1 and M77/2

Reply: Done.

PG: Page 17781, line 2: Add Risgaard-Petersen et al., 2006 to the listed references for denitrification rates.

Reply: Done.

PG: Page 17781, line 7: Exceptionally

Reply: Done.

PG: Page 17784, line 5: Replace 78m by 79m

Reply: Done.

PG: Page 17784, line 10: Indicate that it’s the station at 319m

Reply: Done.

PG: Page 17784, lines 19-27: I suggest to move this paragraph to chapter 3.2

Reply: Done. Furthermore this paragraph has been shortened because often it was just a repetition of data shown in the tables.

PG: Page 17786, line 19: According to Table 4 nitrate storage at 79m is 62.1 μmolL-1

Reply: Done.

PG: Page 17789, line 14: F. cornuta

Reply: Done.

PG: Page 17789, line 15: denitrification

Reply: Done.

PG: Table 2: Replace Piña-Ochoa (2010) with Piña-Ochoa (2010a)

Reply: Done.

PG: Table 2: Please add an explanation for the asterisk next to the nitrate storage value of U. peregrina!

Reply: The asterisk has been removed.

PG: Table 3: The second and third sentences should be rephrased or removed from the caption, it is not clear to me what they mean.

Reply: The sentences have been rephrased:

"The percentage of living individuals of the several species to the total foraminiferal abundances is shown. Without approximation stands for species where literature data for individual was available."

has been change to:

"The percentage of living individuals of the three subgroups of species (without assumption; assumpt. A; assumpt. B) to the total foraminiferal abundances is shown. Individual denitrification rates indicate species where literature data for individual was available."

PG: Table 5, caption line 2: I suggest to rephrase to "...C1 and C2 refers to chambers 1 and 2, repectively."

Reply: Done.

PG: Figure 1: Replace Piña-Ochoa (2010) with Piña-Ochoa (2010a) and add Risgaard-Petersen et al. (2006).

Reply: Done.

References: Corliss, B. H.: Microhabitats of benthic foraminifera within deep-sea sediments, Nature, 314, 435-438, 1985. Lutze, G.F. and Solomon, B.: Foraminiferen-Verbreitung zwischen Norwegen und Grönland: ein Ost-West Profil, Berichte aus dem SFB 313 "Sedimentation im Europäischen Nordmeer" Nr. 6: Beobachtungen an Benthos Foraminiferen, edited by: Altenbach, A. V., Lutze, G.F., and Weinholz, P., 69-78, 1987.

Please also note the supplement to this comment:
http://www.biogeosciences-discuss.net/9/C9370/2013/bgd-9-C9370-2013-supplement.pdf

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