

Interactive comment on “Uptake of phytodetritus by benthic foraminifera under oxygen depletion at the Indian Margin (Arabian Sea)” by A. J. Enge et al.

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This manuscript reports the results of an isotope tracing experiment conducted in the heart of the oxygen minimum zone on the Indian continental margin. The work was well conducted and is well presented, and the taxonomic resolution of foraminiferal C and N uptake is impressive. It is one of only a few studies that have simultaneously quantified organic C and N cycling in benthic ecosystems. It also highlights interesting contrasts with previous studies. I therefore suggest that it is suitable for publication in Biogeosciences.

I have a few comments which I feel should be addressed before publication.

In their comparison of C uptake rates with Woulds et al., 2007, the authors might like to note that there is also a difference in the sieve sizes used by the two studies. The Woulds et al uptake data are only from individuals retained on a 300 micron sieve, therefore a smaller fraction of the foraminiferal community will have been captured. This may have contributed to the difference in observed uptake rates.

- Reply: We agree with this point. We falsely assumed that foraminifera at the 300 m (in situ) site were also sieved through a 150 μm mesh, but were wrong. Hence we agree that the observed differences between the Pakistan margin (Woulds et al., 2007) and our experiment are very likely related to the use of different size classes. Changes were made in the paragraph:

“The only comparable experimental approach to investigate the response of foraminifera to phytodetritus deposition in an OMZ setting was undertaken on the Pakistan margin by Woulds et al. (2007) and Andersson et al. (2008). The foraminiferal uptake in the OMZ core region (300 m depth) of the Pakistan margin ranged between 6 and 20 mg C m^{-2} after 5 days of in situ incubation. The lower uptake compared to Indian margin (114 mg C m^{-2}) is very likely caused by the use of different mesh sizes. In our experiment, we used a 125 μm mesh and found abundances of almost 4000 ind. 10 cm^{-3} , whereas the study at the Pakistan margin yielded in 200-336 ind. 10 cm^{-3} using a 300 μm mesh (Woulds et al., 2007). As the calculation of carbon uptake per area is based on the estimated abundance of foraminifera, it is to assume that the exclusion of the 125-300 μm size fraction at the Pakistan study led to a lower abundance and hence to lower uptake.”

In the second paragraph on page 16 it is implied that the high foraminiferal density at 540 m on the Indian margin compared to at 300 m on the Pakistan margin could be due to the absence of metazoan macrofaunal grazing pressure on the Indian margin. It should be noted that grazing pressure/competition from metazoan macrofauna was also thought to be absent (or almost entirely absent) at 300 m on the Pakistan margin, therefore the presence/absence of macrofauna cannot be used as an explanation.

- Reply: We agree with the reviewer that abundance of macrofauna is similar at both sites (not present at Indian margin, very little present at Pakistan margin) and cannot explain the difference. As stated above the difference in uptake by foraminifera between the sites can be related to different size fractions considered for analysis. Hence we excluded the discussion of grazing pressure of macrofauna to be important for the uptake by foraminifera and shortened and rewrote the paragraph:

“Our results indicate that benthic foraminifera are able to utilize organic matter under oxygen concentrations of $< 0.1 \text{ L mL}^{-1}$ as fast as in non-oxygen-depleted deep-sea environments (Kitazato et al., 2003; Nomaki et al., 2005; Enge et al., 2011; Nomaki et al., 2011). This suggests that foraminifera in the OMZ core on the Indian margin represent species highly adapted to low oxygen in order to be able to ingest large amounts of food. Missing macrofauna at the investigation site (Hunter et al., 2012) might have also positively contributed to the observed uptake of phytodetritus by the foraminifera due to reduced competition for food. Where present on continental margins, metazoan organisms (polychaetes, nematodes) are important consumers of phytodetritus, reacting very quickly to its deposition (Andersson et al., 2008; Blair et al., 1996; Hunter et al., 2012; Levin et al., 1999; Woulds et al., 2007). Comparison

of uptake to other potential consumers of phytodetritus like meiofauna or bacteria is hampered as relevant data are not available so far. In situ experiments in the core region of the Pakistan margin OMZ (300 m) showed greater uptake of phytodetritus by bacteria than by foraminifera (Andersson et al., 2008). Similar environmental conditions between the two sites let assume that foraminifera at the Indian margin could also be important to short-term phytodetritus processing such as at the Pakistan margin.”

Page 18 paragraph 2. The start of this paragraph makes the point that foraminiferal uptake of N was less than that of C in absolute terms. This is unsurprising, as the C:N ratio in the algae with which the sediment was fed will not have been 1:1 (Redfield ratio is 106:16). The way the text is currently worded is therefore a little distracting, as it seems to imply that the lower absolute N uptake compared to C uptake is surprising, and in need of explanation. I would argue that this result is rather trivial, and the only valuable way to compare C and N uptake is to consider C:N ratios in food and foraminifera. Thus, the second point in the paragraph, that relative uptake of N was reduced compared to C (the scale of the difference could be better quantified in the text, using ratios), is certainly interesting, and worthy of discussion. Further, I would appeal for all of the C to N comparisons made in this paragraph to be clarified. It is stated that for other studies certain types of fauna took up ‘more C than N’. It is not clear from this phrasing whether the assimilated material had a higher C:N ratio than the food added to each experiment (i.e. was there actual selectivity occurring in favour of ingestion and retention of C compared to N?), or whether there was simply a greater absolute uptake of C (which is unsurprising). I would suggest that C:N ratios are a good tool for this, but I accept that the authors may prefer a different way of expressing the same idea.

- Reply: We agree with the reviewer that the use of the C:N ratio is a good tool to track possible differences in the uptake of carbon and nitrogen. The higher uptake can be greatly related to the natural higher demand of carbon (Redfield ratio) to nitrogen. Our observation fits with a study on foraminiferal by the recent publication of Jeffreys et al. (2013) which was added to the manuscript. Therefore the paragraph has been rewritten and C:N values were calculated and are discussed:
“The nitrogen uptake was comparably lower than the uptake of carbon for all three species. The high demand of carbon by foraminifera as it has been also observed by Jeffreys et al. (2013) follows the natural higher demand of carbon over nitrogen to meet energetic requirements (known as the Redfield ratio with C:N of 106:16). Although all three species demonstrated higher carbon uptake, the absolute difference of C and N uptake varies strong between species (see chapter 3.3) suggesting species have different metabolic demands to achieve homeostasis (Raupenheimer & Simpson, 2004).”

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