

Interactive comment on “Benthic foraminiferal Mn / Ca ratios reflect microhabitat preferences” by Karoliina A. Koho et al.

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Below we have copied the reviewers' comments one at the time and indicate how we have addressed them or (in a few cases) argue why we respectfully disagree.

Our resubmission contains a typed manuscript, which is accompanied by eight figures, three tables and two appendixes.

REVIEW 1: NINA KEUL

The manuscript entitled "Benthic foraminiferal Mn/Ca ratios reflect microhabitat preferences" by Karoliina Koho and colleagues presents foraminiferal Mn/Ca as a potential tool for paleoceanographic reconstructions of the microhabitat, bottom water oxygenation and/or Mn redox chemistry. The research is original and provides novel, interesting

C1

data about Mn incorporation into foraminifera for the community. The methods used are state of the art and well suited to answer the research questions posed, however, more details need to be provided concerning the ICPMS measurements, especially since two different ICPMS setups in combination with different signal integration techniques were used, to ensure comparability of the data. The presented data is of appropriate quality, however, foraminiferal Mn/Ca ratios are only represented in Figures and DMn values only mentioned in the text so that I strongly encourage the authors to provide this data in tables. In the case of DMn also in a Figure similar to Fig. 5. In a few cases, I cannot confirm drawn conclusions from the data presented here, an urge the authors to revise those statements (indicated below). Furthermore, I would like the authors to encourage to sharpen the manuscript, that those parameters influencing foraminiferal Mn are more clear. Overall, this is a well written manuscript of an interesting study and I would recommend publication after major revisions have been carried out. I wish the authors good luck with the revisions and remain available for further feedback and discussions. Best wishes, Nina Keul

RESPONSE: The authors thank Nina Keul for thorough review of the manuscript. Her comments have substantially improved the new version of our manuscript. This version now contains an appendix with the Mn/Ca measurements and also the calculated DMn values. In addition, we added a figure, in which the DMn-values are presented. More details are now provided concerning the LA-ICPMS analyses, and the discussion concerning the parameters influencing foraminiferal Mn has been sharpened.

Comments by page and line number: major comments: page 5: concerning the methods used 1.1: How long were the measurements on the different species? How long was one cycle of the ICPMS through all masses? Were there any short measurements due to e.g. thin chambers? Where they discarded? How much of the profiles were left out of the integration windows in glitter due to contamination? How many data points were left after this procedure on average? Was the contamination in high Al limited to the beginning and ends of the profiles? RESPONSE: Short profiles (typically <5s

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in length) and profiles containing high Al content contents were excluded from further analysis. A representative profile ranges from 10-30 seconds, depending on species and chamber ablated (final chambers are commonly thinner and hence result in shorter ablation profiles). Some species e.g. *N. labradorica* and *C. fimbriata* had relatively short profiles, as their chamber walls are on average thinner. In case of *E. batialis* longer profiles were obtained due to thicker test calcite. In total, 277 single-chambered measurements were used for our study (Table 2). A new figure (Figure 2) is included, now showing examples of ablation profiles for Al/Ca, Mn/Ca and Mg/Ca. Al contamination was typically observed at the start of the profile (i.e. at the outside surface of the foraminiferal shell), although a very small Al peak was occasionally seen also inside. Often coinciding with these Al-peaks, Mg and Mn contamination peaks were observed inside and outside of the test. The text on the post-processing of the LA-CIP-MS data has been extended by incorporating this information (section 2.5) Regarding a cycle length of the ICPM through all masses, these differ per ICP-MS and masses studied. In NIOZ measurements the cycle length was 0.12 seconds. In Utrecht measurements the cycle length was 0.64 seconds. These are now added to the methods section.

1.6: which mass was measured for Mg? (it is not in the list in 1. 22)? Were high Mg and Mn and high Al always restricted to the same spot? Could you maybe provide a couple of ablation profiles in the appendix to illustrate this? RESPONSE: For magnesium, we measured 24Mg and 26Mg. Two typical ablation profiles have now been added to the methods section. Mg, Mn and Al were usually elevated at the outer surface of the test. With Al, Mg and Mn often peaking at the same time (i.e. depth in ablation profile). A smaller Al peak was also occasionally also observed without the other elements being elevated. The text has been modified and these details have now been included into the manuscript.

1.10/11: was there no matrix matched in-house standard measured? e.g. GJR or JCP? If not, why not as matrix matched standards are common practice and have been used on the second setup? I do not understand, why the measurements were calibrated

C3

against NIST610 values from Jochum et al. 2000 on one machine and against Jochum et al., 2011 on the other machine? Also, in the Jochum et al. 2000 paper cited here I cannot find reported concentrations on NIST610? RESPONSE: The reference to Jochum et al. (2000) was a mistake: all references to certified NIST values were supposed to be Jochum et al., 2011. This mistake is now corrected in the text. As already stated in the original version of our manuscript, we also ablated pressed powders JCp-1, MACS-3 and an in-house foraminiferal 'standard', the NFHS (Mezger et al., 2016) to monitor drift and detect any potential offsets caused by switching between matrices and between materials with varying element concentrations.

l.13: which samples on which machine? Were some samples measured on both systems to ensure comparability? This is especially of importance with the apparently two different NIST610 calibration values used? Could this data be provided in a supplementary table? RESPONSE: Same NIST610 calibrations (Jochum et al., 2011) were used in both set ups. The mistake regarding "Jochum et al. (2000 versus 2011)" is now corrected. Some specimens were measured on both machines, namely *E. batialis* and *Uvigerina* spp. As LA-ICPMS is a destructive technique it is not possible to measure the exact same spot on the foraminifera shell twice, making the analyses not true replica's. Due to within specimen variability in elemental composition, Mn/Ca ratios are expected to vary slightly within specimens. However, as can be seen from comparing the overall distribution and elemental composition of *E. batialis* (Fig 4 and 5), the elemental composition is relatively consistent regardless of the laser ablation ICP-MS system used. This confirms that results from the two platforms are inter-changeable, not only for the standards used but also the samples themselves. A similar result was also published in De Nooijer et al. (2014a) for which three different systems were used and shown to result in comparable foraminiferal El/Ca. This reference is now cited in section 2.5

l.23: "consisted of a blank"? I assume the first 20 seconds the laser was not switched on so this was the background and not a blank? Also, so here values were integrated

C4

manually and not using Glitter, why? RESPONSE: 'Blank' is replaced by 'background'. The use of data reduction software does not mean that the integration windows are not manually selected. The Glitter package was not available on the NWR/iCap platform, but instead the iCap's Qtegra software (Thermo Scientific) was used for data reduction. Both softwares are described in section 2.5, dealing with the laser ablation.

page 6 l. 29: please provide table with Mn/Ca measurements (and also for calculated DMn for stations 6,8,10) RESPONSE: Raw data now provided in appendix, which now also contains the calculated DMn-values.

page 8 l. 3: was only the correlation with station bottom depth stat. significant or were also other parameters tested? It is mentioned in the abstract and Conclusion that Mn/Ca could be a sensitive recorder of redox conditions and or bottom water oxygenation, so a statistical test of this would be highly valuable. RESPONSE: The correlation between Mn/Ca and station depth, as well as bottom water oxygenation (BWO) was tested for all taxa. The Mn/Ca ratios of *Uvigerina* spp. and *B. spissa* increased with water depth and were statistically significant (Section 3.4). Another statistically significant trend was found for Mn/Ca in *B. spissa* and BWO (Statistics are listed in Section 3.4). The correlations were tested for all taxa but these were the only significant trends within our dataset. Due to relatively few data points, correlations for deep infauna were very limited. In the results presented in Koho et al. (2015), a significant trend between Mn/Ca and BWO was also found for the intermediate infaunal species, *Melonis barleeanus*. Correlation of Mn/Ca in *B. spissa* and BWO imply that intermediate infaunal species may be the most prominent recorders of BWO in the setting studied here. This is consistent with the conclusion in Koho et al. (2015) based on the TROXCHEM3 model. Furthermore, although no statistical trends were found for other species and BWO, this study clearly illustrates systematic variations in Mn/Ca with foraminiferal microhabitat, coinciding with changes in pore water redox chemistry. Foraminifera inhabiting more oxygenated sediment layers (i.e. *E. batialis*) systematically showed low Mn/Ca ratios and more infaunal foraminiferal species, experiencing more reducing con-

C5

ditions, showed higher Mn/Ca ratios. Abstract and conclusions have now been adapted to reflect these outcomes.

l.27/l.28: However, some specimen occurred at different depths in the sediment at the same core location, how likely is it, that they also calcify at the same depth (ideally the ALD) for the species to be a good proxy (e.g. *B. spissa* at station 9)? Since in the upper few cm, vast changes wrt redox chemistry occur, potentially influencing foraminiferal Mn/Ca. RESPONSE: Yes it is true that foraminifera are not found only at their ALD and some specimens are found above and below this depth. The low DMn-values also suggests that for example *E. batialis* may calcify at slightly shallower depth than their inferred ALD suggests, whereas DMn-values of deep infaunal species (e.g. *C. fimbriata*) imply that it was found close to its calcification depth (Discussed in section 4.2). However, no systematic ontogenetic trends were seen in this study, where for example Mn/Ca ratios were systematically either higher or lower in the younger or older chambers, or vice versa. We observed no correlation between chamber number and Mn/Ca (See also new appendix 1). Still, variations in the overall Mn/Ca ratios for example in *B. spissa* shells may be due to migration or changes in the ambient pore water conditions during the lifespan of the foraminifera. The influence of migration on foraminiferal Mn/Ca is now discussed in section 4.2, 4th paragraph.

page 9 l.19-29: since the DMn values are not listed in the paper (no table and no figure) I cannot assess this part, please provide data RESPONSE: DMn values are now given in appendix 1

l. 29/ 30: "implies that these taxa are actively growing in dysoxic sediments. . ." *B. spissa* in station 9 also has high Mn values, similar to *C. fimbriata*, please discuss (high Mn values do the not necessarily exclusively occur in deep infaunal species?) RESPONSE: Unfortunately it is not possible to calculate DMn value for *B. spissa* at station 9 as no pore water Mn data is available for this station. At station 8 the DMn was low (0.36), suggesting that *B. spissa* is calcifying shallower than were it was found here. However, it is true that at station 9 the Mn/Ca ratios of *B. spissa* are similar to

C6

that of deep infaunal species. This is now added to discussion.

Also, please discuss: As shown from the Mn porewater profiles (Fig. 5) and since most of the sediment is dysoxic after 1 cm depth (Fig. 2), the porewater concentrations in Mn are very different between station 6 (more or less constant Mn), Stn. 8 (Mn maximum at ca. 10 mm) and station 10 (Mn increases with depth) so in my interpretation of the data high Mn does not necessarily indicate only dysoxic environments, since this is the case in all the calcification environments and must be the signature of some other parameter? RESPONSE: It is true that pore water Mn concentrations are variable between stations and that the highest concentrations are found at the station 10 where bottom waters are relatively well ventilated. We suggest that this is due to variations in the availability of the Mn-oxides between the stations. This (and its implications for paleostudies) is discussed in depth in section 4.3 (3rd paragraph). At the deepest station (with the highest BWO content) Mn-oxides are accumulating in the sediments. As BWO content is relatively high, Mn is trapped and not able to escape into the water column, which may possibly occur at station 6 and 8. In addition it is possible that Mn-oxides are transported along slope, hence accumulating at the deeper and more ventilated areas. Although at each station some Mn-reduction was taking place, as shown by subsurface peaks in Mn, the pool of total dissolved Mn is likely to be related to availability of Mn-oxides in the sediment.

page 10: l. 11" deeper in the sediment where higher Mn conc. are present": I do see the increase in Mn with depth only at station 10, not the others, so this statement in my opinion cannot be drawn. "a clear increase in foraminiferal Mn is observed as well": In this case, it would be very valuable to show a regression of foraminiferal Mn to porewater Mn to underline this statement. RESPONSE: Indeed the largest increase in the pore water Mn with sediment depth is observed at station 10. At the other stations Mn-reduction is more limited, however, a small dissolved Mn- peak is also present at station 6 (at depth of 0.8 cm) and 8 (at depth of 1.3 cm), implying that Mn-reduction occurs in the sediment. Nevertheless, at station 10, where a clear peak in

C7

Mn is present this is also reflected in the foraminiferal Mn/Ca ratios, as we see very low concentrations in the surface dwelling *E. batialis* and high concentrations in deep living *N. labradorica*. The sentence is now modified to make clear that this refers specifically to station 10. In addition, "clear" is omitted. Unfortunately species-specific regressions of foraminiferal Mn to pore water Mn are not possible due to limited pore water data.

page 11: section (4.3). should be revised- at the moment, the paleogeographic implications from the measurements presented here (Mn/Ca in foraminifera and Mn in porewaters), should be the main focus in addition to comparison to literature values (this part is included). However, the present version discusses the relevance of the Troxchem model at length in addition the Mn redox chemistry, however, only very little focus lies on the paleo implications of this study. Please move the discussion of the TROXCHEM model and the redox chemistry into a different paragraph. RESPONSE: Section 4.3 has been revised and the main paragraph dealing with the TROXCHEM model has been moved to section 4.2. However, we have decided to keep the discussion on Mn-redox chemistry as part of 4.3 as it has direct implications for the application of Mn/Ca down core. Our data shows that foraminiferal Mn/Ca is not only reflecting redox conditions but is also influenced by availability of Mn-oxides and hence Mn to be potentially released upon reduction. The availability of Mn-oxides, and hence the MnOx-reduction potential of the sediment, as shown by our results, is recorded in the foraminifera along our study transects. Therefore, paleoceanographic studies should take into account changes in the supply of Mn-oxides as well as changes in sediment oxygenation, as the former is also an important parameter in regulating pore water Mn-concentrations.

Furthermore, I am having a hard time to discern the key messages of the study wrt to what influences foraminiferal Mn/Ca. I agree with conclusion, that deeper fauna displays higher Mn/Ca, and that the deeper species must be calcifying under dysoxic conditions, but from the data presented I am having a hard time to see that "Mn incorporation" reflects RESPONSE: conclusions have been modified 1)bottom water oxygenation (where is the data- regressions/ statistics and or figures? e.g. regression of

C8

foram Mn and BWO) representing this? RESPONSE: A statistically significant correlation was observed between BWO and Mn/Ca ratios in *B. spissa* (Results: section 3.4). Also statistically significant increases in the Mn/Ca ratios were observed along the study transect for *Uvigerina* spp. and *B. spissa* (Results: section 3.4). No regression analyses were carried as there is not sufficient pore water data (i.e. each species was not present at all three sites with available pore water data) to support this.

2) Mn redox chemistry (where is the data? regressions? statistics) RESPONSE: Mn pore water data was collected at three stations only and maximum of 2 taxa were measured at stations with pore water Mn-data. Hence unfortunately there is not sufficient Mn pore water data to carry out such analyses. Conclusions have now been modified to reflect this.

3) no ontogenetic influence (as argued above, it could be that interspecies variability masks this, since on most specimen, only 2,3 chambers are measured. However, I am positive that data can be easily presented in a revised version to be able to make this statement. RESPONSE: the reviewer likely refers to intraspecies variability, not interspecies variability. It is true that most specimens of *Uvigerina* spp. were measured two or three times, however, this is not true for *B. spissa*, which was measured 4 times in 14 out of 23 specimens. In addition, *E. batialis* was measured twice 5 times and once 6 times. None of these specimens showed systematic, statistically significant ontogenetic trends (now added to the appendix 1). Therefore, we can further conclude that no ontogenetic trends were observed in our data. This is now clarified in results section 3.2. with a reference to Appendix 1.

minor comments: page 1 l.16: calcium carbonate tests RESPONSE: ok, done l.19: define BWO or spell out; what are differences exactly? RESPONSE: ok, done l.20: where is this entangling happening in manuscript? RESPONSE: changed "further resolving" l.24: At each station, Mn/Ca (omit "the") RESPONSE: ok, done also Mn/Ca is a ratio of concentrations, not a concentration RESPONSE: ok, changed to ratio l.31: the forams are not the tools, but carry the proxy -> rephrase RESPONSE: changed to

C9

proxies used in paleoceanographic studies. l.32: has a high... RESPONSE: ok, done

page 2 l.4: have been shown to reflect carbonate chemistry (omit "the") RESPONSE: ok, done l.18: are oxygenated and sediments are anoxic... add "and sediments are anoxic" RESPONSE: changed to "In sediments, where bottom waters and surficial sediments are oxygenated and deeper sediments are anoxic..." l.27: omit "the" before shallow RESPONSE: ok, done l.28: than not then RESPONSE: ok, done l.32: why 33 (random?) also omit "the" before foraminifera and change to foraminiferal RESPONSE: 33 is not random this is the lowest BWO content along the study transect, so BWO was always higher than this. "The" is now omitted.

page 3 l.17: change to sth. like this as it is confusing otherwise: "At each site, three separate..." RESPONSE: "Separate cores were collected for pore water- and foraminiferal analyses, and oxygen profiling, all of which were derived from the same multicore cast." l.19: company that produced CTD (seabird?), what is the error of the oxygen microsensor? Is it also called a "micro"sensor when it is attached to a CTD? RESPONSE: The CTD is SBE9plus (Sea-Bird Electronics, S/N 860) and it was equipped with SBE3 thermometer (S/N 4378), SBE4 conductivity sensor (S/N 3307) and SBE43 oxygen sensor (S/N 0781). The details of the equipment are now added into the manuscript (section 2.2). "Oxygen microsensor" replaced with "oxygen sensor". The accuracy specifications of the oxygen sensor are typically within 2% of true value

l.25: Whole sample centrifuged or subsample? RESPONSE: Changed to "Sediment samples were centrifuged..." In general the whole samples were centrifuged. In case of the deepest sediment intervals where the slice thickness was 2 cm, some sediment may have been disregarded. l.30: how much HCl was added? final conc.? What samples were used for storage? Were they acid cleaned? RESPONSE: Text modified "Samples for pore water elemental analyses were acidified with suprapur HCl 37% (10 μ l per ml of sample) and subsequently stored at 4°C until analyses at Utrecht University." The foraminiferal samples were not cleaned other than was indicated in the

C10

original manuscript.

page 4 l.1: I assume cps were measured and then converted to conc. via a calibration curve for those elements measured on the ICPMS? What wavelengths were measured in the OES? Which elements were measured on which machine? Which isotopes were measured on the ICPMS? RESPONSE: Sentence modified to "Seawater elemental concentrations of ⁵⁵Mn were measured with an inductively coupled plasma-mass spectrometer (ICP-MS, ThermoFisher Scientific Element2-XR)." Part about the OES is deleted as only ICP-MS data is reported in this article.

l.5 - 12: As I am unfamiliar with the methods and the custom built incubation chamber please provide a few more details to clarify: I assume the subsample taken with the syringe was analyzed? Stabilization of what? temp. and oxygen? How were the fluctuations in oxygen conc. assessed? Were the stabilization times similar between cores (ca. 9hrs)? Were the oxygen profiles taken continuously or at certain depths? RESPONSE: The O₂ profiles have been published previously in Fontanier et al. (2014) with details of the employed methods. A citation has been added here. Each time a core was left to stabilize under insitu O₂ and temperature conditions for 9hrs (as these parameters are likely to change during core recovery). O₂ conditions were monitored with a microsensor, with no syringe being used. O₂ profiles were made at 100 μ m resolution.

l.13: Change title so it is more precise: e.g. "Foraminifera: sampling an elemental concentrations" RESPONSE: changed to "Foraminifera: sampling and elemental composition"

l.14 et al. RESPONSE: ok done

l.17: Plummer slides? Are they micropaleoslides? RESPONSE: ok done

l.30: So if the crater is 80 μ m I assume all foraminiferal chambers measured are bigger than that to make sure, that only one chamber is ablated per measurement? RE-

C11

SPONSE: The word "generally" was added. In general always single chamber was ablated, however, it can not be completely excluded that in few rare cases two chambers were ablated at once. This would mainly concern small individuals of *B. spissa*, which has very small older chambers.

page 5 l. 26: NFHS: has the homogeneity of this standard been published somewhere? Were JCP21 MACS3 and NFHS all used as the form of pressed powder tablets? RESPONSE: Yes: all these CaCO₃ powders were pressed into tablets. The relative standard deviation in element/Ca based on multiple measurements on the NFHS is comparable to that of other standards (Mezger et al., 2016). A reference to this study is added (section 2.5 5th paragraph)

l.30: I assume seawater= porewater? where is DMn reported? Knowing the good quality of data that usually is published from the Utrecht setup used, I assume that the methods have been written up by two different co-authors, I would strongly encourage the authors to rewrite section 2.5 so that the same details are given for both setups used. RESPONSE: DMn values are all given now in Appendix 2. Yes, seawater changed to pore water. We have carefully checked section 2.5 to check for consistency and modifications have been made. However, the differences in setups and controls of the ICP-MS's used inherently cause the descriptions to differ. For example, tuning of the quadrupole and SF-ICP-MS differ and also the way they cycle through the elements analysed differs fundamentally. Still, all relevant parameters are described in each of the paragraphs.

page 6 l.6: what exactly is pore water chemistry? which parameters? RESPONSE: Sentence modified to "Pore water chemistry, including dissolved oxygen, nitrate, ammonium and manganese, was measured at sites 6, 8 and 10 (Figure 2)."

l.8: in-sediment depth? what depth is this? RESPONSE: Sentence modified to "In all cores, nitrate was rapidly depleted within surficial sediments"

l. 23: App. 1 is missing, I contacted the first author for App. 1, the excel file I re-

C12

ceived looks like there was mostly 2-3 chambers measured on each specimen, so that I doubt that this is enough to support that "there is no correlation between shell size and Mn/Ca" as it could be that interspecies variability masked potential ontogenetic trends in Mn/Ca, if only 2 or 3 chambers were measured on one specimen. I would encourage the authors to provide a figure in the appendix to demonstrate intra-species variability and also to calculate inter- versus intra-species variability for all species studied and provide data in a table. Also I do not see statistical analyses in App. 1 (L. 23: "The statistical analyses were carried out on all data (App.1)"). RESPONSE Appendix is now added, containing all raw data. This is labeled now as appendix 2. In addition, appendix 1 is now supplied where profiles of *B. spissa* and *E. batialis* are shown, based on Mn/Ca ratios in single specimens. Pearson correlation coefficients were calculated, however, all correlations were insignificant with two-tailed significance always being >0.05. This is added to results section 3.2.. Please also consider the response on this same topic earlier in the review.

page 7 l. 28: lowest average (?) Mn/Ca values RESPONSE: Nina Keul was contacted regarding this comment, as it was not clear to the authors what she originally meant with it. In her response she stated " I was wondering whether average shell Mn/Ca is in station 6 the lowest for that species or whether it is actually lower in shells from the same species in station 8, where porewater Mn was higher? (Sorry for the kryptic comment...) If that's the case it should be discussed somewhere. Our response to this comment: The average Mn/Ca ratio at station 6 is 30,1 and at station 8 30,6, so it is little bit higher at station 8 than 6, as should be due to slightly higher pore water Mn-content at station 8. However, the difference is not statistically significant. Based on this comment, it was noted that the standard error is missing in Figure 8 for *Uvigerina* spp (station 8) this is now added to the figure. For station 7 the error bar is so small (1,7) that it is hidden under the data label, and thus hardly visible.

page 8 l.16: "excluded from data": show also in exemplary profile (see comment above) "Due to the nature of the specimens. . ." does this refer to the fact that living foraminifera

C13

most likely do not have diagenetic coatings or some other factor? RESPONSE: representative laser ablation profiles are now provided (figure 2). Indeed as specimens were very recent, diagenetic coatings are unlikely. This is now added into the sentence.

page 9: please add references to figures and tables (also the "new" one with the Mn/Ca and DMn values) RESPONSE: new figure with DMn made and referred to. Values also given in Appendix 2.

l.15/16: bimodal distribution - which species here shows a bimodal distribution? RESPONSE: *B. spissa* at station 7 and *Uvigerina* spp. station 7 and 8 (Fontanier et al. 2014). This is now added into the sentence.

l. 26: delete "are" RESPONSE: Modified to "...it seems that deep infaunal foraminifera, based on their Mn incorporation, are calcifying..."

page 10: l. 20: fluxes must still be relatively RESPONSE: ok, done

l.32 remove "study" at end of sentence RESPONSE: ok, done. This section has also now moved up into the start of section 4.3

page 11: l.6: fig 2 not fig1 RESPONSE: reference to figure corrected.

Last paragraph: good discussion of Mn redox chemistry and availability, but maybe move up in the manuscript, as it is in general relevant for the incorporation of Mn into foraminifera and not necessarily part of the "paleo implications only". RESPONSE: As outlined earlier in the response to the review, we feel that this has direct implications for paleo studies as it shows that the Mn/Ca ratios in foraminifera do not only depend on oxygenation, or redox chemistry, but also on supply of manganese oxides in sediment. Therefore, we have kept this section as part of 4.3.

—END OF REVIEW 1—

Please also note the supplement to this comment:
<http://www.biogeosciences-discuss.net/bg-2016-547/bg-2016-547-AC1->

C14

C15

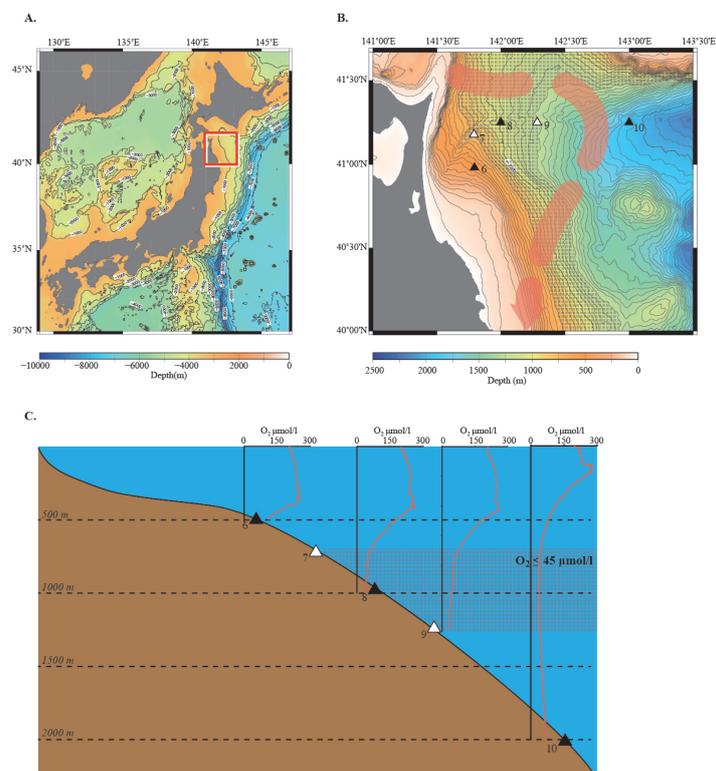


Fig. 1. A Regional map of the study area B: Bathymetric map of the study region, showing the position of Tsugaru warm current (Oguma et al., 2002) and multicore sampling sites. C: Schematized study

C16

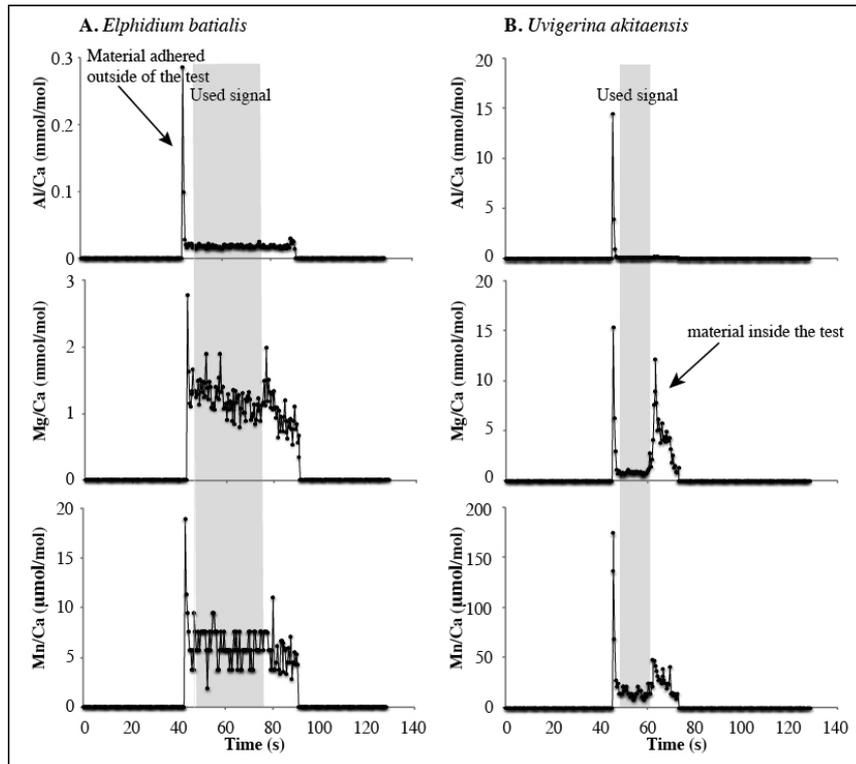


Fig. 2. Laser ablation profile for Al/Ca Mg/Ca and Mn/Ca measured in (A) *E. baliatilis* (station 8, 0-0.5 cm depth) and (B) *Uvigerina akitaensis* (station 7, 0-0.5 cm depth) benthic foraminifera. The se

C17

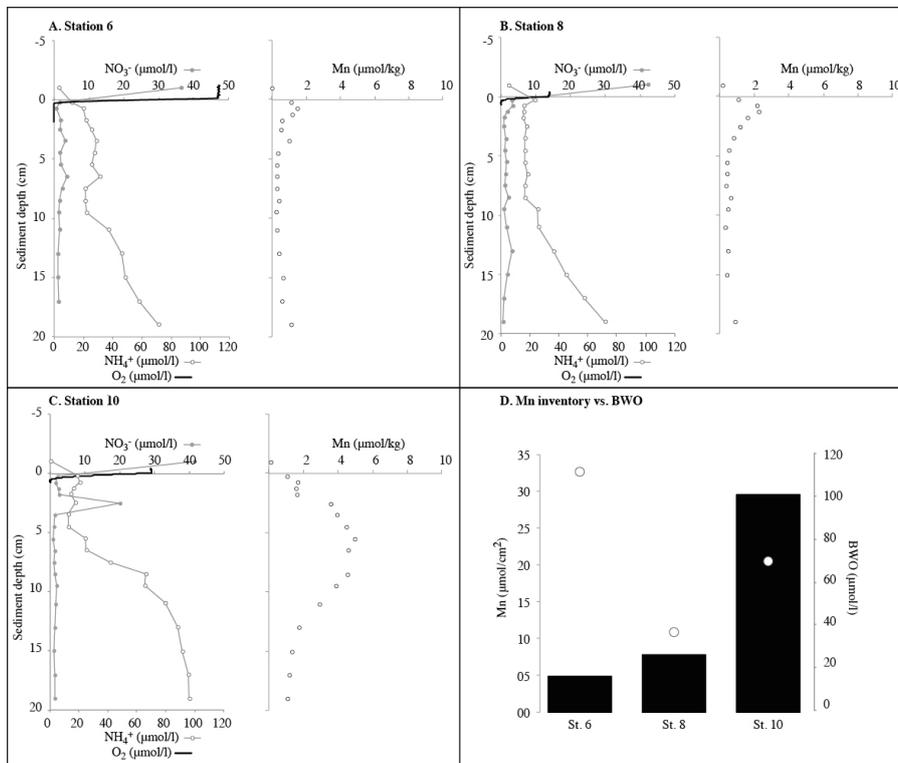


Fig. 3. Pore water profiles of dissolved oxygen, nitrate, ammonium and manganese at station 6 (A), 8 (B) and 10 (C). (D) Pore water manganese inventory in the top 10 cm of sediment and bottom water oxygen con

C18

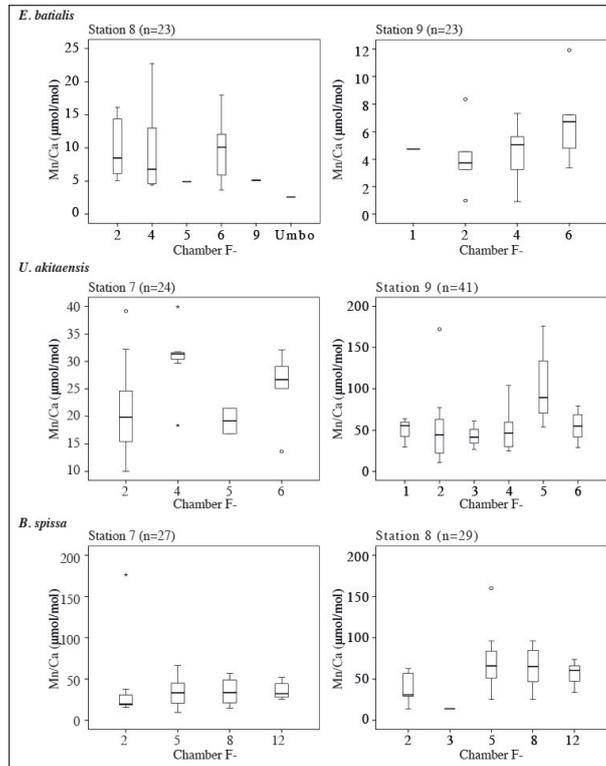


Fig. 4. Figure 4: Box-plots showing chamber-to-chamber variability of Mn/Ca. Error bars display the full range of data variation (from minimum to maximum). Data outliers are represented with an astrix.

C19

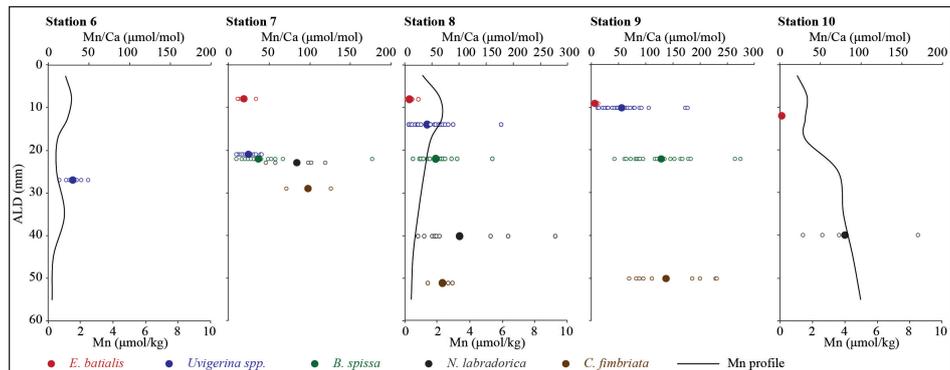


Fig. 5. Figure 5: Individual laser ablation measurements of Mn/Ca in foraminifera versus sediment depth where the specimens were collected.

C20

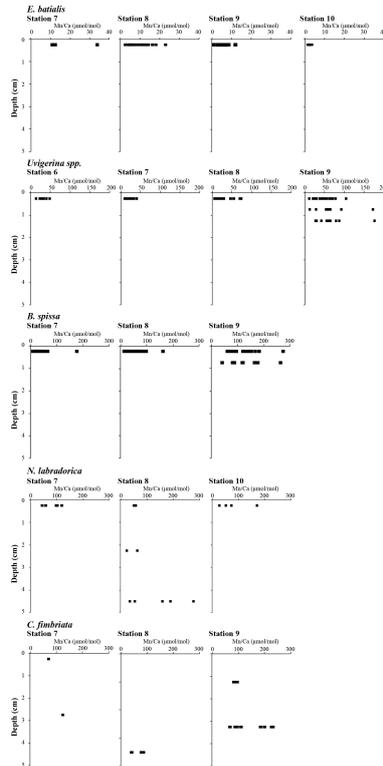


Fig. 6. Mn/Ca ratios in foraminifera as a function of the average living depth of each species. The average of all measurements is indicated with a solid symbol and the individual measurements with open sym

C21

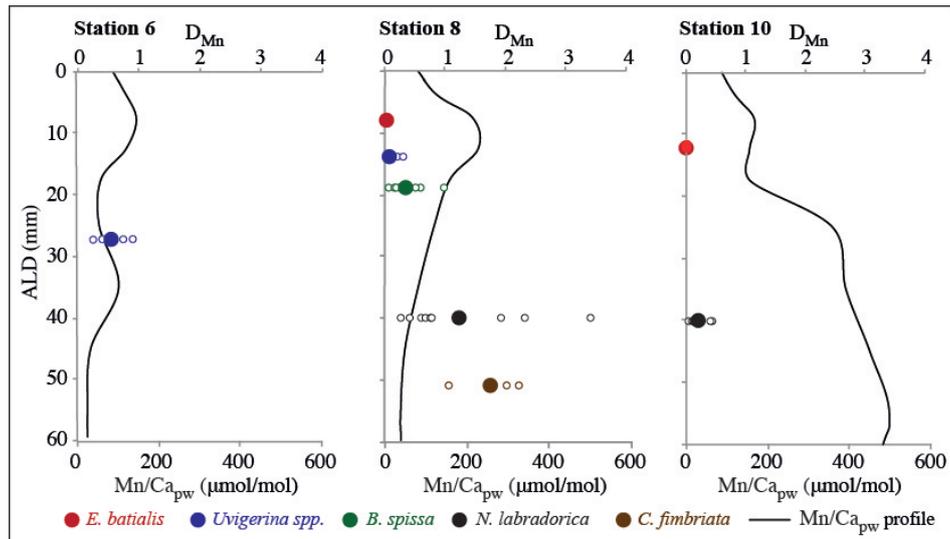


Fig. 7. Manganese partition coefficient DMn in foraminifera as a function of average living depth of each species. In addition, the pore water (pw) Mn/Ca profile is shown.

C22

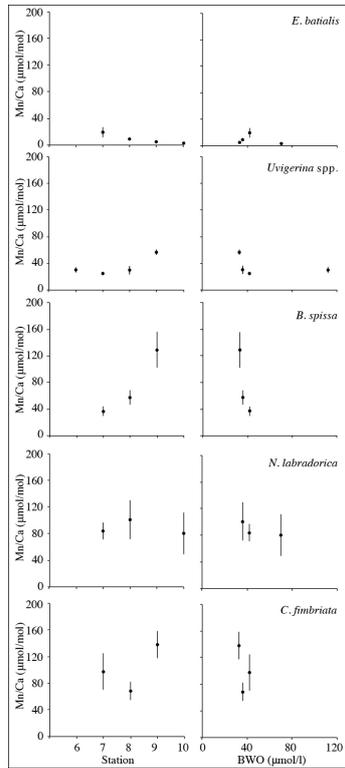


Fig. 8. Variability of average Mn/Ca ratios of each species plotted against the study transect from station 6 to station 10 (left), and along the bottom water oxygenation (right). The error bars represen...