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Interactive comment on "A novel salinity proxy based on Na incorporation into foraminiferal calcite" *by* J. C. Wit et al.

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We kindly thank Joachim Schönfeld for his constructive comments on the manuscript. Below we give point-by-point answers to the issues raised by the referee and how we will incorporate changes to the manuscript. All suggested changes to wording will be incorporated into the manuscript.

J.C. Wit and co-authors

"The methods are not comprehensively explained and many details are missing. If one would have the equipment and chemicals at hand, a skilled technician too, and you would like to redo the experiment in order to verify the conclusions or to obtain more data, you were lost. A genuine experiment reported in the literature should be repeat-

able with the information provided. For instance, I miss a description of the culturing system and procedures, specification of the camera and computer systems for diameter measurements, which cross sections were used to measure the diameter, and details of the software interpreting the elemental cross sections, vitality assessment of foraminiferal specimens etc."

The suggested details on the experimental settings and equipment will be added to the manuscript, including references to publications describing part of the methods:

Upon return in the laboratory, living specimens were isolated from the sediment and placed in filtered (0.2 μm) seawater with a salinity of 35, at 20 oC. Vitality of specimens was assessed by checking for algal content (Dunaliella salina) in the last three chambers, movement within Petridish and presence of active pseudopodia emerging from the aperture.

The culture setup consisted of a closed-system in order to minimize changes to the set salinities. Flasks contained 250 ml of culture media, which was refreshed bi-weekly. All salinity treatments were placed in an incubator set at 20 $\pm$ 0.1 oC.

Diameter of individual foraminifera was determined using a microscope camera (NIKON Digital Sight DS-Fi1), calibrated at the micrometer scale (E. Leitz GMBH WETZLAR) and computer software (NIKON Imaging SOFT NIS-Elements BR).

"Comparing tables 3 and 4 it is evident, that the analytical data are not completely documented. A table is necessary listing all specimens analysed, their initial and final diameter, the number of chambers added, their vitality at the end of the experiment, and all elemental ratios. Mean values and standard deviations (1-sigma) for the respective salinities are to be listed as well."

The initial diameter of each individual at the start of the incubation was not determined due to the small intial sizes. All species introduced to the culture setup had 2-3 chambers and were of similar size ($\pm$ 40 μm) and placed into the culturing setup

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simultaneously. The final size and number of chambers, therefore, reflects growth during the experiment and allows comparison of growth rates between different conditions (i.e. salinities). The final number of chambers of each specimen will be added to table 3 and 4.

“A sincere concern is that the seawater composition was artificially altered by adding NaHCO3 and B(OH)3. This certainly affects the calcification process of foraminifera and hence may bias the shell composition and structure with reference to natural conditions. Higher salinities could be easily achieved by evaporation, similar as it happens in nature every day. A calibration of a paleo-proxy must be done as close to natural conditions as possible.”

Seawater composition was altered so that the four treatments have varying salinities, but similar DIC and boron (boric acid/ borate) contents, ensuring similar seawater carbonate chemistry. Manipulating salinity by evaporating or dilution with freshwater, would have altered alkalinity and DIC concentration. Here we aimed at assessing the isolated impact of salinity, but we agree that also investigating other impacts could be considered in future research.

“Salinities of 36 or 39 units are close to the upper limit of what Ammonia tepida could stand (Bradshaw, 1957, his figure 5). Any conclusions drawn from results at these salinities should therefore taken with caution. This circumstance has not been addressed in the present paper.”

Indeed these salinities may be the upper range of Ammonia tepida. However, tests from these experiments were only marginally smaller than the other experiments, and did not show any calcification anomalies. This shows that, albeit close to their environmental range, they had similar growth rates. There were no signs of dissolution, thinner tests of abnormal shell structures. It is, therefore, highly unlikely that growing specimens over the range used here actually impacted our results. This discussion will be added to the manuscript.

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Furthermore, the smaller test sizes at the higher salinities could indicate that the calcification process is influenced, since these experiments are at the upper limit of the salinity tolerance of Ammonia tepida (Bradshaw, 1957). However, none of the individuals from the higher salinity experiments (36.1 and 38.6) showed any signs of dissolution, more transparent tests or abnormal chamber formation.

"In paleoceanographic studies, elemental ratios in foraminiferal tests are routinely determined with ICP-MS measurements following crushing and homogenisation of 10 to 20 specimens and established cleaning procedures and dissolution of shell fragments. Laser ablation measurements on living specimens record the pristine composition of primary and secondary calcite without subsequent alteration during gametogenesis and early diagenesis in surface sediments. In order to establish the new Na/Ca proxy, the authors must give reference to data obtained by the extensively used wet chemical method on the very specimens grown in culture and compare them with their laser ablation measurements reported in this paper."

Measuring element/Ca ratios by Laser Ablation ICP-MS and the otherwise-used wet chemistry methods are highly comparable. This has been documented in earlier studies using Laser Ablation ICP-MS on foraminiferal calcite (e.g. Wit et al., 2010, Dueñas-Bohórquez et al., 2011, Dissard et al., 2010, Eggins et al., 2003, Sadekov et al., 2008). This will be added to the manuscript in the methods section.

It has furthermore been shown that there is no difference in element/Ca ration between Laser Ablation and solution based ICP-MS when measuring foraminiferal calcite (e.g. Eggins et al., 2003, Sadekov et al., 2008, Dissard et al., 2010, Wit et al., 2010, Dueñas-Bohórquez et al., 2011b).

"The acceptance and utility of a new proxy will be highly promoted by a sound field test. The authors are encouraged to sample living specimens grown at approximately 20_C from tidal flats where different salinities prevail, for instance from the Danish Wadden Sea in late summer (25 salinity units), French coast of Biscay in early summer (32

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units), Gulf of Cadiz in fall (36 units or even more in places). Ammonia tepida is found in all these locations with considerable abundances."

We completely agree with the referee and this will be done in the near future, resulting in a field-based calibration for this proxy. However, field calibrations do have their own caveats (as well as advantages), require different handling of the specimens, etc., which would make the manuscript presented here particularly extensive. Instead, we chose to focus on the laboratory based culture study showing the isolated impact of salinity on incorporation of sodium and magnesium, discuss the potential underlying mechanisms and the correction for Mg/Ca-based temperature reconstructions. This is only possible through manipulated cultures as otherwise several factors co-vary under the natural conditions (e.g. salinity and carbonate chemistry)

"Elemental banding in foraminiferal test walls has been attributed to either vertical movements of specimens in the water column, to adsorption at organic linings in the shell, or to changes in elemental concentration between primary and secondary calcite. In particular the latter point is to be addressed in the discussion."

The potential source of inter-individual variability in relation to elemental banding in foraminiferal calcite and its impact on proxy calibration is now discussed in the manuscript.

The source of these bands has been attributed to vertical movements of individual foraminifera, although the magnitude of the variability and its presence in planktonic as well as benthic species renders this unlikely due to the small in-sediment temperature variability (Sadekov et al., 2008, Wit et al., 2010). Another potential source of these bandings is the periodical change in the carbonate ion concentration. Light-Dark cycles have been reported to influence the activity of photosynthetic symbionts in planktonic foraminifera which in turn effects the carbonate ion concentration of its microenvironment and thereby the incorporation of Mg (Eggins et al., 2004). These same variations have been observed in benthic foraminifera as a result of carbonate ion con-

centration changes with in sediment depth habitat of the foraminifera (Elderfield et al., 2006, Rathmann and Kuhnert, 2008). Alternatively, such banding has been ascribed to variable element adsorption to organic linings and elemental differences between primary and secondary calcite (Erez, 2003). This variability potentially hinders the accuracy of proxies based on the Na/Ca and Mg/Ca values of foraminiferal calcite, but does not impact their applicability in paleoceanography when sufficient specimens are combined to determine element/Ca values to account for the inter- and intra-individual variability in element/Ca ratios (Sadekov et al., 2008, Wit et al., 2012).

"The section 4.2 on correcting Mg/Ca based temperatures for salinity is interesting and certainly a leap forward improving the Mg/Ca temperature proxy, but it is out of the focus of the present approach. The section should be omitted."

Section 4.2 not only contains a correction for Mg/Ca based temperature calibrations, but also shows, for the first time, the impact of salinity on foraminiferal Mg/Ca values independent of changes in alkalinity and DIC. It illustrates how and why Mg/Ca is impacted by salinity through the modeling of elemental speciation in seawater under rising salinity. We, therefore, believe that this section is a useful and justifies to be presented here.

"Section 1, lines 5-10: Jörg Bollmann's (2009) Emiliania huxleyi placolith biometry approach is to be mentioned."

The approach will be mentioned in the manuscript at the suggested section.

Interactive comment on Biogeosciences Discuss., 10, 6039, 2013.