Biogeosciences Discuss., 6, C2421–C2429, 2009
www.biogeosciences-discuss.net/6/C2421/2009/

Biogeosciences
Discussions

Interactive comment on "Interpretation of benthic foraminiferal stable isotopes in subtidal estuarine environments" *by* P. Diz et al.

P. Diz et al.

paula.dizferreiro@univ-angers.fr

Received and published: 7 October 2009

Authors' comments in response to referees' comments on "Interpretation of benthic foraminiferal stable isotopes in subtidal estuarine environments" by P. Diz, F. J. Jorissen, G. J., Reichart, C. Poulain, F. Dehairs, E. Leorri and Y.-M., Paulet

We gratefully thank the two referees for their positive reviews and constructive comments. Below we discuss all points raised by the referees and detail amendments to the manuscript to incorporate the referees' insight.

RESPONSE TO COMMON COMMENTS BY E. THOMAS AND REFEREE #2

*E. Thomas and Referee #2 highlighted that the depth of the sampling sites was not indicated.

We amended this by including in the revised version of the manuscript the depths of the sampling sites with respect to the mean tidal level in Port Navalo.

* E. Thomas and Referee #2 refer to the use of carbon isotopes as a salinity proxy.

(E. Thomas) Pag7462, lines 16-17: gradient in salinity should have been stepper in winter. – you could argue that you indeed see this in the carbon isotopes, confirming your use of these as salinity proxy. (Referee #2): The authors don't use carbon isotope as salinity proxy though they found clear relationship between carbon isotopic compositions and water mixing (i.e. salinity) in the sampled region. Could this serve as a new salinity proxy even though the range of applicable conditions is limited?

It is not very clear from Fig. 5 (right hand side) that the gradient in benthic foraminiferal carbon isotopes is steeper in winter than in spring. The oxidation of isotopically light organic matter may have imprinted the carbon isotopic composition of the two studied species. At present, we cannot quantify this effect, which makes it impossible to directly translate foraminiferal δ13C into a salinity value. Therefore, we prefer to use benthic foraminiferal carbon isotopes as a qualitative proxy of salinity, i.e., we use it to rule out certain calcification periods.

In fact, we think that the relation between carbon isotope composition of benthic foraminifera and water mixing (salinity) should be evaluated separately for each study area prior to using carbon isotopes of benthic foraminifera as a potential salinity proxy. The "organic matter degradation" effect should be estimated for each benthic foraminiferal species and for different parts of the estuary (upper, middle, lower) because the microhabitat, food preferences, and lability of the organic carbon may play a significant role in determining the offset between porewater and bottom water δ13CDIC. It is also important to determine the preferred calcification periods of the measured species. It is impossible to find a steep foraminiferal δ13C gradient along the estuary for species which predominantly calcify in the dry season (e.g., when the salinity gradient between the upper and the lower estuary is subtle). In such a case, the observed foraminiferal δ13C gradient would only be representative for a limited part of the total yearly range of salinities. Consequently, in such a case, benthic foraminiferal carbon isotopes cannot be used to reconstruct the full range of salinities found in the estuary.

*E. Thomas and Referee #2 comment on the surprising fact of foraminifera not calcifying during warm periods or stopping to calcify.

The isotopic data presented in this work clearly show that foraminifera in the upper parts of the estuary did not generally calcify during the warmer months. If they had calcified during summer, the δ18O values of their shells should be well below -0.5 ‰ (Fig. 6).

We are only partially surprised by the fact of foraminifera not calcifying during warm periods. Bradshaw (1957, 1961, referenced in the main text) determined that in culture conditions the optimal growth and reproductive conditions of A. tepida are 25-30°C and 34 salinity units. However, it is questionable whether these values can be applied directly to nature (where other parameters than temperature and salinity, such as inter-species competition, food availability, redox gradients, also influence the faunas). Furthermore, field studies involving high-frequency sampling over longer periods (years) in nearby areas (Morvan et al., 2006, this reference was already in the manuscript, pag. 7466, Line 7) show abundance peaks of A. tepida and H. germanica during cold months (i.e., October-December, February). Also Debenay et al. (2006) show increased abundance of these species in November (now included as a reference in the cited paragraph). It seems that the biotic and abiotic factors that trigger foraminiferal reproduction and growth in subtidal and intertidal environments are not yet fully understood.

Several authors experimentally demonstrated that foraminifera can survive for months under suboptimal environmental conditions (Bernhard and Alve, 1996; Moodley et al., 1997) and grow again once suitable conditions occur (Alve and Goldstein, 2003). There is no reason to think that the periods of survival described for foraminifera in

culture conditions are longer than those in nature. Besides, it has been suggested that foraminifera in nature might become dormant under adverse conditions (Bernhard and SenGupta, 1999) and that encystment or cocoon building, documented in estuarine environments (e.g., Gustafsson and Nordberg, 1999; Polovodova et al., 2009), is a strategy of dormancy during adverse conditions, such as, for example, anoxia.

RESPONSE TO COMMENTS BY E. THOMAS (REFEREE)

* Pag. 7455, Line 8: insert at “mid to high latitudes”

Done

* Pag 7456, Lines 14-15: why are sediments in areas affected by tidal currents enriched in fine fraction and organic matter? Are the currents bringing it in and dropping it during the change in tides, or are they too weak to winnow that material? Is there evidence of sand motion (ripples?) in the sandy areas?

The sentence in Lines 14-15 was incorrect and we re-wrote it in the revised version of the manuscript. Although we do not have evidence of ripples in Locmariaquer, it is probable that the sandy sediments in this station are influenced by strong bottom currents.

* Pag 7458, Line 18: are the plants remains from terrestrial vegetation or from water plants?

We cannot accurately identify the provenance of all plants remains under the binocular. We identify some terrestrial vegetation (tree leaves) as well as some marine plants (Zostera) which probably come from the shore area.

* Section 3.2.2: can you indicate at which depth most living forams were present? It would be good to know whether calcification occurred at sediment water interface or infaunally. And some short notes of what other species (if any) are present? Reference to publication on faunas from the region? Are these the publications given in section 4.3?

We have information on the vertical distribution of living benthic foraminifera in the four studied stations during the two sampling periods in the Auray River estuary. Short notes on the vertical distribution of living specimens and other species are now included in section 4.3. Foraminiferal samples for isotopic measurements were obtained from the 0-1 cm interval as indicated in section 3.2.3

* Pag. 7460, lines 1 and 14: in the first salinity ranges are between 18-36 in lower through upper estuary, in the latter the range is given as 30-32.

In Line 14, (20-32), refers only to the salinity range measured at Bono between the 1st and 3rd of March 2007 when water samples for isotopes measurements were taken. This does not express the salinity range in the lower through the upper estuary.

*Pag. 8, line 15: Indeed, the figure shows a linear relationship with salinity for both carbon and oxygen isotopes. What I do not understand is WHY this relation is linear for carbon isotopes. Oxygen isotopes in mixtures fresh and salt water obviously show a linear relationship, but the relationship between the carbon isotope in dissolved inorganic carbon are linear ONLY if the concentrations of DIC in the fresh and salt water end member are exactly the same – otherwise you get a curve (see our figure in Thomas et al 2000). Are these concentrations the same? Otherwise why the straight line? Or could a curve also be fitted?

Bottom water stable isotope and salinity measurements were performed at Bono station during 3 tidal cycles. Within the measured salinity range during the sampling (20-32), the observed correlation between δ13CDIC and salinity is linear, as indicated in Fig. 3. Although a nonlinear fit for the δ13CDIC: salinity relation would be theoretically more appropriate, there are no data available for the δ13CDIC and DIC of the end member (river water), and therefore we cannot fit the data to a nonlinear (i.e., curved) relation.

*The oxygen isotope values for rain (about minus 5 per mille surprises me somewhat – we get about –10 in Connecticut and you are about 10 degrees further north so I'd

expect from the MWL that you would be more negative than we are.

We have re-checked the data provided by the GRIP (referenced in the main text) and the maps available on their web page (http://www-naweb.iaea.org/napc/ih/GNIP/userupdate/Waterloo/index.html) and there is an agreement between both. Additional information on the δ18O of precipitation over Western Europe and distributional patterns can also be found in Austin et al. (2006).

* 7461 line 16: please spell out what 'some differences' are – referring to the two species under study or abundance of other species?

We corrected the sentence in Line 16, which was unclear; there are changes in the faunal composition, i.e., the relative proportions of these, but also of other species. The most important differences are indicated in lines 17-19. In the next lines we have added some more general information about the composition of the foraminiferal faunas.

*Section 4.4 but if you use the averaged annual temperature measured and the averaged annual salinity, what would you predict for the calcite values if precipitated in equilibrium? Just for a baseline.

The δ18Oeq predicted on the basis of averaged annual temperature and salinity for Bono and Locmariaquer will be -0.3 ‰ and 0.4 ‰ respectively. According to the data provided in Table 1 and Fig. 5, very few benthic foraminiferal samples will record a δ18O value that represents the average annual temperature and salinity. This supports our hypothesis of foraminifera calcifying in different seasons.

*Section 5.1: I really like these plots – but they are a bit small and do not enlarge very well. Is that just my browser or can that be changed?

We absolutely agree with you. We will ask the editorial board to change the size of the plots in Fig. 6 for publication.

* Pag. 7466, Lines 12-13: I do not quite follow the sentence 'that the strong seasonality needs additional constraints from independent proxies' – this cannot be what you

mean, since seasonality cannot be constrained by humans. You mean that we need to evaluate the effect of seasonality on observed proxies?

This was a wrong sentence. We amended it in the revised version of the manuscript.

* Figure 3: is it possible to plot the range of oxygen isotope data (converted to SMOW) as well? In Figure 3 we plotted the δ18Ow and δ13CDIC on a VPDB scale. For δ18Ow, we converted the standard mean ocean water δ18Ow (VSMOW) into VPDB units using a correction factor of -0.27 (Hut, 1987) as indicated in the text and the figure caption. We think that to plot the δ18Ow data also on a VSMOW scale will make Fig. 3 difficult to read.

RESPONSE TO COMMENTS BY REFEREE #2

* Referee # 2 comments on that the indicated prediction of calcification seasons is very broad and that should be discussed with the predicted lifetime of specimens.

As the referee points out the prediction on calcification seasons shows a broad range of possible calcification periods, including, in some cases, two different seasons (Table 2, underlined and bold). This is explained by the fact of that several combinations of temperature and salinity (representing different seasons) yield identical δ18Oeq values. In these circumstances, and with the data available, is not possible to restrict the calcification to only one of the seasons.

In the cases in which the predicted calcification period is constrained to a single season (e.g., A. tepida in Locmariaquer, Spring 2006), it is very difficult, or even impossible, to restrict the calcification to one or two months within the season, or to the life time of the specimens. As indicated in section 5.2, isotopic measurements are performed on several individuals that may or may not have calcified in different months within a particular season. The range of sizes of the individuals used for isotopic measurements varies between 150 and 350 μm (this information is now indicated in the revised version of the manuscript). Culture experiments (Bradshaw, 1957; 1961; the authors′ unpublished re-

sults) showed that under optimum conditions the growth of A. tepida from juvenile to ~150 μm occurs within days. Bradshaw (1957; 1961) calculated that at 20°C and 33.5 salinity units (i.e., salinity and temperature representative of summer conditions in the Auray estuary), A. tepida would necessitate about 75 days (~2.5 months) to grow from 150 μm to 350 μm.We conclude that foraminiferal calcite represents an average picture of the conditions during the calcification period, which can vary from a couple of days to several months. Unfortunately, there is no way to be more precise about this.

*Pag. 7457, line 6: How did isotopes fluctuate during the day (every 2h)? Unfortunately, the only data available for the daily fluctuations in the stable isotopic composition of the bottom waters are presented in Fig. 3. Bottom waters were collected every 2 h (with the exception of two samples sampled every 8h) along 3 tidal cycles. The δ18Ow varies in function of the mixing between river and seawater as indicated in Fig. 3.

REFERENCES:

Alve, E., and Goldstein, S. T.: Propagule transport as a key method of dispersal in benthic foraminifera (Protista), Limnology and Oceanography, 48, 2163-2170, 2003.

Austin, W. E. N., Cage, A. G., and Scourse, J. D.: Mid-latitude shelf seas: a NW European perspective on the seasonal dynamics of temperature, salinity and oxygen isotopes, The Holocene, 16, 937-947, 2006.

Bernhard, J. M., and Alve, E.: Survival, ATP pool, and ultrastructural characterization of benthic foraminifera from Drammensfjord (Norway): response to anoxia Marine Micropaleontology, 28, 5- 17, 1996.

Bernhard, J. M., and Sen Gupta, B. K.: Foraminifera of oxygen-depleted environments, in: Modern Foraminifera, edited by: Sen Gupta, B. K., Kluwer Academic Publishers, London, 201-216, 1999.

Gustafsson, M., and Nordberg, K.: Benthic foraminifera and their response to hydrography, periodic hypoxic conditions and primary production in the Koljö fjord on the

Swedish west coast, Journal of Sea Research, 41 163-178, 1999.

Moodley, L., van der Zwaan, G. J., Herman, P. M. L., Kempers, L., and van Breugel, P.: Differential response of benthic meiofauna to anoxia with special reference to Foraminifera (Protista: Sarcodina) Marine Ecology Progress Series, 158, 151-163, 1997.

Polovodova, I., Nikulina, A., Schönfeld, J., and Dullo, W. C.: Recent benthic foraminifera in the Flensburg Fjord (Western Baltic Sea), Journal of Micropalaeontology, 28, 1-14, 2009.

Interactive comment on Biogeosciences Discuss., 6, 7453, 2009.