

Biogeosciences Discuss., author comment AC2
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Reply on RC2

Daniel François et al.

Author comment on "Acidification impacts and acclimation potential of Caribbean benthic foraminifera assemblages in naturally discharging low-pH water" by Daniel François et al., Biogeosciences Discuss., <https://doi.org/10.5194/bg-2022-91-AC2>, 2022

We thank the referee for recognizing the importance of our work and for the useful input. Below, you will find the answers to the helpful comments and suggestions.

Referee#2 Major comments:

Comment - The paper by Francois et al. reports natural experiments of ocean acidification to understand the impact of Caribbean benthic foraminiferal assemblages near low-pH water discharging spring sites. Since this kind of natural experiments is still rare in foram research, the results are valuable and well-presented using univariate and multivariate analyses. However, I found a major issue for the authors to reconsider prior to publishing this paper.

The main issue is what time scales the authors are discussing. If the authors focus on decadal time scales occurring in this century, the conclusion in this paper is mostly incorrect.

This is because the paper deals with total (live and dead) foram assemblages in sediment and the proportion of live tests identified as stained tests is very low (3%) in the assemblages. That means that 97% of dead foram assemblages are results from long-term accumulations and taphonomic processes from various sources of habitats. Some may be in situ near sample sites, while others are **transported** or **bioturbated** particularly in shallow-water setting (the authors should show the bottom current speed and rates, as well as any benthic organisms inducing bioturbation). Some may be pristine, while others are very old (the authors may be surprised if the authors measure the radiocarbon age of foram tests). Table S3 shows that **most tests are dissolved and/or broken**. This means that dead tests are not pristine and are transported/bioturbated. Nevertheless, this paper discusses the effect of low-pH water gradient occurring in the present time as if all foram tests are in situ and very recent products.

Reply: We agree with the referee`s concern about the influence of post-mortem processes on our interpretations as the samples presented some alteration. However, we highlight that dissolution was not homogenous between species but mainly associated with the occurrence of LBF, specifically *Archaias angulatus* which alone was able to explain 73% of the observed dissolution (Linear regressions, $R^2 = 0.73$). The small, less robust calcifiers (e.g., *Rosalina* spp, *Elphidium* spp) were mainly pristine or in good conditions despite the expectation that these smaller species will dissolve fast and be transported by

current more readily after sedimentation.

In respect to the relatively high degree of dissolution of samples as reported in Table S3, the reason for the high fraction of dissolved tests is because we simply used two general categories (1) Pristine and (2) dissolved tests, with the latter considering any degree of dissolution. To solve this issue we have now sub-classified them as 'optimally', 'well', and 'poorly' preserved (Hohenegger and Yordanova, 2001), demonstrating that most of the tests are assigned as well or optimally preserved (at least until 7.7 pH units), indicating the overall pristine conditions of the samples.

Regarding bioturbation, we are unable to directly investigate its influence on our samples since only surface sediments (>1 cm depth) were collected. However, we analyzed test colors patterns in the forams, which can potentially be used to differentiate relict and pristine tests. The yellow, brown or black tests reflect postmortem chemical alteration from subaerial exposure, implying a longer residence time. In contrast, the white tests would indicate a relatively little reworking of sediments. In our samples the tests were mainly 100% white (we only found 2 brown specimens in Ojo Laja), so mixing of pristine and relict tests are unlikely. Moreover, the sediment is typically of coarse sand size and bioturbation features such as borrows are hard to detect.

Concerning the spatial mixing, the reef lagoon circulation is not significantly affected by tides, and currents due to the microtidal regime of the region and the back-reef setting. In the springs, the waves overtopping on the reef crest and the resulting flow is considered to be the main driving mechanism of the circulation (Coronado et al. 2007, Coral Reefs, DOI: 10.1007/s00338-006-0175-9). Coronado et al. 2007 measured a relatively small current of av. 2–3 cm s⁻¹ circulation, directed towards the shore at the forereef, and a higher current (av. 20 cm s⁻¹) was only observed through northern and southern channels where the water exits the lagoon. Being enclosed by fringing coral reefs and not close to the exits, the currents are not considered to significantly influence the sediments distribution near the springs. Moreover, the coarse sand grain size is less conducive to dispersal by current.

To clarify the taphonomic conditions of the samples we added this discussion to the manuscript.

Comment - If the authors like to discuss OA impacts on foram assemblages occurring in this century, the authors should have sampled phytal and rubble substrates and studied only live assemblages. Even if the authors consider the foram tests are mostly in situ and recent products, the authors should at least show all foram taxa were found as stained tests at the sample sites.

I rather think the results are more applicable to geological OA record if the seawater chemistry of past OA records is similar to those in this study. I suggest that the authors reconsider whether your results are really able to discuss the OA impact occurring by the end of this century on living forams.

Reply: We highlight that the objective of the study was to assess the mid-term responses of the foraminiferal assemblages to carbonate chemistry changes, which information is registered in the sediments with the generational accumulation of foraminifera tests. In contrast, the study on phytal and rubble substrates would rather address the species responses within a particular point in time, as observed in previous studies (Stephenson et al. 2015, Ecological indicators, DOI: 10.1016/j.ecolind.2014.07.004).

The use of living specimens was the initial objective, but most of the tests had some degree of staining with Rose Bengal so it was hard to distinguish those alive from recently dead individuals. We also tried CellTracker Green that is actively taken by the cytoplasm,

but only very few forams got stained so that was not useful for the statistical analysis. This pattern of low stained individuals in the sediments is common in the Caribbean and even in pristine (off-shore) reef environments (Barbosa et al., 2009, 2012, Marine Micropaleontology) as most reef-dwelling taxa tend to live on phytal or hard substrates rather than directly on the sediments. It is important to note, however, that both stained and not stained specimens were in good condition, still recording a good representation of the present-day biocoenosis (i.e., no sign of damage and aging, Yordanova, E. K. & Hohenegger, 2002), which validates the applicability of the data to investigate future impacts of OA. Additionally, the decision for total assemblages was also based in Martinez et al. 2018 (Biogeosciences, DOI: 10.5194/bg-15-6819-2018) and Uthicke et al. 2013 that also used total assemblages to discuss the OA impacts occurring in this century.

Comment - This paper also does not discuss the possibility of dissolution of carbonate sediments including foram tests during daily pH variations (particularly during night). See the following BG paper.

<https://bg.copernicus.org/articles/9/1441/2012/>

Reply: We thank the referee for this suggestion, and we have added this relevant reference.

Referee #2: Minor comments

Comment - Title: be more specific (e.g. ... of Caribbean benthic foraminifera to naturally discharging low-pH water)

Reply: We changed the title to "Acidification impacts and acclimation potential of Caribbean benthic foraminifera assemblages in naturally discharging low-pH water"

Comment - L42-44: this is mainly due to planktonic forams in the outer ocean.

Reply: We changed in the text, accordantly.

Comments

Table 1: add the distance from the center of spring/fracture sites, spring water flow speed and rate, and sediment grain-size distribution.

L97-98: explain in more detail; how far from the center for each site?

L97: sediment grain-size distribution data are necessary to confirm if grain size does not affect foram assemblage compositions.

Reply: We don't have the sediment grain-size distribution data, however, the sediment throughout the backreef lagoon is of coarse sand grain size (e.g., The beach is composed of medium carbonate sand of biogenic origin, with a mean sediment size of ~0.258 mm. Escudero et al. (2020), J. Mar. Sci. Eng.; DOI: doi.org/10.3390/jmse8040247). Moreover, considering that most part of the studied species live on phytal or hard substrates (Stephenson et al. 2015) rather than directly on the sediments little or no influence are expected to our species.

About the distances, the samples were retrieved at >1 m, 1 m, 50 cms, 25 cms from and at the center of discharge. This information was added in the table.

Comment - L128-130: the authors should have sampled macroalgae and rubble.

Reply: As explained above this approach wouldn't provide the information we aimed for.

Comments

L132: 1 ml? Is unit correct? 1 gram of sediment?

L286: ind/ml, unit correct?

Reply: We are now using ind. cm³ as unit.

Comment - Fig. 3: species name should be better to express as lower-case letter to avoid confusion with environmental variables (TA vs. AT). Two ACs are found. AL>AG?

Reply: We thank the referee for this suggestions, the species name were changed to lower-case letter accordantly.

Comments

L262: Fig. 5c>4c. Check all fig numbers in this paragraph.

L263: Fig. 4a>4e

L268: H?

L276: Fig. 4e>4b

L319: table S3>S2?

L371: table S5>S4

L440: table S3>S2

L243: Thoculina>Trochulina in Fig. 2?

L725 and others: check the journal name abbreviations.

L212: Table S1 is not found in the supplementary data.

Reply: We thank the referee for noting these mistakes. We changed them accordingly.

Comment - Fig. 5: foram abundance decreased due to dissolution?

Reply: Yes, the samples close to the springs discharge presented lower abundance than the high pH samples. However, the density of forams was mainly explained by the alkalinity content rather than pH. We noted this correlation by comparing the linear regression models using the AIC following the suggestions of the #referee 1. As discussed in the manuscript it could reduce the dissolution rates and explain the occurrence of foraminifera tests in extremely low pH conditions (e.g., 7.1 pH units).

Comments

Fig. 6: legends are hard to understand. What's 3% mean? Why not listed alphabetically?

Why is Similarity not listed from low to high? What does y-axis variation mean?

Reply: The 3% was the cut off for the analysis and the assemblages were not listed

automatically as plot used was the direct output from the software. Following the suggestions of the #referee 1 the analysis was removed.

Comment - L339: P-value of 0.00 is not correct expression.

Reply: Following the suggestions of #referee 2 and 3 we are using $p = < 0.05$.

Comment - Fig. 7: a) the authors should confirm if results are not affected by spring flow speed. c) the unit of assemblage test size as %? dashed lines in caption?

Reply: We thank the referee for noticing the mistakes in Fig.7, the right unit was corrected and the dashed lines were added.

About the spring flow speed we don't have specific measurements from each sample station, and the temporal variability of discharge at the springs is high (impacted by tides and terrestrial recharge), however the flow is primarily in the vertical position and not laterally or towards the sediment due to buoyancy effect.

Comment - Fig. 8: Charrieau et al. (2022) in Sci. Rep. reports shell dissolution in living *Peneroplis*, the same large symbiotic miliolid forams as *Archaias*. They also show no significant difference in calcite density of living tests between different pH conditions. Even if the authors used pristine tests, the authors cannot tell if the calcite density changed either during living stage or post-mortem stage.

Reply: We have added this relevant reference. Indeed, it is impossible to tell based on our data alone if the calcite density changes were during the living stage or post-mortem. We do know that for corals at this site the low density was in the live stage. Single foraminifera analyses of B isotopes and B/Ca ratios may provide more information.

Comments

L381-382 may be correct for dead tests, but not for living tests.

L389 - but not living ones

Reply: Until 7.7 pH units the tests of foraminifera specimens still presented a good representation to biocoenosis, validly indicating the midterm responses of the local communities. Hence we expect that this holds for both live and post-mortem as the samples include both populations.

Comment - L447-448: maybe due to post-mortem dissolution.

Reply: We added a brief discussion about a possible influence of post-mortem process to *Archaias* lower density close to the springs discharge.

Comment - L453: the authors cannot tell from your results.

Reply: This comment was removed from the manuscript. Yet considering the very high likelihood that the specimens were not transported and represent the local living assemblages the data supports the conclusion regarding calcification yet maybe not the threshold.

Comments

L460: relatively higher resistance of post-mortem shell dissolution to low-pH

L334-336: higher resistance to dissolution by low pH and breakage by sediment transport and bioerosion.

L468: this is what you found in your study.

Reply: This conclusion that SB foraminifera presented higher resistance to low-pH conditions was based in their behavior within the range of 8.1-7.8 pH units, where the dissolution isn't the main driver of foraminifera tests (as observed when pH dropped below 7.7).

Comment - Fig. 4: This graph shows that SB & Agg dead tests are resistant to dissolution, remaining in sediment compared with smaller forams (SM, SR, OP). This is results of dead tests, not meaning that live forams can survive in low pH environments.

Reply: The influence of dissolution to the foraminifera tests was mainly observed between 7.7-7.1. Before this range the physiological resistance of foraminifera was likely the most important factor as the tests were all still in good preservation conditions.

Comment

L387-388: only for dissolution resistant taxa (SB)

Reply: This information was added.