bg-2018-57: R2

"Coral reef carbonate budgets and ecological drivers in the central Red Sea - a naturally high temperature and high total alkalinity environment"

Associate Editor Decision: Publish subject to minor revisions

01 Sep 2018 by Jean-Pierre Gattuso

Comments to the Author:

Dear Author,

Thank you for submitting a revised version of your manuscript submitted to Biogeosciences, which can be accepted for publication after minor revision. Please address the suggestions provided by the reviewers. When submitting the revised version, please let me know which of the changes were not implemented, if any, and why. This will speed up final acceptance.

I look forward to seeing this paper published and thank you for considering Biogeosciences to publish these very interesting results.

Best regards,
Jean-Pierre Gattuso

We thank the editor and reviewers for their positive assessment regarding our manuscript revision. In the following, we attach the two reviewers' reports and respond to their questions and comments in a point-by-point manner. We have addressed and implemented all suggestions. Changed sections or additions to the manuscript are highlighted in the provided revised manuscript.

In brief,

- we now use the more precise unit of kg $CaCO_3$ m^{-2} y^{-1} when referring to carbonate accretion or removal throughout the manuscript.
- we refer to and added a most recent publication of a carbonate budget analysis by Perry et al. 2018 to the Introduction.
- we include more detail about the methodology of the limestone block assay to the Introduction.
- we added more detailed information about the frequency of CTD calibrations to the Materials & Methods.
- we added/reworded parts of the Discussion regarding 1) the observations of the high physicochemical variability in the nearshore reef, 2) coral recruitment on the limestone blocks, and 3) the relationship between coral cover and carbonate budgets.
- we carefully revisited the manuscript to streamline the text and improve reading flow.

Referee #1: Steeve Comeau, comeau@obs-vlfr.fr: accepted subject to minor revisions

Submitted on 30 Aug 2018

The authors did an impressive job to take into account the numerous comments from the reviewers. The manuscript is much improved and clearer. It reads well and the data presented represent an impressive data set. I only have few minor comments:

We thank reviewer 1 for his time and positive feedback. We have addressed the remaining minor comments as outlined below:

-line 33: specify kg CaCO3 m-2 y-1

We agree that the suggested unit "**kg $CaCO_3$ m^{-2} y^{-1}**" is more precise for defining mass weight of accreted or removed $CaCO_3$. We are now using this unit accordingly throughout the manuscript and the supplement.

-line 80: The recently published paper by Perry in Science could be discussed here (I acknowledge that it was not yet published when the authors were revising this manuscript).

We thank the reviewer for pointing out Perry et al 2018. Indeed, we have referred to the new outcomes from the meta-analyses by Perry et al. 2018 in the revised discussion of our data (l. 458-462). We agree it should be included in the introduction as well, as it highlights the application the of carbonate budget data and how it can provide insight into coral reef trajectories. Text reads:

> "Most recently, carbonate budget data were used to explore the relation of vertical reef growth potential and trends in sea level rise suggesting that reef submergence poses a threat as long as climate-driven and human-made perturbations persist (Perry et al., 2018)."

-line 104: There is a lot of introductory material on the census-based approach but nothing on the limestone blocks. It would be good to add few lines on their previous use.

We have added a brief description of the limestone block method to the Introduction. We inserted this in l. 71 – 81 before mentioning of the census-based approach. This order was chosen to reflect the order of reporting in the Methods and Results (limestone block assay first, census-based approach second). Text reads:

> "A number of studies have employed experimental limestone blocks cut from coral skeletons to study reef growth processes (Chazottes et al., 1995; Kiene and Hutchings, 1994; Silbiger et al., 2014; Tribollet and Golubic, 2005). Deployment of such blocks in a reef captures the endolithic and epilithic accretion and erosion agents and forces, simultaneously allowing for the measurement of net-accretion and net-erosion rates. In

particular, these studies have provided insight into the colonization progression and activity of endolithic micro- and macroorganisms."

line 195: How often was the calibration done?

The factory calibration of the CTDs was performed one time, and was in-house verified twice (once before each deployment period). We have included this information and the exact deployment times to the respective paragraph. Text reads:

"Factory-calibrated conductivity-temperature-depth loggers (CTDs, SBE 16plusV2 SEACAT, RS-232, Sea-Bird Electronics, Bellevue, WA, USA) were deployed at the monitoring stations on tripods at ~0.5 m above the reef to collect time series data of temperature, salinity, and pHNBS at hourly intervals. The pH probes (SBE 18/27, Sea-bird Electronics) were factory calibrated before the winter deployment (9th February - 7th April 2014). Calibrations were verified using NBS scale standard buffers (pH 7 and 10, Fixanal, Fluka Analytics, Sigma Aldrich, Germany) before the winter and the summer deployment (19th June - 23th October 2014)."

line 324: it's interesting to see such a high variability in pH despite a low abundance of living organisms.

Noted. We are mentioning the observation of high variability of pH in the nearshore reefs, which is likely due to biotic feedbacks and discuss this now in more detail. We propose that the low water exchange rates in the nearshore site may enhance the biotic feedbacks from photosynthesis, respiration, and dissolution. In addition, not only the benthic community, but also biological activity in the carbonate reef sediments may be a factor affecting diel biochemical cycles at the nearshore site. We have added discussing the biological activity of sediments. Accordingly, we adjusted the paragraph in the Discussion. Now reads:

"The nearshore reef is located on the shelf, surrounded by shallow waters of extended residency time and has a lower water exchange rate compared to the other two reef sites (Roik et al., 2016). Evaporation and limited flow, particularly during summer, may increase salinity, which was overall higher at this reef site. However, the difference to the other sites was minuscule and unlikely to have affected calcifying (Röthig et al., 2016) and bioeroding biota. The variability of diurnal pH on the other hand presumably has stronger impacts on the performance of calcifiers and bioeroders. Previously, pH variability across a reef flat and slope were demonstrated to correlate with net accretion dynamics by showing higher net accretion prevailing in sites of less variable pH conditions (Price et al., 2012; Silbiger et al., 2014), which reflects the pattern observed here. The fluctuation in pH may (in part) represent a biotic feedback signature in reef habitats, which entails changes in sea water chemistry caused by dominant biotic processes, i.e., calcification, carbonate dissolution, and respiration/photosynthesis (Bates et al., 2010; Silverman et al., 2007a; Zundelevich et al., 2007). Commonly, such pH fluctuations are influenced by changes in carbonate system variables, e.g. DIC and TA

(Shaw et al., 2012; Silbiger et al., 2014), which can modify the antagonistic processes of calcification and bioerosion/dissolution (e.g., Andersson, 2015; Langdon et al., 2000; Tribollet et al., 2009). In particular, at our nearshore study site, where benthic macro community abundance was low, biological activity in the sandy bottom (e.g., permeable carbonate sands) might be a crucial factor contributing to the biotic feedback (Andersson, 2015; Cyronak et al., 2013; Eyre et al., 2018)."

line 383: I am not sure to understand here, if bioerosion is very high but net calcification still positive that actually demonstrates pretty high calcification rates from coralline.

We thank the reviewer for pointing this out. Yes, the rates from the limestone block assays in the Red Sea offshore reef clearly showed high calcification from coralline algae, which is a stark contrast to the observation from other block assay studies. It was our intention to emphasize this message. We have revised this section by changing the order of the sentences in order to improve logic and flow. Now read as follows:

> "Generally, most block assay studies conducted in various reef habitats and regions found net-erosive rates. For instance, studies from reefs in the Thai Andaman Sea and Indonesian Java Sea note that the accretion by calcifying crusts, such as coralline algae, were negligible compared to the high degree of bioerosion measured in the limestone blocks (Edinger et al., 2000; Schmidt and Richter, 2013). In contrast, our limestone block assays captured a substantial net accretion rate, in particular for the offshore reef site in the central Red Sea (0.37 kg $CaCO_3$ m^{-2} y^{-1} net accretion), indicating that accretion was substantial, while erosion was negligible. The midshore reef was characterized by a near-neutral or minor net accretion (0.06 kg $CaCO_3$ m^{-2} y^{-1}) on the order of net accretion rates recorded in French Polynesia in reef sites of uninhabited, oceanic atolls (0.08 and 0.62 kg $CaCO_3$ m^{-2} y^{-1}; Pari et al., 1998). Notably, our study recorded a net-erosive state only in the Red Sea nearshore site (-0.96 kg $CaCO_3$ m^{-2} y^{-1}, 30 months deployment). This is a moderate rate compared to the larger net erosion observed in the GBR, French Polynesia, and Thailand (-4 or -8 kg $CaCO_3$ m^{-2} y^{-1}) (Osorno et al., 2005; Pari et al., 1998; Schmidt and Richter, 2013; Tribollet and Golubic, 2005)."

line 407: Any hypotheses to explain the absence of coral recruits?

Not really. Since we did not quantify coral recruitment on the limestone blocks (via e.g. microscopy), we cannot rule out the possibility that newly settled coral polyps might have been missed, although we did not see any during visual inspection. Based on this, we think it is unlikely that corals might have substantially contributed to the accretion on the limestone blocks.

We adjusted the respective text:

> Results addition: "No coral recruits were noticed by the unaided eye."
> Discussion addition: "Given that we could not identify coral recruits on any limestone block, we assume that contribution of corals to the measured accretion was minor.

> However, we acknowledge that we might have missed some that could be detected by more sophisticated methods (e.g. such as microscopic examination)."

line 445: How do the coral covers compare between those "healthy reef" and the present study?

The reviewer makes a valid point here. We now compare our results with previous reports of "high accretion heathy reefs" (Vecsei 2001) by including the percentages of hard coral cover. We added the following lines to the Discussion:

> "The here presented central Red Sea G_{budget} data are within the range of contemporary reef carbonate budgets from the Atlantic (2.55 ± 3.83 kg $CaCO_3$ m^{-2} y^{-1}) and Indian Ocean (1.41 ± 3.02 kg $CaCO_3$ m^{-2} y^{-1}) (Perry et al., 2018). Notably, these data are below the suggested "optimal reef budget" of 5 - 10 kg $CaCO_3$ m^{-2} y^{-1} observed in "healthy", high coral cover fore-reefs (see data in Perry et al., 2018 and comparisons therein; Vecsei, 2001, 2004). The decline in coral cover is likely central to the reduced carbonate budgets in contemporary reefs. For instance, the reef sites investigated in the present study do not exceed a coral cover of 40 % (as observed for the offshore study site). In comparison, the dataset compiled by Vecsei 2001 encompasses hard coral cover of up to 80% for the Indo-Pacific and up to 95 % for Pacific Islands. Further, the reduced contemporary carbonate budgets coincide with the observed decrease in calcification rates of Red Sea corals at large (Cantin et al., 2010; Steiner et al., 2018). As such, the effect of climate change and the corresponding increase in seawater temperature may have severe consequences via overall decrease in coral reef cover as well as via reduced calcification of the resident corals. Hence, although the present G_{budget} data still suggest effective barrier reef formation in the central Red Sea (substantial accretion on the offshore reef), carbonate accretion rates and therefore reef formation in the central Red Sea may be hampered in the long run by the ongoing warming."

Anonymous Referee #2 Decision: accepted as is

Submitted on 01 Sep 2018

The authors did an impressive job to take into account the numerous comments from the reviewers. The manuscript is much improved and clearer. It reads well and the data presented represent an impressive data set. I only have few minor comments:

We thank the reviewer for their time and endorsement of our revised manuscript.