

0. Author Response:

The authors would like to thank the anonymous reviewer #2 for the careful consideration and recommendations on our manuscript. Below, we addressed the individual comments in detail. Our responses are in blue color to help the review process.

Interactive comment on “Seasonal Net Ecosystem Metabolism of the Near-Shore Reef System in La Parguera, Puerto Rico” by Melissa Meléndez et al.
Anonymous Referee #2
Received and published: 18 December 2018

This paper presents estimates of NEC and NEP on a reef in Puerto-Rico based on continuous monitoring of pCO₂ and O₂, and discrete bottle sampling for TA and DIC. The authors used a large dataset and applied a simple 1-D model to estimate the metabolic rates of the reefs. The main result is that the reef is currently dissolving at a rate faster than what has been estimated before using other methods. This result is highly interesting and also shows that other methods such as the reef budget of Perry et al. should be used with caution. The methods used seem to provide reliable results even if large errors in the estimates of TA are problematic. This problem will need to be overcome, likely by increasing the frequency of sampling in further research. The paper is well written and the data presented are of interest for biologist and biogeochemist. However, I regret that the paper is that long. I do understand that some details were needed but I believe that a shorter version of this paper would attract a broader readership. For example the discussion is rather long (~10 pages) with some repetitions. The introduction could also be shortened by maybe not providing trivial information on carbonate chemistry.

We agree with the reviewer that the paper is long, and have modified the introduction, methods, and discussion accordingly. We also removed the section on “free energy”. The specific comments are answered below.

I have listed below some specific comments:

-Introduction: The two first pages could be shorten

We appreciate you bringing this to our awareness, and we have shortened the introduction accordingly. L61-93 will be summarized.

- L133-134: It would be good to add 1-2 sentences on the poor coral cover/health of Caribbean reefs here.

Agree. The text will be added to L133-134 accordingly to explain the declines in hard coral cover and increase in the abundance of the macroalgae over the last 30 years in the region (Gardner et al. 2003). These ecosystem changes are related to the coral mortality from diseases, depletion of herbivorous fishes and the black sea urchin (*Diadema antillarum*), bleaching events and the interaction of multiple anthropogenic stressors such as fishing and sedimentation.

- 160-161: The link NEP NEC is not clear here, why “relative to NEP”?

We have revised the text and modify the sentence by deleting “relative to NEP” and added relative to dissolution processes to clear up the confusion.

- Methods: The method section is a bit confusing as some parts read more like discussion/result material (for example L 249-253). I recommend reformatting this section to make it a bit easier to read by removing all the materials that is not methods.

We will modify the text accordingly so that the methods are easier to follow. Ln 249 -253 were moved to the discussion section.

- L317-319: Please provide more details on the methods used to determine TA and pH (accuracy, etc).

We will add the pH and TA analysis accuracy to Ln 318-319 and modify the text accordingly. The details of the sample collection, analysis, and accuracy are in the supplemental material, section 2 (S2). We chose the supplemental material for these details to shorten the manuscript.

-L336-338: The errors with this method are very large and could potentially bias all further results. Looking at Fig S3 it looks like for a given salinity it is possible to obtain a TA range of up to 200 $\mu\text{mol kg}^{-1}$. . . It would be good to discuss this potential pitfall in the discussion.

We will bolster the discussion of uncertainties. Errors on the TA daily variability at the site arise from the lack of a salinity-dependence on coastal processes such as precipitation and dissolution of carbonates at the site. The use of seasonal TA reduces the potential biases caused by biological processes. Figure 1 the bottle data (TA and DIC) grouped in a composite seasonal cycle and compared with the TA and DIC modeled. Both the modeled and bottle data show similar seasonal dynamics. The mean difference between the average of both vectors is a reasonable 11 and 9 $\mu\text{mol kg}^{-1}$ for TA and DIC, respectively. However, there are limitations due to the interannual changes on TA, which is shown in the standard deviation of the bottle measurements.

The uncertainty of each parameter on the linear relationship between TA and SSS were added as sources of error to the Monte Carlo simulations, so that all random errors are accounted for. This method is preferred over the “propagation of error” because it considers all each individual error that contributes to the total uncertainty. We think the TA Monte Carlo simulations represent reasonable estimates of the TA uncertainty and the potential bias in NEC. To check this, I compared the potential changes on NEC by using the TA and DIC bottle data in the 1-D model. Both approaches (modeled and bottle data) yield considerable results on NEC with an average difference of 1 $\text{mmol m}^2 \text{day}^{-1}$ (see Table 1). The NEC difference between the modeled and bottle data is considered not statistically different at $p\text{-value} < 0.05$. Finally, we point out that the TA is only one term in the estimate of NEC and that the Monte Carlo analyses of the suite of terms show our estimates to be reasonable.

We will provide two additional sentences to the L480-489 about the effect of bottle samples on the NEC rates. This paragraph will be moved to the discussion section.

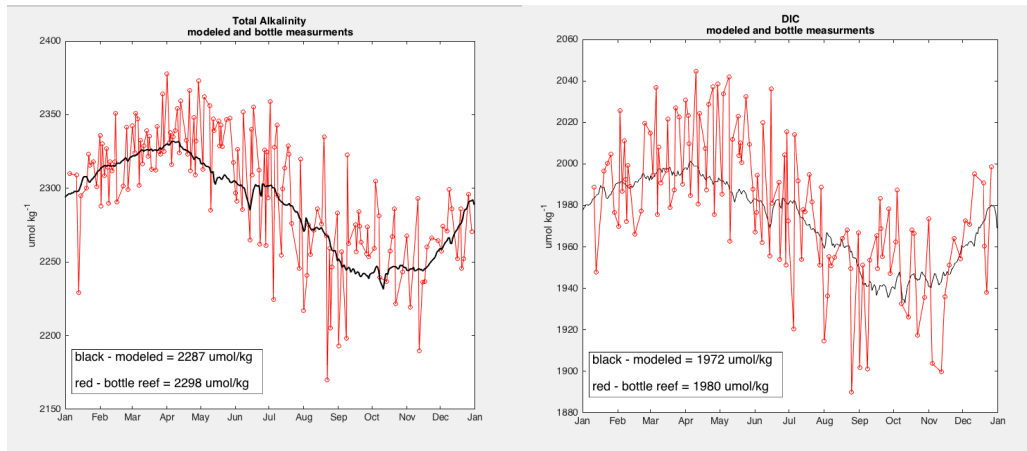


Figure 1: Modeled (black) and bottle (red) Total Alkalinity and Dissolved Inorganic Carbon.

Table 1: NEC calculated using the model and bottle DIC and TA measurements. Average \pm std.

NEC			
units	Bottle TA and DIC	Modeled TA and DIC	Difference
mmol m ² day ⁻¹	-17.26 (87.25)	-16.21(16.81)	1.06

95% confidence interval of this difference: -8.07 to 10.17 mmol m² day⁻¹, SE of difference = 4.65 mmol m² day⁻¹. The mean is not statistically different at p-value < 0.05.

- L480-489: again an example of a section that has nothing to do in the methods.

Agreed. We have revised the text, and the L480-489 about the uncertainties on TA will be moved to the discussion section.

-L517: Did you measure any seasonal changes in phosphate and silicate?

We did not measure seasonal changes in phosphate and silicate at the site. Phosphate and Silicate concentrations were collected at the buoy site and measured six times over the period from 2009 to 2011 in January, February, March, May, November, and December. However, there is unpublished data from Caribbean Time Series (CaTS), about 51 km south of the station, that was occupied monthly from May 1996 to June 2007. There is no seasonal change in nitrate, and the concentrations are < 0.03 μ M. The phosphate shows a maximum in February and May with concentrations no greater than 0.03 μ M. Silicate concentration displays a seasonal cycle with a peak from August to January of \sim 2.5 μ M and lows of <1.5 μ M the rest of the year. The potential contribution of these nutrients to TA, assuming this seasonal cycle and concentration of silicate and phosphate, are insignificant (<0.01%) and therefore neglected.

-L599: What about the changes in coral cover between studies?

Currently, a benthic habitat map has identified most of the submerged habitats for La Parguera (Pittman et al. 2010). However, reports on the seasonal changes on the coral cover at the buoy site are scarce. According to Moyer et al., (2012), who did seasonal benthic habitat characterizations at two reefs (including Enrique) and one seagrass site at La Parguera in 2011, reported that fleshy macroalgae dominated both reef sites, and live coral cover ranged from 8 to 10% in all seasons. Manzello et al. (2017) reported 11 % live coral cover, 17 % macroalgae and turf, 26% soft coral and 34% rubble rock and sand from a single survey performed in August 2015 at Enrique reef.

The highest coral cover in La Parguera is observed southward Enrique along the shelf-edge and westward Enrique. Pittman et al. (2010) analyzed the community compositions from 937 sites and covered an area of 93.7 km² from 2001-2007 and observed that live coral cover varied significantly among some sampling years, but overall live coral cover decreased over the sampling period (2001-2007). Further benthic monitoring would be needed to determine the seasonal changes in % live coral cover at the buoy site.

-L611: Are there any other major calcifying organisms at this site? What about CCA, Halimeda, or forams that can contribute massively to NEC?

We acknowledge that calcifying organisms other than coral are participating in the metabolic processes measured in this study. Manzello et al. (2017) surveyed ~20 m² at the buoy site and reported 0% cover of secondary (coralline algae and other calcareous encrusters) and sediment producers (calcareous algae such as Halimeda and benthic foraminifera). However, information on the seasonal variation of these functional groups is lacking for this site.

The CCA represented the 1.3 % of the hard-bottom habitats. The relative density of benthic forams is unknown for the study site. However, results from La Parguera by Pittman et al. (2010) show that calcareous macroalgae (e.g., Halimeda spp., Udotea spp., and Penicillus spp.) were commonly encountered on soft bottom habitats, but their percent (12%) cover was low relative to those of seagrass (28%) and the non-calcareous algae (e.g., Lobophora, Dictyota, and Padina spp). Published data on the Halimeda calcification rates ranged between 0.4 - 1.6 kg m⁻² yr⁻¹ and for CCA about 0.181 kg m⁻² yr⁻¹. The estimated calcification rates for benthic forams is between 0.030-0.230 kg m⁻² yr⁻¹. The presence of these species in La Parguera reef platform will likely influence the annual NEC rate. However, the mean calcification seen in the wintertime at the buoy site (0.17 kg m⁻² yr⁻¹) is small relative to the mean calcification rates of these species.

The first author's master's thesis reports on the TA concentration in reef sediment porewaters down to 20 cm sediment depth on a 10 m transect at the buoy site. The change in TA ranged from 48.8 to 75.7 μmol kg⁻¹ cm⁻¹ and the annual flux calculated was about 100 μmol m⁻² yr⁻¹. This estimate can represent the 18% of the yearly change in carbonate nTA calculated in this study (556 μmol m⁻² yr⁻¹). Based on observed changes in porewater TA and estimates of vertical flux of TA in sediment porewaters, preliminary data on carbonate dissolution is estimated as 0.003 mmol m⁻² h⁻¹ in the summer of 2011 at Enrique forereef. The calcium carbonate sediment dissolution rates were small and could represent <1% of the NEC at the site.

-L661-663: What about the role of temperature. Could these results also demonstrate that 1) Corals calcify more slowly when temp > 27, and 2) that bacterial activity is enhanced by increasing temperature which favors the dissolution of sediment, etc. in interaction with increasing DOM. It is also interesting to see that there is maybe no relationship NEP

Agree. Our results show that during the calcification months the temperatures range from 26.6 to 27.9 °C, which could be linked to the optimal temperature in which each species can maintain metabolic rates and coral growth (Marshall and Clode, 2004). The increase in temperature during the summertime can reduce calcification rates and make metabolically expensive to maintain high calcification rates. Also, the high respiration rates can be fueled by the increase in organic matter degradation and associated bacterial activity as a result of high temperatures during the summer. During the summer the high temperatures (>29°C) can cause thermal stress to corals and in some instance bleaching, changing the coral's organic matter fluxes. For example, bleached corals may assimilate POM (to fulfill the energetic requirements in the absence of autotrophy) and release carbon as labile DOM (although other studies show a release of DOC by healthy corals as well).

Even though there is the possibility that low calcification rates and NEP may not be associated, there is evidence that shows moderately high levels of sedimentation, bacterial and bacterioplankton counts in Enrique reef and La Parguera inner-shelf reefs during the summer months (Otero, 2009). Still, we don't know exactly from where this organic carbon comes from in this area. We hypothesized this organic carbon could come from nearby mangroves and autochthonous material. Otero (2009) measured isotopic signatures on ¹³C of precipitated particles in different places in La Parguera and found that the content on the organic matter is likely autochthonous from seagrasses or algae. He also measured ¹⁵N and found overall low inputs of anthropogenic nitrogen to the system; however the proportion of N allocated from anthropogenic sources were as high as coastal values in Enrique. These intermediate values found at Enrique could indicate shifts caused by mineralization processes due to in situ microbial processes in the absence of inputs of terrigenous or anthropogenic sources of nutrients. Bacterial abundances ($0.4 - 1.7 \times 10^6 \text{ mL}^{-1}$) and production ($2-35 \text{ ugC L}^{-1} \text{ day}^{-1}$) were high for La Parguera compared to the CATS station and other reef areas (e.g., Ferrier-Pages and Gattuso, 1998). These shifts in coral metabolism, organic matter fluxes and remineralization of associated bacterial during the summer months, can potentially affect NEP and NEC.

Text will be added in the discussion (L661-670) to explain the coral optimum temperature range and the potential role of the bacteria activity and temperature on NEP and NEC.

–nutrient, could that demonstrate that one critical nutrient is missing in the system (e.g., Iron)?

We consider the micronutrients such as Iron of secondary importance and on the NEP because the productivity in the Caribbean basin is limited by the availability of the limited macronutrients (e.g., Nitrogen and Phosphorous). See the previous comment on phosphorous and silica nutrients. It has also been shown that atmospheric transport of aerosols from desert regions of Africa supply nutrients, such as iron, to the Caribbean waters (e.g., Prospero et al., 1981; Justiniano-Santos, 2010).

-L683-684: This decoupling between omega and NEC is very interesting. The role of SST on the biological activity is probably significant here (see my previous comment).

Agree. See the previous comment.

-L712-715: This is a critical point. Is there any reason to believe that Enrique reef is a “special case” or is it likely to observe the same discrepancy on other reefs?

Line 802-803 we mentioned: Based on similarities in environmental characteristics, our results suggest that tropical Caribbean reef ecosystems and adjacent regions are exhibiting periods of net dissolution”. La Parguera shelf is a calcium carbonate platform with emergent fringing reefs, bank-barrier reefs and submerged patch reefs similar to those observed at other areas in the Caribbean such as Yucatan, Jamaica, and Belize (e.g., Morelock et al., 2001). Moreover, the Caribbean coastal ecosystems are susceptible to similar environmental impacts, in part because of their oligotrophic conditions (e.g., Lapointe 1997), and suffer from similar natural and anthropogenic disturbances (e.g., Gardner et al., 2003; Rivera-Monroy et al., 2004, Alvarez-Filip et al., 2009; Eakin et al., 2010; Chollett et al., 2012). Unfortunately, there is not an optimal study or method with which to compare because most of the available data in the Caribbean does not provide a seasonal overview of the carbon to inorganic carbon balance (NEC and NEP).

Figure 2 was amended from Courtney et al. (2016) to offer a better perspective on where our results lie. The figure shows the summation of calcification and mechanical erosion and does not incorporate dissolution (except Courtney’s single NEC chemistry point). Our measurements are located on the graph (red dot, $-0.5 \text{ kg CaCO}_3 \text{ m}^{-2} \text{ yr}^{-1}$ or $0.5 \text{ mmol m}^{-2} \text{ day}^{-1}$) show that our estimates are not that far from other methods (bottle and census) used to estimate NEC in reefs with $\sim 10\%$ live coral cover. For comparing purposes, we assumed the 10% live coral cover present at the buoy site, even though we are somewhat unsure of the spatial extent of our measurements (and hence the % live cover within the active area). Statistically speaking, many of the central tendency measures are not that different than ours because of the high uncertainty. Below are the data for the studies that reported uncertainty measures. For example, if the uncertainty reported is the standard deviation, then there's a $\sim 17\%$ chance that dissolution in $\text{kg CaCO}_3 \text{ m}^{-2} \text{ yr}^{-1}$ will be greater (more negative) than the difference indicated below. At the uncertainties reported, this study may not be particularly anomalous regarding dissolution. This speaks to the difficulties of such measurements.

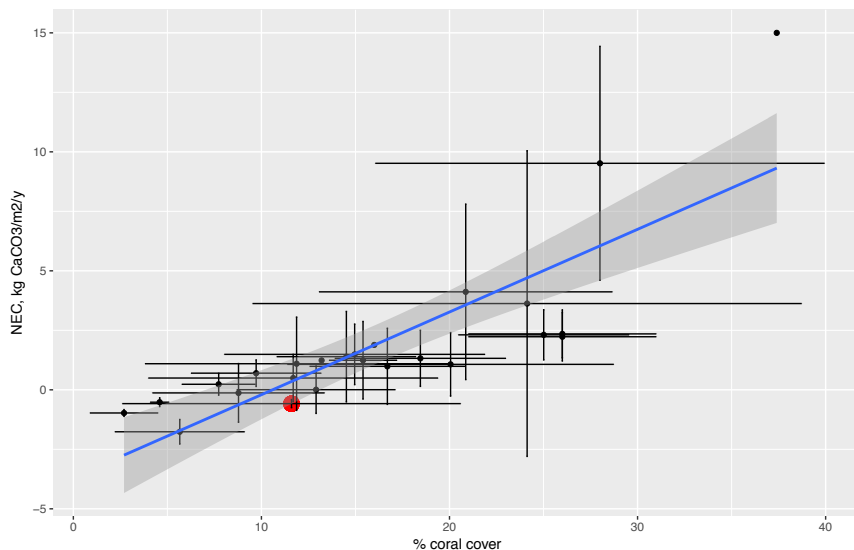


Figure 2: Summary plot of Caribbean Reef percent hard coral cover vs. Net Ecosystem Calcification (NEC) adapted from Perry et al. (2013) and modified from Courtney et al., 2016. This figure shows NEC measurements from the census and bottle methods. The red dot is the result of this study. We can add this figure to the supplemental material.

-L728: Where does that come from? This claim needs a reference because the link between net heterotrophy and algae dissolution is not clear.

We have modified the sentence and add a reference to clarify the link between the heterotrophy and dissolution of carbonate sediments. We want to point out that during periods of net heterotrophy, CO₂ production can enhance CaCO₃ sediment dissolution of highly soluble minerals present in cement, sediments, and organisms such as crustose coralline algae. Reductions in NEC not only depend on the changes of the benthic communities they also can be driven by an increase in dissolution rates that have been enhanced by the metabolic production of CO₂ during the respiration associated with inputs of organic matter.

-Section 4.5: I am not sure about the utility of this section. The manuscript is already rather long, and this section reads like another story.

We agreed. This section will be considered for another article. We have deleted this section (L 739-777) and Figure 10 from the discussion in the revised paper.

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