Natural Coastal Barriers at Risk

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Tropical coral reef ecosystems play a key role in sustaining tourism and fisheries, while also serving as effective physical barriers against erosion and severe coastal damage by dissipating wave energy due to swells and storms. In Puerto Rico, over 5000 km^2 of coral reefs spanning an 884 km of coastline protect the life and property of a half million people. To better understand how ocean acidification affects coral reef systems, a suite of observations from the NOAA moored autonomous pCO_2 buoy (MapCO_2) in La Parguera Marine Reserve in combination with long-track (underway) oceanographic measurements of near-shore surface water were analyzed and collected. This research is part of a new project to identify coral reefs that are at risk of dissolving. The long-term goal of this initiative is to aid in the development of early warning and management policies on small tropical islands.

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Fig.1. The coral reef barrier system in the southwest of Puerto Rico hosts coral reefs, seagrasses and mangroves. Shown here is the MapCO_2 buoy (yellow) along the seaward slope of Enrique cay at La Parguera Marine Reserve. The buoy provides continuous 3-hour measurements of both air and sea CO_2 concentration along with temperature, salinity, pH, and dissolved oxygen. These measurements have been used to track the dynamics and controls on local carbon chemistry at the site since 2009. This project provides the first spatial visualization of the coastal carbon chemistry at the site.

Researchers from the University of Puerto Rico (UPR), the University of New Hampshire (UNH) and the Caribbean Coastal Ocean Observing System (CARICOOS) recently collaborated to develop the first biogeochemical and physical assessment for the La Parguera barrier system. This project provides spatial visualizations of coastal sea surface CO_2 values and carbonate saturation state Ω, which is an index that provides a measure of the availability of carbonate minerals necessary for marine skeletal development.

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The project is also providing other chemical and physical variables including temperature, salinity, total alkalinity, pH, dissolved oxygen and nearshore currents for the site. The assessment enabled detection of coastal ocean acidification hotspots within the coral reef ecosystem and highlighted areas potentially vulnerable to dissolution.

Coral barriers at the breaking point?

Coral reefs and carbonate structures are threatened by the continuous increase of atmospheric CO_2 released by human activity. Since the beginning of the Industrial Revolution, approximately 30% of this CO_2 has been absorbed by the oceans (IPCC, 2014), causing ocean waters to become more acidic. Increased acidity causes coral growth to decrease while increasing dissolution and bioerosion (e.g. Wisshak et al., 2012; Eyre et al., 2018). Bio-erosional processes cause coral skeletons to lose calcium carbonate, resulting in a decrease in skeletal density. As a consequence, coastal reef barriers will be more vulnerable to mechanical degradation during highly energetic wave and wind events; thereby diminishing their effectiveness as a first line of coastal protection. These effects may trigger multi-million-dollar spending in artificial shoreline protection alternatives and may result in the loss of tourism revenue from ocean activities, such as recreational diving and fishing.

If anthropogenic CO_2 emissions continue to increase at the current rate, by next century oceanic waters could be approximately 40% more acidic than current conditions (IPCC 2014, RCP 4.5 scenario). Coastal waters could experience even more acidic conditions as a result of biological activity and interactions with freshwater and sediments. However, our current understanding of natural acidic conditions is biased by the modest number of comprehensively monitored coastal areas and the monitoring challenges barrier ecosystems exhibit due to their spatial heterogeneity and temporal variability.

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Mapping the coastal system

A wide insular shelf in the southwest of Puerto Rico protects La Parguera town, one of the principal tourist destinations and fishing villages of the island. This reef barrier system hosts coral reefs, mangroves, and seagrasses. Their respective ecotones (transitions or divisions where different ecosystems meet and integrate) show considerable spatial variation in their carbonate chemistry. To undertake this research, a recreational fishing boat was converted into a research vessel to survey the region during November 2016, March 2017 and April 2018. For five consecutive days the carbonate chemistry over different communities of the La Parguera reef system was mapped, over regions including the inner mangroves, middle areas of reef and seagrasses, and outer areas of reefs deeper than 15 meters. The general water circulation patterns were also assessed by measuring current profiles at selected locations concurrent with the sampling. An innovative sampling approach included a custom-built continuous underway water system measuring CO_2, dissolved oxygen, temperature, salinity and optical variables, and included measurements from the first commercially-available automated total alkalinity (TA) instrument that eliminates the laborious process of water sample collection and subsequent laboratory analysis. These instruments allowed for sampling seawater CO_2 every second and TA every 7 minutes. This unprecedented high spatial resolution enabled coverage of different habitat types and the spatial mapping of the carbonate system, providing a unique dataset for future research activities.

Hotspots of ocean acidification

A combination of biological activity (i.e. high rates of aerobic respiration of mangrove-derived organic matter, sulfate reduction by anaerobic bacteria (e.g. Cintrón et al., 1979) and physical processes (i.e. vertical mixing events) appear to play important roles in modulating the CO_2-carbonic acid system in this area. Results found naturally acidic waters in the Bioluminescent Bay and inshore channels. The seawater pCO_2 values in mangrove and inshore channels were higher than 1000 *u*atm (Figure 2), suggesting that near-shore areas presently exceed ecological tipping points for barrier systems (Yates and Halley, 2006; Hoegh-Guldberg et al., 2007). At these values, dissolution processes are likely already occurring, threatening carbonate sediments (c.f. Eyre et al., 2018), calcareous algae and inner shelf coral reefs that are largely comprised of detrital coral rubble.

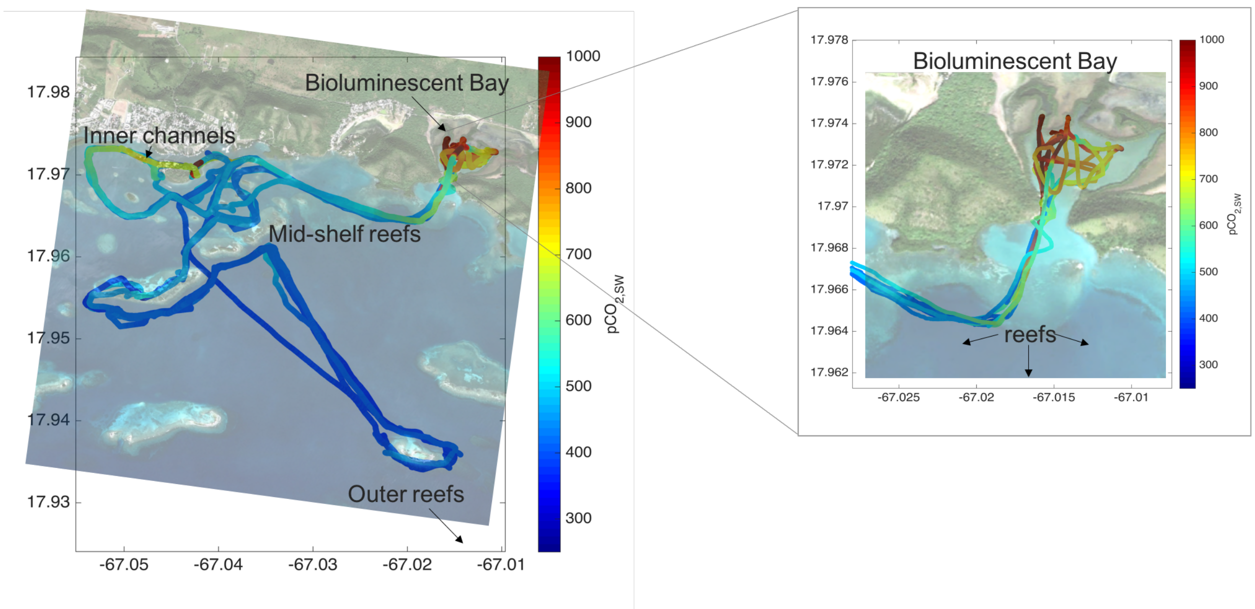

Fig.2. Cruise track on November 2016 within the barrier reef system off La Parguera town, Puerto Rico showing surface seawater CO_2 concentration (as partial pressure of CO_2, pCO$_2$ in micro atmospheres (uatm)). Note the color bar on the outside right: high values are represented with red-yellow-green colors and low values with the blue colors. The left panel is representing the complete spatial extend of the study site. The area is divided in three different regions (inner, middle and shelf-edge (or outer reefs) according to its general morphological characteristic. The Bioluminescent Bay (right panel) is located 3.2 km east of La Parguera. The estimated area of the bay is 0.19 km^2 with an average depth of 2.8 m and is surrounded by red mangrove (*Rhizophora mangle*). Waters from adjacent productive areas (e.g. Bioluminescent Bay and inner channels) show high pCO$_2$ concentrations that could reach reef areas, depending on the water circulation patterns, increasing the reef's susceptibility to erosional processes.

Important reef-building corals such as the Elkhorn coral are more sensitive to ocean acidification and are found in the mid-shelf reefs. However, other organisms such as the green calcareous algae (e.g. *Halimeda spp.)* can tolerate high CO_2 environments and may acclimate to future CO_2 conditions (e.g. Vogel et al.,

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2015). These green calcareous algae are common in the Bioluminescent Bay and inner channels and are the source for most of the carbonate sediments in La Parguera. Studies such as this will help to scale the geographic distribution of surface carbonate chemistry, which is important in the identification of ocean acidification hotspots for sensitive organisms. Moreover, these natural environments exhibit CO_2 conditions projected for the near future and could represent a natural laboratory to study acclimatization processes of calcifying organisms and changes of coral reefs at the ecosystem level.

Can acidic waters from inshore reach the reef?

Early results from this study show that water circulation patterns can influence water chemistry in the area. We hypothesize that during periods dominated by a calm breeze from land, tidally driven currents can carry CO_2-rich waters from mangrove regions to nearby seagrass beds and coral reefs (e.g. Lowe and Falter., 2015). Unfortunately, the extent to which currents affect the physical and chemical properties at the nearshore waters is still unknown. Understanding the role of small-scale hydrodynamic processes in the transport and transfer of nutrients and carbon from inshore and regional waters is necessary to better estimate metabolic rates. High respiration rates can create adverse chemical conditions for the formation of carbonate minerals and might eventually lead to high dissolving rates and weaker structures. However, little is known about how these nearshore processes are linked to ocean acidification. High resolution measurements and interdisciplinary approaches like this can provide baseline data necessary to identify ocean acidification hotspots in particularly challenging ecosystems and to better evaluate management strategies.

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References:

Cintrón, G., Maddux, W. S., and Burkholder, P. R. (1970). Some consequences of brine pollution in the Bahía Fosforescente, Puerto Rico. Limnology and Oceanography, 15 http://dx.doi.org/10.4319/lo.1970.15.2.0246

Hoegh-Guldberg, O., Mumby, P. J., Hooten, a J., Steneck, R. S., Greenfield, P., Gomez, E., … Hatziolos, M. E. (2007). Coral reefs under rapid climate change and ocean acidification. Science (New York, N.Y.), 318(5857), 1737–42. http://doi.org/10.1126/science.1152509

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Lowe, R. J., & Falter, J. L. (2015). Oceanic forcing of coral reefs. Annual Review of Marine Science, 7, 43–66. http://doi.org/10.1146/annurev-marine-010814-015834

Vogel, N., Fabricius, K. E., Strahl, J., Noonan, S. H. C., Wild, C., & Uthicke, S. (2015). Calcareous green alga halimeda tolerates ocean acidification conditions at tropical carbon dioxide seeps. Limnology and Oceanography, 60(1), 263–275. http://doi.org/10.1002/lno.10021

Yates, K.K. and R.B. Halley. 2006. CO_3^{2-}concentration and pCO_2 thresholds for calcification and dissolution on the Molokai reef flat, Hawaii. Biogeosciences. 3: 357–69 https://doi.org/10.5194/bg-3-357-2006 .

Wisshak, M., Schönberg, C.H.L., Form, A., Freiwald,A. 2012. Ocean Acidification Accelerates Reef Bioerosion. PLoS ONE, 7 (9): e45124 https://doi.org/10.1371/journal.pone.0045124

Eyre, B. D., Cyronak, T., Drupp, P., Carlo, E. H. De, Sachs, J. P., & Andersson, A. J. (2018). Dissolving Before End of Century, 911(February), 908–911 http://doi.org/10.1126/science.aao1118

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