Towards Sustained Autonomous Measurements of Coral Reef Metabolism and Health

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Abstract

Coral reefs are a highly dynamic system, where large variability in environmental conditions (e.g., pH, light) occurs on timescales of minutes to hours. Yet, techniques that are capable of monitoring reef calcification rates without artificial confinement on the same frequency are scarce. We have developed the Benthic Ecosystem and Acidification Measurement System (BEAMS) which is capable of simultaneously measuring benthic net community production (NCP) and net community calcification (NCC) under natural conditions without any alteration to the environment. BEAMS measures the chemical gradient and the current velocity profile in the benthic boundary layer using autonomous sensors to calculate the chemical flux (thux metabolism) from the benthos. We have successfully deployed BEAMS in multiple reefs around the world, and currently is capable of continuously measuring metabolic rates at 15 minute intervals for a month. Here, we highlight a deployment from Palmyra Atoll [1], and the potential use of BEAMS to monitor reef health as they transition from a healthy coral dominated state to a degraded algae-dominated state.

BEAMS: Benthic Ecosystem and Acidification Measurement System

BEAMS is based on the gradient flux approach, where vertical gradients in velocity and chemical constituents in the benthic boundary layer (BBBL) are used to calculate chemical fluxes from the benthos [1]. Gradients of O₂ are directly measured, whereas the gradient in TA is calculated using simultaneous measurements of pH and O₂ using [2]:

$$\Delta TA = \frac{\partial O_2 + Q_+ (K^-)}{\partial (K^-)} \Delta A - K(BA+HA) + K(BA'+HA')$$

The flux of O₂ and TA are directly proportional to benthic net community production (NCP) and net community calcification (NCC), respectively. The metabolic rates are calculated as:

$$NCP or NCC = \rho u_N \frac{(C_{O_2} - C_{O_2})}{\ln(\frac{Z}{Z_1})}$$

Where C represents O₂ or TA, p is density, u is friction velocity, k is the Von Karman constant, and Z is the height above the benthos. Subscripts represent values at different heights above the benthos.

Study Site

Figure 1: Map of Palmyra Atoll (top left). The two deployment sites (RT4, blue; LL, red) are located within 1 km, and have significantly different benthic community composition (top right) reflecting a healthy reef (RT4) and a degraded reef (LL). Pictures from each site is shown.

Results

Figure 2: Time series of hourly binned NCP (mmol O₂, m⁻² h⁻¹) and NCC (mmol CaCO₃, m⁻² h⁻¹) from RT4 (blue; healthy reef) and LL (red; degraded reef). Vertical gray lines represent midnight. A clear diel cycle of NCP and NCC is observed at both sites. Gaps in data are due to sensor maintenance or unfavorable flow conditions.

Figure 3: Diel composite plot of hourly NCP (blue) and NCC (red) for RT4 and LL. Error bars are 1 SD, and reflect day-to-day variability. Significantly lower NCC was observed at LL due to lower abundance of calcifying organisms.

Figure 4: Daytime NCP and NCC at RT4 (blue) and LL (red). Lines represent model II regression. Slope at RT4 and LL were 0.50 ± 0.02 and 0.27 ± 0.01, respectively. Significantly different ratio of NCC:NCP was observed between the two sites reflecting their respective reef health.

Figure 5: Daytime NCP (blue) and NCC (red) on 15 September at RT4. PAR (µmol photons m⁻² s⁻¹) shown in the solid pink line, demonstrating the tight coupling between PAR and reef metabolism on time scales of tens of minutes.

Figure 6: Relationship between SNP (mmol O₂ m⁻² d⁻¹), SNC (mmol CaCO₃ m⁻² d⁻¹), and PAR (µmol photons m⁻² s⁻¹), and daily average at both sites. Data from RT4 and LL are shown in blue and red, respectively. Error bars represent uncertainty in the daily integrated metabolic rates. Solid lines represent model II regression results where the slope was significant at the 0.05 level. Dashed lines indicate a nonsignificant slope.

Conclusions and Future Directions

- Successfully demonstrated BEAMS, a novel system which autonomously measures coral reef metabolic rates (NCP and NCC) every 15 minutes for weeks.
- Reef metabolism was highly dynamic and responded to changes in environmental conditions within minutes.
- Detected significantly different ratio of NCC:NCP between a healthy and degraded reef site, demonstrating potential for monitoring reef health.
- No correlation was observed between daily mean O₂ and daily integrated NCC.
- BEAMS deployed in 6 different reefs worldwide. Potential for providing a snapshot of coral reef metabolism using a single method.

References


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