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NCRMP Bioerosion Monitoring Unit (BMU) Standard Operating Procedure

Theory:

The term bioerosion refers to the biological destruction of hard structures, such as coral skeletons. On coral reefs, this process is the antithesis of coral calcification. If rates of bioerosion are higher than calcification, healthy reef habitats can flatten into rubble. Bioerosion Monitoring Units (BMUs) are constructed and placed at reef monitoring sites. After collection, changes in density, volume, and mass indicate rates of bioerosion.

Reference:

Enochs,IC; Manzello, DP; Kolodziej, G; Noonan, SHC; Valentino, L; Fabricius, KE; 2016 Enhanced macroboring and depressed calcification drive net dissolution at high-CO_2 coral reefs. *Proc. R. Soc. B* **283:** 20161742.
http://dx.doi/10.1098/rspb.2016.1742

Construction and pre-deployment analysis:

Materials:

1. Clean coral skeleton block 2 x 5 x 1cm (use *Porites lobata* in Pacific, *Orbicella faveolata* in Atlantic and Caribbean) (*Note: *Isopora sp*. Was used as the first BMU, however future methods will use *Porites lobata* for Pacific locations.)
2. Gray PVC base plate (2cm x ~ 8.5cm with 3/8" hole drilled on one end)
3. Epoxy (JB KWIK)
4. Metal ID tag
5. Cable tie
6. Small plastic bag
7. Analytical balance
8. Drying oven
9. CT scanner (Siemens SOMATOM Volume Zoom/Bruker Skyscan 1174)

Procedure:

1. Dry coral block in oven at 60 ˚C for 24 hrs, until dry.
2. Mark the least clean 5 x 2 block side with BMU number using pencil.
3. Weigh, and input into BMU database.
4. CT scan block using Siemens SOMATOM Volume Zoom CT (Bruker Skyscan 1174 microCT can be used to scan a subset for finer detail) (Figure 2). Also scan appropriate carbonate phantom (calibration standard) for density calibration within the same day.
5. Reconstruct the scanned images into 3D image stacks using Thermo Scientific Amira software to calculate volume and CT-calculated Hounsfield Units.

6. Analyze carbonate phantoms in Amira software to retrieve calculated linear relationship between Hounsfield Units and Real World Density for the carbonate phantom to be used to calculate CT-calculated densities for the BMUs.
7. Epoxy coral block to PVC plate that has been scored to increase epoxy bond (Figure 3).
8. Weigh BMU after epoxy has cured and record the mass.
9. Place completed BMU (Figure 4) into its own small plastic bag (labeled with the ID tag number) along with a zip-tie, and its unique metal ID tag.

Deployment directions (from CRED SOP):

Materials:

1. (5) BMUs per survey site
2. (1) container for carrying/protecting 5 BMUs during the dive (CRED uses a small plastic case…which floods as it is submerged)
3. (5) stainless steel stakes
4. (1-2) sledge hammers
5. (10) 11/16 in. wire rope clips
6. (1) container of Aqua-lube for limiting biofouling on the wire rope clip threads
7. (1-2) 11/16 in. socket drivers
8. (1-2) 11/16 in. wrenches. NOTE: The socket driver works best when tightening the nuts on the wire rope clip. The wrench can be used if the horizontal access to the nuts is hindered, but the nuts on the wire rope clip are so close together that the wrench doesn't get good purchase on the nut, making this tool's use less efficient.
9. (2) tubes of underwater, 2-part, epoxy per survey site
10. (1) marker float
11. (6) 36" cable ties for securing the marker float to the seafloor (CRED uses marker floats as a "nice to have," but they are not necessary and sometimes draw attention to the survey site in populated dive areas)
12. (1) mesh dive bag for carrying above listed supplies

Dive Preparation:

1. Record the BMU serial numbers (found on the blue marker tab, cable-tied onto the BMU) on a metadata sheet.
2. Cover the threaded portion of the wire rope clips in Aqua-lube prior to the dive. By inhibiting marine growth, it becomes much easier to remove the wire rope clips during BMU recovery.

Dive Operations:

1. Hammer the stainless-steel stakes vertically into the benthic substrate, making sure each stake is secure. The stake should be rigid in its placement, and one should not rely on the epoxy to exclusively hold the BMU assembly in place over the duration of the deployment. The epoxy should be used in conjunction with a good stake placement.
2. Use a 2-3-inch amount of the 2-part epoxy stick for each stake placement. Make sure the epoxy is well mixed by squeezing the 2-3-inch mass between your fingers.

A well-mixed amount of epoxy will be all one color (white) and will react evenly. The epoxy will get on your dive gloves, so remove them prior to mixing epoxy in your hand. Pack the epoxy around the base of the stake and into the surrounding substrate (ensuring there isn't sand/debris within the application site is important, as sand/debris will make for a poor contact site with the epoxy).

3. Slide the BMU to the base of the stake and "seat it" into the epoxy mass holding the stake, ensuring that the BMU is flush with the benthos.
4. Secure the BMU in place by sliding an 11/16" wire rope clip down the stake to the plastic base portion of the BMU. Ensure that the wire rope clip is prepared with Aqua-lube and use the socket driver to tighten the nuts (Figure 5).
5. Re-address the epoxy at the base of the stainless-steel stake. If mounting the BMU on the stake has caused the epoxy to no longer be tightly packed around the stake's base, fix the epoxy. It takes approximately an hour for the epoxy to begin to harden.
6. Install a survey site marker float, using cable ties.
7. Collect a waypoint on the survey site with a GPS. CRED uses two waypoint techniques: 1. if the survey site can be seen from the surface, a snorkeler swims the GPS unit over the survey site and records a waypoint. 2. a SCUBA diver takes up the slack in the line of the dive team's surface float, making the line taut from diver to surface float, then holds onto the bottom while repeatedly pulling the float under water. This action signals the coxswain/boat tending the divers to come overhead and record a GPS waypoint at the position where the diver is repeatedly pulling the surface float underwater (this is the technique that CRED uses 98% of the time). The coxswain signals to the divers that a waypoint has been collected by revving the engine 2 times…and the diver signals the coxswain that he understands the GPS point has been taken by no longer pulling on the surface float line.

Post Dive:

1. Record the GPS location of the survey site on a metadata sheet.

Post-deployment:

Collection:

1. Collect after three years in the field
2. Carefully remove BMU and bring to surface along with identification tag
3. Air dry the BMU and place it inside sample bag with identification information

Analysis:

1. Dry BMU in oven at 60 ˚C for 24hrs, until dry.
2. Weigh using analytical balance.
3. Place BMU in a 15% diluted hydrogen peroxide solution for 48 hours to remove non-calcified organics (Kobluk & Risk, 1977).
4. Rinse with fresh water
5. Dry BMU in oven at 60 ˚C for 24hrs, until dry.
6. Weigh using analytical balance.

7. Remove PVC base plate from coral block (optional – necessary if using Bruker Skyscan 1174 microCT scanner to rescan same pre-deployment subset that was scanned).
8. CT scan block using Siemens SOMATOM Volume Zoom CT scanner using the same scan parameters as for pre-deployment scans.
9. Scan the same carbonate phantoms (calibration standards) at least once throughout the course of BMU analysis (at least once per week).
10. Using Amira software, volumetrically partition secondary accretion, external bioerosion (grazing), and internal macroerosion (macroboring) (Figure 6 & 7), as well as mean Hounsfield Units for the remaining BMU material.
11. Calculate CT-calculated density (using carbonate phantom Hounsfield Units to RW Density calibration) of pre and post-scans to calculate microboring.

Functional Group Delineation:

Functional Groups:

1. Accretion of calcium carbonate ($CaCO_3$) from calcifiers on the BMUs surfaces may include scleractinian corals, crustose coralline algae (CCA), sessile molluscs, as well as other taxa that are involved in forming more ephemeral structures (Note: other calcifiers such as *Halimeda* or motile gastropods generally have little impact on framework construction).
2. Grazing is defined as abrasion or erosion on the surface of the BMU, primarily by fishes and urchins that remove carbonates from the surface of reef frameworks often while feeding on benthic algae.
3. Macroboring of the BMU is defined as erosion from animals forming larger cavities and tunnels (> 100μm), such as, clionaid sponges, annelids, bivalves, molluscs, and crustaceans.
4. Microboring of the BMU is defined as erosion from a diverse multi-phyletic consortium of flora and fauna, that create boreholes in reef carbonates (<100μm) in diameter.

Analysis of function groups:

1. BMUs are used to quantify the net result of accretion, grazing, macroboring, and microboring. (Figure 7a.)
2. A three-dimensional reconstruction using a CT scan of the BMU is created (Figure 7b.) pre and post deployment.
3. Accretion rates are determined by calculating the volume of non-original carbonate material on the surface of the BMU and dividing that by number of years the BMU was deployed on the coral reef. (Figure 7c. (green))
4. Grazing rates are determined by calculating the difference in external block volume (pre- versus post-scan) divided by the number of years the BMU was deployed on the coral reef. (Note: not inclusive of internal macroboring or external accretion.)
5. Macroboring rates are determined by calculating the difference in volume found by removing the void space within the BMU and dividing that by number of years the BMU was deployed on the coral reef. (Figure 7c. (blue))
6. Microboring rates are determined as the difference in the density (pre-versus post-scan) of the non-bored, non-grazed BMU multiplied by the final volume of that

area which then is divided by number of years the BMU was deployed on the coral reef. It is important to note that this number may also include changes in density due to abiotic dissolution/ precipitation. Furthermore, the resolution of the CT-scan type is set by the user, it is possible that not all macroboring tunnels (>100μm) were adequately resolved due to different system constraints. These differences are instead detected in the microboring measurement. We therefore may over estimate microboring rates while underestimate macroboring rates, however thorough visual inspection of the scans suggest that this difference is minimal.

1.

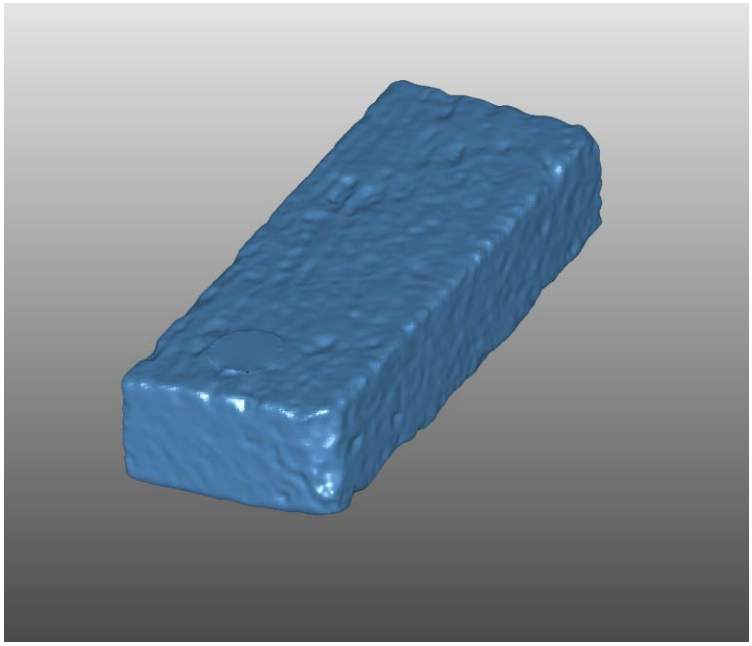

Figure 1. 3D scan of BMU coral block for dimensional analysis and volume calculation.

Figure 2. Side view of microCT scan of BMU coral block.

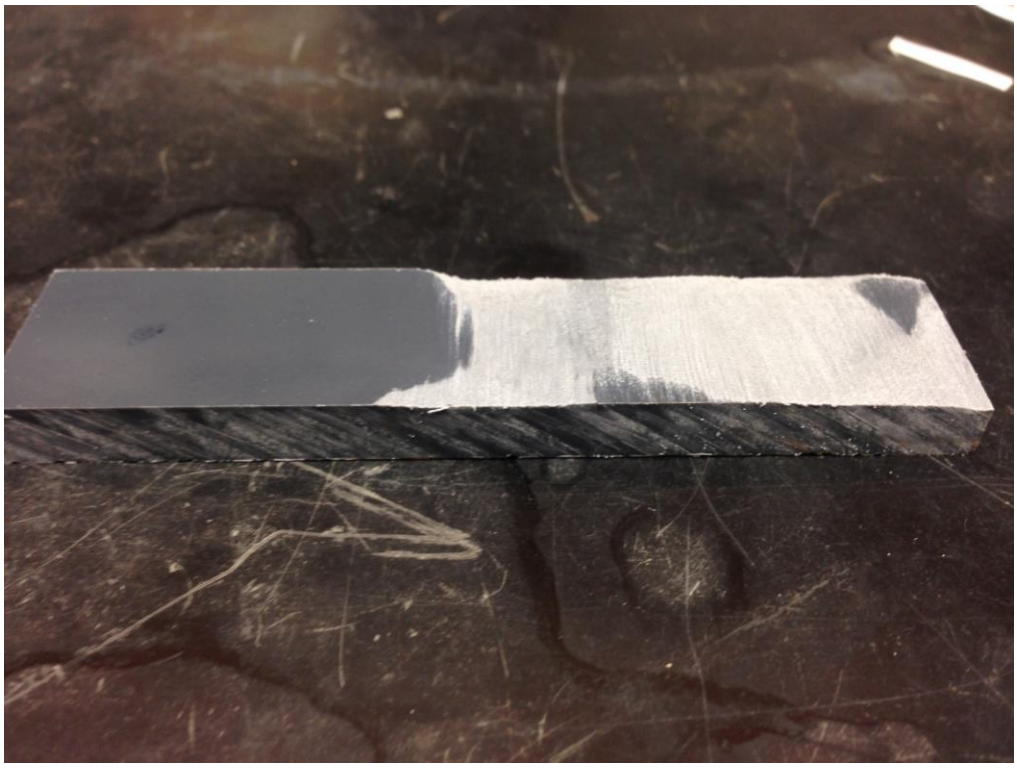

Figure 3. PVC base showing scored area for BMU coral skeleton attachment

Figure 4. Bioerosion Monitoring Unit (BMU) including coral skeleton and PVC base.

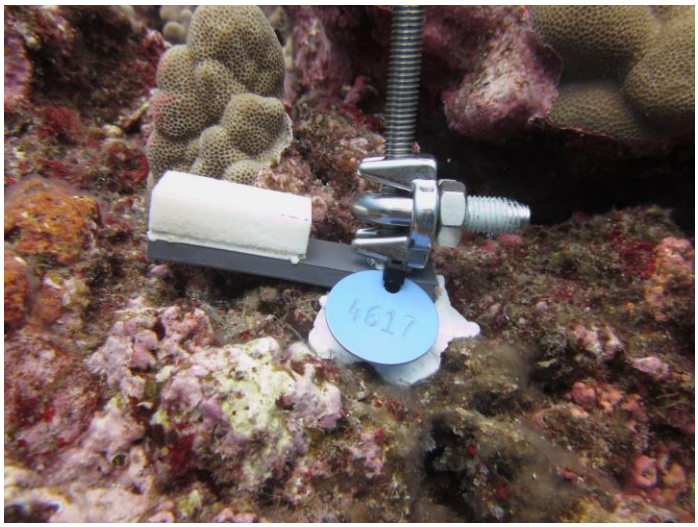

Figure 5. Bioerosion Monitoring Unit deployed at a reef.

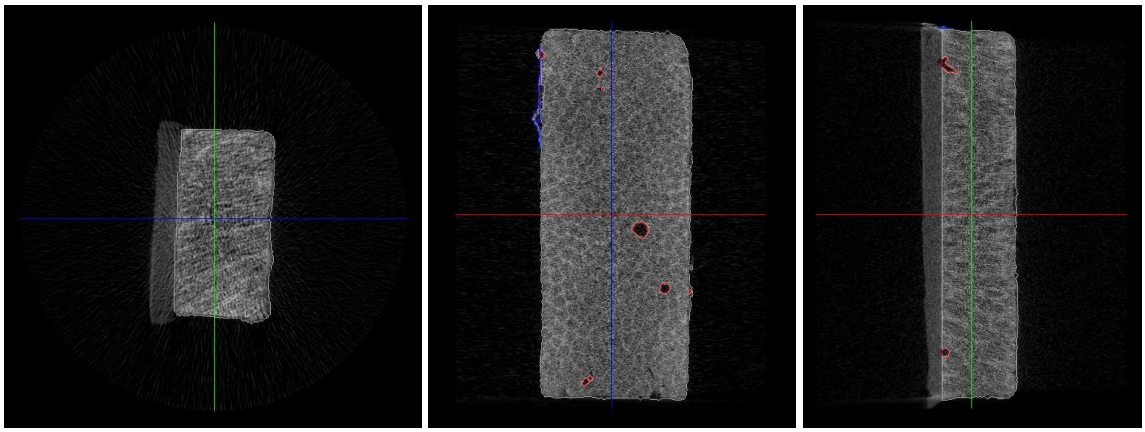

Figure 6. Volumetrically isolated accretion (blue) and macroboring (red).

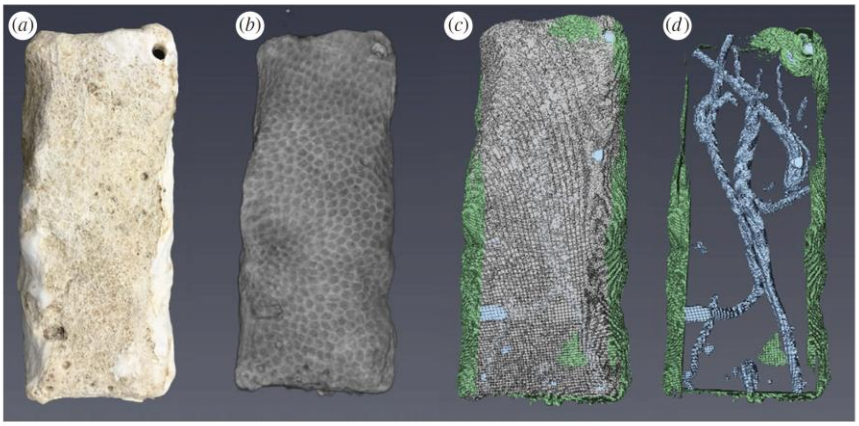

Figure 7. (a)Photograph of a dry BMU; (b) three-dimensional reconstruction of a micro-CT scan of the same BMU; (c) volumetric analysis showing original carbonate (grey), macroboring (blue), and crustose coralline algae (green); (d) view showing only macro-bioerosion and crustose coralline algae.