

Supplementary Information for

Caribbean Coral Reef Restoration and the Trade-off in Risk Management and Conservation with Nature-based Solutions

Benjamin K. Norris^{1,*}, Borja G. Reguero^{2,1}, David Gutierrez-Barcelo¹, Henri Vallès³, Ruleo A. Camacho³, Andrew M. Ross⁴, Suzanne E. Palmer⁵, and Michael W. Beck¹

¹Center for Coastal Climate Resilience, University of California, Santa Cruz, 115 McAllister Way, Santa Cruz, 95060, CA, USA

²Coastal Science and Policy, University of California, Santa Cruz, 115 McAllister Way, Santa Cruz, 95060, CA, USA

³Department of Biological and Chemical Sciences, The University of the West Indies, Cave Hill Campus, Cave Hill, Barbados

⁴Seascape Caribbean, Montego Freeport, St. James, Jamaica

⁵Department of Life Sciences, The University of the West Indies, Mona Campus, Kingston 7, Jamaica

*Corresponding author: Benjamin K. Norris

The change in wave height across the model experiments for a single wave condition ($H = 1.2$ m, $T = 8.5$ s) relative to the restorations is shown in Fig. S1. For both the elkhorn and hybrid reef restorations, shoaling (an increase in wave height) occurs as waves approach the top of the ramped bathymetry around $x/x_0 = 0.4$. For the hybrid reef, significant wave reflections off the reef face disturb the wave field offshore of the restoration, producing a more irregular pattern between $x/x_0 = 0$ and 0.4 (Fig. S1b).

In shallow conditions (light blue lines, Fig. S1), waves break across the elkhorn coral restorations. The rate of wave height reduction is rapid at first where waves break (between $x = 0$ to 20 m, Fig. S1a) and then decreases as waves continue to propagate. In this case, the coral density does not play a significant role in modifying wave height (there is nearly no difference between the lines representing the sparser 0.5 coral/m² and denser 1 coral/m² cases for the elkhorn coral, Fig. S1a). As the water depth increases, waves stop breaking and the impact of the coral on wave height reduction increases. There is a clear difference between the wave height reduction of the sparse and dense coral in water depths, h of 2.0 to 2.5 m, with the greatest difference (about 15%) observed for the deepest conditions at $x = 50$ m (i.e., 10 m behind the restoration). Under these conditions, the friction generated by the dense coral thicket is more effective at removing energy from passing waves (dark blue lines, Fig. S1a).

For the hybrid reef in shallow conditions, wave height reduction is rapid as waves break across the reef structure, reducing nearly 100% of incident wave height (light blue line, Fig. S1b). As the water depth increases, waves continue to break though the wave height reduction diminishes. In the deepest case (dark blue line, Fig. S1b)

at $x = 50$ m (approximately 40 m behind the hybrid reef structure), the total wave height reduction is similar to the corresponding dense elkhorn coral case (dark blue line, Fig. S1a).

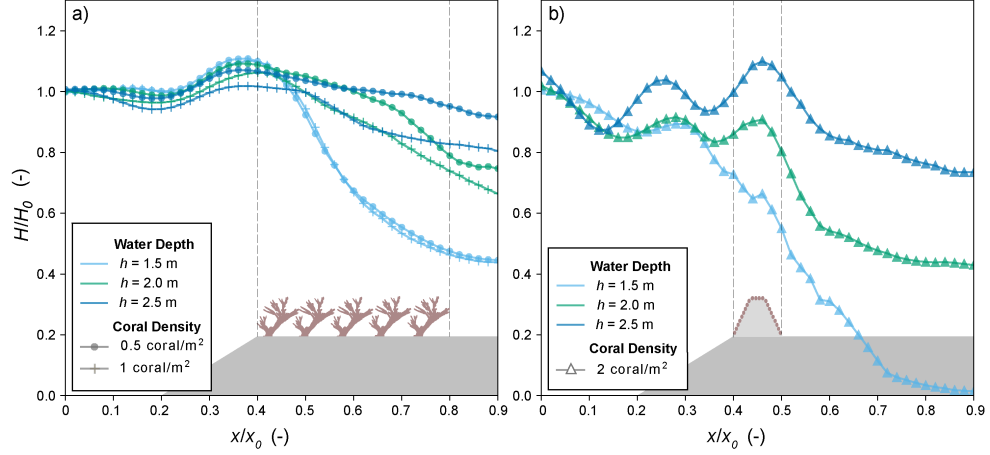


Fig. S1 An example of wave heights normalized by the incident wave height (H/H_0), showing wave transformation across the restorations for the three tested water depths ($h = 1.5, 2.0, 2.5$ m; light blue, green, and dark blue, respectively), the largest wave height ($H = 0.8$ m), and longest period ($T = 8.5$ s). In both panels, the coral elements of the restoration are shown in light red, while the bathymetry (and reef in panel b) are shown in grey. Vertical dashed lines indicate the across-shore extents of the restorations. (a) Wave transformation across the elkhorn restoration for two densities, 0.5 coral/m² (sparse; circles) and 1 coral/m² (dense; crosses). (b) Wave transformation across the hybrid reef restoration for a single smooth star coral density, 2 coral/m² (triangles). In general, waves decrease in height when they break across the restoration ($h = 1.5$ m cases). The effect of the dense elkhorn coral is most evident when the corals are deeply submerged ($h = 2.5$ m). In contrast, the hybrid reef is most effective under shallower conditions.

Attached videos corresponding to the model results shown in Fig. 2 of the main paper are as follows:

1. (Fig.2a) `h1p5_H1p2_T8p5_elkhorn-high.mp4`. High density elkhorn coral in 1.5 m of water under large waves with long period. In this video, the rate of energy loss, via breaker-generated turbulence and frictional dissipation inside the coral lattice, is visualized by the dark-to-light color ramp. The high-density elkhorn lattice clearly provides a lot of frictional dissipation in addition to that of the breaking wave.
2. (Fig.2c) `h1p5_H1p2_T8p5_elkhorn-low.mp4`. Low density elkhorn coral in 1.5 m of water under large waves with long period. Like the former video, the wave still breaks under these conditions. Unlike the former video, the frictional dissipation generated by the now sparse elkhorn coral is much lower than the dense case.
3. (Fig.2e) `h2_H0p6_T4_elkhorn-high.mp4`. High density elkhorn coral in 2.0 m of water under small waves with short period. In this case, frictional dissipation is the only mode of energy reduction as the waves do not break under these conditions. Energy dissipation is principally concentrated underneath the passing wave crest.

4. (Fig.2g) `h1p5_H1p2_T8p5_smooth-star-high.mp4`. The hybrid reef covered with high density smooth star corals in 1.5 m water under large waves with long period. In this case, the reef forces the waves to break steeply across its surface, causing a high degree of energy dissipation. Frictional dissipation along the smooth star coral can be seen at the surface of the reef, but this does not contribute significantly to the total energy dissipation of the hybrid reef design.